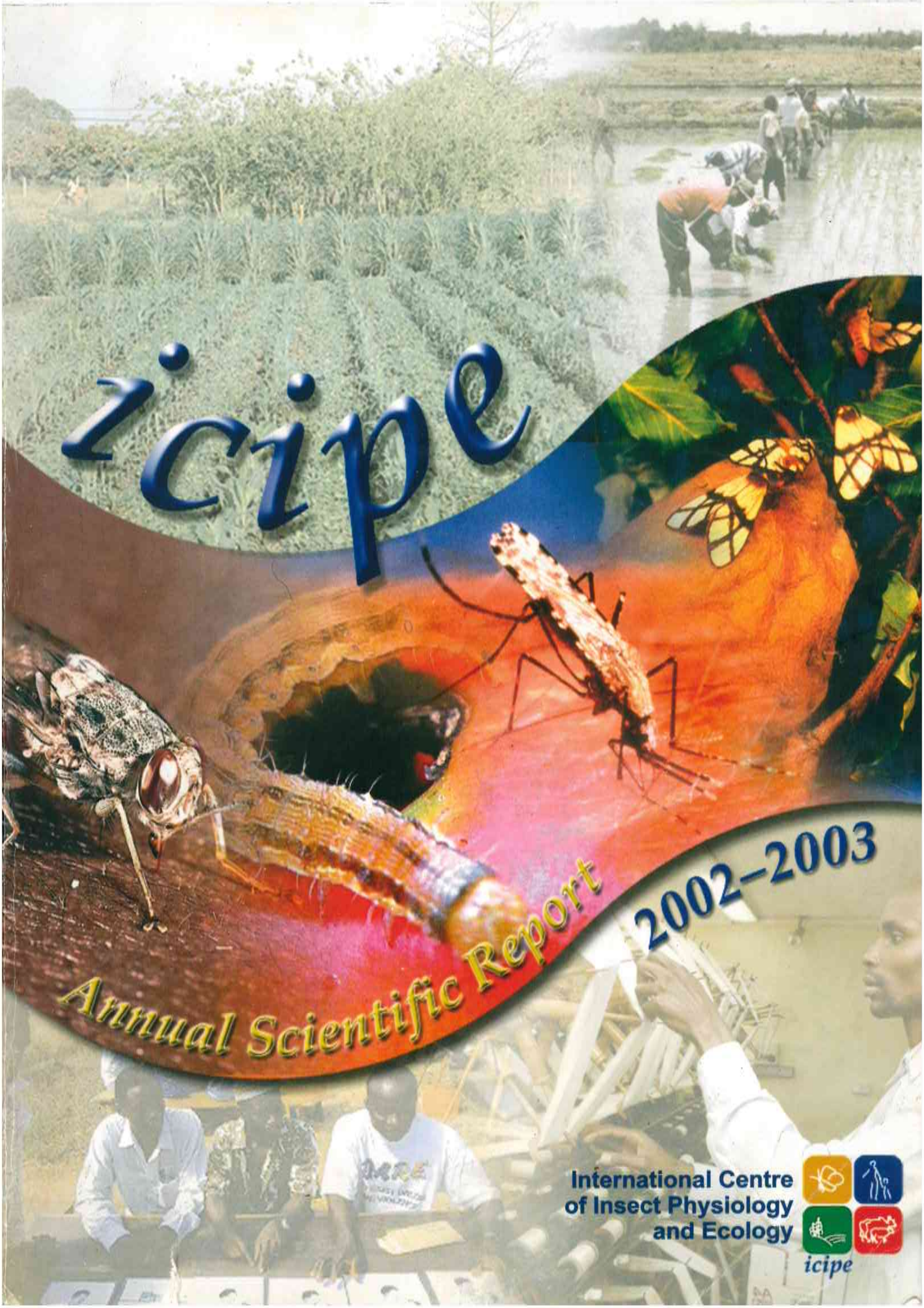

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Annual Scientific Report 2002–2003

International Centre of Insect Physiology and Ecology

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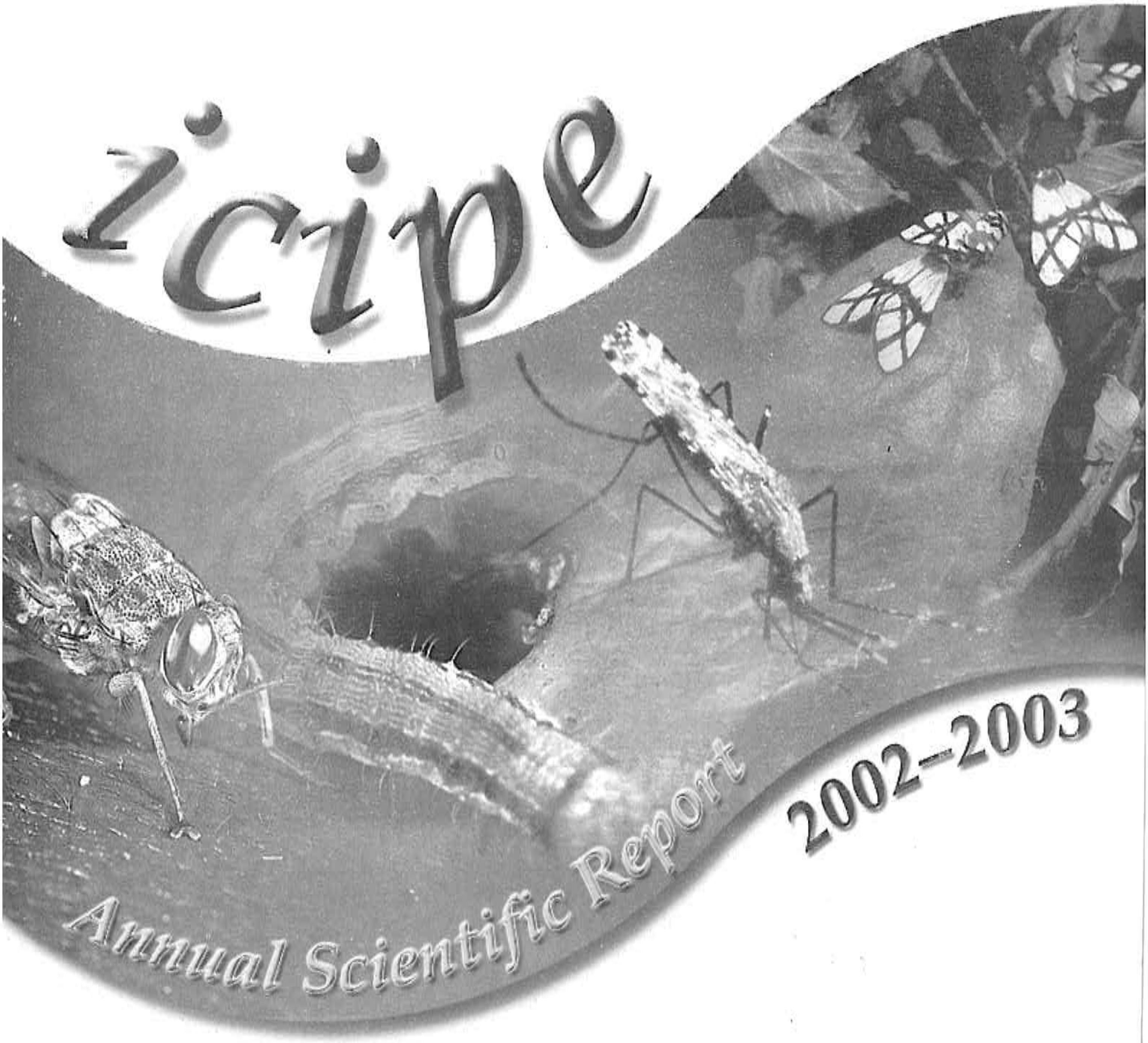

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DEDICATION TO THOMAS R. ODHIAMBO

Thomas Risley Odhiambo

The year 2003 was an important milestone for the International Centre of Insect Physiology and Ecology and its friends and supporters around the world, as it is the year in which its founder and African visionary, Thomas Risley Odhiambo, died on 26 May, 2003.

The history of ICIPE's founding is now somewhat of a legend, both in Africa and abroad. How did TRO, as Odhiambo was known, become interested in insects, or 'dudus' in Kiswahili, and how did this interest give rise to an internationally acclaimed institution? We know this from an interview he gave in 1992 for the magazine *Africa Forum*. He tells of doing simple experiments when he was only 6–7 years old with wasps, altering their environment and seeing if they could find their back to their nests, then digging up the nests and discovering what was inside. He voraciously read science books during his high school years, and on entering Makerere University in 1950, realised that the world of tropical entomology was exceedingly rich. He says that:

> *Many people may not know this, but one of the major reasons we have a theory of evolution was that Darwin actually began his studies when he observed the great diversity of insect life in the tropics, and went on to look at insects for evidence of evolution. The whole science of genetics is based on the fruit fly.*

Furthermore, he realised that insects were important in the livelihood of the tropics, and that far too little study had been done on them. In those days in East Africa, it was difficult to study abroad, but that did not stop him from doing his own research and publishing. By the time he won a place at Cambridge for his PhD studies in 1959, he was already considered one of the world's dozen or so experts on the bugs, an Order of the Phylum Insecta.

> *One of the key issues we were always thinking about was excellence. How does one build that into African endeavours?*

A brief outline of the events follows, paraphrased from many of TRO's own words from a speech he gave in March 2003 on the occasion of the dedication of the Thomas R. Odhiambo Conference Centre on the ICIPE Headquarters campus (Duduville) in Nairobi. As a young professor at the then University College, Nairobi of the University of East Africa, he states that,

> *A "serendipitous opportunity" presented itself in 1967 when I took the challenge from the Editor of the Washington-based journal* Science *to write a major review of the status of science in Africa. In it, I made a strong plea for establishing a few large centres of excellence... I gave, as an example, the pivotal areas of the management of insect populations in a sustainable, ecologically-friendly way, (using technologies) that would be within the means of the resource-poor rural communities. Strong encouragement to actually launch such a centre cascaded from an over-arching positive response—from Stanford, Harvard, the Royal Society of London, Cambridge, Oslo, Stockholm, Uppsala, Copenhagen, Moscow, Prague, New Delhi, Beijing, Tokyo, Cairo, Ibadan, Nairobi and many other world centres.*

This article proved to be a rallying call for attention to be paid to Africa and its development issues. The Centre would provide a mechanism and focal point for linking the world's leading scientists with the problems facing the smallscale farmers of the developing world. Within three years of the *Science* (Vol. 156, pp. 876–881) article, ICIPE was created in Nairobi as a multidisciplinary institute for advanced scientific research, beginning its life in a one-room garage on the University of Nairobi campus in Chiromo. In 1977, ICIPE was granted full international status by the Government of Kenya (our host country), and in 1986 ICIPE was converted into an intergovernmental organisation by the signing of a Charter in a ceremony chaired by UNDP. Today, ICIPE collaborates with over 160 organisations around the world.

In 1990 ICIPE moved from its purpose-built premises at Chiromo to its present beautiful international headquarters at Kasarani. A major field station at Mbita Point was inaugurated in 1986, and six field sites around the country established, as well as others in neighbouring countries. ICIPE still retains some of the best physical facilities for scientific research and development (R&D) on the continent.

Professor Odhiambo had been strongly influenced by Rachel Carson and her book, *The Silent Spring*, that pulled the alarm on the issue of pesticide misuse and the resulting dangers for the entire ecosystem. TRO understood very early on the problems that the use of synthetic pesticides were (and still are) creating, both for the environment and the farmers, as he recognised that pesticides soon lead into a treadmill from which farmers would eventually beg to be taken off. He therefore based the research programmes at ICIPE on the biological and integrated management control track. This approach was far ahead of many scientists in the developed world at the time. He has been proven right many times over, and today ICIPE is continuing with this philosophy, for the benefit of the farmers and the environment.

The new Centre had (and still has) three basic missions:

- to create a body of basic knowledge of key tropical pests and disease vectors that attack the people of Africa, their crops and livestock;
- to transform these discoveries and innovations into strategies for managing these pests;
- to ensure that a motivated, highly talented human capital in insect science is built up, "so as to enable Africa to sustain herself and to lead the entire pan-tropical world in this area of endeavour" (his words).

With regard to the first objective, TRO established research programmes on important pests of field crops such as stemborers, termites and the desert locust; on disease vectors (yellow fever and malaria mosquitoes, and sandflies); and on livestock pests (tsetse and ticks). Today, ICIPE continues with many of these same pests, but at the recommendation of our collaborators and donors, is concentrating on fewer field crop pests, instead introducing the area of horticultural pests, of more recent interest for its income-generating potential for African farmers. R&D on tsetse and malaria vectors has been reinforced by more studies on the chemical ecology and behaviour of these insects. New programmes on commercial insects (keeping of honey bees and silkmoths) and on biodiversity conservation have been added, but all are based on the awareness, as TRO said, that

"Only 0.03% of all insects are actually harmful to humans. The rest are essential parts of our ecosystem".

With respect to the second objective, ICIPE continues to refine, expand and adapt several of the technologies first developed during TRO's time, such as the NGU tsetse traps and biological control of stemborers, but adding new approaches and technologies as more of the basic information from research becomes available. A special Technology Transfer Unit has been established to help bring the ready-to-use output from R&D to farmers at grassroots levels. We know he is pleased with this concept, because he expressed his firm belief that researchers should have much more contact with the communities they are meant to serve.

As regards the third objective, of human and institutional capacity building, it is perhaps in this sphere that ICIPE has been most unique among research organisations. A very successful programme for training PhD scientists was launched in 1983. Called the 'African Regional Postgraduate Programme in Insect Science' (or ARPPIS), by the time TRO left ICIPE, over 120 PhD students had enrolled. These students perform their research at ICIPE, but receive their degrees from one of the (now 27) African universities participating. Since he retired in 1994 , 45 more PhD students have enrolled with full sponsorship, another 65 PhD candidates have enrolled under their own funding, and over 100 have received their MSc degrees. TRO's legacy in building the human capital to solve Africa's problems lives on, and the ARPPIS and other graduates are now filling prominent positions in universities, government departments and R&D institutions, private companies, and international organisations throughout the continent. We are still proud to say that most have not succumbed to the temptation to join part of the 'brain drain', and are still working here in Africa. Networking among Africa's scientists has also been strengthened by his work to help establish and serve as first President of the African Association of Insect Scientists (AAIS).

As part of capacity building, TRO also believed that scientific publication was an integral part of scientific research. African scientists needed access to literature to keep abreast of developments. And he recognised that just as important was the need for African scientists to be heard and exchange information with colleagues abroad. He thus created the infrastructures—the institutions and publications—which included teaching of experts in the art of producing the publications. From his years at ICIPE, two important outputs emerged: The first was the international journal co-hosted by ICIPE and the African Association of Insects Scientists, *Insect Science and Its Application*, for which he served as the first Editor. In its 23rd year in 2003, the journal has continued to provide a forum for reporting original research results, and from 2004 will be called the *International Journal of Tropical Insect Science*, to be co-published with CABI, UK. In 1988, TRO spearheaded the establishment of a new imprint, ICIPE Science Press; publication was moved to Nairobi from the UK. ISP continues to be an active, scientific scholarly publisher.

In terms of his own scholarly output, Odhiambo was the author of over 160 peer-reviewed publications. For this, he was awarded numerous international prizes: Albert Einstein Gold Medal (1991), the Gold Mercury International Award (1982), the Gold Medal Award from the International Congress of Plant Protection (1983), the African Prize for Leadership for the Sustainable End of Hunger (shared with President Abdi Diouf of Senegal in 1987), the ISCTRC Silver Jubilee Award of the African Union (2000), and others. He was also awarded over six honorary doctorate degrees from some of the world's finest institutions, including the University of Oslo in 1986, the DSc from the University of Massachusetts (1990), a Doctor of Laws from Notre Dame University (1992), a Doctor of Humane Letters from John Hopkins University (1991), and closer to home, the DSc from the University of Eastern Africa at Baraton (2002) and the Jomo Kenyatta University of Agriculture and Technology in Kenya (2003).

Under his tenure, ICIPE itself was awarded as an organisation the St Francis Prize for the Environment (1992) by the Franciscan Centre of Environmental Studies in Assisi, and the Alan Shawn Feinstein World Hunger Award of Brown University (1986), among others.

To honour his memory, it is planned to rename ICIPE's Mbita Point Field Station the ICIPE Thomas Odhiambo Campus - Mbita Point in early 2004. ICIPE and another of the institutions he founded and served as President, the African Academy of Sciences (AAS), are launching a Trust Fund in his memory, which will be launched at the 4th International Congress on Entomology in Brisbane, Australia in 2004 and at the Annual Meeting of the AAS in Abuja, Nigeria later in the year.

The legacy of Thomas Odhiambo lives on. TRO's vision when he created ICIPE with a few friends and colleagues back in the late 1960s became a reality, thanks to his perseverance and dedication. He created an absolutely unique institution, that has become known around the globe for scientific excellence in biological and integrated pest and vector management (IPVM) and capacity building for Africa.

We therefore dedicate this *2002–2003 Annual Scientific Report* to the memory of a man who changed the scientific landscape of Africa.

Editor's Note: Parts of this dedication are taken from a Tribute to Professor Odhiambo delivered by ICIPE's Director General, Hans R. Herren, on the occasion of his memorial service on 11 June 2003.

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FOREWORD

Hans R. Herren,
Director General and CEO

This is the first biannual scientific report after the launching of the new ICIPE Strategic Vision document in 2003. It comes also at the time when the performance levels, set out for the Millennium Development Goals (MDGs) developed four years ago, were found to be way off the established targets.

As can be seen in this report, ICIPE's activities over the past two years clearly address the five key priorities (water, agriculture, energy, health and biodiversity) outlined in 2002 by UN Secretary General Kofi Annan. These five key priorities, also known as the WEHAB Initiative, together with the MDGs are very much part of the ICIPE research, capacity and institution building agenda.

ICIPE is unique among international research and capacity building organisations, in having key competencies in the most urgent areas of development identified by the international community. We are thus playing a major role in supporting the MDGs and WEHAB initiative implementation.

In fact, three of the five WEHAB priorities were formally incorporated into ICIPE's ethos in 1996, when the Centre launched its new vision for the next 25 years with a new paradigm for holistic and sustainable development: the 4-Hs. Given its mandate as an intergovernmental research and capacity building agency in the biosciences, ICIPE decided at that time to concentrate its activities in four key areas where insects and related arthropods are central to development problems, i.e. human health, animal health, plant health and environmental health. At the same time, ICIPE resolved to further engage in global partnerships for development through increased efforts in research and capacity and institution building (R&CB). In our latest quest for improved impact of research-based technologies and know-how, ICIPE now incorporates the adaptive management approach in its partnership with farmers and rural communities.

Our latest research agenda has been refocused and the research activities more closely matched to the most pressing needs and requirements expressed by civil society, the poor of this world and the concerned segments of the developed world. How has ICIPE contributed practically to the Millennium Development Goals in the five key areas?

- **Water** and **biodiversity** go very much hand-in-hand from our insect perspective. The conservation and utilisation of biodiversity requires the preservation of large tracts of land (forests, wetlands, drylands, etc.) which also become major sinks or natural reservoirs for clean and abundant water. ICIPE's environmental health research and capacity building activities are developing innovative ways for the conservation and sustainable utilisation of these ecosystems by introducing income-generating incentives that relieve pressure on over-exploited natural resources. These include beekeeping with a broad range of beehive products; sericulture with both Africa-adapted domestic silkworm races and wild indigenous moths; and growing, processing and formulating medicinal, veterinary and pest management products from plant and insect sources, discovered through our bioprospecting activities.

  Under Environmental Health we are also researching pollinators and soil-borne arthropods as key ecosystem service providers that need our urgent attention, as without them, our soils would be mostly deserts and the plant kingdom only one-third of its present size, not to mention reduced crop yields. ICIPE is also very much involved in the identification, surveillance, control and management of invasive species, a major threat to many agroecosystems of this world.

- **Health** has been a key factor in holding back development, burdening people and society at large with enormous costs in terms of research, treatment, prevention and lost opportunities and productivity. Many health problems can be traced back to vectors, in the tropics in particular, but not exclusively. As history has told us, there is little point in trying to control vector-borne diseases by attacking the parasite alone. ICIPE is one of the very few research organisations in the tropics that has an entire division (Human Health) dedicated to R&CB in vector entomology. There is little doubt today that solutions to malaria, sleeping sickness, leishmaniasis, yellow fever, dengue, Rift Valley fever and West Nile fever will only be overcome by including the vector in the control equation. More attention has to go toward the key players in these diseases, and we are using both old and new technologies as well as the latest in genomics research in developing and implementing new vector management tactics as components of an integrated vector and disease management strategy.

  ICIPE has revised the current narrowly focused investment strategy in drugs and vaccines to include the key factor in malaria, the mosquito. In particular we are looking at larval control using a naturally occurring bacterium, *Bacillus thurigiensis* var *israelensis (Bti)* and neem, as well as other potential botanical and microbial candidates. Linked to the health issue is income, as any intervention at individual, family or community level will require money. ICIPE already has integrated this element into our holistic approach to development through our sustainable agriculture and agro-based cottage industries programmes.

- **Agriculture:** Food security is affected to a great extent, both pre- and post-harvest, by insects and mites, and also in a rather indirect way by vectors of animal diseases. Most developing-world farmers are dependent on animal traction for much of land preparation, harvesting and marketing of their farm products. Both the crops and the animals require sustainable and affordable protection methods against the key pests and disease vectors. ICIPE has over 30 years of experience in these areas and has contributed many original solutions to these constraints to livestock productivity and good crop yields. There remains much work to be done, however, as new pests and vectors do appear, and thus better and more sustainable solutions are needed. ICIPE has special competencies in biological control, integrated pest and vector management (IPVM), use of botanicals, the development and utilisation of semio- or info-chemicals, and of late, the use of insect genomics for the development of new and 'smart' insect and vector management tools. Of special interest as we go to press are the latest research results concerning locust management. In the Plant Health area, ICIPE has also added to its key competencies expertise in IPM in horticultural crops, to include fruit, vegetable and flowers. At the same time, we are reducing our activities on the CGIAR-mandated crops when and where appropriate, and promoting complementarity in the IARC system.

- **Energy:** Often overlooked is the impact of poor health and diet on the store of human and livestock energy for efficient agricultural production and other economic and social activities. ICIPE's Human and Animal Health Divisions help by reducing the burden of disease, while our programmes in staple food crop pests are bringing higher yields and so more calories. An improved supply of nutritious fruits and vegetables is a result of our horticultural crops programmes and ensures a more balanced and nutritious diet.

  Our direct contribution to sustaining the supply of energy for fuel comes via our Environmental Health Division, and the fuelwood-conserving activities being introduced to communities adjacent to biodiversity-rich forests.

To support ICIPE's agenda of assisting Africa's universities in their own research, and in developing products from this research, the Centre recently started the 'Africa BioScience Innovation Centre'. This is an incubator for new, bioscience-based companies that will assist Africa in producing its own bioscience-based products for human, animal and plant health. Under a unique and innovative arrangement, ICIPE has agreed to work with an investment company that takes product ideas from ICIPE's research, finds local-, social- and environmentally responsible business partners and co-investors and develops them into commercial products. ICIPE, in return will get a share of the profit, royalties and research contracts.

It is our hope that after reading through this report, you will see ICIPE as a truly unique, innovative and cutting edge R&CB institution with the advantage of being Africa-born and focused on this continent with its enormous needs. Be it in assisting policy makers, developing new technologies and human resources, securing production assets for the rural and urban poor or market access for innovative products—all in close partnership with local institutions—ICIPE is demonstrating that it is delivering good value for the investment.

Hans R. Herren
Director General and CEO

PLANT HEALTH RESEARCH

PLANT HEALTH

HABITAT MANAGEMENT STRATEGIES FOR CONTROL OF STEMBORERS AND STRIGA WEED IN CEREAL-BASED FARMING SYSTEMS IN EASTERN AFRICA

BACKGROUND, APPROACH AND OBJECTIVES

Maize and sorghum are the principal foods and cash crops for millions of poor people in the predominantly mixed crop-livestock farming systems of eastern and southern Africa. In eastern Africa, cereal farming contributes about 50% of the gross domestic product. Smallholder farmers, particularly women farmers, account for the largest share of agricultural output in this region. Maize and sorghum are grown mainly under rainfed conditions and farmers' yields are generally low, averaging about 1 to 1.5 t /ha. With rapid population growth, there is increasing cultivation and cropping pressure on available land. This has important implications for ecosystem sustainability and biodiversity.

Low cereal productivity is associated with several constraints, including unreliable rainfall, land degradation due to soil erosion, pre- and post-harvest pest infestation, pre- and post-harvest losses, poor infrastructure and marketing, and policy bottlenecks. In eastern Africa farmers commonly engage in mixed crop-livestock production with varying degrees of crop and livestock interaction. Livestock play a number of important functions, including provision of milk and meat, traction and transport, manure for crop production, while consuming crop residues and other farm by-products such as failed crops. Utilisation of natural pastures, planted fodder and crop residues by livestock are major considerations in the contribution of livestock to human nutrition and farm incomes.

Research into various aspects of improving cereal and livestock productivity is a top priority among the research organisations working in the region. Improving maize-based farming would enhance food security, increase farm incomes and reduce or replace commercial food imports. Any significant changes in agricultural productivity in the smallscale farm sector will substantially affect national income and food security.

Pest problems in cereal production

Stemborers and the parasitic striga weed are two major biotic constraints to increased cereal production in eastern and southern Africa. At least four species of stemborers infest maize and sorghum in the region. The yield losses caused by stemborers to these crops are reported to vary from 20 to 40% of potential output, depending on agroecological conditions, crop cultivar, agronomic practices and intensity of infestation. Stemborers are difficult to control, largely because of the nocturnal habits of adult moths, and the cryptic feeding behaviour of the larvae in plant stems. The main method of stemborer control being recommended to farmers is chemical pesticides. However, chemical control of stemborers is uneconomical and unpractical for many resource-poor, smallscale farmers.

Parasitic weeds in the genus *Striga* threaten the lives of over 100 million people in Africa and infest 40% of arable land in the savanna region, causing an annual loss of US$ 7 to 13 billion. Around the Lake Victoria basin, striga infestation is quite severe and 30 to 100% loss in maize yield is caused by *Striga hermonthica*. Striga infestation is associated with increased cropping intensity and declining soil fertility. Infestations by weeds of *Striga* spp. have resulted in the abandonment of much arable land in Africa. The problem is more widespread and serious in areas where both soil fertility and rainfall are low.

Striga infestation continues to extend to new areas. Another 40% of arable land may become infested in the next 10 years. Recommended control methods to reduce striga infestation include heavy application of nitrogen fertiliser, crop rotation, use of trap crops and chemical stimulants to abort seed germination, hoeing and hand pulling, herbicide application and the use of resistant or tolerant crop varieties. Farmers have been reluctant to accept all these methods, including the most widely practised hoe weeding, for both biological and socioeconomic reasons. Unfortunately, African women are overworked in weeding of striga, which is a time-consuming and labour intensive activity. Reducing the losses caused by stemborers and striga through improved management strategies could therefore significantly increase maize production, and result in better nutrition and purchasing power of many maize producers in eastern Africa.

No single method of control has so far provided a solution to both the stemborer and striga problems. To put stemborer and striga control within the reach of African farmers, simple and relatively inexpensive measures need to be developed that are tailored to the diversity of African farming systems.

The major objective of this programme is to reduce poverty by improving the livelihood of resource-poor farmers through increased production of maize, sorghum, millet, fodder plants and milk.

'Push-Pull' Strategy

The"push-pull' strategy developed over the past six years is an integrated approach that simultaneously addresses both of the major problems. Push-pull involves trapping stemborers on highly attractive trap plants (the pull) and driving them away from the maize crop using repellent intercrops (the push). Plants which repel stemborers as well as inhibit striga have also been identified.

Previous work *(see ICIPE Annual Scientific Reports for 2000–2001, 1998–1999 and 1995–1997)* has shown that plants which can be used as trap or repellent plants are Napier grass (*Pennisetum purpureum*), Sudan grass (*Sorghum vulgare sudanense*), molasses grass (*Melinis minutiflora*), silver leaf desmodium (*Desmodium uncinatum*) and greenleaf desmodium (*Desmodium intortum*). Napier grass and Sudan grass have shown potential for use as trap plants, whereas molasses grass and silverleaf desmodium repel ovipositing stemborers. Molasses grass, when intercropped with maize, not only reduces infestation of the maize by stemborers, but also increases stemborer parasitism by a natural enemy, *Cotesia sesamiae*. In addition, *Desmodium*, when intercropped with maize, inhibits striga. All the four plants are of economic importance to farmers in eastern Africa as livestock fodder and have shown great potential in stemborer and striga management in farmer participatory on-farm trials. On-farm trials with 1500 farmers in Kenya have confirmed that these approaches, conducted separately and together, do indeed work and result in significant yield increases. These innovations were found to be acceptable at the smallscale farmers level in Kenya.

WORK IN PROGRESS

1. Implementation of 'push-pull' strategies in Kenya and Uganda

The habitat management strategies based on the push-pull and striga suppression-elimination tactics, were introduced to farmers in 10 districts in Kenya and 3 districts in Uganda. Among the more than 1500 participating farmers, maize yields have increased by an average of 20% in areas where only stemborers are present and by more than 50% in areas where both stemborers and striga are problems (Tables 1 and 2).

2. Development of habitat management strategies for sorghum

The Project activity is developing push-pull strategies for control of stemborers and striga weed for sorghum farmers. On-station trials were conducted during 2002–2003 to evaluate greenleaf desmodium (*Desmodium intortum*) in controlling stemborers and striga weed when intercropped with sorghum (Table 3). *Desmodium intortum* is a drought-tolerant species and can intercrop very well with sorghum and millet. These trials were later extended to farms (Table 4). Intercropping sorghum with *D. intortum* significantly reduced stemborer and striga infestation on sorghum both on-station (Table 3) and on-farm (Table 4). Significant increases in crop yields were recorded in both on-station and on-farm trials.

This technology will be particularly applicable for the arid and semi-arid regions of Africa where striga intensity has resulted in the abandonment of arable land. Higher crop yields and improved livestock production for sorghum- and millet-producing farmers could support many rural households under existing socioeconomic and

Table 1. Comparison of stemborer and striga infestation, and yield of maize crops in 'push-pull' and control maize fields in seven districts of Kenya and three districts of Uganda in 2002

Country	District	No. push-pull farmers	Stemborer infestation (%)		Striga infestation Striga /100 maize plants		Yield t/ha	
			'Push-pull'	Control	'Push-pull'	Control	'Push-pull'	Control
Kenya	Trans Nzoia	425	17.1	32.2**	–[1]	–[1]	5.1	4.0*
	Suba	325	10.7	21.3*	2.4	576.9**	3.4	1.4**
	Kisii	50	5.0	12.0*	16.6	476.3**	4.1	2.8*
	Rachuonyo	50	6.3	18.4**	11.1	322.7**	3.7	2.0*
	Bungoma	50	12.8	27.7*	7.2	368.2**	3.8	1.6*
	Busia	30	14.0	35.7*	11.4	421.3**	3.9	2.8*
	Vihiga	25	4.1	22.6**	20.1	409.1**	4.9	2.9**
Uganda	Kapchorwa	10	11.9	26.7**	–[1]	–[1]	3.4	2.0*
	Bugiri	14	13.0	25.0*	2.2[2]	2.9[2]	2.9	1.9*
	Tororo	17	14.3	28.5*	2.1[2]	2.6[2]	2.0[3]	1.8[3]

[1]No striga infestation in Trans Nzoia (Kenya) and Kapchorwa (Uganda).
[2]In Uganda, striga infestation was rated on a 1–5 scale.
[3]The yield difference was not expressed due to drought in eastern Uganda.
*Difference significant ($P < 0.05$), **difference significant ($P < 0.01$).

Table 2. Average of stemborer and striga infestation and maize yields in 'push-pull' and control plots in various districts of Kenya and Uganda (2003)

Country	District	No. push-pull farmers	Stemborer infestation (%)		Striga infestation Striga /100 maize plants		Yield t/ha	
			'Push-pull'	Control	'Push-pull'	Control	'Push-pull'	Control
Kenya	Trans Nzoia	550	7.1	17.2*	–[1]	–[1]	5.5	4.2*
	Suba	375	6.1	34.9**	12.8	296.0**	3.4	1.3**
	Kisii	130	7.4	20.0**	20.3	166.5**	3.8	2.4*
	Rachuonyo	120	5.1	11.8*	20.4	257.5**	3.3	1.8*
	Bungoma	150	12.8	27.7*	7.2	368.2**	3.8	1.6*
	Busia	130	14.0	35.7*	11.4	421.3**	3.9	2.8*
	Vihiga	50	15.7	29.6*	356.1	1076.4**	4.1	1.8**
	Migori[2]	10	6.2	10.6ns	318.0	521.0*	4.3	3.2*
	Homa Bay[2]	10	6.3	17.7*	141.0	431.1**	3.4	2.3*
	Siaya[2]	10	16.9	32.8*	257.3	575.7*	3.7	1.8**
Uganda	Kapchorwa	45	12.1	29.4**	–[1]	–[1]	3.9	2.2*
	Bugiri	46	26.5	42.5*	2.1[3]	3.8[3]*	2.6	1.2**
	Tororo	43	15.4	22.2ns	2.0[3]	3.0[3]*	2:0[4]	1.6ns, 4

[1]No striga infestation in Trans Nzoia (Kenya) and Kapchorwa (Uganda).
[2]New districts added to study in 2003 in Kenya.
[3]In Uganda, striga infestation was rated on a 1–5 scale.
[4]The yield difference was not expressed due to drought in Tororo, Uganda.
*Difference significant ($P < 0.05$), **difference significant ($P < 0.01$).

Table 3. Use of greenleaf desmodium, *Desmodium intortum*, for management of striga weed and stemborers in sorghum, on-station trials, ICIPE 2002–2003[1]

Cropping season	Treatment	Stemborer damage (%)	No. of striga/84 sorghum plants	Av. plant height (cm)	Yield (t/ha)
2002 Long Rains	Sorghum monocrop	–[2]	970.0**	103.0*	0.8**
	Sorghum with *D. intortum*	–[2]	2.5	143.0	2.2
2002 Short Rains	Sorghum monocrop	57.6*	937.0**	98.0*	1.3**
	Sorghum with *D. intortum*	23.8	9.5	151.0	3.1
2003 Long Rains	Sorghum monocrop	44.6*	519.0**	129.0ns	1.3
	Sorghum with *D. intortum*	23.8	13.0	141.0	2.3*
2003 Short Rains	Sorghum monocrop	26.3*	604.0*	91.0ns	1.1*
	Sorghum with *D. intortum*	14.5	23.0	115.0	2.6

[1]Average of 8 replications in each season.
[2]Data was not collected.
*Difference significant ($P < 0.05$); **difference significant ($P < 0.01$); ns, not significant.

Table 4. Use of greenleaf desmodium, *Desmodium intortum*, for management of striga weed in sorghum, on-farm trials in Kenya, 2003

Location	Treatment	Stemborer damage (%)	No. of striga/84 sorghum plants	Av. plant height (cm)	Yield (t/ha)
Suba District	Sorghum monocrop	–+	373.0**	119.0*	0.8**
	Sorghum with *D. intortum*	–+	2.5	55.0	2.2
Rachuonyo District	Sorghum monocrop	–+	243.0**	61.0ns	1.3*
	Sorghum with *D. intortum*	–+	75.0	76.0	1.9

+Data was not collected.
*Difference significant ($P < 0.05$); **difference significant ($P < 0.01$).

agroecological conditions, reducing human migration to environments designated for protection.

3. Evaluation and perceptions of 'Push-pull' of practising farmers in Uganda

Farmers in Uganda's Bugiri and Tororo districts evaluated two push-pull plots and control plots during a field day in 2003. The factors scored included estimated maize yield in shelled bags, health of the maize cob, size of the cob, stemborer infestation, and striga weed infestation in the two plots. Table 5 summarises the results.

The major benefits of the push-pull technology listed by farmers in both districts were:

- reduction in striga infestations
- reduction in stemborer infestations
- higher yields and bigger maize cobs
- conserving soil moisture.

The major hindrances to the adoption of the push-pull technology were listed as:

- being labour intensive in the first year
- desmodium being difficult to maintain in the off-season, due to free-grazing of cattle in some areas.

Table 5. Farmer rating % of two push-pull plots compared to the control (in parentheses)

	a		b		c		d	
	Bugiri	Tororo	Bugiri	Tororo	Bugiri	Tororo	Bugiri	Tororo
Health of maize crop[1]	20 (–)	15 (–)	80 (33)	55 (–)	– (34)	30 (38)	– (33)	– (60)
Size of maize cobs[2]	50 (–)	23 (–)	47 (33)	54 (23)	3 (53)	23 (31)	– (14)	– (46)
Stemborer infestation[3]	– (60)	– (46)	– (40)	– (31)	58 (–)	54 (23)	42 (–)	46 (?)
Striga infestation[4]	– (73)	– (88)	– (27)	– (21)	63 (–)	51 (–)	37 (–)	49 (?)

[1]a = excellent, b = good, c = average, d = poor.
[2]a = very big, b = big, c = small, d = very small.
[3]a = very high, b = high, c = low, d = very low.
[4]a = very high, b = high, c = low, d = very low.
(Bugiri N = 65, Tororo N = 55).

Interaction with farmers during the field day and through interviews has shown that:

- farmers in the project area have gained a lot of knowledge about striga and stemborer control and in the use of improved farming methods;
- farmers have embraced the technology since it takes into account their restricted resource base and also addresses soil fertility management aspects;
- farmers who have had training in striga and stemborer biology and their control methods have adopted the technology more readily and are now able to explain the technology to fellow farmers, hence helping in the dissemination of the technology.

The participating farmers (N = 50) reported an increasing number of friends and neighbours showing an interest in the technology. Each participating farmer reported knowing an average of four farmers who have or are in the process of utilising the technology based on the exposure they have acquired from the push-pull plots.

4. Commercial production of desmodium seed

ICIPE and its partners see the importance of involvement of a commercial seed company in desmodium seed multiplication so that the seed becomes freely available at an affordable price to farmers. ICIPE and its partners support the commercial development of farmer seed-producers with a seed company being a facilitator. Growing desmodium for seed will also be an income-generating activity for seed producers.

The specific objectives of this activity are to:

- establish close working relations of research institutes and private seed companies;
- establish community-based commercial desmodium seed production units in eight districts in Kenya to achieve a minimum of 3 tonnes per annum seed production;
- train farmers and other groups to acquire the necessary skills to multiply clean seeds for income generation;
- link a private commercial seed company within Kenya with the trained farmers to produce desmodium seed.

The Western Seed Company Limited in Kitale, Kenya in collaboration with ICIPE and its partners, is undertaking a major drive for commercial seed production through farmers and local community groups. Farmers and communities were asked to select participating farmers and groups interested in income generation through seed production to become contract seed producers for the seed company. In May 2003, a planning workshop, attended by representatives of farmers, frontline extension staff and area chiefs was organised by Western Seed Company in collaboration with ICIPE, Rothamsted Research and KARI to lay down strategies for implementing the project. In-depth training to participating farmers from each location in cultivation of *Desmodium uncinatum* and *Desmodium intortum* plants and processing of seed materials was offered.

In the first year of the commercialisation of the seed project (2003), the seed company provided 250 g seed to each of 300 trained farmers in two districts of Kenya (Bungoma and Trans Nzoia) for planting. The Western Seed Company guaranteed that the harvest of these 300 contract farmers will be purchased by them. The company will clean the seed, check germination and viability, and properly pack and store it. In the first year (2003), ICIPE will purchase 1000 kg seed from Western Seed Company; in year 2, Western Seed Company will provide 250 g seed to 600 contract farmers in four districts of Kenya for seed multiplication and will purchase the entire harvest, of which ICIPE will purchase 2000 kg. In year 3 (2005), seed multiplication will be undertaken by 1000 farmers in eight districts of Kenya, which should supply 3000 kg seed for ICIPE.

It is expected that this level of planting will produce at least 3 tonnes of high quality desmodium seed in Kenya per year. After Year 3, the Western Seed Company will continue purchasing desmodium seed from the contract farmers and cleaning and packing them for sale at an affordable price (of not more than Kshs 1000/kg or about US$ 12/kg). The seed company will check germination and viability and will provide appropriate storage facility for the seeds. Depending on demand, the seed company will expand the number of participating farmers.

The Kenya Plant Health Inspectorate Service (KEPHIS) is responsible for quality control of the seed and planting material. Rothamsted will analyse the airborne volatiles of these plants from selected samples from time to time using GC and GC-MS to establish that the quality of the product is maintained in terms of appropriate production of semiochemicals. Behavioural studies with stemborer females and parasitoids will also be conducted to ensure that the plants continue to produce volatile chemicals to repel stemborers, and that there is no generic drift in seeds multiplied by farmers. Similarly, quality control of the striga-inhibiting effects of desmodium in seed samples will be undertaken by ICIPE.

5. Use of food legumes for the management of stemborers and striga in maize and sorghum crops

To find out if any food legume could be as effective as desmodium in controlling stemborers and striga weed, several food legumes were intercropped with maize or sorghum in on-station trials. Data on striga emergence, stemborer infestation and yield were collected. Intercropping with desmodium resulted in significantly lower stemborer and striga infestation and significantly higher maize and sorghum yields than any of the five food legumes tested (Table 6).

6. Integrated management of striga, stemborers and declining soil fertility in the Lake Victoria basin

In collaboration with CIMMYT, TSBF-CIAT, and various national programmes, this project activity is developing and disseminating an integrated pest and soil fertility management approach and strategy (IPSFM), in particular against *Striga* spp., stemborers, and declining soil fertility. These three factors are the major constraints to maize production in the Lake Victoria Basin (Figure 1). This project will help enhance food security, income generation, and environmental sustainability, leading to reduction in poverty in the Lake basin of Kenya, Uganda and Tanzania, and result in an overall improvement in rural livelihoods.

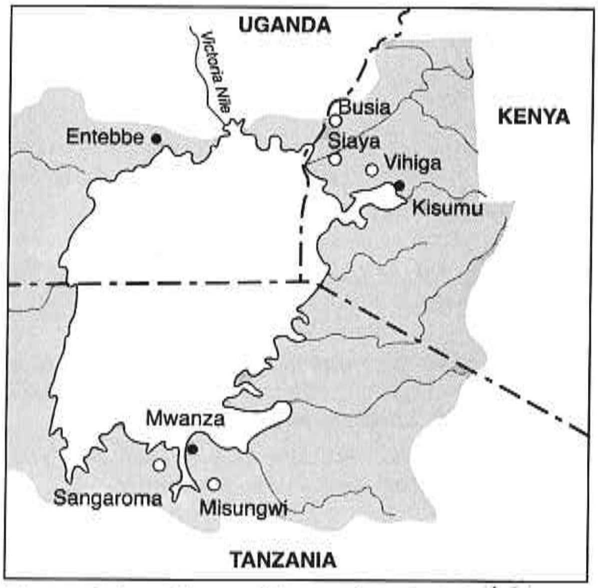

Figure 1. Locations of the project in Lake Victoria basin

A range of technologies have been developed, including ICIPE's 'push-pull' technology to control stemborers and striga, CIMMYT's imazapyr herbicide-resistant (IR) maize to control striga weed, and TSBF's various crop rotation options for improving depleted soils.

One such novel approach for striga control in maize combines low doses of imazapyr herbicide (30 g/ha), as a seed coat with herbicide-resistant maize prior to planting. This manner of delivery acts before or at the time of striga attachment to the maize root and prevents the phytotoxic effect of striga on the maize plant, which usually occurs even before striga emergence. Additionally, imazapyr that is not absorbed by the maize seedling diffuses into the surrounding soil and kills non-germinated striga seeds.

TSBF's contribution to this project is rotation of maize with legumes, which very often results in

Table 6. Use of food legumes for the management of stemborers and striga in maize and sorghum crops, 2003*

Treatment	Mean striga count/54 plants	% stemborer infestation	Yield (t/ha)
Maize:			
Maize + *Desmodium uncinatum*	0.7 d	0 c	5.4 a
Maize + Beans *(Phaseolus vulgaris)*	33.7 c	5.1 b	4.4 ab
Maize + *Crotolaria ochroleuca*	38.9 c	3.7 bc	4.2 ab
Maize + Groundnut *(Arachis hypogaea)*	99.4 b	7.9 b	2.7 b
Maize + Green gram *(Vigna radiata)*	87.0 b	6.0 b	2.8 b
Maize + Cowpea *(Vigna unguiculata)*	69.9 b	5.1 b	3.4 bc
Maize Mono	123.0 a	11.6 a	1.9 c
Sorghum:			
Sorghum + *Desmodium uncinatum*	0.2 d	4.6 c	3.7 a
Sorghum + Beans	21.3 b	23.6 ab	1.9 b
Sorghum + *Crotolaria*	7.6 c	19.0 b	1.6 b
Sorghum + Groundnut	38.4 b	26.6 ab	1.4 b
Sorghum + Green Gram	4.2 c	33.3 a	0.9 c
Sorghum + Cowpea	14.6 bc	29.2 a	1.0 c
Sorghum Mono	65.4 a	35.2 a	0.8 c

*Means followed by the same letter are not significantly different from each other ($P < 0.05$).

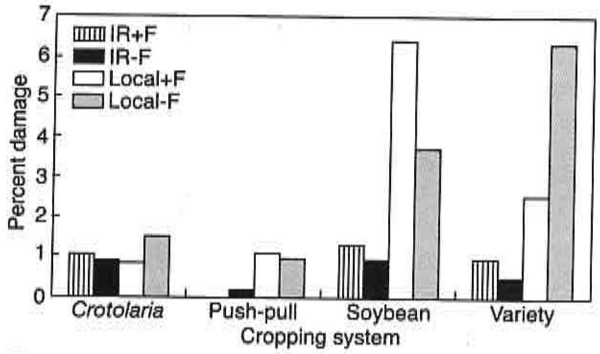

Figure 2. Effect of cropping system and management options on striga emergence at Nyalgunga village, Siaya district, short rains 2003

F = recommended fertiliser; IR = imazapyr-resistant maize; local = local variety grown by farmers

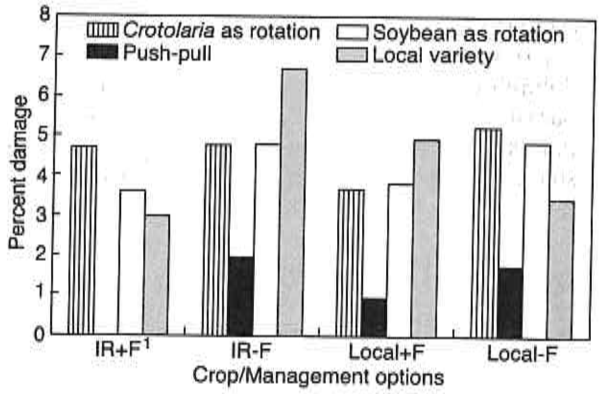

Figure 3. Percent stemborer damage in Siaya, Kenya, short rains 2003

[1]No stemborers were observed when push-pull was used with IR maize and fertiliser

enhanced cereal performance compared with a cereal–cereal rotation. This enhanced cereal performance can be the result of the net nitrogen (N) inputs into the soil after growing a legume crop. Legumes are able to fix part of their N requirements from the atmosphere through biological N fixation after establishment of a symbiosis with the correct rhizobial bacteria. Including a legume crop in a cropping system, however, also potentially results in other benefits, such as improved soil available phosphorous (P) status, enhanced soil physical conditions, and reduced pest and disease pressure.

In on-farm trials, it has been demonstrated that ICIPE's push-pull strategy (see previous sections) controls both stemborers and striga weed (Figures 2 and 3). However, a combination of push-pull strategy with CIMMYT's IR maize provides even better control of striga weed (Figure 2).

7. Evaluation of gross margins for various striga control strategies in western Kenya

Gross margin refers to the difference between total revenue and total variable costs. In collaboration with CIMMYT, TSBF and KARI, various technologies for striga control were evaluated for gross margins in the short rainy season of 2003–2004 in Siyaya and Vihiga districts of western Kenya. In each district, evaluation was undertaken in two villages. Various options included IR (imazapyr-resistant) maize on its own, IR maize in rotation with soybean (*Glycine max*), IR maize in rotation with sun hemp (*Crotolaria ochroleuca*), local maize on its own, local maize in rotation with soybean, local maize in rotation with sun hemp, 'push-pull' strategy with local maize and 'push-pull' strategy with IR maize. Each option was tested with and without fertiliser.

The results (Figure 4) showed that push-pull with local maize and no fertiliser (PP4) had the best gross

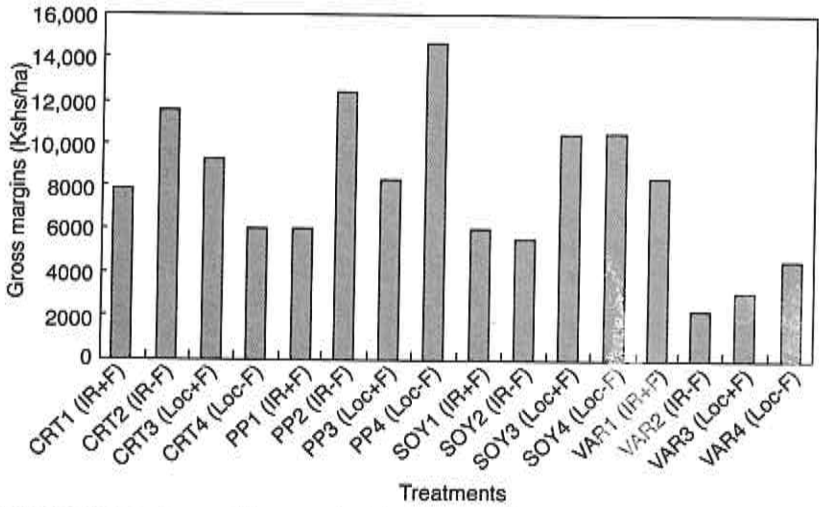

Figure 4. Gross margins for various striga control treatments in two villages in western Kenya, short rains 2003–2004

PP = Push-pull using maize + Desmodium uncinatum + Napier grass, VAR = maize varieties grown over two seasons, CRT = Crotolaria in rotation with maize over 2 seasons, SOY = soybean in rotation with maize over 2 seasons, Loc = local land race, F = fertiliser, IR = imazapyr-resistant maize.
US$ 1.00 = Kshs 78

margin, followed by push-pull with IR maize and no fertiliser (PP2). Similarly, push-pull with local maize and fertiliser (PP3) was better than push-pull with IR maize and fertiliser (PP1). Growing IR maize on its own without fertiliser (VAR 2), which is a common practice in western Kenya, did more poorly than local maize without fertiliser (VAR 4).

Growing IR maize in crop rotation with sun hemp and application of fertiliser (CRT 1) and IR maize in crop rotation with soybean with fertiliser (SOY 1) had poorer gross margins than use of local maize grown under similar conditions (CTR 3 and SOY 3). Local maize in rotation with soybean without fertiliser (SOY 4) was also better than IR maize in rotation with soybean without fertiliser (SOY 2).

Treatments without fertiliser had generally better gross margins than treatments with fertiliser because of insufficient soil moisture due to drought, which affected crop growth and the result that investments in fertiliser could not be recovered. The push-pull cropping system had better gross margins than other treatments. This could be attributed to the low input costs, since desmodium and Napier grasses are perennial crops, and once planted provide fodder in subsequent years.

8. Mechanisms of *Striga hermonthica* suppression by *Desmodium uncinatum*

In field trials in Kenya, it was discovered that inhibition of witchweed, *Striga hermonthica*, in maize –*Desmodium uncinatum* intercrops was significantly greater than that observed with other legumes, e.g. sun hemp, soybean and cowpea. The objective of this study was therefore to investigate the mechanisms by which *D. uncinatum* inhibits the parasitic plant. This could be by increasing available nitrogen, by offering shade, or by an allelopathic effect, all of which are known to give some control of these parasitic weeds.

A field trial was established to determine the role of shading, nitrogen (N) and allelopathy in striga suppression by *D. uncinatum*. The treatments were maize intercropped with *D. uncinatum* without/with 120 kg N/ha, maize monocrop without/with 120 kg N/ha, and maize monocrop with artificial ground shading made of maize straw without/with 120 kg N/ha. Emergence and attachment of *S. hermonthica* to maize was measured and maize plant height and grain yield were recorded.

To investigate the possibility of an allelochemical mechanism, effluent from *D. uncinatum* roots was used to irrigate maize planted in pots, each with approximately 3000 *S. hermonthica* seeds. Maize and *D. uncinatum* were planted in different sets of pots in previously autoclaved soil. Distilled water dripped into *D. uncinatum*-containing pots which were placed above the pots containing maize. Comparison was made between maize plants irrigated by root exudates of *D. uncinatum* against those irrigated with water passing through pots with autoclaved soil but without *D. uncinatum*. Emergence and attachment of striga to maize was monitored in all treatments.

In field trials, although soil shading and addition of nitrogen fertiliser showed some benefits against *S. hermonthica* infestation, a clear allelopathic mechanism was also observed. This was confirmed by a dramatic reduction in *S. hermonthica* infestation when eluate from *D. uncinatum* roots was introduced into pots of maize growing in soil seeded with high levels of *S. hermonthica* (Figure 5). Growth of the parasitic weed was almost completely suppressed, whereas extensive infestation occurred with the water-only control eluate. The allelopathic mechanism was found to involve inhibition of development of haustoria (growth of the striga root-like structure into the maize roots) of *S. hermonthica*.

Work is continuing to identify the compounds released from the *D. uncinatum* roots involved in suppression of the parasitic weed. Three new isoflavanones (Figure 6) and a previously known isoflavanone (genistein) have so far been isolated and characterised spectroscopically. One of the new isoflavanones (uncinanone-B) is a striga germination stimulant, and another (uncinanone-C) moderately inhibits radical growth of the germinated striga seeds.

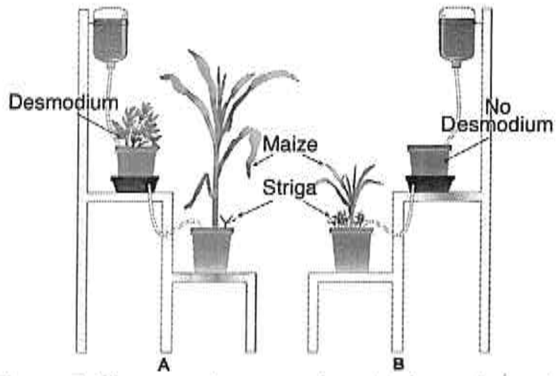

Figure 5. Diagram of an experiment to investigate the allelochemical mechanism of* Desmodium uncinatum *in suppressing* Striga hermonthica *infestation in maize. Comparison was made between maize plants potted with a high number of striga seeds and irrigated by root elutes of* D. uncinatum *(A) with those irrigated by water passing through pots containing only autoclaved soil (B)

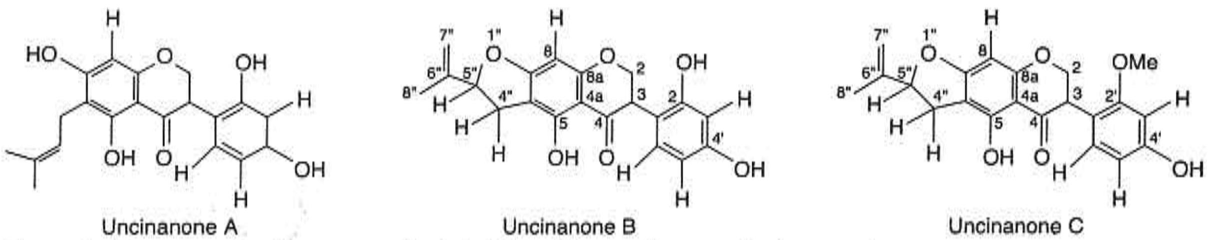

Figure 6. Three new isoflavanones isolated from* Desmodium uncinatum *roots

Uncinanone-A is inactive as a germination stimulant or as a post-germination growth inhibitor. Isolation and assays of other constituents are expected to clarify the precise biochemical traits associated with *Desmodium* effects on *Striga* spp. and to assess their bio-technological potential.

The sophisticated mode of action demonstrated here, when fully elucidated, may give more exploitable leads which are needed not only in subsistence agriculture, but also to answer future world demands in agricultural production and in developing new approaches through molecular biology research in *S. hermonthica* suppression.

9. Kairomone production by cultivated and wild hosts of *Busseola fusca* and *Chilo partellus*

Laboratory and field studies conducted in both eastern and southern Africa have demonstrated a differential attraction of gravid stemborer females, particularly *Busseola fusca* and *Chilo partellus*, to a range of cultivated and wild host plants. However, while some of the kairomones (specifically octanal, nonanal, linalool, 4-allylanisole, eugenol and naphthalene), mediating attraction to *Zea mays*, *Sorghum bicolor* and *Pennisetum purpureum* have been previously identified by ICIPE, their production by the host plants does not appear to account for the large differences in attractiveness observed in the behavioural studies. In order to provide the underpinning science base for the push-pull strategy, a more detailed understanding of the chemical ecology, particularly relating to the identity and production of kairomones mediating host location by stemborer females, is required.

The key semiochemicals associated with the cultivated hosts, *Z. mays* and *S. bicolor* and the wild grasses *P. purpureum* and *Hyperrhenia tamba* were identified by a combination of electrophysiological and chemical approaches. A total of 45 compounds, derived from air entrainment samples from all four host plants, were identified as eliciting EAG activity from either *C. partellus* or *B. fusca* antennae (Table 7). Of these 12 compounds, (Z)-3-hexen-1-ol (6), 3-methylbutyl acetate (7) α-pinene (12), 6-methyl-5-hepten-2-one (14), octanal (15), (Z)-3-hexenyl acetate (16), α-terpinolene (24), nonanal (25), linalool (26), (*E*)-4,8-dimethyl-1,3,7-nonatriene (27), methyl salicylate (32) and decanal (34) elicited responses in all four air entrainment samples. In contrast, electrophysiologically significant levels of 4-allylanisole (33) and eugenol (39) were found only in the wild hosts, *P. purpureum* and *H. tamba*, and for 4-ethylacetophenone (38), only in the *S. bicolor* volatiles. EAG activity associated with naphthalene (31) was not found in the *Z. mays* samples. Although these results are in contrast to previous studies which showed GC-EAG activity in volatile samples from *Z. mays*, *P. purpureum* and *S. bicolor* to be associated with 4-allylanisole, eugenol and naphthalene (see Khan et al., in publications list), this may simply reflect differences in overall levels of volatiles used in the two GC-EAG studies. Authentic samples of all three compounds were found to elicit significant EAG responses from both *C. partellus* and *B. fusca* antennae.

A number of compounds showed a differential response between *C. partellus* and *B. fusca*. Thus, in the GC-EAG studies, (*E*)-2-hexenal (5), pentyl acetate (9), α-copaene (40) 1,8-cineole (19) and the three unidentified compounds (2), (8) and (36) were active only against *B. fusca* female antennae while compound (3) elicited responses only from *C. partellus* (Figure 7). In addition, dose response studies with authentic compounds showed the major aldehyde components, octanal (15), nonanal (25) and decanal (34) as well as acetophenone (21), naphthalene (31) and indole (37) to elicit significantly larger EAG responses from *B. fusca* than from *C. partellus*.

Studies were also conducted to investigate the diel periodicity of semiochemical production by the cultivated and wild host plants. Particularly in the case of the wild hosts, *H. tamba* and *P. purpureum*, production of the green leaf volatiles (*E*)-2-hexenal, (Z-)3-hexen-1-ol and (Z)-3-hexenyl acetate increased dramatically during the first two hours of the scotophase, the same period when *B. fusca* and *C. partellus* female activity is highest (the first few hours of the scotophase) (Figure 8). For the rest of the night and during the photophase overall levels of production remained low. This increase in volatile production during the first two hours of the scotophase was less for *Z. mays*. Although detailed behavioural studies are required to confirm that the identified semiochemicals are associated with host location by gravid stemborer females, this elevation in volatile production by *H. tamba* and *P. purpureum* during the peak stemborer activity period could account for the differential attractiveness of the plants observed in the laboratory and field.

In addition to studies on semiochemical production by stemborer host plants, work has also been done to provide quality assurance of molasses grass (*Melinis minutiflora*) seed multiplied by the project. Volatiles collected from intact plants in Kenya grown from project seed, using the portable air entrainment system specifically developed for this purpose, were subsequently analysed by GC and GC-MS in the UK. Determination of the presence of high levels of (*E*)-4,8-dimethyl-1,3,7-nonatriene in these samples (Figure 9) was of particular importance, since this is the key compound in the push-pull strategy which mediates both repellency of gravid stemborer females and attraction of their parasitoids.

10. Economic analysis of the push-pull technologies in Suba and Trans Nzoia districts of Kenya

To determine the cost-benefit ratio, data were collected on outputs amounts (i.e. 1999–2003). In the case of an output being consumed at home, its opportunity cost was considered as the price it would fetch in the local market closest to the homestead. Where a product was sold, farm gate prices were used for the outputs. Input amounts and prices were also obtained. The costs included the transport costs involved in delivering

Table 7. Compounds in volaties of host plants active to *Busseola fusca* and *Chilo partellus*. Identified from coupled GC-EAG. Identity confirmed by co-injection on polar and non-polar GC columns and GC-MS

			Busseola fusca				*Chilo partellus*		
Compounds		Kovats index	*P. purpureum*	*H. tamba*	*S. bicolor* G	*Z. mays* 502	*P. purpureum*	*H. tamba*	*S. bicolor* G
1	(*E*)-2-pentenal	725		+					
2	unidentified	743	+	+	+				
3	toluene	755		+			+	+	
4	(*Z*)-3-hexenal?	815					+	+	+
5	(*E*)-2-hexenal	831	+		+				
6	(*Z*)-3-hexen-1-ol	852	+?	+	+	+	+		+
7	3-methylbutyl acetate	862	+	+	+	+			
8	unidentified	877				+			
9	pentyl acetate	888		+					
10	unidentified	911		+				+	+
11	benzaldehyde	934	+					+	+
12	α-pinene	934	+	+?	+	+?	+	+	+
13	propyl benzene	958			+	+	+		+
14	6-methyl-5-hepten-2-one	964	+	+	+	+		+	+
15	octanal	980	+	+	+	+	+	+	+
16	3-hexen-1-yl-acetate	984	+	+	+	+	+		+
17	hexyl acetate	995	+					+	
18	phenylacetaldehyde	1011	+		+	+	+	+	
19	1,8-cineole	1023	+			+			
20	limonene	1024	+	+	+	+			+
21	acetophenone	1039	+	+		+	+	+	
22	(*E*)-β-ocimene	1043	+	+		+	+	+	
23	methyl benzoate	1072		+		+		+	
24	α-terpinolene	1085	+	+	+	+	+	+	+
25	nonanal	1085	+	+	+	+	+	+	+
26	linalool	1087	+	+	+	+	+	+	+
27	nonatriene derivative	1106	+	+	+	+	+	+	+
28	2-ethylbenzaldehyde	1117	+?	+?	+?	+	+?	+	+
29	3-ethylbenzaldehyde	1142			+	+	+		+
30	4-ethylbenzaldehyde	1157				+			+
31	naphthalene	1169	+	+	+	no	+	+	+
32	methyl salicylate	1178	+	+	+	+	+	+	+
33	4-allylanisole	1178	+	+	no	no	+	+	no
34	decanal	1188	+	+	+	+	+	+	+
35	unidentified	1206					+		+
36	unidentified	1245			+?	+			+
37	indole	1263	+		+	+	+	+	+
38	4-ethylacetophenone	1267	+ ?	no (MS)	+	no (MS)	+	no (MS)	+
39	eugenol	1337	+		no		+		no
40	α-copaene	1386		+?	+	+			
41	(*E*)-β-caryophyllene	1432	+		+				+
42	bergamotene	1452	+		+	+	+	+	+
43	(*E*)-β-farnesene	1452	+	+ ?	+	+	+	+	+
44	humulene	1466						+	+
45	tetraene	1575	+ ?			+		+	

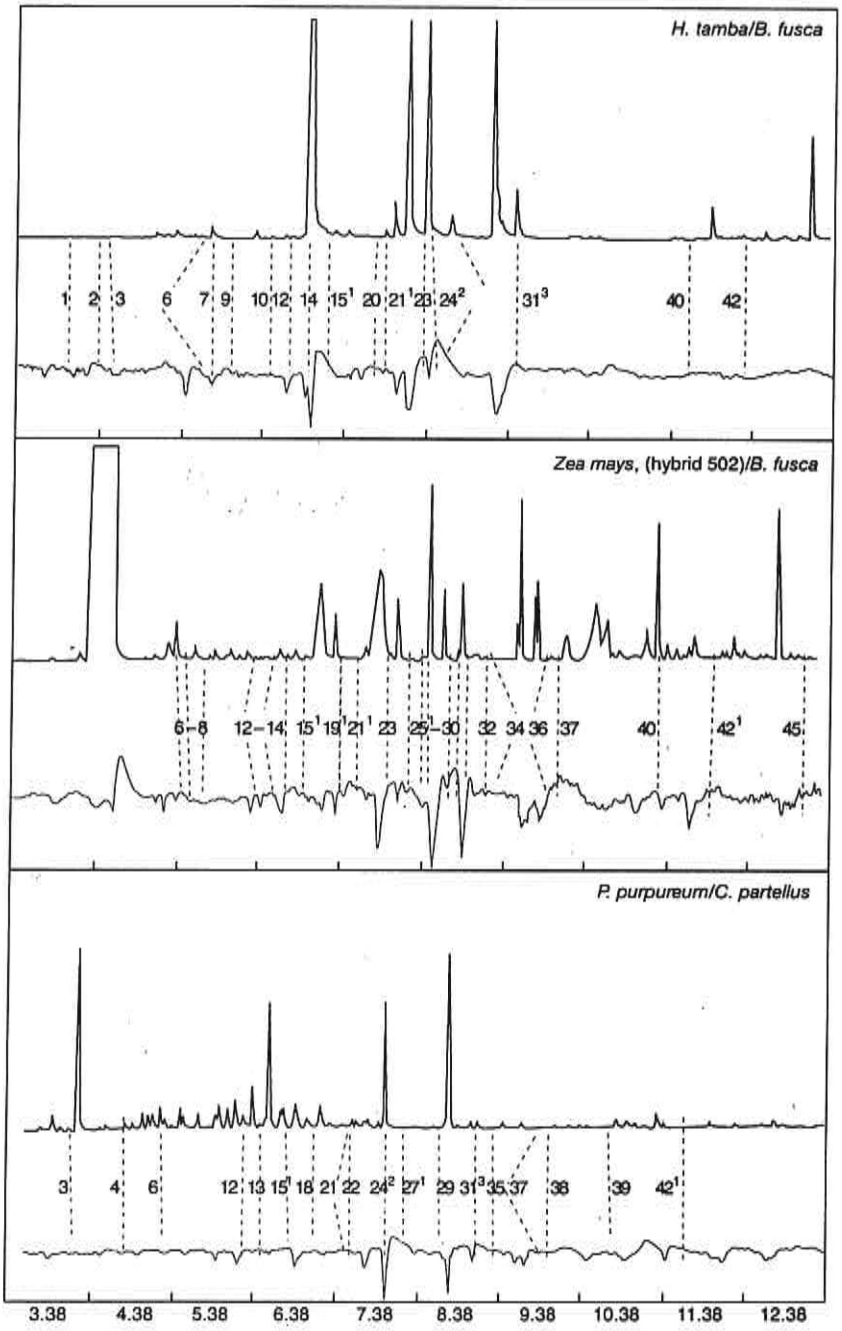

Figure 7. GC-EAG recordings of stemborers' response to host plant volatiles

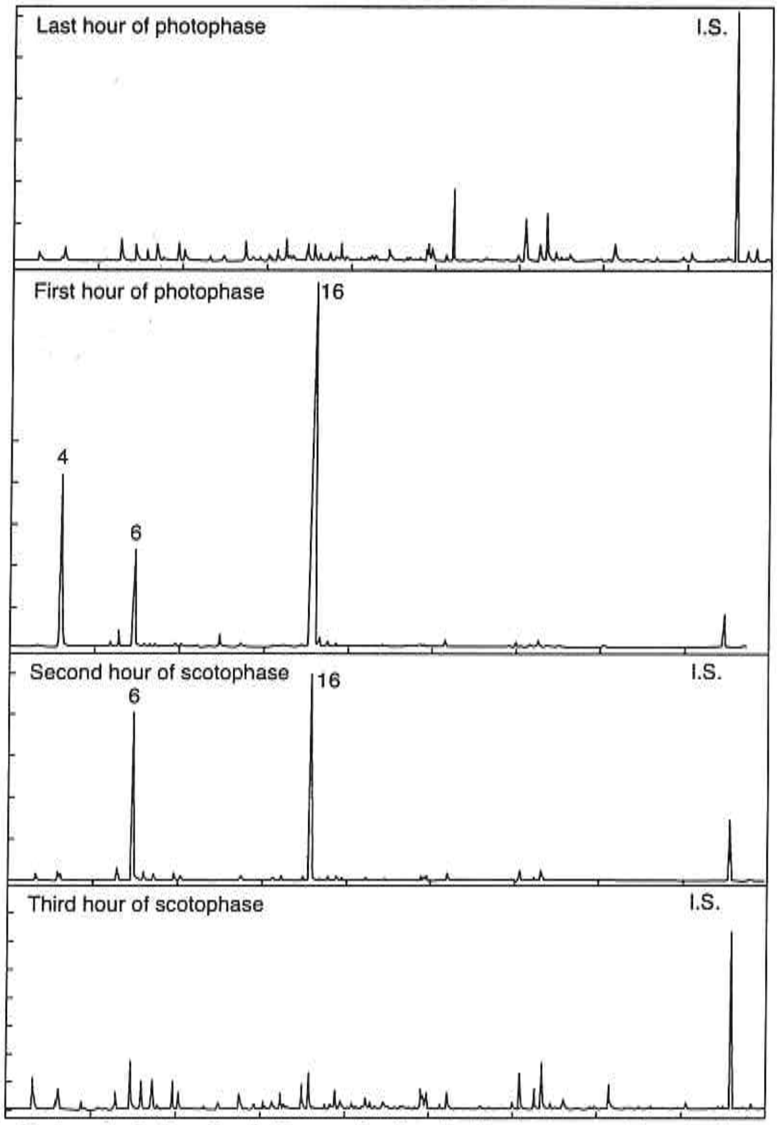

Figure 8. Diel periodicity of volatile production in Napier grass, Pennisetum purpureum

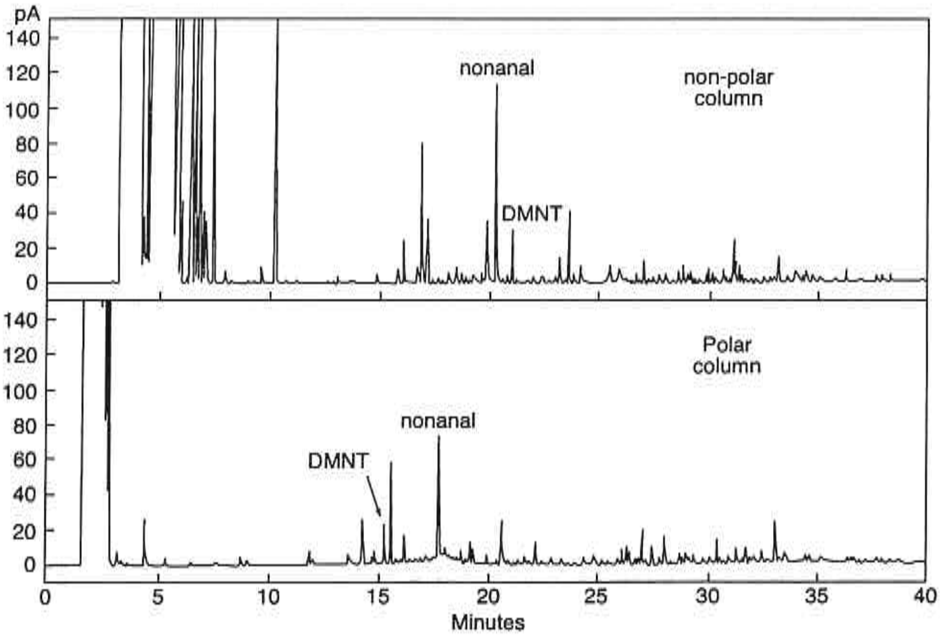

Figure 9. GC volatiles from Melinis minutiflora. *DMNT,* (E)-*4,8-dimethyl-1,3,7-nonatriene*

Table 8. Comparison of push-pull and farmers' practices. Treatments in Trans Nzoia district, Kenya

Farmer practice 1	Farmer plants hybrid maize as a monocrop. No insecticide applied
Farmer practice 2	Farmer plants hybrid maize intercropped with beans. No insecticide applied
Farmer practice 3	Farmer plants hybrid maize as a monocrop and applies insecticide to control stemborers
Technology 1 *(Planting Napier around maize)*	Farmer plants three rows of Napier grass around hybrid maize monocrop (pull component)
Technology 2 *(Push-pull: maize, Napier and desmodium)*	Farmer plants three rows of Napier around his hybrid maize crop (pull component) and intercrops maize with desmodium (push component) after every 5 rows of maize
Technology 3 *(Push-pull: maize, Napier and molasses grass)*	Farmer plants three rows of Napier around hybrid maize crop (pull component) and intercrops maize with molasses grass (push component) after every 10 rows of maize

Table 9. Comparison of push-pull with farmers' practices. Treatments in Suba district, Kenya

Farmer practice 1	Farmer plants local maize as a monocrop and does not control stemborers and striga weed
Farmer practice 2	Farmer plants local maize and intercrops it with beans but does not control striga or stemborers
Farmer practice 3	Farmer plants hybrid maize as a monocrop and does not control for stemborers and striga weed
Farmer practice 4	Farmer plants hybrid maize and intercrops it with beans but does not control for stemborers and striga weeds
Push-pull: Maize, Napier and desmodium	Farmer plants three rows of Napier around hybrid maize crop (pull component) and intercrops it with desmodium (push component)

Table 10. Economic gains due to increase in maize yield in Suba district, Kenya. Data from five farmers, 1999–2003

Economic gains from increase in maize production	Joseph Odek	Mary Rabillo	Deborah Odhiambo	Margaret Okode	Rispa Ouso
Difference in maize yield in 2003 and before push-pull	868	628	90	356	540
Best price in Kshs/kg of maize			Kshs 13		
Worst price in Kshs/kg of maize			Kshs 9		
Monetary gain due to push-pull technology in 2003 (maize price = 13 Kshs/kg)	11,284	8164	1170	4628	7020
Monetary gain due to push-pull technology in 2003 (maize price = 9 Kshs/kg)	7812	5652	810	3204	4860
Monetary gain due to push-pull technology for five years (maize price = 13 Kshs/kg)	56,420	40,820	5850	23,140	35,100
Monetary gain due to push-pull technology for five years (maize price = 9 Kshs/kg)	39,060	28,260	4050	16,020	24,300

All prices in Kenya shillings (Ksh). US$ 1.00 = Ksh 76 (2003).

Table 11. Economic gains due to increase in maize yield in Trans Nzoia district, Kenya. Data from five farmers, 1998–2003

Economic gains from increase in maize production	Lilian Wang'ombe	William Nyongesa	Bilia Nekesa	Elizabeth Kaberi	Christopher Kamau
Difference in maize yield in the year 2003 and before push pull (kg)	990	720	540	540	900
Best price of maize (Kshs/kg)			Kshs 13		
Worst price of maize (Kshs/kg)			Kshs 9		
Monetary gain due to push-pull technology in 2003 (maize price =13 Kshs/kg)	12,870	9360	7020	7020	11,700
Monetary gain due to push-pull technology in 2003 (maize price = 9 Kshs/kg)	8910	6480	4860	4860	8100
Monetary gain due to push-pull technology for six years (maize price = 13 Kshs/kg)	64,350	46,800	35,100	35,100	58,500
Monetary gain due to push-pull technology for six years (maize price = 9 Kshs/kg)	44,550	32,400	24,300	24,300	40,500

All prices in Kenya shillings (Kshs). US$ 1.00 = Kshs 76 (2003).

the input up to the farm, where applicable. If the input was available in the household, its cost in the nearest market was used as the shadow price. Labour, even when provided by members of the household, was also estimated as opportunity costs at the rates paid in the neighbourhood per day for an equivalent piece of work. Only the direct benefits and costs were considered in the analysis.

Due to the differences in climate conditions in the above two districts and the subsequent farming systems, the push-pull technology treatments and the farmer practices under observation were different. In the high potential Trans Nzoia, there were six (6) treatments involving 3 farmer practices and 3 push-pull technology variations. Table 8 summarises the treatments in Trans Nzoia district.

Data collection was started in 1998–1999 from the Trans Nzoia farmers. In the first two years, information was collected from 10 farms but this sample was increased to 45 farmers from 2001. The data available is for 6 years in Trans Nzoia, 1998–2003.

Suba district, a semi-arid agroecology, had 5 treatments which considered the variety of maize (one local and one hybrid) and cropping systems, and whether the maize was monocropped or intercropped with beans compared to the push-pull treatment where farmers intercropped maize with desmodium and surrounded it with Napier grass (Table 9).

Data collection was started in 1999 for the Suba farmers. In the first two years, information was collected from 10 farms in both districts but this sample size was increased to 25 from the year 2001. Data is available for five years from the push-pull fields, farmers were able to increase their maize yield between 90 to 868 kg in Suba district (Table 10) and between 540 to 999 kg in Trans Nzoia district (Table 11).

Calculating the economic gains using the worst and the best price for 1 kg of maize in both districts, farmers have gained between Kshs 4050 to 56,420 (± 10%) (between 540 and 999 kg) in Suba district and between Kshs 24,300 to 64,350 (± 10%) in Trans Nzoia

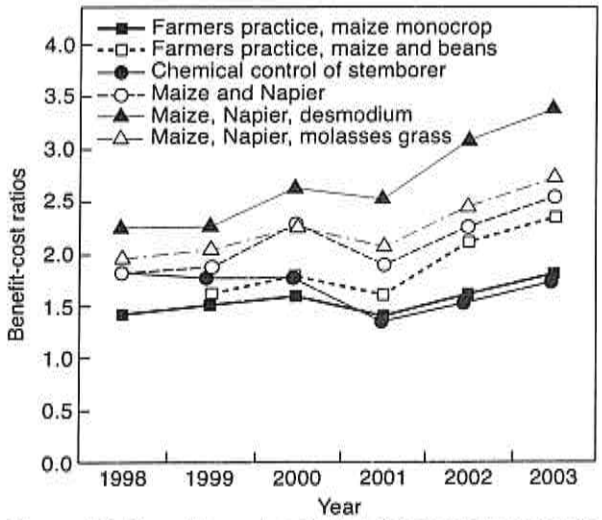

Figure 10. Benefit-cost ratio for different treatments in Trans Nzoia district

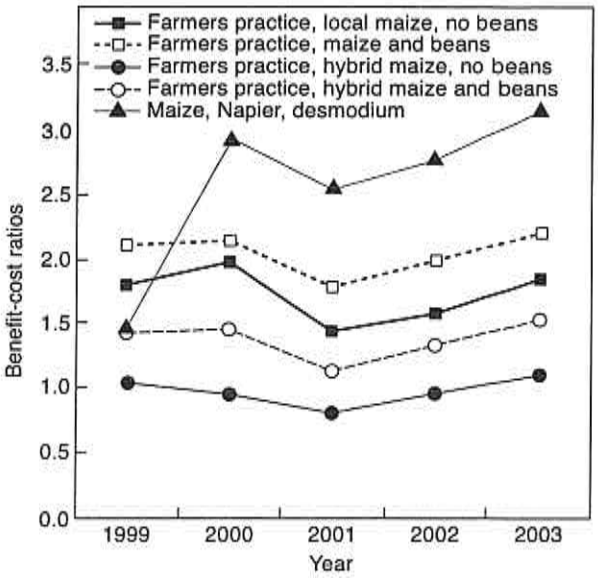

Figure 11. Benefit-cost ratio for different treatments in Suba district

district over the 5 years they have practised push-pull technology (Tables 10 and 11).

In agricultural projects of a subsistence nature, economists consider a benefit-cost ratio of 2.0 as the basis of accepting a farming enterprise as being economically viable (Impact assessment training, KARI 2001). This is because of the high climate risks farmers' experience, market failures, and distortions in output and input markets that hinder farmers from obtaining the best prices for their crops and outputs while paying higher prices for inputs than would be the case in a perfect market environment. On analysis of the treatments for the benefit-cost ratio index, the push-pull technologies posted benefit-cost ratios of greater than 2, implying the technology is efficient, thereby consistently giving farmers returns for their investments in Trans Nzoia district (Figure 10).

In Suba, local maize with beans intercrop and push-pull technology treatments registered a benefit-cost ratio of approximately 2.0 and 2.6 respectively. They are the most efficient treatments in returns to investment in the district for the subsistence smallscale farmers. Push-pull is therefore a viable technology for the farmers in this semi-arid district. The results are illustrated in Figure 11.

11. Impact on livelihood of farmers due to adoption of push-pull technology

In order to assess the impacts of push-pull technology in the farms, a total of 10 farmers were selected for in-depth interviews, five in Suba and five in Trans Nzoia district (Tables 10 and 11). They were among the first farmers to adopt push-pull technology between 1998 and 1999. A questionnaire was used to guide an in-depth discussion with the farmers. Figure 12 illustrates in summary form the impacts of the push-pull technology on the farming households, as identified by the farmers.

For instance, from their own testimonies, Lilian and John Wang'ombe have been able to own cows

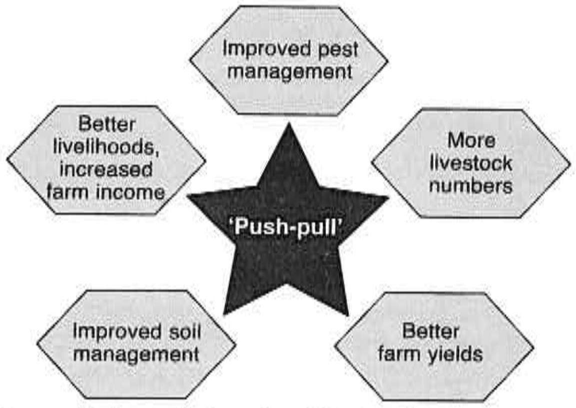

Figure 12. Impact of push-pull technology on farming households. Impressions of 10 farmers

after adopting the push-pull technology. The Odek brothers have been able to meet their basic food needs, while Mrs Mary Rabillo can supplement her cows' feed with high-protein, homemade rations.

FUTURE OUTLOOK

The habitat management project is fairly unique in the way that it has developed from basic science to technology transfer, to farmer take-up, and spontaneous technology transfer between farmers. Although the experience to date has been restricted to maize-based farming systems, the general approach is applicable to a much wider range of pest problems in a variety of crops, such as sorghum. This project is intended to be a model for other researchers in their efforts to minimise pest-induced yield losses in an economically and environmentally sustainable manner.

The push-pull approach is now expanding in Kenya and into Uganda and Tanzania. A farmer teacher programme has been initiated in Kenya where each trained farmer has to teach five new farmers a year. Sasakawa Global 2000, an international NGO, will help to expand the push-pull programme into Ethiopia and Mozambique. A pilot programme has been initiated in South Africa, addressing stemborer control in the arid and semi-arid areas of the Northern Province. Each region has, in addition to varying climate conditions and use of alternative cultivars, some differences in crops that must be taken into account, and considerable experience has been gained in this aspect by the pilot studies in various countries. Wherever these approaches are developed for the specific needs of local farming practices and communities, the scientific basis of the modified systems will be completely elucidated.

Using push-pull strategies, field trials have been initiated in South Africa on the development of resistance management for transgenic maize. This strategy will use fodder grasses such as Napier grass as trap plants, which are highly attractive to ovipositing stemborers but do not allow stemborer development. On the other hand, the repellent plants such as molasses grass, which not only repel ovipositing stemborers (push) from the main crop, but also are highly attractive to natural enemies, are used. Combining the push-pull strategy with *Bt* maize, it may be possible to reduce the selection pressure on transgenic maize by the stemborer population. The increased population of natural enemies in *Bt* maize fields could also help in significantly reducing the number of *Bt*-resistant stemborer larvae, which eventually would develop into *Bt*-resistant moths.

CAPACITY BUILDING

PhD students

Mohamed Hassan Mohamud (Somalia). Interactions between *Striga hermonthica* (Del.) Benth, and stemborer *Chilo partellus* (Swinhoe) (Lepideptora: Pyralidae) on maize plant (*Zea mays*). Kenyatta University, Kenya.

Charles Midega (Kenya). Impact of a habitat management system and *Bt*-maize on stemborer natural enemies and biodiversity of ground-dwelling arthropods and soil fauna in Africa. Kenyatta University, Kenya.

Esther Njuguna (Kenya). Push-pull technology for the control of stemborer in the Lake Victoria region: Hidden impacts on the farming systems. University of Nairobi, Kenya.

IMPACT

- Over 1500 'push-pull' farmers have at least doubled their maize yields and increased milk production by 50%.
- Fodder produced by 2000 'push-pull' farmers contribute in production of one million litres of milk annually.
- 500 smallscale farmers produce desmodium seed for income generation and are linked to a private seed company.
- Extra income for 'push-pull' has helped more than 300 farmers to send at least one child to secondary school.
- By end of 2006, at least 10,000 farmers will benefit from 'push-pull' strategy.
- By 2006, at least 3 tonnes of desmodium seed will be produced annually by 1000 smallscale farmers.

OUTPUT

Journal articles

Khan Z. R., Hassanali A., Overholt W., Tsanuo M. K., **Hooper A. M., Pickett J. A., Wadhams L. J. and Woodcock C. M. (2002)** Control of witchweed *Striga hermonthica* by intercropping with *Desmodium* spp., and the mechanism defined as allelopathic. *Journal of Chemical Ecology* 28, 1871–1885. **(Call No.: 02-1649)**

During investigations into the control of insect damage to maize crops in subsistence farming in Kenya, which involved intercropping with repellent plants, the fodder legumes silverleaf *(Desmodium uncinatum)* and greenleaf *(D. intortum)* were also found to reduce dramatically the infestation of maize by parasitic witchweeds such as *Striga hermonthica*. This effect was confirmed by further field testing and shown to be significantly greater than that observed with other legumes, e.g., cowpea, as were the concomitant yield increases. The mechanism was investigated, and although soil shading and addition of nitrogen fertilizer showed some benefits against *S. hermonthica* infestation, a putative allelopathic mechanism for *D. uncinatum* was observed. In screenhouse studies, a highly significant reduction in *S. hermonthica* infestation was obtained when an aqueous solution, eluting from pots in which *D. uncinatum* plants were growing, was used to irrigate pots of maize planted in soil seeded with high levels of *S. hermonthica*. Growth of the parasitic weed was almost completely suppressed, whereas extensive infestation occurred with the control eluate. Laboratory investigations into the allelopathic effect of *D. uncinatum*, using samples of water-soluble chemical components exuded from cleaned roots, demonstrated that this involved a germination stimulant for *S. hermonthica* and also an inhibitor for haustorial development.

Gohole L. S., Overholt W. A., Khan Z. R., **Pickett J. A. and Vet L. E. M. (2003)** Effects of molasses grass, *Melinis minutiflora* volatiles on the foraging behavior of the cereal stemborer parasitoid, *Cotesia sesamiae*. *Journal of Chemical Ecology* 29, 731–745. **(Call No.: 03-1678)**

Olfactory responses of the cereal stemborer parasitoid *Cotesia sesamiae* to volatiles emitted by gramineous host and nonhost plants of the stemborers were studied in a Y-tube olfactometer. The host plants were maize (*Zea mays*) and sorghum (*Sorghum bicolor*), while the nonhost plant was molasses grass (*Melinis minutiflora*). In single-choice tests, females of *C. sesamiae* chose volatiles from infested and uninfested host plants and molasses grass over volatiles from the control (soil). In dual-choice tests, the wasp preferred volatiles from infested host plants to those from uninfested host plants. There was no discrimination between molasses grass volatiles and those of uninfested maize, uninfested sorghum, or infested maize. The wasp preferred sorghum volatiles over maize. Combining uninfested maize or sorghum with molasses grass did not make volatiles from the combination more attractive as compared to only uninfested host plants. Infested maize alone was as attractive as when combined with molasses grass. Infested sorghum was preferred over its combination with molasses grass. Local growth conditions of the molasses grasses influenced attractiveness to the parasitoids. Volatiles from Thika molasses grass were attractive, while those from Mbita molasses grass were not. Growing the Thika molasses grass in Mbita rendered it unattractive and *vice versa* with the Mbita molasses grass. This is a case of the same genotype expressing different phenotypes due to environmental factors.

Gohole L. S., Overholt W. A., Khan Z. R. **and Vet L. E. M. (2003)** Role of volatiles emitted by host and non-host plants in the foraging behaviour of *Dentichasmias busseolae*, a pupal parasitoid of the spotted stemborer *Chilo partellus*. *Entomologia Experimentalis et Applicata* 107, 1–9. **(Call No.: 03-1722)**

The role of volatiles from stemborer host and non-host plants in the host-finding process of *Dentichasmias busseolae* Heinrich (Hymenoptera: Ichneumonidae) a pupal parasitoid of *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae) was studied. The non-host plant, molasses grass (*Melinis minutiflora* Beauv. (Poaceae)), is reported to produce some volatile compounds known to be attractive to some parasitoid species. The studies were conducted to explore the possibility of intercropping stemborer host plants with molasses grass in order to enhance the foraging activity of *D. busseolae* in such a diversified agro-ecosystem. Olfactometric bioassays showed that volatiles from the host plants maize, *Zea mays* L., and sorghum, *Sorghum bicolor* (L.) (Poaceae), were attractive to the parasitoid. Infested host plants were the most attractive. Volatiles from molasses grass were repellent to the parasitoid. Further tests showed that volatiles from infested and uninfested host plants alone were preferred over those from infested and uninfested host plants combined with the non-host plant, molasses grass. In dual choice tests, the parasitoid did not discriminate between volatiles from maize infested by either of the two herbivore species, *C. partellus* or *Busseola fusca* Fuller (Lepidoptera: Noctuidae). Volatiles from sorghum infested by *C. partellus* were preferred over those from *C. partellus*-infested maize. The study showed that the pupal parasitoid *D. busseolae* uses plant volatiles during foraging, with those from the plant–herbivore complex being the most attractive. The fact that volatiles from molasses grass were deterrent to the parasitoid suggested that intercropping maize or sorghum with molasses grass was not likely to enhance the foraging behaviour of *D. busseolae*. Volatiles from the molasses grass may hinder *D. busseolae*'s host location efficiency.

Midega C. A. O. **and** *Khan Z. R.* **(2003)** Impact of a habitat management system on diversity and abundance of maize stemborer predators in western Kenya. *Insect Science and Its Application* 23, 301–308. **(Call No.: 03-1717)**

Studies were conducted in farmer's field, Lambwe School of the Deaf, and Mbita Point Field Station of ICIPE (ICIPE-Mbita) in western Kenya during the long rains of 2001 and 2002 to assess the impact of a diversionary stemborer management strategy on the pest's predators. Treatments consisted of a maize monocrop (control) and an intercrop of maize and desmodium, *Desmodium uncinatum* Jacq., with Napier grass, *Pennisetum purpureum* (Schumach), as trap crop around the field ('push-pull') in the farmer's field and Lambwe School of the Deaf. Sudan grass, *Sorghum vulgare sudanense* (Pers.), was used in place of Napier on the station. A combination of sticky traps, direct observation and hand-collection methods were employed. Predator groups encountered included 12 families from 7 insect orders and 4 families from one arachnid order, with most of the foregoing represented in both maize monocrop and 'push-pull' plots. A *Cheilomenes* sp. and *Chrysopa* sp. were, however, recovered from 'push-pull' plots only. Ants, earwigs and spiders were the main predators encountered. Both overall and individual group populations of these predators as well as ant diversity were significantly higher in 'push-pull' than monocrop plots in all the sites during the vegetative, flowering and mature maize growth stages ($P < 0.05$, t-test). The results thus indicate a numerical enhancement of stemborer predators by use of this habitat management system.

Tsanuo M. K., Hassanali A., **Hooper A. M.,** *Khan Z.*, **Kaberia F., Pickett J. A. and Wadhams L. J. (2003)** Isoflavanones from the allelopathic aqueous root exudate of *Desmodium uncinatum*. *Phytochemistry* 64, 265–273. **(Call No.: 03-1751)**

Three isoflavanones, 5,7,2',4'-tetrahydroxy-6-(3-methylbut-2-enyl)-isoflavanone (**1**), 4",5"-dihydro-5,2',4'-trihydroxy-5"-isopropenylfurano-(2",3",7,6)-isoflavanone (**2**) and 4",5"-dihydro-2'-methoxy-5,4'-dihydroxy-5"-isopropenylfurano-(2",3",7,6)-iso-flavanone (**3**) and a previously known isoflavone 5,7,4'-trihydroxyisoflavone [genistein (**4**)] were isolated and characterised spectroscopically from the root exudate of the legume *Desmodium uncinatum* (Jacq.) DC. We propose the names uncinanone A, B and C for compounds **1**, **2** and **3**, respectively. Isolated fractions containing uncinanone B (**2**) induced germination of seeds from the parasitic weed *Striga hermonthica* (Del.) Benth. and fractions containing uncinanone C (**3**) moderately inhibited radical growth, the first example of a newly identified potential allelopathic mechanism to prevent *S. hermonthica* parasitism.

Book chapters

Khan Z. R. **(2002)** Cover crops, pp. 155–158. In *Encyclopedia of Pest Management* (Edited by D. Pimentel). Marcel Dekker Inc., New York. **(Call No. 02-1756)**

Khan Z. R., Overholt W. A. **and** *Ng'eny-Mengech A.* **(2003)** Integrated pest management case studies from ICIPE, pp. 441–452. In *Integrated Pest Management in the Global Arena* (Edited by K. M. Maredia, D. Dakouo and D. Mota-Sanchez). CAB International, UK. **(Call No. 03-1740)**

Conferences attended and papers presented

International Conference on IPM in Sub-Saharan Africa, Kampala, Uganda. 8–12 September 2002. Presentation on 'Integrated management of cereal stemborers and striga weed in maize-based farming systems in Kenya'. Z. R. Khan.

The Rockefeller Foundation's Conference on Biotechnology, Breeding and Seed Systems for African Crops. Entebbe, Uganda, 3–8 November 2002. Invited lecture on 'Control of witchweed, *Striga hermonthica*, by intercropping with *Desmodium* spp.'. Z. R. Khan.

2nd International Agronomy Congress, Indian Agricultural Research Institute, New Delhi, India, 26–30 November, 2002. Invited presentation on 'Push-pull strategy: Utilisation of agricultural biodiversity for integrated pest management in Africa'. Z. R. Khan.

Entomological Society of America Annual Meeting, Cincinnati, Ohio, USA, 26–30 October, 2003. Albert B. Sabin Cincinnati Convention Center. Invited Symposium Presentation on 'Combined use of trap and repellent plants in a 'push-pull strategy to control cereal stemborers (Lepidoptera: Pyralidae; Noctuidae) in Africa'. Z. R. Khan.

National Symposium on Frontier Areas of Entomological Research, Indian Agricultural Research Institute, New Delhi, India. 5–7 November 2003. Invited Plenary Lecture on 'Chemical ecology based push-pull strategy for insect pest management'. Z. R. Khan.

Research proposals

Integrated pest and soil management to combat *Striga*, stemborers and declining soil fertility in the Lake Victoria basin. Funded.

Implementation and dissemination of habitat management strategies for maize and sorghum production in eastern Africa (2003–2006). Funded.

Coordination of on-farm expansion of the habitat management strategies for maize and sorghum production in eastern Africa (2003–2006). Funded.

Implementation and dissemination of 'push-pull} habitat management strategies for control of stemborers and striga weed in maize-based farming systems in eastern Tanzania. Funded.

Participating scientists: Z. Khan (Project leader), A. Hassanali

Assisted by: N. O. Dibogo, D. O. Nyagol, G. O. Genga, A. O. Ndiege, S. M. Mokaya, S. G. Ogechi, S. Juma

Collaborators: Rothamsted Research, Harpenden (UK); Kenya Agricultural Research Institute (KARI); Ministry of Agriculture (Kenya); National Agricultural Research Organisation (NARO), Uganda; Ethiopian Agricultural Research Organisation (EARO), Ethiopia; Ministry of Agriculture and Food Security (Tanzania); Sasakawa Global 2000, Addis Ababa (Ethiopia); CIMMYT; TSBF-CIAT

Donors: Gatsby Charitable Foundation (UK), DFID, Rockefeller Foundation

BIOLOGICAL CONTROL OF CEREAL STEMBORERS IN EAST AND SOUTHERN AFRICA

BACKGROUND, APPROACH AND OBJECTIVES

A new 4-year project started in the second quarter of 2002. The Project builds and extends on the results of past efforts in East and southern Africa on biological control of stemborers. Additionally, the project will test and disseminate habitat management techniques for stemborer and striga weed control which are compatible with biological control (BC) and have been shown to enhance activity of natural enemies. The Project technically and financially supports activities in 11 countries, including Eritrea, Ethiopia, Kenya, Madagascar, Malawi, Mozambique, Uganda, Tanzania, Zambia, Zanzibar and Zimbabwe. Each of the above countries manages its own project, initiated in the previous phase, with the exception of Madagascar. These projects are linked in a network coordinated by ICIPE, who provides training for partner countries and conducts scientific research to support implementation of biological control and habitat management.

Activities include collection of baseline ecological information on distribution of stemborers and associated natural enemies in cultivated and wild habitats; release of natural enemies at targeted locations; and economic and biological impact assessments. Biological control and habitat management techniques are being integrated into small maize systems in a participatory manner and training at all levels, from farmers to graduate students, is a primary feature of the project. In addition to the work on cereals stemborers, new exotic targets amenable to classical biological control are being identified, to capitalise on the expertise developed over the years in national programmes and at ICIPE.

ICIPE's responsibilities in the project are to:

- identify new natural enemies;
- conduct basic research to predict the efficiency of a natural enemy and its effects on non-target species;
- mass-rear natural enemies for collaborating countries;
- examine the macro-economic impact of BC of stemborers on cereal production in the eastern and southern Africa region (ESA) using field data, modelling and GIS;
- conduct R&D of other IPM techniques (e.g. habitat management);
- gather information on new exotic pests amenable to biological control;
- organise short-term training courses for NARES scientists, supervise graduate students, assist countries with extensionist and farmers training.

The activities of the national programmes are to:

- conduct country-wide surveys on pest distribution;
- conduct biological studies in the laboratory and field;
- mass-rear natural enemies;
- conduct post-release surveys to determine establishment;
- study the impact of BC on pest composition and on crop yield;
- gather information on exotic pests amenable to BC;
- study the integration of BC with other IPM tactics, such as habitat management;
- organise training of extensionists and farmers.

Three planning workshops were held over the review period to establish the network. Principal investigators for each country programme were made responsible for the implementation of project activities, reporting (both technical and financial) and development for in-country research network. A steering committee was inaugurated in 2002 with one representative per country and two representatives from ICIPE. The planning workshops attended by 37 participants, were combined with courses in statistics, sampling procedures and taxonomy.

WORK IN PROGRESS

A. Regional Activities

1. Madagascar

Surveys

Field surveys were carried out in the highlands of the country in the four main regions, Antananarivo, Antsirabe, Itasy and Fianarantsoa, to inventory the stemborer species and their natural enemies, their spatial distribution, the degree of infestation and damage to maize. Four stemborer species, *Sesamia calamistis, Chilo sacchariphagus, Busseola fusca* and *Sciomesa biluma*, were found to be common in the areas surveyed. *Sesamia calamistis* was recorded in 80% of the sites sampled, from 1210 to 1453 masl. Various age classes were recovered from the stems as well as from the cobs. *Chilo sacchariphagus* was almost absent except in one site in the northern part of Fianarantsoa where it was abundant; it was hardly found in the three other regions. *Busseola fusca* was recorded at three sites at the northern part of Fianarantsoa at 1287 masl and in three sites in Antananarivo region.

Wild host plant surveys were conducted in fields in the four regions where surveys on maize had been done. Infested plants were located and stemborer species were collected. Insect rearing and identification were condutced in the laboratory. Nine species of host plants were recorded: *Saccharum officinarum*, *Sorghum* sp., *Panicum maximum*, *Hyparrhenia rufa*, *H. cymbaria*, *Cymbopogon citratus*, *Pennisetum polystachion*, *Pennisetum kisozi*, *Phragmites* sp. Six species out of nine were infested by *Sesamia calamistis*. *Chilo* spp. frequently infested *Hyparrhenia* spp.

> ***Participating scientists:*** J. Ravololonandrianina, N. Rahalivavololona, L. Ravaomanarivo
>
> ***Assisted by:*** H. T. Andrianaivo, L. A. Rasamizafy

2. Eritrea

Releases of parasitoids

Cocoons of the parasitoid *Cotesia flavipes* were imported from ICIPE for release in Eritrea on 5 October, 2003. About 100,000 cocoons were imported, of which 50,000 were released in each of Alla and Hamelmalo areas where the incidence of *Ch. partellus* is very high. Another import was made in November 2003 for releases in Tesseney and along the coast of the Red Sea.

Surveys

Surveys of lepidopteran stemborers were done in major sorghum, maize and millet growing areas of the highlands and eastern and western lowlands and coastal region of Eritrea from January to September 2003. Six lepidopteran stemborer species were found on sorghum, maize and pearl millet in different agroecological zones of the country (Table 1). *Busseola fusca* and *S. calamistis* on sorghum and maize, and an unknown pyralid on pearl millet were the main stemborer species recorded in the highlands (Table 1). *Busseola fusca* was the dominant pest attacking these three crops. *Sesamia calamistis* reached only small populations and caused damage at head setting and milk stages of the crops and mostly on sorghum heads partially covered by the last sheath leaf.

In the western lowlands (550 to 1400 m), *Ch. partellus*, *S. calamistis* and an unknown pyralid were the most important stemborer species. In this region *Ch. partellus* is the major stemborer of sorghum, pearl millet and maize. *Chilo orichalcociliellus*, *Ch. partellus* and *S. calamistis* were the stemborer species recorded in the eastern lowland and coastal region of the Red Sea in Sheib and Zula. In these areas *Ch. partellus* was again the major stemborer, followed by *Ch. orichalcociliellus* in Zula. According to growers, the population of stemborers in the coastal region sometimes reached very high levels, causing complete crop failure. *Chilo orichalcociliellus* was recorded both in stems and on heads of the sorghum.

Cultivated sorghum, maize and pearl millet were frequently found infested with high stemborer population in all agroecological zones. In the highlands, wheat, barley, African finger millet and unidentified grasses were attacked by young stemborer (*B. fusca* ?) larvae, causing deadheart. Among the wild host plants, *Sorghum halepensis*, *S. arundinaceum*, *Pennisetum* spp. and *Hyparrhenia* spp. were found with high infestations of stemborers throughout the survey period. Ants, earwigs and spiders were observed as predators of stemborer larvae.

> ***Participating scientists:*** Adugna Haile, Kidane Negassi
>
> ***Collaborators:*** Ministry of Agriculture

3. Malawi

Habitat management strategies for stemborer and witchweed control

Malawi established four on-station and 10 on-farm habitat management trials, in collaboration with NGOs, extension and livestock officials and researchers. Five farmers were chosen around Bvumbwe and the other five from the Shire valley at Ngabu. The main objective of this study was to assess the effects of intercropping maize with other cereals and some legumes on the infestation levels of cereal stemborers. At both sites, plots with maize as a pure stand had the lowest stand count and also significantly more witchweed (*Striga* spp.) and stemborer infestations, and significantly fewer numbers of cobs compared to maize with desmodium or maize with desmodium and Napier or Banda grass ($P < 0.05$). *(See also the previous report on the push-pull strategy.)*

In a mixed cropping experiment during winter of 2003, maize intercropped with cowpea surrounded by sorghum had higher yields than pure maize crops ($P < 0.05$).

Table 1. Lepidopteran stemborer species recorded on sorghum, maize and pearl millet in Eritrea, 2003

Common name	Scientific name	Family	Distribution altitude (m)	Pest status
Maize stemborer	*Busseola fusca* Fuller	Noctuidae	1450 – 2350	Major
Spotted stemborer	*Chilo partellus* Swinhoe	Pyralidae	20 – 1400	Major
Pink stemborer	*Sesamia calamistis* Hampson	Noctuidae	15 – 2000	Minor
Pink stemborer	*Sesamia* spp.	Noctuidae	0 – 1200	Minor
Coastal stemborer	*Ch. orichalcociliellus* Strand	Pyralidae	15 – 100	Minor
Pearl millet stemborer	Unknown crambid	Pyralidae	15 – 1800	Minor

Release, establishment and spread of exotic parasitoids

Cotesia flavipes was again released in areas where *Chilo* was the major pest, especially in the southern region. Additional release sites were identified in Mulanje and Nsanje and Zomba. During the months of June, July and August post-release surveys were carried out in previous release sites to monitor the current status of stemborers and the establishment of *Co. flavipes.* The parasitoid was recovered from most release sites. In Mulanje, *Xanthopimpla* sp. was collected. ICIPE will send *X. stemmator* for mass releases. As more winter crops are being grown in Mulanje, Nsanje and Chikwawa districts, more releases are planned in areas where the natural enemy has not yet been recovered.

Farmers' perception of stemborers

Most farmers questioned responded that stemborers, locally known as *kapuchi,* were a serious problem, especially in winter. While most farmers responded that they did nothing to control stemborers in their gardens, some reported that they applied chemicals such as carbaryl and pyrethroids. Farmers that apply chemicals are those that also grow cotton, as they use the left-over chemicals after spraying their cotton fields.

Participating scientists: E. Kapeya, E. Muwalo

Collaborators: Bvumwe Agricultural Research Station

4. Zimbabwe

Cotesia flavipes *post-release surveys*

Four years after the initial release of *Co. flavipes* in Zimbabwe (see publications list for Chinwada et al., 2001; Chinwada, 2002), no firm conclusions can yet be drawn as to whether or not successful establishment occurred. Since their inception, surveys in release locations have been hampered by a crippling fuel crisis that is now in its fourth year. All *Cotesia* specimens collected were *Co. sesamiae.* It is felt that though difficult, these surveys are still necessary as release and establishment of *Co. flavipes* in all *Chilo partellus* 'hotspots' in the region is a key activity of the current PPRI/ICIPE project. In order to make trips to the release sites more meaningful and cost-effective, simultaneous release of parasitoids at the time of the sampling visits is being considered.

Cotesia sesamiae *and* Sturmiopsis parasitica *overwintering/seasonal carryover mechanisms*

Cotesia sesamiae and *Sturmiopsis parasitica* are both common larval parasitoids of *B. fusca* in the highlands of Zimbabwe. In contrast to *S. parasitica, Co. sesamiae* develops successfully in *S. calamistis.* While it has been shown that *S. parasitica* overwinters in diapausing *B. fusca,* the overwintering mechanism of *Co. sesamiae* is not known. Thus, two possible carryover mechanisms were investigated: (a) carryover as quiescent cocoons, and (b) continuous development on non-diapause stemborer populations that probably infest winter-grown wheat during the dry season.

For possible carryover as quiescent cocoons, all cocoons found in plant tunnels were first examined under a microscope to check for adult emergence. A marked reduction in percentage adult emergence towards the end of the season would be an indication for a quiescent state of the parasitoid. For possible carryover of *Co. sesamiae* in non-diapause stemborer populations in winter-grown wheat, wheat fields in the Harare area were checked for stemborer damage symptoms (leaf scarification/'window-paning' and 'deadhearts'). Plants exhibiting such symptoms were removed and taken to the laboratory for dissection. Larvae found feeding inside stems were reared on maize stems (glasshouse-grown) for identification (at the adult stage) and determination of their fate.

Results showed that there was no discernible difference in adult emergence patterns among cocoon masses collected or emerged from larvae at different times during the growing season. Similarly, there was no indication that the parasitoid could survive through non-diapause host larvae that probably move over to winter-grown wheat at the end of the normal maize and sorghum cropping season. Thus, no firm conclusions can yet be drawn regarding the two possible carryover mechanisms for *Co. sesamiae.* By contrast, earlier studies reported overwintering of *S. parasitica* in diapausing *B. fusca* larvae, from which it emerges at termination of the diapause; consequentely there is no likelihood of the braconid sharing the same overwintering mechanism with *S. parasitica.*

Participating scientists: P. Chinwada, E. Zitsanza

Collaborators: Plant Protection Research Institute, Zimbabwe; University of Zimbabwe

5. Uganda

Pre-release surveys and releases in western and eastern Uganda

Results from the sampling during pre-release surveys of *Cotesia flavipes* indicate that *Chilo partellus* was the predominant stemborer (> 70%) in eastern Uganda with the exception of the districts of Jinja and Kamuli, where 50% of the stemborers collected were *Busseola fusca.* In western Uganda, over 50% of the stemborers were *B. fusca* while *Ch. partellus* accounted for 11–44%. Further work on *Co. flavipes* will only be conducted in districts/areas with *Ch. partellus* stemborer populations of over 40%. *Cotesia flavipes* was recovered from 6 sites out of 9 in Tororo district implying that the parasitoid had already colonised the area from Iganga and Mbale where it is already established. No *Co. flavipes* was recovered from Bugiri, Kamuli and Jinja.

Three consignments of *Co. flavipes* parasitoids cocoons were received from ICIPE and a total of 98,900 wasps were released in these regions. Fields of sorghum or maize at least 6 weeks old were selected for release and 20 plants showing stemborer damage were sampled from each field before release to monitor the stemborer species composition and determine expansion of the parasitoid from previous releases. Collected stemborers were identified and brought to the laboratory for rearing to assess rate of parasitism.

Post-release data at the four sites visited shows that *Co. flavipes* has colonised these areas. Monitoring was also conducted in Kumi and Soroti districts and parasitism of *Ch. partellus* was found to be 37.1% and 52.3%, respectively. These results show that the parasitoid has colonised extensive areas since some of the fields sampled were located far from previous 1998–2000 release sites.

Abundance and distribution of wild host plants of cereal stemborers

Wild host surveys were conducted in five agroecological zones (AEZs) where maize and sorghum are important food and cash crops. Two surveys were carried out, one during the dry season (February–March) and the other during a cropping season (May–July). Four stemborer species (*Ch. partellus, B. fusca, S. calamistis, E. saccharina*) and two unknown stemborers were recovered from wild hosts. Many grasses showed stemborer damage, however only eight grass species harboured stemborer larvae and pupae. It was also observed that *S. calamistis* had a wider range of hosts compared to the other stemborer species. Stemborer populations were very low on these grasses. *Cotesia* spp. cocoons were obtained from *Ch. partellus* and *S. calamistis* larvae in *Sorghum arundinaceum*.

Participating scientists: J. Ogwang, S. Kyamanywa

Assisted by: T. K. Matama

Collaborators: National Agricultural Research Organisation (NARO), Makerere University

6. Mozambique

Country-wide surveys

Several country-wide surveys were carried out in the southern, central and northern provinces for stemborers and their associated natural enemies on maize. The surveys were concentrated in Xai Xai, Moamba, Manhiça, Machipanda, Nhamatanda, Lichinga, Nhacoongo, Matutuine and Guija.

Three stemborer species including the exotic *Chilo partellus* and the native *Busseola fusca* and *Sesamia calamistis* were found. With the exception of *B. fusca*, which was found only at Machipanda and Lichinga, *Ch. partellus* and *S. calamistis* were found at all locations. Table 2 shows stemborer abundance, number of stemborers per plant and levels of plant infestation at each location. With the exception of Machipanda and Lichinga, *Ch. partellus* was the most abundant stemborer species at all locations. At Machipanda, both *Ch. partellus* and *B. fusca* occurred in nearly equal proportions of 55.1 and 44.4%, respectively; *B. fusca* was the most abundant at Lichinga accounting for more than 90%. Often two or all of the three borers were found together in the same plant or part of the plant (stalk, tassels and cobs). Significant differences were found in stemborer infestations among sites (Table 2).

Larval and pupal parasitoids including the introduced *Co. flavipes* and several indigenous parasitoids were grouped according to stemborer species from which they emerged. The exotic parasitoid *Co. flavipes* was recovered at all sampling sites and reared from field-collected larvae of all the three stemborer species. Again, significant differences in parasitism were found among sites on both stemborer species (Table 3). Most of *Co. flavipes* cocoon masses were reared from *Ch. partellus* larvae.

Other parasitoids collected were *Trichogramma* sp., the larval parasitoids *Co. sesamiae, Syzeuctus ruberrimus* Benoit (Hymenoptera: Ichneumonidae), *Stenobracon rufa* (Hymenoptera: Braconidae) and *Sturmiopsis parasitica* (Diptera: Tachinidae) and the pupal parasitoids *Dentichasmias busseolae* Heinrich, *Pediobius furvus* (Gahan) (Hymenoptera: Eulophidae) and *Procerochasmias nigromaculatus* (Cameron) (Hymenoptera: Ichneumonidae). Of these, *Trichogramma* sp., *Co. sesamiae* and *D. busseolae*, egg, larval and pupal parasitoids, respectively, were the most abundant and widespread. The highest levels of parasitism were 78.4% due to *Trichogramma* sp. on *Ch. partellus* eggs, 22.9% due to *Co. sesamiae* on *Ch. partellus* larvae and 69.2% due to *P. nigromaculatus* on *B. fusca* pupae.

Impact of natural enemies using exclusion methods

A total of three trials to evaluate the impact of natural enemies on the stemborer populations were installed at each of three agroecologically different zones: South, central region and northern region. The impact of egg, larval and pupal parasitoids was assessed. Yield loss due to stemborers was evaluated as well as stemborer and parasitoid population abundance. Three stemborer species were registered at the study locations: *Ch. partellus* and *S. calamistis* at Chokwe and *Ch. partellus* and *B. fusca* at Machipanda. *Chilo partellus* was the most abundant in the lowland area (Chokwe), accounting for 87.7% of the total stemborer population collected from the field, while at Machipanda, *Ch. partellus* and *B. fusca* occurred

Table 2. Number of stemborers per infested maize plant and stemborer species composition and abundance at some *Cotesia flavipes* release sites in Mozambique

			Cumulative number of borers by species		
Location	% infestation	Stemborers/ plant	*Chilo partellus*	*Sesamia calamistis*	*Busseola fusca*
Xai Xai	–	2.5 ± 27.1 a	368.0 ± 20.0	81.0 ± 8.0	–
Moamba	–	2.1 ± 19.1 a	385.0 ± 19.1	45.0 ± 3.9	–
Manhiça	58.5 ± 11.8 a	1.2 ± 6.4 b	227.0 ± 7.3	19.0 ± 2.2	–
Machipanda	55.5 ± 14.6 a	1.0 ± 3.4 b	109.0 ± 4.4	7.0 ± 1.1	82.0 ± 3.4
Nhamatanda	70.0 ± 11.1 a	1.1 ± 7.5 b	265.0 ± 7.2	9.0 ± 0.8	–

(–) Stemborer species not recorded; means with the same letter in a column are not significantly different (SNK, P > 0.05).

Table 3. Levels of parasitism due to the exotic parasitoid, *Cotesia flavipes* on stemborer species on maize at some release sites in Mozambique

Location	N	*Chilo partellus*	N	*Sesamia calamistis*	N	*Busseola fusca*
Xai Xai	106	28.8 ± 4.2 b	5	6.2 ± 1.0 b	–	–
Moamba	157	40.8 ± 3.4 a	10	22.2 ± 1.3 a	–	–
Manhiça	24	10.6 ± 1.7 c	0	0.0 ± 0.0 c	–	–
Machipanda	21	19.3 ± 1.9 c	0	0.0 ± 0.0 c	7	8.5 ± 1.1
Nhamatanda	18	6.8 ± 1.1 c	1	11.1 ± 0.3 b	–	–

(–) Stemborer species not recorded; means with the same letter in a column are not significantly different (SNK, P > 0.05)

with nearly equal proportions of 46.6% and 53.4%, respectively (Table 4).

At Chokwe, stemborers were significantly more abundant in the dimethoate treatment than in the control. However, at Machipanda, there were no differences between the two treatments on the abundance of *Ch. partellus*, but *B. fusca* was significantly more abundant in the dimethoate treatment compared with the control (Table 4). At both sites, the numbers of stemborers per infested plant were significantly higher in the dimethoate treatment than in other treatments. The same trend was observed at Chokwe for plant infestation, while at Machipanda no statistical differences were observed among the three treatments. At Lichinga, *B. fusca* was the most abundant with more than 90% of the total stemborer population. It was significantly more abundant on the dimethoate treatment than the control.

Egg batch abundance and percent parasitism due to egg parasitoids are shown in Table 5. At Chokwe, egg batches were significantly more abundant in the dimethoate treatment than in the control, but there were differences between the control and cypermethrin treatments. However, egg parasitoids were significantly more abundant in the control than in the dimethoate and cypermethrin treatments.

Table 6 shows the percentage of parasitism of stemborers due to larval and pupal parasitoids. At Chokwe, the highest level of parasitism due to larval

Table 4. Stemborer species composition and abundance in the different treatments on maize at three locations in Mozambique

				Cumulative number of borers per species			
Location	Treatment	Percentage infestation	Stemborers per infested plant	*Chilo partellus*	*Sesamia calamistis*	*Busseola fusca*	Total
Chokwe	Ctrl	75 b	3.3 b	231	35	–	266
	Dimet	90 a	5.8 a	406	56	–	462
	Cyper	15 c	0.5 c	36	3	–	39
	Cv (%)	59.9	50.4	273.8	–	–	
Machipanda	Ctrl	45 a	1.7 b	72	0	60 b	132
	Dimet	55 a	1.9 a	63	0	9 a	153
	Cyper	5 b	0.4 c	10	0	16 c	35
	Cv(%)		77.7	134.4	0	134	
Lichinga	Ctrl	32.5 ± 6.5 b	2.7 ± 0.7 b	2.0 ± 1.2	4.0 ± 1.0	94.0 ± 8.4	100
	Dimet	57.5 ±13.2 a	5.3 ± 1.5 a	5.0 ± 2.6	7.0 ± 1.5	192.0 ±13.8	204
	Cyper	10.0 ± 4.1 c	0.3 ± 0.2 c	0.0 ± 0.0	0.0 ± 0.0	10.0 ± 2.4	10
	Cv(%)	26.5	35.9	66.6	154.1	38.2	

(–) Stemborer species not recorded.
Means with the same letter in a column are not significantly different (SNK, P > 0.05).
Ctrl = Control; Dimet = Dimethoate; Cyper = Cypermethrin.

Table 5. Egg batches infestation and egg parasitoid abundance on maize with different treatments from three locations in Mozambique

Treatment	Mean number egg batches	Plant infestation by egg batches	Mean egg batches parasitised (N)	Percent parasitism
Control	8.8 ab	17.5 ab	7.8 ab	87.5 a
Dimethoate	13.5 a	27.0 a	8.3 a	61.6 ab
Cypermethrin	8.0 b	16.0 b	3.0 b	38.5 b
Cv(%)	33.6	33.7	46.9	32.3

Means with the same letter in a column are not significantly different (SNK, P > 0.05).

parasitoids observed was due to *Co. sesamiae* (13.2%) and of pupal parasitoids due to *D. busseolae* (36.7%). At Machipanda, the same parasitoids were also the most abundant, with 20.4 and 20.9%, respectively, while at Lichinga the highest level of parasitism was due to *P. nigromaculatus* (63.6%) reared from *B. fusca* pupae.

Table 6. Levels of stemborers parasitism in the three different treatments in three locations in Mozambique

Location	Treatment	*Cotesia flavipes*	*Cotesia sesamiae*	*Sesamia parasitica*	*Dentichasmias busseolae*	*Pediobius furvus*	*Procerochasmias nigromaculatus*	Overall
Chokwe	Ctrl	0	13.2 ± 9.6 a	–	36.7 ±17.9 a	16.1 ±12.5 a	–	16.9
	Dimet	0	0.9 ± 1.3 b	–	10.3 ±15.8 b	4.2 ± 8.4 ab	–	1.9
	Cyper	0	0.0 b	–	0.0 b	0.0 b	–	0.0
	Cv (%)	–	70.7	–	67.2	122.3	–	
Machipanda	Ctrl	7.2 ± 0.1 a	20.4 ± 0.1 a	7.2 ±0.1 a	20.9 ± 0.1 a	6.1 ± 0.2 a	0	47.7
	Dimet	2.2 ± 0.0 a	5.1 ± 0.0 b	1.5 ±0.0 a	4.0 ± 0.0 b	4.7 ± 0.1 a	0	12.4
	Cyper	0.0 a	0.0 b	0.0 a	0.0 b	0.0 a	0	0.0
	Cv(%)	197.3	80.9	138	83.2	169.4	0	
Lichinga	Ctrl	–	5.3 ± 2.1 a	8.5 ±3.1 a	18.2 ± 2.6 a	0	63.6 ± 12.4 a	22.0
	Dimet	–	1.6 ± 1.3 a	1.0 ±0.2 b	0.0 b	0	22.2 ± 8.7 a	4.4
	Cyper	–	0.0 b	0	0.0 b	0	0.0 b	0.0
	Cv(%)	–	63.5	43.4	112.3	0	35.6	

–Stemborer species not recorded. Means with the same letter in a column are not significantly different (SNK, P > 0.05).
Ctrl = Control; Dimet=Dimethoate; Cyper=Cypermethrin.

At Chokwe, 16.9% overall parasitism was observed in the control against only 1.9% in the dimethoate treatment, while at Lichinga and Machipanda the opposite pattern was observed (Table 6). At all sites, no parasitoids were recovered from the cypermethrin-treated plots.

The exotic parasitoid *Co. flavipes* was recovered only at Machipanda where it was released in 1999. There were no significant differences in the stemborer parasitism due to *Co. flavipes* between the control and dimethoate. However, its African congener *Co. sesamiae* was significantly more abundant in the control than in the dimethoate treatment at both study sites. The same pattern was observed for the pupal parasitoid *D. busseolae* which was recovered from field-collected pupae at both locations (Table 6).

The highest yields were recorded from the cypermethrin-treated plots, 1.83 t/ha at Machipanda, 2.6 at Chokwe and 2.5 at Lichinga, followed by the control plots and lowest yields were from the dimethoate-treated plots. Yield losses were highest at Machipanda (32.2%) followed by Chokwe (23.1%) and Lichinga (20%). The impact of parasitoids was estimated at 46.8, 15 and 5% at Machipanda, Chokwe and Lichinga, respectively.

Habitat management strategy

One trial integrating biological control, habitat management and chemical control was conducted at Chokwe Research Station (Tables 7, 8 and 9).

Release of exotic parasitoids

Releases of two exotic parasitoids *Cotesia flavipes* and *Xanthopimpla stemmator* were conducted in the three agroecological zones of Mozambique during the reporting period. *Cotesia flavipes* releases were continued in March. *Xanthopimpla stemmator* has been released at several sites since March 2003. Figure 1 shows the areas covered during the reporting period. Table 10 shows the levels of parasitism due to this exotic pupal parasitoid on the stemborer species at some release sites. *Xanthopimpla stemmator* was recovered only from *Ch. partellus* pupae in the southern region of Mozambique.

No samples of *X. stemmator* were collected from the central and northern sites of the country. This may be due to the low numbers of pupae collected at each location associated with the abundance of *B. fusca*, mainly at the northern site of Lichinga. At this site, high adult mortality was observed (approximately 25%) due to the low temperature during the release

Table 7. Parasitoid abundance and percent parasitism in different habitat management treatments at Chokwe, Mozambique

Treatment	Total of parasitoids	Percent parasitism *Chilo partellus*	Percent parasitism *Sesamia calamistis*
Maize monocrop	7 a	11.5 ab	0
Maize + elephant grass (Napier grass)	4 a	5.6 b	0
Maize + wild sorghum	4 a	8.0 ab	0
Maize + desmodium + elephant grass	10 a	14.3 ab	0
Maize + desmodium + wild sorghum	9 a	11.5 ab	0
Maize + cypermethrin	8 a	20.5 a	0
Maize + desmodium	9 a	18.0 ab	0

Means with the same letter in a column are not significantly different (SNK, P > 0.05).

Table 8. Percentage of plant infestation, number of stemborers per infested plant and yield of maize grain from different habitat management treatments at Chokwe

Treatment	Percentage infestation	Stemborer density (no./plant)	Grain yield (t/ha)
Maize monocrop	60.0 a	2.0 a	2.3 ab
Maize + elephant grass (Napier)	51.7 ab	2.4 a	1.7 b
Maize + wild sorghum	41.7 b	1.7 a	1.8 b
Maize + desmodium + elephant grass	53.3 ab	2.3 a	1.9 ab
Maize + desmodium + wild sorghum	39.9 b	2.6 a	1.7 b
Maize + cypermethrin	14.9 c	1.3 b	2.7 a
Maize + desmodium	53.3 ab	1.6 a	1.6 b
Cv(%)	21.8	41.9	

Means with the same letter in a column are not significantly different (SNK, P > 0.05).

Table 9. Stemborer species composition and percentage of infested plants in the different habitat managment treatments at Chokwe

Treatment	% *Chilo partellus*	% *Sesamia calamistis*	Total stemborers
Maize monocrop	96.7	3.3	61 ab
Maize + elephant grass (Napier)	94.4	5.6	72 ab
Maize + wild sorghum	96.0	4.0	50 ab
Maize +desmodium + elephant grass	95.7	4.3	70 ab
Maize + desmodium + wild sorghum	100.0	0.0	78 a
Maize + cypermethrin	100.0	0.0	39 b
Maize + desmodium	92.0	8.0	50 ao
Cv(%)	5 7	163.4	35.4

Means with the same letter in a column are not significantly different (SNK, P > 0.05).

period. However, there were no significant differences among locations where the parasitoid was recovered. The recovery of *X. stemmator* at the release sites is an indication that the exotic parasitoid was able to colonise the release areas in the southern region where *Ch. partellus* is the most abundant stemborer species. Releases and monitoring activities are being conducted to increase the numbers and to evaluate field colonisation in other release sites (see Figure 1).

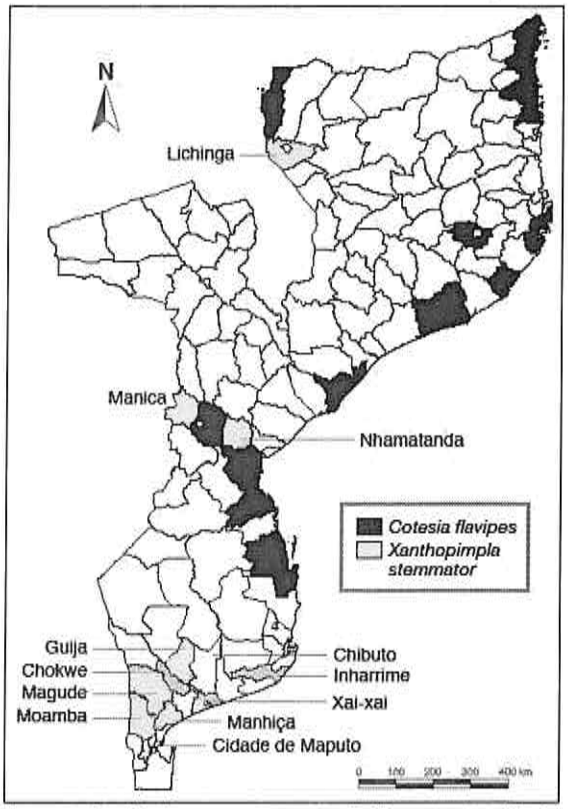

Figure 1. Release areas of the parasitoids* Cotesia flavipes *and* Xanthopimpla stemmator *in Mozambique

Table 10. Levels of parasitism due to *Xanthopimpla stemmator* in Mozambique

Location	*Chilo partellus*	*Busseola fusca*	*Sesamia calamistis*
Xai Xai	15.4 ± 2.0 a	–	0
Moamba	7.9 ± 1.0 a	–	0
Manhiça	12.3 ± 0.8 a	–	0
Nhamatanda	11.2 ± 1.2 a	–	0
Lichinga	0	0	0
Machipanda	0	0	0

Participating scientists: D. Cugala, E. Mambo

Collaborators: Eduardo Mondlane University, Department of Plant Protection

7. Kenya

Integration of cropping systems and biological control for stemborer management in maize

This study was conducted on-station at Katumani and Kiboko field stations in the semi-arid areas of eastern Kenya during the short rains of 2002. Plots of size 7.2 x 6 m were established and subjected to 6 different treatments (i.e. pure maize; pure maize plot surrounded by sorghum borders(B); interplanting of maize and millet in one row, then alternated with single bean rows(Bn); interplanting of maize and millet in one row, then alternated with single bean rows, then surrounded by a sorghum border; pure millet; pure sorghum) and replicated three times in a randomised complete block design.

The stemborer species recovered from both sites were *Chilo partellus, Busseola fusca* and *Sesamia calamistis*, with *Ch. partellus* being the dominant species in both sites. Maize plants in the cropping systems with millet had shorter tunnelling length (TL), lower number of bored internodes (NBI), exit holes (EXH) and stemborers (NS) (Table 11) than in the pure-stand maize in Katumani. However at Kiboko, interplanting maize with millet only had a significant reduction of EXH and NS (Table 11). Pure stand millet (monocrop) had comparatively lower TL, NBI, EXH and NS, than purestand maize, purestand sorghum and all the other cropping systems at both sites. It is suggested that millet, which is unsuitable for development of stemborers, acted as a trap plant, reducing borer infestations on maize.

Sorghum, on the other hand, in some cases increased pest damage to maize. Purestand sorghum had a higher TL, NBI, EXH and NS than all the other treatments including maize (Table 11). It is concluded that sorghum is highly attractive to ovipositing female moths and guarantees high survival of larvae, thereby causing increased infestation on maize via increased oviposition or larvae migrating from sorhgum to maize.

Parasitism was higher at Kiboko than at Katumani (Table 12). The cropping systems did not seem to have a significant effect on the level of parasitism, although the maize/millet with sorghum border cropping system generally had a higher parasitism level in absolute terms. However, no conclusions can be drawn without further investigations of density dependence effects. It can be concluded that interplanting millet with maize, in a maize–bean cropping system, was the most favourable cropping system in terms of reducing stemborer damage in maize. Both associated crops are very popular in eastern Kenya.

Pre-release survey and release work

During the year 2002, pre-release surveys conducted in the eastern and western provinces of Kenya showed that *Chilo partellus* was the dominant

Table 11. Mean (± SEM) number of exit holes and internodes tunnelled, percentage tunnelling and numbers of stemborers per plant in various cropping systems, and in sorghum and millet in pure stands at Katumani and Kiboko, Kenya during the long rains, 2003

Treatment/ Location	Tunnelled internodes	Exit holes/ plant	Tunnelling %	No. stemborers/ plant
Katumani				
Maize and Mill/Bn	0.66 ± 0.08	0.70 ± 0.10	2.6 ± 0.35	0.26 ± 0.05
Maize and Mill/Bn–SorgB.	0.69 ± 0.11	0.83 ± 0.17	2.5 ± 0.48	0.13 ± 0.03
Maize-SorghB	1.96 ± 0.17	2.56 ± 0.31	7.6 ± 0.68	0.67 ± 0.15
Maize mono	1.13 ± 0.12	1.50 ± 0.20	5.5 ± 0.73	0.48 ± 0.07
Millet mono	0.18 ± 0.03	0.20 ± 0.04	0.85 ± 1.8	0.06 ± 0.03
Sorghum mono	1.61 ± 0.11	2.01 ± 0.19	11.4 ± 1.0	1.26 ± 0.14
Kiboko				
Maize and Mill/Bn	1.44 ± 0.11	1.81 ± 0.19	5.1 ± 0.5	0.65 ± 0.08
Maize and Mill/Bn-SorghB.	2.34 ± 0.33	2.14 ± 0.25	7.8 ± 0.85	0.96 ± 0.14
Maize-SorghB	2.24 ± 0.15	2.72 ± 0.21	6.3 ± 0.50	1.22 ± 0.16
Maize mono	2.15 ± 0.23	2.71 ± 0.24	7.0 ± 0.55	1.39 ± 0.15
Millet mono	0.64 ± 0.08	0.69 ± 0.09	2.4 ± 0.31	0.25 ± 0.05
Sorghum mono	3.69 ± 0.15	4.17 ± 0.28	23.6 ± 1.2	3.67 ± 0.20

Bn = bean; B = border.

Table 12. Percentage parasitism of stemborers in different cropping systems in Katumani and Kiboko, Kenya during the long rains, 2003

Cropping system	Crop	Parasitoid species	N	Parasitism
Katumani				
Maize and Mill/Bn	Maize	*Cotesia sesamiae*	36	2.8
Maize and Mill/Bn–SorgB	Maize	*Co. sesamiae*	17	5.9
Maize-SorghB	Maize	*Dentichasmias busseolae*	2	100.0
Maize mono	Maize	*Co. sesamiae*	55	1.8
Millet mono*	Millet	–	–	–
Sorghum mono	Sorghum	*Co. sesamiae*	163	1.8
Kiboko				
Maize and Mill/Bn	Maize	Eulophidae	73	1.4
	Maize	*Cotesia flavipes*	73	6.9
	Millet	*Co. flavipes*	4	25.0
Maize and Mill/Bn–SorgB	Maize	*Co. flavipes*	48	12.5
Maize-SorghB	Maize	*Co. flavipes*	120	10.0
Maize mono	Maize	*Co. curvimaculatus*	30	6.7
Millet mono	Millet	*Co. flavipes*	4	25.0
Sorghum mono	Sorghum	*Co. flavipes*	180	0.55

N = Total number of susceptible stemborers, Bn = bean; B = border.
*No results due to bird damage.

stemborer species followed by *Sesamia calamistis* and *Cryptophlebia leucotreta* in both regions. The stemborers recovered from maize in the western region were *Busseola fusca* followed by *Chilo partellus* and *S. calamistis*. The importance of *Ch. partellus* in both regions justified releases of *Cotesia flavipes* in 2003. Releases of *Co. flavipes* were conducted in the long rains of 2003, during the mid-reproductive stage of the maize plants in 15 farms in each region. In each of the selected regions, a total of up to 100,000 *Co. flavipes* adults were released in farmers' maize crops, giving a total of 300,000 *Co. flavipes* released on-farm during the long rains, 2003. The releases were made by using blackened cocoons in glass vials, which were in turn taped to maize plants in the release fields.

Monitoring of egg parasitism at Kiboko (altitude 900 masl) and Katumani (1500 masl) and suitability studies in the laboratory using the scelionid *Telenomus busseolae* and *Ch. partellus*, *S. calamistis* and *B. fusca* eggs started in 2003.

Post-release surveys

During the short rains of 2002, post-release surveys in the eastern and central regions were conducted three times a season, at the vegetative, reproductive and maturity stages, in the farms where *Co. flavipes* had been released. Parasitism was low in both the regions. Most species recovered were of the larval parasitoids, with the most common ones being *Cotesia flavipes* and *Co. sesamiae*. In the eastern region in Kitui, the pupal parasitoid *Dentichasmias busseolae* was recovered. Although *Co. flavipes* was recovered from both regions, the parasitism level was very low, but *Co. flavipes* releases were made only once in each site during the season. It may therefore be necessary to conduct at least two releases in each of the regions per season, in order to enhance establishment of this parasitoid.

Training of farmers and extensionists

A total of 33 farmers (20 men and 13 women) and 8 extension personnel (7 men and 1 woman) from Machakos and Kitui districts were trained together in Kitui Farmers' Training Centre in the Eastern province of Kenya. Topics covered biology of stemborers, the different stemborer species, various management tactics including cultural and chemical control, and biological control. The advantages and disadvantages of each of these methods were discussed. Evaluation of the course showed that the farmers now understood about the importance of biological control, the general mode of action of predators and parasitoids on stemborers and the reason why *Cotesia flavipes* is being introduced.

Participating scientists: J. Songa, C. Ogol

Collaborators: Kenya Agricultural Research Institute (KARI), Moi University

8. Zambia

Release and establishment of **Cotesia flavipes**

Four shipments of *Cotesia flavipes* cocoons were released during the period under review. A total of 300,000 cocoons were released as follows: Hotela, Luangwa district (50,000); Kakaro, Luangwa district (50,000); Chirundu, Siavonga district (100,000); Kalobolelwa Sesheke district (50,000); and Luzu, Sesheke district (50,000). Post-release surveys were carried out in these locations. There were high levels of stemborer infestation in the fields. In Luangwa, *Cotesia* spp. cocoons were found in five fields which were sampled, whilst in Siavonga-Chirundu area the cocoons were found in eight of the sampled fields. Samples of adult insects that emerged from the cocoons were sent to ICIPE for identification.

The identification results show that *Co. flavipes* has been recovered for the first time in Zambia at both Luangwa and Chirundu.

Pre-release survey and introduction of new natural enemies

This activity will be conducted during the period December 2003 through March 2004 in the major maize growing areas of the country. Another survey will be conducted during June to September 2004 in areas that have a winter crop. Results from these surveys will determine additional release sites for *Co. flavipes* and first releases of *Xanthopimpla stemmator*.

Mass rearing/biological studies

Small colonies of *Chilo partellus*, *Busseola fusca* and *Sesamia calamistis* as well as *Co. flavipes* are maintained on a natural diet of maize. Currently the colony is being used to train members of staff attached to the project to differentiate the three predominant species and their development stages.

Participating scientists: A. Sumani, P. Nkunika

Collaborators: Mount Makulu Research Station, University of Zambia

9. Ethiopia

Field experiments

A field trial was conducted at Abergelle, while laboratory activities were carried out at Mekele and Melkassa Research Centres. Field activities included investigations on the influence of intercropping on plant damage level and occurrence of stemborers and their natural enemies. Laboratory activities were carried out to determine the parasitism level of field-collected stemborers. Abundance of egg masses, larval/pupal stages of sorghum stemborers, foliar damage, nodal damage (borer entry/exit holes), stem tunnelling, and panicle damage were significantly greater in the sorghum monocrop plots than in the sorghum–cowpea intercrop plots. Total grain yield and yield per plant was higher in the intercropped plots than in the sorghum monocrop plots. Significantly more predators (ants, spiders and ladybird beetles) were also recorded in the intercropped plots than in the sorghum monocrop plots. However, there was no significant difference in parasitism level. From this study, it can be concluded that sorghum–cowpea intercropping significantly reduces the damage by stemborers. Hence, this production system can be recommended as a management option.

Surveys on distribution of stemborers and their natural enemies

Surveys were carried out in Gojam, Gondar Wolo and Shoa Provinces of Amhara State. The entire survey route is around 4500 km, excluding off-route locations where researchers occasionally travel into the remote countryside. The first survey trip was carried out from 15–30 July 2003. The second was done in September and October, 2003. The objectives of the surveys were to sample maize and sorghum stemborers and their natural enemies. A total of 185 fields were visited to determine the borer damage levels, borer population and their natural enemies. *Busseola fusca* was found to be the major stemborer in western Amhara, while *Sesamia calamistis* was a minor pest. Nematodes were the major natural enemies in this region of western Amhara. *Chilo partellus* was the major stemborer in eastern Amhara, and *S. calamistis* was of minor importance. The major natural enemy in eastern Amhara is *Cotesia flavipes*. *Sorghum arundinaceum* was found to be highly attacked by *B. fusca* in western Amhara.

Participating scientist: Difabachew Belay

Assisted by: Melaku Wale

Collaborators: Ethiopian Agricultural Research Organisation

10. Tanzania

Release of natural enemies

In June 2003, a total of 350,000 cocoon masses of *Cotesia flavipes* were shipped from ICIPE, Nairobi and released in 21 sites in Coast, Tanga, Kilimanjaro and Arusha regions (Table 13) where *Chilo partellus* was found to be predominant during a pre-release survey. The cocoon masses were left for the adults to emerge and mate before releases were made. In order to determine the percentage emergence, a known number of cocoon batches were kept in a vial covered with cotton wool and left in the laboratory. The number of emerged parasitoids from each vial was determined.

In July 2003, a shipment of *Xanthopimpla stemmator* pupae was received from ICIPE. The adults were allowed to emerge and mate before they were released. Sampling was done in the release sites to obtain baseline data on stemborer density, species composition, and field infestation. About 1000 adult *X. stemmator* were released in 3 test release sites in Coast and Arusha regions on 9th, 14th and 16th July, 2003 (Table 14). Stemborer infestation ranged from 45–88%. The predominant borer species in Arusha was *B. fusca*, while in the Coast region the predominant species was *Ch. partellus* (Table 14).

Monitoring of establishment and spread

Establishment and spread of *Co. flavipes* was studied in August in the Coast region in the fields where releases were made in December 2002. Samples were taken from release fields at a distance of 100, 300, 500 m and 1, 2, and 3 km. No *Co. flavipes* were recovered from the release sites, but were found in the neighbouring fields

Table 13. *Cotesia flavipes* releases in Coast, Tanga, Kilimanjaro and Arusha regions of Tanzania, June 2003

District	Release site	GPS Latitude	GPS Longitude	Host plant	Borer spp.	% Field infestation (N)	No. of cocoons	Release dates
Bagamoyo	Pugini	S 06° 21.456	E 038° 22.795	Maize/Sorghum	Cp	63.3	11,700	21.6.03
Muheza	Mkanyageni	S 05° 08.729	E 038° 51.548	Maize/Sorghum	Cp	46.4	15,480	09.6.03
	Kwafungo	S 5° 14.308	E 038° 42.149	Maize	Cp	60	15,000	09.6.03
	Misozwe	S 05° 04.730	E 038° 47.285	Maize	Cp	64	12,960	01.7.03
	Maramba	S 4° 50.997	E 038° 48.615	Maize	Cp	77.4	15,345	22.6.03
	Mwele S/F	S 04° 51.901	E 038° 48.321	Maize	Cp	76	13,400	01.7.03
Korogwe	Majani mapana	S 05° 18.995	E 038° 37.210	Maize	Cp	58.1	15,345	23.6.03
	Kwamdulu Estate	S 05° 11.838	E 038° 28.236	Maize	Cp	43.8	12,375	23.6.03
	Msambiazi	S 05° 08.311	E 038° 25.251	Maize	Cp	46.7	12,375	23.6.03
	Kiloza	S 05° 05.791	E 038° 21.091	Maize	Cp	48	11,970	23.6.03
Handeni	Michungwani	S 05° 20.709	E 038° 32.519	Maize	Cp	80	15,345	21.6.03
	Komkonga	S 05° 38.475	E 038° 24.054	Maize	Cp, Cs	23.3	11,700	21.6.03
Mwanga	Kwamlaki	S 03° 29.334	E 037° 33.026	Maize	Cp,Bf	50	13,050	23.6.03
	Kileo	S 03° 29.158	E 037° 33.120	Maize	Cp	60	50,000	11.7.03
Moshi rural	Pumwani	S 03° 22.775	E 037° 25.873	Sorghum/Maize	Cp	50	12,960	20.7.03
Hai	Kimashuku A	S 03° 20.586	E 037° 14.671	Maize	Cp,Sc	86.4	12,375	02.7.03
	Kwasadala	S 03° 18.330	E 037° 12.787	Maize	Cp,Bf,Sc	31.8	11,925	02.7.03
	Kimashuku B	S 03° 20.795	E 037° 14.605	Maize	Cp,Sc	45	49,900	11.7.03
	Bomang'ombe	S 03° 18.996	E 037° 08.329	Maize	Cp,Bf,	30	12,150	02.7.03
Simanjiro	Majengo	S 03° 28.987	E 037° 01.628	Maize	Cp	70	12,375	02.7.03
Arumeru	Kambi ya Mkaa	S 03° 23.207	E 036° 58.630	Maize	Cp	40.6	12,100	02.7.03
							Total 349,830	

Cp = *Chilo partellus*, Bf = *Busseola fusca*, Sc = *Sesamia calamistis*.

at 100 m, 1 km and 3.3 km from the release fields. Due to drought, post-release surveys were not conducted in the Lake zone (Mara region).

Push-pull habitat management trial

A push-pull trial *(see habitat management report)* with maize + Napier grass, maize + cowpea + Napier grass, maize + desmodium + Napier, and maize monocrop as a control was planted at Kibaha station during the dry season in August 2003. Infestation with *Ch. partellus* was low in all treatments. There were significant differences in percentage of stemborer infestations among treatments ($P < 0.10$) whereby the maize monocrop and maize + Napier had the highest level of infestation followed by maize + cowpea + Napier treatment, while maize + desmodium + Napier had the lowest infestation (Table 15).

Host suitability and non-target hosts

The preference for five gramineous hosts by stemborers was tested in a randomised complete block design with three replications at Kibaha station where *Ch. partellus* is endemic. Four wild hosts (Giant Napier, Bana grass, Guatemala and Narrow Napier) were tested and compared with maize. All hosts were equally accepted for oviposition by *Ch. partellus*. The number of exit holes, tunnelling length and number of borers were significantly higher in maize compared to the treatments ($P < 0.01$). Stem diameter was smaller in Narrow Napier compared to other treatments. There was no significant difference in stem diameter between maize and Guatemala grass, and also for Bana grass and Giant Napier. Plant height did not vary significantly among Giant Napier, Bana grass and Narrow Napier. Guatemala and maize had almost

Table 14. ***Xanthopimpla stemmator*** **releases in Coast and Arusha regions, Tanzania, July 2003**

District	Location	GPS Latitude	GPS Longitude	Host plant	Borer species	% Field infest-ation	No. of *X. stemmator*	Date
Arumeru	Arusha S/farm	S 30° 016.818	E 036° 037.309	Maize	Bf	88.2	35	09.7.03
Kibaha	Boko	S 06° 049.74	E 038° 055.489	Maize	Cp	45.0	397	14.7.03
	Kidimu	S 06° 041.986	E 038° 002.429	Maize	Cp	50.0	600	16.7.03
					Total	**183.2**	**1032**	
					Mean	**61.08**	**344**	

Cp = *Chilo partellus*, Bf = *Busseola fusca*, Sc = *Sesamia calamistis*.

Table 15. Percentage of stemborer infestation in maize using various push-pull intercropping treatments

S/no.	Treatment	% *Chilo partellus* infestation
1	Maize + Napier	6.1 a
2	Maize + Cowpea + Napier	5.1 ab
3	Maize + *Desmodium* + Napier	4.0 b
4	Maize (Control)	6.3 a
	Cv %	22.1
	SE	0.54

Numbers followed by the same letter in the same column are not statistically significantly different (DMRT), P ≤ 0.05.

equal plant height, which varied significantly from other treatments (Table 16).

Awareness creation and farmer training

A 3-day training course on cereal stemborer biocontrol was conducted at Kibaha Biocontrol Centre from 8–10 October, 2003. The training was organised in collaboration with the Ministry of Agriculture, Tanzania and ICIPE. Participants were trained on biocontrol concepts and practices, identification of cereal stemborers, damage symptoms and natural enemies, sampling methodology, release and monitoring of natural enemies, and use of the habitat management strategy *(see preceding programme report)* for cereal stemborer management.

The Biocontrol team participated in *Nane-Nane* (eight-eight) Exhibition organised by the Ministry of Agriculture in the Morogoro region, 1–10 August, 2003. A total of 21 District Plant Protection Officers (DPPOs) and two Research Officers from Central, Eastern, and Northern zones were trained (Table 17). The DPPOs were expected to train about 940 Village Extension Officers (VEOs) through monthly meetings organised under District Local Governments. As each VEO supervises at least 10 farmers, it was expected that the knowledge would reach at least 500 farmers in each district (Table 17). However the participants cited funds and transport as the major limiting factors which are encountered and therefore hinder the dissemination process. Post-training follow-up will be conducted after one season to determine the number of VEOS and farmers exposed to the knowledge.

Public awareness creation

During the training course above, mass media including radio and newspapers were used to create public awareness on cereal stemborer management. The training was covered on Radio Uhuru on 9th October, Radio Free Africa on 10th October, the Kiswahili newspaper *Uhuru* and English newspaper *The African* of 13 and 15 October, 2003 respectively.

During the Nane-Nane Exhibition about 2000 people including the Minister for Agriculture, scientists from various institutions, agricultural officers, publicity officers, politicians, farmers and others were exposed to cereal stemborer management. More than 1000 leaflets with information on cereal stemborers and natural enemies were distributed.

Participating scientists: B. Pallangyo, R. Makundi

Collaborators: National Biological Control Centre, Kibaha; Sokoine University

Table 16. Acceptability for egg laying and suitability of wild hosts for the development of *Chilo partellus* larvae

Treatments	Egg batches	Exit holes	Tunnelling length	Number of borers	Stem diameter	Plant height
Giant Napier	0.71	0.74 b	0.77 b	0.77 b	1.77 ab	188.3 a
Bana grass	0.87	0.71 b	0.90 b	0.77 b	1.71 ab	178.8 a
Guatemala grass	1.25	0.72 b	0.77 b	0.73 b	2.09 a	102.9 b
Narrow Napier	0.75	0.74 b	0.84 b	0.81 b	1.29 b	181.0 a
Maize (Control)	0.90	2.58 a	4.51 a	2.71 a	1.85 a	124.33 b
SE	0.19	0.16	0.38	0.25	0.11	9.7
Cv %	36.7	26.6	43.2	38.8	11.8	8.7

Numbers followed by the same letter in the same column are not statistically significantly different (SNK) at (P ≤ 0.05).

Table 17. Number of farmers supervised by District Plant Protection Officers (DPPOs) in Central, Eastern and Northern zones of Tanzania, 2003

Zone	Region	District	No. VEOs trained	No. farmers' groups	No. farmers/ group
Central	Singida	Manyoni	27	5–10	20
		Singida	28	2–5	6–15
		Iramba	26	52	8–15
	Dodoma	Dodoma	47	17	15
		Kongwa	20	2	5–12
		Mpwapwa	42	–	–
Northern	Kilimanjaro	Same	60	15	15–20
		Mwanga	58	–	10–15
Eastern	Coast	Kibaha	25	–	–
		Bagamoyo	52	–	–
		Kisarawe	76	2	–
	Morogoro	Ulanga	30	30	7
		Kilosa	79	15	15–20
		Morogoro	135	–	–
		Kilombero	45	15	10–15
	Tanga	Muheza	39	–	15
		Handeni	65	45	15–20
		Korogwe	86	–	5–39
		Total	**940**		
		Mean	**52**		

VEO = Village Extension Officer.

11. Zanzibar

Continued releases of Cotesia flavipes

A shipment of 800,000 cocoons of *Cotesia flavipes* was received from ICIPE at the end of the long rains, June–August 2003. They were released in Unguja and Pemba in maize or sorghum fields at the reproductive stage, to ensure that preferred host larval stages (3rd–6th instars) were available. The releases were made at 37 sites, 20 from former release sites and 17 from additional sites.

Farmers' training

Training of cereal farmers in biological control and habitat management techniques (especially push-pull), were conducted from 21–23 January 2003. The participants were farmers from the Isles of Unguja and Pemba. A total of 100 farmers (65 male and 25 female) from Unguja participated; 50 were already aware of the concept of biological control as their fields had been used as release sites of *Co. flavipes* in 2000. From Pemba Island, 60 farmers (45 males, 15 females) participated in the participatory training. Farmers had time to share experiences with each other and with the resource people.

Participating scientists: Z. Abdala, V. Lada

Collaborator: Department of Plant Protection

B. Activities at ICIPE

12. Development of the pupal parasitoid *Xanthopimpla stemmator* (Thunberg) (Hymenoptera: Ichneumonidae) in various cereal stemborers (Lepidoptera)

As pupal parasitism in eastern Africa is exceedingly low, the Asian pupal parasitoid *Xanthopimpla stemmator* was imported to Kenya from South Africa for laboratory trials in February 2000. Studies were carried out to assess the applicability of this parasitoid in controlling stemborers found in eastern and southern Africa. The stemborers tested were *Busseola fusca, Chilo partellus, Eldana saccharina* and *Sesamia calamistis*.

Studies showed that all four stemborer species were acceptable (received ovipositor probe wounds). The parasitoid also completed development in all the four hosts (Table 19). Two-day-old *Ch. partellus* pupae were more suitable and these pupae can therefore be used for mass rearing of the parasitoids in the laboratory. *Eldana saccharina* was found to be a poor host for *X. stemmator* in Kenya. When provided with hosts daily in the laboratory, *X. stemmator* females tended to have a male-biased sex ratio as they advanced in age (Figure 2). Hence females used for mass rearing have to be 2–25 days old.

Life table studies were carried out on *B. fusca* and *Ch. partellus*. The intrinsic rates of natural increase and the net reproductive rates were not different for parasitoids emerging from either stemborer species. Hence, parasitoids emerging from both *B. fusca* and *Ch. partellus* can be used during mass rearing and *X.*

Table 19. Fate of stemborer pupae of different ages exposed to naive *Xanthopimpla stemmator* females 25 days post-parasitisation

Host	N	Parasitoid emergence (% female)		Moth emergence	Dead
Busseola fusca	364	40.9 a	(63.3 bc)	43.1 a	15.9 b
Chilo partellus	372	39.8 a	(55.5 c)	45.7 a	14.5 b
Eldana saccharina	372	15.1 b	(86.2 a)	44.8 a	40.1 c
Sesamia calamistis	371	33.9 a	(72.8 ab)	47.3 a	18.8 b
Statistical parameters	F	25.5		1.52	46.3
	df	3,1476		3,1476	3,1476
	P	0.0001		0.2081	0.0001

Means within the same column with different letters are significantly different at $P < 0.05$ (Student-Newman-Keuls multiple comparison test).

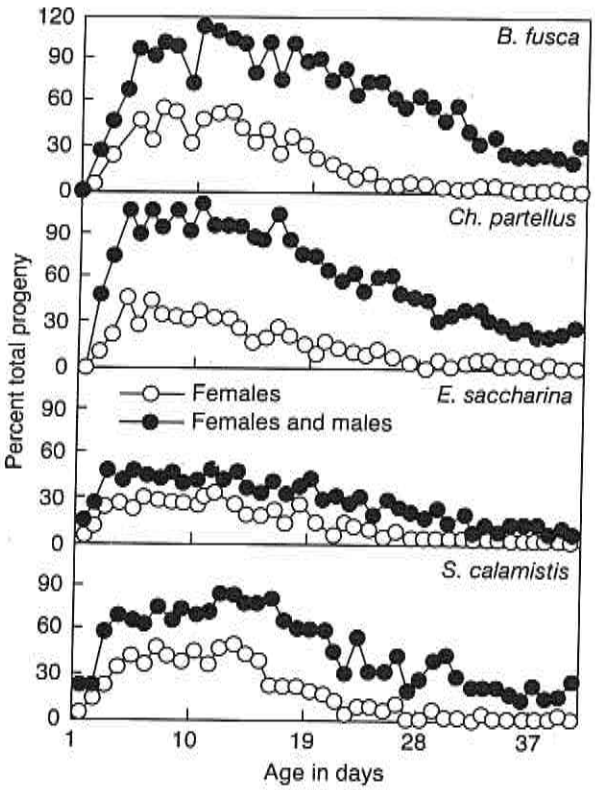

***Figure 2. Progeny production for the first 40 days of oviposition of* Xanthopimpla stemmator *reared on* Busseola fusca, Chilo partellus, Eldana saccharina and Sesamia calamistis**

stemmator can be released non-preferentially in the fields against both species.

Xanthopimpla stemmator females showed a tendency to mate only once. Multiple mating by females did not have any significant effect on either sex ratio or longevity. Multiple mating, when it occurs in *X. stemmator*, is hence purely accidental and inconsequential.

Xanthopimpla stemmator is a potential candidate for the control of cereal stemborers in eastern and southern Africa and may be released in fields against the tested lepidopteran stemborers in Kenya. Surveys need to be conducted on *X. stemmator* biology in a field context. Further studies on whether *X. stemmator* completes development in other lepidopteran stemborers and the non-target Lepidoptera species that are likely to be attacked by this parasitoid are in progress.

13. Accessibility of host pupae to *Xanthopimpla stemmator* in various host plant species and interspecific competition between *X. stemmator* and *Pediobius furvus*

The objective of this study is to evaluate the potential of the exotic *Xanthopimpla stemmator* for use in classical biological control of cereal stemborers in Kenya as well as its effects on non-target borer species. This study aims at (a) determining the location of pupae of *B. fusca*, *Ch. partellus* and *S. calamistis* in various cultivated and wild African host plants in order to predict the accessibility of pupae to *X. stemmator*, (b) examining the suitability of target and non-target borer species such as *Ch. partellus*, *B. fusca*, *S. calamistis* and *E. saccharina*, and (c) evaluating interactions between *X. stemmator* and the gregarious indigenous pupal parasitoid *Pediobius furvus* in the laboratory.

The depth of pupae located depended on borer and plants species, but it never exceeded the length of the ovipositor of *X. stemmator*, indicating that the parasitoid would successfully parasitise pupae in *Sorghum versicolor*, *Hyparrhenia rufa*, *Pennisetum purpureum*, maize and sorghum.

14. Geographical variations in developmental success of *Cotesia* parasitoids on *B. fusca*: Coevolutionary dynamics and molecular basis

The objective of this study is to (a) assess the geographical variation between locations in Kenya of the ability of *Co. sesamiae* and *Co. flavipes* to parasitise *B. fusca*, (b) establish whether the origin of this variation is the host or the parasitoid, and (c) identify the molecular basis of this variation and molecular markers of parasitoid virulence that can be used to enhance biological control. In order to maximise differences in resistance and virulence among *B. fusca*, *Co. sesamiae* and *Co. flavipes* populations, 10 collection sites which vary in climate (altitude) have been selected in the different ecozones of Kenya. Colonies of *B. fusca* from two sites and of *Co. sesamiae* and *Co. flavipes* from one site have been initiated so far. Sympatric interactions between borers and parasitoids are being studied.

15. Intrinsic interspecific competition between *Cotesia sesamiae* (Hym: Braconidae) and *Sturmiopsis parasitica* (Dip: Tachinidae)

In eastern Africa, the stemborer *Busseola fusca* is attacked by two indigenous larval parasitoids, the braconid *Cotesia sesamiae* and the tachinid *Sturmiopsis parasitica*. *Cotesia sesamiae* is widely distributed but parasitism is usually less than 2%. In contrast, *S. parasitica* has a limited distribution, but parasitism of up to 60% was obtained in Zimbabwe from *B. fusca* and in Benin, West Africa from *S. calamistis* and *E. saccharina*, while the parasitoid was never recovered in Cameroon and South Africa. Hence, *S. parasitica* often has been mentioned as a redistribution candidate and a West African strain has already been introduced into South Africa against *E. saccharina* in sugarcane. However, before release there needs to be an evaluation of whether or not *S. parasitica* might displace *Co. sesamiae*. To this end, interspecific competition studies have been initiated in the laboratories. The results showed that *S. parasitica* and *Co. sesamiae* can co-occur in the same system and their actions are complementary; there was an increase in parasitism when both were used.

16. Effect of *Chilo partellus* and parasitism by *Cotesia flavipes* on maize growth dynamics and yield component

The effect of the crambid stemborer *Chilo partellus* and its braconid larval parasitoid *Cotesia flavipes* on dry matter production and yield of maize was examined in field and cage experiments. Leaf area index and water content decreased with increasing borer density, while proportion of borers living in stems increased. Yield differences without *Co. flavipes* were between 15–30% (Figure 3). Yields increased 1.8–2.5-fold when the parasitoid was released, depending on the parasitoid–borer ratio.

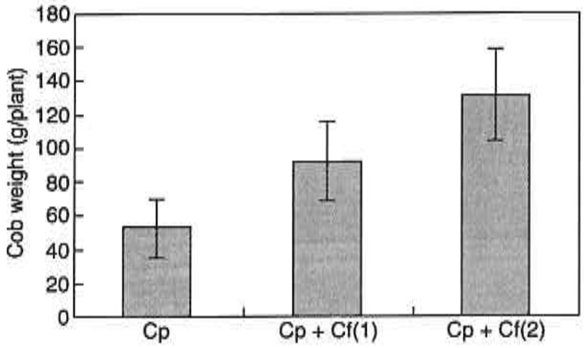

Figure 3. The effect of* Chilo partellus *without parasitoid, and with low and high densities of* Cotesia flavipes *on yield of maize

Cf(1) = Cp/Cf, ratio of 1:1
Cf(2) = Cp/Cf, ratio of 1:2

17. Effect of temperature and host stage on *Cotesia flavipes* parasitising *Chilo partellus*

Plant Health Division

The effect of larval stage of *Ch. partellus* and temperature on the life tables of *Co. flavipes* was studied in the laboratory in order to explain eco-regional variation of the efficacy of the parasitoid in the field. *Chilo partellus* mortality was higher when parasitised at the 3rd host instar, and the development duration of *Co. flavipes* was longer at low temperatures and young larval instars. More progeny were produced at L4 and higher temperature. The optimal conditions for parasitism was using L4 at 26° C (Table 20). The sex ratio of *Co. flavipes* varied from male- to female-biased with increase in temperature. Body weight of the parasitised larvae increased faster than non-parasitised. Parasitism had no effect on diet consumption. The results of this study suggest that establishment and spread of *Co. flavipes* will occur slowly in regions with lower temperature (<26° C) due to slower development of the parasitoid, higher mortality at the immature stage and a male-biased sex ratio.

Table 20. Development time to cocoon formation (days) for *Cotesia flavipes* parasitising *Chilo partellus* in L3 and L4 stages and at three temperatures

	L3	L4
Temperature	Mean ± SE (days)	Mean ± SE (days)
22° C	17.80 ± 0.74 a	14.08 ± 0.44 a
26° C	13.62 ± 0.73 b	11.60 ± 0.20 b
30° C	12.50 ± 1.03 b	10.30 ± 0.21 c

18. BorerSIM: A stochastic dynamic cereal stemborer biological control population model

A need exists for an integrated modelling package capable of simulating development of organisms (plant, stemborers and parasitoids) accurately in heterogeneous landscapes. The system model must be capable of predicting the economic benefit realised in biocontrol of stemborers.

A generic tritrophic (plant-herbivore-natural enemy) simulation model (BorerSIM) consisting of host plants (*Zea mays, Sorghum bicolor*), stemborer (*Chilo partellus*), and its natural enemies (*Cotesia flavipes, Co. sesamiae, Telenomus isis* and *Xanthopimpla stemmator*) is chosen to quantify the population dynamics of stemborers and their natural enemies. Simulation modules written in C++ have been integrated to operate from a control framework written in Visual Basic. The objective is to produce a suitable package capable of simulating biological control of stemborer population dynamics. One of the key features of a modular approach is that models should relate to the real world components or processes.

A beta version of the BorerSIM simulation package is under development for use in pest management programmes in eastern and southern Africa. BorerSIM simulates the growth and development of maize and stemborer-parasitoid population dynamics interactions as influenced by abiotic factors (edaphic and weather). The model contains four modules: Soil, Plant, Weather and Insect (Figure 4). Principles of the object-oriented approach are followed to implement the model in C++ programming language. The modular structure is used to depict classes and provide them with the right programming language.

The insect module simulates the population dynamics of stemborer-parasitoids in maize fields from the onset of a growing season and terminates with the physiological maturity of the crop. The life stages of the stemborer-parasitoid described by the module include eggs, larvae, pupae, and adults. The module focuses on describing the factors that affect processes that cause changes in the population density of each stage (Figure 5). Numbers of stemborer-parasitoid in each life stage and numbers of eggs laid by female moths and parasitoids are expressed as the absolute population (number/m^2).

The plant growth module computes crop growth and development based on daily values of maximum and minimum temperatures, radiation and the daily value of two soil-water stress factors: deficit and surplus. This module also simulates leaf area index (LAI), which is used in the soil water module to compute evapotranspiration. The weather module is called by BorerSIM to input, generate or calculate the daily and hourly weather values used by other parts of the model.

The beta version will be further evaluated and upgraded to Release Version 1.0 suitable for evaluation and use by a range of users. This includes

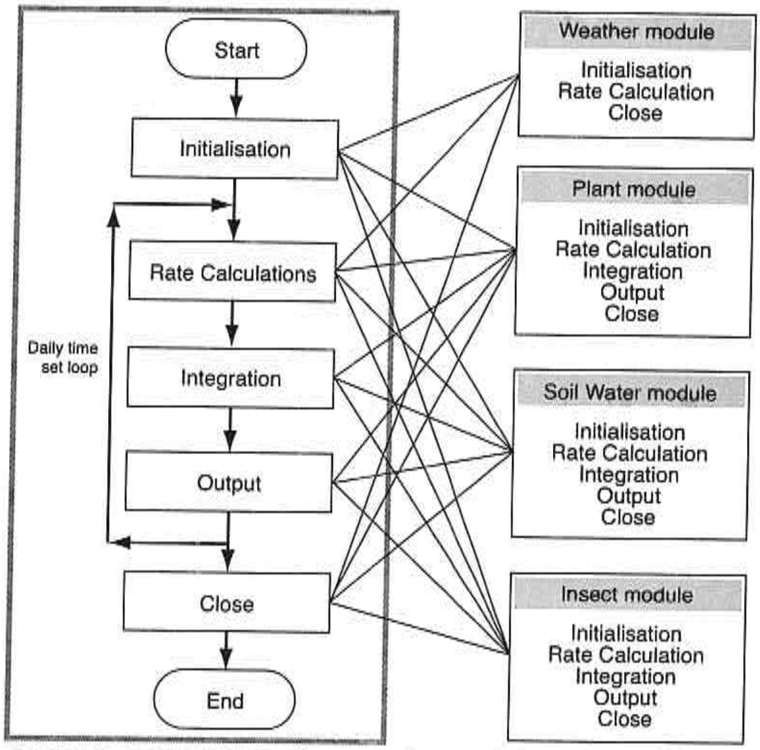

Figure 4. A schematic diagram of a modular crop and insect model

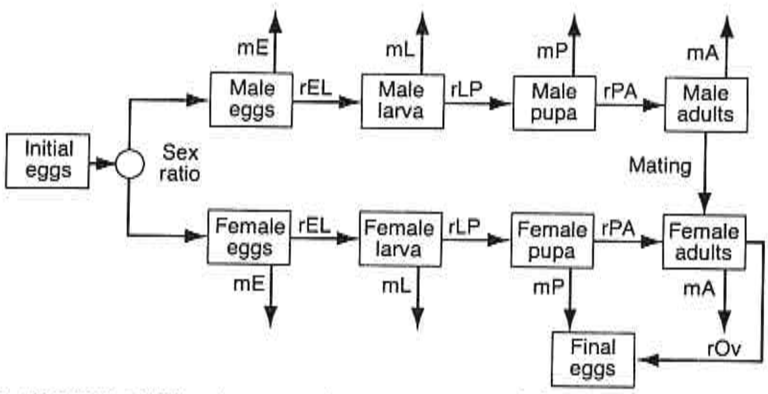

Figure 5. Schematic diagram of life stages and processes used for describing population dynamics of stemborers-parasitoids in the model

mE = egg stage mortality rate; mL = larval stage mortality rate; mP = pupal stage mortality rate; mA = adult stage mortality rate; rEL = egg to larval stage development rate; rLP = larval to pupal stage development rate; rPA = pupal to adult stage development rate; rOv = oviposition rate

Table 21. Stemborer species composition in each region and its geographic condition

Region	Altitude (m)	Rainfall (mm)	Cp	Co	Sc	Bf	Es
A	L (< 500)	1000 – 1200	Dom	Some	Some		
B	L (500–1200)	500 – 1000	Dom	Few		Non-suitable	
C	H (> 1500)	800 – 2500	Few		Some	Dom	
D	M (1000–1500)	1000 – 2000	Dom			Suitable	Some

Cp: *Chilo partellus*, Co: *Chilo orichalcociliellus*, Sc: *Sesamiae calamistis*, Bf: *Bussola fusca*, Es: *Eldana saccharina*, Dom: dominate species.
For regions A–D, refer to Figure 6.

refinement and testing of the revised insect module as other natural enemies are included in biocontrol of stemborers. Other future plans call for inclusion of the nutrient module, especially for nitrogen.

19. Modelling maize growth as affected by *Ch. partellus* and *Co. flavipes*

There are several stemborer species in eastern and southern Africa, of which *Chilo partellus* is an exotic species. The introduction of the exotic parasitoid species *Cotesia flavipes* not only faces adaptation problems of both habitat and its host, but also competition with the indigenous parasitoid species *Co. sesamiae*.

A two-host two-parasitoid model was formulated to simulate the dynamics of the stemborer and its larval parasitoids. The model aims to answer whether biological control in eastern Africa would eventually suppress *Ch. partellus* populations at an economically harmless level and if so, what would be the role of other secondary stemborer species. What would be the effect of species competition on parasitism and the species composition of parasitoids?

The model assumes that there is no host discrimination of both parasitoids and that *Co. flavipes* is a superior competitor that is able to eliminate *Cotesia sesamiae* when *Ch. partellus* is the host. Interspecific competition between the parasitoids was not considered owing to the fact of their low density. The regions studied in Kenya were selected according to their geographic features (Figure 6, Table 21). The results showed that in coastal region, *Ch. partellus* and another stemborer species could coexist with the parasitoid species at low densities with intra-specific competition. In this case, biological control would be expected to be successful. In eastern Kenya, where *B. fusca* is not a suitable host of both parasitoids, *Ch. partellus* could be controlled under the economically harmful level (EIL), but *B. fusca* could experience an outbreak. Once *B. fusca* reaches a high density, then intraspecific competition can occur, which can bring the system to a stable level.

In the highlands of Kenya, if parasitoids can not develop in *B. fusca* and if *Ch. partellus* is not abundant, then a *B. fusca* outbreak will occur and the parasitoids will die out. Otherwise, the two stemborer populations will fluctuate under low population densities in the presence of the parasitoids. Results from Lake Victoria are similar to region B if *B. fusca* is a non-suitable host, and with region A when *B. fusca* is the suitable host.

Using this model, it was shown that cereal stemborers, especially the exotic species *Ch. partellus*, can be controlled by *Cotesia flavipes*. This is very encouraging since it shows the prospect for successful biological control in Africa. In most cases, *Co. sesamiae* can co-exist with *Co. flavipes*. Therefore, the introduction of *Co. flavipes* into Kenya has an added (complementary) effect rather than causing elimination of the indigenous species. If and when *B. fusca* is a suitable host of both parasitoids, it makes it possible for the successful biological control of the borer species.

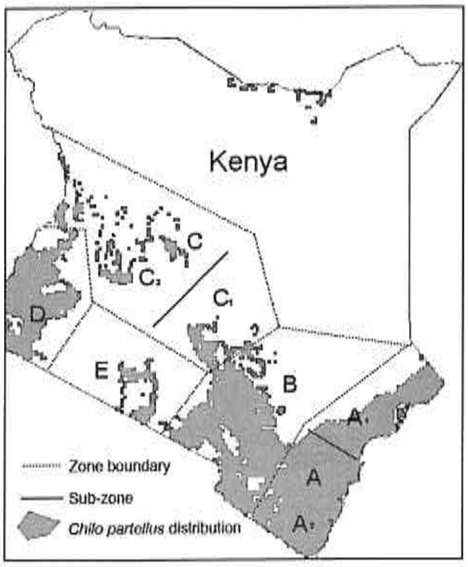

Figure 6. Regions studied in Kenya for stemborer prevalence. A, < 500 masl; B, 500–1200 masl; C, > 1500 masl; D, 1000–1500 masl

Participating scientists: W. A. Overholt (Project coordinator to mid-2002), M. Sétamou (Project coordinator 2002), F. Schulthess (Project coordinator 2003), C. O. Omwega, A. J. Ngi-Song, N. Jiang, E. Muchugu

Assisted by: G. Sequiera, D. Mungai, H. Mwadime, G. Okuku, J. Ochieng, P. Owuor

Collaborators: Moi University, Kenyatta University, University of Nairobi, Jomo Kenyatta University of Agriculture and Technology (Kenya), IRD-CNRS (France); NARO (Uganda); EARO (Ethiopia); CIMMYT

FUTURE OUTLOOK

Increased emphasis will be given to yield loss assessments, either via surveys or insecticide exclusion experiments. This is the prerequisite for a realistic assessment of the macro-economic impact of biological control on a region-wide basis. Simultaneously, the effect of soil fertility on plant, borers and parasitoids will be elucidated. Results will be used for construction of tritrophic models, which will be integrated in the Project's GIS work. Special emphasis will also be given to the role of wild host plants and associated wild borer species in the perennation of the parasitoid when the crop is not present.

The follow-up work at the Kenyan coast showed that *Co. flavipes* can have a considerable impact on pest infestation levels and crop yields but it does not offer a complete solution. Likewise, the major indigenous pest *(B. fusca)* has not been tackled yet. Although *X. stemmator* successfully parasitises *B. fusca* in the laboratory, it is too early to say if it attacks the pest in the field. Thus, additional parasitoid species will be introduced from other regions of Africa or Asia for laboratory testing and release.

In West Africa and Cameroon, *Telenomus* spp. egg parasitoids are major biotic control factors of noctuid pests, and their efficiency depends on the presence of natural habitats which maintain both pest and natural enemy populations. In the Dahomey gap, the *T. busseolae–T. isis* complex produce up to 95% of *S. calamistis* egg mortality. In the humid forest zone of Cameroon, *Telenomus* prevent *B. fusca* from becoming major pest during the second season. Whereas *T. busseolae* is ubiquitous in Africa, *T. isis* has never been reported from East Africa; therefore *T. isis* was introduced into Kenya in mid-2003. Suitability and interspecific competition studies with indigenous borers and parasitoid species will be carried out, respectively, before releases are made.

Sturmiopsis inferens is a natural tachinid larval parasitoid of noctuids and pyralids in Asia, among them *Chilo* spp. and *Sesamia* spp. It is planned to introduce the species in 2004. *Sturmiopsis parasitica* is a larval parasitoid of noctuid and pyralid stemborers in Africa. High parasitism of up to 70% was obtained from *S. calamistis* and *E. saccharina* in West Africa. A West African strain was introduced into South A frica against *E. saccharina* on sugarcane. In Zimbabwe, *S. parasitica* is one of the most important parasitoids of *B. fusca*, while *S. calamistis* is not a suitable host, thus, parasitoid populations crash when *B. fusca* goes into diapause. The West African strain, which also parasitises the non-diapausing *S. calamistis*, may maintain higher parasitism levels during the off-season. The strain was reared at the South African Sugar Experimental Station near Durban and will be introduced into the ICIPE laboratories in 2004.

In coastal Kenya it took five years to see an exponential increase in parasitism level and concomitant decrease in pest populations. In most project countries, the parasitoids were released in the late 1990s and early 2000 only. Thus, for an assessment of the impact of 'old' and new natural enemies the project requires several more years.

The project includes limited diagnostic work on candidates amenable to classical biological control other than field pests of cereals. One of the most serious problems in sub-Saharan Africa to date is the larger grain borer *Prostephanus truncatus*, an invasive storage pest introduced into East Africa in the early 1980s. The predator *Teretrius nigrescens*, introduced a few years later, proved to be efficient in humid, hot areas only. The pest was declared a problem of regional importance by the ASARECA board of directors. In 2003, the Kenyan Minister for Agriculture formed a task force to develop an IPM strategy to combat the larger grain borer. The ICIPE Project Coordinator is a member of this task force. During the Annual Working Planning and Training Workshop in October 2003 it was decided to invest some funds into monitoring the pest in nine member countries in 2004. It is planned to introduce two geographic races, currently reared by CIMMYT in Mexico, adapted to cool and hot, dry climates.

Ear damage by stemborers renders the grain susceptible to *Aspergillus flavus* infection, resulting in subsequent high levels of aflatoxin of field and stored maize. Thus, in the future additional emphasis will be given to combating mycotoxin-producing fungi in the field and stores.

CAPACITY BUILDING

PhD students

Catherine Gitau (Kenya) Description and origin of the geographic variations of *Cotesia–Busseola fusca* immunological interaction and molecular basis of virulence. Kenyatta University, Kenya.

Teddy Kauma Matama (Uganda) Role of wild host plants in population dynamics of cereal stemborers and associated natural enemies in Uganda. Kenyatta University, Kenya.

Domingos Cugala (Mozambique) Biologically-based integrated cereal stemborers management approaches in Mozambique. Kenyatta University, Kenya.

Melaku Wale (Ethiopia) Integration of biological control of cereal stemborers and habitat management on maize and sorghum based agroecosystems of the Amhara state, Ethiopia. Kenyatta University, Kenya.

Anderson Kipkoech (Kenya) The economics of biological control of cereal stemborers in maize growing belts of eastern and southern Africa. Moi University, Kenya.

Bruce Yaovi Anani (Togo) Host suitability and interspecific competition of the West African stemborer egg parasitoid *Telenomus isis* Polaszek (Hymenoptera: Scelionidae). Kenyatta University, Kenya.

MSc students

Jamleck Muturi (Kenya) Assessment of the potential effect of *Xanthopimpla stemmator* (Hymenoptera: Ichneumonidae) on target and non-target

Lepidoptera and parasitiods in graminaceous plants. Kenyatta University, Kenya.

Dennis Wanyama (Kenya) Effects of *Bt* toxins on non-target arthropods. University of Nairobi, Kenya.

James Kanya (Kenya) Quantification and qualification of vegetation in the proximity of maize fields in Trans Nzoia District. Jomo Kenyatta University of Agriculture and Technology, Kenya.

Evans Okoth (Kenya) Species diversity, success of an artificial release and parasitism trends of maize stemborers egg parasitoids in mixed cropping system in Kenya. Kenyatta University, Kenya.

Benjamin Muli (Kenya) Interspecific competition against *Xanthopimpla stemmator* Thunberg (Hymenoptera: Ichneumonidae), *Pediobius furvus* Gahan (Hymenoptera: Eulophidae) and *Dentichasmias busseolae* Heinrich (Hymenoptera: Ichneumonidae) on *Busseola fusca* Fuller (Lepidoptera: Noctuidae) and *Chilo partellus* Swinhoe (Lepidoptera: Crambidae) pupae on maize (*Zea mays* L.). Jomo Kenyatta University of Agriculture and Technology, Kenya.

IMPACT

- In coastal Kenya, the reduction of stemborer densities following the release of *Co. flavipes*, was close to 60%, which translates into 10–15% yield gains or ca. 140 kg/ha.
- Following the success in southeastern Kenya the project expanded to 11 countries in East and southern Africa. The parasitoid is now established in nine countries. It is estimated that if the wasp only establishes in 10% of the area infested with stemborer in this region, and has only half of the impact that has been measured in southeastern Kenya, then the savings in the region will be about $25 million per year, or enough food to feed one million people.
- While 11 PhD and 7 MSc have been trained between 1992–2001, 6 PhD and 15 MSc have been recruited thus far in the present phase of the Project. Under the supervison of ICIPE senior staff, they carry out most research work in-country and at ICIPE headquarters.

OUTPUT

Journal articles

Bekele J., Ngi-Song A. J. **and** *Overholt W.* **(2003)** Olfactory responses of *Cotesia flavipes* (Hymenoptera: Braconidae) to target and non-target Lepidoptera and their host plants. *Biological Control* 28, 360–367. **(Call No.: 03-1702)**

The attraction of *Cotesia flavipes* Cameron to volatiles from a range of non-target lepidopteran larvae and their host plants (grasses and trees) or food substrate (honeycomb) was evaluated using a Y-tube olfactometer. The non-target host larvae used in the study included *Galleria mellonella* (L.), *Charaxes cithaeron* Felder, *Bombyx mori* L., and *Eldana saccharina* Walker. The target insects, *Chilo partellus* (Swinhoe) and *Chilo orichalcociliellus* (Strand), were used as controls. Host plants included *Afzelia quanzensis* Welw., *Morus alba* L., *Cyperus papyrus* L., *Pennisetum purpureum* Schumach, and *Zea mays* L. The response of *C. flavipes* to volatiles from the non-target larvae and their food was variable. Attraction to uninfested maize was not significantly different from uninfested plants of non-target hosts or honeycomb. Only maize and honeycomb were preferred over clean air. *C. partellus* infested maize plants were significantly more attractive than *M. alba*, *A. quanzensis*, and honeycomb infested with their herbivores. Infested maize and *C. papyrus* were more attractive than uninfested ones. When odors from naked larvae were tested, *C. flavipes* preferred odors from *C. partellus* larvae over those of *E. saccharina* and *C. cithaeron* and larvae of *C. partellus* and *G. mellonella* were preferred to clean air. The implications of these findings for biological control and its effect on non-target organisms are discussed.

Chinwada P., Overholt W. A., Omwega C. O. **and Mueke J. M. (2003)** Geographic differences in host acceptance and suitability of two *Cotesia sesamiae* populations in Zimbabwe. *Biological Control* 28, 354–359. **(Call No.: 03-1707)**

Three lepidopteran stemborers, *Busseola fusca* Fuller (Noctuidae), *Sesamia calamistis* Hampson (Noctuidae), and *Chilo partellus* (Swinhoe) (Crambidae), were evaluated for their acceptability for oviposition and suitability for development by two populations of the larval endoparasitoid *Cotesia sesamiae* (Cameron) (Hymenoptera: Braconidae) occurring in the highveld (> 1200 m) and lowveld (< 600 m) regions of Zimbabwe. Mating studies were also conducted to determine reproductive compatibility between the populations. Both *C. sesamiae* populations preferred the noctuids to *C. partellus* for oviposition, possibly reflecting differences in evolutionary history. Although *B. fusca* was partially suitable for development of lowveld *C. sesamiae*, all three hosts were suitable for development of the highveld population. Crosses between highveld and lowveld *C. sesamiae* were compatible, and were generally not different from the intra-population crosses in developmental time, % adult emergence and sex ratio. However, broods were much larger when highveld males were used in the mating combinations. We conclude that although there is host overlap and probably a considerable degree of outbreeding between the two *C. sesamiae* populations, there are still significant genetic differences between them. Within Zimbabwe, it is unlikely that the deliberate introduction of either population outside its region of occurrence will give meaningful stemborer control.

Cole T. J., Ram M. S., Dowell F. E., ***Omwega C. O., Overholt W. A.*** **and Ramaswamy S. B. (2003)** Near-infrared spectroscopic method to identify *Cotesia flavipes* and *Cotesia sesamiae* (Hymenoptera: Braconidae). *Annals of the Entomological Society of America* 96, 865–869. **(Call No.: 03-1714)**

Parasitoids of the *Cotesia flavipes* complex (*C. flavipes* and *Cotesia sesamiae*) are natural enemies of stemboring lepidopteran pests in sub-Saharan Africa. The two species are difficult to differentiate using morphological markers, and a quick, reliable test was sought for their correct identification. After numerous, unsuccessful attempts at developing species-specific monoclonal antibodies that could differentiate between the two species, we were successful in using near-infrared spectroscopy to distinguish the cocoons of the two species with an accuracy of better than 85%. Calibrations were established using partial least squares analysis, enabling identification of cocoons of known species, cocoons from an alternative host, as well as in blind tests. This technology would greatly expedite identification of field-caught insects used to determine ecological parameters and parasitization rates of an individual species.

Emana G., Overholt W. A., **Kairu E.,** ***MacOpiyo L.*** **and** ***Zhou G.*** **(2002)** Predicting the distribution of *Chilo partellus* (Swinhoe) and its parasitoid *Cotesia flavipes* Cameron in Ethiopia using correlation, step-wise regression and geographic information systems. *Insect Science and Its Application* 22, 123–129. **(Call No.: 02-1685)**

The recent development of geographic information systems (GIS) provides new avenues for analysing spatial patterns in insect populations. Field survey data, along with GIS and statistical models were used to predict the distribution of *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae) and *Cotesia flavipes* Cameron (Hymenoptera: Braconidae) in Ethiopia. The results obtained suggested that the distributions of *Ch. partellus* and *Co. flavipes* were affected by rainfall and temperature. The predicted distributions of *Ch. partellus* and *Co. flavipes* were similar. Validation of predicted values is discussed.

Getu E., ***Overholt W. A.,*** **Kairu E. and** ***Omwega C. O.*** **(2003)** Evidence of the establishment of *Cotesia flavipes* (Hymenoptera: Braconidae), a parasitoid of cereal stemborers, and its host range expansion in Ethiopia. *Bulletin of Entomological Research* 93, 125–129. **(Call No.: 03-1682)**

Three lepidopteran cereal stemborers, *Chilo partellus* (Swinhoe) (Crambidae), *Busseola fusca* Fuller, and *Sesamia calamistis* Hampson (Noctuidae) were collected from maize and sorghum in Ethiopia. The noctuid stemborers are indigenous to Africa while *C. partellus* is an introduced species from Asia. In 1999, the Asian stemborer parasitoid, *Cotesia flavipes* Cameron (Braconidae) was found to be widespread in Ethiopia, even though it had never been released in the country. In addition to attacking *Chilo partellus*, *Cotesia flavipes* was reared from *B. fusca* and *S. calamistis*. The origin of *C. flavipes* in Ethiopia may have been Somalia where it was released in 1997 near the border with eastern Ethiopia. Percent parasitism of borers by *C. flavipes* was higher in eastern Ethiopia than other surveyed regions, and parasitism was higher in 2000 than 1999. Parasitism was higher when cereals were intercropped with other plants and when wild grass hosts of stemborers were present.

Mbapila J. C., ***Overholt W. A.*** **and Kayumbo H. Y. (2002)** Comparative development and population growth of an exotic stemborer, *Chilo partellus* (Swinhoe), and an ecologically similar congener, *C. orichalcociliellus* (Strand) (Lepidoptera: Crambidae). *Insect Science and Its Application* 22, 21–27. **(Call No.: 02-1634)**

Studies were conducted to determine the effect of temperature and diet on the development of *Chilo partellus* (Swinhoe) and *Chilo orichalcociliellus* (Strand) (Lepidoptera: Crambidae). Developmental times of *C. partellus* and *C. orichalcociliellus* for the egg, larval and egg–adult life stages were inversely related to temperature. The larval developmental period of *C. orichalcociliellus* reared on artificial diet was longer than the developmental period on natural diet. *Chilo partellus* had a higher intrinsic rate of natural increase than *C. orichalcociliellus* at all diet/ temperature combinations except natural diet at 31°C.

Mochiah M. B., Ngi-Song A. J., Overholt W. A. and Botchey M. (2002) (Short communication) Effects of calyx fluid from a population of *Cotesia sesamiae* (Cameron) (Hymenoptera: Braconidae) on the immune response of its host *Busseola fusca* Fuller (Lepidoptera: Noctuidae). *Insect Science and Its Application* 22, 81–85. **(Call No.: 02-1635)**

Busseola fusca Fuller is one of the major lepidopteran stemborers of maize and sorghum in Africa. *Cotesia sesamiae* (Cameron) (Hymenoptera: Braconidae) is an indigenous, gregarious larval endoparasitoid that attacks mid- to late-instar stemborer larvae, which is reported to be one of the most important larval parasitoids of *B. fusca* in many countries in sub-Saharan Africa. Previous work has shown that two biotypes of *C. sesamiae* occur in Kenya which express differential abilities to develop in *B. fusca*. A biotype from western Kenya successfully develops in *B. fusca*, while a biotype from the eastern coastal area does not. We treated fourth-instars of *B. fusca* with calyx fluid from *C. sesamiae* from western Kenya (Kitale) before offering them to *C. sesamiae* from the Coast (Mombasa) for oviposition, and found that the eggs were not encapsulated. This suggests that factors in the calyx fluid of *C. sesamiae* from the western Kenya biotype were responsible for suppressing the immune system of *B. fusca*. We speculate that polydnaviruses in the calyx fluid were involved in disarming the host immune system, and that the polydnaviruses in the two biotypes are genetically different.

Mochiah M. B., Ngi-Song A. J., Overholt W. A. **and Stouthamer R. (2002)** *Wolbachia* infection in *Cotesia sesamiae* (Hymenoptera: Braconidae) causes cytoplasmic incompatibility: Implications for biological control. *Biological Control* 25, 74–80. **(Call No.: 02-1639)**

Cotesia sesamiae (Hymenoptera: Braconidae) is an indigenous, gregarious, larval endoparasitoid that attacks mid- to late-instar of the stem borer larvae. Although the parasitoid is distributed widely throughout Africa, not all local populations appear to be equally effective in controlling stem borers. Consequently, there is an interest in releasing the more effective strains in areas that already have very low populations of *C. sesamiae*. Some *C. sesamiae* populations are infected with bacterial symbionts in the genus, *Wolbachia*, which may induce cytoplasmic incompatibility. Using an antibiotic treatment, we have established that the *Wolbachia* infection causes cytoplasmic incompatibility of the female mortality type in *C. sesamiae*. Using a simple recurrent equation model, we showed that mixing infected and uninfected populations that exhibit cytoplasmic incompatibility causes a transient, but possibly long, reduction in population growth rate. Knowledge of the infection status of native populations and populations that would be introduced could be used to avoid the incompatibility problems, by adjusting the population that will be introduced to the infection status of the native population.

***Mochiah M. B., Ngi-Song A. J., Overholt W. A.* and Stouthamer R. (2002)** Variation in encapsulation sensitivity of *Cotesia sesamiae* biotypes to *Busseola fusca*. *Entomologia Experimentalis et Applicata* 105, 111–118. **(Call No.: 02-1665)**

Many braconid wasp species inject polydnaviruses to overcome their host's immune system. In the species *Cotesia sesamiae*, two biotypes exist that differ in their ability to develop in the host *Busseola fusca*. The biotype from coastal Kenya is infected with *Wolbachia* and is not able to develop in larvae of *B. fusca*, whereas the uninfected inland biotype of this wasp can develop in *B. fusca*. The genetic transmission of the developmental ability was studied through a series of genetic crosses and superparasitization experiments. The *Wolbachia* infection of the coastal type did not play a role in the encapsulation response of the host. Experiments show that the polydnaviruses of the wasps could not prevent the encapsulation of the coastal parasitoid eggs. Most likely, larval characteristics such as surface proteins played a more important role in the encapsulation response of the host even in the presence of a functional polydnavirus.

***Mochiah M. B., Ngi-Song A. J., Overholt W. A.* and Botchey M. (2003)** Variation in total and differential haemocyte count of *Busseola fusca* (Lepidoptera: Noctuidae) parasitised by two biotypes of *Cotesia sesamiae* (Hymenoptera: Braconidae) and larval growth responses. *Environmental Entomology* 32, 247–255. **(Call No.: 03-1703)**

Cotesia sesamiae (Cameron) is an indigenous larval endoparasitoid that attacks mid- to late-stage gramineous stem borer larvae in Africa. Two biotypes of *C. sesamiae* have been reported with differential abilities to suppress the immune system of *Busseola fusca* Fuller. Eggs of a *C. sesamiae* population from Mombasa were encapsulated, whereas eggs of a population from Kitale were not. Total and differential haemocytes were counted in larvae of *B. fusca* at six times (2 h, 14 h, 24 h, 72 h, 120 h, 168 h) after being exposed to parasitoids from Kitale and Mombasa. The total numbers of haemocytes in a larva parasitized by the *C. sesamiae* population from Mombasa were higher as compared with larvae parasitized by the *C. sesamiae* population from Kitale. Plasmatocytes, in particular, were reduced in larvae parasitized by *C. sesamiae* from western Kenya from 72 to 168 h after oviposition. Our results suggest that plasmatocytes probably play an important role in the immune response of *B. fusca*. Significant proportions of the host larvae were still at the larval stage for those parasitised by *C. sesamiae* from Mombasa and another species of *Cotesia*, *Cotesia flavipes* Cameron at day 12. A reduction of *B. fusca* larval weight was observed on day 12 after oviposition by *C. sesamiae* from Kitale.

***Sallam M. N., Overholt W. A.* and Kairu E. (2002)** Intraspecific and interspecific competition between *Cotesia flavipes* and *Cotesia sesamiae* (Hymenoptera: Braconidae), gregarious larval endoparasitoids of lepidopteran stemborers. *Biocontrol Science and Technology* 12, 493–506. **(Call No.: 02-1633)**

Super and multiple parasitism of *Chilo partellus* (Lepidoptera: Pyralidae) and *Sesamia calamistis* (Lepidoptera: Noctuidae) by *Cotesia flavipes* Cameron and *Cotesia sesamiae* (Cameron) (Hymenoptera: Braconidae) were investigated in the laboratory. Progeny production of ***Co. flavipes*** increased as a result of increasing the number of ovipositions, from one to three per one *Ch. partellus* host larva, then decreased as a result of four and five ovipositions per larva. Cocoon weight, sex ratio and emergence of the parasitoid progeny were not affected by superparasitism. Low progeny production of *Co. sesamiae* and poor survival of *Ch. partellus* host larvae were found as a result of superparasitism. When *S. calamistis* was the host, the duration of immature stages of *Co. flavipes*, parasitoid emergence, progeny production and sex ratio were not affected by superparasitism, but cocoon weight, adult longevity and the potential fecundity of adult females decreased. Superparasitism of *S. calamistis* by *Co. sesamiae* did not affect emergence, longevity or sex ratio of adult progeny of the parasitoid, but prolonged immature development, lowered cocoon weight and decreased potential fecundity of adult female progeny. *Co. flavipes* out-competed *Co. sesamiae* when *Ch. partellus* was parasitised by both species. The potential for local displacement of *Co. sesamiae* by *Co. flavipes* in areas dominated by *Ch. partellus* in East Africa is discussed.

Songa J. M., *Overholt W. A.*, Mueke J. M. and Okello R. O. (2002) Farmers' perceptions of aspects of maize production systems and pests in semi-arid eastern Kenya: Factors influencing occurrence and control of stemborers. *International Journal of Pest Management* 48, 1–11. **(Call No.: 02-1605)**

A farmer survey was conducted in six agro-ecological zones (AEZs) in semi-arid eastern Kenya to verify the socio-economic importance of maize, identify its pests and farmers' perceptions of the relative importance of the pests. We also determined some agronomic practices that may influence stemborer infestation and identified the stemborer control methods used. Pests reported included chafer grubs, stemborers, termites, 'red ants', yellow-necked spur fowls, squirrels, monkeys, porcupines, rats, wild pigs and storage insect pests. Their relative importance in each AEZ is discussed. The squirrel was the most widely distributed and important vertebrate pest of maize in the study AEZs. Stemborers infested maize in all the zones, and ranked first among insect pests in the Upper Midland zone 4 (UM4), Lower Midland zone 3 (LM3) and LM4, and second in LM5, but were unimportant in UM2. Agronomic practices that may influence stemborer infestation in maize, including cropping system, sowing time, fertilizer/manure use, stover storage usage and disposal and maize varieties are discussed. Most farmers preferred local to improved maize varieties, and maize was mostly grown as an intercrop. This emphasizes the need for more research effort to identify pests and develop pest management technologies in local maize varieties, contrary to the current research agenda which has focused on improved varieties. Pest management technologies developed also should be compatible with intercropping before dissemination to farmers. Farmers use insecticides, wood ash, soil, saw dust, chilli pepper powder, dry cell powder and mexican marigold (*Tagetes minuta*) to control stemborers.

Songa J. M., *Overholt W. A.*, Okello R. O. and Mueke J. M. (2002) Control of lepidopteran stemborers in maize by indigenous parasitoids in semi-arid areas of eastern Kenya. *Biological Agriculture and Horticulture* 20, 77–90. **(Call No.: 02-1679)**

Stemborers of maize and their associated indigenous parasitoids were studied at Katumani, Kiboko and Ithookwe in the semi-arid areas of eastern Kenya over a period of four seasons (short rains, 1996–long rains, 1998). Maize fields established at each site were sampled at least weekly up to plant maturity, and all the stemborer life stages recovered were reared individually in the laboratory for possible parasitoid emergence. The stemborers that attacked maize at the three sites were *Chilo partellus*, the dominant and most widespread stemborer, *Sesamia calamistis*, *Cryptophlebia leucotreta* and *Busseola fusca*. A complex of 22 mainly larval parasitoids attacked the stemborers, but the parasitism was generally low. *C. partellus* was the most frequently parasitized stemborer. The most widespread larval parasitoid was *Cotesia sesamine*, followed by *Chelonus curvimaculatus*, while *Dentichasmias busseolae* and *Pediobius furvus* were the most common pupal parasitoids. The low percentage parasitism by indigenous parasitoids and the knowledge that the exotic stemborer *C. partellus* was dominant suggest the potential of classical biological control in reducing stemborer damage in this region. The need for suitable conservation measures to enhance the parasitoid populations and their effectiveness is emphasized, and ideas on how to implement this suggested.

***Zhou G., Overholt W. A.* and *Kimani-Njogu S. W.* (2003)** Species richness and parasitism in an assemblage of parasitoids attacking maize stem borers in coastal Kenya. *Ecological Entomology* 28, 109–118. **(Call No.: 03-1664)**

Parasitoids were reared from four species of lepidopteran stem borer collected in maize in southern coastal Kenya from 1992 to 1999. The stem borers included three native species, *Sesamia calamistis* Hampson, *Busseola fusca* Fuller, and *Chilo orichalcociliellus* (Strand), and one exotic borer, *Chilo partellus* (Swinhoe). A total of 174 663 caterpillars was collected, of which 12 645 were parasitised.

Twenty-six primary parasitoid species were reared from the exotic borer, *C. partellus*, indicating a rapid accumulation of native parasitoids on the alien borer.

The three most abundant parasitoids were the larval parasitoids *Cotesia sesamiae* Cameron, *Cotesia flavipes* (Cameron), and the pupal parasitoid *Pediobius furvus* Gahan. The pupal parasitoid *Dentichasmias busseolae* Heinrich and the larval parasitoid *Goniozus indicus* Ashmead were also common. All used an ingress-and-sting method of attack.

Cotesia flavipes, introduced into Kenya in 1993, was found in all seasons from 1997 onwards, and has become the most abundant stem borer larval parasitoid in the area. A native congener, *Cotesia sesamiae*, appeared in all seasons from 1992 to 1999. Together, these two parasitoids accounted for 83.3% of the parasitised borers.

Thirty parasitoid species were recovered in Kilifi district, 27 in Kwale, and 15 in Taita Taveta. Parasitism was much greater in Taita Taveta district than in Kilifi or Kwale districts.

Books

Kfir R., *Overholt W. A., Khan Z. R.* and Polaszek A. (2002) Biology and management of economically important lepidopteran cereal stem borers in Africa. *Annual Review of Entomology* 47, 701–731. **(Call No.: 02-1632)**

James B., Neuenschwander P., Markham R., Anderson P., Braun A., *Overholt W. A., Khan Z. R.*, Makkouk K. and Emechebe A. (2003) Bridging the gap with the CGIAR Systemwide Program on integrated pest management, pp. 419–434. In *Integrated Pest Management in the Global Arena* (Edited by K. M. Maredia, D. Dakouo and D. Mota-Sanchez). CAB International, UK. **(Call No.: 03-1754)**

***Khan Z. R., Overholt W. A.* and *Ng'eny-Mengech A.* (2003)** Integrated pest management case studies from ICIPE, pp. 441–452. In *Integrated Pest Management in the Global Arena* (Edited by K. M. Maredia, D. Dakouo and D. Mota-Sanchez). CAB International, UK. **(Call No.: 03-1740)**

(See also the report on Molecular Biology and Biochemistry/Biotechnology Department)

Donor: Directorate General for International Cooperation (DGIS), The Netherlands

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BIODIVERSITY AND CHEMICAL ECOLOGY OF GRAMINEOUS NOCTUID STEMBORERS IN AFRICA

BACKGROUND, APPROACH AND OBJECTIVES

In Africa, the noctuid (Family: Noctuidae) stemborers' abundance, regulation by antagonists and economic importance are highly variable, according to the environment, phyto-geographic characteristics and altitude. The reasons for this variability in population abundance are not well understood in spite of extensive studies over the past 50 years. Currently, the most accepted reasons for this variation are the existence of bio-geographic races, the more or less close proximity of the natural environments and the inefficiency of natural enemies (mainly parasitoids) in cultivated environments.

In 2001, Institut de Recherche pour le Développement (IRD) initiated a project which focuses on assessing the genetic variation in the populations of selected pests species: *Busseola fusca*, *Sesamia calamistis*, *Sesamia nonagrioides* and related genera. In addition, the Project looked at the larval parasitoid *Cotesia sesamiae*, which is one of the main antagonists of noctuid borers attacking cereals in two of Africa's regions, West Africa (represented by Benin, Togo and Ghana) and East Africa (represented by Kenya).

The research involves the following main activities:

- Description of the taxonomic diversity of the noctuid stemborers *Busseola* spp., *Sesamia* spp., and related genera (*Manga*, *Sciomesa*, *Carelis*, *Poeonoma*, *Speia*) in different ecoregions;
- Study of the genetic diversity of *B. fusca*, *S. calamistis* and *S. nonagrioides* populations at the geographic and ecological level using molecular tools and characterisation of pheromonal communication systems;
- Study of coevolutionary processes between *B. fusca* and its main parasitoid *Cotesia sesamiae*;
- Determination of the selective values (fitness) of the differences observed among populations in terms of habitat foraging capacity, reproductive (oviposition) success and development performance;
- Analysis of host plant selection mechanisms by stemborers with special reference to *B. fusca*, and the importance of physical and chemical characters of the host plant on oviposition;
- Study of the role of host plants in the adaptive radiation of stemborers (*Busseola*, *Sesamia* and related genera) in Africa;
- Study of the role of wild habitats in the colonisation of crop fields by stemborers.

In addition to gaining a better taxonomic knowledge of African stemborers in cultivated and wild habitats, the results of the Project will lead to:

- development of evolutionary scenarios explaining the present day interactions between host plants, herbivores and parasitoids. This will help to predict how global changes (global warming) or human activities (use of GMOs, deforestation and/or displacement of wild habitats) may modify these interactions.
- a better understanding of the population dynamics and an improvement of existing strategies to manage stemborers on crops;
- a better understanding of the carry-over effects of wild habitats in biological control by introduced and indigenous natural enemy species.

WORK IN PROGRESS

1. Distribution and abundance of stemborers in maize and sorghum fields

Since February 2001, a survey has been undertaken in all maize and sorghum-growing areas of Kenya (Figure 1). The surveyed areas cover all the agro-climatic zones (Kenya Soil Survey, 1980), ranging from sea level to 2700 m altitude (masl), including areas that have never been surveyed before, such as the Tana River area (Garissa, Bura, Garsen), the Tanzania border (Loitokitok, Namanga, Nguruman), the northern Rift Valley (Baringo, Kerio Valley, Cherangani, Lodwar) and the northern part of Eastern province (Nyembene, Kyuso, Isiolo, Marsabit). Assessments of the pests are done on subsistence farmers' fields at an average of 50-km intervals. At each of the 73 sites, 3–5 farmers' fields were sampled 1–2 times per cycle (long and short rainy seasons).

Since February 2001, 891 maize and sorghum fields have been sampled, with 37,546 stems collected and 63,159 stemborers recovered. Five main lepidopteran stemborer species were found: *Chilo partellus* (Swinhoe) (49%), *Chilo orichalcociliellus* (Strand) (2%), *Eldana saccharina* (Walker) (1%), *Sesamia calamistis* Hampson (5%) (Figure 1a) and *Busseola fusca* Fuller (43%) (Figure 1b). Other stemborer species recovered during the survey included *Busseola phaia* Bowden (Figure 1c), *Sciomesa piscator* Fletcher (Figure 1d), *Sc. cretiza* Lederer, *Sesamia* sp. nov. (Figure 1e), *Sesamia nonagrioides* Lefebvre (Figure 1f), *Eldana saccharina*, *Chilo* sp. and four unknown species of Pyralidae.

Although the study is still in progress, our data show that all stemborer species are more widespread than reported by other recent surveys (Seshu Reddy, 1983 and Zhou et al., 2001) and that there is a great variability of abundance from year to year in sites located between 1000 and 1700 masl. The distribution and abundance of stemborer species in the areas thus far surveyed agree with these earlier findings. *Chilo partellus* was found at all elevations, from sea level up to 2300 m but accounted for less than 2% at elevations above 1800 m (Tables 1 and 2). *Chilo orichalcociliellus* was found mainly in the coastal areas at elevations below 500 m with 99% of this species being recorded in this zone, although small numbers were also found in Nguruman (781 m) and in Muranga (1179 m). *Eldana saccharina* was found in the Lake Victoria lakeshore

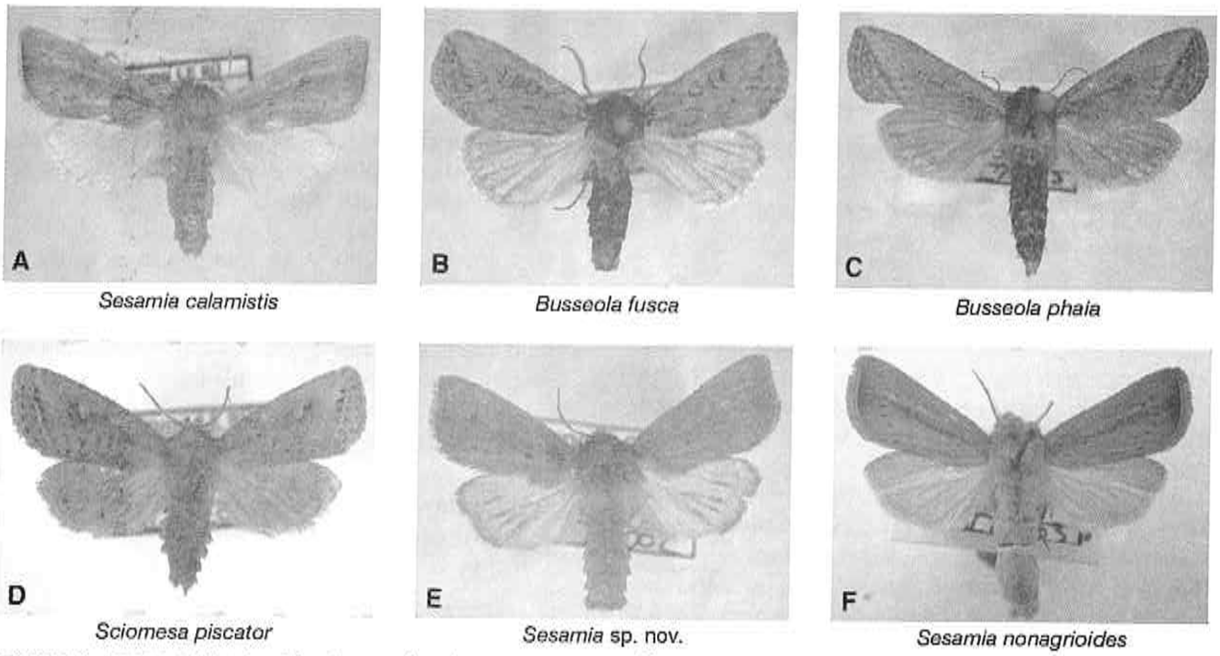


Figure 1. Some of the lepidopteran stemborers recovered in a survey of all the agroclimatic zones of Kenya, 2001–2002. Stemborers (A) and (B) are two of the five most important species

area, accounting for 1% of all species, but was also found in the coastal area near Garsen and Malindi. *Sesamia calamistis* occurred in all zones, from sea level to 2500 m, accounting for 8% in the coast and less than 2% above 2000 m. *Busseola fusca* occurred everywhere above 700 m, accounting for 3.8% below 1000 m and more than 88% above 1500 m; it also was found in the coastal area near Malindi and Kwale and in northern Kenya (Marsabit and Kalokol on the Lake Turkana banks).

Table 1. Mean (%) stemborer species composition in the main agro-climatic zones in Kenya

	% species composition			
Agroclimatic zone	*Busseola fusca*	*Sesamia calamistis*	*Chilo partellus*	*Chilo orichalcociliellus*
Moist high tropics	91.3	0.9	8.0	–
Dry high tropics	96.4	3.3	0.3	–
Moist mid-altitude	44.9	4.3	50.8	–
Dry mid-altitude	28.3	6.4	65.3	–
Severe water stress	1.4	3.4	95.2	–
Moist low tropics	0.1	7.9	87.1	4.9

Table 2. Seasonal variability in mean (± SE) percentage stemborer species composition in different agro-climatic zones in Kenya, 2002–2003

Agroclimatic zone	Seasons and (No. of fields surveyed)	*Busseola fusca*	*Sesamia calamistis*	*Chilo partellus*	*Chilo orichalcociliellus*
Moist high tropics	LR (45)	96.2 ± 1.9	2.0 ± 1.5	01.7 ± 1.2	–
	SR (24)	88.8 ± 5.3	1.2 ± 0.7	10.0 ± 5.4	–
Dry high tropics	LR (37)	96.3 ± 2.0	3.5 ± 1.9	00.2 ± 0.1	–
	SR (15)	99.3 ± 0.5	0.4 ± 0.4	00.3 ± 0.2	–
Moist mid-altitude	LR (34)	46.1 ± 6.7	7.5 ± 2.2	46.4 ± 7.1	–
	SR (42)	60.3 ± 6.6	6.0 ± 2.1	33.8 ± 6.7	–
Dry mid-altitude	LR (41)	43.9 ± 6.8	3.7 ± 1.5	52.3 ± 7.0	–
	SR (40)	18.1 ± 4.3	9.6 ± 2.2	72.3 ± 4.5	–
Severe water stress	LR (34)	03.3 ± 1.6	6.5 ± 2.1	90.2 ± 2.9	–
	SR (22)	03.4 ± 3.2	8.2 ± 2.9	88.4 ± 4.6	–
Moist low tropics	LR (19)	00.1 ± 0.1	5.9 ± 1.9	84.3 ± 3.5	9.7 ± 3.6
	SR (25)	00.1 ± 0.1	21.2 ± 5.5	74.5 ± 5.6	4.2 ± 1.4

LR = long rains, SR = short rains, – not recorded.

2. Biodiversity of stemborers

A survey carried out in western Kenya in 2002–2003 identified two genetically and faunistically independent compartments: one occupied with *Busseola fusca* on cultivated plants and the other occupied by at least eight other species of Noctuidae on wild grasses. From January 2003, therefore, an extensive survey on wild host habitats in East Africa was launched. The surveyed area currently covers all of southern Kenya from the coast to the Ugandan border (42 localities), all of central Uganda (from the Kenya border to the Congo border, 31 localities) and several localities in Tanzania (7 localities). Thus far, 8614, 1995 and 482 stemborer larvae have been collected in Kenya, Uganda and Tanzania, respectively, belonging to at least 81 species (37 species of Noctuidae, 43 species of Pyralidae, 1 species of Cossidae) on 44 wild grass species (24 Poaceae, 19 Cyperaceae, 1 Typhaceae) (Figure 2). Nineteen of these host plants are reported for the first time, thus the number of host plants is now 63 in East Africa.

Comparison of the numbers of borers by species found on some common host plants and across all wild host plant species in Kenya showed some discrepancies between some previous findings and collections of the IRD team. *Busseola fusca* appears in the present study to be exceedingly rare on wild hosts (Table 3). On the other hand, *Chilo* spp. and *S. calamistis* were either found to be absent on some of the hosts described previously by ICIPE workers and on some hosts they were much more common than previously found. Surveys in Uganda and Tanzania will start at the beginning of 2004.

Preliminary results from these countries indicate that most stemborer species are localised and specialised in attacking only a narrow range of host plant species. In particular, *B. fusca* is nearly absent on wild grasses, while more than 95% of *Ch. partellus* was found on wild sorghum. The great majority (71.3%) of *Ch. orichalcociliellus* was found on *Panicum* sp. and the host range appears to be wider than for *Ch. partellus* (Table 4).

3. Differences among *B. fusca* populations in reproductive success and development performance

PCR analysis was done on several *B. fusca* individuals from the field in Kenya and showed the presence of two mitochondrial haplotypes or populations (Figure 3). The haplotype I is characterised by 2 DNA fragments (880 and 100 bp) and the haplotype II by 3 DNA fragments (600, 300 and 100 bp).

In Kenya, although these two populations are living in sympatric conditions, the individuals from population II are more abundant than those from population I. Under laboratory conditions, it was possible to cross-mate these two populations. All cross-mate possibilities were obtained: female II x male II, female II x male I, female I x male II and female I x male I. Consequently, there is no cross-mating barrier between these two populations. This indicates that the males can mate with females from a population of different origin, suggesting that the pheromonal compositions are similar between females from populations I and II.

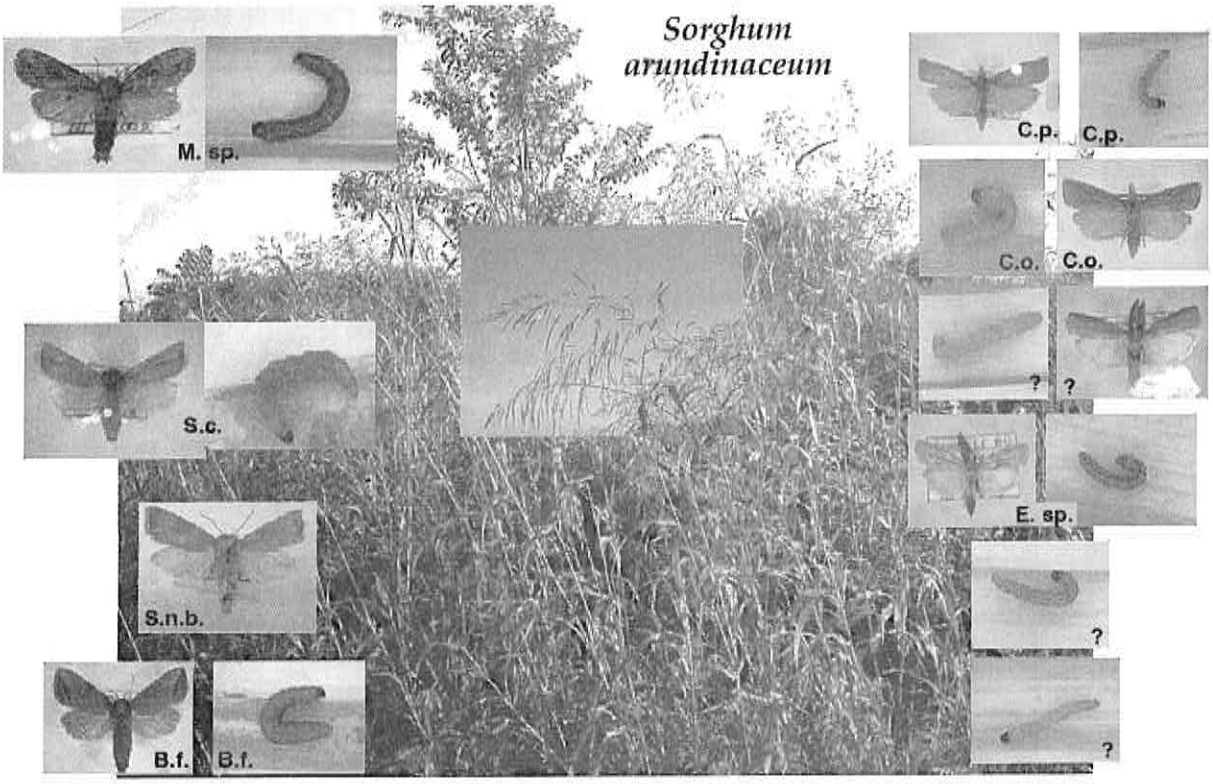


Figure 2. Stemborers collected from a wild sorghum species

B.f. = Busseola fusca, *S.c.* = Sesamia calamistis, *S.n.b.* = Sesamia nonagroides, *C.p.* = Chilo partellus, *C.o.* = Chilo orichalcociliellus. ? = not yet identified, *E. sp.* = Ematheudes *sp.*, *sp.* = unknown species, *M. sp.* = Manga *sp.*

Table 3. Comparison of number of borer species found on several common host plants in three studies: Randriamananoro (1996) and Khan et al. (1998) (total in light font) and IRD team (bold)

	Main stemborer species				Other borer species		
Host plant	C sp	Bf	Sc	Es	Pyr	Noct	No. of species
Sorghum sp 1	512	432	28	1			
	1815	**13**	**25**	**0**	**65**	**48**	**8**
Panicum sp 1	36	11	11	0			
	274	**0**	**5**	**0**	**505**	**1481**	**5**
Panicum sp 2	0	40	0	0			
	3	**0**	**0**	**0**	**1**	**251**	**6**
Pennisetum sp 1	63	181	79	0			
	8	**2**	**6**	**0**	**27**	**520**	**5**
Pennisetum sp 2	8	1	3	0			
	70	**0**	**67**	**0**	**0**	**95**	**3**
Echinochloa sp 1	23	86	43	0			
	0	**0**	**2**	**2**	**33**	**153**	**8**
Rottboellia sp 1	80	1	8	0			
	41	**0**	**1**	**0**	**52**	**0**	**2**
Phragmites sp 1	0	0	5	0			
	0	**0**	**0**	**0**	**0**	**10**	**2**
All wild host plants	1077	893	591	482			
together	**2183**	**15**	**170**	**25**	**1138**	**5083**	**81**

C sp. = *Chilo* sp., Bf = *Busseola fusca*, Sc = *Sesamia calamistis*, Es = *Eldana saccharina*, Pyr = Pyralidae, Noct = Noctuidae.

Table 4. Relative importance of the four main lepidopteran stemborer species in cultivated and wild plants in Kenya

	Number stemborers collected and percentage abundance (in bold)			
Host plants	Bf	Sc	Cp	Co
Maize, sorghum, finger and candle millet, sugarcane	22695 **(37.6)**	2383 **(4.0)**	34835 **(57.7)**	408 **(0.7)**
All wild grasses	15 **(0.6)**	170 **(7.2)**	1853 **(78.3)**	330 **(13.9)**
Sorghum sp 1	13 **(0.7)**	55 **(2.9)**	1812 **(95.7)**	13 **(0.7)**

Cp = *Chilo partellus*, Co = *C. orichalcociliellus*, Bf = *Busseola fusca*, Sc = *Sesamia calamistis*.

The females from population II have a tendency to call the males earlier than those from population I (Table 5). However, there is no statistical difference and thus this biological parameter is not useful in distinguishing these two populations. The other biological parameters, also including the developmental time of the progenies (data not shown), do not allow the distinguishing of these two populations (Table 5). Females from both populations presented similar fecundity and fertility, and thus these results do not explain why females from population II are more abundant in the field.

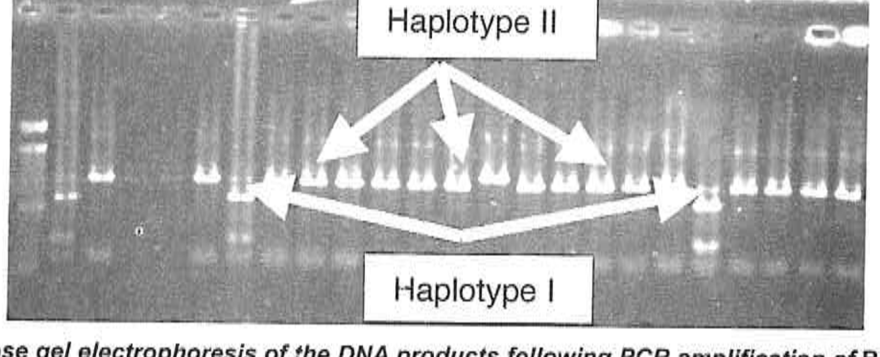


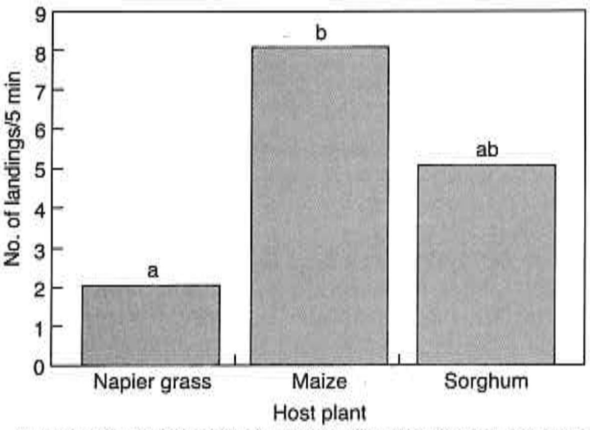
Figure 3. Agarose gel electrophoresis of the DNA products following PCR amplification of* Busseola fusca *mitochondrial DNA by using the primer CytB Cp1-Tser.

Results show the presence of two mitochondrial haplotypes labelled I and II. (1 = 100 bp DNA ladder)

Table 5. Calling time behaviour (after nightfall), fecundity (total number of eggs laid per female after 3 nights) and egg fertility (in %) in two populations of *Busseola fusca* females from Kenya

	Calling time (h)	Fecundity	Fertility (%)
Population I	7.3 ± 0.5 (15)	469.1 ± 90.0 (9)	76.0 ± 14.4 (9)
Population II	6.6 ± 0.2 (47)	367.2 ± 42.7 (35)	70.2 ± 7.5 (35)

Means (± SE) are not different at the 5% level, Student's t-test (population comparisons). Number of replicates are in parentheses.



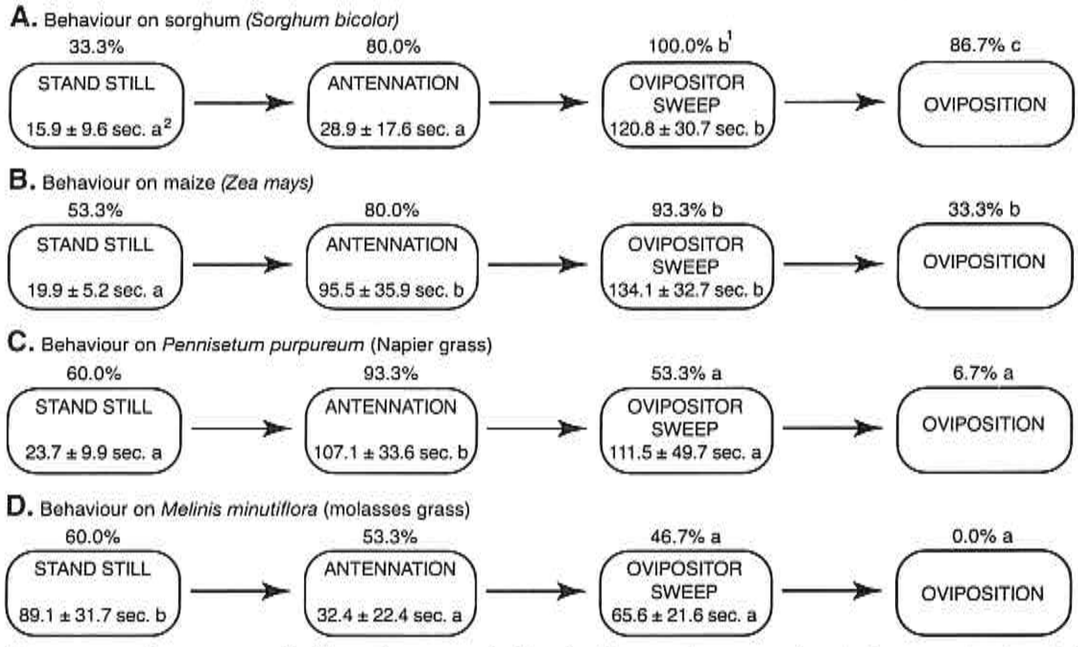
Values with different letters are significantly different using an experiment- wise error rate of $\alpha = 0.05$ (χ^2-test, contingency table [2 x 2])

Figure 4. Number of landings by* Busseola fusca *on Napier grass, maize and sorghum over 5 minutes of observation. All landings ended in oviposition on these three hosts

4. Analysis of host plant selection mechanisms by stemborers with special reference to *B. fusca*, and importance of physical and chemical characters of the host plant on oviposition

The stemborer *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) is an important pest of maize and grain sorghum in East Africa. To control this pest, novel habitat-management strategies have been recently developed using 'push-pull' or stimulo-deterrent diversionary tactics *(see the previous report on 'push-pull')*. Proper and efficient use of such strategies needs an accurate understanding of the host selection process of the insect pest. Our first aim was to study under laboratory conditions host plant selection behaviour, including pre-alighting, host alighting and oviposition.

Three distinct plant species, maize (*Zea mays*), sorghum (*Sorghum bicolor*) and Napier grass (*Pennisetum purpureum*) were used for wind tunnel observations. Maize and sorghum are considered



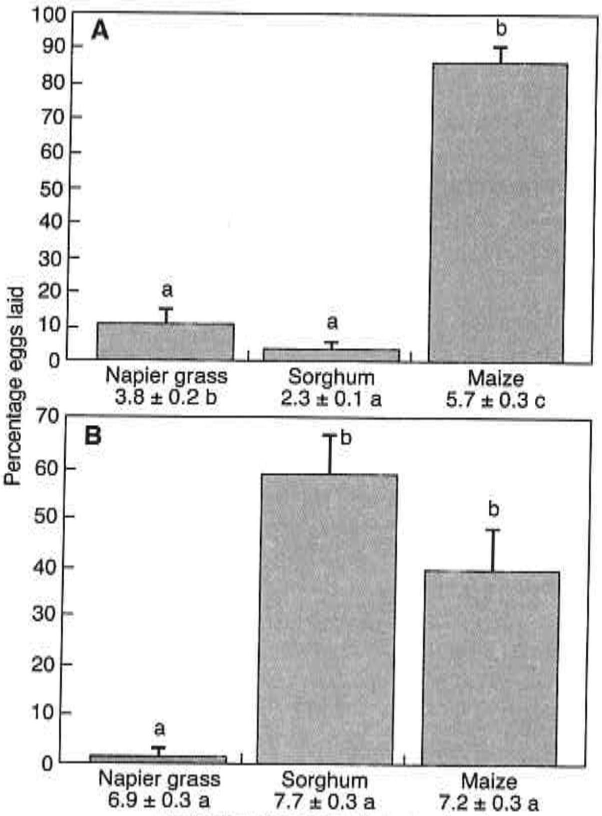
[1] Percentages of occurrence with different letters are significantly different using an experiment-wise error rate of $\alpha = 0.10$ (χ^2 square test, contingency table [2 x 2]).

[2] The duration is given in seconds (mean ± SE). Means accompanied by different letters are significantly different using an experiment-wise error rate of $\alpha = 0.05$, except for 'ovipositor sweep' duration rate for which $\alpha = 0.10$ (ANOVA followed by a Fisher's PLSD test.

Figure 5. Transitions (arrows) duration and percentage occurrence of the behavioural steps of* Busseola fusca *on sorghum (A, N = 15), maize (B, N = 15), on* Pennisetum purpureum *(C, N = 15) and* Melinis minutiflora *(D, N = 15)

to be the main hosts of *B. fusca*. Napier grass is usually identified as a trap plant and is used in the 'push-pull' strategy. In addition, *Melinis minutiflora* (molasses grass), known to be repellent to *B. fusca* for oviposition, was also used for post-alighting observations.

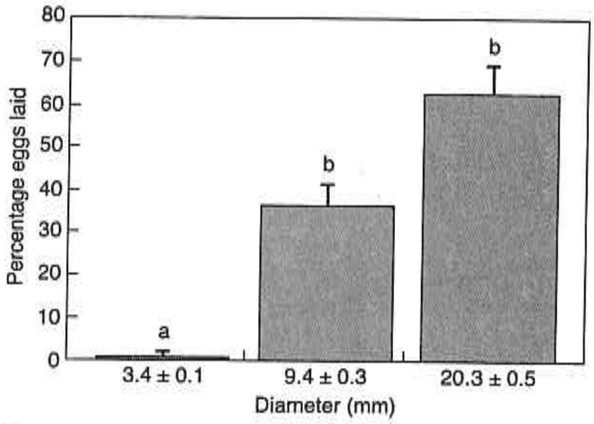
In wind tunnel tests, it was shown that *B. fusca* could select the host plant at long ranges for oviposition. Olfactory and visual stimuli guide the insect onto the plant. Surprisingly, both maize and sorghum were usually selected for oviposition as compared to Napier grass (Figure 4). In post-alighting observations, the insect behaviour could be sequenced into several steps (Figure 5): First the insect stands still on the plant. On maize and sorghum, the duration of this step is shorter than on Napier grass and molasses grass. Afterwards, the insect walks up and down along the plant, touching the plant surface with its antennae. This behavioural step occurs irrespective of the plant species and seems to involve plant surface prospecting in which contact-chemoreception stimuli seem to be mostly involved. On reaching the stem, the insect begins to sweep its ovipositor on the stem surface. The duration of this behavioural step strongly depends on the plant species used. Tactile and contact-



Means accompanied by different letters are significantly different using an experiment-wise error rate of $\alpha = 0.05$ (ANOVA followed by a Fisher's PLSD test). Total eggs for (A) = 4506, (B) = 3591.

Figure 6. Relative proportions (in %) of eggs laid by female* Busseola fusca *after four nights on three plant species with either (A) same age but different stem diameter or (B) different age but similar stem diameter.

Means ± SE, N = 15.



Means with different letters are significantly different using an experiment-wise error rate of $\alpha = 0.05$ (ANOVA followed by a Fisher's PLSD test). Total eggs = 3712. Means ± SE, N = 15.

Figure 7. Relative proportions of eggs laid by female* Busseola fusca *after four nights on surrogate paper stems of 3 diameters

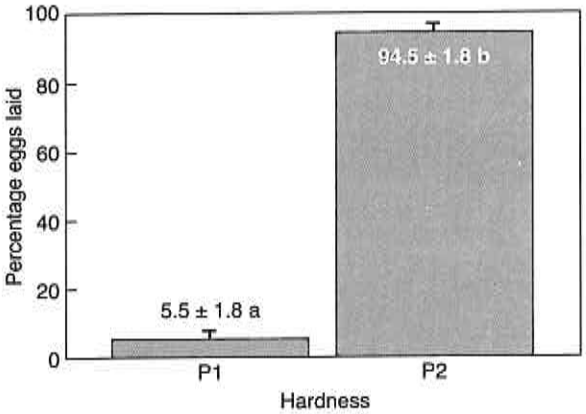
chemoreception stimuli from the plants seem to play a major role in the oviposition decision. The insect spends much more time sweeping its ovipositor on maize and sorghum than on *P. purpureum* and *M. minutiflora*. Finally, oviposition occurs only on sorghum and maize, with sorghum being the most preferred.

In conclusion, it was confirmed that maize and sorghum are highly preferred for oviposition, whereas *P. purpureum* is less preferred and *M. minutiflora* is a non-preferred host. Furthermore, the results indicate that Napier grass cannot be considered as a trap plant in the 'push-pull' strategy to control *B. fusca* in the field. It was shown that the host selection process for oviposition may be influenced by both physical and chemical characteristics of the plant.

Our second aim was to show that plant physical factors (stem diameter, plant surface texture and leaf sheath hardness) influence oviposition of *B. fusca*. Although sorghum is more preferred than Napier grass for oviposition, the preference for sorghum diminishes with thinner stem diameters (Figure 6). The influence of support diameter on *B. fusca* selection for oviposition was confirmed using surrogate stems, made of wax papers rolled into a helix. An increase in diameter of such cylinders induced a significant increase in oviposition (Figure 7).

The surface quality of the support also can be assessed by the gravid females (data not shown). *Busseola fusca* could distinguish between a smooth and rough surface, and preferred smooth waxy outer surfaces, confirming that the location of a suitable site for oviposition is partly thigmotactic, as was shown in the above study, and that the pubescence characteristics of the plant surface should disturb *B. fusca* oviposition.

The moisture content of the support also influences the oviposition of *B. fusca* (data not shown). The insects preferred to oviposit on the support with the lowest moisture content. It was also shown that the hardness of the paper sheet conditioned the oviposition (Figure 8). Supports with the lowest sheet hardness are the most preferred, probably due to easier insertion of the



Means ± SE, N = 13. Means accompanied by different letters are significantly different using an experiment-wise error rate of $\alpha = 0.05$ (Student's t-test). Total eggs = 2688.

Figure 8. Relative proportions of eggs laid by female* Busseola fusca *after four nights on two cylindrical surrogate stems of distinct hardness

(P1 at 7.8 ± 0.12 mg/cm² and P2 at 4.3 ± 0.05 mg/cm²)

insect ovipositor, thus indicating that plants having a stronger leaf sheath hardness should be less preferred for oviposition.

The antennae and the ovipositor of *B. fusca* females were observed by scanning electron microscopy to confirm the presence of chemoreceptor sensillae. Similarly to Lepidoptera in general, the antennae of *B. fusca* females possess multiporous and uniporous sensillae involved in olfaction and contact evaluation (or 'gustation') respectively along the ventral part of the antennae (Figure 9A). The ovipositor sensillae are mostly mechanoreceptors extended both on the ventral and dorsal parts (Figure 9B). However, some small sensillae on the extremity of the ovipositor are uniporous and thus potentially involved in contact evaluation.

The influence of chemical cues from gramineous plants in mediating host selection and oviposition behaviour of the stemborer *B. fusca* is in progress.

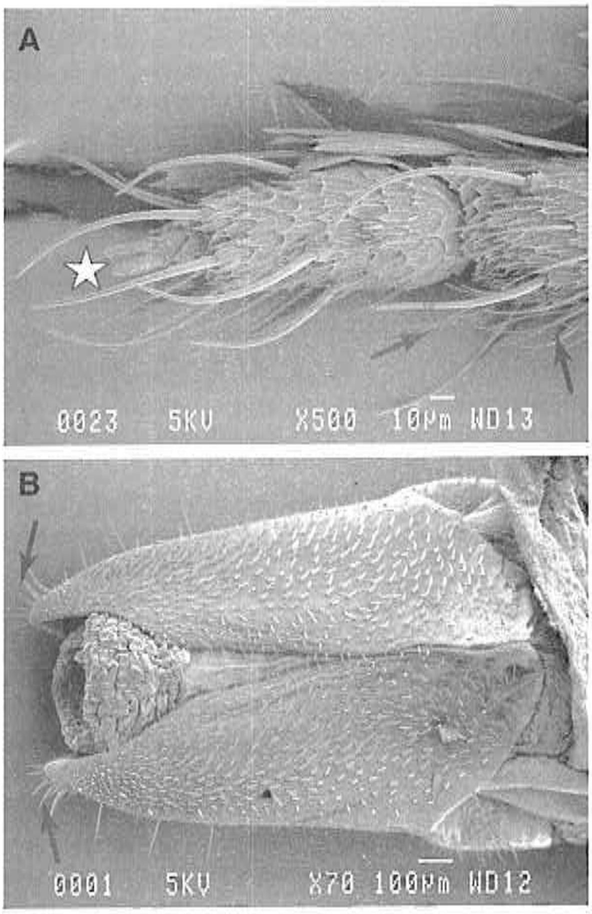


Figure 9. View of the distal part of an antenna (A) showing uniporous sensillae (star) and multiporous sensillae (arrows) and view of the ovipositor (B) showing small uniporous sensillae located between the claw (arrows)

CAPACITY BUILDING

MSc students

Dorothée Baille (DESS) Gestion de la biodiversité: méthodologie d'étude et de valorisation des ressources génétiques), Université de Paris, France. "Recherche de marqueurs moléculaires utilisables pour étudier la structure génétique des populations de *Busseola fusca* (Lepidoptera: Noctuidae), ravageur du maïs en Afrique."

Sébastien Epinette, Diplôme d'Etude Supérièrer Spécialisé (DESS) Gestion de la biodiversité: méthodologie d'étude et de valorisation des ressources génétiques. Université de Paris, France. Research completed in 2003. "Diversité spécifique et moléculaire des noctuelles foreuses de tige de graminées de la forêt de Kakamega (Kenya) en fonction de la plante hôte".

George Otieno Ong'amo (Kenya) Distribution and abundance of stemborer wild grasses in Kenya. Kenyatta University, Nairobi.

Edwin Etabale Akhusama (Kenya) The influence of the different stemborer species *C. partellus*, *S. calamistis* and *B. fusca* on maize damage and yield. Kenyatta University, Nairobi.

Gerald Juma (Kenya) Role of chemical cues from gramineous plants in mediating host selection and oviposition behaviour of the stemborer *Busseola fusca*. Kenyatta University, Nairobi.

OUTPUT

Conferences and papers presented

XXXème Journées des Entomophagistes, 10–12 Avril 2002, Rennes, France. Paper presented: Utilisation of PCR markers for the survey of *Cotesia flavipes* introduction in eastern Africa. Dupas S., Le Rü B. and Silvain J. F.

Vème Conférence Internationale Francophone d'Entomologie, 14–18 juillet 2002, Montréal, Canada. Paper presented: Etude de l'hétérogénéité populationnelle du foreur du maïs *Busseola fusca* (Lepidoptera, Noctuidae) en Afrique sub-saharienne. I. Aspects écologiques. Le Rü B., Le Gall P., Sézonlin M., Dupas S., Silvain J. F. and Moyal P.

Vème Conférence Internationale Francophone d'Entomologie, 14–18 juillet 2002, Montréal, Canada. Paper presented: Etude de l'hétérogénéité populationnelle du foreur du maïs *Busseola fusca* (Lepidoptera, Noctuidae) en Afrique sub-saharienne. II. Aspects phylogéographiques. Sézonlin M., Dupas S., Silvain J. F., Le Rü B., Le Gall P. and Moyal P.

ICIPE Seminar, 22 October 2003, Nairobi, Kenya. Role of wild host grasses and sedges as a source of stemborers: Biodiversity of Lepidopteran stemborers revisited. Le Ru B.

Participating scientists: B. P. Le Rü, P.-A. Calatayud, S. Dupas, P. Le Gall, P. Moyal, J. F. Silvain

Assisted by: B. Musyoka, L. Ngala, A. Njambi

Collaborators: CNRS, France; INRA, France; Muséum National d'Histoire Naturelle, France; IITA, Bénin; University of Natal, Scottsville, South Africa

Donor: IRD (French Government: Department of Education and Foreign Ministry)

CONSERVATION OF GRAMINEAE AND ASSOCIATED ARTHROPODS FOR SUSTAINABLE AGRICULTURAL DEVELOPMENT IN AFRICA

BACKGROUND, APPROACH AND OBJECTIVES

Grasses, common throughout the African landscape from the highlands to the valleys, are important food- and energy-providers to billions of people and animals, including livestock and wildlife. This regional project is being implemented in Ethiopia, Kenya and Mali to improve the environment and increase farmers' incomes by utilising the positive values of grass and insect diversity around their farms. The Project is based on the premise that there is much beyond the grasses and their associated arthropods to unravel practices that may provide alternative ways to utilise grasses to repel insect pests and attract farmers' friends—the beneficial species of parasitoids and predators—for a sustainable agriculture much needed by the smallscale and resource-poor farmers in Africa.

The Project objectives are to:

- document the diversity of Gramineae and associated insects in different selected agroecosystems and socioeconomic surroundings and their adjacent natural habitats in Ethiopia, Kenya and Mali;
- identify and implement conservation and management measures necessary to prevent loss of biodiversity of certain grasses and their associated insects in and around agroecosystems;
- develop and promote best practice(s) in Ethiopia, Kenya and Mali for self-regulatory pest management and sustainable agriculture.

The activities undertaken during 2002–2003 include:

- systematic sampling of grasses from three agroecologies: maize + grass, sorghum + grass and natural grassland for presence of stemborers;
- development of a rearing protocol in handling field-collected stemborer larvae in the laboratory and processing emerging stemborer moths and their associated parasitoids;
- collection of Gramineae for identification and herbarium preparation including grass germplasms for deposition in museums and the national genebanks;
- identification of the stemborer complex and associated parasitoids;
- determination of grass and arthropod diversity and analyses of collection dates for spatial and temporal changes;
- strengthening national agricultural research and extension systems (NARES) and non-governmental organisations' capacity in each of the participating countries to collect, curate and identify Gramineae and associated insects, including monitoring, protecting, and promoting biodiversity of grasses and associated insects;
- development of computerised identification tools for both vegetative and reproductive stages of grasses;
- development of a computerised database of key Gramineae-associated insects;
- identification of key pest and beneficial insects associated with both cultivated and wild grasses;
- identification of insects specific to wild grasses but which also serve as alternate hosts/prey of natural enemies regulating crop pests;
- assessment of potential of wild grass stemborers to become pests of cultivated crops if wild hosts are endangered or eliminated;
- collection of baseline information on community-based grass *in situ* conservation activities and community consultations for knowledge or input on how farmers integrate new agrobiodiversity practices into their farming systems;
- promotion of public awareness on the importance and values of grasses through dissemination of leaflets, brochures and booklets;
- development of directory of grass workers.

WORK IN PROGRESS

1. Diversity, distribution and relationship of grasses and insects in and around selected agroecosystems

The grass cover of East and West Africa is well defined and its distribution throughout the two regions established. But understanding the diversity and relationship of the grass and insect coexistence in and around selected agroecosystems, and utilising this knowledge for grass conservation and self-regulatory pest management in order to help resource poor farmers is far from resolved. The literature available mostly deals with the three major cereal stemborers [(*Busseola fusca* Fuller, *Chilo partellus* (Swinhoe) and *Sesamia calamistis* Hampson)] and their natural enemies. Very limited information is available about the stemborers and associated parasitoids from the wild grasses in Africa. The current project deals with interaction of grasses and insects in three countries, namely Ethiopia, Kenya and Mali, in 24 ecologically different sites.

Systematic sampling and comparison of grasses and associated insect diversity in key areas

Grasses were systematically sampled in the three different agroecologies, namely maize and grass, sorghum and grass, and natural grassland, in Kenya, Ethiopia and Mali. The grass species were recorded and dissected and noted for the presence or absence of stemborers. All stages of insects (egg, larva, pupa and adult) found were reared individually inside plastic Petri dishes following agreed-upon protocols. All biological information was recorded in a logbook. For herbarium preparation and identification, grasses

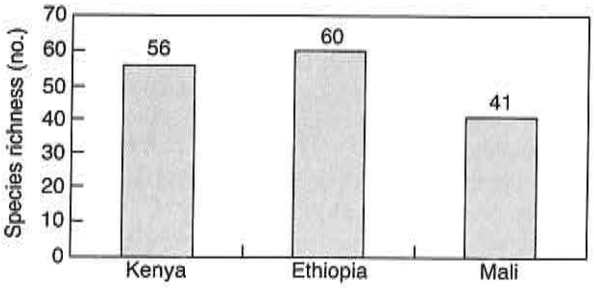


Figure 1. Diversity of grasses sampled for stemborers in Kenya, Ethiopia and Mali

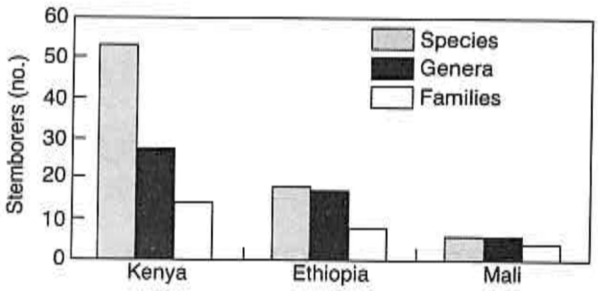


Figure 2. Diversity of gramineous stemborer taxa collected in Ethiopia, Kenya and Mali

were collected at the reproductive and maturity stages.

Grasses: A total of 132 grass species belonging to 46 genera were collected from the three agroecologies in the three countries. There were found 60 species of Gramineae in Ethiopia, 56 in Kenya and 41 in Mali (Figure 1). The grass similarity index following Sorensen's similarity index was calculated:

$$(Cs = 2\,(j) / a + b),$$

where j = the number of grass species common between two countries; a = total number grass species in country a; and b = total number of grass species in country b.

The low values obtained revealed distinct floral dissimilarity. The grasses in Ethiopia have a closer similarity to Kenya with a Cs value of 0.26 or 15 species common in both countries. Mali had the lowest Cs value of 0.08 to 0.14 compared to Ethiopia and Kenya (Table 1). Only four species of grasses are common to Mali and Ethiopia and seven species to Mali and Kenya. Overall, only 2.27% (3 species) were shared by all three countries, namely, *Zea mays* L., *Sporobolus pyramidalis* Beauv. and *Rottboellia cochinchinensis* (Lour.) Clayton.

Stemborers: A cumulative total of 26,493 specimens of stemborer larvae, pupae and adults have been collected from the three different agroecological sites in Kenya (19,801 specimens), Ethiopia (3189) and Mali (3503). The cereals yielded more stemborers (76.82%, 20,351 specimens) than the grasses (23.18%, 6142 specimens). Total stemborer collection was highest in Kenya in all the agroecologies, from which 9111 specimens were obtained from maize and grass, 6727 from sorghum and grass, and 3963 from natural grassland. The low grass stemborer population in Ethiopia could be attributed to the communal ownership of agricultural lands for pasture after crop harvest, resulting in overgrazing. In Mali severe drought coupled with overgrazing also affected stemborer collection. The pattern of stemborer species diversity in decreasing order is Kenya (53 species) > Ethiopia (18 including 10 unidentified taxa) > Mali (6) (Figure 2).

Table 1. The similarity index (Cs) of the grasses in Kenya, Ethiopia and Mali based on systematic samplings

Country	Similarity index (Cs)		
Kenya	*	0.26	0.14
Ethiopia		*	0
Mali			*

Fourteen families of stemborers were found in Kenya, about eight in Ethiopia and four in Mali. The grass stemborers in Kenya are represented by the beetles (Order Coleoptera) belonging to six families: Anthribidae, Cerambycidae, Curculionidae, Languriidae, Mordellidae and Tenebrionidae; moths (Order Lepidoptera) represented by five families: Pyralidae, Noctuidae, Cossidae, Tortricidae and Gelechiidae; and the flies (Order Diptera) in three families: Chloropidae, Diopsidae and Muscidae. All stemborer families present in Ethiopia and Mali were found in Kenya except the undetermined Symphyta reported in Ethiopia. No specimen of the latter is available for identification. It is anticipated, however, that different species are involved in each of the three countries. Most of the stemborers were identified to the species level with the exception of new taxa requiring species diagnosis and description.

Parasitoids: A total of 10,580 parasitoid specimens were recovered from the three countries up to early 2004 (Table 2). Of the total, 86.7% (9167 specimens) were reared from cereal stemborers and 13.3% (1413 specimens) from the grass stemborers. Kenya had the highest number of parasitoids (9944 specimens) reared from both cereal and grass stemborers with 8675 and 1269, respectively. Mali came second with only 510 parasitoid specimens (389 from cereals and 121 from natural grassland). Surprisingly, Ethiopia, considered the centre of diversity of many Gramineae species, had the least number of parasitoids with 126 specimens. Most of the parasitoids in Ethiopia were reared from cereal stemborers (81.7%) and from grasses (18.3%).

Table 2. Total number of parasitoids associated with gramineous stemborers from cereals and wild grasses

	Reared parasitoids (no.)*			
Country	Cereals	%	Grasses	%
Kenya	8675	82.0 (87.2)	1269	12.0 (12.8)
Ethiopia	103	1.0 (81.7)	23	0.2 (18.3)
Mali	389	3.7 (76.3)	121	1.1 (23.7)
Total	**9167**		**1413**	
Percentage (%)		86.7		13.3

*Numbers in parentheses are percentages by countries of cereal *vs* grass parasitoids.

Parasitoid diversity numbered 70 taxa present in the three countries. The highest number of parasitoids was found in Kenya with 65 species belonging to 38 genera under 14 families. The dominant parasitoid group belongs to the superfamily Ichneumonoidea represented by the braconid (*Cotesia, Habrobracon, Triaspis, Dolichogenidea, Rhaconotus,* and *Protapanteles*) and ichneumonid (*Dentichasmias, Holcopimpla,* and *Syzeuctus*) wasps. The eulophid *Pediobius* spp. is common on the pupae of grass stemborers. The parasitoids associated with the grass stemborers in Kenya were 9.3 and 10.8 times richer compared to Ethiopia and Mali, respectively (Figure 3). The high level of parasitoid diversity recorded in Kenya reflects the early start and intensity of groundwork done in the three agroecological sampling sites (Busia, Machakos and Suba) that amassed much higher numbers of individual stemborer hosts as compared to Ethiopia and Mali.

Identification of collected grasses and insects for deposition into herbaria or museums

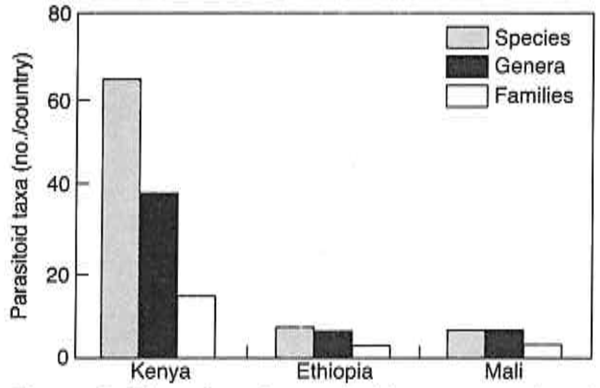


Figure 3. Diversity of parasitoid taxa associated with gramineous stemborers in Ethiopia, Kenya and Mali

The field collection of grasses was done during the maturity stage of the grass inflorescences/flowers in October–November to ensure collection of good materials. Grasses were collected from the field and kept in between layers of used newspapers prior to press framing and strapping. The samples were sun-dried and mounted on a standard size board 42 cm long and 27 cm wide. All the necessary data pertinent to the grass species were noted following the technique recommended by the staff of the East Africa Herbarium of the National Museums of Kenya during the GEF Training Project-Nairobi Workshop on 9–20 April, 2002. With the newly deposited GEF Grass Herbaria Materials, information about insects associated with grasses such as the stemborers and their parasitoids was incorporated into the label of each grass species. This is the first time that such herbaria collections of grasses contain well documented insect association records that can be utilised for future pest management directions. Grass germplasms were collected and prepared in March when the grass seeds are fully matured.

Table 3. Materials deposited in the herbaria and genebanks and prepared insect collections in three countries

	Deposited/prepared materials (no.)		
Country	Grasses	Grass seed germplasms	Insects[2]
Kenya	80	41	10,209
Ethiopia	14[1]	40	<200
Mali	27	13	<25

[1]Some 33 species await identification.
[2]Combined total of dry and slide-mounted specimens.

Insects associated with the grasses were prepared differently. This followed standard protocols on how to handle grass stemborer larvae and how to prepare an insect collection. Due to the discovery of a diverse number of species new to science, the deposition of specimens will be done immediately after full descriptions of the taxa have been done and published. Table 3 shows the number of deposited grasses to the herbaria and germplasm collections to the genebanks, as well as the number of prepared insect specimens in the three countries.

Strengthen capacity in each country to collect, curate and identify Gramineae and associated insects

The project has been active in working with technicians on the ground in all three countries for training in the following areas:

- systematic sampling of grasses for the presence of stemborers;
- field-spotting of grasses with stemborer damage and symptoms;
- collection, handling and rearing stemborers and their parasitoids;
- collection and preservation of grasses for herbarium and germplasm collections;
- grass and insect preservation, curation and identification.

Training of a trainer (TOT) was also conducted at ICIPE-Mbita Point Field Station in October 2003 for a Malian to improve his training capability and confidence to train his fellow technicians in Mali upon his return.

By the end of 2003, a total of 120 staff comprised of scientists, technicians, extension workers and community youths had received training on collection, curation and identification of grasses and stemborers (Table 4). The participation of out-of-school youth from the community in the three districts of Kenya (Busia, Machakos and Suba) increased the number of nationally-trained staff. Trained staff in Ethiopia increased 5-fold in 2003 but many left prior to the completion of the project. A new country collaborator from the Ethiopian Agricultural Research Organisation (EARO) was recruited to handle the project more effectively in Ethiopia and who will push forward the Project's implementation on the ground.

Table 4. Number of trained national staff in the collection, curation and identification of grasses and insects

Country	Year 2002	Year 2003	Total
Kenya	4	77	81
Ethiopia	3	16	19
Mali	14	6	20

Capture targeted data from existing collections of Gramineae and associated insect specimens in Africa and abroad and analyse collection dates for changes over time and space

The grass collections in African herbaria and insect museum collections revealed almost no data on grass and associated insects, particularly the stemborers and their parasitoids, with the exception of Mali where 26 grasses had records for six species of stemborers. Literature records, however, showed that 325 insect species belonging to 68 families utilised the grasses. The list included stemborers. Based on these records, both the lepidopteran and coleopteran stemborers were observed to be expanding their distribution ranges. For instance, the pyralid *Chilo orichalcociliellus* (Strand), found previously in the coastal region in the 1960s, is at present in Suba District, Kenya. Another coastal species, *Chilo thyrsis* described by Bleszynski in 1963, has moved northeast to Machakos district attacking maize and sorghum based on the 2003 collections. Both species were never found in Ethiopia and Mali. The third species, *Ematheudes* sp. recorded in 1956 from Uganda has moved eastward to Kenya on the grass *Rottboellia cochinchinensis* (Lour.) Clayton, as shown in our surveys in 2003 (Figure 4) and is likely to be present now in Ethiopia and Mali. The noctuid borers, *Busseola fusca* and *Sesamia calamistis* were previously common in both Kenya and Ethiopia, and are still visible in 2003. However, another noctuid, *S. penniseti* Tams and Bowden described in 1953, was recently found for the first time in Kenya on maize and the grass *Hyparrhenia rufa* (Figure 5).

New developments have been recorded in the coleopteran stemborers, mostly all new records for East Africa. Four families—Cerambycidae, Curculionidae, Languriidae and Mordellidae—represented by at least 16 species, are either new taxa or new records

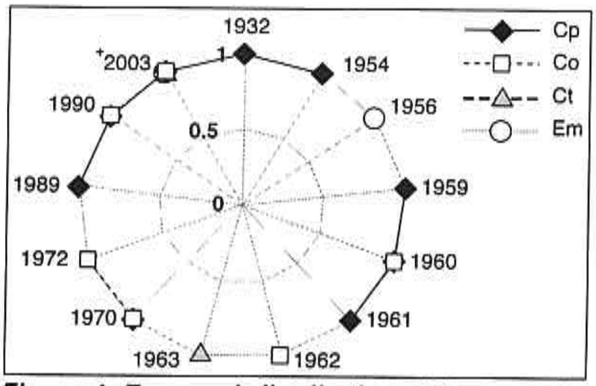


Figure 4. Temporal distribution of four pyralid stemborers in Kenya

Cp = Chilo partellus; *Co* = Chilo orichalcociliellus; *Ct* = Chilo thyrsis; *Em* = Ematheudes *sp.*
+Em, Co and Ct all present

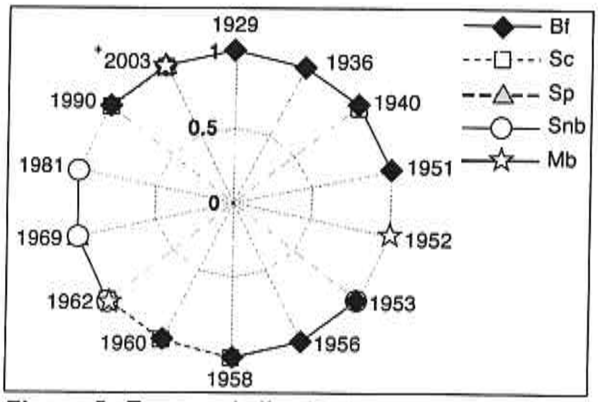


Figure 5. Temporal distribution of five noctuid stemborers in Kenya

Bf = Busseola fusca; *Sc* = Sesamia calamistis; *Sp* = Sesamia penniseti; *Snb* = Sesamia nonagriodes botanephaga; *Mb* = Manga *nr.* basilinea
**Bf, Sc nd Sp all present*

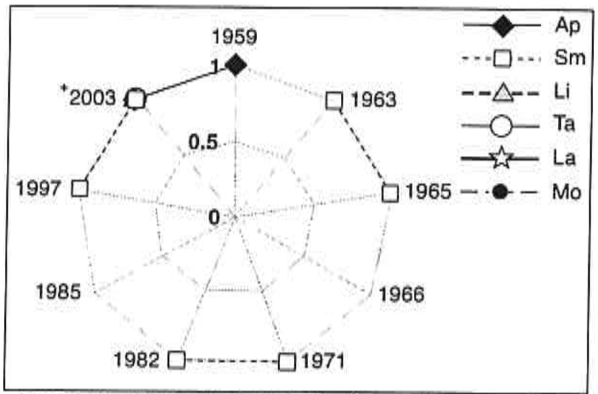


Figure 6. Temporal distribution of coleopteran stemborers in Kenya

Ap = Amphistylus (= Hypamazso) pauli; *Sm* = Smicronyx *spp.*; *Li* = Lixus *sp.*; *Ta* = Tanymecus *sp.*; *La = Languriidae; Mo = Mordellidae*
**Mo, La and Li all present*

(Figure 6). Of these, the grass stemborer *Hypamazso pauli* (Fairmaire) (Cerambycidae) and *Smicronyx* spp. (Curculionidae) are new potential pests of maize and sorghum in western Kenya. The former also has been recently observed to be infesting maize in Ethiopia. In 1959, *H. (Amphistylus) pauli* was found from *Hyparrhenia rufa* in Uganda. This grass borer had since moved in a southeastern direction, finding its way to Kenya on cereals in Busia and Suba districts around Lake Victoria.

Development of computerised identification tools for both vegetative and reproductive stages of key grasses for use by scientists in national programmes

Accurate identification of African grasses is an integral component of the 'Grasses Project' in its conservation and utilisation for self-regulatory pest management objective. Unfortunately, no identification tool is available to identify the vegetative stages of the African Gramineae. The Project embarked on this activity to fill the void and put identification of grasses at this early stage vital in achieving pest management strategies on the fast track.

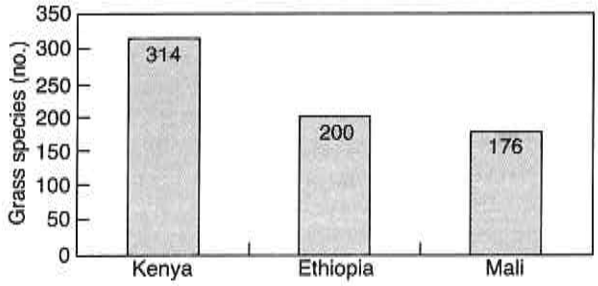


Figure 7. Number of grasses recorded from Kenya, Ethiopia and Mali

A grass taxonomist was contracted for two years beginning in August 2002 to prepare the computerised identification tool. A total of 502 grass species reported in Kenya, Ethiopia and Mali were targeted for incorporation in the computerised tool to identify the vegetative and reproductive stages of the identified grasses (Figure 7). To date, the completed works include the technical components of the identification tool. The illustrated glossary, glossary of botanical terms and the references are complete. Drawings of 374 species and scanning for entry in Visual Basic program (VBP) were completed. VBP was chosen for its user-friendliness, thus allowing anyone to identify the grass(es) collected from any of the three countries of Kenya, Ethiopia and Mali without requiring formal training in grass taxonomy and computer operations. The identification tool will be made available in CD-ROM and on the Internet in October 2004 and will initially feature only 380 species.

2. Wild grasses as reservoirs of key pests and beneficial insects and that protect and promote arthropod diversity

Wild grasses of East and West Africa have been poorly studied in terms of the refugia roles they play for key pests and their associated natural enemies as well as for their importance in promoting arthropod diversity. To generate information, grasses in Kenya were sampled regularly on a monthly basis from June 2002 to January 2004 for the presence and absence of stemborers and associated natural enemies. The activity was subsequently done in 2003 in Ethiopia and Mali and will be completed in March 2005. Harmful and beneficial insects that share cultivated and wild host plants were identified and documented in targeted sites. Data showed that a number of key cereal stemborers and associated natural enemies were provided refugia by the wild grasses. Evaluation of six key stemborers and five key natural enemies were conducted in the laboratory to examine the functional host ranges of both the pests and the parasitoids.

Identification of key pests and beneficial insects associated with cultivated and wild tall grasses in selected agroecosystems and their ecological roles

In all three countries, 10 wild grass species belonging to eight genera were identified from the sampling data as top hosts of key pests, namely *Panicum maximum, Sporobolus pyramidalis, Pennisetum purpureum, Hyparrhenia rufa, Eleusine coracana, Sorghum versicolor, Rottboellia cochinchinensis, Sorghum arundinaceum, Pennisetum pedicellatum* and *Andropogon gayanus*. Two pyralid stemborers (*Chilo partellus* and *Coniesta ignefusalis*); two noctuids (*Busseola fusca* and *Sesamia calamistis*); and a muscid fly (*Atherigona soccata*) were commonly found on wild grasses. Of the five key parasitoids, two braconids (*Cotesia flavipes* and *Co. sesamiae*), an ichneumonid (*Syzeuctes senegalensis*), a nematode (*Agamermis* sp.) and a tachinid fly (*Siphona* sp.) tracked the stemborers on the wild grasses.

The overall impact of key parasitoids on cereal stemborers on wild grasses was relatively low but provided strong indications that grasses are a valuable refuge for natural enemies. Table 5 shows the number of stemborers specific to seven dominant wild grasses, cereal crops and those shared between cereals and wild grasses in Kenya.

Identify insects specific to wild grasses serving as alternate hosts or prey of natural enemies important in controlling pests

In Kenya, four key species of grass stemborers belonging to three families—Cerambycidae and Curculionidae (Coleoptera) and Pyralidae (Lepidoptera)—were evaluated in the laboratory as potential refugia or alternate hosts of four

Table 5. Number of stemborer species specific to wild grasses, cereal crops and shared taxa between wild grasses and cereals in Kenya

	Stemborer species (no.)			
Species	Wild host only	Cereal only	Shared	Stemborer population
Zea mays	–	–	21	4650
Sorghum bicolor	–	1	18	3584
Panicum maximum	11	–	20	3219
Rottboellia cochinchinensis	6	–	16	2043
Hyparrhenia rufa	10	–	16	1076
Cymbopogon nardus	4	–	10	1066
Sorghum versicolor	2	–	16	963
Sporobolus pyramidalis	3	–	11	581
Pennisetum polystachion	1	–	9	534

hymenopteran parasitoids, namely *Cotesia flavipes* and *C. sesamiae* (Braconidae), *Dentichasmias busseolae* (Ichneumonidae) and *Pediobius homoeus* (Eulophidae). All four parasitoids are important in controlling crop pests. Of the grass stemborers, all but *Ematheudes* sp. are potential pests of cereal crops, having been dissected from the stalks of maize and sorghum in the field. Figure 8 shows the performance of *Cotesia flavipes* exposed to the larvae of four grass stemborers. The sample size for the test was 45, 45, 30 and 60 larvae each for *Amphistylus (=Hypamazso) pauli*, *Smicronyx* spp., *Lixus* sp. and *Ematheudes* sp., respectively.

No *C. flavipes* parasitisation occurred but the number of probes (22–48 stings/species) on the larval body induced pathogen infection causing 33.2–85.4% mortality. A related species native to Africa, *C. sesamiae* was less aggressive, providing 6–42 stings per stemborer species to all four grass borer larvae. The sample size was similar to *C. flavipes*, except for *Smicronyx* with only five observations. *Cotesia sesamiae* failed to develop on the grass larvae but killed 69.05 and 73.3% of *Ematheudes* sp. and *Amphistylus (= Hypamazso) pauli*, respectively, due to pathogen infection. The stings inflicted no damage to the two curculionid larvae of *Smicronyx* sp. and *Lixus* sp. (Figure 9).

One female ichneumonid wasp, *Dentichasmias busseolae* Heinrichs, a pupal parasitoid of *Chilo partellus*, was exposed to a matured larva of the grass stemborer, *Ematheudes* sp. that was about to pupate. The wasp initially rejected the new host, only to approach it 12 min later. Two short probes were observed but no successful parasitisation developed. Additional tests are needed to confirm parasitoid development and extent of parasitism onto the new host. The pupal parasitoid, *Pediobius homoeus* Waterston (Hymenoptera: Eulophidae), a common cereal stemborer natural enemy was tested against the grass stemborer, *Ematheudes* sp. A pair of eulophid wasps newly emerged from the pupa of *C. partellus* taken from maize was released to each of the two L4 or nearly pupating *Ematheudes* sp. Complete parasitoid development was observed after a week, producing a total of 83 parasitoids (Figure 10). The results confirmed that grass stemborer pupae of *Ematheudes* are excellent refuge the *P. homoeus*. Similar evaluations will be done in Ethiopia and Mali using different species of stemborers and parasitoids.

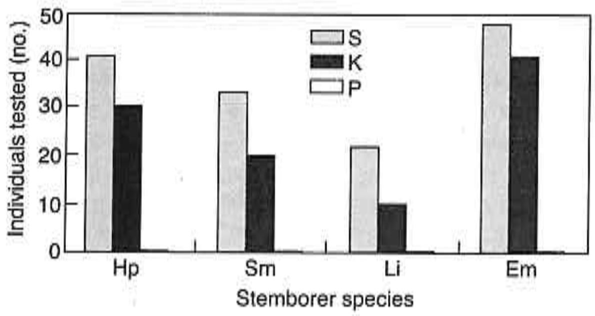


Figure 8. Performance of* Cotesia flavipes *on the larvae of coleopteran stemborers in the laboratory

Hp = Hypamazso pauli; *Sm* = Smicronyx; *Li* = Lixus *sp.; Em* = Ematheudes *sp; S = stung; K = killed; P = parasitised*

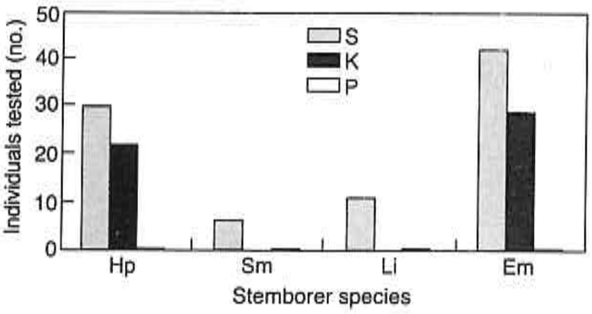


Figure 9. Performance of* Cotesia sesamiae *on the larvae of coleopteran stemborers in the laboratory

Hp = Hypamazso pauli; *Sm* = Smicronyx *sp.; Li* = Lixus *sp.; Em* = Ematheudes *sp; S = stung; K = killed; P = parasitised*

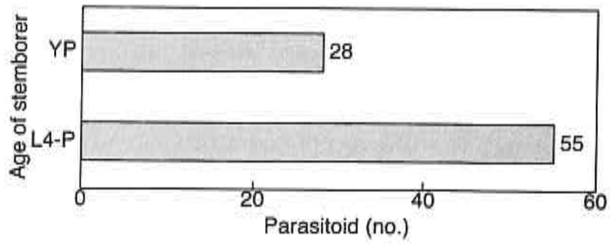


Figure 10. Acceptance of the grass stemborer,* Ematheudes sp. *as host of the cereal stemborer parasitoid,* Pediobius homoeus *Waterston in the laboratory

YP = young pupa; L4-P = matured larva nearing pupation

Potential of insects specific to wild grasses to become pests of cultivated crops or endangered if the hosts are destroyed

Two species of beetles were newly discovered on the stems of maize and sorghum during field dissection in Kenya. The beetles are the cerambycid *Hypamazso pauli* Fairmaire and the curculionid *Smicronyx* spp. The larvae of the former were mis-identified as *Chilo orichalcociliellus*. Figure 11 shows the occurrence of the two coleopteran stemborers on cereals (maize and sorghum) and grasses. The cerambycid stemborer had a wider distribution and was present on 32 Gramineae

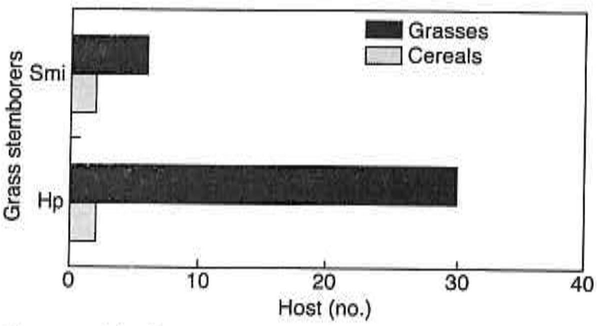


***Figure 11. Occurrence of coleopteran grass stemborers on Gramineae in Kenya. Hp =* Hypamazso pauli*, Smi =* Smicronyx sp.**

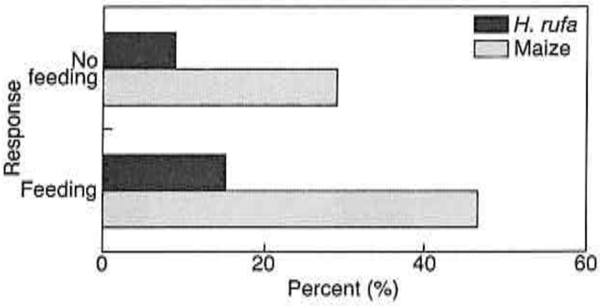


***Figure 12. Preferential test for* Hypamazso pauli *larvae on the cut stems of maize and* H. rufa**

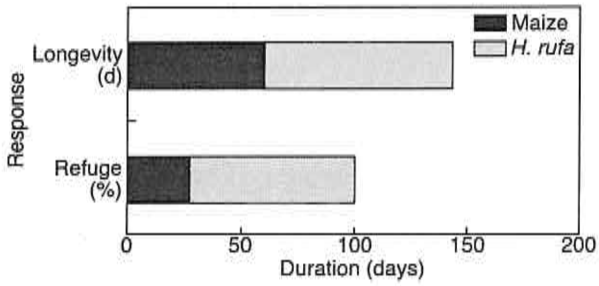


***Figure 13. Laboratory evaluation of old grass stems of maize and* Hyparrhenia rufa *as refuge for adult* Hypamazso pauli**

including maize and sorghum. *Hypamazso pauli* was found also in Ethiopia only in the grass *Hyparrhenia rufa*, but laboratory evaluation proved it damages maize like any other lepidopteran stemborer under a free choice and no-choice experiment. The stemborer has not been found yet in Mali.

In the laboratory, a preference test for *Hypamazso pauli* larvae on cut stems of maize and *Hyparrhenia rufa* was conducted using 90 larvae for each test. The number of larvae entering the stem were counted and observed for signs of feeding. Figure 12 shows a strong preference of the larvae towards maize compared to *H. rufa*. However, not all enter the stem and 28.9% of those that entered merely rested inside the stem. The majority of the larvae did not enter the stem of *H. rufa*; barely 16% of larvae entered and fed inside the stem. The non-feeding 9% settled inside. Figure 13 shows the potential of abandoned old stems of maize and *H. rufa* for refuge and the duration for which these stems can support life of the *A. pauli* adults. Maize was less suitable as a refuge (26.9%) than *H. rufa*. The dense and compact stump of *H. rufa* provided better shelter for adults than the single-stem maize, but in the field, the *H. rufa* population was constantly subjected to fire and this factor may have forced the coleopteran stemborer to shift to maize.

The present data show the population density of the two coleopteran stemborers on cereals were very low to pose a risk to maize and sorghum. Although the cerambycid stemborer, *H. pauli* is present in two districts in Kenya, its broad host range may reduce the potential threat to crops. The occurrence of *H. pauli* on maize and sorghum was found to be quite high only when the host grasses were burned, strongly suggesting that grass conservation is very important in preventing pest risk to maize and sorghum.

3. Complementary conservation of important grasses and associated insects

While grasses are an undisputed vital resource to the people and animals including livestock throughout Africa, however there exists limited information on how communities put importance to grasses. Efforts are underway to gather information about the value of grasses to the African people and justify ways on how to promote grass conservation that ultimately enhance arthropod biodiversity in and around farmers' fields for self-regulatory pest management.

Baseline information on community-based in situ *conservation activities utilising wild grasses*

Baseline information on community-based *in situ* conservation activities utilising wild grasses was gathered in the three countries of Kenya, Ethiopia and Mali. The initial results from Kenya showed that 39 grass species play an important role in the lives of people in the districts of Busia, Machakos and Suba. Of these, some species are strongly linked to fodder and grazing (26), thatching (4), tick repellents (3), soil erosion control (2) and broom and rope making (2). A large number of grass species were left as fallows. The value or use of grasses is shown in Figure 14. Uses of grasses vary by districts, as does the innovative approaches to grass conservation. Results show that high- to mid-altitude areas with fertile soils and without livestock are better candidates for adopting innovative techniques towards grass conservation. Inhabitants of tropical lowland were less interested in grass conservation but were more focused on grazing their livestock to support their families.

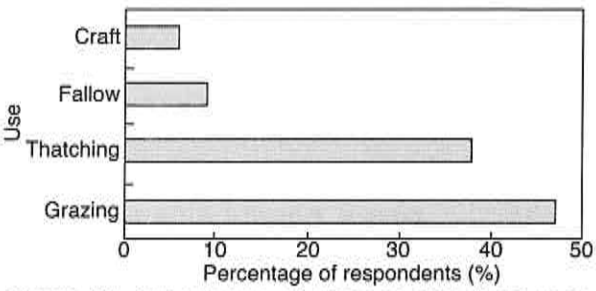


Figure 14. Importance of grasses and their uses in three districts of Kenya (Busia, Machakos and Suba)

The *Hyparrhenia* species (*H. filipendula*, *H. pilgerana* and *H. rufa*) and *Themeda triandra* were primarily used for thatching, while three *Cymbopogon* (*C. caesius*, *C. popischilii* and *C. schoenanthus*) were reported to have tick repelling properties.

A similar study explored the ethnobotanical knowledge of 61 species of grasses in the Showa District of Ethiopia. The Ethiopians have different ways of using grasses than Kenyans. Around 61% of grass species are regarded as weeds, 19 species are used for forage, 13 species for thatching and one for craft material (Figure 15). During drought, the seeds of *Sporobolus pyramidalis* P. Beauv. are harvested for human consumption.

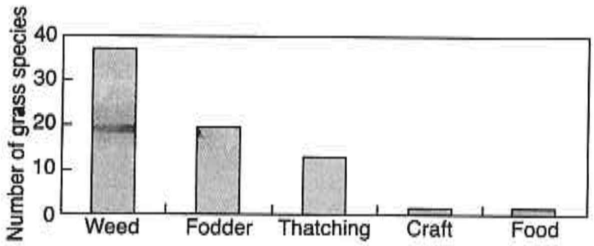


Figure 15. The uses of grasses in Showa District, Ethiopia

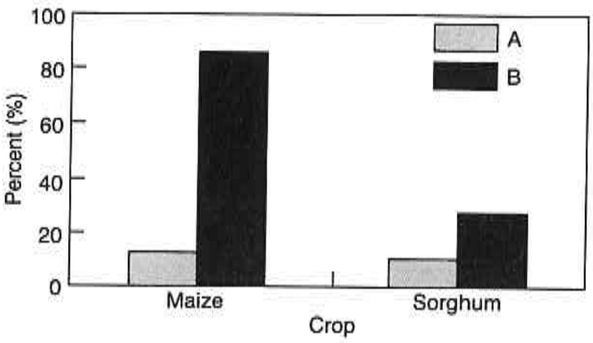


Figure 16. Yield loss to insect pests in maize and sorghum (A) and the percentage of farmers (B) experiencing crop loss in the three districts of Busia, Machakos and Suba, Kenya

(N = 312)

Adoption of new agrobiodiverse practices by trial communities

Participatory rural appraisal (PRA) was conducted in 11 communities in three districts of Kenya (Busia, Machakos and Suba) involving 385 farmers so as to know the value and importance of grasses found on farms and to survey their perception on integrating key grass species into their farming systems. The study showed that grasses are a valuable resource to the majority of smallholder farmers in the communities, with grasses having many uses, including fodder crop for grazing and livestock; soil erosion control; increasing soil fertility; building materials; cottage industries (baskets and other products); medicines; and in rituals and for cultural values. However, wild grasses around farming systems also served as hosts to stemborers. A follow-up study focusing on individual household surveys using a structured questionnaire was implemented in nine communities (3 in each of the three districts) involving 108 farmers in Suba, 101 in Busia and 103 in Machakos.

Preliminary results indicate that the majority of the farmers are willing to test new technologies or best practice(s) that will alleviate their problem about insect pests, particularly stemborers. In all three districts, 83–90% of 312 farmers interviewed have experienced losses in the range of 4.5–16% due to insect pests attacking maize, sorghum and millet (Figure 16). Farmers' acceptance of testing new technologies is clearly driven by the increasing number of smallholder farmers experiencing yield loss of their most important food security crop, i.e. maize. A summary of the potential areas for strong farmer participation and community involvement is shown in Table 6.

Ethiopia and Mali are yet to generate information along this line. PRA was not completed in Ethiopia. In terms of revenue, Figure 17 shows the value of grasses to the farmers in three districts (Busia, Machakos and Suba) in Kenya.

Work continues on assessing the barriers or potentials for conserving agrobiodiversity within farming systems and on-site participatory demonstration to other stakeholders. Educational material on new agrobiodiverse techniques are being developed and feedback from the communities will be discussed and the materials disseminated on a broad scale.

4. Database of Gramineae germplasm

A database of Gramineae germplasm available in target countries on paper, CD-ROM and on Internet, to enhance exchange of African Gramineae germplasm, and to enhance access by many different users through a diversity of media has been developed in answer to the paucity of interest in preserving the

Table 6. Potential areas for strong community participation in testing new technologies or best practices in Kenya

Area of interest	Current problems	Expected scale of participation
Stemborer control	4.5–15% crop loss	High
Weevil management	23–61% grain loss[1] 5–17% grain loss[2]	High
Pasture grass management	2.5–3.7 months shortage of pasture grass	High
Grass conservation	Grass disappearance and overgrazing	High
Cash from grasses	Low family income	Low–High
Soil erosion control	Loss of soil and grasses in 12–15% of total area surveyed	Low–Moderate
Handicraft making	Low demand Limited knowledge	Low–Moderate

[1]Without insecticide.
[2]With insecticide.
Low to moderate depending on the location of the district.

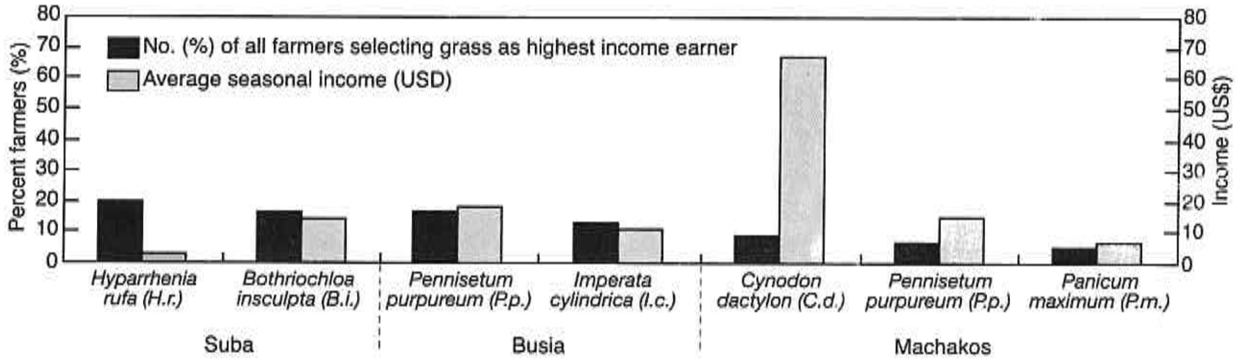


Figure 17. Top six money-making grass species for farmers in three districts in Kenya

germplasms of Gramineae with the exception of those species providing our daily breads. The database of Gramineae germplams will be available for future use to promote sustainability in agriculture, such as serving as sources of resistant genes for use in breeding programmes against insect pests and diseases and for breeding in tolerance to environmental stress such as drought, acid soil and many others.

The International Plant Genetic Resources Institute (IPGRI) developed the Gramineae database for the GEF Grasses Project.

The system was designed to incorporate relevant information about the arthropods (stemborers and their associated parasitoids) living on grasses. A total of 156 germplasm collections have been deposited in the National Genebank of Kenya for incorporation into the National Database. The deposition aims to share and exchange information about the GEF Grass germplasm collections in Africa. It is envisioned that similar approaches will soon be in place in Ethiopia and Mali.

CAPACITY BUILDING

Short courses

Short-term training courses to enhance taxonomic expertise of national scientists in collection, identification and use of Gramineae and insects in environmental monitoring and sustainable agriculture systems have been offered over the review period. To date, a total of 120 national staff from three participating countries of Ethiopia (19), Kenya (81) and Mali (20) have received formal as well as hands-on training in the collection and identification of Gramineae and their associated insects.

In Kenya, the three lead technicians and support staff conducting the best practice were provided training on the identification of beneficial species, often called "friends of the farmers" such as spiders, earwigs, green lacewings, coccinellid beetles, carabid beetles, rove beetles, ants, anthocorid bugs, parasitic wasps and bees in the field. Farmer collaborators in the best practice were likewise invited to see for themselves the friendly arthropods coming to their crops when certain species of grasses are grown around maize crops. Similar training will be done in Ethiopia and Mali once the best practice activity is on the ground.

OUTPUT

Journal articles

Barrion A. T. and **Khan Z. R.** **(2003)** *Hypamazso* Barrion and Khan 2003: A replacement genus name for *Amphistylus* Gahan 1890 (Coleoptera: Cerambycidae). *The Philippine Entomologist* 17, 87–89.

Conferences/Conference papers

Barrion A. T., Khan Z. R. and **Muyekho F. N.** **(2003)** Distribution, abundance and development of a new grass stemborer, *Amphistylus pauli* Fairmaire (Coleoptera: Cerambycidae) in Kenya, p. 72. In *Integrated Pest and Vector Management (IPVM) in the Tropics: Perspectives and Future Strategies (Abstracts)*. 15th Biennial Congress of the African Association of Insect Scientists (AAIS) and Silver Jubilee Celebrations jointly organised by the Entomological Society of Kenya (ESK), Nairobi, Kenya, 9–13 June 2003 (Edited by J. Bahana, A. B. Bal, D. Dakouo and C. O. Omwega). ICIPE Science Press, Nairobi.

Barrion A. T., Khan Z. R. and **Muyekho F. N.** **(2003)** Discovery of a new maize stemborer, *Amphistylus pauli* Fairmaire (Coleoptera: Cerambycidae) in Kenya. 51st Annual meeting of the Entomological Society of America (ESA), Cincinnati, Ohio, 16–29 October 2003.

Getu E., Khan Z. and **Barrion A.** **(2003)** Grass species growing in the vicinity of maize and sorghum agroecosystem in Ethiopia and their economic and social value, p. 68. In *Integrated Pest and Vector Management (IPVM) in the Tropics: Perspectives and Future Strategies (Abstracts)*. 15th Biennial Congress of the African Association of Insect Scientists (AAIS) and Silver Jubilee Celebrations jointly organised by the Entomological Society of Kenya (ESK), Nairobi, Kenya, 9–13 June 2003 (Edited by J. Bahana, A. B. Bal, D. Dakouo and C. O. Omwega). ICIPE Science Press, Nairobi.

Muyekho F. N., Barrion A. T. **and** *Khan Z. R.* **(2003)** Grass diversity and conservation: A case study of their indigenous roles and associated boring insects in selected agroecosystems in Kenya, pp. 72–73. *ibid.*

Muyekho F. N. **and** *Khan Z. R.* **(2003)** Exploiting multiple uses of fodder crops to increase livestock feeds on smallholder farms: Case study from push-pull strategies for the control of cereal stemborers and striga weed in maize. Animal Production Society of Kenya at the National Animal Husbandry Research Centre, Naivasha-KARI, 6–7 March 2003.

Other publications

Leaflet: *Beyond the Grasses…Conservation of Graminene and their Associated Arthropods for Sustainable Agricultural Development in Africa.*

A Primer on Grass Identification and Their Uses in Kenya. Development Communication Ltd, Nairobi, Kenya (in press).

How To Handle Grass Stem Borer Larvae. Development Communication Ltd, Nairobi, Kenya (in press).

Directory of Grass Workers, listing 203 people from all walks of life (administrators, scientists, agriculturists, germplasm conservationists, pasturalists, seed growers, biodiversity experts, managers, livestock specialists, nutritionists, systematists, out-of-school youths, students and farmers) has been developed and is currently on the GEF Grass webpage to promote exchange of ideas about grass conservation and uses for self-regulatory pest management. URL: http://www.gras-insect.net

Conferences/Workshops attended

The Animal Production Society of Kenya held at the National Animal Husbandry Research Centre in KARI-Naivasha on 6–7 March 2003.

15th Biennial Congress of the African Association of Insect Scientists jointly organised with the Entomological Society of Kenya (ESK), Nairobi, Kenya on 9–13 June 2003.

Annual Review and Planning Worshop of the GEF Grass Project, Addis Ababa, Ethiopia on 28–30 July 2003.

51st Annual Meeting of the Entomological Society of America (ESA), Cincinnati, Ohio, 26–29 October 2003.

National Symposium on Frontier Areas in Entomological Research, Indian Agricultural Research Institute (IARI), 5–7 November 2003.

Workshop organised

Annual Review and Planning Worshop of the GEF Grass Project held at Hotel Ararat, Addis Ababa, Ethiopia, 28–30 July 2003.

Participating scientists: Z. R. Khan (Project leader), A. T. Barrion, F. Muyekho, N. Ng'ang'a

Assisted by: S. Ojwang, E. Kidiavai, M. Kithokoi, P. Ollimo

Donors: United Nations Environment Programme (UNEP)/Global Environment Facility (GEF); ICIPE; International Plant Genetic Resources Institute (IPGRI); the Governments of Ethiopia, Kenya and Mali; Kew Gardens (UK); Natural History Museum (formerly British Museum of Natural History, UK); Environment Liaison Centre International (ELCI)

Collaborators: Kenya Agricultural Research Institute (KARI); Ethiopian Agricultural Research Organisation (EARO); Institut d'Economic Rurale (IER), Mali; East Africa Herbarium/National Museums of Kenya (NMK); Kenya Wildlife Service (KWS); International Plant Genetic Resources Institute (IPGRI); the Governments of Ethiopia, Kenya and Mali; Kew Gardens (UK); Smithsonian Institution (USA); Royal Botanic Garden (UK); Environment Liaison Centre International (ELCI); SOS Sahel; National Gene Bank of Kenya; Biodiversity Conservation Institute of Ethiopia; Unite des Resources Genetiques of Mali; Centre Regional de Recherche-Agronomique de Sikasso, Mali; Equipe Systeme de Production et de Gestion des Resources Naturelles de Mopti, Mali

PLANT HEALTH

DEVELOPMENT OF BIOCONTROL-BASED IPM FOR THE DIAMONDBACK MOTH, *PLUTELLA XYLOSTELLA* (L.), IN EASTERN AND SOUTHERN AFRICA

BACKGROUND, APPROACH AND OBJECTIVES

Effective chemical control of the diamondback moth (DBM), the key insect pest of crucifers in eastern and southern Africa, has become difficult and uneconomical. DBM has developed resistance to common insecticides, which furthermore are detrimental to indigenous natural enemies. Farmers increasingly use insecticide cocktails and spray more frequently. This has resulted in rising production costs, environmental contamination, health risks and high residues in produce. The recorded level of parasitism by indigenous parasitoids, including those of the genus *Diadegma*, is low compared to the Southeast Asian and South African (SA) situations.

To enhance effective, economical and environmentally acceptable control of the pests, an IPM programme based on improved biological control of DBM was designed by the Centre. This programme was conceived as a collaborative regional research and development effort with the following components: collection of basic information on distribution and efficiency of the indigenous natural enemy complex in the region; study of the taxonomy and bionomics of these native species in comparison to parasitoids of proven value in Southeast Asia and South Africa; and importation, multiplication and release of superior parasitoids from Asia with support of the Asian Vegetable Research and Development Centre (AVRDC) or South Africa. The improvement of biological control in tropical lowlands through exploration for additional parasitoids adapted to high temperature environments was another aim of the Project. This latter activity was coordinated by ICIPE's partner institution, AVRDC.

The first project phase ended officially on June 30th, 2003 but was extended until the end of the year. A second phase of the project continues with emphasis on releasing *D. semiclausum* in all project countries and introduction and release of *Cotesia plutellae* for hotter areas.

WORK IN PROGRESS

1. Surveys for natural enemies of DBM

Surveys for indigenous natural enemies of the diamondback moth were conducted in cooperation with national research institutions of four countries: Ethiopia, Kenya, Tanzania and Uganda. Data analysis was started in Ethiopia and a paper was submitted to a conference on DBM Biocontrol in Montpellier in October 2002. Detailed data analysis of survey data for Kenya and Uganda has been completed and is in progress in Tanzania. A comprehensive report from the survey on indigenous parasitoids of DBM is being compiled.

From the survey data it is evident that local natural enemies do not play a major role as controlling factors of DBM populations. The dominant species recorded in the three countries were *Oomyzus sokolowskii* (Hymenoptera: Eulophidae), *Diadegma mollipla* and one undescribed *Diadegma* species (Hymenoptera: Ichneumonidae). The average parasitism rates recorded were below 15% in Kenya, Tanzania and Uganda. In Ethiopia, in addition to the above species, an undescribed *Apanteles* sp. (Hymenoptera: Braconidae) was frequently collected and parasitism rates were slightly higher.

2. Taxonomic status of the genus *Diadegma* in Africa

One of the hypotheses of the project—that the African *Diadegma* species are not identical with *D. semiclausum*—has been confirmed in two ways: Firstly, in the period between proposal writing and project initiation, all African *Diadegma* parasitoids of DBM were lumped together under the name *D. mollipla*. In addition, molecular taxonomic work conducted by the project using mitochondrial and ribosomal DNA as genetic markers, clearly indicates differences between *D. semiclausum* from Taiwan and *D. mollipla* from Kenya and Tanzania. However, DBM parasitoids (genus *Diadegma)* from South Africa and Ethiopia are different, both morphologically and based on DNA studies.

The molecular studies on *D. semiclausum* were completed with the sequencing of specific DNA regions. A region of the mitochondrial genome (COI) and the 1T52 of the nuclear ribosomal DNA were analysed by PCR-RFLP (polymerase chain reaction restriction fragment length polymorphism). From both studies it is clear that the local species, *Diadegma mollipla* Holmgren, is different from *D. semiclausum*. Samples of *D. mollipla* from Kenya, South Africa and Reunion were all closely related, while a *Diadegma* sp. collected in Ethiopia is clearly an undescribed species. To date, no differences have been found between populations of *D. mollipla* of Kenya, Tanzania and Uganda in the 11 populations analysed so far.

DNA sequencing of specific regions in the genome of the specimens of different locations will help to make a clear statement about relationships of *Diadegma* species. To study phylogenetic relationships, a novel method, amplified fragment length polymorphism (AFLP) was established at ICIPE.

3. Studies of *Diadegma mollipla* and *Cotesia plutellae*

Studies were completed on the biology of the major local parasitoid species, *D. mollipla* Holmgren. Studies of its performance at different temperatures and the competition between the local and the exotic *Diadegma* species have been concluded and the data is being analysed.

Work at the Plant Protection Research Institute of South Africa on the SA strain of *Cotesia plutellae* has been finalised.

4. Introduction and releases for classical biological control

In October 2001, *D. semiclausum* was hand-delivered to ICIPE from AVRDC. Another shipment was received in January 2002. Upon request by KEPHIS (Kenya Plant Health Inspectorate Service), comparative studies of the local (*D. mollipla*) and the exotic *Diadegma* were conducted. When confined in small containers with DBM larvae, *D. mollipla* reaches similar numbers of progeny as *D. semiclausum*. However in choice situations, *D. mollipla* avoids cabbage plants, no matter whether infested with host larvae or not, and parasitism rates are significantly higher when DBM larvae are exposed on pea than on cabbage. Upon presentation of these results, a conditional release permit was granted by Kenyan authorities.

Diadegma semiclausum adults were released in three pilot sites in Kenya. The releases in Taita-Taveta were made in July 2002 while the releases in Limuru and Kisii were made in September 2002. Between 100 and 125 female parasitoids and a similar number of males were released at these sites. In November, the first release was made in Tanzania on the slopes of Mount Meru. The total number of females released here was approximately 700, with a slightly higher number of males. From September 2003 onwards, releases of *D. semiclausum* were made in several cabbage growing areas of central Kenya.

Work in 2003 has shown that *D. semiclausum* has established at the release sites and the parasitoid is spreading. Average parasitism rates have greatly increased since the releases.

Field life-table studies were initiated in Kenya to assess the contribution of the newly introduced species to overall mortality of DBM. The contribution of *D. semiclausum* to DBM mortality at the first release site in Taita Hills has surpassed 60% and has remained consistently at or above 50%. At the second release site, parasitism picked up more slowly but has also passed 40%. Exclusion experiments 7 and 12 months after release have demonstrated the increasing impact of the parasitoid. In addition, it has been shown that the killing effect of the parasitoid is about twice as high as the recorded parasitism rate of field-collected larvae. A general release permit covering the whole of Kenya was granted in the Kenya Standing Technical Committee on Imports and Exports in May 2003.

A monitoring survey was conducted in the release area in Tanzania. Forty farmers' fields were surveyed and it appears *D. semiclausum* is well established. From 10 plants in each field, 1431 diamondback moth larvae/pupae were collected, of which 36.2% were parasitised. This constitutes a more than 10-fold increase in parasitism as compared to the pre-release situation.

5. Impact assessment

A concerted effort is currently being made to generate the baseline data for an impact assessment of the Project. Work is being conducted on economic assessment of cabbage growing, DBM damage and the economics of current crop protection practices.

For the first time in a biological control project, an ex-ante economic impact assessment was conducted for the prediction of the effect of one single parasitoid, *D. semiclausum*. Using conservative assumptions and an economic surplus model, a cost to benefit ratio of 1: 31 was calculated for the release of *D. semiclausum* in Kenya alone and only for cabbage production, which accounts for only half of the area planted to crucifers.

Biological impact assessment was conducted in the form of studies of the contribution of the introduced parasitoids to DBM mortality of field populations in two of the pilot areas and the laboratory. Combined, these studies will allow for biological and economic impact assessment of the releases of *D. semiclausum*.

Biocontrol-compatible pesticides for aphid control are also being tested. Among the products are wood ash and chilli extract (widely used by farmers), a mineral oil, two neem-based products and a pyrethroid as standard. Tests were started in the laboratory, moved on to the greenhouse and a field trial done in 2003. The results so far are dissappointing, with only the pyrethroid providing an accepatbale level of control. *(See also the abstracts in the following report on biocontrol of* Helicoverpa armigera.*)*

6. Exploration for additional pupal DBM parasitoids conducted in areas of DBM origin

The pupal parasitoid *Diadromus collaris* (Kurdjumov), collected by Dr Alan Kirk in Uzbekistan was evaluated for its temperature adaptability at AVRDC. Unfortunately, it was not sufficiently tolerant to high temperature. Additional material was collected in Turkey and quarantined in France. However, when evaluated at AVRDC, it also did not meet the expectations in terms of high temperature adaptation. The search continues.

CAPACITY BUILDING

The Project has conducted three courses for Training of Trainers (ToTs) in 2003. The aim of the ToT courses is to provide the necessary knowledge needed to reduce pesticide application for the control of DBM and use of alternative pesticides that have no adverse effects on parasitoids to extension officers to help them prepare farmers for the introduction of parasitoids. In cooperation with the Plant Health Services of the Ministry of Agriculture of Tanzania, a one-week training course in January 2003 was held at the Horticultural Research Institute Tengeru. A similar course was conducted in December in collaboration with the National Agricultural Research Organisation at the Namulonge Research Station in Uganda. Participants were drawn from major crucifer growing regions in Tanzania and Uganda, respectively.

In June 2002, participants from major crucifer growing regions in Kenya and northern Tanzania were trained. In addition, a number of farmer training sessions have been conducted in Limuru, Kisii and Meru. *(See also the report of the Technology Transfer Unit.)*

The following students participated in the Project:

PhD students

Ayalew Gashawbeza (Ethiopia) Bioecology of DBM and its indigenous natural enemies in Ethiopia.

Rudo Sithole (Zimbabwe). Comparative biology of African and exotic parasitoids of the genus *Diadegma*.

Barbara Wagener (Germany) Molecular characterisation of African and exotic *Diadegma* spp.

MSc students

Florence Nagawa (Uganda) Population dynamics of DBM and its natural enemies in Mpigi District of Uganda.

Robert Nofemela (South Africa) Bionomics of a South African diamondback moth parasitoid, *Cotesia plutellae* Kurdjumov (Hymenoptera: Braconidae).

Ibrahim Macharia (Kenya) Economic impact assessment of the importation and release of the exotic DBM parasitoid, *Diadegma semiclausum* in cabbage production in Kenya.

Caleb Momanyi (Kenya) Biological impact assessment of the importation and release of the exotic DBM parasitoid, *Diadegma*.

OUTPUT

Journal articles

Löhr B. L. **and** *Gathu R.* **(2002)** Evidence of adaptation of diamondback moth, *Plutella xylostella* (L.), to pea, *Pisum sativum* L. beyond its normal host range. *Insect Science and Its Application* 22, 161–173. **(Call No.: 02-1687)**

A strain of diamondback moth (DBM), *Plutella xylostella* (L.) (Lepidoptera: Plutellidae), adapted to peas was detected in 1999 in the export vegetable growing area south of Lake Naivasha in the Rift Valley Province of Kenya. The pea strain (DBM-P) was compared in laboratory studies to the normal crucifer strain (DBM-C). Whereas DBM-P performed comparably well on kales and peas, the cabbage strain (DBM-C) suffered heavy mortality on peas. Out of the 250 DBM-C first instars, only six reached adult stage on pea. In addition, larval development was prolonged by five days on peas as compared to kale, and larval growth was greatly reduced. Pupal weights of DBM-C survivors on pea were significantly lower (3.8 mg) than of DBM-P (4.6 mg) and those of both strains on kale (5.7 and 5.3 mg, respectively). Neonate larvae of the pea strain mined on both kale and pea but both the proportion of larvae mining and the number of mining days lower than for DBM-C on kale. The latter failed completely to mine on pea.

A laboratory culture was started with the DBM-C survivors on pea and the performance of the progeny compared on kale and pea in three additional generations of selection. Larval survival increased from 2.4% in the first generation to 28.6%, 41.3% and 49.7% in the second, third and fourth generation, respectively. Pupal weight of larvae reared on pea increased with each generation of selection, but it remained significantly lower than of larvae reared on kale. In spite of the large differences in larval mining on the two host plants, performance on peas was not related to the ability

of DBM-C to mine on pea but rather to the ability to initiate feeding without the normal stimuli present in crucifers. Pupal mortality for larvae from both hosts was similar when larvae of equal weight were compared, suggesting acceptable suitability of pea for larval development once the new host is accepted. The implications of these findings on adaptability of DBM to plants beyond its normal host range are discussed.

Conference papers

Paper presented: Diamondback moth (*Plutella xylostella* L.) (Lepidoptera: Plutellidae) and its parasitoids in Ethiopia. International Symposium Improving Biocontrol of *Plutella xylostella*. 21 to 24 October 2002, Montpellier, France. Ayalew G., Löhr B., Baumgärtner J. and Ogol C. K. P. O.

Paper presented: Molecular identification of *Diadegma* species parasitising diamondback moth in eastern and southern Africa. IOBC Symposium on the Role of Genetics and Evolution in Biocontrol, 14–18 October 2002, Montpellier, France. Wagener B., Löhr B. L., Reineke A. and Zebitz C. P. W.

Paper presented: Discrimination of *Diadegma* species parasitising diamondback moth in eastern and southern Africa by polymerase chain reaction restriction fragment length polymorphism analysis. International Symposium Improving Biocontrol of *Plutella xylostella*. 21 to 24 October 2002, Montpellier, France. Wagener B., Löhr B. L., Reineke A. and Zebitz C. P. W.

Research proposals

Promoting farmer-based IPM for crucifer production in East Africa.

Biological and economic impact of biocontrol of the diamondback moth (*Plutella xylostella* L.) with the exotic parasitoid *Diadegma semiclausum* in Kenya.

Development of private sector service providers for the horticultural industry in Kenya.

Participating scientists: B. Löhr (Project Leader and Head, Plant Health Division), A. Rossbach

Assisted by: R. Gathu, F. Nyamu, N. Mwikya

Donors: German Federal Ministry of Economic Cooperation and Development (BMZ)

Collaborators: Ethiopian Agricultural Research Organisation, Melkassa Research Centre, Nazareth; Kenya Agricultural Research Institute, National Biological Control Centre, Muguga and Regional Agricultural Research Centre, Kisii; Ministry of Agriculture and Rural Development (MOARD), District Agricultural Office, Taita Taveta District (Kenya); Plant Protection Research Institute (PPRI) (South Africa); German-Tanzanian IPM Project/Plant Health Division, Kibaha Biocontrol Centre (Tanzania); National Agricultural Research Organisation, Namulonge Agriculture and Animal Research Institute Biocontrol Unit (Uganda); Plant Protection Research Institute (Zimbabwe); United States Department of Agriculture, Agric. Res. Station, Montpellier (France); University of Hohenheim; Institut für Phytomedizin, University of Gottingen and Inst. für Pflanzenpathologie und Pflanzenschutz (Germany); Asian Vegetable Research and Development Centre (AVRDC) (Taiwan)

DEVELOPMENT OF BIOCONTROL-BASED MANAGEMENT OF *HELICOVERPA ARMIGERA* (HÜBNER) IN EASTERN AND SOUTHERN AFRICA

BACKGROUND, APPROACH AND OBJECTIVES

The African bollworm, *Helicoverpa armigera* (Lepidoptera: Noctuidae), is an important constraint to production and marketing of several vegetable crops on the continent, especially tomatoes, capsicum, okra, French beans and snowpea. These crops are grown by a multitude of smallholder farmers in the region. Chemical pesticide use for controlling this pest has been found to be unsustainable, as well as raising consumer concerns about harmful residues in the produce. The tendency to resort to preventative or calender-based rather than need-based application of pesticides has already led to pesticide resistance. The national agricultural research and extension systems (NARES) are keen to assist farmers with safer technology options, but are not yet equipped with the required range of alternative options such as biological control.

Among the biocontrol agents that could be locally developed, egg parasitoids offer good scope for control of the bollworm. Globally, these bioagents (mainly trichogrammatids) are being used successfully in many countries and on several target crops for control of *Heliothis/Helicoverpa* species. The major goal of this project is to contribute to sustainable horticultural production through the promotion of egg parasitoid-based biocontrol of *Helicoverpa armigera* (Hb) on vegetable crops in eastern and southern Africa. The project has involved national partners in Kenya, Ethiopia, Tanzania and Uganda over a 3-year timeframe for the first phase (2001–2004). The objectives of the project are to:

- develop and implement biocontrol-based integrated pest management (IPM) programmes through improved utilisation of egg parasitoids for the fruit borer (*H. armigera*) on important vegetable crops in eastern Africa;
- improve regional collaboration among NARES with international agricultural research centres (IARCs) and advanced research institutions for strengthening IPM-linked biocontrol research in the region;
- enhance capacity within NARES to develop and implement egg parasitoid-based biocontrol programmes.

The major focus of the first phase (2002–2003) was to assemble baseline information required for developing appropriate strategies for biocontrol-based management of *Helicoverpa armigera*, through improved utilisation of native egg parasitoids, especially trichogrammatids.

WORK IN PROGRESS

1. Egg parasitoid survey collections and local reference repository

On-farm surveys and collection of egg parasitoids were completed after extending this activity by one more season. The parasitoids were identified by conventional taxonomic study of the trichogrammatid collections from *H. armigera* and the use of molecular techniques for additional characterisation. Overall, 320 egg parasitoid accessions were assembled from the region. A total of 123 accessions were assembled from the on-farm visits in the three major ecologies—low (18), mid- (23) and high (82) altitudes. The host plants of *H. armigera* from which these collections were made included tomato (100), okra (4), pigeonpea (4), cotton (4), sunflower (3) and maize (6). Two collections were also made from cabbage, which is regarded a non-host of *H. armigera*.

Supplementary collections from on-station (benchmark) sites yielded 197 accessions with representation from low (84), mid- (68) and high (45) altitudes (Figure 1). The *H. armigera* host plants here are shown in Figure 2. Among all accessions assembled from *H. armigera* on tomato crops alone, 77 were identified as *Trichogrammatoidea* spp. and 16 as *Trichogramma* spp., as well as 51 belonging to the family Scelionidae (Table 1). Preliminary identifications have shown the occurrence of two additional species of *Trichogramma* (possibly new records), other than those already reported to occur in the region. The regional *Trichogramma* live repository was strengthened, with additional live collections from the surveys (Table 2). GIS information was assembled for cataloguing the species/strains collections.

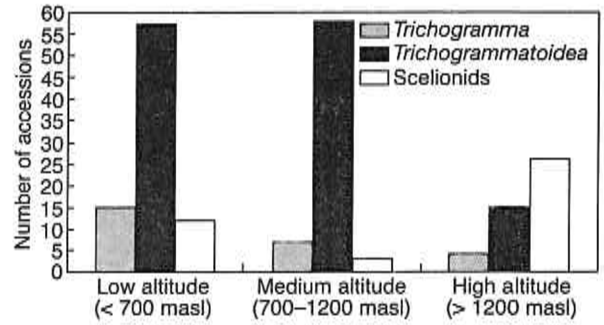


Figure 1. Egg parasitoid accessions assembled in on-station surveys at different altitudes (metres above sea level)

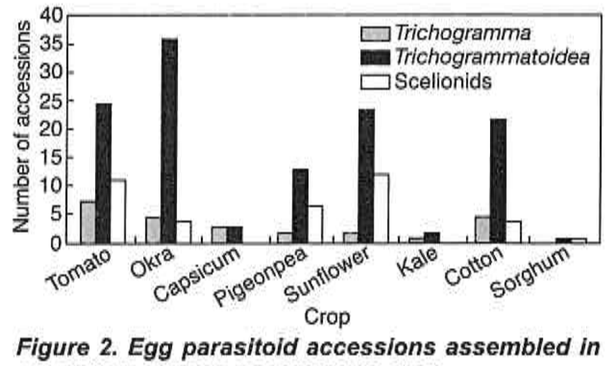


Figure 2. Egg parasitoid accessions assembled in on-station surveys according to crop

Table 1. Combined number of egg parasitoid accessions on *Helicoverpa armigera* assembled from on-station and on-farm surveys on various crops and at different altitudes

Crop/	Kenya			Tanzania			Uganda			Ethiopia		
Altitude	*Trichogramma*	*Tricho-grammatoidea*	Scelionids	*Trichogramma*	*Tricho-grammatoidea*	Scelionids	*Trichogramma*	*Tricho-grammatoidea*	Scelionids	*Trichogramma*	*Tricho-grammatoidea*	Scelionids
Tomato	13	49	22	2	11	3	0	8	1	1	7	23
Okra	4	34	4	1	2	1	0	5	0	0	0	0
Capsicum	3	3	0	0	0	0	0	0	0	0	0	0
Pigeonpea	2	14	1	0	0	10	0	0	0	0	0	2
Sunflower	2	25	6	0	2	7	0	0	1	0	0	0
Cotton	5	19	1	0	1	2	0	4	1	0	3	0
Sorghum	0	1	1	0	0	0	0	0	0	0	0	0
Maize	2	0	0	0	0	0	0	2	2	0	0	0
Total	**31**	**145**	**35**	**3**	**16**	**23**	**0**	**19**	**5**	**1**	**10**	**25**
Low altitude	14	66	9	1	3	7	0	0	0	0	0	0
Medium-altitude	10	48	3	0	0	4	0	18	5	0	0	1
High altitude	7	31	23	2	13	12	0	1	0	1	9	24

Altitude: Low = < 700 metres above sea level (masl); mid = 701–1200 masl; high = > 1200 masl.

2. Evaluation of species/strain adaptation to stresses

Studies on adaptation to temperature were concluded with ranking for key biological attributes including attack rate (Table 3). Among four promising trichogrammatid strains tested for host plant effects, greater parasitism was recorded on tomato by two of them, while greater parasitism on okra was observed with the other two strains under field cage preference studies (Figure 3). Data analysis on adaptation to climatic stresses led to the determination of the relative attack rates and related attributes among representative native species/strains. The relative safety of additional pesticides (mainly miticides and fungicides) to adults of the two common genera (*Trichogramma* and *Trichogrammatoidea*) was evaluated. New pest control products which were found to be safer for adults of these native species included Match, Milraz, Antracol and Kelthane (Figure 4). They were also relatively harmless to the developing stages of the parasitoids. Pot culture studies on host plant effects were also completed.

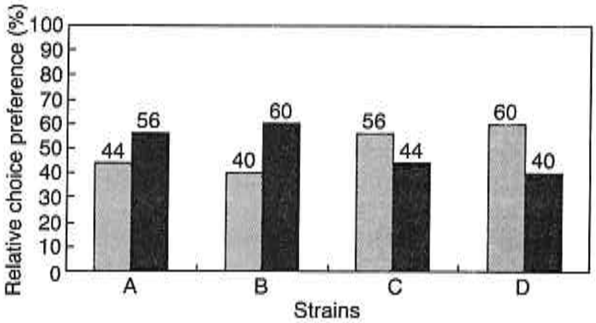


Figure 3. Relative choice preference (%) of* Helicoverpa armigera *on tomato and okra by four trichogrammatid species/strains from low (L), medium (M) and high (H) altitudes in laboratory and field cages.

(A = Trichogramma *sp. nr.* mwanzai *(L), B =* T. *sp. nr.* lutea *(H), C =* T. *sp. nr.* mwanzai, *D =* T. *sp. nr.* lutea (M)

3. Field studies relating to *Trichogrammma* impact evaluation

The assessment of relative egg numbers of *H. armigera* eggs on target crops was done and their data analysis completed. Analysis of *H. armigera* egg abundance data from six benchmark sites in Kenya provided useful information on the egg abundance pattern in three main reproductive periods of the crop: early (weeks 1–2), mid- (weeks 3–4) and late (weeks 5–6). Pigeonpea tended to be the crop with greatest egg load in at least one of these periods compared to tomato and okra (Figure 5). Peaks in egg numbers tended to occur at 1–2 weeks after peaks in adult catches in traps. Minimum temperature in the same week and/or 1–2 weeks earlier was found to have a significant correlation with trap catches of the *H. armigera* adults in one site at Muguga (Kenya). Net house studies pointed out the role of cultivars as a factor in *Trichogramma* parasitism (Figure 6).

Table 2. Number of native trichogrammatid accessions available as live cultures in gene bank at ICIPE

Crop/altitude	Host insect	On-station surveys: Pooled collection	On-station surveys: Isofemale lines	On-farm surveys: Pooled collections	On-farm surveys: Isofemale lines
Tomato	*Helicoverpa armigera*	9	11	28	27
Okra	*H. armigera*	18	16	1	1
Capsicum	*H. armigera*	1	1	0	0
Pigeon pea	*H. armigera*	3	3	0	0
Sunflower	*H. armigera*	7	8	0	0
Cotton	*H. armigera*	7	12	1	0
Sorghum	*H. armigera*	0	1	0	0
	Chilo spp.	7	8	0	0
Maize	*H. armigera*	0	0	1	1
Total		**52**	**60**	**31**	**29**
Low altitude (< 700 masl)		21	34	9	11
Mid-altitude (701–1200 masl)		21	13	11	8
High altitude (> 1200 masl)		10	13	11	10

Table 3. Ranking of three *Trichogramma* species for biological traits for warmer temperature adaptation

Species	Temp (°C)	Attack rate	Ranking score (Among six species/strains)[+]: Longevity	Ranking score (Among six species/strains)[+]: Progeny sex ratio
Trichogramma sp. nr. *mwanzai* (L)	25	4	1	3
	30	1	6	4
	35	2	1*	1
Trichogramma sp. nr. *mwanzai* (M)	25	3	2	1
	30	3**	2	2
	35	1	3*	5
Trichogramma bruni (H)	25	6	6	2
	30	5	5	1
	35	5	5*	NA (6)

[+]1 = highest score, 6 = lowest, NA = Not applicable.
L = low-, M = medium- and H = high altitude.
*Not significant at P = 0.05, **Same value.

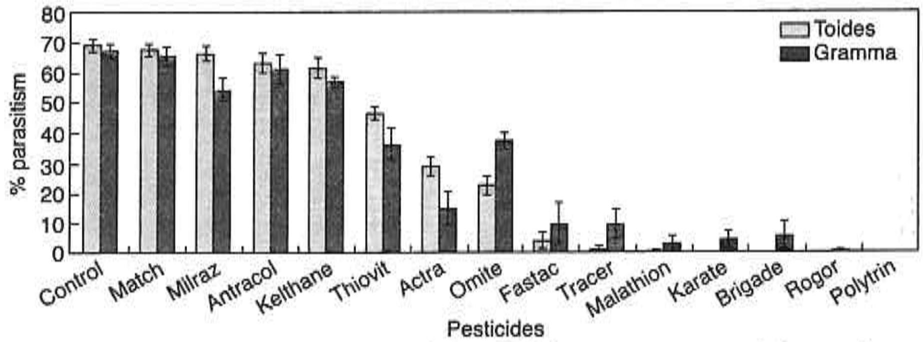


Figure 4. Percentage parasitism of host eggs by adults of* Trichogramma *sp. nr.* lutea *and* T. *sp. nr.* mwanzai *after exposure to pesticide spray deposits on glass surface

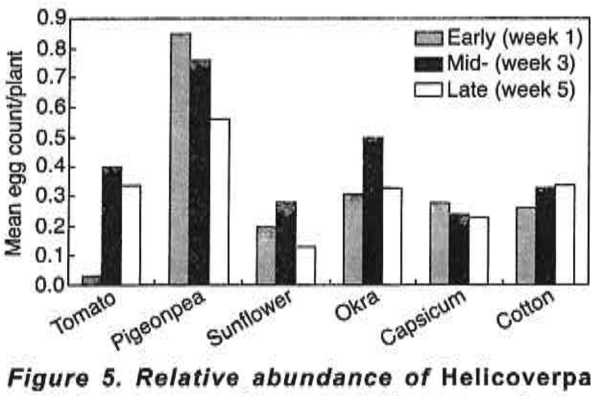


Figure 5. Relative abundance of* Helicoverpa armigera *eggs on six crops at three reproductive phases, Mwea, Kenya 2001–2003

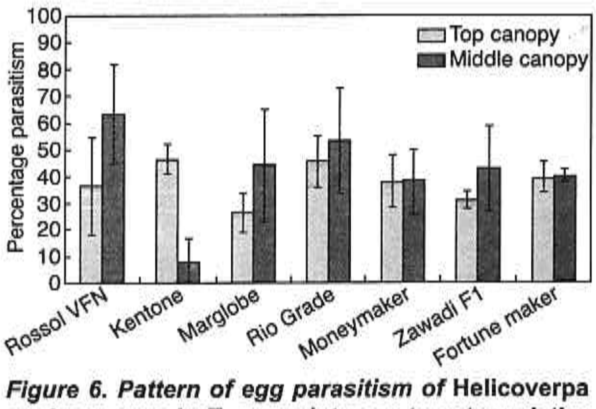


Figure 6. Pattern of egg parasitism of* Helicoverpa armigera *eggs by* T. *sp. nr.* lutea *on tomato varieties at two canopy levels. Net house study, ICIPE, 2003

4. *Trichogramma* mass production and in-country demand assessment

Evaluation of local materials as larval feeds for host (*Corcyra cephalonica*) culture was completed. Maize was identified as the most productive larval feed for the mass production host (*C. cephalonica*) (Figure 7). National stakeholders' workshops held in Ethiopia and Kenya confirmed the potential demand for the parasitoid and need for its local production. Cotton researchers from Kenya (KARI) have expressed an interest in the potential use of *Trichogramma* for bollworm biocontrol. The guidelines for regulating mass production and quality control were also availed to Kenyan NARES through an invited paper presented at the National Workshop for Legislative Guidelines for Promoting and Regulating Biopesticides in Kenya.

5. Development of methodologies for non-target studies

Laboratory studies on non-target butterflies was continued on additional butterfly species of local importance, including study of the host plant role. Among two trichogrammatid strains studied, one was not able to produce any progeny on butterfly (*Papilio demodocus*) eggs. The progeny sex ratio was also different among the hosts compared. Baseline studies in benchmark sites established the variation in incidence of egg parasitoids (scelionids) across directions and distances of egg sampling.

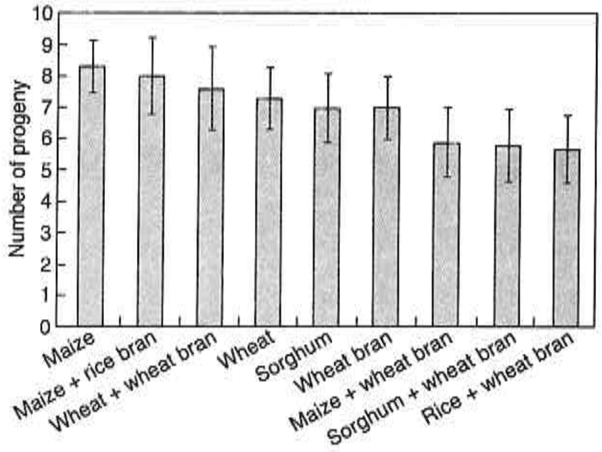


Figure 7. Number of progeny produced per female **Trichogramma** ***sp. nr.*** **mwanzai** ***when reared on*** **Corcyra** ***eggs, in relation to larval diets of the host. Laboratory study, ICIPE, 2003***

CAPACITY BUILDING

PhD students

Joseph Baya (Kenya) Taxonomic studies on native *Trichogramma* occurring on *Helicoverpa armigera* in Eastern Africa. Jomo Kenyatta University of Agriculture and Technology (JKUAT) (Continuing)

Andrew Kalyebi (Uganda) Adaptation studies on native *Trichogramma* for climatic stresses, especially temperature. Kenyatta University (Continuing)

Ann Margaret Akol (Uganda) Completed 2002 and degree awarded 2003. ICIPE supervisor: S. Sinthanantham.

Monica Waiganjo (Kenya). Bioecology and preventive management of onion thrips, Kenyatta University (Completed 2003). ICIPE supervisor: S. Sinthanantham.

MSc students

Zipporah Osiemo (Kenya) Role of temperature and cohabiting on sex ratio in *Trichogramma* species, MSc, JKUAT, 2002.

Constance Muholo (Kenya) Host specificity and non-target studies on *Trichogramma* species, MSc, University of Addis Ababa, 2002.

Lorna Migiro (Kenya) Studies on mass production efficiency for *Trichogramma*, JKUAT, 2003.

George Momanyi (Kenya) Evaluating relative safety of pesticides to *Trichogramma* species, MSc, JKUAT, 2003.

Jackline Makatiani (Kenya) Role of companion crops on diamondback moth infestation in brassica crops, MSc, Kenyatta University, 2003.

Short-term training

- For NARES scientists and technical personnel: Two scientists from Tanzania and Ethiopia and two technicians were trained on *Trichogramma* research activities and field demonstration.
- For private sector managers: Managers from two private sector biocontrol producers (Hortico Ltd, Zimbabwe and Dudutech, Kenya) were trained in *Trichogramma* production.

OUTPUT

Journal articles

***Abera T. H.*, Hassan S. A., Ogol C. K. P. O., *Baumgärtner J.*, *Sithanantham S.*, Monje J. C. and Zebitz C. P. W. (2002)** Temperature-dependent development of four egg parasitoid *Trichogramma* species (Hymenoptera: Trichogrammatidae). *Biocontrol Science and Technology* 12, 555–567. **(Call No.: 02-1646)**

Trichogramma species have been successfully utilised for biocontrol of several lepidopteran pests worldwide. The development, survival and progeny production of two Kenyan species, *Trichogramma bournieri* Pintureau and Babault and *Trichogramma* sp. nr. *mwanzai* Schulten and Feijen (collected from Kenya), *Trichogramma evanescens* Westwood (Germany) and *Trichogramma chilonis* Ishii (India) was studied at four constant temperatures (13, 18, 25 and 34° C) with the aim of assessing the relative biotic potential of the two native species for biocontrol of *Helicoverpa armigera* and *Plutella xylostella* in Kenya. The study was conducted at the Institute for Biological Control (BBA), Darmstadt, Germany. The *Trichogramma* species tested showed variations in fertility, developmental time, percent emergence, progeny production and sex ratio at the four temperature regimes. Fertility decreased as temperature increased from 25 to 34° C. *T. chilonis* and *T. evanescens* completed development at all temperatures tested, but *T. bournieri* and *T.* sp. nr. *mwanzai* failed to complete development at 13° C. The developmental period for all the species decreased as the temperature increased. The duration of development from oviposition to adult emergence varied from 8 days to 12 weeks shorter at 34° C than at 13° C for *T. chilonis* and *T. evanescens*. For the various temperatures tested, a linear model was satisfactory for egg to adult development at $P = 0.05$ for *T. chilonis* and *T. evanescens*. The lower temperature thresholds for development and duration in degree-days were 8.83° C and 188 for *T. chilonis* and 9.23° C and 192 for *T. evanescens*, respectively. For all temperatures tested, *T.* sp. nr. *mwanzai* had the highest preimaginal survivorship. Adult emergence was lower at 13° C and 34° C than at 18 and 25° C. The highest fertility (mean ± SE) (50.37 ± 2.32 adult female^{-1}) and progeny production (44.03 ± 2.02 adult female^{-1}) was recorded at 25° C for *T. evanescens*. Sex ratio was biased towards female at all temperatures in *T. bournieri* and *T. chilonis*. At all temperatures tested, *T.* sp. nr. *mwanzai* produced more males than females. For all species tested, favourable parasitism was between 18 and 25° C. The results from this study will be useful for mass rearing purposes as well as for future field release programmes.

***Abera T. H.*, Hassan S. A., *Sithanantham S.*, Ogol C. K. P. O., *Baumgärtner J.* (2002)** Comparative life table analysis of *Trichogramma bournieri* Pintureau and Babault and *Trichogramma* sp. nr. *mwanzai* Schulten and Feijen (Hym., Trichogrammatidae) from Kenya. *Journal of Applied Entomology* 126, 287–292. **(Call No.: 02-1625)**

Egg parasitoids of the genus *Trichogramma* (Hym., Chalcidoidea: Trichogrammatidae) have been successfully utilised for biocontrol of several lepidopteran pests worldwide. *Trichogramma bournieri* Pintureau and Babault and *Trichogramma* sp. nr. *mwanzai* Schulten and Feijen, which are native to Kenya and recovered from *Chilo partellus* eggs, were compared with the aim of evaluating them for field releases in Kenya for the control of lepidopteran pests, particularly *Helicoverpa armigera* and *Plutella xylostella* in tomato and kale, respectively. Age-specific life tables were constructed at the Institute for Biological Control (BBA), Darmstadt, Germany in 1999 using a cohort of 60 mated females each at 26 ± 1° C, 70 ± 10% relative humidity and 16 h light : 8 h dark photoperiod. The adult female performance and population growth statistics with associated standard errors were computed. There was no significant difference in adult longevity between selected strains of the two species. *Trichogramma* sp. nr. *mwanzai* showed significantly higher cumulative as well as daily mean fertility (75.97 and 18.11, respectively) compared with *T. bournieri* (47.83 and 13.24, respectively), and the respective proportion of female progenies were 52 and 72%. The intrinsic rate of natural increase was 0.309 and 0.306, while the net reproductive rate was 35.16 and 31.22 for *T.* sp. nr. *mwanzai* and *T. bournieri* strains, respectively. The study has also shown that there is no significant difference in the intrinsic rate of natural increase and the net reproductive rate between the two native species. In summary, there is difference between the two strains in their parasitization potential but not in population growth potential. Consequently, no preference can be given to one species when selecting for mass rearing purposes. Adult female performance is superior in *T.* sp. nr. *mwanzai* than in *T. bournieri*. Hence, the former strain should receive particular attention in future studies.

Other collaborations

***Akol A. M.*, *Njagi P. G. N.* and *Sithanantham S.* (2003)** Effect of two neem insecticide formulations on the attractiveness, acceptability of diamond moth larvae to the parasitoid, *Diadegma mollipla* (Holmgren) (Hymenoptera: Ichneumonidae). *Journal of Applied Entomology* 127, 325–331. **(Call No.: 03-1684)**

Behavioural responses of female *Diadegma mollipla* to volatiles from cabbage plants and host-infested [*Plutella xylostella* (L.)] cabbage plants sprayed with two neem insecticide formulations were investigated in a Y-tube olfactometer. Parasitoids were significantly more attracted to volatiles from cabbage and host-infested cabbage sprayed with the powder formulation than to clean air. In contrast, parasitoid response to volatiles from cabbage and host-infested cabbage sprayed with the oil formulation was not significantly different from clean air. In choice tests between infested plants sprayed with water (control) or the powder formulation, parasitoids showed no preference for volatiles from either of the treatments. In similar tests with the oil formulation, parasitoids showed a preference for volatiles from control plants over plants sprayed with the oil formulation. In host acceptance and suitability tests, parasitism rates in the neem- and water-sprayed hosts were, with one exception, not significantly different. However, the neem-sprayed larvae died earlier than control larvae and were therefore not able to support parasitoid development. The implication of these findings for the combined use of neem insecticides and parasitoids in the management of *P. xylostella* is discussed.

Akol A. M., Sithanantham S., Njagi P. G. N., Varela A. and **Mueke J. M. (2002)** Relative safety of sprays of two neem insecticides to *Diadegma mollipla* (Holmgren), a parasitoid of the diamondback moth: Effects on adult longevity and foraging behaviour. *Crop Protection* 21, 853–859. **(Call No.: 02-1666)**

The non-target safety of two neem-based insecticides, Neemroc EC (an oil formulation) and Neemros (an oil-free powder formulation) to adults of *Diadegma mollipla* (Holmgren), a larval parasitoid of the diamondback moth, *Plutella xylostella* (L.), was investigated in laboratory bioassays. The neem insecticides were compared against Karate (a synthetic pyrethroid insecticide) and water as sprays. Karate caused 100% mortality in treated wasps within 6 h, while the two neem insecticides did not cause any significant mortality. The mean longevity of wasps was not significantly affected by exposure to the two neem insecticides. The time allocation to different components of foraging behaviour by adult females was not significantly altered by the neem treatments. The mean proportion of second instar *P. xylostella* larvae parasitised by water-sprayed wasps was not significantly different from that of the neem insecticide-sprayed wasps. It is concluded that the field dose rate of the neem insecticides recommended for *P. xylostella* control did not cause any apparent adverse effects on the survival and foraging behaviour of *D. mollipla*. Evidently, the neem insecticides are compatible with the activity of *D. mollipla* and could, therefore, constitute complementary components in the integrated management of *P. xylostella* on cabbage.

Maniania N.K., Sithanantham S., **Ampong-Nyarko K.**, *Ekesi S., Baumgärtner J., Löhr B.* and *Matoka C.* **(2003)** A field trial of entomogenous fungus *Metarhizium anisopliae* for the control of onion thrips, *Thrips tabaci*. *Crop Protection*, 22, 553–559. **(Call No. 03-1675)**

Sileshi G., Baumgärtner J., Sithanantham S. and **Ogol C. K. P. O. (2002)** Spatial distribution and sampling plans for *Mesoplatys ochroptera* (Coleoptera: Chrysomelidae) on *Sesbania*. *Journal of Economic Entomology* 95, 499–506. **(Call No.: 02-1642)**

With the widespread introduction of the nitrogen-fixing legume sesbania, *Sesbania sesban* (L.) Merril, in agroforestry systems, the defoliating beetle *Mesoplatys ochroptera* Stål has become a serious pest of the trees in Africa. To determine within-field and within-plant spatial distribution of *M. ochroptera* on both seedlings and trees of sesbania, distribution statistics were computed using Iwao's mean crowding regression model. In 1- to 3-mo-old seedlings, the model accounted for 29.8, 32.2, and 61.0% of the variation observed in mean crowding to mean relationships in egg masses, larvae and adults, respectively. The model slopes of the regression were greater than unity for all stages indicating aggregated spatial distribution. Values of the intercept were greater than zero for egg masses, larvae and adults indicating that the basic components of the population are groups of individuals. The highest density (> 80%) of mating and feeding adults was found in the upper third of 1- to 2-mo-old seedlings, while most of the egg masses were found in the lower half of seedlings. In trees, > 60% of the individuals of all stages were found in the lower third of the foliage canopy, while <10% were found in the upper third. Sampling adults was found to be easier and gave better density estimates of *M. ochroptera* population than egg masses and larvae. Therefore, sampling plans useful for population studies and decision-making in pest management were developed for adults.

Sileshi G., Sithanantham S., **Mafongoya P. L., Ogol C. K. P. O. and Rao M. R. (2003)** Biology of *Mesoplatys ochroptera* Stal (Coleoptera: Chrysomelidae), a pest of *Sesbania* species, in southern central Africa. *African Entomology*, 11, 49–58.

Book chapters

Sithanantham S., Seif A.A., Ssennyonga J., Matoka C.M. and *Mutero C.* **(2002)** Integrated pest management (IPM) in irrigated agriculture: Recent initiatives and future needs to promote IPM adoption by smallholder farmers in eastern Africa, pp. 231–261. In *The Changing Face of Irrigation in Kenya: Opportunities for Anticipating Change in Eastern and Southern Africa* (Edited by H. G. Blank, C. M. Mutero and H. Murray-Rust). International Water Management Institute (IWMI), Colombo, Sri Lanka.

Proceedings

Sithanantham S. (2003) Research approaches for non-target risk assessment in biological control of lepidopteran pests and needs in developing countries, pp. 225–239. In *Biocontrol of Lepidopteran Pests*. Proceedings of a Symposium July, 2002, Bangalore, India (P. L. Tandon *et al.* eds.). PDBC/ISBC, Bangalore, India.

Consultancies

- Provided technical advice to directorship of BIOP.
- Resource person for Kenya Plant Health Inspectorate Service (KEPHIS) task team on pests of export horticulture.
- Technical consultancy in *Trichogramma* commercial production to Dudutech (Kenya).

Conferences attended

International Workshop on *Helicoverpa armigera* Management, December 2001, ICRISAT, Hyderabad, India. Biological control of *Helicoverpa armigera* with entomophagous insects: Research status, constraints and opportunities. (Invited paper). Sithanantham S., Singh S. P., Romeis J. and Matoka C. M.

Biopesticides Legislation Guidelines Development Workshop, 14–16 May 2003, Nakuru, Kenya. Regulatory guidelines for mass produced parasitoids and predators: A case study of *Trichogramma* and recommendations for Kenya. (Invited paper). Sithanantham S., Kariuki C.W., Macharia I., Matoka C. M., Muholo C., Kuria B. N. and Rabindra J.

National Symposium on Frontier Areas of Entomological Research, 5–9 November, 2003, New Delhi, India (jointly convened by IARI and ESI, India). Enhancing the impact potential for biocontrol of *Helicoverpa armigera* (Hb.): Case study of initiatives in utilizing native trichogrammatid Egg Parasitoids in Africa. (Invited paper). Sithanantham S.

International Symposium on egg parasitoids, Perugia, Italy, September, 2002; chaired a session and presented 3 papers
Symposium on Frontiers in Entomological Research, New Delhi, India, November, 2003; invited paper
AAIS symposium on utilisation of egg parasitoids for biocontrol in Africa, Nairobi, Kenya, June, 2003; presented 2 papers
AAIS Symposium on African bollworm management, Nairobi, Kenya, June, 2003; presented an invited paper and chaired the session.
Seminar on horticulture in the tropics, Maseno, Kenya, November, 2003; presented two papers

Conferences organised

- National Workshop on *Helicoverpa* Management, Ethiopia, April, 2002
- National Workshop on *Helicoverpa* Management, Kenya, Nov. 2002
- AAIS symposium on use of egg parasitoids for biocontrol in Africa, June, 2003
- AAIS symposium on integrated *Helicoverpa* management in Africa, June, 2003

Research proposals

- *Trichogramma* commercial production.
- Training/technical assistance to Dudutech in commercial *Trichogramma* production.
- *Helicoverpa* management in Eastern Africa (ICRISAT-led).
- Global challenge for water—Integrated Management of Bollworms (led by CIAT, collaboration with IWMI).

Participating scientists: S. Sithanantham (Project leader), E. Osir, S. Kimani-Njogu, W. A. Overholt, S. Mamoudou

Assisted by: C. Matoka, G. Jira, A. Wanyonyi, J. Ondijo, J. Kilovu, L. Masambu, S. Opiyo, D. Agengo, K. Nguya, J. Mucheru

Collaborators: Kenyatta University and Jomo Kenyatta University of Agriculture and Technology (JKUAT), (Kenya); University of Addis Ababa (Ethiopia); Ethiopian Agricultural Research Organisation (Ethiopia); National Agricultural Research Organisation (Uganda); Kenya Agricultural Research Institute; University of Hohenheim (Germany); Institute for Biological Control (BBA) (Germany), MAFS

Donor: German Ministry of Technical Cooperation (BMZ)

DEVELOPMENT OF ENVIRONMENTALLY FRIENDLY MANAGEMENT METHODS FOR RED SPIDER MITES IN SMALLHOLDER TOMATO PRODUCTION SYSTEMS IN EASTERN AND SOUTHERN AFRICA

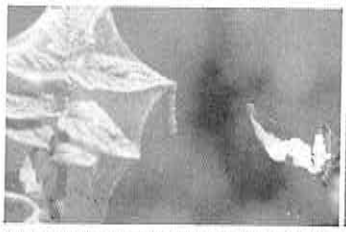
BACKGROUND, APPROACH AND OBJECTIVES

Tomato is one of the most important vegetables in eastern and southern Africa, yet yields in smallholder production systems are far below the crop's potential. The red spider mite (RSM), *Tetranychus evansi* Baker & Pritchard is currently the most serious pest of tomatoes in southern Africa and is spreading rapidly in the semi-arid tomato production areas of Kenya. It is likely of American origin and was accidentally introduced to Africa in the late 1970s. It was first recorded in Zimbabwe in 1979 and has spread northwards, reaching Zambia around 1985 and Malawi in 1990. In 2001 the RSM was found in Kenya and in 2002 it was recorded from Somalia.

Since it is an introduced species, most indigenous natural enemies do not feed on it. This leads to rapid population build-up, mainly in the dry season, frequently leading to total crop loss (see photos). Current control practices involve regular application of highly toxic acaricides with long pre-harvest intervals, which result in pesticide contamination of producers, the produce and the environment. In addition, these pesticide treatments are often not effective since the spraying techniques used by African smallholders are inadequate for the control of spider mites.

The project, which began in 1998, aims to develop an integrated pest management (IPM) strategy for red spider mites in eastern and southern Africa. The biology of *T. evansi* has been investigated extensively and the damage to the crop established. The IPM strategy is now focusing on classical biological control, host plant resistance, acaricide resistance management, improved crop management and improved pesticide application techniques.

Since *T. evansi* is probably of South American origin, surveys for natural enemies have been conducted in areas of Brazil that are climatically similar to the major tomato production areas of Kenya and Zimbabwe. Predators found are tested for their suitability for introduction into Africa.



***LEFT:* Web of** Tetranychus evansi **on a heavily infested tomato plant. *RIGHT:* Tomato damaged by the red spider mite**

A mass-screening programme has been designed to identify accessions of tomato and its wild relatives with resistance to *T. evansi*. Promising accessions are currently being tested in the field and the resistance mechanisms investigated. The next step will be to start a breeding programme to improve the agronomic traits of resistant varieties.

The project is also working on the development of botanicals and fungal pathogens to control *T. evansi* and testing new, environmentally friendly acaricides. Commonly used acaricides are being tested with *T. evansi* strains from major tomato producing areas of Zimbabwe and Kenya to establish the resistance status of the populations. The results are used for recommendations to farmers and in a training programme on pruning and staking of tomatoes and proper pesticide application.

WORK IN PROGRESS

1. Temporal and spatial dynamics of *Tetranychus evansi* in tomato fields

The temporal dynamics of *T. evansi* in a tomato field were investigated at Muzarabani (Zimbabwe) for three seasons. Sampling was conducted weekly for 5–7 weeks starting 4–6 weeks after transplanting, depending on the occurrence of the first mites, mite population development and senescence of plants due to mite damage.

The mite population generally increased with time in all three seasons, however the magnitude of increase differed (Figure 1). The highest mite densities were reached 10 weeks after transplanting in Season 1 with 1507 mites per 3 terminal leaflets and in Season 2 at 8 weeks after transplanting (699 mites per 3 terminal leaflets) and in season 3 at 13 weeks after transplanting (296 mites per 3 terminal leaflets). These differences were related to climate patterns during the growing seasons, mainly temperature and rainfall. Season 1 was moderately hot and dry. In Season 2 exceptionally high temperatures caused premature senescence of the tomato plants. Rainfall inhibited population development in Season 3. A detailed analysis of these interactions is in progress.

The distribution of mites was aggregated within as well as between plants. The highest proportion

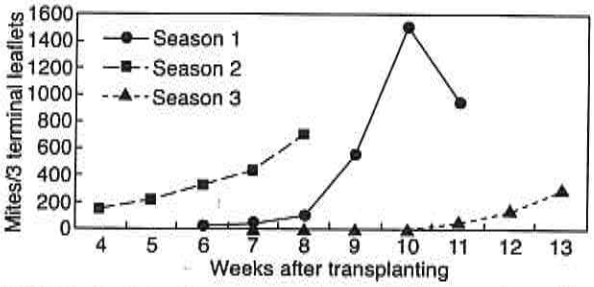


Figure 1. Development of populations of motile stages of* Tetranychus evansi *in 3 seasons at Muzarabani, Zimbabwe

of mites was found in the lower and middle parts of the tomato canopy at low mite densities at the beginning of the sampling period. At higher densities towards the end of the season, the mites were more equally distributed among plant strata. *(See also report of the Population Ecology and Ecosystem Science Department.)*

2. Impact assessment of naturally occurring predators on *T. evansi* populations and their damage on tomatoes

The impact of predators on populations of *T. evansi* and their damage on tomatoes was assessed using experimental exclusion of natural enemies with Ambush (permethrin) at Mwea, an intensive year-round tomato-growing area in Kenya. The density of *T. evansi* was low both in the permethrin-treated plots and unsprayed controls, even though the latter showed higher mean density per leaf over most of the tomato growth stages. The maximum total mite density per leaf was 134 in the permethrin treatment and 274 in the unsprayed control. The mite feeding damage increased over time and a leaf damage index greater than 2 was reached during the harvest period in both treatments. There was no significant difference in the average yields of the treated plots (9.6 t/ha) and the control (9.9 t/ha).

The predators associated with *T. evansi* were *Phytoseiulus persimilis* (Phytoseiidae), *Neoseiulus* sp. (Phytoseiidae), *Pronematus* sp. (Tydeidae), *Oligota* sp. (Staphylinidae) and *Stethorus* sp. (Coccinellidae). However, these were few in number and their control effect on the mite was negligible. These results confirm the experience from earlier survey work that indigenous natural enemies in Africa cannot control *T. evansi* effectively.

3. Exploration for biocontrol agents for *T. evansi* in Brazil

A climatic similarity model based on coordinates of areas in Kenya and Zimbabwe where *T. evansi* has been found was used to determine the priority areas for exploration for natural enemies for introduction into similar climate conditions in Africa (Figure 2). Surveys for *T. evansi* and its natural enemies on wild and cultivated host plants were conducted in the Brazilian States of Paraíba, Ceara, Pernambuco. Alagoas, Sergipe, Bahia, Minas Gerais, Espirito Santo, Rio de Janeiro, Mato Grosso do Sul, Sao Paulo, Parana, Santa Catarina and Rio Grande do Sul. Leaves were collected from wild and cultivated Solanaceae and brought to the laboratory in cool boxes. All mites and insects known to be predators of mites were collected from the leaves using a microscope and identified. A total of 27 species of Phytoseiidae were collected. So far, three are new to science. However, *T. evansi* was rarely found during the surveys.

Regular monthly sampling was conducted around Barbalha/Crato and Juazeiro/Petrolina (Ceara) on tomatoes and wild Solanaceae. In total 17 species of predatory mites (Phytoseiidae) and one predatory

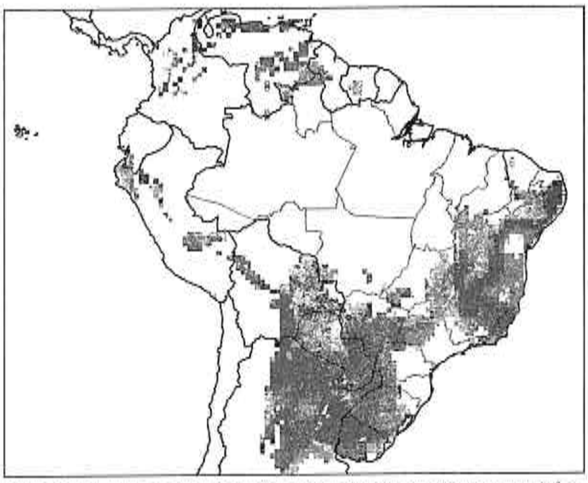


Figure 2. Areas in Brazil and neighbouring countries climatically similar to major tomato-growing areas in eastern and southern Africa

Cecidomyiidae were found. *Tetranychus evansi* and predatory mites were much more abundant in Barbalha/Crato than in Juazeiro/Petrolina. *Phytoseius guianensis* DeLeon was the dominant Phytoseiidae in most places.

Monthly sampling was also conducted on *Solanum asperolatum* on two sites near Crato to determine the seasonality of *T. evansi* and the predators associated with it. Samples were taken separately from dusty and clean plants to evaluate the influence of dust on mite populations. Dusty plants were taken from the side of a dirt road and clean plants from at least 50 m away from the road. The most common phytophagous species both on dusty and clean plants were *T. evansi* and *Brevipalpus* sp. The number of phytoseiids was consistently higher on clean than on dusty plants.

In coastal Pernambuco, monthly sampling was carried out between September 2002 and May 2003 in six different locations. *Tetranychus evansi* was the most abundant phytophagous mite in the samples, followed by *Brevipalpus phoenicis*. *Asca* sp., *Phytoseius guianensis* and *Paraphytoseius orientalis* were the most common predatory mites. Predatory insects of the families Coccinellidae, Cecidomyiidae, Staphylinidae and Thripidae were also found.

The suitability of *Asca* sp., *Paraphytoseius orientalis*, *Phytoseius guianensis*, *Phytoseiulus macropolis*, *Proprioseiopsis cannaensis* and *Neoseiulus ideaus* as predators of *T. evansi* was investigated in the laboratory. Survivorship and oviposition were very low in all species when fed on *T. evansi*.

4. Resistance of tomato accessions to RSM

Resistant varieties are an environmentally friendly, and in general, a cost-effective way of reducing pest damage, rendering them a most desirable tool for resource-poor smallholder agriculture. Resistance is incorporated in the seed and needs little or no extra cost to make it work.

The resistance of more than 400 accessions of cultivated tomato and other species of the genus *Lycopersicon* to *T. evansi* was investigated in a

Table 1. ***Lycopersicon esculentum*** **accessions with low oviposition of** ***Tetranychus evansi*** **in the laboratory**

Accession name	Source	Eggs/mite/day
Chico Grande	AVRDC	0.00
94RT 338	ICIPE	0.00
LO3279	AVRDC	0.03
Allround M.R.	Netherlands	0.07
LO0218	AVRDC	0.09
Marglobe	Kenya (commercial variety)	0.09
LO2852	AVRDC	0.10
LO2800	AVRDC	0.12
CLN2026D	AVRDC	0.13
LO0338	AVRDC	0.14

laboratory-screening programme on leaf discs using mite survival and oviposition as indicators for resistance. Newly emerged female mites were singly put on leaf discs of the tomato accessions and survival and oviposition were followed for 12 days. The leaf discs were kept under controlled conditions in an incubator and changed every 4 days. On eight accessions, the mites laid no eggs during the 12 days. Two of these accessions belong to the cultivated tomato *Lycopersicon esculentum*, the others to *L. hirsutum*, *L. peruvianum* and *L. pennellii*. Oviposition was very low in several other *L. esculentum* accessions (Table 1). Experiments are continuing to confirm the resistance in the greenhouse and field and resistance mechanisms are being investigated.

5. Susceptibility of *T. evansi* to frequently used acaricides

Farmers frequently complain that acaricide treatments to control *T. evansi* are not efficient. To investigate if this is caused by resistance of the pest to the products used or due to other factors, e.g. poor application techniques, the most commonly used acaricides were tested in the laboratory to establish their efficiency in controlling the mites. *Tetranychus evansi* strains were collected from different important tomato growing areas in Zimbabwe to establish local differences in acaricide resistance. This work is currently on-going. In the populations tested so far (Seke, Mutoko and PPRI) amitraz and dicofol achieved the highest mortality, while dimethoate performed poorly in all populations.

6. Use of pathogenic fungi to control *T. evansi*

Nineteen strains of the pathogenic fungi *Beauveria bassiana* and *Metarhizium anisopliae* from the ICIPE Germplasm Centre were tested in the laboratory to determine their pathogenicity to adult *T. evansi*. All fungal strains were pathogenic to the mite. The LT_{50} for the most active *B. bassiana* and *M. anisopliae* strains was 4.6 and 3.9 days, respectively. The LC_{50} for the most active *B. bassiana* strain (GPK) was 1.1 x 10^7 conidia/ml while the LC_{50} for the most active strain of *M. anisopliae* (ICIPE 78) was 0.7 x 10^7 conidia/ml.

The effect of pathogenic fungal infection on developmental stages of *T. evansi* was studied in the laboratory using these strains of *B. bassiana* and *M. anisopliae*. Mortality was low in larvae, protonymphs and deutonymphs at all concentrations tested. Both fungi significantly reduced egg hatchability. *Metarhizium anisopliae* strain ICIPE 78 and *B. bassiana* strain GPK also significantly reduced the fecundity of female *T. evansi* compared to the control treatment.

Semi-field experiments were conducted on potted tomato plants to evaluate the potential of *M. anisopliae* strain ICIPE 78 and *B. bassiana* strain GPK as biocontrol agents. An oil emulsion formulation and simple conidial suspension in water were applied at the concentration that produced the highest mortality in the laboratory. Compared with the controls, both formulations significantly reduced mite populations. However, the oil formulation caused higher mortality compared to the simple conidial suspension. *(See also report of the Arthropod Entomopathology Unit.)*

7. Control of *T. evansi* with botanicals

Three neem-based botanicals available in Kenya (Neemroc, a water-miscible formulation with 0.03% azadirachtin and 32% neem oil; Neem & Corn, a water-miscible formulation with 0.03% azadirachtin and 32% corn oil; and Achook, a neem kernel extract-based formulation with 0.15% azadirachtin) and one non-neem based botanical (GC-Mite, 40% garlic extract and 60% inert ingredients) were tested for their efficiency in the control of *T. evansi*. All formulations caused significant mortality of adult spider mites after 96 h when sprayed directly on leaf discs infested with the mites (Figure 3). The highest mortality was caused by Neem & Corn (90%), followed by Neemroc (54%), GC-mite (54%) and Achook (33%). However, when mites were put on 1-hour-old residues of the botanicals, the mortality after 96 h was lower in all treatments except for Achook (Figure 4). In this experiment Neem & Corn caused the highest mortality (53%), followed by Neemroc (49%), GC-mite (38%) and Achook (34%).

All botanicals had a strong repellent effect on the mites.

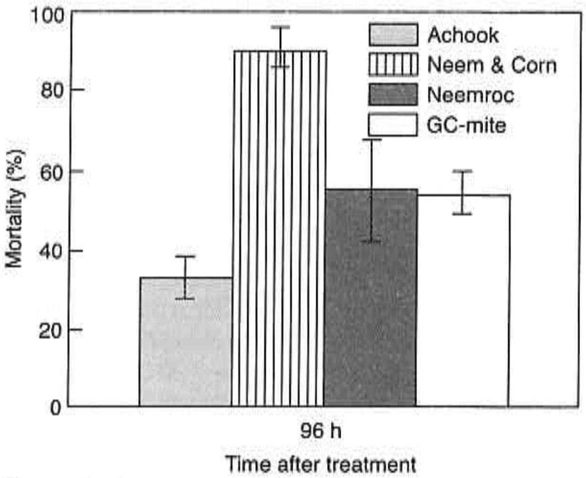


Figure 3. Average mortality of Tetranychus evansi ***96 hours after direct spraying with different botanicals on tomato leaf discs***

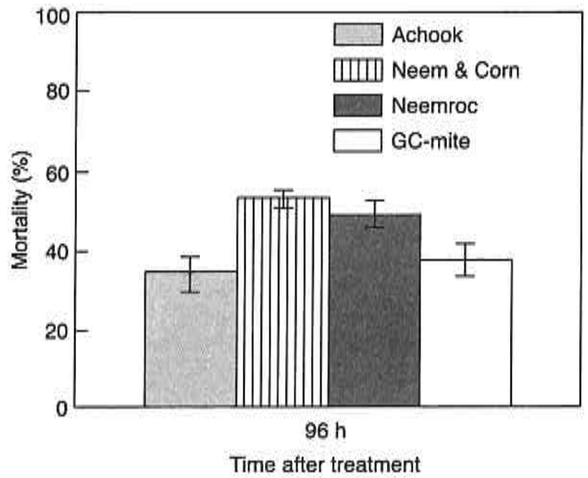


Figure 4. Average mortality of T. evansi 96 hours after contact with 1-hour-old dried residues of different botanicals on tomato leaf discs

Field and greenhouse trials were conducted using six treatments: the four botanicals (Neemroc, Neem & Corn, GC-mite, Achook), a synthetic acaricide (Omite) and water control. The botanicals had a significant effect on spider mite populations and leaf damage of tomatoes compared to untreated plants, however the acaricide Omite controlled *T. evansi* significantly better than the botanicals.

8. Evaluation of synthetic acaricides

The efficacy of the new acaricide spiromefisen (Oberon 240SC) was compared with other acaricides in field and laboratory experiments. In the laboratory, 100% of the *T. evansi* eggs treated with Oberon 240SC did not hatch while there was no significant mortality in the juvenile stages and adults. DC-Tron Plus (mineral oil), achieved 100% mortality on all the motile stages, compared to 0% for the control. Eggs treated with DC-Tron Plus in the laboratory achieved less than 10% hatch compared to 74% in the control. Field experiments included Oberon 240SC, DC-Tron Plus, a mixture of the Oberon 240SC and DC-Tron Plus, a rotation of Oberon 240SC and DC-Tron Plus, Dynamec 1.8EC (abamectin) and a control. There was a significant difference between treatments regarding the damage scores and mite populations. The average mite population went up after the start of the treatments in the control and the DC-Tron Plus treatment. A decrease of the population was noted with Oberon 240SC and Dynamec 1.8EC as well as Oberon/DC-Tron Plus mixture and rotation. The damage score increased in the control and DC-Tron Plus treatments to maximum but remained low in the others. These experiments are being repeated.

FUTURE OUTLOOK

- Introdution of natural enemies for classical biological control is planned for 2005. Breeding of resistant varieties will be started in 2004.

CAPACITY BUILDING

The following postgraduate students participated in the project in 2002–2003:

PhD students

Ivy G. M. Saunyama (Zimbabwe) The bio-ecology and control of red spider mites, *Tetranychus evansi*, Pritchard & Baker (Acari: Tetranychidae) on tomatoes in Zimbabwe. University of Zimbabwe.

Ibrahima Sarr (Senegal) Biology and population dynamics of red spider mites (Acari: Tetranychidae) on tomato in smallscale production systems in Kenya. PhD, Kenyatta University, 2003. Supervisors M. Knapp, J. Baumgärtner, C.P.K.O. Ogol).

Komi Kouma Mokpokpo Fiaboe (Togo) Studies of potential predators of the tomato red spider mite *Tetranychus evansi* (Baker & Pritchard) in Brazil for possible introduction as biocontrol agents in Africa. Kenyatta University.

Imeuda Peixoto Furtado (Brazil) The biology of selected predatory mites (Acari: Phytoseiidae) and their suitability as control agents for *Tetranychus evansi* (Baker & Pritchard). ENSA Montpellier.

MSc students

Debora Mugada Apiyo (Kenya) Resistance of tomato (*Lycopersicon esculentum* Miller) germplasm to the tobacco spider mite (*Tetranychus evansi* Baker and Pritchard). JKUAT, 2002. Supervisors: M. Knapp, Prof. S. G. Agong.

Rowena Judith Kwaramba (Zimbabwe) Resistance status of tobacco spider mite (*Tetranychus evansi*) to currently recommended acaricides on tomatoes and the effects of these acaricides on natural enemies of vegetable pests. MSc, University of Zimbabwe, 2002. Supervisors: M. Knapp, P. Jowah.

Vitalis Wafula Wekesa (Kenya) Evaluation of pathogenic fungi *Beauveria bassiana* and *Metarhizium anisopliae* for the control of tobacco spider mite, *Tetranychus evansi* Baker & Pritchard (Acari: Tetranychidae). JKUAT.

Justin Mabeya Machini (Kenya) Evaluation of a new acaricide ("Oberon") in the control of red spider mites (*Tetranychus evansi*) on tomatoes (*Lycopersicon esculentum*) and its effect on the predator *Phytoseiulus persimilis*. University of Nairobi.

Grace Gladys Kithusi (Kenya) Evaluation of biopesticides in control of red spider mites (*Tetranychus evansi*) on tomatoes (*Lycopersicon esculentum*). University of Nairobi.

Lucy Kananu Murungi (Kenya) Evaluating the activity of leaf-emitted volatile compounds in tomato accessions against the tobacco spider mite *Tetranychus evansi* Baker and Pritchard. JKUAT.

Gladys K. Onyambu (Kenya) Studies of the role of non-volatile phytochemicals in the resistance of tomatoes (*Lycopersicon esculentum* Mill.) to the tobacco spider mite *Tetranychus evansi* Baker and Pritchard. JKUAT.

OUTPUT

Journal articles

***Knapp M.*, and *Kashenge S. S.* (2003)** Effects of different neem formulations on the two spotted spider mite (*Tetranychus urticae* Koch) on tomato (*Lycopersicon esculentum* Mill.) *Insect Science and its Application* 23, 1–7. **(Call No.: 03-1692)**

The effects of four different neem formulations (Neemros®, Neemroc EC®, Neemroc Combi and Saroneem) and a combination of Neemros® with a synthetic acaricide (Mitac®) on the twospotted spider mite (*Tetranychus urticae* Koch) were compared with Mitac® on tomato (*Lycopersicon esculentum* Mill.) leaf discs in the laboratory. The following LC_{50} were determined: Neemroc EC® 12.9 ml/l, Saroneem 5.8 ml/l, Neemroc Combi 1.0 ml/l and Mitac® + Neemros® 1 ml/l + 17.6 g/l. No LC_{50} was determined for Neemros® since the highest mortality observed was 11.4 %. The combination of Mitac® and Neemros® resulted in the highest mortality after 24 hours (83.3%), followed by Neemroc EC® (78.3%), Saroneem (53.4%), Mitac® (50.8%), Neemroc Combi (38.9%), the control (4.5%) and Neemros (0.0%). All neem formulations also caused repellence and oviposition deterrence in *T. urticae*.

***Knapp M.*, *Mugada D. A.*, and Agong S. G. (2003)** Screening tomato (*Lycopersicon esculentum* Mill.) accessions for resistance to the two spotted spider mite *Tetranychus urticae* Koch: Population growth studies. *Insect Science and Its Application* 23, 15–19. **(Call No.: 03-1693)**

The resistance of 63 tomato (*Lycopersicon esculentum* Mill.) accessions to the twospotted spider mite *Tetranychus urticae* Koch (Acari: Tetranychidae), was investigated in screen house experiments and compared to Money Maker, a *T. urticae*-susceptible variety widely grown in Kenya. The number of motile mite stages 12 days after inoculation with 5 adult female mites was significantly lower than in the control variety (Money Maker) in seven accessions (Marglobe, Roma-VF, 94 RT 330, Continental Michel, Early Pearson, ARP 366-4 and 94 RT 316). Egg numbers were significantly lower than in the control in 14 accessions (Marglobe, Cal-J-VF, Roma-VF, Beauty, 95 RT 315, 93 KT 20, EC.3504, 94 RT 313, EC-1193, Continental Michel, Early Pearson, ARP 366-4, 94 RT 316 and Malawi Local 3). This study reveals the existence of resistance to *T. urticae* in the tomato accessions.

***Knapp M.*, *Wagener B.*, Navajas M. (2003)** (Short communication) Molecular discrimination between the spider mite *Tetranychus evansi* Baker & Prichard, an important pest of tomatoes in southern Africa, and the closely related species *T. urticae* Koch (Acarina: Tetranychidae). *African Entomology* 11, 300–304.

***Saunyama I. G. M.* and *Knapp M.* (2003)** Effects of pruning and trellising of tomatoes on red spider mite incidence and crop yield in Zimbabwe. *African Crop Science Journal* 11, 269–277. **(Call No.: 03-1734)**

Red spider mite, *Tetranychus evansi* Baker & Prichard, is a relatively new pest of tomato (*Lycopersicon esculentum*) in Africa, accidentally introduced into southern Africa around 1980. Since then, the species has spread and was recorded for the first time in Kenya in 2001. ICIPE, together with national research institutions of eastern and southern Africa is developing integrated control methods for this new pest. The effects of pruning and trellising on red spider mite incidence, damage and yield of tomatoes were investigated in two important tomato production areas of Zimbabwe (Mutoko and Muzarabani). The practices, considered singly or combined, had no direct effects on initial infestation. Damage levels and population development became apparent in the later crop stages at Mutoko, while at Muzarabani, mite population levels remained low throughout the season, and showed no significant ($P<0.05$) differences between treatments. Unpruned and untrellised plots had an average of 37.7 and 30.2 mites per leaf, respectively, in Mutoko, while in the pruned and trellised plots had 4.6 and 17.3 mites per leaf. In Muzarabani, mite densities were at 4.8 in the pruned and trellised plots, and 4.6 in the control. Chemical control was more effective on the pruned and trellised plots resulting in a yield increase of 60% in both trials at Mutoko, but not at Muzarabani. Pruning and trellising at Mutoko resulted in better mite management, less disease incidence, better disease management, less fruit rots and a reduced damage in fruits. Pruning and trellising resulted in additional profit of US$ 18,780 per hectare at Mutoko.

Reports

Knapp M. Development of environmentally friendly management methods for red spider mites in smallholder tomato production systems in eastern and southern Africa. Final Report (Phase I) submitted to Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), April 2003.

Knapp M. Development of environmentally friendly management methods for red spider mites in small-holder tomato production systems in eastern and southern Africa. Annual Report 2002. Submitted to Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), August 2003.

Conferences papers

XI International Congress of Acarology, Merida, Yucatan, Mexico, 8–13 September 2002. Invited contribution: Important mite crop pests in Africa. Knapp M.

XI International Congress of Acarology, Merida, Yucatan, Mexico, 8–13 September 2002. Paper presented: Impact of predators on *Tetranychus evansi* Baker and Pritchard populations and damage on tomatoes (*Lycopersicon esculentum* Mill.) in Kenya. Sarr I., Knapp M., Ogol C. K. P. O., Baumgärtner J.

International Conference on IPM in Sub-Saharan Africa, Kampala 8–12 September 2002. Paper presented: Impact of predators on *Tetranychus evansi* Baker and Pritchard populations and damage on tomatoes (*Lycopersicon esculentum* Mill.) in Kenya. Sarr I., Knapp M., Ogol C. K. P. O., Baumgärtner J.

International Conference on IPM in Sub-Saharan Africa, Kampala 8–12 September 2002. Paper presented: The effects of pruning and trellising of tomatoes (*Lycopersicon esculentum*) on red spider mite (*Tetranychus evansi*) incidence and crop yield in Zimbabwe. Saunyama I.G.M., Knapp M.

15th Biennial Congress of the African Association of Insect Scientists (AAIS) jointly organised with the Entomological Society of Kenya, 9–13 June 2003, Nairobi, Kenya. Paper presented: Prospects of pathogenic fungi for the control of tobacco spider mite, *Tetranychus evansi*. Wafula V.W., Maniania N. K., Knapp M., Boga H.

15th Biennial Congress of the African Association of Insect Scientists (AAIS) jointly organised with the Entomological Society of Kenya, 9–13 June 2003, Nairobi, Kenya. Paper presented: Comparative efficacy of Oberon (spiromesifen) and other acaricides in the control of red spider mites, *Tetranychus evansi* Baker & Pritchard, in tomatoes. Mabeya J., Knapp M., Nderitu J. H., Olubayo F.

15th Biennial Congress of the African Association of Insect Scientists (AAIS) jointly organised with the Entomological Society of Kenya, 9–13 June 2003, Nairobi, Kenya. Paper presented: *Tetranychus evansi* in Africa: Status, distribution damage and control options. Knapp M., Saunyama I. G. M., Sarr I., de Moraes G. J.

Deutscher Tropentag 2003. International Research on Food Security, Natural Resource Management and Rural Development. Georg-August-Universität Göttingen, Germany, 8–10 October, 2003. Poster and abstract presented: *Tetranychus evansi* in Africa—Status, distribution damage and control options. Knapp M., Saunyama I. G. M., Sarr I., de Moraes G. J.

6th Conference of the African Crop Science Society, Nairobi, Kenya, 12–17 October 2003. Paper presented: Field and laboratory investigations of Oberon 240 SC (spiromesifen) and other acaricides in the control of red spider mites (*Tetranychus evansi* Baker & Pritchard) in tomatoes (*Lycopersicon esculentum*). Mabeya J., Knapp M., Nderitu J. H., Olubayo F.

Kenya Horticultural Seminar, 27–29 November 2003, Maseno University, Maseno, Kenya. Paper presented: Potential of fungi as biocontrol agents of *Tetranychus evansi* (Acari: Tetranychidae). Wafula V., Maniania N. K., Knapp M., Boga H.

IV Simpósio de Pesquisa e Pós-Graduação da Ufrpe, 2003, Recife. Paper presented: Busca de predadores potenciais do ácaro vermelho do tomateiro, *Tetranychus evansi*, para possível introdução como agente de controle biológic na África. Fiaboe K. K. M., Gondim Jr. M. G. C.; de Moraes G. J., Ogol C. Knapp M.

Research proposals

Predator–prey coevolution among plant-inhabiting mites: *Tetranychus evansi* and its predators on solanaceous plants in Brazil. Proposal developed in collaboration with Prof. M.W. Sabelis, University of Amsterdam.

Mechanisms of resistance in tomato (*Lycopersicon esculentum*) and other *Lycopersicon* species to red spider mites (*Tetranychus evansi*).

Participating scientists: M. Knapp, A. Hassanali, N. K. Maniania, J. Baumgärtner

Assisted by: B. Muia, M. Kungu, C. Kyalo, S. Chikomwe (2002), P. Chokutamba (2002)

Donors: German Federal Ministry of Economic Cooperation and Development (BMZ) and Bayer East Africa Ltd.

Collaborators: Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya; Plant Protection Research Institute, Harare, Zimbabwe; Plant Protection Research Institute, Pretoria, South Africa; National Irrigation Research Station, Mazabuka, Zambia (2002); Asian Vegetable Research and Development Centre (AVRDC), Taiwan; Escola Superior de Agricultura "Luiz de Queiroz", University of São Paulo, Brazil; Universidade Federal Rural de Pernambuco, Recife, Brazil; Universidade Rural de Cariri, Crato, Brazil; Ecole Nationale Superieure Agronomiques, Montpellier, France; University of Amsterdam, The Netherlands

PREPARING SMALLHOLDER EXPORT VEGETABLE PRODUCERS OF FRENCH BEANS AND OKRA FOR COMPLIANCE WITH EU REGULATIONS ON MRLS AND HYGIENE STANDARDS

BACKGROUND, APPROACH AND OBJECTIVES

The annual average export value of French beans and okra in Kenya is about KShs 4.1 billion (US$ 53 million) (*Horticultural News Journal*, 2001). As many as 60,000 farming families and up to 2 million Kenyans depend directly or indirectly on export vegetable production for their livelihoods. However, this lucrative export trade is now facing serious challenges:

(a) strict European Union (EU) regulations on pesticide residue limits (MRLs) have become more demanding;
(b) EUREPGAP (European Retailers Programme on Good Agricultural Practices) production standards are likewise strict; and
(c) exporters are shifting production to large units for fear of not being able to have the necessary control over smallholder production to ensure compliance.

ICIPE has developed integrated pest management (IPM) approaches and a manual on IPM for Frenchbean production, described in the previous reporting period. The objectives of the Project over the current reporting period include:

- training master trainers and French beans farmers' groups on IPM and hygiene standards to conform to EU quality requirements;
- developing an MRL-compliant IPM production approach for okra;
- producing a manual and posters on IPM in okra production;
- training master trainers and farmers' groups in okra IPM.

Implementation of this Project, by virtue of the fact it is dealing with export crops, would not be possible without public-private partnerships. Public partners involved in the project include MOARD, HCDA and KARI. Their major contribution is staff time and logistical support, particularly in surveys and providing links to farmers within their areas of jurisdiction. The MOARD and HCDA benefit from the project through capacity building (retraining) of their personnel directly involved in the project. Private partners involved in the project are mainly exporting companies and NGOs. Their contribution is staff time and introducing the project to their outgrowers. Likewise, extension personnel of private institutions and their outgrowers are retrained by the project at no cost. More importantly are the smallholder producers who are the main target beneficiary of this project and who are not outgrowers of exporting companies. They constitute the bulk of export vegetables producers. Most of those involved in farmer groups training belong to this category of private partnership.

Training of trainers (ToTs) in IPM for French beans production

WORK IN PROGRESS

1. Meeting of stakeholders

The first meeting of principal stakeholders was held at ICIPE Headquarters on 30 May 2002. Thirteen institutions were invited to the meeting. They included CARE Kenya; exporting companies (East African Growers Ltd., Kenya Horticultural Exporters Ltd., Sunripe Ltd.); Fresh Produce Exporters Association of Kenya (FPEAK); GTZ/Ministry of Agriculture Promotion of Agricultural Extension Services project; Horticultural Crops Development Authority (HCDA); Kenya Agricultural Research Institute (KARI); Kerio-Green International; Ministry of Agriculture and Rural Development (Horticulture Division); Tegemeo Institute; USAID Kenya Mission; Winrock International; and ICIPE, as implementing agency. The agenda included:

(a) statement of the goal and objectives of the Project;
(b) roles of partner institutions and ICIPE in Project implementation;
(c) timeframe for Project activities.

The deliberations were circulated to the 13 institutions, including the donor agency.

2. Ex-ante assessment of French beans farmers involved in farmer group training

The exercise began in February and ended in May 2003. Highlights of the study were:

- Farmers believe that production of French beans is not possible without routine weekly application of pesticides (this translates to 10 sprays for a crop cycle).
- The two biggest components in production costs are labour (21%) and pesticides (14%).
- Average costs for pesticides, including application, constituted about 8% of crop value.

- Average crop yield per unit holding of 0.3 acres is 0.52 tonnes (0.3 acre is the average land size for French bean production by smallholder growers).
- Average gross margin per season per unit holding of 0.3 acre is Kshs 9228 (US$ 118).
- A fairly high proportion (about 21%) of farmers reported having visited clinics for treatment for maladies related to pesticide usage.
- Hygiene requirements in the production chain were not being met by smallholder farmers.
- Gender ratios (F/M) were fairly favourable. The ratio in the training of trainers (see below) for French beans and okra was 1: 2 while for French beans farmer group training it was almost 1: 1 (176: 171).

3. Survey to collect baseline information on smallholder okra production

The survey was conducted between June 2002 and January 2003. Areas covered in the survey were Kajiado, Kibwezi, Kilifi, Makindu, Matuu, Mbeere, Mitunguu, Mtito wa Ndei, Mwea, Nguruman, Taita Taveta and Yatta. Institutions assisting in the survey were CARE Kenya, East African Growers Ltd., HCDA, KARI, MOARD and Winrock International.

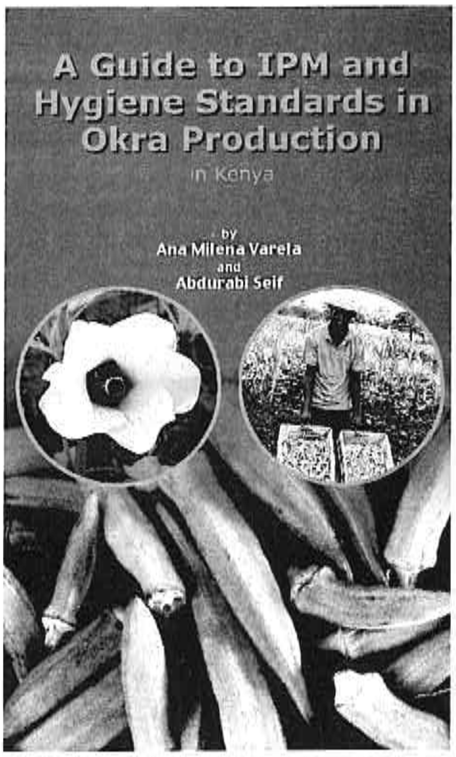
The survey methodology involved assessing 10 random farm units per designated area; 10 random okra beds per farm unit for pests and diseases; and use of a questionnaire (farmer interviews).

Highlights of the survey include the following:

- The area under okra ranges from 0.25 to 0.8 acres. About 27% of farm income is derived from okra. Experience in okra growing varied from 2.6 to 25 years (Rift Valley and Coast, respectively).
- Women manage about 12% of okra farm units.
- All farmers except those at the coast grow okra for export; the most popular variety grown for export is 'Pusa Sawani'.
- All farmers seed okra directly.
- Four out of five (81%) of farmers use certified seed. Of these, 82.9% buy certified seed from 'Agro-Vet' outlets.
- 93.3% of farmers use irrigation in okra production, while 97.5% of farmers use pesticides for management of pests and diseases. Most farmers buy pesticides from 'Agro-Vet' shops.
- About two-thirds (70.8%) of farmers apply pesticides as mixtures.
- All farmers who use pesticides apply routine sprays as prescribed by exporters (risk aversion to ensure blemish-free produce in compliance with export standards). The pre-harvest intervals for various pesticides are prescribed by exporters, in many cases extended to avert risks of non-compliance with maximum pesticide residue limitations.
- Three-fourths (75.1%) of farmers use proprietary fertilisers, while 44.7% use farmyard manure.
- All farmers practise crop rotation. Popular rotation crops include maize, tomatoes, brinjals, chillies and French beans (restricted to French-bean producing areas such as Matuu, Mitunguu and Mwea).
- Major production problems reported by farmers are pests and diseases, poor marketing and particularly erratic price fluctuation, high input costs, low seed purity, doubtful pesticide purity, water shortage and land shortage.
- Losses due to pests and diseases account for two-thirds of the crop (67.5%) according to farmers. The major pests reported are aphids, pod borers, spider mites, flea beetles and bugs. Major diseases reported are powdery mildew and nematodes. A field survey by ICIPE staff showed aphids, flea beetles, pod borers, bugs, powdery mildew and nematodes as the main pests and diseases, which is in accordance with the farmers' perceptions.
- The majority (73.5%) of farmers sort and grade produce in the field.
- Slightly over a third (38%) of farmers keep records.
- About a third (36.4%) of farmers have 'contracts' (not legally binding) with exporters.

4. Development of an okra manual

Based on the results of the surveys, two MSc students were recruited to conduct IPM field-related research on management of aphids and nematodes. Information includes digital photo images derived from the survey. Additional information from major okra producing countries is being assessed from the Internet and from the Project's field research in Kenya and is being used to develop an IPM manual for okra production. The manual will be published and distributed to target beneficiaries and other interested parties in early 2004.



Okra IPM manual (in press)

FUTURE OUTLOOK

The project aims eventually to improve the management of agricultural resources and overall environmental conservation and compliance. As such, the project preaches the 'gospel' of regular scouting; minimum pesticide use (only on a need basis as a last resort based on scouting information); rigorous adherence to pre-harvest interval if pesticide use is a necessity (a prerequisite to compliance with minimum residue limits (MRLs); good hygiene standards in the crop production chain (a prerequisite to food safety); optimising use of farm inputs such as farmyard manure and compost (reduction of external inputs); and proper record keeping (a prerequisite to traceability compliance criteria for export produce). Impact assessment will later focus on these issues and the adoption rate of these practices/technologies by farmers.

CAPACITY BUILDING

Training of trainers (ToTs) in IPM and hygiene standards for production of French beans and okra

A retraining (refresher course) of trainers in hygiene standards was conducted in June 2002 at ICIPE. Three IPM trainers who were earlier trained by GTZ-ICIPE IPM Project for Horticultural Crops participated in the course on hygiene standards in the production chain as stipulated by European Union (EU) regulations. One participant was from HCDA and two from the Ministry of Agriculture and Rural Development (MOARD).

A second training of trainers (ToTs) in IPM and hygiene food safety standards for French beans production was done through two one-week courses in August 2002. The training had two components: communication skills/group dynamics/group management, and season-long hands-on field training on IPM. Twelve persons from partner institutions participated.

Major themes covered in the IPM training were agroecological system analysis; scouting; identification of pests and diseases; identification of beneficial insects (parasitoids/predators/pollinators); pesticide selection, application and handling; pre-harvest intervals and maximum pesticide residue levels (MRLs); hygiene standards (food safety); and record keeping (traceability). The training also incorporated group dynamics and communications skills.

In the case of okra production, course for training of trainers in IPM and hygiene standards was structured similar to that for French beans IPM training above. The duration of the training was drastically reduced from 11 weeks (i.e. season-long/crop cycle) to eight days (a crash course) in October and November 2003. All crop stages—from seedlings to post-harvest stage—were covered by selecting farm(s) having their okra crops staggered for continuous production, a normal practice of smallholder producers to ensure a consistent supply to exporters throughout the year. Ten institutions participated: East African Growers Ltd; FPEAK; HCDA; Kenya Horticultural Exporters Ltd.; Makindu Growers Ltd.; MOARD; Reach the Children (NGO); Sunripe Ltd; VegPro Ltd. and Woni Veg-Fru Exporters Ltd.

Training of farmers' groups in IPM and hygiene standards for French beans and okra production

Training of farmers' groups in IPM and hygiene standards for French beans production was held between March and July 2003 for 15 farmers' groups. Ten trainers out of the 15 graduates from ToT courses (see above) were involved in the group training of almost 350 farmers. The groups were drawn from Kathiani, Kerio Valley, Kirinyaga, Kiserian, Kitale, Maragua, Meru, Mitunguu, Mwea, Nyeri and Subukia in Kenya.

(See also the report of the Technology Transfer Unit.)

MSc students

Allan Mueke (Kenya) Management of root-knot nematodes in okra using nematode suppressive plants and organic soil amendments. University of Nairobi.

Francisca Malenge (Kenya) Bio-rationale management of aphids in okra. University of Nairobi.

Participating scientists: A. A. Seif, A. M. Varela, B. Nyambo, B. Löhr, R. Nyagah

Collaborators: Winrock International; CARE Kenya; Kerio-Green Tradewinds, Kenya; Kenya Ministry of Agriculture and Rural Development (MOARD); Horticultural Crops Development Authority (HCDA); Kenya Agricultural Research Institute (KARI); Kenya Institute of Organic Farming; and exporters (East African Growers, Kenya Horticultural Exporters, SunRipe).

Donors: USAID Regional Economic Development Services Office for East and Southern Africa (REDSO/ESA), USAID Kenya Mission

THE AFRICAN FRUIT FLY PROGRAMME

BACKGROUND, APPROACH AND OBJECTIVES

Fruits are of unquestionable importance for the nutritional security of local populations in Africa. However, fruit growing on the continent is fragmented, underdeveloped and of low productivity. Yet, export of horticultural produce is the most dynamically developing sector in East Africa, and is the second (after tourism) income earner for Kenya. Among tropical fruits, mango and citrus have the greatest market potential (both local and export). For instance, mango constitutes an attractive income source for smallholder farmers, who produce 80% of mango in Africa. However, a complex of indigenous fruit flies, and the recent introduction of a new fruit fly pest to East Africa, can ruin production and export of mango.

Vast pest reservoirs such as indigenous forests with fruiting trees and shrubs, abandoned fruit trees, and others are commonly present in most fruit production areas. Under such circumstances, fruit fly eradication methods cannot be considered as a viable option. The alternative solution is management of the pests through application of a generic IPM package, effective against the whole complex of fruit flies.

Development of such a package, using mango as a model crop, is a primary objective of this second phase of the African Fruit Fly Initiative (AFFI). Application of localised food-based baiting stations for control of adult fruit flies, combined with soil inoculation with fungal pathogens for control of immature stages (larvae and puparia), are being developed locally as primary tools of the IPM toolbox. These can then be complemented by various supportive measures, such as orchard sanitation, conservation of natural enemies, and others.

Other objectives include the training of young African scientists at academic level and capacity building by creating National Fruit Fly Teams through training of a cadre of experts/trainers in each of the participating African countries.

WORK IN PROGRESS

1. Detection of a new invasive fruit fly pest in East Africa

During the period 25th February–3rd March 2003, three fruit fly specimens resembling the oriental fruit fly, *Bactrocera dorsalis*, were collected at the Kenyan coast by scientists from ICIPE's African Fruit Fly Initiative (AFFI). The Kenyan authorities (KEPHIS) and the local FAO Office were immediately notified about the finding. Intensive surveys covering a transect of over 2300 km revealed that the insect is already widely spread within Kenya. Its presence was confirmed over a wide area (Figure 1). The species infests mangoes, and hence is regarded as a pest. It

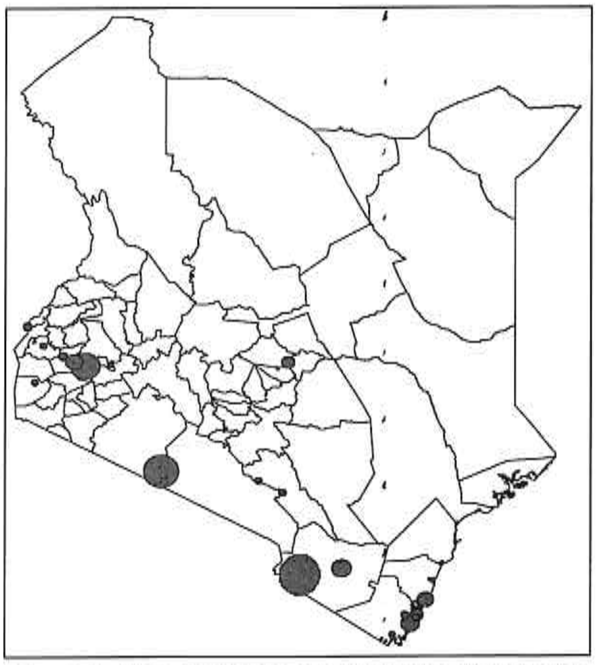


Figure 1. Map of Kenya showing the distribution pattern of the new invasive fruit fly species

Size of dots shows relative pest densities expressed as 'average daily trap catches'

is also capable of reproducing in wild fruits available in the coastal forests, therefore providing a sufficient reproductive base even during the low fruit season.

Over 1000 specimens were collected and sent to two independent taxonomic experts in UK and Australia for identification. Final confirmation of the pest's identity was difficult, because the pest population detected in Kenya is unusually variable, with some specimens resembling *B. dorsalis*, others *B. carambolae*, and yet others *B. kandiensis*. A population with similar features and high degree of variability was recently discovered in Sri Lanka, which is now considered to be the aboriginal home of this species. The pest is now being described as a new species.

As the pest responds well to methyl eugenol (ME), an extremely powerful lure, its containment and eradication through the male annihilation technique (MAT) might have been technically possible at the early stage of invasion. However, its broad distribution in the region, as confirmed at the end of 2003, makes eradication economically questionable and technically unfeasible. If left uncontrolled and not contained, apart from causing damage where already present, the new pest may ultimately spread beyond East Africa to most of the continent. In countries where horticulture is highly developed, such as South Africa, potential losses could be enormous.

A colony of the new species has been established at ICIPE and the biology of the pest is under investigation. At the end of 2003, an FAO Technical Coordinated Programme (TCP) grant was approved to undertake intensive surveys on a regional scale and to define response actions. This project is expected to start in mid-2004.

Participating scientists: S. A. Lux, R. Copeland, A. Manrakhan, M. Billah

Assisted by: P. Nderitu

Donors: IFAD

Collaborators: KEPHIS, Nairobi, Kenya; Agricultural Research Institute, Mikocheni, Dar es Salaam, Tanzania; Plant Protection Division, Ministry of Agriculture, Zanzibar, Tanzania; Kawanda Agricultural Research Institute, Kampala, Uganda

2. Research on fruit fly feeding behaviour

This study on feeding behaviour was undertaken to provide a rational basis for implementation of food baits in the management of three target fruit fly pests, *Ceratitis cosyra*, *C. fasciventris* and *C. capitata*.

Feeding activities of all three species were found to be confined mostly to host trees, occurring mainly on the upper leaf surfaces which usually contain honeydew, birds' droppings and accumulated dust. Feeding was also recorded on fruits. Flies exhibited distinct diurnal patterns of feeding, which varied according to species and sex.

The lifetime consumption patterns of various dietary components (carbohydrates and proteins) also varied among the three species. Intake of sugar for all adult flies was highest soon after emergence. Total sugar intake throughout their lifetime was also found to be similar for males and females of all three fly species (Table 1). However, in the case of proteins, the species differed both in regard to their consumption patterns, as well as in their lifetime requirements. The peak of protein intake for males and females of *C. cosyra* occurred in the third week of adult life, while for *C. fasciventris* and *C. capitata*, it occurred in the first week for both males and females. Males and females of *C. cosyra* were found to consume less protein in total than males and females of *C. fasciventris* and *C. capitata*. Sex differences in protein consumption differed among species: females of *C. cosyra* consumed less protein than males in contrast to females of *C. fasciventris* and *C. capitata* which consumed more protein than males.

Responses to the odours emitted by various food sources were species- and sex-specific. Although adult physiological states (reproductive maturity) were found to affect fly responses, the nutritional state of a fly (specific hungers caused by protein or carbohydrate deprivation) was the most influential factor in guiding their responsiveness to food odours. Mating status was the least important factor in influencing fly responses to food sources. Although odours from various food baits competed well with those of the natural food sources, the latter were found to be more attractive for all fly species. These results indicate that in orchards where natural food sources (birds droppings, honeydew, etc.) are easily available, the effectiveness of management methods based on food baits could be compromised.

Participating scientists: A. Manrakhan, S. A. Lux

Assisted by: P. A. Oreng

Donor: IFAD, DSO

3. Fruit fly reproductive behaviour and the role of host plants

Studies on the behaviour of *Ceratitis cosyra*, *C. fasciventris* and *C. capitata* focused on sexual behaviour and effect of various stimuli relative to host plants. Diurnal, temporal and spatial distributions of basic behavioural activities throughout the lifetime of the target fruit flies were also quantified. The objective of this study was to create a rational basis for possible application of parapheromones in monitoring of these flies, and provide hints for future development of fruit-mimicking devices for fruit fly management.

The periodicity of activities varied with time of day, fly age and sex. Calling and mating in *C. cosyra* and *C. fasciventris* occurred at 1700–1900 hrs. In contrast, *C. capitata* was sexually active for much of the daylight morning hours to early afternoon. Calling and mating occurred on lower leaf surfaces and mainly on host plants. In the three fruit fly species, male pheromone calling and intermittent wing fanning was essential for female attraction during courtship. The onset of

Table 1. Sugar and protein consumption: Comparison between males and females of *Ceratitis cosyra*, *C. fasciventris* and *C. capitata*

		Average consumption (mg/fly) over 20 days		
Food type	Sex	*C. cosyra*	*C. fasciventris*	*C. capitata*
Sucrose	Male	16.00[1] (a)[2]	19.04 a (a)	17.88 a (a)
	Female	16.92 a (a)	18.56 a (a)	16.78 a (a)
Protein (yeast hydrolysate	Male	0.80 c (a)	2.67 a (b)	1.55 b (b)
	Female	0.29 b (b)	3.64 a (a)	3.32 a (a)

[1]Within rows, means followed by the same letter are not significantly different at the 0.05 level (Tukey's HSD test following Proc Rank for the sex food category.

[2]Means followed by the same letter in parentheses between rows for each food type are not significantly different at the 0.05 level (Kruskal-Wallis test).

sexual activities in all species occurred 5–10 days after emergence. Following sexual maturation, calling activity lasted throughout the lifetime (> 50 days) in all species, but after a peak during the second week, mating was sporadic with complete absence on many days.

Fruit fly response to the stimuli (odours, colours and shape) from the host plant canopy and fruits was largely determined by age, sex, mating status and time of day. The highest response to the odours emanating from mango leaves (canopy) was observed in all species in 1-day-old females and males, as well as in mated females (8–10 days and 13–15 days-old). Response to host plants was greater in females than males in all species and both sexes responded more to host plants in the afternoon than in the morning hours, except in sexually mature males of *C. fasciventris*, in which the reverse was true. All species tested were more attracted to fruits than leaves, irrespective of sex, age and mating status.

Colour preference tests showed that yellow spheres (7-cm diam.) were most attractive to the three fruit fly species compared to other colours. Both males and females of all species responded to similar visual stimuli, but all spheres captured more females than males. Yellow spheres of 28 cm diameter caught more flies than the commercial McPhail trap in all species. The attraction of yellow 7-cm-diameter spheres to the flies was enhanced when they were baited with ripe or mature guava fruit puree.

Participating scientists: P. Nemeye, S. A. Lux

Assisted by: P. Nderitu

Donors: IFAD, DSO

4. Evaluation of synthetic food lures for medfly

Medfly (*Ceratitis capitata*) detection and population monitoring relies largely on the use of trimedlure for males and hydrolysed protein for females. The latter, although effective and reliable, has a limited lifespan in the field and, being formulated in a liquid form, makes trap and specimen handling labour-intensive. Recently, much effort has been devoted to the development of a potent, durable, more selective attractant formulated in a dry form, which would be based on synthetic components and easy to standardise. These efforts led to discovery of synergistically acting putrescine (P), ammonium acetate (A) and trimethylamine (T).

Various combinations of components of this food-based attractant are being evaluated globally under the FAO-IAEA Coordinated Research Program. Results of trials conducted in Kenya on coffee plantations showed that attractiveness of bi-component combinations (TA and PA) did not differ from that of the tri-component (PTA) (Table 2). The same results were obtained in screenhouse evaluations, where responses of five fruit fly species (*C. cosyra, C. rosa, C. fasciventris, C. anonae* and *C. capitata*) were evaluated. The mean proportion of females caught in the various combinations ranged from 50–81%, while in the case of Nulure, it ranged from 63–88%. All treatments attracted a number of non-target insects, with dipterans and ants predominating.

Participating scientists: S. A. Lux, S. Ekesi, M. K. Billah, A. Manrakhan

Assisted by: P. Nderitu, J. Kiilu, P. A. Oreng, M. Wanyonyi

Donor: IAEA

5. Development of food baits

Within the IPM package being developed by AFFI, localised bait applications, such as bait stations, was adopted as a primary tactic for management of the complex of mango-infesting fruit flies. The food baits (described above) based on controlled release of synthetic components, albeit effective, are rather expensive. Hence, development of a bait which can be produced from locally available materials was chosen as a priority objective. The aim is to develop an effective, locally produced, inexpensive bait, which can be formulated into a dry baiting station, and which will be effective in the field for a minimum period of 8 weeks. (The concept of application of baiting stations was evaluated during the first phase of AFFI in 2000–2001 in smallholder mango orchards, and

Table 2. Response of fruit flies to various combinations of ammonium acetate (A), trimethylamine (T) and putrescine (P) in coffee fields in Ruiru, Kenya

	Ceratitis capitata			*Ceratitis fasciventris*		
Treatments	Females	Males	% of females	Females	Males	% of females
Nulure	18.3	7.2	72	5.1	2.9	64
A + H_2O + Triton	39.9	22.9	64	8.6	4.8	64
TA + H_2O + Triton	28.3	20.5	58	7.2	4.2	63
PA + H_2O + Triton	24.6	11.2	69	4.0	2.2	65
PTA + H_2O + Triton	33.6	16.6	67	7.4	4.0	65
PTA + Sticky insert	41.6	21.1	66	7.8	6.2	56

was found viable, since a 70% reduction in fruit fly population was achieved in small [50 x 50 m] non-isolated plots.)

Various bait compositions and formulations were prepared and evaluated according to a standard protocol, by determining (i) the attraction and feeding responses of all the target fruit fly species, (ii) persistence of the bait under field conditions, and (iii) effects of storage (shelf life). All the materials used for the baits are readily available locally. The attraction and feeding responses to candidate food baits were found to be sex- and species-specific. Among the six species, the *Bactrocera* sp. displayed the strongest responses to odours from the baits. Both males and females of *Bactrocera*, *C. cosyra* and *C. rosa* as well as females of *C. capitata* were highly attracted to odours emanating from several of the candidate baits. Feeding responses of the flies followed similar patterns to responses to the bait odours. Preliminary evaluations indicate that the dry-formulated baits might be persistent in the field for at least 6–8 weeks, but storage of bait material in wet form is likely to adversely affect its attractiveness. Work is continuing on improving bait composition and formulation, in order to meet the pre-set target specifications described above.

Participating scientists: S. A. Lux, A. Manrakhan, S. Ekesi

Assisted by: P. Nderitu

Donor: IFAD

6. Fruit fly pathogens

Use of pathogens is an important component of the fruit fly IPM package being developed by AFFI. Two tactics for their application are being evaluated: (i) soil inoculation with entomopathogenic fungi to create a hostile environment for pupariating larvae and puparia, and (ii) application of fungi in localised baiting stations as a killing agent for the attracted adult flies as an alternative to pesticides.

Fifteen isolates of *Metarhizium anisopliae* and *Beauveria bassiana*, obtained from the ICIPE microbial Germplasm Centre, were screened and all were found to be pathogenic to the target fruit flies (*C. cosyra*, *C. rosa*, *C. fasciventris*, *C. anonae* and *C. capitata*), although pathogenicity varied among isolates. The isolates reduced adult emergence from treated soil by 6 to 68%. Efficacy of the four most virulent isolates is presented in Figure 2.

Exposure of the adult flies to dry conidia of *M. anisopliae* and *B. bassiana* resulted in mortality ranging from 9 to 100% within 5 days post-inoculation. Among the various isolates, isolate *M. anisopliae* ICIPE 20 was found to be effective over a broad range of temperatures (15, 20, 25 and 30 °C) and soil moisture levels (-0.1, -0.001, -0.0055 and -0.0035 mega Pascal, MPa) and was selected for further evaluation under field conditions. Soil inoculation of different formulations of the isolates was observed to significantly reduce adult emergence even 6 months after application, indicating a high persistence of the inocula in the soil. The granular dry formulation of the conidia of ICIPE 20, apart from being easier to apply, was also found more efficacious than the aqueous or oil/aqueous formulations. *(See also the report of the Arthropod Pathology Unit.)*

Participating scientists: S. Ekesi, S. Dimbi, N. K. Maniania, S. A. Lux

Assisted by: R. Rotich

Donor: IFAD

7. Biosystematic studies of fruit fly parasitoids (*Psyttalia* species) in Africa

Biosystematic studies of *Psyttalia* species and populations (Hymenoptera: Braconidae), parasitoids of fruit-infesting tephritids in Africa, were conducted to resolve their taxonomy and develop species-specific diagnostic characters to facilitate their reliable use as biological control agents. Morphological comparison showed that ratios of ovipositor/tibia (OTR) and ovipositor sheath/tibia (STR) could differentiate *Psyttalia cosyrae* and *P. phaeostigma* from the other species/populations. Parasitoids reared on host larvae other than their natural hosts showed significant changes in linear measurements as well as body colour. Morphometric studies on representative populations produced three clear clusters.

Cross-mating studies between morphologically distinct and morphologically similar species produced

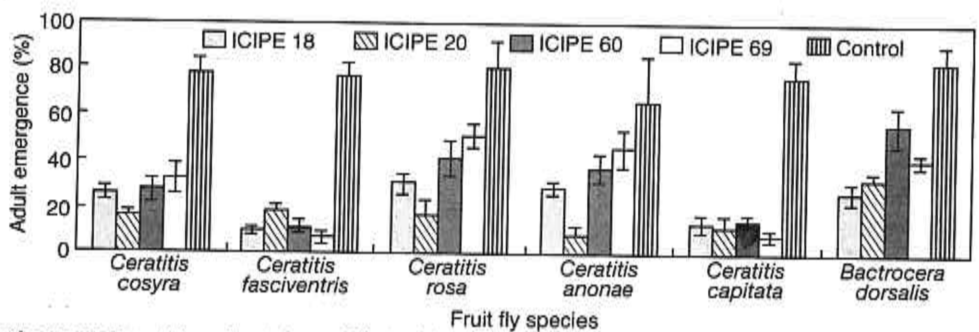


Figure 2. Pathogenicity of four isolates of Metarhizium anisopliae to different fruit fly species

viable female offspring in all crosses up to F_2, indicating the absence of post-copulatory isolating mechanisms, and suggesting the inadequacy of the biological species concept (BSC) alone in separating species in this genus.

Total genome comparison by AFLP showed the presence of bands across common loci, which also matched the groupings defined by morphometric analyses. The population from Shimba Hills in Kenya was similar to *P. perproximus* and that from Tafo, Ghana in the morphological and DNA studies, and they were clustered together by morphometric analysis. It is suggested that the populations from Shimba Hills and Tafo belong to *P. perproximus*, and the Shimba Hills population is a new record of *P. perproximus* occurrence in Kenya.

Participating scientists: M. K. Billah, S. W. Kimani-Njogu, W. A. Overholt

Assisted by: M. Wandago

Collaborators: Texas A&M University (USA); USDA-ARS European Biocontrol Laboratory (France); University of Hawaii (USA)

Donors: DSO, IFS

CAPACITY BUILDING

PhD students

Susan Dimbi (Zimbabwe) Evaluation of the potential of Hyphomycetes fungi for the management of the African tephritid fruit flies *Ceratitis capitata* (Weidemann), *C. cosyra* (Walker) and *C. fasciventris* (Bezzi) in Kenya. PhD, Kenyatta University, Nairobi, Kenya (2003). Supervisors: S. A. Lux (ICIPE), J. M. Mueke (Kenyatta University) Currently working in the national agriculture research system in her home country.

Samira A. Mohamed (Sudan) Biology, host and host plant relationships of two *Psyttalia* species (Hymenopetra: Braconidae): Parasitoids of fruit flies (Diptera: Tephritidae) in Kenya. PhD, University of Gezira, Sudan (2003). Supervisors: W. A. Overholt and S. A. Lux (ICIPE), E. M. Eltoum (University of Gezira). Dr Mohamed was absorbed by the national agriculture research system in her home country.

Frederick N. Baliraine (Uganda) Development of molecular markers for species diagnosis and analysis of genetic diversity in African fruit fly populations. PhD, University of Nairobi, Nairobi, Kenya (2003). Supervisors: E. O. Osir and S. A. Lux (ICIPE), Anna Malacrida (Pavia University, Italy). Dr Baliraine was absorbed by the national agriculture research system in his home country.

Pontiano S. Nemeye (Uganda) Behavioural ecology of three African fruit fly species, *Ceratitis cosyra*, *C. fasciventris* and *C. capitata*, with emphasis on their sexual behaviour and host-plant relationships. Mr Nemeye was absorbed by the NARS in his home country, and recruited as a national consultant for FAO/TCP project on invasive *Bactrocera* fruit fly in Uganda.

Aruna Manrakhan (Mauritius) Feeding behaviour of three African fruit flies: *Ceratitis cosyra*, *C. fasciventris* and *C. capitata* (Diptera: Tephritidae). University of Mauritius. Miss Manrakhan was absorbed by the NARS in her home country.

Maxwell K. Billah (Ghana). Biosystematic studies of *Psyttalia* species (Hymenoptera: Braconidae) parasitoids attacking fruit-infesting flies (Diptera: Tephritidae) in Africa. University of Ghana, Accra. Mr Billah continues his training with AFFI, while at the same time providing taxonomic services to the Programme.

Courses and workshops organised

AFFI-RELMA training workshop on management of mango infesting fruit flies. ICIPE, Nairobi, Kenya. 7–11 October, 2002.

AFFI-RELMA regional workshop on tree health and fruit fly control. ICIPE, Nairobi, Kenya. 17–21 November, 2003.

IMPACT

Award: First runner-up for the first poster competition for ICIPE Governing Council (S. Mohamed).

OUTPUT

Journal articles

Baliraine F. N., Bonizzoni M., *Osir E. O., Lux S. A.,* **Mulaa F. J., Zheng L., Gomulski L. M., Gasperi G. and Malacrida A. R. (2003)** Comparative analysis of microsatellite loci in four fruit fly species of the genus *Ceratitis* (Diptera: Tephritidae). *Bulletin of Entomological Research* 93, 1–10. **(Call No.: 03-1636)**

The possibility to cross-species amplify microsatellites in fruit flies of the genus *Ceratitis* was tested with the polymerase chain reaction (PCR) by analysing 23 *Ceratitis capitata* (Wiedenmann) microsatellite markers on the genomic DNA of three other economically important, cogeneric species: *C. rosa* (Karsch), *C. fasciventris* (Bezzi) and *C. cosyra* (Walker). Twenty-two primer pairs produced amplification products in at least three species tested. The majority of the products were similar, if not identical in size to those expected in *C. capitata*. The structures of the repeat motifs and their flanking sequences were examined for a total of 79 alleles from the three species. Sequences analysis revealed the same repeat type as the homologous *C. capitata* microsatellites in the majority of the loci, suggesting their utility for population analysis across the species range. A total of seven loci were differentially present/absent in *C. capitata*, *C. rosa*, *C. fasciventris* and *C. cosyra*, suggesting that it may be possible to differentiate these four species using a simple sequence repeat-based PCR assay. It is proposed that medfly-based microsatellite markers could be utilised in the identification and tracing of the geographical origins of colonist pest populations of the four tested species and in the assessment of their risk and invasive potentials; thereby assisting regulatory authorities in implementing quarantine restrictions and other control measures.

Copeland R. S., **Wharton R. A., Luke Q. and De Meyer M. (2002)** Indigenous hosts of *Ceratitis capitata* (Diptera: Tephritidae) in Kenya. *Annals of the Entomological Society of America* 95, 672–694. **(Call No.: 02-1691)**

To study the relationship of Mediterranean fruit fly or medfly, *Ceratitis capitata* (Wiedemann), to native plant hosts in an area within its original home range, fruits were sampled in diverse areas of Kenya from 1999 to 2001. Sampling effort was concentrated in and around forested areas in coastal, central highland, and western highland habitats. Medflies were reared from fruits of 55 species of plants, 51 of them indigenous; 46 of these species represent previously unknown hosts in Africa. Fruits infested by *C. capitata* were collected in all study sites, east and west of the Gregory Rift Valley, in xeric habitats between the coast and the central highlands, and at altitudes from sea level to 2164 m above sea level. The conditions for year-round breeding of medfly in indigenous fruits are present at the coast, and possibly in highland areas as well. Infestation indices were comparable to those reported elsewhere from cultivated fruits. Although polyphagous in its home range, *C. capitata* was not distributed uniformly among species within two important host-plant families, Sapotaceae and Rubiaceae.

Dimbi S., Maniania N. K., Lux S. A., Ekesi S. **and Mueke J. M. (2003)** Pathogenicity of *Metarhizium anisopliae* (Metsch.) Sorokin and *Beauveria bassiana* (Balsamo) Vuillemin, to three adult fruit flies species: *Ceratitis capitata* (Wiedemann), *C. rosa* (Walker) var. *fasciventris* Karsch and *C. cosyra* (Walker) (Diptera: Tephritidae). *Mycopathologia* 156, 375–382. **(Call No.: 03-1712)**

The pathogenicity of two isolates of *Beauveria bassiana* and 12 of *Metarhizium anisopliae* towards adult fruit flies, *Ceratitis capitata* and *Ceratitis rosa* var. *fasciventris* was tested in the laboratory. Fruit flies were exposed to dry conidia evenly spread on velvet material covering the inner side of a cylindrical plastic tube. All isolates tested were pathogenic to both species of fruit flies. Mortality ranged from 7 to 100% in *C. capitata* and from 11.4 to 100% in *C. rosa* var. *fasciventris* at 4 days post-inoculation. Six isolates, *M. anisopliae* ICIPE 18, 20, 32, 40, 41 and 62, were highly pathogenic to both *C. capitata* and *C. rosa* var. *fasciventris*. The LT_{90} values of the most pathogenic isolates ranged between 3–4 days in both insects. Because of the difficulties in rearing *C. cosyra*, only the isolates that were highly pathogenic to both *C. rosa* var. *fasciventris* and *C. capitata* were tested against adult *C. cosyra*. They caused mortality of between 72–78% at 4 days post-inoculation. The LT_{90} values in all the isolates did not exceed 4 days. One of the most pathogenic isolates, *M. anisopliae* ICIPE 20, was evaluated against *C. capitata* and *C. rosa* var. *fasciventris* in cage experiments using three autoinoculators (maize cob, cheesecloth and Petri dish) in an autoinoculative device consisting of plastic mineral bottle. Mortality of between 70–93% was observed in flies of both species that were captured from the cages and held under laboratory conditions. These results indicate the possibility of fruit fly suppression with entomopathogenic fungi using an autoinoculative device.

Dimbi S., Maniania N. K., Lux S. A. **and Mueke J. M. (2003)** Host species, age and sex as factors affecting the susceptibility of the African tephritid fruit fly species, *Ceratitis capitata*, *C. cosyra* and *C. fasciventris* to infection by *Metarhizium anisopliae*. *Journal of Pest Science* 76, 1–5.

Ekesi S., Maniania N. K. **and** ***Lux S. A.*** **(2002)** Mortality in three African tephritid fruit fly puparia and adults caused by the entomopathogenic fungi, *Metarhizium anisopliae* and *Beauveria bassiana*. *Biocontrol Science and Technology* 12, 7–17. **(Call No.: 02-1628)**

The pathogenicity of 13 isolates of *Metarhizium anisopliae* and two isolates of *Beauveria bassiana* to *Ceratitis capitata* and *Ceratitis* var. *rosa fasciventris* exposed as late third instar larvae in sand was evaluated in the laboratory. All isolates caused a significant reduction in adult emergence and corresponding large mortality on puparia of both species. All isolates also induced large deferred mortality in emerging adults following treatment as late third instar larvae. On *C. capitata*, seven isolates (*M. anisopliae* ICIPE 18, 20, 32, 60 and 69 and *B. bassiana* ICIPE 44 and 82) caused significantly higher mortality on puparia than other isolates. With the exception of ICIPE 32, the other four isolates of *M. anisopliae* above were the most pathogenic against *C. r. fasciventris*. Dose-response study carried out with these isolates of *M. anisopliae* on the two species of flies above plus another species, *Ceratitis cosyra* showed that the dose-mortality regression lines of ICIPE 18 and 20 were steeper with lower LC_{50} values when compared with ICIPE 60 and 69 on the three species. When these two isolates were evaluated with regard to their pathogenicity to different pupal age, adult emergence was found to increase with increasing pupal age with a corresponding decrease in mortality in puparia and emerging adults in the three species of fruit flies. *M. anisopliae* ICIPE 18 and 20 were equally pathogenic to all pupal ages tested in *C. capitata* and *C. cosyra* but ICIPE 18 was more pathogenic to older puparia of *C. r. fasciventris* than ICIPE 20. Our results suggest that soil inoculation with *M. anisopliae* under mango trees might form an important component of integrated pest management strategies in areas where these three species of fruit fly coexist.

Ekesi S., Maniania N. K. **and** ***Lux S. A.*** **(2003)** Effect of soil temperature and moisture on survival and infectivity of *Metarhizium anisopliae* to four tephritid fruit fly puparia. *Journal of Invertebrate Pathology* 83, 157–167. **(Call No.: 03-1700)**

The infectivity of 4 isolates of *Metarhizium anisopliae* to puparia of *Ceratitis capitata* treated as late third-instar larvae in unsterilized soil was investigated in the laboratory under controlled temperature and moisture. At 20–30 °C, mortality in puparia was highest at water potential of –0.1 and –0.01 mega Pascal (MPa) and lowest at water potential of –0.0055 and –0.0035 MPa in all the isolates. In wetter soil however, isolates ICIPE 20 and 60 caused significantly higher mortality than ICIPE 18 and 69. The survival of conidia in drier soil (–0.1 MPa) was not adversely affected at all temperatures. However, in wet soil (–0.0035 MPa) there was drastic reduction in colony counts in ICIPE 18 and 69 at 25 and 30 °C but conidial density in ICIPE 20 and 60 remained at the initial level at 14 days after inoculation at all temperatures. When ICIPE 20 was evaluated against three other fruit fly species (*Ceratitis cosyra*, *Ceratitis rosa*, and

Ceratitis fasciventris), significant reduction in adult emergence and higher pupal mortality occurred in *C. cosyra* and *C. fasciventris* than in *C. rosa* at a combination of 15 and 20 °C and –0.1 and –0.0035 MPa. However, at higher temperature and the same moisture level, the isolates were equally pathogenic across the 3 species. It is probable that in addition to pathogen cycling and multiplication from dead infected insects in the soil, a balance between microbial degradation and replenishment of inoculum of virulent isolates occur through fluctuations in, and intricate interactions between temperature and moisture levels. This study is indicative of the potential of using isolate ICIPE 20 for soil inoculation against pupariating third-instar larvae of fruit flies, thus providing a novel alternative to chemical soil application.

Lux S. A., **Vilardi J. C., Liedo P., Gaggl K., Calcagno G. E.,** *Munyiri F. N.*, **Vera M. T. and Manso F. (2002)** Effects of irradiation on the courtship behavior of medfly (Diptera: Tephritidae) mass reared for the sterile insect technique. *Florida Entomologist*, 85, 102–112. **(Call No.: 02-1731)**

The effects of routine irradiation of the mass-reared males of the medfly, *Ceratitis capitata* on their mating performance were re-evaluated. Male courtship behavior was observed and quantified both in laboratory (video recording cages) and field cage conditions. For the experiments, samples of the strains routinely mass-reared for SIT operations at Seibersdorf, Austria; Mendoza, Argentina and Metapa, Mexico, were used. No major qualitative differences were found in the courtship pattern between irradiated and non-irradiated males. However, the results revealed that the process of routine irradiation as commonly used in the mass rearing facilities at the time of the experiments, reduces the mating performance of the sterilized males nearly two-fold. A whole range of quantitative differences between the irradiated and non-irradiated males were detected and described, and their implications for the efficiency of SIT operations are discussed. In contrast, partial sterilization with low doses of radiation did not affect the mating competitiveness of the treated males to a noticeable degree. In view of the results obtained, and due to the current wider use of 'male-only' strains in SIT operations, a re-evaluation of the sterilisation strategy and irradiation doses for males used in SIT is recommended.

Lux S. A., Munyiri F. N., **Vilardi J. C., Liedo P., Economopoulos A., Hasson O., Quilici S., Gaggl K., Cayol J.-P. and Rendon P. (2002)** Consistency in courtship pattern among populations of medfly (Diptera: Tephritidae): Comparisons among wild strains and strains mass reared for SIT operaions. *Florida Entomologist* 85, 113–125. **(Call No.: 02-1739)**

The objective of the study was to compare courtship behavior of various wild and mass reared medfly strains, in order to document the degree of diversity in courtship behavior among medfly populations and to assess its implications for strategy of application of the Sterile Insect Technique. Recordings of medfly courtship behavior were collected from several locations world-wide using a standard protocol. Qualitative and quantitative analysis of the collected behavioral materials was conducted. No major differences were found among the strains both in male and female behavioral repertoire, which indicates general lack of behavioral incompatibility among the strains studied. However, the analysis revealed several qualitative and quantitative differences in courtship details among locations. The females from Madeira strain were more "choosy" then those from other strains, rejecting male courtship most frequently in spite of the fact that the males from this strain displayed their courtship activities in the most expressed manner. It has been suggested, therefore, that development of an efficient strain for world-wide application shall be based on the most competitive strains (such as Madeira strain), and only individuals with the most pronounced pattern of male courtship should be selected as founders.

Mohamed S. A., Overholt W. A., **Wharton R. A.,** *Lux S. A.* **and Eltoum E. M. (2003)** Host specifity of *Psyttalia cosyrae* (Hymenoptera: Braconidae) and the effect of different host species on parasitoid fitness. *Biological Control* 28, 155–163. **(Call No.: 03-1699)**

Psyttalia cosyrae (Wilkinson) (Hymenoptera: Braconidae) is a synovigenic, koinobiont larval-pupal parasitoid of *Ceratitis cosyra* (Walker) (Diptera: Tephritidae), and possibly other tephritid fruit flies. Host acceptance and suitability of medfly, *Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae), mango fruit fly, *Ceratitis cosyra*, Natal fruit fly, *Ceratitis rosa* Karsch, *Ceratitis fasciventris* (Bezzi), *Ceratitis anonae* Graham, and melon fruit fly, *Bactrocera cucurbitae* (Coquillett) (Diptera: Tephritidae), for oviposition and development of this parasitoid were investigated. The effect of different host species on traits widely used to assess parasitoid fitness was also evaluated. *Psyttalia cosyrae* accepted all host species tested, but acceptance varied. In no choice tests, *C. cosyra* and *C. capitata* were accepted at a significantly higher rate than the other four species. The parasitoid successfully developed only in *C. cosyra* and *C. capitata*. Eggs oviposited in *C. rosa*, *C. fasciventris*, *C. anonae*, and *B. cucurbitae* were encapsulated. Developmental time was shorter in *C. capitata* than in *C. cosyra*, but parasitoid progeny emerging from the latter host were more fit, as measured by percent female progeny, adult size, egg load, and adult survival.

Book chapters and other publications

De Meyer M., *Copeland R. S., Lux S. A.*, **Mansell M., Quilici S., Wharton R., White I. M. and** *Zenz N. J.* **(2002)** Annotated checklist of host plants for Afrotropical fruit flies (Diptera: Tephritidae) of the genus *Ceratitis*. *Documentation Zoologique, Musée Royale de l'Afrique Centrale Tervuren*, Belgique. Vol. 27. 91 pp. **(Call No.: 595.773.4 (048.2) MEU)**

Lux S. A., Ekesi S., Dimbi S., Mohamed S. **and** *Billah M.* (2003) Mango-infesting fruit flies in Africa: Perspectives and limitations of biological approaches to their management, pp. 277–293. In *Biological Control in IPM Systems in Africa* (Edited by P. Neuenschwander, C. Borgemeister and J. Langewald). CABI, Wallingford.

Conferences papers

6th International Symposium on Fruit Flies of Economic Importance, 6–10 May, 2002. Stellenbosch, South Africa. Paper presented: Development of entomopathogenic fungi for the management of African fruit flies: *Ceratitis cosyra*, *C. fasciventris* and *C. capitata*. Dimbi S., Ekesi S., Maniania N. K., Lux S. A. and Zenz N.

6th International Symposium on Fruit flies of Economic Importance, Stellenbosch, South Africa. 6–10 May, 2002. Paper presented: Behavioural responses of three African fruit flies: *Ceratitis cosyra*, *C. fasciventris* and *C. capitata* to natural and artificial food sources. Manrakhan A. and Lux S. A.

6th International Symposium on Fruit Flies of Economic Importance. 6–10 May, 2002. Stellenbosch, South Africa. Poster presented: Tritrophic interactions of two *Psyttalia* spp. (Braconidae), six fruit flies (Tephritidae) and four fruits. Mohamed S. A.

6th International Symposium on Fruit flies of Economic Importance, 6–10 May, 2002. Stellenbosch, South Africa. Paper presented: Courtship patterns, periodicity of mating behaviour and the role of host plants in reproductive bahaviour of three African fruit flies *Ceratitis cosyra*, *C. fasciventris* and *C. capitata*. Nemeye P. S., Lux S. A., Gikonyo N. K. and Kaddu J. B.

6th International Symposium on Fruit flies of Economic Importance, 6–10 May, 2002. Stellenbosch, South Africa. Paper presented: Reconstituted annual host chain for *Ceratitis cosyra* in the coastal area of Kenya and Tanzania. Seguni Z., Lux S. A., Ekesi S., and Zenz N.

6th International Symposium on Fruit flies of Economic Importance, 6–10 May, 2002. Stellenbosch, South Africa. Keynote address, Fruit flies in sub-Saharan Africa: A long-neglected problem devastating local fruit production and a threat to horticulture beyond Africa. ole MoiYoi O.K. and Lux S. A.

Consultancies

International consultant to the FAO/TCP regional project on the invasive *Bactrocera* fruit fly, recently detected by AFFI in East Africa.

AFRICAN TEPHRITIDAE: INVASIVE SPECIES THREATENING FRUITS AND VEGETABLE PRODUCTS GLOBALLY

BACKGROUND, APPROACH AND OBJECTIVES

The genus *Ceratitis* MacLeay (Diptera: Tephritidae), of Afrotropical origin, contains some of the most polyphagous tephritid pests. These species have a direct impact on fruit production within their native range. With the recent liberalisation in trade, and owing to poor quarantine infrastructure in African countries, they also pose a serious threat of accidental introductions to other countries importing fruits from Africa. Two of these species have already escaped the African continent and become established elsewhere. *Ceratitis capitata* (Weidemann) has spread to nearly all tropical and warm temperate areas of the world, and *C. rosa* Karsch invaded the Indian Ocean islands of Mauritius in the 1950s. On the other hand two species of multivoltine, polyphagous *Bactrocera* genus have invaded Africa from Asia.

The diversity of parasitoids of tephritid fruit flies in sub-Saharan Africa is very high. Recently, there has been considerable interest in obtaining more effective parasitoids from this region for biological control of these pests. However, information on their biology and host range is lacking, except for a few species collected by Silvestri, Bridwell, and Fullaway and established in Hawaii for biological control of the medfly, *C. capitata*. The objective of this project is to search for and identify promising parasitoid candidates that could be used for augumentative and classical biological control for management of fruit flies where these pests become invasive. The project also is studying the biology and host range of these parasitoids.

WORK IN PROGRESS

1. Surveys for African fruit flies and their parasitoids

From the ongoing surveys, several promising parasitoid species were identified and laboratory colonies of several, namely *Psyttalia cosyrae* (Wilkinson), *P. concolor* (Szépligeti) (Kenyan strain), *P. phaeostigma* (Wilkinson) and *Tetrastichis giffardii* Silvestri were established. Some of these parasitoids were shipped to collaborators in different countries (Table 1).

Table 1. Parasitoid species shipped overseas

Parasitoid species	Country
Psyttalia cosyrae	Guatemala
P. lounsburyi	France, California (via France)
P. phaeostigma	Hawaii, Saint Helena (South Africa)
Fopius caudatus	Guatemala, Hawaii

2. Response of *Psyttalia concolor* and *P. cosyrae* to volatiles of infested and uninfested fruit

Host-habitat finding was studied by evaluating the response of two parasitoid species, *Psyttalia concolor* and *P. cosyrae* to volatiles of infested and uninfested fruits (coffee, mango, guava and marula) in a Y-tube olfactometer. Except for coffee, which was not attractive to *P. cosyrae*, the two parasitoid species were attracted to volatiles of the uninfested fruits when compared to clean air in the Y-tube olfactometer. Generally, infestation increased the parasitoids' attraction. *Psyttalia concolor* preferred infested coffee to all other fruits infested with *C. capitata*.

3. Host acceptability and host suitability of *P. concolor* and *P. cosyrae* to six species of fruit flies

Host acceptability for oviposition and host suitability for parasitoid development were investigated for two parasitoid species, *Psyttalia concolor* and *P. cosyrae*, on six hosts: Mediterranean fruit fly, *Ceratitis capitata*; mango fruit fly, *Ceratitis cosyra* (Walker); Natal fruit fly, *Ceratitis rosa*; *Ceratitis fasciventris*; *Ceratitis anonae* Graham; and the melon fruit fly, *Bactrocera cucurbitae* (Coquillett).

Host acceptability studies revealed that all hosts tested were accepted by the two *Psyttalia* species. However, acceptance varied among the different hosts. There was no significant difference in host acceptance between *C. capitata* and *C. cosyra* by either parasitoid species. Other host species were significantly less accepted. *Ceratitis rosa* was least accepted by both *P. concolor* and *P. cosyrae* (Figure 1).

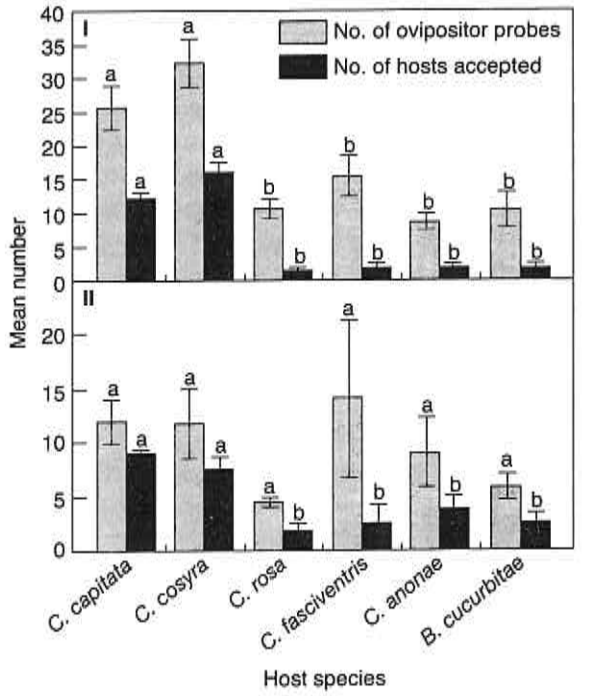


Figure 1. Acceptance of six fruit fly species for oviposition by* P. concolor *(I) and* P. cosyrae *(II).

Bars capped with same letter for the same category are not significantly different (SNK, P = 0.05)

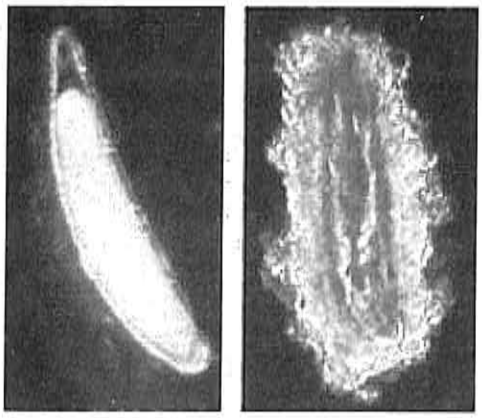


Figure 2. Normal freshly laid egg of* P. concolor *in* C. capitata *(left), and encapsulated, 2-day-old egg of* P. concolor *in* C. fasciventris *(right)

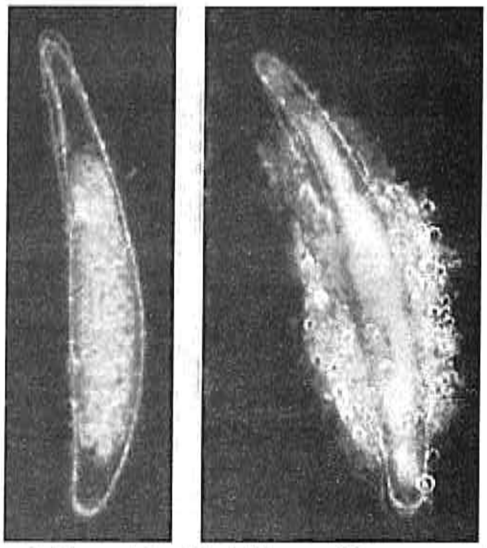


Figure 3. Normal freshly laid egg of* P. cosyrae *in* C. cosyra *(left), and encapsulated, 1-day-old egg of* P. cosyrae *in* C. anonae *(right)

Out of the six hosts tested, only *C. capitata* and *C. cosyra* were suitable for development of the two parasitoid species. Eggs of the two *Psyttalia* species oviposited in *C. rosa*, *C. fasciventris*, *C. anonae* and *B. cucurbitae* were encapsulated (Figures 2 and 3). The results of this experiment indicate that *P. concolor* and *P. cosyrae* are fairly specific and may have no effect on non-target species.

The percentage female progeny production was higher for *P. concolor* when it was reared on *C. capitata* than when it was reared on *C. cosyra*, while the converse was true for *P. cosyrae*. Additionally, *P. cosyrae* reared on *C. cosyrae* were more fit than those reared on *C. capitata* in terms of adult size, potential fecundity and adult survival.

CAPACITY BUILDING

PhD student

Samira A. Mohamed (Sudan) Biology, host and host plant relationships of two *Psyttalia* species (Hymenopetra: Braconidae): Parasitoids of fruit flies (Diptera: Tephritidae) in Kenya. PhD, University of Gezira, Sudan (2003). Supervisors: W. A. Overholt and S. A. Lux (ICIPE) and E. M. Eltoum (University of Gezira). Dr Mohamed was absorbed by the national agriculture research system in her home country.

Participating scientists: S. A. Mohamed, F. Schulthess, W. A. Overholt, S. A. Lux

Assisted by: P. Machera, P. M. Ireri

Donor: Texas A&M Research Foundation, USA

Collaborators: Texas A&M University (USA)-USDA-ARS European Biocontrol Laboratory (France); University of Hawaii (USA)

DEVELOPMENT OF A LOCAL, INTERNATIONALLY ACCREDITED CERTIFICATION BODY FOR ORGANIC AND OTHER STANDARDS

BACKGROUND, APPROACH AND OBJECTIVES

The international trade agreements now in place under the World Trade Organization (WTO) affect agricultural food and foodstuff producers, retailers and processors from all over the world, including Africa. These agreements have liberalised world trade and opened up international markets. This has been accompanied by increased scrutiny of food products, aimed at reducing the risks arising from food-related operations through the development of systems aimed at providing a total quality management approach in the whole food chain.

In order to verify these systems, the private sector in most of the developed countries has put in place a number of private standards (EUREPGAP, BRC, SQF, etc.), aimed at assuring quality and safety of foods, food products and the environment. Compliance with these standards leading to certification is often voluntary, but depending on the buyer and the market, this can be mandatory. For instance, compliance is mandatory for the Kenyan horticultural export industry.

Certification and the related costs as well as organisational changes required in the marketing chain are threatening the participation of the smallholder producers in the Kenyan (and African) horticultural export industry, however. At present, there are no local, accredited certification bodies in Kenya. European certifiers carry out direct inspections, especially for export produce, or they engage a local co-certifier for the inspection. Certificates are issued from Europe and the costs are considerable, far beyond the means of smallholder producers.

ICIPE has therefore taken up the task with support from GTZ to create a local certification body in order to bring certification costs down and safeguard the continued participation of smallholders in export production.

WORK IN PROGRESS

The documentation required for accreditation of a certification body according to ISO 65 or EN 45011 specifications was developed during 2003. Future company staff were trained in EUREPGAP (European Retailers Programme on Good Agricultural Practices) standards and as EUREPGAP inspectors. The training programme is continuing.

AfriCert Ltd. was established on November 28, 2003 and is now ready for the accreditation audit. Certification activities should start in the second half of 2004.

Participating staff: B. Löhr, R. Nyagah, F. Akivaga

Donors: Gesellschaft für Technische Zusammenarbeit (GTZ), Germany

Collaborators: Gesellschaft für Technische Zusammenarbeit (GTZ), Germany; Gesellschaft für Resourcenschutz, Göttingen, Germany

PLANT HEALTH

DEVELOPMENT OF SEMIOCHEMICAL-BASED MANAGEMENT STRATEGIES FOR THE DESERT LOCUST, *SCHISTOCERCA GREGARIA* (FORSKAL)

BACKGROUND, APPROACH AND OBJECTIVES

Gregarisation—the ability of an insect to transform reversibly between two extreme phases, solitaria and gregaria—is central to the biology and pest status of the desert locust and other locusts and aggregating/migratory insect pests. The goal of ICIPE's locust semiochemicals research has been twofold:

- to explore the use of the insect's own communication signals to manipulate the process of gregarisation for control purposes; and
- to develop an understanding of gregarisation in order to assemble the components of a preventive intervention strategy.

The project initially started with behavioural and physiological studies relating to three important characteristics of gregarious locusts, i.e. cohesive behaviour, synchronous maturation, communal oviposition, and characterisation of their mediating pheromone systems (*see 1994 ICIPE Annual Report Highlights* and *1994 ICIPE Annual Scientific Report*). One of the most interesting results of this phase of the study was the finding that different pheromone blends mediate the aggregation behaviour of nymphal and adult stages. Exposure of nymphs to the adult blend, or vice versa, resulted in a loss of aggregation behaviour. Phenylacetonitrile (PAN), the major component of the adult pheromone, elicits an immediate arrestment of the marching behaviour of hopper bands (*1995–1997 ICIPE Annual Scientific Report*). Affected individuals become disoriented, hyperactive, feed less and gradually solitarise. The stressed insects become susceptible to enhanced predation and other mortality factors (*1998–1999 ICIPE Annual Scientific Report*).

Project funding was significantly affected by lack of locust outbreaks during the last 10 years. However, limited funds during the period allowed validation trials on the effects of PAN on mass-reared insects to be undertaken. In addition, two PhD students (under ARPPIS) joined the Project in 2001 and this allowed a number of outstanding questions relating to locust gregarisation and effects of PAN to be addressed over this review period.

The following specific activities were undertaken during 2002–2003:

- Detailed trials in boomas (enclosed field arenas) using mass-reared nymphs were conducted to validate the effects of PAN in reducing the levels of pesticides needed for optimum control of hoppers.
- A 12-day workshop at the Port Sudan field station was organised to familiarise participants from locust-affected countries to the pheromone and *Metarhizium*-based biopesticide, Green Muscle.
- Physiological studies to throw some light on the mechanism that underlies the novel effects of PAN on gregarious nymphs were undertaken.
- Studies on the reproductive behaviour of solitary-phase desert locusts to generate further insights on the processes associated with gregarisation were initiated.

WORK IN PROGRESS

1. Boomas trials to validate the effects of PAN

The effect of exposing crowd-rearing (gregarious) hoppers to PAN (at 100 μl/ha) on the level of mortality resulting from treatment of the hoppers with different doses of a biopesticide [Green Muscle (GM)], and chemopesticides (Marshal and Fipronil) was conducted in a series of boomas (2 x 6 m plots) on cultivated vegetation. Typical results obtained are depicted in Figures 1 and 2. The results confirm previous cage experiments on the effect of PAN in predisposing hoppers to higher infection and mortality at almost all doses. These trials are due to be repeated on actual hopper bands in the field.

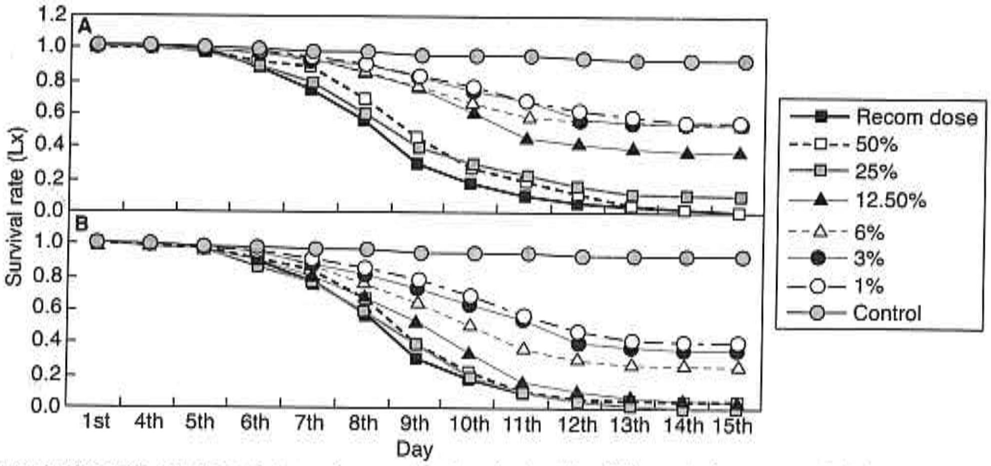


Figure 1. Mortality rate of desert locust nymphs treated with different dosages of (A) Green Muscle (GM) alone and (B) GM + phenylacetonitrile (PAN)

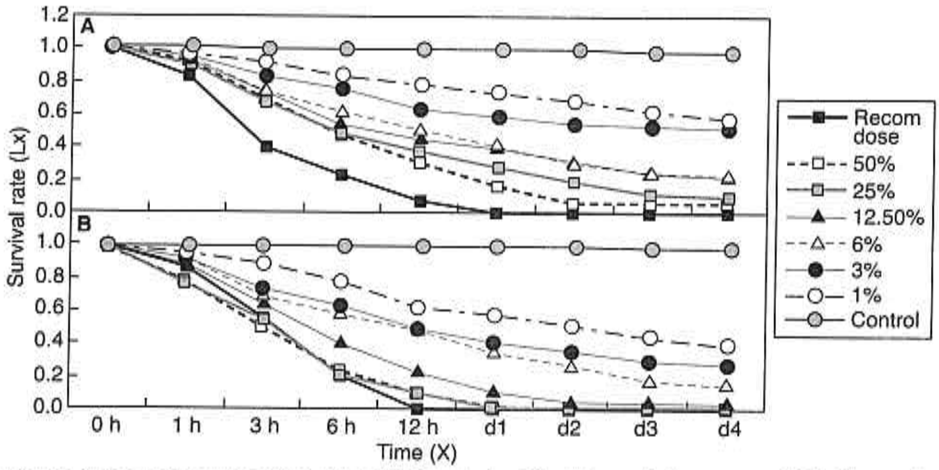


Figure 2. Mortality rate of desert locust nymphs treated with different dosages of (A) Fipronil alone and (B) Fipronil + PAN

2. Organisation of workshop at ICIPE field station (Port Sudan)

The workshop was organised in collaboration with the Plant Protection Department of Sudan (PPD) and the FAO-EMPRES during 10–20 January 2003. Participants were drawn from Sudan, Ethiopia, Mauritania, Egypt, Libya, Syria, Saudi Arabia, Yemen, Eritrea and Niger. The programme was made up of (a) lectures on biological control and modes of action of a *Metarhizium*-based biopesticide (Green Muscle) and PAN, as well as on possible non-target effects of these agents; (b) observations on the effects of the recommended doses of the biopesticide on hoppers in boomas; and (c) comparisons of the effects of PAN on nymphs treated with fractional doses of Green Muscle and a chemical pesticide (Dursban) with/without PAN in boomas and in laboratory cages. The participants were able to see the method of deployment and efficacy of PAN in predisposing hoppers to infection/toxication at substantially reduced doses of the pesticides. The need for another workshop on natural hopper bands was recognised and this is being planned.

3. Physiological studies on the effects of PAN on gregarious nymphs

Two sets of studies were undertaken as outlined below.

An electroantennogram (EAG) study was carried out to investigate the effects of phenylacetonitrile (PAN) on olfactory detection of the nymphal aggregation pheromone blend (NPB) by fifth instar nymphs. Nymphs held in small aluminium cages were exposed to PAN vapour (3.90 ± 0.14 mg/day) for 6, 24, 48 and 72 h and the antennae tested with varying doses (20–150 µg) of NPB. Antennal receptors of control (untreated) insects had significantly higher amplitudes compared to those of PAN-treated nymphs (Figure 3). The results represent inhibition levels of 67–94% in the detection of NPB by treated nymphs relative to the control. A similar pattern is also emerging in tests involving one of the major constituents of plant volatiles.

The effect of exposing crowd-reared fifth instar nymphs to PAN on the immune system was evaluated on the basis of the density of different haemocytes in the haemolymph. Over a 3-day exposure period, there was a general increase in the numbers of granulocytes, plastocytes and coagulocytes in the haemolymph of PAN-treated insects compared to

Table 1. Effect of exposing 5th-instar, crowd-reared (gregarious) desert locust nymphs to phenylacetonitrile (PAN) on haemocyte counts on days 3, 4 and 5

Cells/Day	3	4	5	Average*
Granulocytes (x10^5)				
Control	4.50 ± 1.04	4.83 ± 0.93	3.25 ± 0.78	4.30 ± 0.54
Exposed	7.95 ± 1.62	8.65 ± 0.90	5.45 ± 0.64	3.35 ± 0.71
Plasmatocytes (x10^5)				
Control	6.25 ± 0.98	7.17 ± 1.32	3.75 ± 0.75	5.95 ± 0.72
Exposed	6.25 ± 0.31	8.50 ± 1.04	6.30 ± 2.19	7.01 ± 0.81
Coagulacytes (x10^5)				
Control	5.75 ± 1.14	8.17 ± 1.14	4.31 ± 0.96	6.33 ± 0.74
Exposed	10.70 ± 3.45	7.90 ± 1.07	7.90 ± 1.80	8.83 ± 1.30

*Average of day 3, 4 and 5 counts.

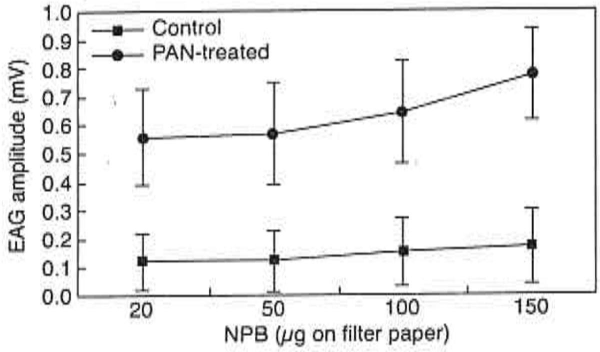


Figure 3. EAG responses of 5th instar nymphs of desert locust to the nymphal pheromone blend (NPB), a blend of 10 compounds

those of control insects. This was particularly evident for the granulocytes since their number (per unit volume) almost doubled in haemolymph of treated insects (Table 1).

Thus, the sensory inhibition resulting from exposure of gregarious hoppers to PAN is reflected in an immune response (stress?) and accounts for observed behaviours of exposed hoppers (arrestment of marching, reduced feeding, hyperactivity, gradual dispersal, etc.) as well as their enhanced susceptibility to natural mortality factors and to fractional doses of pesticides.

4. Aspects of mating behaviour of solitarious locusts

The responses of solitary-reared males and females to visual and olfactory signals from conspecifics upwind were studied in a wind tunnel. The responses (scanning, walking/running, jumping distance traversed, proportion that reached the source) of males that were elicited with a combination of visual and olfactory signals were significantly more pronounced compared to controls or those that were exposed to only olfactory signals. Interestingly, in the presence of male olfactory and visual signals, females also demonstrated significantly more frequent scanning and mobility activities, although their overall translational movement toward the males upwind was not significant.

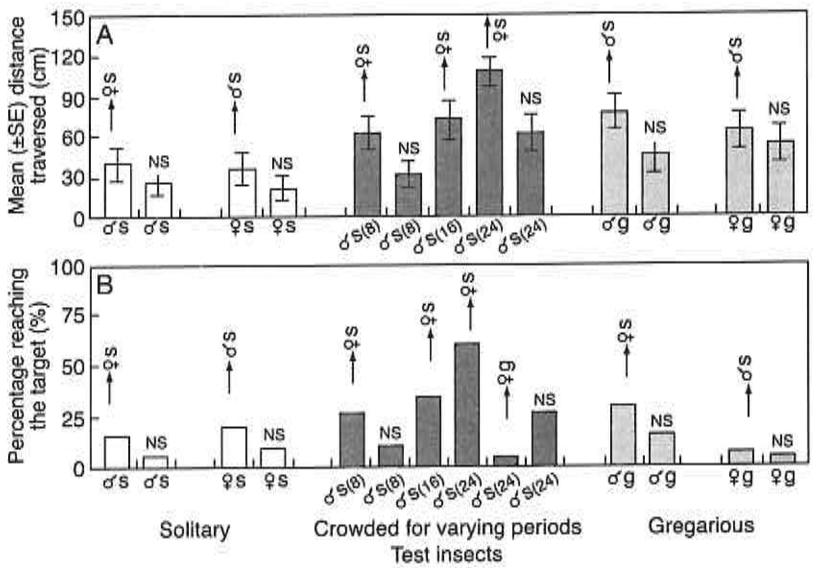


Figure 4. (A): Mean (±SE) distance traversed by desert locusts toward the signal source (visual + olfactory). (B): Percentage of test insects that reached the signal source after 30 min.

♂s (8), (16), (24), solitary male crowded for 8, 16 and 24 days;
♀s (8), (24); solitary female crowded for 8 and 24 days;
♂ g, gregarious male; ♀ g, gregarious female; NS: No signal.

Of special interest is the finding that solitary-reared males crowded for 8, 16 and 24 days showed increased responses to olfactory signals with/without the visual signal from solitary-reared females (illustrated partly in Figure 4) compared to their uncrowded counterparts. These results demonstrate that solitary females are more attractive to males that experience crowding and that this may constitute an important mechanism of recruiting solitary females into gregarising populations.

FUTURE OUTLOOK

The gradual greening of patches of the Sahelian belt indicated by satellite pictures and increased activity of solitary locusts on the ground suggests that new outbreaks may not be too far off. It is hoped that new funding to reactivate the programme's R&D and capacity building activities will soon become available.

CAPACITY BUILDING

PhD students

Cherif Mohamed Habib Kane (Mauritania) Cross-stage physiological effects of the desert locust, *Schistocerca gregaria,* aggregation pheromones on their behaviour and susceptibility to control agents. Kenyatta University.

Sidi Ould Ely (Mauritania) Reproductive behaviour of the solitarious desert locust, *Schistocerca gregaria* (Forskål), in relation to semiochemical attributes of desert plants. PhD, University of Khartoum, Sudan (2003). Supervisors: A. Hassanali, N. Njagi and M. O. Bashir (ICIPE) and S. El Tom Amire (University of Khartoum).

Fathiya Mbarak Khamis (Kenya) Biochemical changes in developing embryos of *Schistocerca gregaria* induced by pheromone produced by ovipositing gregarious females. Jomo Kenyatta University of Agriculture and Technology.

OUTPUT

Journal articles

Njagi P. G. N. and *Torto B.* (2002) Evidence for a compound in Comstock-Kellog glands modulating premating behavior in male desert locust, *Schistocerca gregaria. Journal of Chemical Ecology* 28, 1065–1074. **(Call No.: 02-1654)**

> The Comstock-Kellog glands in adult females of certain acridid species, including the desert locust, *Schistocerca gregaria* have been implicated as a source of volatiles that play a role in mating behavior. A dichloromethane extract of the glands was analysed for metabolites by gas chromatography, coupled gas chromatography-electroantennographic detection, and mass spectrometry. Coupled gas chromatography-electroantennographic detector (GC-EAD) analysis revealed a component that elicited an electroantennogram response from the antenna of adult male *S. gregaria.* The compound was identified by GC-MS as pentanoic acid. The levels of the compound in the gland extract varied with age of female locust; it was present in detectable amounts only in 14- to 16-day-old females. In bioassays, pentanoic acid significantly stimulated pre-mating behavior in male desert locust. These results are discussed in relation to the biology of the locust.

Five other publications including a major review arising from field and ARPPIS students' work are being prepared for publication.

Participating scientists: M. O. Bashir, P. N. Njagi and A. Hassanali (Programme Leader)

Assisted by: Haider Hassan Korena, Abdul-Rahim W. Bashir, E. C. Rono

Collaborators: Department of Plant Protection, Sudan; FAO-EMPRES

Donors: Swiss Development Corporation (through FAO); GTZ (for the workshop)

BIOCHEMICAL CHANGES IN DEVELOPING EMBRYOS OF *SCHISTOCERCA GREGARIA* INDUCED BY PHEROMONE OF OVIPOSITING GREGARIOUS FEMALES

BACKGROUND, APPROACH AND OBJECTIVES

The onset and subsequent stages of phase transition (solitaria to gregaria) of locust eggs is associated with induced biochemical events. The goal of this project is to assess the impact of gregarising primer pheromone associated with egg laying by gregarising/ gregarious ovipositing females on locust eggs. The objectives are to compare the different embryonic proteins expressed at the onset and subsequent stages of phase transition.

WORK IN PROGRESS

Two-dimensional gel electrophoresis was carried out successfully on all samples and the protein profiles obtained were analysed by a 2-D gel analytical software. The results showed that at early stages of embryogenesis, the eggs derived from the two phases are essentially similar, and that phase-related differentiation is discernable in the later stages and at hatching following exposure to the pheromone. The 'pheromone-induced gregariousness' of the solitary eggs was found to be dose-dependent, that is, the higher the dose the more they tended towards the gregarious phase. *(See also report of the Molecular Biology and Biochemistry/Biotechnology Unit.)*

Participating scientists: E. O. Osir and A. Hassanali

Assisted by: J. Kabii

Collaborators: Jomo Kenyatta University of Agriculture and Technology (JKUAT)

Donor: ICSC-World Laboratory and ICIPE core fund donors

DEVELOPMENT OF BIOPESTICIDES FOR GRASSHOPPER AND LOCUST CONTROL IN SUB-SAHARAN AFRICA

BACKGROUND, APPROACH AND OBJECTIVES

Integrated pest management (IPM) interventions have not yet been employed for control of locusts and grasshoppers in sub-Saharan Africa. The availability of alternative locust control methods is a crucial limiting factor to IPM programmes and the variety of techniques comprising an IPM 'toolbox' is lacking. Both large-scale and local or village grasshopper or locust control programmes have relied in the past almost exclusively on using chemical insecticides to control outbreaks. Effective, economical, and safe alternative methods are needed to control acridids and to prevent widescale environmental contamination and the high costs associated with synthetic pesticides.

Because entomopathogens can be applied using the same application technology as the chemicals that currently form the basis for control, they are a suitable focus for generating alternative control measures. The specific objective of this project is to increase the efficacy of entomopathogens used as biopesticides by increasing their virulence and environmental persistence sufficiently to develop them into marketable products.

Microsporidia of the genus *Nosema* isolated from grasshoppers and locusts have been tested under field conditions with varying results. The microsporidium *Johenrea locustae* was first described by Lange and co-workers in 1996 from the Malagasy migratory locust, *Locusta migratoria capito*. So far no studies have been carried out to evaluate the pathogenicity of this new microsporidium against locusts. The Entomopathology Unit of ICIPE *(see also their report under Research Units)* has carried out an investigation of the susceptibility of *L. migratoria* and the desert locust, *Schistocerca gregaria* to infection by *J. locustae* and its effects on fecundity and feeding.

WORK IN PROGRESS

1. Virulence and development of *Johenrea locustae* in two locust species: *Locusta migratoria* and *Schistocerca gregaria*

Schistocerca gregaria and *Locusta migratoria* were obtained from the ICIPE Animal Rearing and Containment Unit (ARCU) *(See report of ARCU in this document)*. Insects were reared in 50 x 50 x 50 m cages and maintained at 30 ± 2 °C, 50 ± 10% RH under a photoperiod of 12 L:12 D. Insects were fed on wheat seedlings supplemented with bran.

Johenrea locustae originated from dead samples of *L. migratoria* collected from the laboratory at Ambatobe, Madagascar and acquired in May 2001. The samples had been kept in poor conditions, but a few of the dead locusts were taken at random and brought to Nairobi. They were surface-sterilised with sodium hypochlorite and rinsed thrice in sterile distilled water, then ground in a mortar. The mixture was then suspended in sterile distilled water and served as initial stock to produce enough quantities for bioassays. Second-instar *L. migratoria* (approx. 100) were infected with *J. locustae* by feeding them with wheat seedlings on which spores had been sprayed. Dead insects were crushed using a mortar and the resulting suspension in sterile water was sieved using a fine netting and centrifuged, after which the pellet obtained was washed and suspended in sterile distilled water and stored at 4–6 °C before being used in the bioassays.

Susceptibility of **S. gregaria** *and* **L. migratoria** *to* **J. locustae**

Three concentrations of the microsporidium were used (10^6, 10^7 and 10^8 spores/ml) for the bioassays. Wheat seedlings were sprayed with 20 ml of *J. locustae* suspension using Burgerjon's spray tower (1956); treatment was repeated the following day. Treated wheat seedlings were then transferred into aluminum cages and 15 insects introduced in each cage and maintained at 27–33 °C and 12 L:12 D. The experiment was replicated five times. In the control treatments, wheat seedlings were treated with sterile distilled water. Wheat seedlings were changed every day. Mortality was recorded daily for 21 days. Specimens of dead locusts were selected at random, crushed and examined as fresh preparations in order to confirm the causal agent.

Second-instars nymphs of both *S. gregaria* and *L. migratoria* were susceptible to *J. locustae* infection at the three exposure concentrations used. Mortality varied between 80 and 100% 32 days after treatment. The LT_{50} values varied between 18.8–20.8 days with *L. migratoria*, and between 21.8–24.9 days with *S. gregaria*. Spores of *J. locustae* remained virulent to both *L. migratoria* and *S. gregaria* after three passages through *L. migratoria* (Table 1). On the other hand, spores of *J. locustae* produced from *S. gregaria* hosts were only virulent against *S. gregaria* (Table 2). The

Table 1. Mortality of *Locusta migratoria* and *Schistocerca gregaria* following exposure to wheat seedlings treated with *Johenrea locustae* produced on *L. migratoria* for three successive generations

Host insect /Concentration (spores/ml)	% Mortality ± SE		
	1st passage	2nd passage	3rd passage
L. migratoria			
10^6	86.7 ± 6.7	82.2 ± 9.8	80.6 ±10.0
10^7	83.3 ± 3.3	93.3 ± 3.8	100.0
10^8	96.7 ± 3.3	96.7 ± 3.3	100.0
S. gregaria			
10^6	95.5 ± 2.2	88.9 ± 8.0	–
10^7	100.0	100.0	–
10^8	97.8 ± 2.2	100.0	–

–Bioassays not performed.

Table 2. Mortality of *Locusta migratoria* and *Schistocerca gregaria* following exposure to wheat seedlings treated with *Johenrea locustae* produced on *S. gregaria*

Host insect /Concentration (spores/ml)	% Mortality ± SE		
	1st passage	2nd passage	3rd passage
L. migratoria			
10^6	20.0 ± 10.0	–	–
10^7	20.0 ± 11.5	–	–
10^8	26.7 ± 8.8	–	–
S. gregaria			
10^6	82.2 ± 11.1	–	–
10^7	64.2 ± 9.7	–	–
10^8	73.3 ± 3.8	–	–

- Bioassays not performed.

pathogen failed to complete its developmental cycle in *S. gregaria* after the first passage.

Effect of infection on feeding

This experiment was carried out only on *S. gregaria* nymphs. Both sides of 3-cm diam. spinach leaf discs were sprayed once with 10 ml of a suspension of *J. locustae* using Burgerjon's spray tower. Concentrations of 10^4, 10^5 and 10^6 spores/ml were used; leaf discs treated with sterile distilled water were treated as the control. Twenty insects were used to test each concentration. Insects were placed individually in plastic containers (15.0 x 10.5 x 6.0 cm) and maintained in the room conditions described above. After 24-h exposure to treated leaf discs, the latter were removed and replaced by weighed fresh untreated spinach leaf discs. The percentage of food eaten was calculated by weighing the discs after feeding, taking into account natural water loss.

For *S. gregaria* exposed to concentrations of 10^4, 10^5, or 10^6 spores/ml, there was a decrease in dry weight of food eaten at 10^6 spores/ml, but not at the lower concentrations.

Reproductive potential experiment

The effect of the microsporidium on the reproductive potential of female survivors, total egg production and egg viability was investigated. Wheat seedlings were sprayed with 20 ml of *J. locustae* suspension using a Burgerjon's spray tower at concentrations of 10^6, or 10^7 and 10^8 spores/ml. One hundred (100) fifth-instar nymphs were introduced in each rearing cage and maintained until they reached the adult stage, after which they were sexed. Twenty pairs were transferred to clean rearing cages and fed with treated wheat seedlings. The experiment was repeated four times. Control treatments consisted of wheat seedlings treated with sterile distilled water. Food was changed daily for 10 days.

After the first mating was observed, oviposition pods were filled with sterile sand and introduced. The egg pods were recovered every two days for 3 weeks and were divided into two groups. Eggs in the first group were incubated under room conditions and the number of hatchings recorded. Nymphs that emerged from these eggs were observed for the presence of microsporidia. In the second group, destructive sampling was carried out to determine the number of eggs per pod. Twenty nymphs per treatment were selected at random, transferred to aluminium cages (20 x 20 x 20 cm) and maintained up to the adult stage. Mortality was also recorded. The experiment was replicated three times.

Infected female *S. gregaria* nymphs did not survive long enough as adults to reproduce. Female *L. migratoria* nymphs surviving infection by *J. locustae* laid significantly fewer pods than untreated controls at the three concentrations of 10^6, 10^7 and 10^8 spores/ml. The number of eggs per female was also significantly lower in treated lots than in the controls. Egg viability was significantly lower in lots treated with the higher dose (10^8 spores/ml) than other treatments.

(See also report of the Arthropod Pathology Unit.)

CAPACITY BUILDING

MSc students

Frederick Musieba (Kenya) Evaluation of the adult gregarisation pheromone, phenylacetonitrile (PAN) in combination with *Metarhizium anispoliae* var. *acridum* to enhance mortality of the gregarious nymphs of *Schistocerca gregaria* (Forskål) (Orthoptera: Acrididae). University of Nairobi.

Training course

Short training in Germplasm Conservation, IITA, Benin, May 2002. E. O. Ouna.

OUTPUT

Conference paper

Virulence and development of the microsporidium *Johenrea locustae* in two locust species: *Schistocerca gregaria* and *Locusta migratoria*. Maniania N. K., Vaughan L. J., Osir E. O and Ouna E. O. 36th Annual Meeting of the Society for Invertebrate Pathology, Burlington, 26–30 July 2003, USA.

Participating scientists: N. K. Maniania, P. Arama, E. Osir

Assisted by: E. Ouna, R. Rotich, E. Wesonga

Collaborators: Virginia Polytechnic Institute and State University (USA); USDA; Insect Biological Control Laboratory (France); Locustox (FAO); DLCO (East Africa); INRA (France); Département de protection des végétaux (DPV) (Sénégal); DPV (Madagascar); FOFIFA (Madagascar); Centre National Antiacridien (CNA) (Madagascar)

Donors: USAID/Africa Bureau

ANIMAL HEALTH RESEARCH



DIFFUSION OF NEW TSETSE CONTROL TECHNOLOGIES FOR IMPROVED LIVESTOCK HEALTH AND PRODUCTIVITY IN SMALLHOLDER INDIGENOUS COMMUNITIES OF SUB-SAHARAN AFRICA

BACKGROUND, APPROACH AND OBJECTIVES

In the last two decades, much progress has been made in identifying some of the key kairomones tsetse flies use to locate their preferred hosts. As a result of this knowledge, effective olfactory baits have been developed, especially for the savanna group of tsetse. Repellents, on the other hand, have received little attention. In the last few years ICIPE has focused its work on the search for and evaluation of several candidate repellents. The research has followed two approaches:

- development of more potent synthetic analogues of a mild natural repellent;
- identification of natural repellent blends from un-preferred animals such as waterbuck, zebra and impala, which are common in tsetse habitats but are rarely fed on.

A potent synthetic repellent for savanna tsetse has been developed by molecular optimisation studies. This repellent acts as an olfactory antagonist of a key phenolic kairomone which flies use to locate their host for feeding (Saini and Hassanali, patent).

As reported previously, this repellent reduces the feeding efficiency of *Glossina pallidipes* on cattle (as determined by electric screen experiments) by more than 80%. A prototype dispenser for on-host use has been developed so that a constant release rate of the repellent can be maintained for more than a month, while allowing the cattle to graze freely with the dispenser attached to a collar.

WORK IN PROGRESS

1. Determination of the minimum proportion of cattle needed to carry the synthetic repellent dispensers

Previous studies undertaken by ICIPE (see *ICIPE Annual Scientific Report Summaries 2000–2001*) indicated that all cattle in a herd need not be treated with the synthetic repellent due to its diffusion properties and its relatively high volatility, a result of which untreated cattle in proximity to treated ones are also protected. These studies also indicate that treating 50 to 75% of the cattle may provide protection to the entire herd. During the current review period, experiments were undertaken in collaboration with KETRI and ILRI to determine the optimum proportion of cattle that need to be treated with repellents.

In December 2002 three communal herds totalling 404 animals were randomly selected for field trials in each of the three different locations (Sampu, Oloibortoto and Konei) in Nguruman, southwestern Kenya. The livestock owners were selected on the basis of their willingness to participate in the trials and commitment to provide cattle. Prior to any repellent treatment, all animals in the nine herds were block-treated with the trypanocide diminaphen (diminazene diaceturate) at doses of 3.5 mg/kg body weight, estimated using weighing bands.

After treatment with Diminaphen the three herds in each locality received one of the following randomly selected treatments: 50 or 75% of the animals were provided with repellent dispensers hanging around their necks or none at all (unprotected controls). The number of animals involved in the field trials is shown in Table 1.

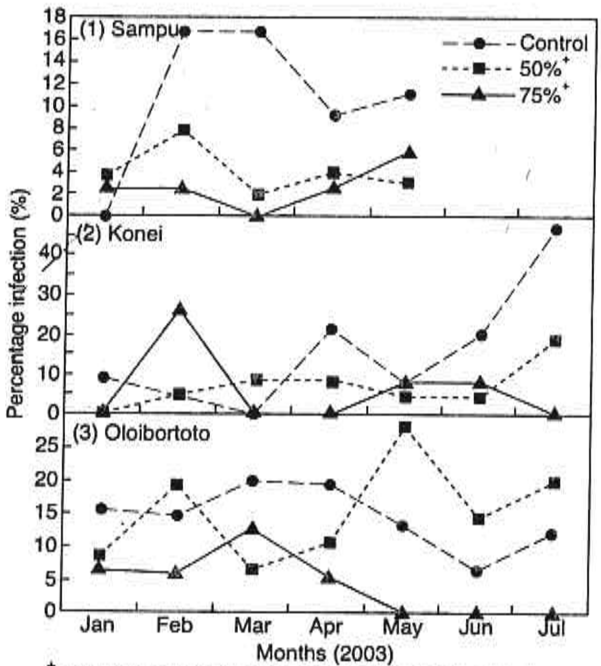
Beginning in January 2003, the trypanosomosis infection rates in all the experimental cattle were monitored by the buffy coat technique at monthly intervals. Any infected animals were treated with diminaphen supplied by the Project. This acted to reassure livestock keepers and encourage them to remain in the trials.

A two-way analysis of variance (ANOVA) (Proc. Glm, SAS Institute 1990) with three (3) levels for the factors 'treatment' (control, 50% and 75% protected animals) and three (3) levels of the factor 'locations'

Table 1. Number of animals sampled per month in three different localities in Nguruman, SW Kenya, under various treatments

			December 2002		No. of animals sampled in 2003						
Locality	Farmer	Treatment with repellent (% of herd)	No. of animals block-treated with trypanocide	No. treated with repellent	Jan	Feb	Mar	Apr	May	Jun	Jul
Oloibortoto	Munii	None (control)	36	0	32	34	36	36	31	33	34
Oloibortoto	Sarara	75%	23	18	30	33	31	18	9	9	12
Oloibortoto	Nikotimi	50%	62	31	59	57	62	67	57	14	15
Sampu	Musenya	None (control)	14	0	12	12	12	11	9	8+	11+
Sampu	Nteetu	50%	110	55	110	103	99	103	95	104+	99+
Sampu	Nairuko	75%	77	58	78	76	67	76	51	56+	62+
Konei	Nkisongoi	None (control)	37	0	35	25	18	14	14	15	15
Konei	Oltimbau	50%	20	10	22	20	23	24	22	23	21
Konei	Kisheiyan	75%	25	19	20	19	16	13	12	12	12
Total animals			**404**	**191**	**398**	**379**	**364**	**362**	**300**	**274**	**281**

+Herds moved out of the study area.



+Indicates proportion of animals protected in a herd. Control animals are unprotected.

Figure 1. Percentage infection in communal herds protected with the synthetic repellent at 3 different locations in Nguruman, Kenya

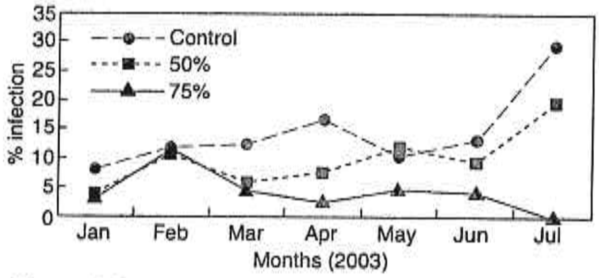


Figure 2. Percentage overall infection in cattle herds protected with the synthetic repellent in Sampu, Oloibortoto and Konei locations in Nguruman, Kenya

(Konei, Oloibortoto and Sampu) was conducted on the infection rates. Pair-wise Multiple Comparisons were conducted using the Bonferroni t-test to determine which treatments differed from one another.

The infection rates in the communal herds in the three locations are shown in Figure 1. Analysis of variance showed significant differences between the treatments ($F_{2,52} = 6.09$, $P < 0.001$), however there was no significant difference between the locations ($F_{2,52} = 2.06$, P = NS). Overall comparisons of the mean infection rates indicated that these were significantly lower in the 75%-protected herds as compared to the unprotected herds (control) or the 50%-protected herds. There was no significant difference in infection between the unprotected herds and the 50%-protected herds. These trends are also evident in the overall infection rates (Figure 2). In the 75%-protected herds, the mean infection rate was reduced by more than 70%.

Examination of the infection rates within the herds shows clearly that the majority of the infections in the protected herds occur in animals without the repellent collars, however, indicating that it would be better to protect all the animals in a herd (Table 2).

A consultative workshop with the pastrolists involved in the field trials in Nguruman was held on 27 February 2003 with the project staff from ICIPE, ILRI and KETRI. The objective of the workshop was to brief everyone on the new trials with the repellent, address any concerns and provide a forum for discussion. The main concern of the farmers was that they wanted more of their cattle involved in the trials, as they knew from previous trials that the repellent was effective. The pastoralists included in the trials evaluated the repellent technology as being simple, requiring minimum maintenance, and most importantly, being mobile (i.e. the animal wears the repellent wherever it goes) and consistent with their production practices. Farmers also continued to report that animals protected with repellents showed reduced infection from biting flies.

Table 2. Infection within herds protected with the synthetic repellent in Nguruman, Kenya

Location	Treatment (% protected animals)	Mean infection (%) Protected animals (with repellent collars)	Unprotected animals (without repellent collars)
Oloibortoto	50	8.2	91.8
	75	0.0	100.0
Konei	50	0.0	100.0
	75	14.2	85.8
Sampu	50	0.0	100.0
	75	0.0	100.0
All 3 locations combined	50	4.8	95.2
	75	5.6	94.4

2. Repellents from unpreferred animals (waterbuck)

Tsetse flies are known to be very selective in their choice of hosts as bloodmeal sources. Host preference has been shown to be independent of the numerical availability of different vertebrate hosts in a given habitat. The most preferred hosts for the savanna tsetse are the warthog, rhinoceros and buffalo, and the least preferred are the impala, oribi and waterbuck. Work has been continuing at ICIPE to determine what factors make unpreferred hosts like the waterbuck refractory to the flies. Studies on chemical volatiles of the skin of preferred hosts (ox and buffalo) and the unpreferred host (waterbuck) revealed that non-hosts have additional allomonal compounds that may mask the effect of the common attractant compounds (*see ICIPE Annual Scientific Report Summaries 2000–2001*).

In their study, using GC-EAD and GC-MS techniques, 14 of these putative allomonal chemical compounds from the waterbuck volatiles were electrophysiologically identified and chemically characterised. These include straight chain carboxylic acid homologues (C_5–C_{10}), ketone homologues (C_6–C_{13}); phenols (guaiacol and carvacrol) and δ-octalactone. Wind tunnel experiments with *Glossina morsitans morsitans* teneral flies indicated that blends of these compounds had an adverse effect on fly upwind flight and landing responses. Work is in progress to determine the optimal repellent blend of these waterbuck-specific compounds for maximum repellency. (*See also the report of the Behavioural and Chemical Ecology Department*).

The present study has three major objectives:

- determine the key constituents of the waterbuck repellent needed for optimal repellency of tsetse flies using baited traps;
- study the relative feeding efficiency of tsetse flies on live cattle with/without the waterbuck repellent blend; and
- compare the repellency of the synthetic repellent with the optimum waterbuck repellent blend and assess any augmentative effects.

The repellent blend responsible for making waterbuck refractory to tsetse has been identified (patent pending). Field trials with the identified waterbuck-specific allomonal compounds indicated that for maximum repellency, a blend of selected carboxylic acid homologues, ketone homologues, phenols and octalactone is essential. Individually, these sets of compounds or their combinations are not as effective as the total blend. Since these compounds are of varying volatility, they may be affecting both long-range and short-range behaviours of the flies towards unpreferred/refractory animals.

3. Effect of the waterbuck repellent blend on feeding efficiency of *Glossina pallidipes*

The feeding efficiency of *Glossina pallidipes* on animals treated with the waterbuck repellent blend (WBR) was determined using the method developed by Vale (1977). In this experiment, an ox was tethered in the middle of an incomplete ring of five electric screens (1.5 x 1.0 m). The screens covered 20% of the circumference of the circle. These rings were constructed at two different locations. The experiment used a randomised complete block design and treatments were: (1) ox alone and (2) ox + total WBR blend repellent, which were randomly assigned to the two sites. At the sites which received repellent treatment, sachets containing the repellent were placed on the post to which the animals were tied. The animals were kept stationary while the treatments were rotated after each experimental period.

At the end of the experiment, the number of flies caught inside and outside the ring were recorded. Flies were also classified as fed or unfed based on the presence of fresh blood visible through the abdominal wall. The number of flies approaching the target (animals) with a repellent or without a repellent were estimated and statistically analysed. Following Vale (1977), feeding efficiency was estimated as the number of fed tsetse on the inside of the ring expressed as a proportion of the total catch from the inside of the ring of nets (fed + unfed flies).

The results (Table 3) indicate that the waterbuck repellent blend reduces the feeding efficiency of *G. pallidipes* on treated cattle by nearly 95%. This experiment is being replicated further.

These repellents may be used to either enhance or augment the potency of the synthetic repellent, or provide a cheaper or more effective alternative.

Table 3. Mean catches (± SE) and percentage feeding efficiency of *Glossina pallidipes* on cattle treated with/ without waterbuck repellent blend

Treatment	Total catch (inside screen)	Total fed (inside screen)	Feeding efficiency
Ox alone	729 (± 52.5) a	238.5 (± 77.5) a	32.7%
Ox with repellent	546 (± 124.5) a	8.0 (± 1.0) b	1.4%

Means followed by the same letter are not significantly different, P < 0.05 (t-test).

Table 4. Catches of *Glossina swynnertoni* in Narok district, Kenya with four different tsetse traps tested

Trap type	Total catch	Catch/trap/day
Biconical	43	4.2 a
NG2B	29	2.6 a
NZI	28	2.2 a
Pyramidal	27	2.0 a

Means followed by the same letter are not significantly different, P = NS (t-test).

4. Field site selection and effect of the synthetic repellent on *Glossina swynnertoni*

Field work was undertaken to identify other probable project sites in addition to Nguruman in order to replicate the field experiments and also to evaluate the repellent technology through farmer-managed trials. This was also necessitated due to contraction of tsetse-infested areas within the Nguruman region due to horticultural farming.

A preliminary survey of Narok District was undertaken by ICIPE and KETRI scientists in November 2002 for evaluation as a possible site. Socioeconomic, entomological and epidemiological data were collected. The survey results indicated that the district was a potentially suitable site with two species of *Glossina* present, *G. swynnertoni* and *G. pallidipes*, with the former being more predominant. Livestock keepers kept cattle herds ranging from 50–300 animals and the trypanosomosis prevalence was about 12%. However, low fly numbers were caught due to the inappropriate trapping device used.

In view of the above survey, a series of experiments was conducted to determine the most suitable trapping device and olfactory bait for *G. swynnertoni*, for which no good visual or odour bait is known. In addition, both the synthetic repellent and waterbuck repellent blend were evaluated for repellency for *G. swynnertoni*. The results of these experiments are presented below.

Experiment 1—Evaluation of different traps for G. swynnertoni

Unbaited NG2B, biconical, pyramidal and NZI traps were evaluated for attractancy in a 4 x 4 Latin square design experiment replicated three times. The results indicated that though the biconical trap caught the most flies, the mean catch was not significantly different from other traps tested ($F_{3,39}$ = 1.41, P = NS) (Table 4).

Experiment 2—Determination of odour baits for G. swynnertoni

The biconical trap was selected for further evaluation with known odour baits [acetone, 1-octen-3-ol (octenol) and cow urine] in a 5 x 5 Latin square design experiment.

The results (Table 5) indicated that the odour baits tested significantly affected the biconical trap catch of *G. swynnertoni* ($F_{4,52}$ = 4.33, P < 0.001), with most flies being caught with a blend of acetone, cow urine and octenol. However, as there was no significant difference in the trap catch when octenol was removed from the blend, it is recommended that a blend of acetone and cow urine be used for monitoring purposes.

Table 5. Catches of *Glossina swynnertoni* with biconical traps baited with various known tsetse attractants

Treatment	Total catch	Catch/ trap/day	Index of catch
A Trap + acetone	217	14.5	2.6 ab
B Trap + ac + oct	363	24.3	4.4 ab
C Unbaited trap	82	5.5	1.0 b
D Trap + ac + cu + oct	544	34.1	6.6 a
E Trap + ac + cu	469	31.3	5.6 a

The index of catch is with respect to unbaited biconical trap (C).
Means followed by the same letter are not significantly different, P < 0.001 (t-test).
ac = acetone, oc = octenol, cu = cow urine

Experiment 3—Evaluation of the synthetic repellent and waterbuck repellent blend against G. swynnertoni

The best performing (biconical) trap (Experiment 1) baited with the best odour blend (Experiment 2)

Table 6. Biconical trap catches of *Glossina swynnertoni* with the synthetic repellent and the waterbuck (WB) repellent blend

Treatment	Total catch	Catch/ trap/day	Index of catch[+]
A Baited trap alone	302	25.2	1.0 a
B Baited trap + synthetic repellent (9 mg/h dose)	51	4.3	0.16 b
C Baited trap + synthetic repellent (13.5 mg/h dose)	53	4.4	0.17 b
D Baited trap + WB repellent blend	103	9.2	0.37 b

[+]Number of flies trapped was expressed as a proportion of the number of files caught in the baited control trap (A) to determine the index of decrease.
Means followed by the same letter are not significantly different at P < 0.0001 (t-test).

was treated with either the synthetic repellent at the normal dose of 9 mg/h or a high dose of 13.5 mg/h or the identified waterbuck repellent blend. A 4 x 4 Latin square design experiment was replicated three times to determine the effect of the repellents on the catch of the flies. A biconical trap baited with acetone, cow urine and octenol served as a control. The mean number of flies caught were expressed as a proportion of the number of flies caught in the control trap to determine the index of decrease.

The results (Table 6) clearly show that both the synthetic repellent and the waterbuck repellent blend significantly reduce the number of flies caught ($F_{3, 30} = 17.26$, $P < 0.0001$). There is an urgent need to identify and optimise olfactory and visual baits for *G. swynnertoni*. *(See also report of the Behavioural and Chemical Ecology Department, BCED.)*

Participating scientists: R. K. Saini (Head, Animal Health Division and Tsetse Programme Leader), A. Hassanali (Head, BCED)

Assisted by: J. A. Andoke, P. Muasa, R. Tumba, M. ole Pukare

Collaborators: ILRI; Kenya Trypanosomiasis Research Institute (KETRI); Olkaramatin Group Ranch, Nguruman, Kenya; Kenya Agricultural Research Institute, National Veterinary Research Centre (NVRC)

Donor: IFAD

ENTOMOLOGICAL FACTORS INFLUENCING THE TRANSMISSION OF HUMAN AFRICAN TRYPANOSOMOSIS (HAT) IN AN ENDEMIC FOCUS IN CHAD

BACKGROUND, APPROACH AND OBJECTIVES

In preparation for an integrated disease and vector control operation in an endemic focus of human African sleeping sickness, a study was undertaken (August to October 2003) to determine the vectors involved, their distribution, infection rates and bloodmeal preferences. In Bodo Canton (District) in the Lagone area of Chad, the relative importance of livestock as reservoirs of human African trypanosomosis (HAT) was also assessed.

WORK IN PROGRESS

The study revealed that *Glossina fuscipes fuscipes* is the only *Glossina* species inhabiting the riverine vegetation in the eight galleries along the Logone river. The density of flies was highest in galleries where more watering points were present and where flies congregate when following hosts to get a blood meal. In galleries where riverine vegetation is reduced as a result of expansion of farming, no flies were trapped.

Fly dissection did not reveal any infection in the mouthparts, salivary glands or in the gut. Failure to detect infection in *G. f. fuscipes* could have been due to the limited sensitivity of the method used, as *Trypanosoma gambiense* may be infecting flies in low concentrations. However, other studies using more sensitive methods such as inoculating susceptible mice with homogenates of mouth parts and salivary glands would have revealed more information on infection in *G. f. fuscipes* flies, but were not done due to the unavailability of susceptible mice at LVRZ.

Bloodmeal analysis revealed the following feeding preference: 50% reptiles, 33.3% cattle and 16.6% humans. Though the proportion of fed flies encountered were too few to draw definitive conclusions about feeding preferences, they clearly point to the fact (as has been shown by ICIPE previously) that reptiles are among the most preferred hosts of these flies. Further studies in which bloodmeal samples are collected through different seasons would reveal more information on the feeding behaviour of *G. f. fuscipes* along Logone river.

Livestock (cattle and pigs) showed *T. vivax* as the predominant circulating trypanosome species. Other investigative methods such as xenodiagnosis and inoculation of livestock blood into susceptible mice would have given more information regarding cattle and pigs as reservoirs of *T. gambiense* but were not carried out due to lack of colonised *G. f. fuscipes* and susceptible mice in Chad, as mentioned above. *Trypanosoma vivax* prevalence observed in cattle was very high. Although the parasite cannot infect humans, it is lethal in cattle, and its impact on cattle production in Chad is currently unknown.

Although the study did not reveal any *T. gambiense* infections in livestock or flies, probably due to the short duration and limited sensitivity of the methods used, HAT continues to be a health hazard in Logone. Two young boys who had been diagnosed as HAT positive succumbed to the disease at the time the studies were being conducted. Detailed studies covering a longer period and employing more sensitive methods should be carried out to investigate further the factors involved in transmission of HAT in the endemic areas of Chad.

Participating scientist: R. K. Saini

Assisted by: E. Mpanga

Collaborators: WHO; Government of Chad; Laboratoire de Recherches Veterinaires et Zootechniques (LRVZ), Chad

Donor: WHO

THE ROLE OF SMALL RUMINANTS AND PIGS IN THE EPIDEMIOLOGY OF HUMAN SLEEPING SICKNESS

BACKGROUND, APPROACH AND OBJECTIVES

Trypanosomosis is a major impediment to livestock farming in sub-Saharan Africa and limits the full potential of agricultural development in the 37 countries where it is endemic. It is estimated that the annual loss to agricultural GDP on the continent is a staggering 4.75 billion dollars. In humans, sleeping sickness is fatal if untreated and causes severe morbidity. About 60% of Kenya's rangelands are infested with tsetse flies, severely limiting the potential contribution of livestock to the rural economy. The current study was undertaken in western Kenya, an area where trypanosomosis in livestock is present at high levels of endemicity, and human African trypanosomosis (HAT) or sleeping sickness, occurs at low levels over long periods, interpersed with epidemics. This picture underscores the complexity of the disease's epidemiology.

In this study, the prevalence of trypanosomes in small ruminants and pigs was investigated and also the potential of these livestock as hosts of potentially human-infective trypanosomes. The study was undertaken in five villages and addressed two key questions: Are small ruminants and pigs important in the transmission dynamics of trypanosomosis? And, do they harbour potentially human infective trypanosomes? Answers to these questions are important in developing strategies for the control of both livestock and human trypanosomosis.

WORK IN PROGESS

Over 400 animals from three villages were sampled and trypanosomes detected by PCR analysis. Molecular markers were used to identify trypanosomes to subspecies level, and to undertake further genotyping to identify trypanosomes that are potentially human-infective. Our results show that:

- Small ruminants and pigs naturally acquire trypanosomes that are serious pathogens of livestock (principally *Trypanosoma congolense* and *T. vivax*). These smaller livestock therefore can act as reservoirs of pathogens for cattle, which are more susceptible to trypanosomosis.
- All three animals studied (sheep, goats and pigs) were found infected with *T. brucei*, some sub-species of which are human-infective. Further characterisation of the infections using microsatellite markers showed that these livestock species were infected with trypanosomes that were of similar genotype to *T. brucei rhodesiense*, the pathogen responsible for sleeping sickness in this region of Africa. These livestock therefore contribute to the transmission dynamics of sleeping sickness. *(See also report of the Molecular Biology and Biotechnology Unit.)*

CAPACITY BUILDING

MSc student

Musa Otieno Ng'ayo (Kenya) Molecular characterisation of tryanosomes in small ruminants and pigs from western Kenya. MSc, Kenyatta University (2003). Supervisors: D. Masiga (ICIPE), E. U. Kenya and G. Muluvi (Kenyatta University).

Participating scientists: D. Masiga, E. O. Osir, E. Kenya, G. Muluvi

Assisted by: Z. Njiru

Collaborators: Kenya Trypanosomiasis Research Institute (KETRI), Kenyatta University

Donor: International Foundation for Science (IFS)

MOLECULAR STUDIES ON TSETSE-TRYPANOSOME INTERACTIONS

BACKGROUND, APPROACH AND OBJECTIVES

An important step in the establishment of gut-adapted trypanosome infections within the tsetse fly vector involves their differentiation from bloodstream into procyclic (midgut) forms. Consequently, most studies on tsetse-trypanosome relationships have concentrated on elucidating the fly midgut factors that mediate this process. Of the many factors that have been implicated, lectins, trysin-like molecules, and lysins appear to be the most important. ICIPE's research in this area is to define the specific interaction between tsetse flies and trypanosomes at the molecular level.

WORK IN PROGRESS

1. Cloning of tsetse fly midgut molecules involved in differentiation of African trypanosomes

This study dealt with cloning and expression of the lectin-trysin gene from *Glossina fuscipes fuscipes* and provides evidence for its involvement in triggering transformation of bloodstream-form *Trypanosoma brucei brucei* into procyclic (midgut) forms. The specific objectives were to prepare a tsetse fly midgut cDNA expression library; clone and sequence the lectin and trypsin cDNA from the tsetse midgut cDNA library; characterise the cloned lectin-trypsin cDNA; and assess the role of the molecule in trypanosome differentiation.

Tsetse midgut cDNA library construction and sequence analysis

Total RNA was extracted from the midguts of *G. fuscipes fuscipes* fed twice (24 h and 48 h after emergence) and starved for 72 h. Enriched cDNA was synthesised from the total RNA and a cDNA library constructed in the λTriplEx2 cloning vector. The library was plated using *E. coli* XL1-blue cells and screened with the tsetse lectin-trypsin polyclonal antibody and goat anti-rabbit conjugated alkaline phosphatase secondary antibody. Twelve positive clones were identified. Subsequent PCR screening of these clones using degenerate primers resulted in three positive clones.

Plasmid DNA was extracted from the colonies containing the selected inserts grown on Agar/ LB/Ampicillin plates and subjected to automated sequencing. A full-length clone of 933 bp that encodes a polypeptide chain of 274 amino acids was isolated (Figure 1). The three amino-acid residues essential for the active centre in serine proteases (His 72, Asp 119, Ser 219) were observed (shown in bold). The sequence contained a potential adenosine and AMP deaminase sites (191–197). The full sequence of the lectin-trypsin was analysed against databases using the BLASTP. Sequence alignment and statistical analysis of alignment were performed with a MultAlign program. Identical sequence residues included six conserved cysteine residues, residues in the catalytic triad and substrate-specific residues typical of invertebrate trypsins.

Expression and purification of recombinant* Gpl *by affinity chromatography

Cultures of *E. coli* JM109 containing the recombinant plasmid were grown in Luria-Bertani medium in 125 μg/ml Ampicillin and expression induced by addition of IPTG (final concentration of 0.1 mM). A sample of the recombinant bacterial lysate was loaded on a glucosamine-coupled affinity column and eluted with 0.2 M glucosamine (GlcN). Bound fractions were collected and assayed for trypsin activity and their ability to agglutinate bloodstream trypanosomes. The sample was also analysed by SDS-PAGE (Figure 2).

The role of recombinant lectin-trypsin in trypanosome differentiation was assessed as follows: Bloodstream *Trypanosoma brucei brucei* (5 x 10^6 parasites/ ml) were separately incubated at 27 °C with a purified lectin-trypsin complex or a *cis*-aconitate supplemented medium. The control consisted of bloodstream trypanosomes incubated in procyclic media only (Figure 3). Transformed parasites expressing procyclin were also confirmed by staining with monoclonal anti-procyclin antibody (EP) followed by fluorescein-conjugated goat anti-mouse secondary antibody.

A bloodmeal-induced gene with both lectin and trypsin activities was isolated by antibody screening of tsetse midgut cDNA library. The cDNA (933 bp) encoded a mature protein of 274 amino acids containing the highly conserved trypsin residues. The recombinant protein (M_r~ 32,500) compared favourably with the predicted molecular weight (M_r~ 29,179). The expressed protein was specific for D-glucosamine. The recombinant protein induced the transformation of bloodstream trypanosomes to procyclic (midgut) forms. The rate of transformation by lectin-trypsin was not significantly different from the transformation rate observed with *cis*-aconitate supplemented procyclic medium ($P > 0.05$).

2. Expression of *Glossina* proteolytic lectin (*Gpl*) gene in tsetse flies and other haematophagous arthropods

The aim of this activity was to study the expression of *Gpl* in tsetse flies and other haematophagous arthropods. The objectives were to screen for presence of the *Gpl* gene in other haematophagous arthropods following a bloodmeal; to determine the expression levels of the *Gpl* gene in tsetse flies at different intervals post-bloodmeal; and to determine the expression of the *Gpl* gene in tsetse flies following *Trypanosome* infections.

```
1                                    M K F F A V F A L
1    ggccattacggccggggagtacaatttcgatcatcATGAAGTTCTTTGCAGTGTTCGCTT
10   C V A S V S A A N L D A I A K P G F P A
61   TATGTGTGGCTAGTGTGAGTGCGGCAAACTTGGATGCTATCGCCAAACCAGGTTTTCCGG
30   G R I I N G H E A D K G E A P F I V S L
121  CAGGACGCATTATTAACGGACATGAGGCCGACAAAGGTGAAGCTCCTTTTATTGTGTCTT
50   K A G K G H F C G G S I I A E N W V L T
181  TAAAGGCCGGTAAAGGTCATTTCTGCGGTGGTTCTATTATTGCTGAGAACTGGGTTTTGA
70   A G H C L I F D E F E I V A G L H S R N
241  CTGCGGGTCACTGCTTGATCTTCGATGAATTCGAAATTGTAGCTGGATTACATTCGCGAA
90   D E S D V Q I R K V T G K H Q Q I V H E
301  ACGATGAGTCTGACGTTCAAATTCGCAAGGTTACTGGTAAACATCAACAAATTGTCCATG
110  K Y G G G V G P N D I G L I Y V D K P F
361  AAAAATATGGCGGTGGCGTTGGTCCCAACGATATTGGTCTCATTTACGTGGATAAACCAT
130  N L N A L T R D G T A A V A K V N L P T
421  TCAATTTGAATGCCTTAACTCGTGACGGAACAGCTGCAGTAGCCAAGGTGAATTTGCCAA
150  G K Y E S T G K G K L Y G W G L D N S G
481  CCGGCAAATATGAGTCTACTGGCAAGGGCAAATTGTATGGCTGGGGACTAGACAATTCCG
170  F S P N I L N T L D V D I I G Y E E C K
541  GCTTCTCACCTAACATTCTGAACACTCTGGATGTAGACATTATTGGATACGAAGAATGCA
190  N A L N S D D P L D P V N I C S Y T A G
601  AGAACGCTTTGAACAGCGATGATCCTTTAGATCCTGTCAATATCTGTTCCTACACAGCTG
210  A I D G A C N G D S G G P M V R I T P D
661  GCGCTATTGATGGCGCCTGTAATGGCGATTCCGGTGGTCCAATGGTGCGTATCACACCTG
230  G T E L V G I V S W G Y Q P C A S T T M
721  ACGGTACCGAATTAGTTGGCATTGTATCTTGGGGTTACCAACCTTGTGCCAGTACAACAA
250  P S V Y T W T S A F D K W I E D S I K N
781  TGCCATCTGTTTATACTTGGACTTCTGCTTTCGACAAATGGATTGAAGACAGCATCAAGA
270  Y A Q L L
841  ACTATGCGCAACTTTTGTaacttactaccgttattgaatgtgaaaataaaagtatgcccc
901  cccgaaaaaaaaaaaaaaaaaaaaaaaaaaaaa
```

Serine,proteases, trypsin family, serine-active site.
Site: 213 to 224 GACNGDSGGPMV. Identity.
Randomised probability: 7.319e-08

Serine proteases, trypsin family, histidine-active site.
Site: 68 to 73 LTAGHC. Identity
Randomised probability: 2.601e-07

aataaa = Possible polyadenylation signal

M K F F A V F A L C V A S V S A A N L = The putative signal peptide sequence.

Potential adenosine and AMP deaminase signature site (191–197)
Site: 191 to 197 ALNSDDP.

Figure 1. 933 residue sequence 'Full-length* Gpl *(Glossina proteolytic lectin)'

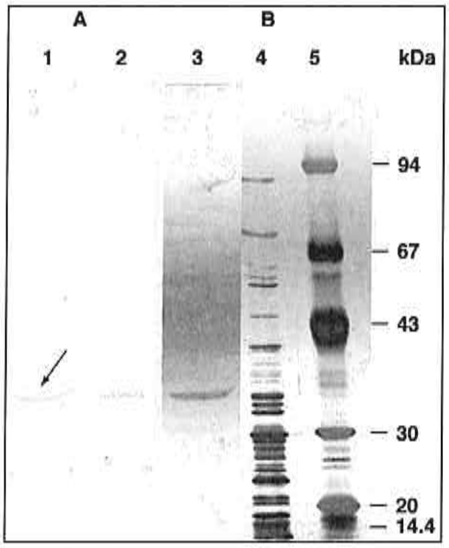


***Figure 2. SDS-PAGE and immunoblot of expressed* Gpl**

A = immunoblot: (1) purified Gpl, *(2) recombinant* E. coli—Gpl *lysate. B = silver stain gel: (3) purified* Gpl, *(4) recombinant* E. coli—Gpl *lysate, (5) low molecular weight standards*

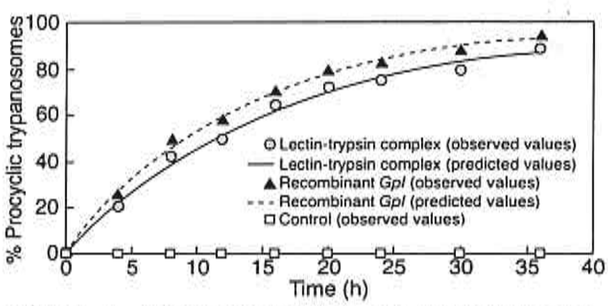


***Figure 3. Transformation of bloodstream trypanosomes by* Gpl**

Screening for the *Gpl* gene in other haematophagous arthropods revealed that it is only expressed in *Glossina* species. No trace of the gene was found in other haematophagous arthropods (Figure 4). Work on expression of the *Gpl* in tsetse flies at different intervals following a bloodmeal and following trypanosome infection is in progress.

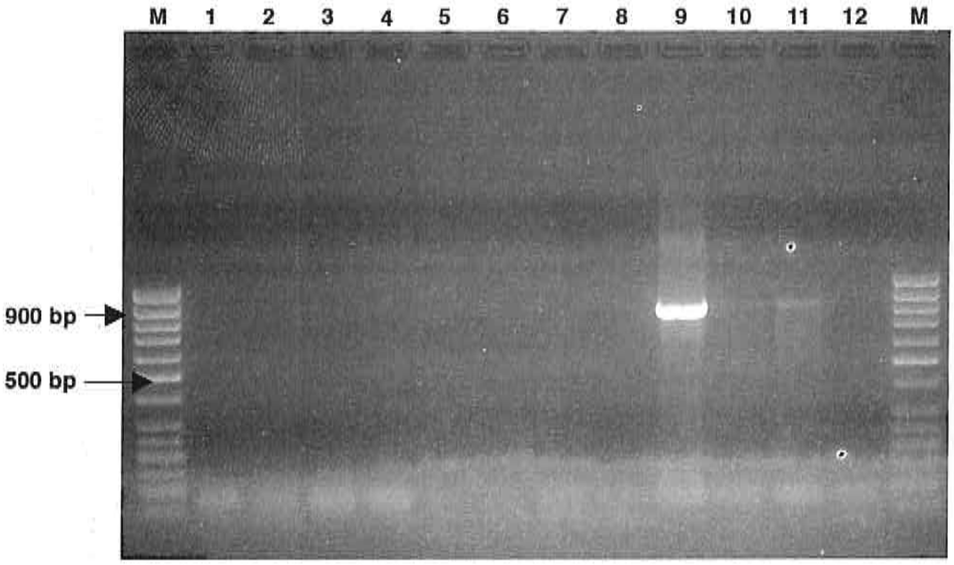


Figure 4. Ethidium bromide-stained 1.5% agarose gel of* Gpl *expression in arthropods

Lanes M, 50 bp DNA marker; 1 and 2, fed and unfed Anopheles gambiae; *3 and 4, fed and unfed* Rhipicephalus appendiculatus; *5 and 6, fed and unfed* Phlebotomus duboscqi; *7 and 8, fed and unfed* Stomoxys calcitrans; *9 and 10, fed and unfed* Glossina fuscipes fuscipes; *11 and 12, fed and unfed* Glossina austeni

Bloodmeal identification system (ELISA) for tsetse

This activity continues as a paid-for service, with 139 samples identified during the review period, and 1200 to date. *(See also the report of the Molecular Biology and Biotechnology Unit.)*

CAPACITY BUILDING

PhD students

Mathew Bett (Kenya) Identification of repellents from unpreferred hosts of tsetse for integrated management of tsetse. Moi University, Eldoret.

Spala Oduor Ohaga (Kenya) Optimisation of olfactory and visual baits for *Glossina swynnertoni*. Kenyatta University.

MSc students

Patrick S. Musyoki (Kenya) Optimising the dispenser design for a tsetse repellent. University of Nairobi.

Peninah Munyua (Kenya) Toxicological assessment of the tsetse repellent. University of Nairobi.

Workshops and training

John Andoke, Research Assistant at ICIPE working with the repellent project was sent to Addis Ababa, Ethiopia for training in kriging/mapping technology for use in tsetse control operations from 1–10 April 2003.

A consultative workshop with pastoralists involved in the field trials in Nguruman was held on 27 February 2003. The objective of the workshop was to brief everyone on the new trials with the repellent, address any concerns and provide a forum for discussion.

Training of livestock keepers in Narok to educate them on tsetse trapping and repellent technologies was undertaken from 23–28 October 2003.

For publications, see the report of the Molecular Biology and Biotechnology Unit

Participating scientists: E. O. Osir, L. Abubakar and F. Mulaa

Student: M. W. Burugu

Assisted by: J. Kabii

Donors: WHO-TDR and ICSC-World Laboratory

Collaborators: Kenyatta University and University of Nairobi (Kenya)

OUTPUT

Journal articles

Abubakar L. U., **Bulimo W. D., Mulaa F. J. and** *Osir E. O.* **(2003)** Molecular and functional characterization of a proteolytic lectin from midgut of the tsetse fly, *Glossina fuscipes fuscipes*. *Insect Biochemistry and Molecular Biology* (submitted).

Abubakar L. U., **Zimba G., Wells C., Mulaa F. and** *Osir E. O.* **(2003)** Evidence for the involvement of a tsetse midgut lectin-trypsin complex in differentiation of bloodstream-form trypanosomes. *Insect Science and Its Application* 23, 197–205. **(Call No.: 03-1748)**

We have previously described a bloodmeal-induced molecule (lectin-trypsin complex) from the midgut of the tsetse fly, *Glossina longipennis*, with both lectin and trypsin activities (Osir et al., 1995). In this paper, we report on the isolation of a similar molecule from the midguts of *Glossina fuscipes fuscipes* and provide direct evidence for its involvement in the development of African trypanosomes. The molecule (native M_r ~65,700) has two non-covalently linked subunits, M_r ~28,800 and M_r ~35,700. The native moleculae was found to be capable of inducing differentiation of bloodstream-form trypanosomes into procyclic (midgut forms) *in vitro*. In the assays, specific antibodies against procyclin were used to monitor the transformation of the bloodstream-form trypanosomes into procyclic forms. This induction was specifically inhibited by D-glucosamine. *Cis*-aconitate was also capable of inducing the transformation process with the same efficiency as that of the lectin-trypsin complex. While increasing the concentrations of the lectin-trypsin complex ($\geq$ 100 μg/ml) in the incubation assays resulted in higher transformation rates, it also led to high parasite mortality. These results provide evidence for the involvement of the midgut lectin-trypsin complex in the differentiation of bloodstream-form trypanosomes within tsetse midgut.

Gikonyo N. K., Hassanali A., Njagi P. G. N. and *Saini R. K.* (2003) Responses of *Glossina morsitans morsitans* to blends of electroantennographically active compounds in the odors of its preferred (buffalo and ox) and nonpreferred (waterbuck) hosts. *Journal of Chemical Ecology* 29, 2331–2345. **(Call No.: 03-1705)**

In a previous study, comparison of the behavior of teneral *Glossina morsitans morsitans* on waterbuck, *Kobus defassa* (a refractory host), and on two preferred hosts, buffalo, *Syncerus caffer*, and ox, *Bos indicus*, suggested the presence of allomones in the waterbuck odor. Examination of the volatile odors by coupled gas chromatography-electroantennographic detection showed that the antennal receptors of the flies detected constituents common to the three bovids (phenols and aldehydes), as well as a series of compounds specific to waterbuck, including C_8–C_{13} methyl ketones, δ-octalactone, and phenols. In this study, behavioral responses of teneral *G. m. morsitans* to different blends of these compounds were evaluated in a choice wind tunnel. The flies' responses to known or putative attractant blends (the latter comprising EAG-active constituents common to all three animals and those common to buffalo and ox, excluding the known tsetse attractants, 4-methylphenol and 3-*n*-propylphenol), and to putative repellent (the blend of EAG-active compounds specific to the waterbuck volatiles), were different. A major difference related to their initial and final behaviors. When a choice of attractant blends (known or putative) and clean air was presented, flies initially responded by flying upwind toward the odor source, but later moved downwind and rested on either side of the tunnel, with some preference for the side with the odor treatments. However, when presented with a choice of waterbuck-specific blend (putative repellent) and clean air, the flies' initial reaction appeared random; flies flew upwind on either side, but eventually settled down on the odorless side of the tunnel. Flies that flew up the odor plume showed an aversion behavior to the blend. The results lend further support to previous indications for the existence of a tsetse repellent blend in waterbuck body odor and additional attractive constituents in buffalo and ox body odors.

Gikonyo N. K., Hassanali A., Njagi P. G. N., **Gitu P. M. and Midiwo J. O. (2002)** Odor composition of preferred (buffalo and ox) and nonpreferred (waterbuck) hosts of some savanna tsetse flies. *Journal of Chemical Ecology* 28,969–981. **(Call No.: 02-1626)**

A previous study on the feeding responses of tsetse flies, *Glossina morsitans morsitans*, implicated the existence of allomonal barriers, both volatile and nonvolatile, on the nonpreferred host, waterbuck, *Kobus defassa*. In the present study, electroantennogram-active compounds in odors from waterbuck were compared with those of two preferred hosts of tsetse flies, buffalo, *Syncerus caffer*, and ox, *Bos indicus*. Odors from the three bovids were trapped on activated charcoal and/or reverse-phase (octadecyl bonded) silica and analyzed with a gas chromatography-linked electroantennographic detector (GC-EAD) and, where possible, identified by using gas chromatography-linked mass spectrometry (GC-MS) and chromatographic comparisons with authentic samples. The GC-EAD profiles (with *G. m. morsitans* antennae) of the odors of the two preferred hosts were comparable, comprising medium-chain, saturated or unsaturated aldehydes and phenols, with buffalo emitting a few more EAG-active aldehydes. Waterbuck odor gave a richer profile, consisting of fewer aldehydes but more phenolic components and a series of 2-ketones (C_8–C_{13}) and δ-octalactone. This bovid also emits moderate amounts of C_5–C_9 straight-chain fatty acids, some of which were detected in buffalo and ox only in trace amounts. However, these did not elicit significant GC-EAD responses. Waterbuck profiles from the antennae of *G. pallidipes* showed broad similarity to those from *G. m. morsitans*, although the composition of aldehydes and ketones was somewhat different, indicating species-specific difference in the detection of host odors. Certain waterbuck-specific EAG-active components, particularly the 2-ketones and lactone, constitute a candidate allomonal blend in waterbuck odor.

Kongoro J. A., Osir E. O., **Imbuga M. O. and Oguge N. O. (2002)** Comparison of midgut trypsin/lectin activities and trypanosome infection rates in three *Glossina* species. *Insect Science and its Application* 22, 295–301. **(Call No.: 02-1671)**

Midgut trypsin and lectin levels were determined in three tsetse species, namely *Glossina morsitans morsitans*, *G. longipennis* and *G. fuscipes fuscipes*. In addition, the abilities of midgut homogenates prepared from these flies to transform bloodstream-form *Trypanosoma brucei brucei* and *T. congolense* were compared *in vitro*. In all the species examined, trypsin levels did not differ significantly up to 24 h post-bloodmeal. There were similar rates of transformation of the bloodstream-form trypanosomes into procyclic (midgut) forms *in vivo*, so that all species had similar levels of infection in the midgut. However, trypsin levels continued to increase beyond 24 h, reaching a peak between 48 and 72 h. The peak was lowest in *G. m. morsitans*. The midgut homogenates in this species also had the lowest levels of lectin. The species had the highest levels of mature *T. congolense* and *T. brucei* infections. We propose that the lower levels of peak midgut trypsin and lectin in *G. m. morsitans* is important in the establishment of trypanosome infections in this species of tsetse.

***Mireji P. O.*, Mabveni A. M., Dube B. N., *Ogembo J. G.*, *Matoka C. M.* and Mangwiro T. N. C. (2003)** Field responses of tsetse flies (Glossinidae) and other Diptera to oils in formulations of deltamethrin. *Insect Science and Its Application* 23, 317–323. **(Call No.: 03-1732)**

Investigations were conducted to establish field responses of *Glossina pallidipes*, *G. m. morsitans*, muscoids and tabanids to castor, raw linseed, paraffin and chlorinated paraffin oils in deltamethrin suspension concentrate (sc) formulation, through randomised Latin square experiments. Tsetse landing responses on targets treated with 400 ml/m² of any of the oils in 2 g/m² deltamethrin formulation were significantly lower than on non-oil-containing deltamethrin formulations, for both *G. pallidipes* ($F_{(4,32)} = 4.855$, $P = 0.00357$) and *G. m. morsitans* ($F_{(4,32)} = 2.421$, $P = 0.06862$).

The landing response indices, relative to the control formulation without oil, were 0.60, 0.70, 0.61 and 0.41 in *G. pallidipes* and 0.92, 0.82, 0.75 and 0.42 in *G. m. morsitans* and for paraffin, chlorinated paraffin, castor and raw linseed oils respectively. *Glossina pallidipes* and *G. m. morsitans* landing responses were inversely proportional to raw linseed oil concentrations. None of the oils significantly affected muscoid ($F_{(4,32)} = 1.6959$, $P = 0.1753$) or tabanid ($F_{(4,32)} = 1.7546$, $P = 0.1624$) landing response, or tsetse fly resting persistence ($F_{(4,32)} = 0.9641$, $P = 0.4406$) on the targets.

The reduced tsetse fly response to targets treated with any of the oils can be attributed to adverse effect of the oil treatments on the tsetse fly olfactory responses to the targets. Since the oil formulations reduce target efficiency by reducing tsetse responses to the targets, application of the oil formulations on targets deployed in *G. pallidipes* and *G. m. morsitans* control programmes is not recommended.

***Saini R. K.* and *Hassanali A.* (2003)** A novel method for controlling tsetse flies and other blood feeding insects (patent application).

Conferences, workshops and papers presented

3rd International Course on African Trypanosomes (ICAT), Lisbon, Portugal, 20–25 May 2003. Jointly organised by World Health Organisation (WHO), International Atomic Energy Agency (IAEA), Médicins Sans Frontières (MSF) and Association Against Trypanosomiasis in Africa (ATA). Practicals on dissection of tsetse were conducted and invitational lectures given by R. K. Saini on:

- Integrated vector control.
- *Glossina* morphology, biology and ecology
- *Glossina* classification and identification keys.

14th European Conference of the Society of Vector Ecology (SOVE) Bellinzona, Switzerland 2–7 September 2003. Paper presented: Repellents as tools for integrated tsetse management. R. K. Saini.

FAO/PAAT Coordinators meeting in Pretoria, South Africa, 24–25 September 2003. Paper presented: Practical research to increase efficiency of tsetse and trypanosomiasis intervention operations. R. K. Saini.

27th Meeting of the International Scientific Council for Trypanosomiasis Research and Control (ISCTRC), Pretoria, South Africa, 28 September–3 October 2003. Paper presented: Repellents for protection of pastoralist cattle from tsetse and trypanosomiasis avoidance of refractory 'hosts' by tsetse and identification of mediating semiochemicals. R. K. Saini.

Recent advances in livestock keeper-based tsetse control. Workshop organised by Department of International Development (DFID) AHP, Nairobi, Kenya, 21–23 October 2003. R. K. Saini.

52nd Annual Meeting of American Society of Tropical Medicine and Hygiene (ASTMH), Philadelphia, USA, 3–7 December 2003. Paper presented: Integrated disease and vector control for the management of trypanosomiasis. R. K. Saini.

14th European Conference of the Society of Vector Ecology (SOVE) Bellinzona, Switzerland, 2–7 September 2003. Paper presented: Avoidance of refractory 'hosts' by tsetse and identification of the mediating semiochemicals. A. Hassanali.

A team of ICIPE experts attended a workshop on tsetse/trypanosomosis control organised by the 'Farming in Tsetse Controlled Areas (FITCA)' in Benshangul Gumuz, Amhara and Oromiya Regional States. The team presented papers on adaptive tsetse management and on the community-based tsetse control initiative approach. The team also demonstrated the ICIPE activities in a technology transfer workshop and exhibition organised by MOARD in collaboration with ILRI and CIDA.

Technical reports

Saini R. K. and Hassanali A. (2002) Enhancing the Diffusion of New Tsetse Control Technologies for Improved Livestock Health and Productivity in Smallholder Indigenous Communities of Sub-Saharan Africa. Implementation Progress Report (IPR), October 2001–September 2002.

Saini R. K. and Hassanali A. (2003) Enhancing the Diffusion of New Tsetse Control Technologies for Improved Livestock Health and Productivity in Smallholder Indigenous Communities of Sub-Saharan Africa. Implementation Progress Report (IPR), October 2002–September 2003.

Research proposals

Fighting Africa's Deadly Sleep with New Eco-friendly Solutions.

Capability Strengthening through Postgraduate Research on Trypanosomosis and Tsetse Vectors.

Towards Improved Animal and Human Health in Africa through Better Management of Riverine Tsetse amd Trypanosomosis.

Management of Human Sleeping Sickness in Chad through Integrated Disease and Vector Control—Funded.

Development of Sustainable Community-based Management of Tsetse (and Trypanosomosis) in Ethiopia through Strategic Deployment and Improved Odour-baited Trap Technology—Funded.

Expression of Surface Genes of *T. brucei* in Insect Larvae for Diagnosis and Diseases Staging—Funded.

Specific Molecular Targets as Novel Anti-parasitic Drugs (WHO-TDR)—Partially funded.
Community-based Tsetse and Trypanosomosis Control in Mwea Area of Kenya—Funded.
Community-based Tsetse Roll Back Initiative (SDC/Helvetas/Biovision)
Community-based Tsetse Roll Initiative (Oromiya Regional State)
Community-based Tsetse Roll Back Initiative (Benshangul Gumuz Regional State)
Community-based Integrated Tsetse Adaptive Management Approach (Gurage Development Association).

Collaborators in tsetse research: World Health Organisation (WHO); International Livestock Research Institute (ILRI), Nairobi; Kenya Trypanosomiasis Research Institute (KETRI), Nairobi; Laboratoire de Recherches Veterinaires et Zootechniques (LRVZ), Chad; Livestock Research Institute (LIRI), Uganda; University of Glasgow, UK; University of Buenos Aires, Argentina; South African Institute of Bioinformatics (SANBI); International Foundation for Science (IFS); Kenya Wildlife Service (KWS), Nairobi; Kenya Agricultural Research Institute, National Veterinary Research Centre (NVRC, KARI) Kenya; Ministry of Livestock and Fisheries, Kenya; Ministry of Education, Science and Technology (Kenya); Department of Zoology, University of Nairobi, Kenya; Kenyatta University, Kenya; Olkaramatin Group Ranch, Nguruman, Kenya

ADAPTIVE TSETSE POPULATION MANAGEMENT IN ETHIOPIA

BACKGROUND, APPROACH AND OBJECTIVES

In Ethiopia, disease-carrying tsetse flies and mosquitoes have dictated the pace and pattern of economic development in the western and southern parts of the country. Some 10–14 million head of cattle and an equivalent number of equines and small ruminants (goats and sheep) are exposed to the risk of trypanosomosis, with losses of some US$ 1.4 million being reported, excluding losses of animal traction and manure. Livestock, and particularly cattle, cannot be introduced and used for agricultural production in about 150,000 km² of fertile valleys in the west and southwest parts of Ethiopia due to the tsetse threat. At the same time, human and livestock populations are concentrated in the tsetse- and trypanosomosis-free, but ecologically fragile, highlands, with the resultant effect of overgrazing, over-ploughing, soil erosion, land degradation, loss of resources and poverty.

The Ethiopian government is obliged to spend the substantial amount of US$ 1 million of scarce resources annually in order to curb the effects of trypanosomosis and related problems. About US$ 1 million is spent for trypanocidal drugs every year yet the problem remains.

Traditionally, animal health improvement has been sought by increasing host resistance or tolerance to the disease, by drug administration to hosts to control the disease, and by vector control to reduce disease transmission. Several control technologies have been developed and integrated vector and disease management schemes have been proposed. For the area under study, a team of experts relied on the encouraging results of previous operations in Ethiopia. They recommended an integrated management scheme with vector control by mass trapping using odour-baited traps and complementary drug administration as key elements.

Tsetse control by species-specific odour-baited traps requires tsetse population surveys and deployment of traps to cover the control area, with a predefined trap density of 4 to 16 per km². The Food and Agriculture Organisation (FAO) of the United Nations recommends 4 control traps per km². An important factor is the mobility of tsetse flies, which cover vast areas and render large-scale operations indispensable for satisfactory control operations. Mass trapping requires a high number of traps, resulting in costs that are a burden to resource-poor communities.

The systems approach enables the identification of compartments that, as a first step, can be studied separately. For example, separate teams can deal with tsetse-trypanosomosis-cattle, mosquito-malaria-human hosts, and plant pest-crop compartments. The tsetse-trypanosomosis-cattle compartment is the best entry point in attempts to improve the livelihoods of Ethiopian farmers.

Ecological systems are characterised by high complexity, multiple causalities and uncertainties. The traditional experimental approaches used by most scientists are not adequate to study these systems, and adaptive management procedures ('learning by management') have been proposed instead. (*See report of the Population Ecology and Ecosystem Science Department in this document.*) Tsetse management provides a case study for population systems study and management.

Several sites have been chosen for adaptive management of tsetse in Ethiopia. Each site passes through four implementation phases:

Phase 1: Awareness building, training
Phase 2: Tsetse fly suppression followed by the design of an adaptive tsetse population management system (APM) (including monitoring, system design and precision-targeted control operations)
Phase 3: Implementation of APM, undertaking of measures to enhance sustainability (and initiation of an additional 4-phase project, such as malaria control)
Phase 4: Technical backstopping (and continuation of the additional 4-phase project).

In 2003, the Luke project was in Phase 2. This report focuses on the Luke site and the work done from October 2002 to December 2003.

WORK IN PROGRESS

The project site is located at Luke, in Cheha Woreda of Gurage zone, and covers about 50 km² of tsetse-infested area at altitudes ranging from 1100 to 1800 metres above sea level (masl). The study area is located in southwest Ethiopia at N 80°10' 9" latitude and E 37° 35' 35" longitude. The Luke site is divided into three villages and six sub-villages, whereby residential areas are located in the plateaus, and the settlers from the respective villages use the tsetse-infested lowlands for animal grazing and watering during the dry season. These vast and fertile lowlands have not been used for farming purposes for close to three decades, apparently because of increasing tsetse and trypanosomosis problems.

The vegetation in the area is characterised as woody savanna grassland with scattered acacia trees and thickets along rivers and streams which are suitable habitats for tsetse populations. Various wildlife present in the area are potential hosts for tsetse species.

Since 1996, tsetse (*Glossina* spp.) control operations based on use of odour-baited traps have been carried out in the Luke area. Our survey results of the area showed that *Glossina morsitans submorsitans* Newstead is the dominant species in the plains area, but *Glossina pallidipes* Austen and *G. fuscipes fuscipes* Newstead were also present along the escarpment of the Gibe river system. *Glossina morsitans submorsitans* Newstead is the dominant species in the plains area, but *G. pallidipes* Austen and *G. fuscipes fuscipes* were also present along the escarpment of the Gibe river system. Here, we refer to the combined number of these three species and report the work undertaken to render the control system more efficient by maintaining the previously-reached levels of tsetse occurrence and trypanosomosis prevalence.

This was done by the design and implementation of an adaptive tsetse population management system. It consists first of an efficient community-participatory monitoring system that allowed the number of traps to be reduced from 217 to 107 monitoring and 25 control traps. Geostatistical methods, including kriging and mapping, allowed identification and monitoring of the spatio-temporal dynamics of patches with increased fly densities, named as 'hotspots'.

1. Adaptive tsetse population management system

Monitoring operation

Two hundred seventeen (217) Monoconical traps (Vavoua version) baited with cow urine were deployed on January 2003 along several paths, at 250 m within and 500 m between rows. Trap locations were geo-referenced using the geographic positioning system (GPS). Trap catch collection was done weekly and catches were classified and identified using standard keys. The fly catch during the monitoring period from 18 January to December 2003 is presented in Figure 1.

Spatial analysis

Tsetse fly catch data was used to analyse the spatial distribution of flies and design a monitoring system for obtaining information on tsetse occurrence in space and time and subsequently derive rules for the precision tsetse mass trapping operation. Surfer version 8.02 (Golden software, Golden CO, USA) was used to construct contour maps of tsetse distribution. Autocad release 14.0 (Auto Desk Inc., San Rafael CA, USA) was used for setting of scale and coordinates of base maps.

Adaptive tsetse management strategy development

The development of the adaptive management scheme required two periods. During the first period, an adequate trap deployment strategy was developed

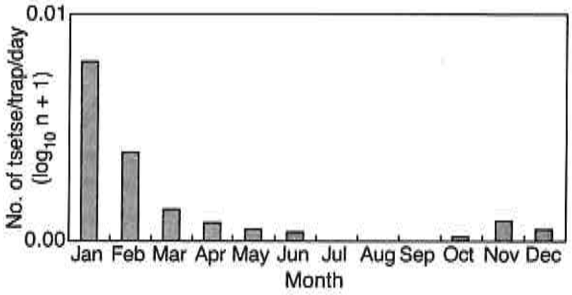


Figure 1. Tsetse monitoring trap catch from January to December 2003

using 217 monitoring traps. Spatial analysis allowed the study of the weekly occurrences and the identification of those patches with a higher catch than the others defined as hot spots.

Statistical analysis of catches of monitoring traps using different numbers and arrangement of traps (from 100 to 33% of traps) showed that the tsetse distribution information obtained from 50% of the traps was adequate to determine the distribution of the fly population. Thus, monitoring trap numbers were reduced from 217 to 107 traps and used for the second year's operation.

To respond to hotspots, the Luke community was advised and assisted in control trap deployment. Adaptive management was shown to be more efficient than the previously used mass trapping system. Trap numbers could be substantially reduced by maintaining previous levels of tsetse occurrences and disease prevalence.

2. Disease management

A number of animals from different sub-villages were examined repeatedly for trypanosomosis. Blood samples were subjected to different blood analysis methods. The Packed Cell Volume (PCV) was also adopted to determine the level of anaemia. Animals with low PCV (i.e less than 20%) were classified as anaemic or in poor condition. Wet smear methods were also used for parasite identification (Table 1).

3. Preliminary impact assessment

In 2003, 100 different household heads were randomly sampled for a socioeconomic survey of the Luke village.

Table 1. Trypanosomosis prevalence, species occurrence and mean PCV[1] in Luke, 2003

Date	Number of cattle examined	Percentage infected cattle	Species of trypanosome detected (no. of positive animals)	Mean PCV (wet blood smear)
January 2003[2]	240	8.75%	*T. congolense* (8) *T. vivax* (13) *T. brucei* (0)	20.2
June–July 2003	89	10.1%	*T. congolense* (2) *T. vivax* (7) *T. brucei* (0)	22
December 2003	214	10.75	*T. congolense* (6) *T. vivax* (17) *T. brucei* (0)	23

[1]PCV = Packed cell volume.
[2]The intervention took place from January to December 2003.

The number of animals in Luke by the end of 2003 has been estimated at 2250. The cattle population of the village increased from 2000 levels and productivity also improved. Overall, the total animal population in Luke grew by 136% between 2000 and end-2003. The milk yield/cow/day improved substantially from 0.25 litres to over 1.0 litre/cow/day, a 3-fold increase. The calving interval has improved, the abortion rate has been minimised or stopped, and farmers are buying new animals; relatives living in tsetse-infested villages are moving their animals to the tsetse-controlled Luke village for grazing.

Before the intervention farmers used to till only their backyards, using a hand hoe. The availability of oxen has allowed farmers to grow field crops for home consumption and income generation, which helps to assure the sustainability of the intervention. Between late 1999 and 2003, cultivated cropland increased 10-fold, from 5 ha to 50 ha.

The increased number of cattle and more intensified land use may be seen as indicators for cattle health improvement and rural development. However it is noted that the increase in cattle numbers might result in overgrazing and contribute to biodiversity losses at the genetic, species and ecosystem levels.

FUTURE OUTLOOK

Efforts to enhance human health and reduce poverty have to take into consideration the fact that the livelihood of people in eastern Africa is constrained by more than one factor. The removal of one factor, such as famine, for example, does not improve the livelihood of people who may also be seriously affected by malaria, for example. The inhabitants of the Luke community were pleased with the results of tsetse control operations, but stated that their livelihood had not improved since they are also suffering from malaria. Malaria is not only a serious cause of mortality and morbidity, but reduces the time available for agricultural activities such as land cultivation and bee keeping. This means that a system approach has to be used in attempts to improve the livelihoods of rural people.

Future work will focus on:

- strengthening the on-going tsetse trypanosomosis control operation;
- development of a long-term programme to sustain the intervention;
- expand the tsetse-trypanosomosis control to Oromiya Regional State, if funding permits;
- mobilise regional governments to support and take over the tsetse control programmes in their respective areas.

CAPACITY BUILDING

Practical training on tsetse trapping technology was given to 75 farmers on 20 December, 2002. The demonstrations included tsetse control techniques from trap design and functions to trap making, deployment and servicing.

A workshop and training course was given to professionals from Addis Ababa University, Biofarm Enterprise and the Ethiopian Agricultural Research Institute (EARO). The aim of the workshop was to pass the kriging/mapping technology from Molise University (Italy) to ICIPE, to discuss tsetse population movements with respect to barrier construction, and to prepare a plan of action for the second phase of the project.

Research proposals

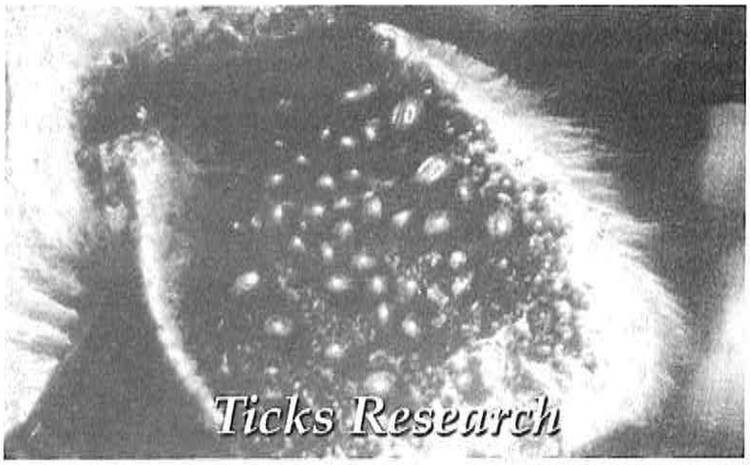
Development of Sustainable Community-based Management of Tsetse (and Trypanosomosis) in Ethiopia through Strategic Deployment and Improved Odour-baited Trap Technology—Funded.
Community-based Tsetse Roll Back Initiative (SDC/Helvetas/Biovision)
Community-based Tsetse Roll Initiative (Oromiya Regional State)
Community-based Tsetse Roll Back Initiative (Benshangul Gumuz Regional State)
Community-based Integrated Tsetse Adaptive Management Approach (Gurage Development Association).

Participating scientists: Getachew Tikubet (Team Leader and Project Executant), J. Baumgärtner (Project Supervision), G. Melaku (Entomologist and Tsetse Ecologist), Shifa Ballo (Socio-economist), Teame Hagos (Veterinarian), G. Gilioli (Systems Analyst, Epidemiologist), A. Sciarretta (Geographic Information System Specialist)

Assisted by: B. Lulseged, A. Tilahun, G. Girma, Y. Murad, A. Tesfaye, A. Assefa, Mrs Tobiya Asseged, Mrs W. Alemtsehai

Collaborators: Oromiya, Gurage Zone and Benshangual Gumuz Bureaus of Agriculture; Ethiopian Social Rehabilitation and Development Fund (ESRDF); Addis Ababa University

Donors: Swiss Development Corporation (SDC); Biovision Foundation (Zurich, Switzerland); Oromia Regional Government (Ethiopia); Ethiopian Social Rehabilitation and Development Fund (ESRDF); Benshangul Gumuz Regional Government (Ethiopia); Gurage Community Development Association (Ethiopia)



EVALUATION AND APPLICATION OF ANTI-TICK NATURAL PRODUCTS USED BY THE BUKUSU IN LIVESTOCK HEALTH MANAGEMENT IN BUNGOMA DISTRICT, KENYA

BACKGROUND, APPROACH AND OBJECTIVES

The Bukusu are a group in western Kenya who combine both arable and pastoral lifestyles for their survival. The objective of this study is to survey, document and evaluate the Bukusu community's anti-tick ethnopractices in the suitable management and control of the vector of the deadly cattle disease, East coast fever (ECF), carried by the brown ear tick, *Rhipicephalus appendiculatus* Neumann.

The study's approach includes the following:

- Undertaking group and individual interviews and discussions with identified key community-based ethnopractitioners, veterinarians and field staff from the Ministries of Health, Agriculture, Livestock and Fisheries by a community-based participatory appraisal (AP) approach.
- Analysing the generated information and comparing it with the existing literature.
- Selecting potential anti-tick ethnobotanicals for an in-depth scientific study and subsequent appropriate application in 'push' and 'push-pull' strategies for community use in managing the threat posed by livestock ticks to animal welfare and productivity.

WORK IN PROGRESS

1. Orientation behaviour of *Rhipicephalus appendiculatus* on the host

Studies were undertaken to investigate the directional movement and feeding site preference of *R. appendiculatus* on the host. The objective is to eventually evaluate ethnobotanicals from the Bukusu community, which will be used to intercept these orientation pathways, some distance away and closer to the feeding site.

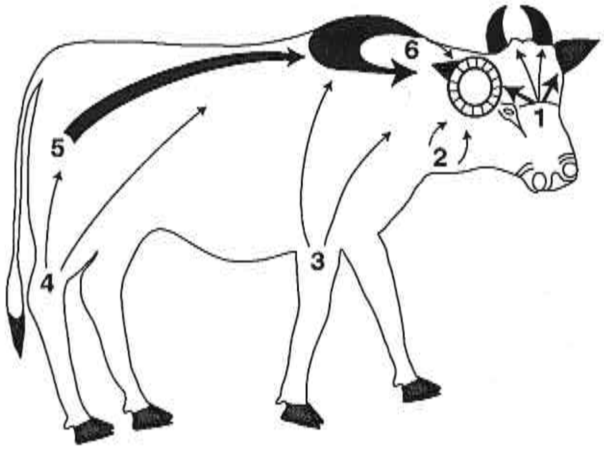


Figure 1. General pathways of ticks on the host. Numbers indicate points where ticks were released

In order to investigate this behaviour, individual ticks of mixed age and both sexes were released at one of the six sites on a cow as shown in Figure 1. The navigation patterns were observed for 8 hours between 0700 to 1800 hr.

The results clearly show that the preferred predilection site of *R. appendiculatus* ticks is the ear, and no matter where the ticks are released on the animal, they orient themselves towards the ear.

2. Laboratory bioassays with host semiochemicals

Host odours were trapped from the inner side of host ear pinna using either activated charcoal or reverse-phase C_{18}-bonded silica and dissolved in dichloromethane (25 ml) to give an approximately 80 ppm solution. The responses of the ticks to the odours were evaluated using a 2-choice climbing assay, shown in Figure 2.

Our observations suggest the operation of both avoidance (away from the feeding site) and attraction (closer to the predilection feeding site) responses in the ticks. In the laboratory, odour trapped from cattle ears attracted *R. appendiculatus*, whereas that from the anal region repelled the ticks (Figure 3). This

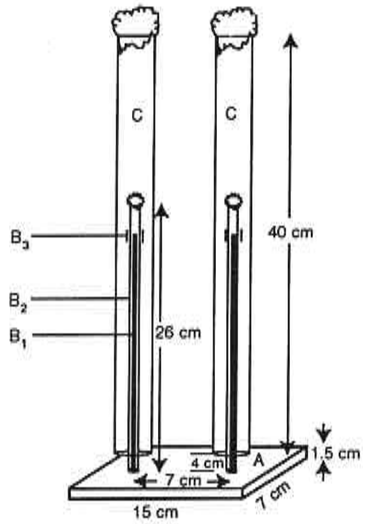


Figure 2. Tick climbing bioassay apparatus (placed in a tray of shallow water)

A = aluminium base; B_1 = aluminium rod (26 cm l x 0.7 cm diam.); B_2 = 0.8 cm diam. glass tube; B_3 = collar of filter paper; C = 4.5 cm diam. glass tube

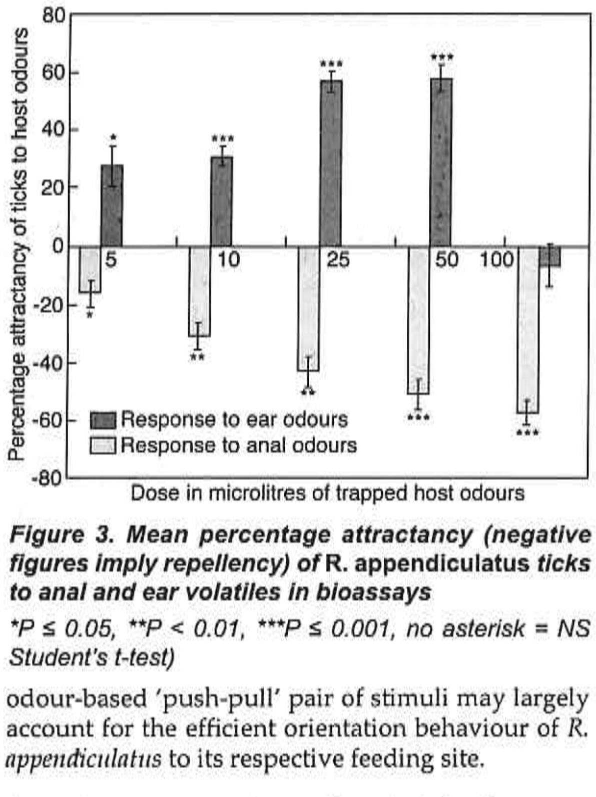


Figure 3. Mean percentage attractancy (negative figures imply repellency) of* R. appendiculatus *ticks to anal and ear volatiles in bioassays

**P ≤ 0.05, **P < 0.01, ***P ≤ 0.001, no asterisk = NS Student's t-test)*

odour-based 'push-pull' pair of stimuli may largely account for the efficient orientation behaviour of *R. appendiculatus* to its respective feeding site.

3. Literature review of anti-tick plants as acaricides

Using the Internet, libraries of research institutions, NGOs, CBOs and herbaria, a scientific database of over 140 anti-tick plants evaluated in different communities worldwide has been made. These anti-tick plants are potentially useful for developing sustainable and effective botanical acaricides suitable for different rural livestock farmers. The database contains details of the plant species and family name, the parts of the plant used, the form of application, action of the ethnobotanicals, place in the world where the study was done, and source and references.

Characteristics of the ethnoknowledge leading to the identification of botanicals can be searched at three levels: individual-specific, community/society-specific and geographical location-specific.

The bioactive properties of the ethnobotanicals for use in tick control have been categorised as being toxic, repellent, antifeedant, oviposition and embryogenesis inhibitor, and as having the potential to control target tick species.

From the literature, it is obvious that in different areas, communities have different anti-tick knowledge. There is a danger that much of this anti-tick knowledge may disappear if it is not documented and evaluated. Developing and applying the anti-tick knowledge known by a given group is likely to be more successful than imposing control methods from a different area or community.

4. Anti-tick ethnoknowledge from the Bukusu community

A modest survey on the indigenous anti-tick knowledge of the Bukusu used approaches and methods drawn from Rapid Rural Appraisal, Participatory Rural Appraisal and Participatory Learning and Action. The survey involved 272 women and men of mixed ages ranging from 18 to 118 years old. School-based questionnaires and focus group and individual interviews with discussions with some key respondents, veterinarians and field staff from the Ministry of Agriculture, Rural and Livestock Development formed the participatory appraisal approaches used. The survey helped community ethnopractitioners regain confidence in their rich ethnoveterinary knowledge based on their own oral tradition, shared information and life experience as individuals.

Ticks and tick-borne diseases were consistently recognised as a major livestock problem in the area. Ticks were traditionally controlled and managed by a variety of methods, including use of ethnobotanicals, hand picking, burning pastures, livestock quarantine, grazing practices, cleaning of the cattle shed and burning/burying residues, bird predation, feeding animals on natural salty soils (locally called *silongo*) and application of kerosene, Magadi soda (sodium bicarbonate), urine and grease. Ethnobotanicals were applied by fumigation, pour-on of decoctions, steaming, dusting, hanging bouquets in the cattle shed, rubbing on of bolus/paste, and grazing animals in the pasture of anti-tick plants.

About 141 anti-tick plant species spread over 103 genera and 48 families were suggested and documented, together with four other non-botanical anti-tick ethnoagents. From the literature search, 11 out of the 141 plants documented with the help of Bukusu community ethnopractitioners have been scientifically evaluated and found to have acaricidal properties. Based on bioactive, pesticidal, insecticidal, acaricidal and taxonomic information from the literature search, 51 plant species not evaluated previously for acaricidal properties were selected for further studies.

5. Key characteristics of anti-tick indigenous knowledge

The following lessons were learned from this study. Anti-tick indigenous knowledge is:

Ubiquitous—The application of traditional knowledge in tick control and management is widespread in almost every community holding or owning livestock

Specific—Anti-tick ethnoknowledge (ethnobotanicals), like any other system of traditional knowledge, is characteristically individual-specific, community/society-specific and geographical location-specific.

Secretive—The knowledge on remedies is kept secret for the owners' economic survival.

Ownership—It is believed that ancestors own the knowledge, the living being the custodian of this knowledge, depending on ethnicity, age, sex and societal status.

Storage and transmission—Storage of the knowledge is largely by remembrance of factual knowledge. It is rarely recorded in books and is transmitted from one generation to another by word of mouth and only to a few trusted individuals who are believed to be anointed by the ancestors.

Types—Traditional knowledge exists in three systems: (i) herbal remedies (purely plant-derived materials), (ii) ritual remedies (non-plant derived materials and or mixture of the two systems), and (iii) magic-religious systems based on religious beliefs and animal offerings and sacrifices. However, herbalism is the most favoured, widely accepted, recognised and used system of traditional knowledge.

Integration of these anti-tick ethnopractices in sustainable tick control and management strategies to improve the local livestock industry gives the impoverished livestock-dependent rural economy a fresh impetus, particularly, following elucidation of the scientific rationale of these ethnopractices and deployment of some of them in an integrated approach to tick management.

6. Optimisation of semiochemical blend for the attraction of *Amblyomma variegatum* ticks

The attraction of ticks to the attraction-aggregation-attachment pheromone (AAAP) in the presence/absence of CO_2 has been previously investigated. The objective of the present study is to investigate the effect of an additional semiochemical component, 1-octen-3-ol, on the performance of AAAP in attracting ticks. This compound is known to be present in volatiles of different life-stages of both *Amblyomma variegatum* and *A. hebraeum* ticks. It is also a constituent of cattle breath and skin surface lipids.

Attraction of A. variegatum *to AAAP and 1-octen-3-ol in the laboratory*

Various amounts of 1-octen-3-ol were mixed with a standard blend of AAAP previously shown to be optimal for attraction of *A. variegatum* in a T-tube olfactometer in the laboratory. The results (Figure 4) show that whereas the males were attracted to increasing proportions of 1-octen-3-ol, the females were repelled. A combination of 8 ng of 1-octen-3-ol

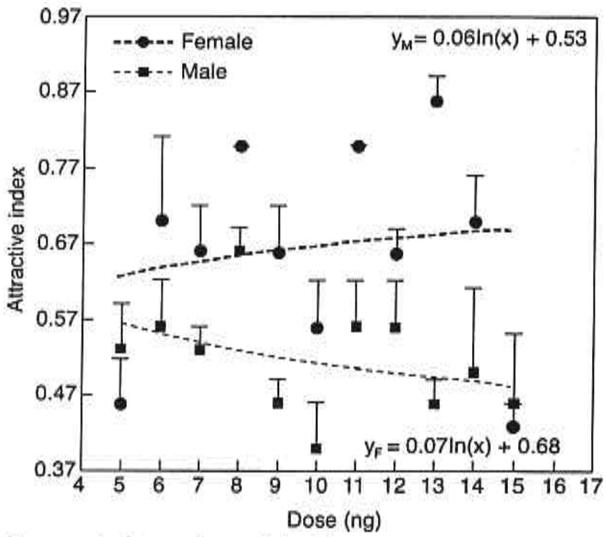


Figure 4. Attraction of* Amblyomma variegatum *to standard AAAP blended with different doses of 1-octen-3-ol

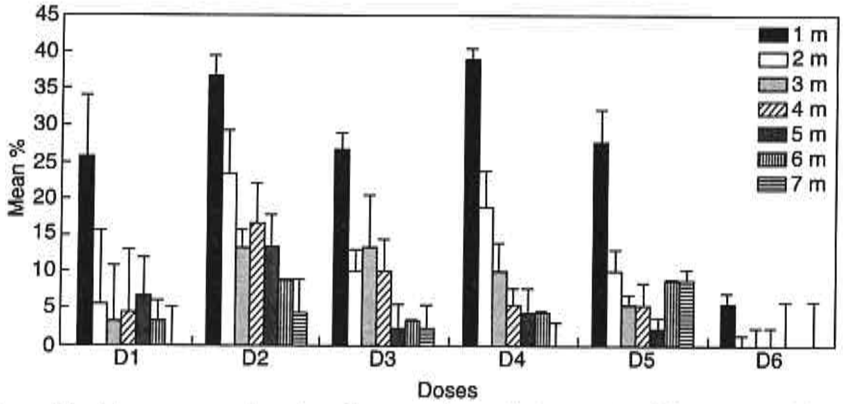


Figure 5. Attraction of* Amblyomma variegatum *from various distances to different combined doses of AAAP and 1-octen-3-ol

with 1.1 mg of AAAP was adopted as the optimum blend for the attraction of both sexes.

Attraction of A. variegatum *to AAAP and 1-octen-3-ol in the field*

The purpose of this study was to investigate the relationship between different doses of AAAP plus 1-octen-3-ol combinations and the attraction of *A. variegatum* from various distances in the field. Several circular plots of 7-m radius were measured. Ticks marked with different colours were released from various distances and attracted to the centre of the plots where the pheromones were placed.

It was observed that the longest distance from which ticks were significantly attracted by the combined doses of AAAP and 1-octen-3-ol was 7 m. The combination of 2.2 mg of AAAP and 16 ng of 1-octen-3-ol (D2 in Figure 5) was found to be the most attractive dose in the field, at the 5% level of significance (SNK test).

(See also reports of the Behavioural and Chemical Ecology Department and the Molecular Biology and Biotechnology Department.)

CAPACITY BUILDING

PhD students

Alioune Toure (Senegal) An assessment of the use of botanical extracts and pheromones for the off-host and on-host control of *Amblyomma variegatum* tick. Kenyatta University, Kenya.

Wycliffe Wanzala (Kenya) Evaluation of anti-tick natural products used in livestock health management by the Bukusu in Bungoma District, Kenya. Wageningen University, the Netherlands.

OUTPUT

Journal articles

Demas F. A., Hassanali A., Mwangi E. N., **Kunjeku E. C. and Mabveni A. R. (2002)** Cattle and *Amblyomma variegatum* odours used in host habitat and host finding by the tick parasitoid, *Ixodiphagus hookeri*. *Journal of Chemical Ecology* 26, 1079–1093. **(Call No.: 02-1657)**

The role of host size, movement, feeding status, color, and species in the visual host evaluation and recognition behavior of the tick parasitoid, *Ixodiphagus hookeri* Howard was investigated. Freshly emerged female parasitoids were subjected to a choice bioassay, where the test materials were placed in sealed vials and the vials placed in a Petri dish. When presented with *A. variegatum* live and mummified nymphs, females examined: larger nymphs significantly longer than smaller nymphs, fed nymphs significantly longer than unfed nymphs, dead and live nymphs for similar lengths of time, and grey live nymphs and yellow-brown and dark brown mummified nymphs for similar lengths of time. The total number of visits to vials containing these test materials were also not significantly different, except there were significantly more visits to yellow-brown mummies when compared to the number of visits to dark brown mummies. When presented with *A. variegatum* (host) and *R. appendiculatus* (nonhost) nymphs, the females examined *A. variegatum* nymphs significantly longer than *R. appendiculatus* nymphs. The total number of visits to vials containing *A. variegatum* nymphs were significantly more than the visits to the vials containing *R. appendicualtus* nymphs. Furthermore, females spent significantly more total examination time per visit on larger and fed *A. variegatum* nymphs when compared to smaller and unfed nymphs, respectively. Direct and indirect detection were significant when females were presented with fed versus unfed *A. variegatum* nymphs, grey nymphs versus yellow-brown mummies, and *R. appendiculatus* versus *A. variegatum* nymphs. Direct and indirect detection for the rest of the bioassays were not significantly different. Finally, the percentages of females contacting large fed *A. variegatum* nymphs first were significantly different from those of females contacting small unfed *R. appendiculatus* nymphs first. The first contact percentages for the rest of the bioassays were not significantly different.

Kinyua J. K., *Osir E. O.,* **Ogoyi D. O. and Nguu E. K. (2002)** Characterization of protective antigens from the midgut of *Amblyomma variegatum* ticks. *Experimental and Applied Acarology* 26, 101–113. **(Call No.: 02-1648)**

Separation of midgut membrane proteins from the tick, *Amblyomma variegatum*, using a non-ionic detergent (Triton X-114), resulted in two protein fractions, namely DET (detergent) and AQ (aqueous). In immunoblotting analysis with polyclonal antibodies against these fractions, 4 proteins (M_r ~27,000, 67,000, 86,000 and 95,000,) and 2 proteins (M_r ~54,000 and 67,000) were detected in the DET and AQ fractions, respectively. Three of the DET fraction proteins M_r ~27,000, 67,000 and 95,000 were glycosylated since they bound to the lectin, concanavalin A. In 2-dimensional gel electrophoresis, the AQ and DET fraction proteins were found to be acidic in nature. In a series of bioassay experiments, rabbits were first immunised with both DET and AQ fractions and then infested with ticks. The egg batch weights of these ticks were reduced by 50% compared to control ticks. Furthermore, there was a significant reduction in the hatchability of eggs laid by ticks fed on rabbits previously immunised with both DET (14%) and AQ (33%) fractions. Based on the egg hatchability, the reproductive capacity of ticks was reduced by 77 and 48% by DET and AQ fractions, respectively.

***Maranga R. O., Hassanali A., Kaaya G. P.* and Mueke J. M. (2003)** Attraction of *Amblyomma variegatum* (ticks) to the attraction-aggregation-attachment pheromone with or without carbon dioxide. *Experimental and Applied Acarology* 29, 121–130. **(Call No.: 03-1696)**

> The responses of adult *Amblyomma variegatum* ticks released from various distances to different doses of the synthetic attraction-aggregation-attachment pheromone (AAAP) (made up of *ortho*-nitrophenol, methyl salicylate and nonanoic acid in paraffin oil), dispensed from the center of circular field plots, were studied in the presence or absence of elevated levels of CO_2. Up to 90% of the ticks released were attracted to the pheromone source in the presence of CO_2 within 3h. CO_2 alone was unattractive, similar to previous findings in Zimbabwe, but unlike results from a Caribbean *A. variegatum* population, which was significantly attracted to this signal. In the absence of CO_2, smaller but significant proportions of the released ticks were attracted to the pheromone, albeit more slowly, suggesting another variation in the responses of this bont tick to inter- and intra-specific signals. Our results are interpreted in the light of a study undertaken elsewhere demonstrating relatively high heterozygosity among tick populations. Possible directions of further research to explore the use of the pheromone in off-host control of the tick are also highlighted.

Takasu K., Takano S.-I, Sasaki M., *Yagi S.* and *Nakamura S.* (2003) Host recognition by the tick parasitoid *Ixodiphagus hookeri* (Hymenoptera: Encyrtidae). *Environmental Entomology* 32, 614–617. **(Call No.: 03-1750)**

> We conducted laboratory experiments to determine whether the tick parasitoid *Ixodiphagus hookeri* Howard uses chemicals of the host tick *Amblyomma variegatum* F. as host recognition cues. When given a piece of polyethylene sheet containing an air bubble (a dummy host) treated or untreated with hexane, *I. hookeri* females did not respond to the dummy. However, when females contacted the dummy host treated with hexane extracts from unfed nymphs, engorged nymphs, or unfed adults of the host ticks, they probed the dummy with their ovipositors. When given a choice of dummies treated with hexane extracts of engorged nymphs, hexane or nothing, they did not demonstrate any selective attraction for the dummy with hexane extract from engorged nymphs over the other dummies. A fraction (hexane 9: ether 1) of hexane extract from engorged nymphs strongly stimulated ovipositor probing by females. These results suggest that *I. hookeri* females use chemicals contacted on host ticks as host recognition cues.

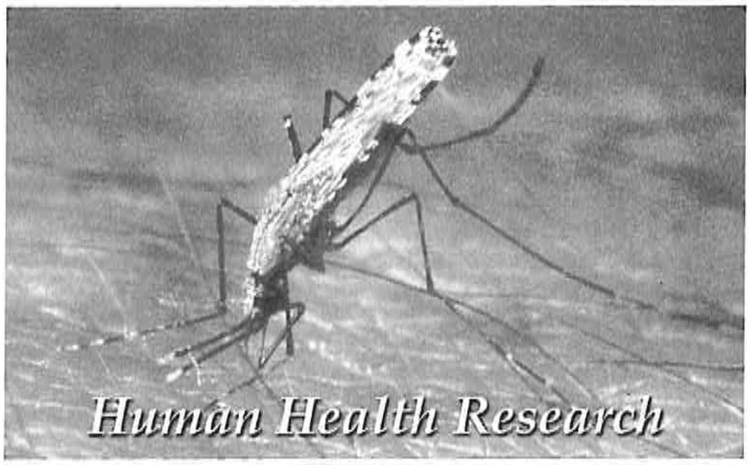
Participating scientists: A. Hassanali, E. Osir

Collaborators: University of Nairobi

Donor: IFS

HUMAN HEALTH RESEARCH





AFRICAN MALARIA VECTORS PROGRAMME: LARVAL ECOLOGY OF *ANOPHELES* SPP.

BACKGROUND, APPROACH AND OBJECTIVES

The distribution of malaria transmission is a function of the spatial and temporal distribution patterns of the malaria vectors. In Kenya, the primary vectors are *Anopheles funestus* and three members of the *Anopheles gambiae* complex: *A. gambiae, A. arabiensis* and *A. merus*. There are also at least six other anopheline species not considered to be vectors. The extent to which environmental heterogeneity affects patterns of vector production, important for malaria parasite transmission, is unknown.

The factors affecting larval survival and the mechanisms controlling adult production are largely unknown for even the most important vector species. For example, it is not known whether populations of *Anopheles* species in Africa are regulated primarily through competition or predation in the diverse aquatic habitats. A basic understanding of the aquatic stages of vectors would be highly relevant to malaria control.

Source reduction through modification of larval habitats was the key to malaria eradication efforts in the United States, Israel and Italy, but there are only limited examples from Africa. Environmental management techniques pioneered in the early 1900s are no longer being taught to the current generation of vector control specialists. Interest in basic environmental management dwindled with the era of cheap and promising insecticides.

The larval ecology of African malaria vectors is a neglected area of malaria research. There have been very few in-depth studies on this subject. The malaria situation on the Indian Ocean coast of Kenya provides an ideal setting for investigating how the transmission of *Plasmodium falciparum* malaria parasites by African malaria vector populations is affected by ecological interactions between mosquito larvae in aquatic habitats and local environmental factors. This should help in addressing fundamental questions about mosquitoes in their natural habitats and how the dynamic influences of the environment and climate affect patterns of malaria infection and disease in residents of the endemic areas. A challenging aspect of this research is to develop new approaches for studying mosquito larval ecology in Africa.

The present project seeks to achieve (i) an improved understanding of the larval stages of African malaria vectors which can lead to better methods for controlling malaria infection and disease in rural communities, and (ii) increase in the basic understanding of environmental/climatic factors affecting the development of larvae in natural aquatic habitats commonly found throughout Africa.

There are three specific aims: (i) determine through district-level field studies of *Anopheles* larval habitats the key environmental determinants regulating the spatial and temporal distributions of malaria vectors and *Plasmodium falciparum* transmission, (ii) determine through longitudinal village-level field studies the impact of climate on the relationships between the dynamics of larval populations of *Anopheles*, the production of adult mosquitoes, the behaviour of adult mosquitoes and the transmission of *Plasmodium falciparum* malaria to humans, and (iii) develop new approaches for the control of larval populations of *Anopheles* mosquitoes by conducting small-scale pilot control projects that involve local communities as organisers and participants.

WORK IN PROGRESS

1. Environmental factors associated with larval habitats of malaria vectors along the Kenya coast

The larval habitats of malaria vectors at three sites, namely Jaribuni, Mtepeni and Majajani in Kilifi District along the Kenya coast, were sampled from May 2000 through April 2002 to determine larval abundance and to identify environmental factors associated with high larval density in three ecologically different zones. Base maps were created using the global positioning system (GPS) and geographic information system (GIS) data to develop distribution maps of the specific larval habitats. The larvae were collected using the standard dipping technique. Three primary habitats were identified: stream pools, ponds and swamps. These habitats were classified as permanent, semi-permanent or temporary pools. Eighteen variables were quantified to describe each habitat.

A total of 9490 *Anopheles* larvae were collected from the three sites with the majority of larvae collected from Jaribuni. The mean number of *Anopheles* larvae per dip collected in the three sites was 0.47 (95% CI 0.38–0.59). The mean larvae per dip collected in each site were: Jaribuni 0.82 (95% CI 0.55–1.09), Majajani 0.22 (95% CI 0.14–0.30) and Mtepeni 0.36 (95% CI 0.11– 0.22).

The primary vector along the coast, *A. gambiae s.s.* occurred in water with a wide range of values for environmental factors, including pH, percentage of surface covered with floating vegetation, dissolved oxygen, conductivity, and content of nitrate, ammonia, phosphate and chlorophyll *a*. One-way ANOVA showed that there was a significant site-to-site variation in the *Anopheles* larval densities ($F_{(2, 2122)}$ = 23.503, $P < 0.001$). Tukey's HSD analysis further indicated that Majajani and Mtepeni were similar in terms of *Anopheles* larvae densities (P = 0.05) but they were different from Jaribuni.

Stepwise multiple linear regression analysis showed that habitat type (P = 0.003) and the emergent plants (P = 0.021) were the most significant predictors for the abundance of anopheline larvae in the three sites. The results suggest that larval *Anopheles* is capable of developing in a wide range of stagnant and freshwater habitats in the coastal zone of Kenya.

2. Distribution patterns, gene flow and dispersal capabilities of anopheline species

This study was initiated in November 2001 at the three sites above along the Kenyan Coast. Mark-release-recapture (MRR) experiments were conducted at two sites, Jaribuni and Mtepeni, from February to June 2002. Experimental procedures for the MRR were developed, in which anopheline mosquito larvae were collected from the larval habitats and reared to adults in temporary field insectaries constructed at the two sites. Emergent adults were marked with fluorescent dyes and released in their original larval habitat. With the assistance of seven trained field workers, recapture of the released mosquitoes began a day after the release date in selected study houses using three methods: hand-held aspiration for collecting indoor resting mosquitoes, human landing catches at night (both indoors and outdoors), and light traps. This combination of collection methods was employed in order to maximise the recapture rate. Night-time collections were done from 1900 to 2400 hrs whereas daytime collections were from 0900 hrs till 1200 hrs (noon).

A total of 739 *Anopheles* mosquitoes were marked and released at the Jaribuni site, and 1254 at the Mtepeni site. Recapture efforts at both sites were conducted for 14 days with recapture rates of 24.6% for Jaribuni and 4.33% for Mtepeni. At the Jaribuni site, *A. funestus* were more abundant than *A. gambiae* (species ratio 4:1). Survival probability rates were 0.95 and 0.96, respectively and population density estimates ranged from 38,694 to 51,747 for *A. funestus* and 8673 to 12,937 for *A. gambiae*. Results from the Mtepeni site indicated a survival probability of 0.95 for *A. gambiae* and 0.83 for *A. funestus*. A higher abundance of *A. gambiae* was recorded here compared to *A. funestus* (species ratio 24:1). Population density estimates were lower compared to the Jaribuni site, and ranged from 3259 to 5158 for *A. gambiae* and 136 to 215 for *A. funestus*. Data analysis is in progress to model the dispersal capabilities of anopheline mosquitoes.

To address the spatial and temporal variations of anopheline species distribution, data collection was conducted in a longitudinal study pattern, including daily records of rainfall, temperature and relative humidity. Weekly collections of *Anopheles* mosquitoes were conducted in households at the three sites over a one-year period. The mosquitoes were morphologically identified, and processed in the laboratory for ELISA tests to determine the source of bloodmeals for blood-fed mosquitoes and to investigate if the mosquitoes were infected with *Plasmodium falciparum*. Field data collection was completed in March 2003.

All ELISA tests have been completed and data entered in Visual FoxPro. Currently, PCR tests are under way for species-specific identification. At the same time, data analysis on spatio-temporal variations is continuing in order to investigate the relationship between species distribution patterns and changes in climatic factors. In order to provide a broad picture of these variations, the one-year data collected in 2002–2003 will be combined during analysis with data previously collected in 2001.

3. Influence of structural complexity on trophic interactions in *Anopheles* larval habitats

The structural complexity present in a habitat influences the magnitude of predation pressures. By decreasing predator-predator antagonism, an increase in structural complexity allows higher predator species diversity within a habitat, thereby increasing predation pressure on lower trophic levels. Although well documented for other ecosystems, the small ground pools in which mosquito larvae develop have not been evaluated for the influence of structural complexity on predation pressure.

Three permanent stream pool habitats in coastal Kenya were evaluated before and after flooding to compare the effect of changing habitat complexity. In five highland valleys, variables influencing and influenced by structural complexity were measured in spatially matched pairs. One hundred (100) habitats in a single highland brick-making valley were evaluated for effect of habitat disturbance on structural complexity, predator diversity and mosquito larvae densities. Finally, a structural equation model describing the magnitude of the effect of structural

Figure 1. Searching for mosquito larvae in stream pools

complexity on trophic interactions was developed using water scorpions (Heteroptera: Nepidae), backswimmers (Heteroptera: Notonectidae) and *A. gambiae* mosquito larvae (Diptera: Culicidae).

In stream pools along the Jaribuni River (Figure 1), structural complexity was high prior to flooding (filled with emergent vegetation) and low after flooding (all vegetation removed). This corresponded with a pre-flood absence of *Anopheles* larvae and high predator diversity, and a post-flood presence of *Anopheles* larvae and low numbers of predator species. In five highland valleys, low complexity habitats were more recently disturbed by brick-makers than high complexity habitats. The former contained higher densities of mosquito larvae and fewer predator species. In 100 brick-making pits in a single highland valley, time since disturbance was positively correlated with the number of predator species present and negatively correlated with mosquito density, while the true age of the habitat was not correlated with either. In age-matched habitat pairs containing different amounts of emergent vegetation, low-complexity pits contained fewer predator species and higher mosquito densities than high complexity pits. A structural equation model describing the impact of complexity on trophic interactions was developed. Structural complexity mitigates predator-predator antagonism in the small ground pools inhabited by mosquito larvae.

Elucidating the ecological mechanisms for mosquito larvae distribution provides direction for disease-control programmes, both in targeting larvae with conventional methods, as well as habitat management, which will encourage predation pressure as a natural mechanism for vector suppression. Predator diversity was positively correlated with habitat age and negatively correlated with the mosquito species present. Experiments showed that *A. gambiae* larvae are dramatically more susceptible to predation by backswimmers than *Culex quinquefasciatus* larvae. Malaria vectors are found disproportionally more often in highly temporal pools along the Kenyan coast than in the western Kenya highlands. *Anopheles gambiae* is found during the early stages of biological succession, when predator diversity is low. In areas with many temporal habitats, outbreaks of this malaria vector are a risk. While temporal habitats are not stably present, the trade-off with diminished predatory pressure has led to the continent-wide success of this species.

4. Social science-directed studies for community-based vector control

Community groups are potentially efficient channels for mosquito control activities. However, these groups lack knowledge on mosquitoes and malaria and questions on motivation, sustainability and community acceptance hinders their progress. Until recently, mosquito control activities have been too sporadic and fragmented to build a 'critical mass' sufficient to impact behaviour change in a community. Furthermore, information has often been didactic and not easily accessible, nor has it been culturally relevant or sufficiently targeted to reach enough of the right people. Rarely has there been any community consultation.

In Malindi on the northern Kenya coast, quantitative information was collected by tape recording of interviews and discussions, transcription of recordings and sorting out the data. The aim of this exercise was fourfold: (i) conduct training needs assessment through social science focus group discussions and surveys in community-organised groups dealing with mosquito control activities, (ii) determine what types of control measures are useful to the community, (iii) develop a training programme aimed at strengthening the capacity of community-organised groups dealing with mosquito control activities for efficiency and accountability, and (iv) implement and evaluate the training programme. Preliminary findings indicate that malaria was the most common illness affecting communities in Malindi, especially children.

A massive programme of community mobilisation, started in Malindi in 2001, continued during the

Figure 2. Training materials used in community education about mosquitoes and malaria

review period. A major component of this programme is the creation of community groups, as described above, for the observance of 'Malaria Mosquito Day', during which awareness campaigns are undertaken in the town to promote inter-sectoral collaboration and community participatory action for malaria control. Mosquitoes are believed to cause malaria but the knowledge about the immature stages of mosquitoes in relation to adult mosquitoes was lacking.

Focus group discussions and meetings were conducted with community groups to design and develop training programmes that are appropriate, socially relevant and acceptable to the people. The community groups were identified through meetings to establish their location and the nature of their activities. A total of 34 groups were identified in Malindi and 19 were involved in mosquito control and environmental management. Their activities include insecticide treating of manholes, pest control, making and selling treated mosquito nets, draining stagnant water, organising clean-ups, garbage collection, tree planting, bush clearing and making and selling neem soap. A total of eight focus group discussions were held in succession.

Locally appropriate educational materials are being developed in conjunction with the groups for use in training so as to bring about changes in both knowledge and behaviour, which will be measured in the evaluation phase of the intervention (Figure 2).

The Project emphasises the importance of understanding the existing knowledge, beliefs, and practices when planning or evaluating vector control activities. Some of the activities from this on-going training programme include:

- developing strategies for enhancing community participation in vector control;
- developing criteria for selecting trainers and training of trainers;
- defining the role of the Malindi Municipal Council and the community groups;
- acquiring knowledge and awareness of malaria;
- malaria treatment and prevention;
- improving the community's understanding of types of mosquitoes and their immature stages.

FUTURE OUTLOOK

The Project has established three study sites for in-depth longitudinal studies of larval ecology and malaria parasite transmission, and the analysis of associations between anopheline larval abundance and environmental factors is nearing completion. The community-based education and vector control initiatives are being expanded from the urban areas to include rural sites.

Studies on the population genetic structure of anopheline mosquitoes in other East African countries in addition to Kenya have been initiated.

CAPACITY BUILDING

PhD students

Midega J. T. (Kenya) Studies on the distribution patterns, gene flow and dispersal capabilities of anopheline vectors of malaria at three ecological zones along the Kenya coast. University of Ghana.

MSc students

Mwangangi J. M. (Kenya) The influence of nutritional status of a larval habitat on the body size of *Anopheles* mosquitoes. MSc, Kenyatta University (2003). Supervisors: C. Mbogo and J. Githure (ICIPE) and E. Kabirū (Kenyatta University).

Ohaga S. O. (Kenya) Field evaluation of *Piper guineense* and *Spilanthes mauritiana* powder as mosquito larvicides in Kilifi District, Kenya. MSc, Kenyatta Univerity (2003). Supervisors: A. Hassanali and C. Mbogo (ICIPE), E. Kabirū (Kenyatta Univesity).

Muiruri S. K. (Kenya) Determination of predator feeding preference on immature stages of *Anopheles* mosquitoes along the Kenya Coast. Kenyatta University.

Participating scientists: C. Mbogo, J. Githure (Human Health Division Head and Programme Leader), J. C. Beier, G. Yan, J. Mwangangi, J. Keating, S. Kahindi, R. Novak

Assisted by: J. Nzovu, P. Seda, N. Njoki, R. Kasati

Collaborators: Kenya Medical Research Institute (KEMRI); Division of Vector Borne Diseases, Kenya Ministry of Health; Kenyatta University (Kenya); Tulane University, State University of New York at Buffalo and University of Miami (USA)

Donors: NIH-ICIDR (International Centre of Infectious Disease Research)

BEHAVIOURAL AND CHEMICAL ECOLOGY OF *ANOPHELES GAMBIAE*

BACKGROUND, APPROACH AND OBJECTIVES

There are three specific aims to this project: (i) identify the semiochemicals influencing the major life-history behaviours of African malaria mosquitoes, (ii) utilise the chemicals identified to develop novel tools to interrupt host-vector contact (sex and behaviour-specific catching devices such as ovitraps, host odour-baited traps, and flower odour-baited traps), and (iii) assess the potential of such tools both for monitoring populations of malaria mosquitoes and for reducing human–vector contact.

WORK IN PROGRESS

1. Oviposition behaviour and chemical ecology of *A. gambiae*

The scope of these studies is built around the following evolving set of hypotheses:

- Oviposition selection behaviour is related to potential fitness and chances of survival of the progeny in different pools associated with biotic and abiotic factors. The biotic microenvironment is shaped, on one hand, by organic matter arising from habitat vegetation and the microbial population structure it sustains, and, on the other, by the presence of competing species or potential predators in these environments. Gravid females use the chemical characteristics resulting from microbial activity and/or those associated with competitors as interspecific cues to select suitable habitats for oviposition.
- *Anopheles gambiae*'s characteristic tendency to spread egg laying spatially may be regulated by both the interspecific signals referred to the above and intraspecific signals associated with eggs or larvae. We hypothesised that at low egg/larval densities, the signal may reinforce/synergise the interspecific signals, but that at high densities, it may function as a deterrent.
- As an extension of the above, it is further hypothesised that different strains of *A. gambiae* may respond differently to the eggs/larvae-associated signals, i.e. there may be discernible strain differences in the chemical nature of the intraspecific signal.
- Among the abiotic factors, reflectance of the background of the oviposition site had earlier been implicated as a contributory factor. Accordingly, it was hypothesised that *A. gambiae* may respond to specific reflectance wavelength bands in the process of oviposition site location.

Effect of aqueous substrates on oviposition behaviour

Studies on the effect of different aqueous substrates on the oviposition behaviour of *A. gambiae* were conducted in both the conventional net cages (30 x 30 x 30 cm) and in a newly constructed 2-choice wind tunnel (100 x 30 x 30 cm) designed to minimise mixing of volatile emissions from the two sides. The following summary gives highlights of the research.

Assays to study the influence of soil microorganisms in oviposition choices of *A. gambiae* (laboratory and wild gravid females), reported previously, was extended to include some microbiological work. The results confirm the hypothesis that microorganisms mediate attraction of gravid females to preferred oviposition sites. A revised manuscript is being submitted for publication.

Comparisons of diel oviposition patterns of *A. gambiae* provided with different substrates has continued. Although the diel oviposition patterns were not significantly affected by the substrates (anopheline pond water, filter sterilised pond water, distilled water) more eggs were laid in anopheline pond water earlier in the night (2100–2200 hrs). These studies are continuing and detailed analyses of data generated will help decide if diel oviposition patterns in the early part of the night can be used as a reliable measure of *A. gambiae* preferences for oviposition in different substrates.

Oviposition responses of *A. gambiae* to choices of (a) water collected from ponds with predominantly anopheline and culicine larvae, and (b) distilled water with/without *Culex* spp. egg rafts, were compared in the 2-choice wind tunnel. In both cases, significantly fewer eggs were laid in culicine-associated water or distilled water with the *Culex* egg rafts ($P = 0.03$ and 0.01, respectively). The results suggest that a factor associated with *Culex* spp. egg rafts acts as an oviposition repellent of *A. gambiae*. The possibility that the oviposition attractant pheromone associated with *Culex* egg rafts is the key repellent signal was investigated, however evaluation of a synthetic stereoisomeric mixture of the pheromone was found to *promote* oviposition by *A. gambiae*. Whether the activity (repellency/attraction) is linked to stereochemical purity remains to be determined.

Oviposition choices of *A. gambiae* to pond water with different densities of eggs and/or early and later instar larvae, are being investigated in detail. Eggs showed no significant effects. However, at low densities (0.5 –1.0 larvae/ml), the presence of larvae somewhat enhanced the attraction of anopheline pond water. On the other hand, at high densities (2.5 – 3.0 larvae/ml) they were deterrent. Preliminary results with Ifakara and Mbita strains of *A. gambiae* indicate a significant strain difference in the responses of the gravid females to their own larvae and those of the other species.

The oviposition responses of *A. gambiae s.s.* to targets of different colours have been studied in 60 x 60 x 60 cm Plexi®-glass cages. Targets with a blue background received significantly more eggs than those with red, yellow, green, brown, black or white background in that order. Semi-field studies (in the Malariasphere, *see ICIPE Annual Scientific Report Summaries 2000–2001*) using containers of different colours as oviposition targets are underway. Reflectance spectra of the target have been obtained and the relation between attraction of different targets and the reflectance spectra is being analysed.

2. Chemical characterisation of oviposition signals

Chemical characterisation of inter- and intraspecific oviposition signals that have been implicated are focused on several fronts as follows.

A versatile static headspace technique (using C-18 or C-8 reverse phase silica) for trapping natural odours emanating from ponds has been developed. Replicate collections from ponds of different types (anopheline, culicine, empty) have been made. GC-MS analyses of the trapped materials show the presence of complex mixtures of constituents (as many as 400–500). Differences between pool types are both quantitative (largely with respect to major components) and qualitative (with respect to minor components). For mass spectral identification of candidate constituents that contribute to the behaviourally active blend, the volatile collections from bacterial cultures and from tree holes (which appear to be compositionally less complex), are continuing. Electrophysiological detection technique linked to gas chromatography also will be needed to locate the candidate constituents; this is being addressed.

Bioassay-guided identification of putative larval semiochemicals associated with intraspecific effects on the oviposition behaviour of *A. gambiae* is a priority. Different adsorbents and techniques for trapping headspace volatiles and non-volatiles associated with *A. gambiae* have been evaluated and the adsorbed material analysed by chromatography. Bioassay-guided identification of the active combination of the components is in progress.

Elucidation of the basis of repulsion of gravid *A. gambiae* associated with egg rafts of *Culex* spp. is in progress. All components of *C. quinquefasciatus*, including the stereochemically pure oviposition attractant pheromone, are targeted for isolation and assays.

3. Host-finding behaviour and mediating semiochemicals of *A. gambiae*

These studies are built around the hypothesis that host location by the malaria vector involves two distinct steps:

(i) an upwind anemotactic flight from some distance to hosts/host dwellings guided by plumes of volatile, predominantly breath odour chemicals (including carbon dioxide);
(ii) chemotactic responses closer to hosts move down concentration gradients of odours emanating from preferred feeding sites (e.g. human feet).

Previous attempts elsewhere to characterise the full blend of host attractants were frustrated by the compositional complexity of human odours coupled with inefficient odour trapping techniques. The strategy used in these studies seeks to converge on the blend of active constituents through the following succession of steps:

- grading the attractiveness of foot odour and breath (separately) from different individuals, comparing the total chemical compositions (gas chromatography) of the most and least attractive odours;
- identification of constituents unique to or present in higher relative amounts in the collections from the most attractive individuals;
- electrophysiological (EAG) identification of candidate active compounds (GC-EAD) and spectral analyses of the constituents;
- subtraction assays in the laboratory and in the screenhouse with blends of EAG-active constituents.

The relative attractiveness of bulk foot odour collections (on nylon and cotton-polyester socks) from 16 male volunteers under standard conditions in CFG traps in a screenhouse indicated large and significant differences, with collections from the most attractive subject being 8-fold more attractive than the least attractive individual. Comparison of the GC-MS profiles of odour collections (Porapak Q and C-18 reverse phase silica) showed both quantitative and qualitative differences between the most and least attractive subjects. Collections from the former are richer in carbonyl, alkylated benzene and alcoholic compounds (representing about 17–18% of over 300 components) and include compounds not previously reported as constituents of human odour.

The performance of different (a) antennal preparations (simple, multiple in tandem, mosquito heads with/without thorax and electrodes attached to antennae, whole mosquito), (b) electrodes (silver, golds, Syntech for multiple parallel antennae), (c) physiological saline preparations, and (d) humidity conditions, among others, have been compared. Use of whole mosquitoes (5–7 day-old) with silver electrodes and Beadle-Ephrussi saline medium showed higher and sustained (~1.5 hr) sensitivity when EAG recordings were made at high humidity. The stage is now set for both EAG and GC-EAD analyses of the odour collections and synthetic blends.

A two-choice wind-tunnel was designed and fabricated to study the upwind flight behaviour of individual mosquitoes to plumes derived from human breath. Initial comparison of breath collections from different individuals also indicates variations (although smaller than foot odours) in their attractiveness. The study is scheduled to provide a basis for the identification of the minor constituent, which together with carbon dioxide, confer attraction to human breath.

In summary, both interspecific and intraspecific signals appear to regulate the oviposition selection behaviour of *A. gambiae*. The former include those that originate from bacterial activity and those that originate from culicine species. The intraspecific signal is associated with *A. gambiae* larvae, which shows a very interesting dose-effect: it appears to augment the attractiveness of bacterial semiochemicals at low doses and acts as a deterrent at higher doses. These insights provide some scientific understanding of spatial oviposition strategy associated with *A. gambiae*.

The wide difference in the attraction of foot odours from different human subjects and in their chemical compositions provides a useful basis of narrowing down the group of attractant candidates. Optimisation of the electrophysiological detection technique is expected to facilitate further narrowing of potential attractant constituents for behavioural studies. *(See also the report of the Behavioural and Chemical Ecology Department.)*

CAPACITY BUILDING

PhD student

Leunita Sumba (Kenya) Oviposition behaviour of the African malaria mosquito *Anopheles gambiae* Giles (Diptera: Culicidae): Influence of external factors on oviposition site selection. Egerton University, Kenya.

MSc students

Maurice Omolo (Kenya) Isolation, identification and synthesis of behaviourally active semiochemicals from human foot odour. Kenyatta University.

Brandon Ogbungafor (USA) Fullbright Fellow. Working on aspects of strain differences and oviposition behaviour of *A. gambiae* in tree holes among other topics.

Participating scientists: A. Hassanali, B. Knols (2002), P. Njagi

Assisted by: B. Njiru

Donors: NIH-ICIDR

VECTOR COMPETENCE IN THE *ANOPHELES GAMBIAE–PLASMODIUM FALCIPARUM* SYSTEM

BACKGROUND, APPROACH AND OBJECTIVES

There are three specific aims to this project: (i) evaluate the effects of abiotic environmental factors on *Plasmodium falciparum* sporogonic development in African malaria vectors with particular emphasis on ambient temperature, (ii) evaluate the effects of biotic factors on *Plasmodium falciparum* sporogonic development in African malaria vectors, (iii) determine the genetic mechanisms of vector competence in the *Anopheles gambiae/Plasmodium falciparum* system.

WORK IN PROGRESS

1. Influence of sugar availability and indoor microclimate on survival of *A. gambiae* under semi-field conditions in western Kenya

The influence of indoor microclimate on survival of female *Anopheles gambiae s.s.* mosquitoes fed on different nutritional sources was evaluated in a semi-field experimental hut (the 'Malarisphere') exposed to ambient temperature in western Kenya. The effect of diet on survival was significant, with mean survival times of 6.25 ± 0.30 days for mosquitoes fed on blood alone, 14.67 ± 0.48 days for those fed on sugar alone and 15.86 ± 0.65 days for those fed on blood and sugar. Sugar availability decreased the odds of mortality by approximately 70% compared to the blood-fed group, suggesting that the availability of sugar clearly increases the longevity of female *A. gambiae*. Micro-heterogeneities of temperature but not relative humidity also influenced survival, although to a much lesser extent. Our results suggest that malaria transmission may be substantially enhanced by the availability of sugar sources to vector populations.

2. Effect of mosquito age and blood feeding history on the susceptibility of *A. gambiae* infected with natural gametocyte populations

A study to determine whether the age and nutrition of the mosquitoes have any effect on *P. falciparum* parasite sporogony was carried out using laboratory-reared *A. gambiae s.s.* mosquitoes infected with natural parasites obtained from naturally infected gametocyte-positive volunteers (density > 16 gametocytes/μl). The oocyst prevalence rate on day 7 post-infection was 4.3% (21/487) for mosquitoes aged 0–3 days, 7.2% (19/265) for 4–7 days and 3.8% (6/160) for 8–11 days. There were no significant differences in mean oocyst count between the mosquito age groups. The prevalence of oocyst infections was influenced by the type of food (either blood or sugar alone) on which the mosquitoes had been subjected to in the past 8 –11 days. The infection rates were higher for the blood-fed (8.77%) than the sugar-fed mosquitoes (5.35%). In addition, higher oocyst prevalence was found in mosquitoes provided with two bloodmeals (11.66%) than in mosquitoes provided with a single bloodmeal (5.66%). When considering mosquito fitness in terms of size, the size of the mosquito influenced the probability of a mosquito becoming infected and its size was directly related to successful infection.

3. Effect of larval habitat 'quality' on the vector competence of laboratory and field populations of *A. gambiae* for *P. falciparum*

The objective here was to establish if there is a relationship between larval habitat 'quality' and mosquito fitness and to investigate whether differences in larval habitats affect the infectivity of emerging adult mosquitoes to *P. falciparum*. The breeding habitats were characterised using parameters that show the possible variations in water source, quality and productivity and the vector competence of emerged anopheline mosquito species determined.

The influence of larval habitat substrates from two ecological distinct sites on the larval development and infectivity of the adult *A. gambiae* mosquito with *P. falciparum* were studied in the laboratory. Soil substrates collected from the drying larval habitats identified in a marshy area in Rusinga Island and from the Lwanda mainland on the shores of Lake Victoria were used to rear *Anopheles* mosquitoes from the first larval instar. Adults emerging from these larval substrates were fed on blood obtained from gametocyte-positive human volunteers.

Higher infection prevalence was observed in mosquitoes from the mainland larval habitat soils (11.8%) than from the island soils (3.36%). Similarly, the infection intensity was higher in the Lwanda larval habitat soil, with oocyst density of 7.29 compared to 0.714 oocysts per midgut in mosquitoes from the Rusinga habitat soil. These densities are greater than in the control group of mosquitoes reared under insectary conditions (mean of 0.40 oocysts per midgut). This study suggests that ecological differences in larval habitat substrate may influence larval development and to a large extent the infectivity of adult mosquitoes. This aspect is being investigated under the project described above on oviposition behaviour of mosquitoes.

4. Effect of high temperatures on the development of *P. falciparum* in laboratory-infected *A. gambiae s.s.*

The development of natural malaria parasites from 44 gametocyte-positive volunteers in *A. gambiae* was shown to be sensitive to high temperatures (30 °C and 32 °C), but the response of early sporogonic stages to high temperature was negligible. At the ookinete stage, the highest impact was seen at the higher temperature of 32 °C, where there was an overall 25-fold reduction in parasite numbers compared to 10-fold and 13-fold reductions at 27 °C and 30 °C, respectively.

The dramatic loss occurring at the higher temperatures may suggest that under natural conditions, temperatures greater than 30 °C bear a strong impact on malaria transmission by reducing the prevalence of infected mosquitoes. Although exposure of parasites at high temperatures greater than 30 °C may reduce the parasite load of early pre-oocyst stages, no complete knockout was observed. The relative temperature tolerability (absence of knockout effect) of *P. falciparum* under field conditions contrasts sharply with previous laboratory-based studies where high temperatures completely inhibited the development of cultured parasites within the mosquito midgut.

5. Efficiency of early *P. falciparum* sporogonic development in relation to ambient temperature under semi-natural and natural conditions

We assessed the climatic conditions in the village houses used in the field experiments above and investigated the effect on parasite development within mosquitoes. Temperature profiles were highly variable over the experimental period and were influenced by house type. Warm temperatures bordering the upper thermal limits (>30 °C) of the parasite favoured high infection prevalence in mosquitoes, as observed in mosquitoes that were held in ambient laboratory conditions where temperatures were warmer and higher than in the semi-field village hut (in the Malarisphere) or under incubator conditions. This observation was confirmed in the validation studies conducted in the natural habitats inside village houses, where a higher infection rate was recorded in iron-roofed houses, which had higher mean temperatures than thatch-roofed dwellings. However, in the former microhabitat where there were larger temperature fluctuations experienced by mosquitoes, it is difficult to separate the direct effect of low and high temperatures on parasite development. Overall, of the original number of ingested macrogametocytes, there was a 20- to 30-fold parasite loss in mosquitoes exposed to fluctuating field temperature. The outcome or yield in oocyst numbers observed in the mosquito midgut under these conditions was only 4% yield. However it is expected that hot temperatures experienced in Suba District, western Kenya, would exceed those of the lower and upper temperature limits where sporogony stops. Our study indicates that the conditions in the grass-thatched hut are the most suitable for malaria parasite development.

A reliable system for experimentally infecting *A. gambiae* mosquitoes has been established at ICIPE's Mbita Point Field Station. This includes an insectary with high production of *A. gambiae* mosquitoes adapted on membrane feeding (the production averages 2000 pupae per day), a laboratory facility for infection of mosquitoes, and a parasitological team with year-round access to a large number of gametocyte-positive volunteers among the community populations and at the outpatient clinic from which blood can be sampled.

Most of the previous studies by other workers on vector competence have focused on placing infected mosquitoes in a temperature- and humidity-controlled incubator. The vector competence studies relating to microhabitat climate have proved logistically challenging because they require the development of holding conditions that simulate the natural environment. During the present reporting period, the ICIPE team has carefully evaluated some of the test systems critical to studies on the influence of biotic and abiotic factors on the sporogonic development of parasites.

CAPACITY BUILDING

PhD student

Bernard Ochieng (Kenya) Factors affecting the infectivity and early sporogonic development of *Plasmodium falciparum* in the malaria vector *Anopheles gambiae*. Kenyatta University.

Participating scientists: L. Gouagna, J. Githure, J. Beier, G. Yan

Assisted by: P. Obare

Collaborators: Tulane University, USA

Donor: NIH

AGROECOSYSTEM MANAGEMENT IN THE MWEA RICE SCHEME

BACKGROUND, APPROACH AND OBJECTIVES

Classification and diversity of larval habitats

The larval habitats present in villages within and at the periphery of Mwea rice irrigation scheme were identified and classified. The diversity of mosquito larval habitats identified in nine villages falls within three categories, namely organised irrigated, unorganised irrigated ('Jua Kali') and non-irrigated areas. Ten different types of larval habitats were identified. With the exception of Mbui Njeru and Kiuria villages, each of which had only two types of larval habitats, rice-growing villages (both organised and Jua Kali) had at least five different types of larval habitats including the canals and rice paddies, which are known breeding habitats for mosquitoes. Some of these larval habitats were man-made (tyre tracks, ponds and pits), while others were natural (marshes, swamps). In the non-irrigated villages, slow-moving streams, hoof prints, ponds, tyre tracks, marshes and dams were identified as important larval habitats.

WORK IN PROGRESS

1. Demographic studies

To obtain this information, various health facilities were visited. Data from three dispensaries, namely Kandongu, Kangaru and Murinduko, was obtained. Records of all patients visiting the dispensary each day of the year and the diseases treated were also available. In the year 2002, malaria accounted for 38.2% and 42.3% of the total cases reported in Kangaru and Murinduko dispensaries, respectively, whereas in the year 2003, the proportion of cases with malaria was 38.1, 36.8 and 38.3% in Kandongu, Kangaru and Murinduko dispensaries, respectively. The overall proportion of malaria cases based on the available data for the two years was 39.4%.

The proportion of malaria cases ranged between 20.4 and 52.9% with the lowest value occurring in Murinduko in the month of March 2003, and the highest value occurring in Kandongu in the month of April 2003.

Participating scientist: J. Githure

Assisted by: E. Mpanga

Collaborators: University of Nairobi; Kenya Medical Research Institute (KEMRI); Kenya Ministry of Agriculture-National Irrigation Board; International Water Management Institute (IWMI)

Donor: IDRC

TECHNICAL ASSISTANCE TO THE ERITREAN NATIONAL MALARIA CONTROL PROGRAMME

(Editor's note: This project, although beginning in 1999–2001 is included in this report, as it has not been reported previously and contains activities in progress in 2002–2003.)

BACKGROUND, APPROACH AND OBJECTIVES

Malaria is a major public health problem in Eritrea. Data available from the Ministry of Health indicate that malaria is the most common cause of death among adults and children over five years old and the third most common cause of death in children under five. Two-thirds of the population is at risk of infection, and cases diagnosed as malaria account for 32% of outpatient visits and 24% of hospital admissions at government health facilities. *Plasmodium falciparum* is responsible for over 90% of malaria infections in the country.

Eritrea has six zones (districts) that comprise the principal political units of the country. All levels of malaria endemicity exist. In the lowlands, malaria is generally endemic with moderate to high intensities of transmission. The country also experiences serious malaria epidemics. The most recent malaria epidemic occurred in 1998, resulting in approximately 150,000 cases in all zones except Southern Red Sea.

The National Malaria Control Programme (NMCP)

In its Five Year Plan of Action, the NMCP (1999–2003) has set goals for itself. The general objective is "to reduce morbidity and mortality due to malaria to such low levels that malaria is no longer a public health problem in Eritrea". The Plan articulates several specific objectives, priorities, cross-cutting themes, interventions, and strategies (see box). It describes an integrated approach, combining the use of available interventions (case management, chemoprophylaxis, bednets and vector control) with efforts to improve surveillance, programme management, operational research and community awareness and mobilisation.

In order to accomplish these objectives, ICIPE, in collaboration with the Environmental Health Project of Washington DC (EHP) provided technical support with two goals to:

- increase/improve the capacity of the NMCP for collecting, managing, analysing, and using data through improvements to surveillance systems, operational research programmes, and information systems;
- improve NMCP's programmes for vector control and environmental management, resulting in more effective and more efficient actions to control vector populations and reduce the human–vector contact.

WORK IN PROGRESS

1. Spatial distribution of anopheline mosquitoes in Eritrea

The spatial distribution of anopheline mosquito species was studied throughout Eritrea during the 1999–2001 malaria transmission seasons. Of the 302 villages sampled, 59 were visited in both the 1st and 2nd year. Overall, 13 anopheline species were identified (Table 1), with the *A. gambiae* complex predominating during the first (75.6%, N = 861) and

Eritrea National Malaria Control Program (NMCP)
Five Year Action Plan

Specific Objectives

- Reduce overall morbidity from malaria by 80%
- Reduce the incidence of malaria during epidemics by 90%
- Reduce mortality due to malaria during epidemics by 80%
- Reduce human–mosquito contact
- Reduce mosquito density

Priority Actions

- Improve malaria case management at all levels
- Predict, prevent, detect and contain epidemics
- Improve the vector control programme
- Mobilise communities for action and 'ownership'

Cross-cutting Themes

- Increasing community awareness
- Building capacity for operational research
- Strengthening the health system, improving responsiveness
- Strengthening the information system so that future planning is evidence-based

Table 1. Species composition and relative abundance of adult *Anopheles* mosquitoes collected between October 1999 and April 2001 in Eritrea

Species*	Gash Barka	Anseba	Debub	Maekel	NRS	Total
*A. gambiae s.l.**	1294	606	147	8	69	2124
*A. d'thali**	0	216	2	0	17	235
A. cinereus	0	12	24	48	0	84
A. squamosus	0	0	0	20	0	20
A. rhodesiensis	0	19	1	0	0	20
A. rupicolus	0	11	0	0	1	12
A. harperi	1	0	0	0	0	1
A. demeilloni	0	3	1	0	0	4
A. garnhami	0	3	0	0	0	3
A. funestus	0	0	2	0	0	2
A. chrysti	0	0	0	3	0	3
A. wellcomi	0	0	1	0	3	4
A. pharoensis	0	0	0	1	0	1
	1295	870	178	80	90	2513

*Known vectors.

second year (91.9%, N = 1262) of the study. Intra-zonal variation accounted for 90% of the total variation in mosquito distribution. Polymerase chain reaction (PCR) results indicated that 99% (N = 1309) of the *A. gambiae s.l.* specimens were *Anopheles arabiensis*, indicating that this may be the only member of the *gambiae* complex present in the country.

There was a high degree of aggregation of anophelines within zones and villages, with over 80% of the total anophelines being collected from less than 20% of the villages and from only 10% of houses sampled. At least 80% of the anopheline mosquitoes were collected from grass-thatched mud-walled (Agudo-type) housing. Vector abundance showed an inverse relation with elevation, with the highest densities found in the low-lying western lowlands. Multiple regression analysis of log-transformed mean density of *An. arabiensis* with rainfall and the normalised difference vegetation index (NDVI) showed that these independent variables were not significantly associated with mosquito densities ($R^2 = 0.058$) (Table 2).

This study contributes to the basic understanding of the ecology and distribution of malaria vectors with respect to species composition and spatial heterogeneities important for guiding vector control operations in Eritrea. For example:

- Indoor residual spraying with DDT has been re-evaluated and substantial reduction in spray coverage has been achieved through targeting only high-risk areas based on presence of larval habitats and vector densities.
- Secondly, house characteristics such as wall type have been assessed with regard to their amenability to residual spraying. The Northern Red Sea (NRS) zone has withdrawn indoor residual spraying as a vector control strategy due to inappropriate house types and vector presence.

2. Seasonal abundance, vector behaviour, and malaria parasite transmission in Eritrea

Entomological studies were conducted over a 24-month period (1999–2001) in eight villages to establish the behaviour patterns, seasonal densities, and variation in entomological inoculation rates (EIR) of *A. arabiensis*, the main vector of malaria in Eritrea. A total of 5683 anopheline mosquitoes were collected through indoor sampling (1613), human landing catches (2711) and outdoor pit shelters (1359). Overall, *A. arabiensis* was the predominant species at all eight study sites, with its population increasing during

Table 2. Multivariate regression summary for the dependent variable, mean *Anopheles arabiensis* density

Variables	Regression coefficients	Std Error	t	P-value
Constant	-0.384	0.152	-2.525	0.012
Rainfall	-0.345	0.016	-3.831	< 0.001
Average NDVI	0.023	0.001	0.152	0.879
Maximum NDVI	0.097	0.003	0.500	0.618
Minimum NDVI	0.248	0.003	1.789	0.075

Number of observations = 302; $R^2 = 0.058$; Adjusted $R^2 = 0.046$.
NDVI, normalised difference vegetation index.

the rainy season. Peak indoor resting densities were observed during September and October. The biting rates of *A. arabiensis* were highly seasonal with activity concentrated in the wet season between June and October in the highlands and western lowlands, and between December and March for the coast. The biting rates in the western lowlands were twice as high as in the western escarpment and 20 times higher than the coastal region.

Human landing indices for *A. arabiensis* averaged 1.9 and 3.8 per person per night in October and September, respectively. Peak biting/ landing rates occurred between 2000–2200 hrs and 0100–0300 hrs (Figure 1). Of the total number of bites throughout the night, 44.7% occurred between 1800 and 2300 hrs, and at least 56.5% of the total bites occurred outdoors, indicating the species was partially exophagic. The fed: gravid ratio for *A. arabiensis* in indoor resting collections was 2:1 indicating some degree of exophily.

The sporozoite rates for *A. arabiensis* ranged from 0.54% in Anseba to 1.3% in Gash-Barka zones. One mosquito each of *A. d'thali* (SR = 0.45%) and *A. cinereus* (SR = 2.13%) was found to be positive. Of the total positive *A. arabiensis* (N = 64), 18.2% came from human

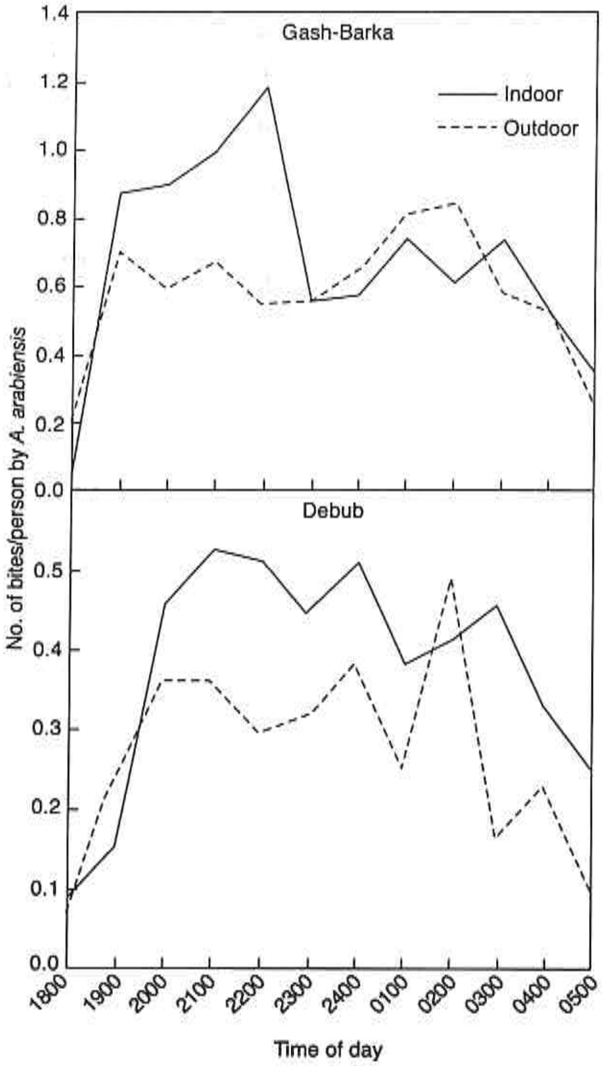


***Figure 1. The biting rhythm of* Anopheles arabiensis**

landing collections outdoors. The risk of infection ranged from zero on the coast to 70.6 infective bites per year in the western lowlands. The number of days it would take for an individual to receive an infective bite (ib) from an infected *A. arabiensis* was variable among villages (range 2.8–203.1 days).

The data revealed the presence of only one main malaria transmission period falling between July and October for the highlands and western lowlands (Figure 2). Peak inoculation rates were recorded in August and September (range 0.29–43.6 ib/p/month) at all sites over the two years. The annual entomological inoculation rates (EIR) varied greatly depending on year and location (Table 3). The EIR profiles indicated that the risk of exposure to infected mosquitoes is highly heterogeneous and seasonal with high inoculation rates during the rainy season, with little or no transmission during the dry season. On average, there is a greater risk of infection in Hiletsidi, Gash-Barka zone (6.5 infective bites per month). Bloodmeal analysis by ELISA for *A. arabiensis* indicated that species was partially zoophilic with a human to bovine ratio of 2:1 being recorded.

This study demonstrates the need to generate spatial and temporal data on transmission intensity on smaller scales to guide targeted control of malaria operations in semi-arid regions. Furthermore, EIR estimates derived in the present study provide a means of quantifying levels of exposure to infected mosquitoes in different regions of the country and could be important for evaluating the efficacy of vector control measures, as Eritrea makes significant steps in reducing the burden of malaria based on WHO's Roll Back Malaria (RBM) initiative.

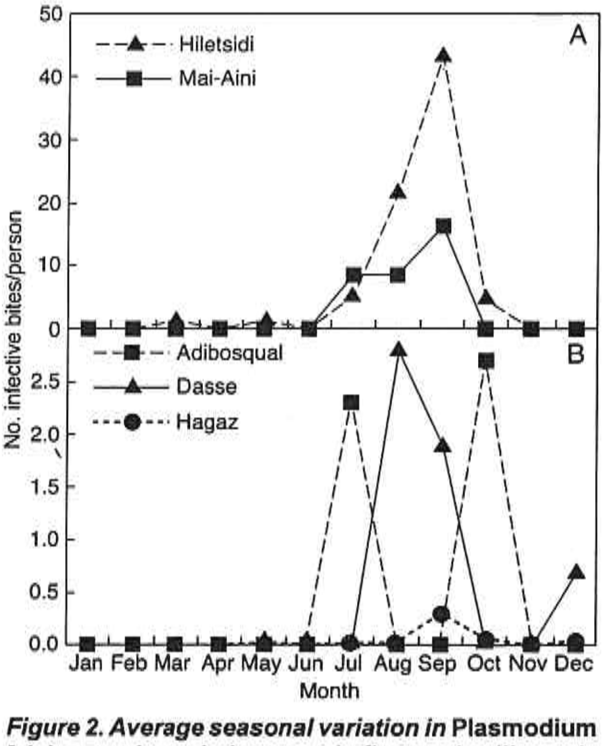


Figure 2. Average seasonal variation in* Plasmodium falciparum *inoculation rates in five study villages in Eritrea, October 1999–September 2001

Table 3. *Plasmodium falciparum* sporozoite rate and EIR for *Anopheles arabiensis* in different ecological zones in Eritrea, 1999–2001

Ecological zone, altitude (masl) and annual rainfall (mm)	Study villages	No. tested	CS⁺ positive	Sporozoite rate (%)	Mean annual EIR
Western lowland wet zones: 500–1000 m, > 200 mm	Hiletsidi Dasse	2657	43	1.61 (0.012–0.022)	39.3
Western escarpments: 1000–1600 m, > 200 mm	Adibosqual Hagaz Mai-Aini	2053	18	0.88 (0.005–0.014)	12.8
Highlands: > 1800 m, > 400 mm	Shekaeyamo	73	0	0	0
Eastern escarpments: 200–900 m, > 200 mm	Ghinda	23	0	0	0
Dry coastal lowlands: < 500 m, < 200 mm	Gahtelay	80	0	0	0

⁺Sporozoite rates based on ELISA determination of the *P. falciparum* CS antigen in head and thorax of female *A. arabiensis*; exact 95% confidence intervals (in parentheses) calculated according to binomial distribution.
EIR, entomological inoculation rate; masl, metres above sea level.

The behavioural patterns observed in the present study pose important challenges to vector control. The exophilic behaviour and early evening biting of *A. arabiensis* present obstacles for control using treated bednets and indoor residual spraying within the context of integrated malaria control, and calls for greater focus on strategies such as larval control and other tools beyond bednets.

3. Larval habitat diversity and ecology of anopheline larvae in Eritrea

Studies on the spatial distribution of anopheline mosquito larvae were conducted in 302 villages over two transmission seasons in Eritrea. Additional longitudinal studies were also conducted at eight villages over a 24-month period to determine the seasonal variation in anopheline larval densities. Eight anopheline species were identified, with *Anopheles arabiensis* predominating in most of the habitats. Other species collected included *A. cinereus*, *A. pretoriensis*, *A. d'thali*, *A. funestus*, *A. squamosus*, *A. adenensis* and *A. demeilloni*. *Anopheles arabiensis* was found in five of the six aquatic habitats found positive for anopheline larvae during the survey. *Anopheles* larvae were sampled predominantly from stream edges and streambed pools, with samples from this habitat type representing 91.2% (N = 9481) of the total anopheline larval collection in the spatial distribution survey (Table 4). Other important anopheline habitats included rain pools, ponds, dams, swamps, and drainage channels at communal water supply points.

Anopheline larvae were abundant in habitats that were shallow, slow flowing and had clear water. The presence of vegetation, intensity of shade, and permanence of aquatic habitats were not significant determinants of larval distribution and abundance. Larval density was positively correlated with water temperature. Larval abundance increased during the wet season and decreased in the dry season but the timing of peak densities was variable among habitat types and zones (Figure 3). Anopheline larvae were collected all year round with the dry season larval production restricted mainly to man-made aquatic habitats such as drainage channels at communal water supply points. This study provides important information on seasonal patterns of anopheline

Table 4. Density of anopheline larvae sampled from different aquatic habitats in six zones in Eritrea, 1999–2001

Habitat type	Total no. larval habitats	Positive larval habitats (%)	Negative larval habitats (%)	Total *Anopheles* larvae	Percentage of total larvae (%)	Density (No./100 dips)
Water barrels	2	0.0	100.0	0	0.0	0.0
Dams	18	11.1	88.9	16	0.2	0.4
Ponds	35	37.1	62.9	316	3.0	20.9
Rain pools	15	53.3	46.7	333	3.2	20.6
Stream⁺	163	71.2	28.8	9481	91.2	55.4
Swamps	12	58.3	41.7	155	1.5	12.9
Water points	12	25.0	75.0	90	0.9	7.5
Wells	5	0.0	100.0	0	0.0	0.0

⁺The values indicate the number of the different water pools along stream edges and drying streambeds.

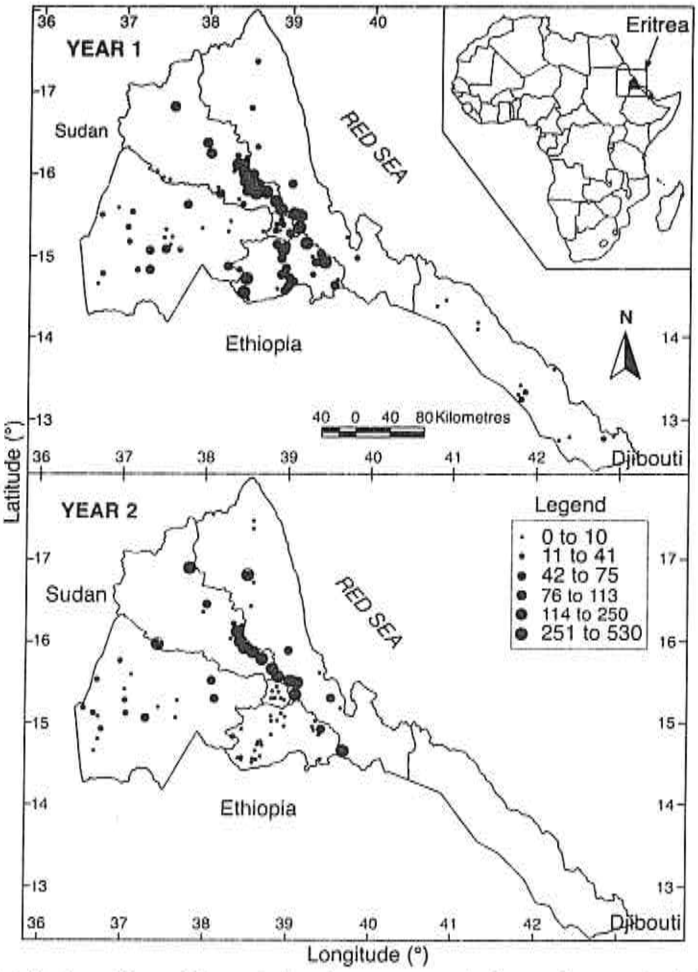


Figure 3. Spatial variation in densities of* Anopheles *larvae sampled over two malaria transmission seasons in the countrywide studies in Eritrea, 1999 and 2000

larval production and larval habitat diversity on a countrywide scale that is useful in informing larval control operations in Eritrea.

4. Efficacy of *Bacillus thuringiensis, B. sphaericus* and temephos for managing *Anopheles arabiensis* larvae in Eritrea

The larvicidal activity of the granular formulation of *Bacillus thuringiensis israelensis* (*Bti*) serotype H-14 (Vectobac® G, 200 ITU/mg) and *Bacillus sphaericus* (*Bsph*) serotype H5a5b (Vectolex® CG, 670 Bs ITU/mg) was evaluated against *A. arabiensis* and other mosquitoes in breeding habitats in three sites, Gash-Barka, Anseba, and Debub zones, in Eritrea. The primary objective was to determine the optimal application rate and duration of effect for *Bti* and *Bsph* in representative larval habitats as compared with the organophosphate temephos. The biolarvicides were tested at the 100% (high) and 50% (low) dosages of the maximum recommended application rate. Temephos was applied at a rate of 100 ml/ha. At least 4 replicate experiments with Vectobac® G (5.6 and 11.2 kg/ha), Vectolex® CG (11.2 and 22.4 kg/ha) were conducted in each of the study sites. All three larvicides caused significant mortality of the main malaria vector species (Figure 4) *Anopheles arabiensis*, and other mosquito species (*A. cinereus, A. pretoriensis, Culex quinquefasciatus*).

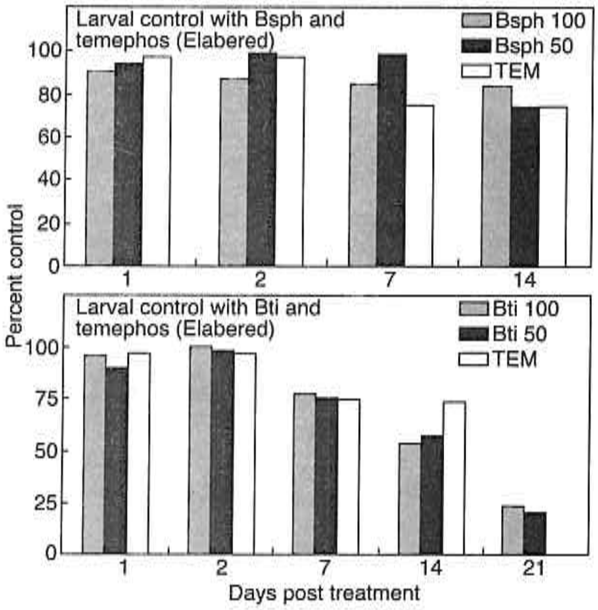


Figure 4. Percentage control of* Anopheles *larvae in Elabered, Anseba zone, Eritrea with* Bacillus sphaericus *(Bs),* B. thuringiensis israelensis *(Bti) and temephos (TEM)

The larvicidal activity for *Bti* and *Bsph* was variable depending upon breeding habitat, mosquito species and general ecology of the area. Both biopesticides had a similar duration of activity (2–3 wks) and were generally as effective as temephos for these time periods (Figure 4). In some cases, the high and low application rates for *Bti* and *Bsph* produced equivalent control over 2–3 weeks. The two *Bacillus* biopesticides were less effective in habitats with high algal content and in fast flowing streams, primarily because of the inability to penetrate algal mats and dilution effect, respectively. The results indicate that application of the two biolarvicides bi-monthly to streambed pools, rain pools and similar habitats would maintain control of the anopheline mosquito population.

5. Strengthening larval control and malaria surveillance in Eritrea

Larval control pilot studies and demonstration projects have effectively been undertaken in two villages in Anseba, Debub, Gash-Barka and NRS zones. The main objective of this project is to demonstrate that larval control is a feasible control strategy in a semi-arid ecosystem, and if applied effectively would complement other malaria control efforts. The project is also aimed at sensitising communities on larval control. This study addressed two major questions critical to the implementation of larval control as a viable means to help reduce the incidence of malaria in Eritrea:

1. What is the effect of larval mosquito management on the adult anopheline populations?
2. Can year-round mosquito control reduce the incidence of malaria over time?

The studies have involved mapping of larval breeding and weekly surveillance of mosquito larval populations within a 0.5 km radius of a study village. Adult densities were tracked using light traps within the study villages to assess the impact of systematic larval control operations on entomological indices. Meteorological data has been collected in each of the sites. Analysis of the results indicates a strong negative association between larval control and mosquito densities (Figure 5). In treatment villages where larval control has been implemented, generally low numbers of *Anopheles* mosquitoes have been collected. The implication of this result is that under specific ecological conditions such as is experienced in Eritrea, larval control can be a strong and useful component of an integrated malaria control programme.

Arising from this initial survey, a standard operating protocol for larval control has been developed. Malaria staff at the sub-zone level and also communities have been trained in mapping, surveillance and control of larval stages of malaria vectors, thereby increasing the participation of communities in larval control activities. This project is continuing in 2004.

Sentinel/surveillance sites

One of the major steps towards improving the knowledge base for making informed predictions of malaria is through routine surveillance. The NMCP recognises this as a key component of its strategies towards improving control of malaria in the country. There is a plan to establish 32 sentinel sites throughout the country for malaria surveillance, integrated with entomological and meteorological data. Fourteen (14) sentinel sites are operational. The sentinel sites will also serve as centres for conducting various operational research activities that will also form valuable training opportunities for staff and communities.

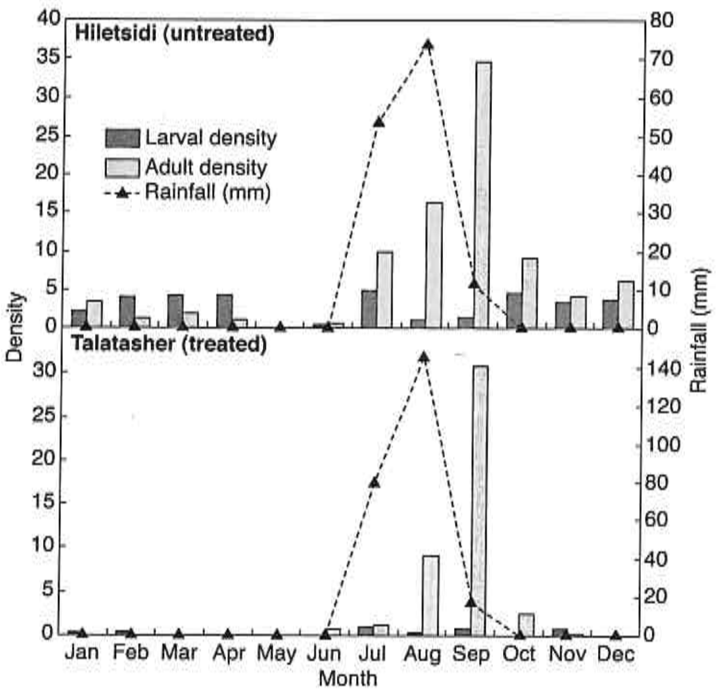


Figure 5. Relationship between larval and adult mosquito densities and rainfall in treated and untreated villages in Gash-Barka, Eritrea

The objectives of the activities include:

- improving the capacity at the sentinel sites to forecast and to prepare for pending malaria outbreaks or epidemics;
- improving the NMCP malaria/vector control activities through implementation and coordination of operational research activities;
- strengthening the capacity of staff and communities through training opportunities in disease surveillance, operational research methods and vector control methods.

CAPACITY BUILDING

Entomological training for NMCP staff, Eritrea, November 2002, Mbita.

Training in laboratory management and entomological techniques for 8 Eritrean NMCP staff, ICIPE, Nairobi; KEMRI, Kilifi, June 2003.

Participating scientists: J. I. Shililu, J. I. Githure, C. M. Mbogo, J. Beier, R. Novak, Tewolde G/M

Assisted by: Y. Bein, H. Fekadu, S. Mengistu

Collaborators: Eugene Brantly (Environmental Health Project); Jomo Kenyatta University of Agriculture and Technology (Kenya); Tulane University and University of Illinois at Champaign (USA); Kenya Medical Research Institute (KEMRI)

Donors: USAID through the Environmental Health Project (USA)

MALARIA CONTROL AND PREVENTION IN THE HIGHLANDS OF WESTERN KENYA

BACKGROUND, APPROACH AND OBJECTIVES

Since the 1990s, both the incidence of malaria and the frequency of epidemics in the western Kenyan highlands have been increasing, with severe outbreaks in 1995, 1998/99 and in May–July 2002. Various possible etiologies of these malaria outbreaks have been proposed, including climate change favouring vector and parasite survival; reduced efficacy of medication; intrinsic vector population dynamics responsible for mosquito fluctuations; and lack of community awareness, preparedness, communication and personal protection. ICIPE's investigations conducted in the highlands over the last 2.5 years show the occurrence of a dramatic change in land use over the last two decades. These anthropogenic environmental changes have resulted in the formation of countless new larval breeding sites for malaria mosquitoes.

The present study which started in February 2002, has thus focused on these habitats and nearby homesteads as the most important entomological intervention targets for community-based integrated vector management (IVM). These mosquito breeding sites may be mainly responsible for the deteriorating malaria situation in this area and elsewhere.

Selected community-based malaria prevention activities are being implemented as a key strategy for long-term sustainable mosquito and malaria control. They are supported by entomological studies and constitute the core prongs of this project in the Kisii, Gucha and parts of Nyamira districts of Nyanza Province in western Kenya. The main goal is to reduce morbidity and mortality due to malaria in the area through integrated vector management, with special emphasis on:

- coordinating all stakeholders (e.g. community groups, governmental structures and participating partners) for concerted action;
- investigating and addressing land-use change as an environmental issue and its relationship to larval habitats as the main sources of malaria mosquitoes;
- indoor residual spraying (IRS) of target houses where malaria mosquitoes are identified and their location related to the proximity of larval habitats through coordination with public health officers;
- developing and testing locally available and inexpensive plant-based raw materials for larval control under various weather conditions;
- applying these larvicides on a large scale in man-made larval habitats with community participation;
- holding community 'Malaria and Environment' workshops (including follow-ups) to serve as a forum for educational discussion and as a planning forum for self-help groups and government officers;
- implementating an area-wide malaria early warning system (MEWS) aimed at correct and timely prediction of malaria outbreaks;
- conducting parasitometric surveys within the communities (carried out by the Ministry of Health) on a monthly basis to confirm malaria cases and sentinel sites for entomological assessments to provide the data required for MEWS.

WORK IN PROGRESS

This project seeks to determine which types of habitats contain consistently high larval densities of malaria vectors in the highlands and to relate the numeric importance of these key habitats to the location of houses. Special emphasis is placed on vector populations during the dry season, when only limited amounts of stagnant water is available to gravid female mosquitoes for oviposition. The answers to these questions provide essential knowledge necessary for targeted vector control interventions and malaria prevention.

The majority of larval habitats in the three districts are man-made (Figure 1). They are also important sources of malaria vectors during the dry seasons (Table 1), and show the highest population densities of *Anopheles gambiae*. Man-made habitats have low levels of vegetation (Table 2) and low species diversity of predators.

Houses next to man-made habitats were found to be more frequently inhabited by malaria mosquitoes than houses next to swamps. The local public health officers are making use of this information by targeting such homesteads for indoor residual spraying (IRS).

Both community integration and sustainability represent critical elements in any malaria intervention projects. Data obtained through field assessments are being communicated in part to high-risk community groups (e.g brickmakers) through 'Malaria and Environment' workshops. Over 260 community members were trained in 2002/2003 on malaria

Figure 1. Functional (right, stagnant water) and abandoned (left, stagnant water containing vegetation) brick-making pits are assessed

Table 1. Dry season assessment of larval habitat types, 2002

Habitat	Number of assessed habitats	Number of habitats with *Anopheles* larvae	Habitats with *Anopheles* larvae (%)	Total *Anopheles* habitats (%)
BMS (F)	6	6	100.0	37.5
Quarry (F)	4	3	75.0	18.8
BMS (A)	14	3	21.4	18.8
Quarry (A)	10	1	10.0	6.3
Treehole	5[+]	1	20.0	6.3
Swamp	6	1	16.7	6.3
Drainage ditch	7	1	14.3	6.3
Fish pond	1	0	0.0	0.0
Stream pool	2	0	0.0	0.0
Total	**55**	**16**		**100.3**

BMS (F): Functional brickmaking site.
BMS (A): Abandoned brickmaking site.
[+]Four tree holes were dry.

Table 2. Comparison of functional and abandoned brick-making sites as larval habitats of malaria mosquitoes

Factor	Use	N	Mean	Standard deviation	t-statistic[+]	P
Percent vegetation	Functional	15	0.27	0.46	-47.116	< 0.001
	Abandoned	15	94.27	7.71		
Habitat age (months)	Functional	15	0.62	0.17	-5.734	< 0.001
	Abandoned	15	24.20	15.92		
Predator biodiversity	Functional	15	5.13	2.36	-3.586	0.001
	Abandoned	15	9.07	3.53		
Average number of *Anopheles*/dip (5 dips per pit)	Functional	15	2.87	2.04	3.402	0.002
	Abandoned	15	0.91	0.90		
Average number of *Culex*/dip	Functional	15	3.77	3.60	2.435	0.025
	Abandoned	15	1.32	1.51		

[+]SPSS 11.0 t-test for independence.

symptoms and treatment, malaria vector biology, and protection, prevention and interventions. Interventions and self-protection are discussed, planned and executed by the participants. All workshops are attended by MoH officers and other stakeholders, including Merlin and World Vision, who bring their expertise and contribute to sustainability.

Participatory rural appraisals (PRA) have revealed an increasing trend of brickmaking in the highlands over the last 15 years (Figure 2), an activity which is associated with the creation of new mosquito breeding habitats.

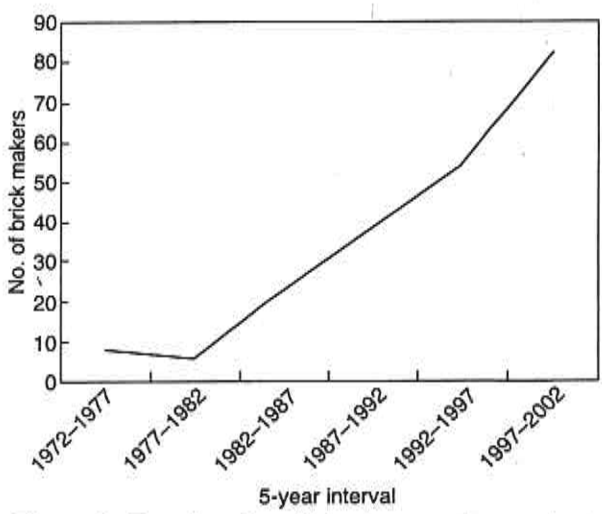


Figure 2. Results of participatory rural appraisals (PRA) showing the development of brickmaking as a trade over the past two decades in western Kenya

Since man-made habitats were revealed to have the highest malaria mosquito densities, environmental water management was taken over by the communities themselves to eliminate or reduce stagnant water sources.

Tests of raw materials from neem (*Azadirachta indica*) and chinaberry (*Melia azedarach*) have shown high mosquito larvicidal activity (96% mortality of L3 pupae). These botanical blends are now being used on a large scale within the Kisii and Gucha districts. *(See also the report of the Behavioural and Chemical Ecology Department.)*

CAPACITY BUILDING

PhD students

John Carlson (USA) MD/PhD programme. Tulane University.

Stephen Barasa (Kenya) PhD programme. ICIPE (Behavioural and Chemical Ecology Department).

IMPACT

- TV documentaries: German and Swiss TV

Participating scientist: F. X. Omlin (Programme Leader)

Assisted by: S. K. Gichia

Collaborators: Community groups (self-help groups); NGOs (Merlin, Medical Emergency Relief International; PSI, Population Services International; and World Vision); local, provincial and national Kenya Ministry of Health (MoH) officials; National Malaria Control Programme; Kenya Medical Research Institute (KEMRI); Ministry of Agriculture (Fisheries Department); Kenya Marine and Fisheries Research Institute (KEMFRI); Tulane University (USA)

Donors: Government of Finland; BioVision International, Switzerland

OUTPUT

Journal articles

Barasa S. S., **Ndiege I. O.,** *Lwande W.* **and** *Hassanali A.* **(2002)** Repellent activities of stereoisomers of *p*-menthane-3,8-diols against *Anopheles gambiae*. *Journal of Medical Entomology* 39, 736–741.

Bousema J. T., *Gouagna L. C.,* **Meutstege A. M.,** *Okech B. E.,* **Akim N. I. J.,** *Githure J. I., Beier J. C.* **and Sauerwein R. W. (2003)** Treatment failure of pyrimethamine-sulphadoxine and induction of *P. falciparum* gametocytaemia in children in western Kenya. *Tropical Medicine and International Health* 8, 427–430.

Chen H., *Nyanjom S. R. G.,* **Teshome G./M., Bekele E.,** *Shililu J., Githure J., Beier J. C.* **and** *Yan G.* **(2003)** Population genetic structure of *Anopheles arabiensis* mosquitoes in Ethiopia and Eritrea. *Journal of Heredity* 94, 457–463.

Eisele T. P ., Keating J., Swalm C., *Mbogo C. M.,* **Githeko A.K., Regens J. L.,** *Githure J. I.,* **Andrews L. and** *Beier J. C.* **(2003)** Linking field-based ecological data with remotely sensed data using a geographic information system in two malaria endemic urban areas of Kenya. *Malaria Journal* 2, 44.

Gouagna L. C., Okech B. A., **Obare P., Miyare P., Ombonya S., Kabiru E. W.,** *Beier J. C., Yan G., Knols B. G. J., Githure J. I.* **and** *Killeen G. F.* **(2003)** Seasonality of *Plasmodium falciparum* infection and risk factors for gametocyte carriage in patients attending a rural health centre in western Kenya. *East African Medical Journal* 80, 627–634.

Gu W., *Killeen G. F., Mbogo C. M.,* **Regens J. L.,** *Githure J. I.* **and** *Beier J. C.* **(2003)** An individual-based model of *Plasmodium falciparum* malaria transmission on the coast of Kenya. *Transactions of the Royal Society of Tropical Medicine and Hygiene* 97, 43–50. **(Call No.: 03-1701)**

Individual-based models provide powerful tools to model complex interactions characterized by individual variability. This paper presents an object-oriented design for individual-based modelling of *Plasmodium falciparum* malaria transmission. Two kinds of objects, human and mosquito, that exhibit variability among individuals for parameters such as recovery and survival rates are defined. The model tracks the dynamics of human hosts and adult female mosquitoes individually. Immunity, modelled as a function of exposure history, is represented by reduced susceptibility and increased recovery rate. The model was calibrated using epidemiological data collected at 30 sites along the coast of Kenya. The sites were grouped into low, intermediate and high transmission based on mean daily human-biting rates. Simulation results show that malaria transmission was stable even in low transmission areas where the human-biting rate is approximately 0.5 bite per day. The model was used to examine the effect of infection control programmes that aim at interrupting transmission by reducing human–vector contact rates and implementing active case detection and drug treatment of infections. With this intervention, local elimination of malaria is likely with a probability of extinction of approximately 0.8 in low transmission areas. However, a small amount of immigration (> 0.3%) by infected people into the community could prevent local extinction of the parasite. In intermediate and high transmission areas, reduction in prevalence is short-lived and the probability of local elimination is low, even at high coverage levels of the intervention.

Gu W., *Mbogo C. M., Githure J. I.*, Regens J. L., *Killeen G. F.*, Swalm C. M., *Yan G.* and *Beier J. C.* (2003) Low recovery rates stabilise malaria endemicity in areas of low transmission in coastal Kenya. *Acta Tropica* 86, 71–81. **(Call No.: 03-1677)**

The prevalence of *Plasmodium falciparum* malaria in African communities can be high and stable even in areas of relatively low transmission where people expose to only a few infectious bites per year. We show in this field study conducted in 30 sites along the coastal Kenya that prevalence in school children was consistently high, although there were many sites where transmission intensity measured by exposure to infectious bites was less than 10 per year. Statistical analyses revealed that prevalence was significantly correlated with the infectious exposure occurring 10–11 months previously, suggesting that long-lived infections were commonplace and one of the major contributors for the stability of malaria in these sites. Using mechanistic models of malaria transmission, we found that the association of high prevalence and low transmission could be due to low recovery rates. Therefore, significant reductions of malaria prevalence and burden require substantial reductions of the duration of acquired infections, even in areas that have quite low transmission intensities by the standards of sub-Saharan Africa. Infection control featured by active detection and drug treatment as well as vector control is critical to combat malaria in areas of relatively low transmission intensity.

Jacob B. C., Regens J. L., *Mbogo C. M.*, Githeko A. K., Keating J., Swalm C. M., Gunter J. T., *Githure J. I.* and *Beier J. C.* (2003) Occurrence and distribution of *Anopheles* (Diptera: Culicidae) larval habitats on land cover change sites in urban Kisumu and urban Malindi, Kenya. *Journal of Medical Entomology* 40, 777–784. **(Call No.: 03-1718)**

A multitemporal, land use land cover (LULC) classification dataset incorporating distributions of mosquito larval habitats was produced in ERDAS Imagine using the combined images from the Multispectral Thermal Imager (MTI) at 5 m spatial resolution from 2001 with Thematic Mapper-classification data at 28.5 m spatial resolution from 1987 and 1989 for Kisumu and Malindi, Kenya. Total LULC change for Kisumu over 14 yr was 30.2%. Total LULC change for Malindi over 12 yr was 30.6%. Of those areas in which change was detected, the LULC change for Kisumu was 72.5% for nonurban to urban, 21.7% urban to nonurban, 0.4% urban to water, 4.5% water to urban, and 0.9% water to nonurban. The proportion of LULC change for Malindi was 93.5% for nonurban to urban, 5.9% urban to nonurban, 0.2% urban to water, 0.3% nonurban to water, and 0.1% water to urban. A grid (270 m x 270 m cells) was overlaid over the maps stratifying grid cells based on drainage and planning. Of 84 aquatic habitats in Kisumu, 32.1% were located in LULC change sites and 67.9% were located in LULC nonchange sites. Of 170 aquatic habitats in Malindi, 26.5% were located in LULC change sites and 73.5% were located in LULC nonchange sites. The most abundant LULC change per strata with anopheline habitats was unplanned and poorly drained. Ditches and puddles in Kisumu and car tracks in Malindi displayed the highest number of anopheline larval habitats for all LULC change sites. The proportion of site positive aquatic habitats for anopheline larvae was higher in LULC change sites than for LULC nonchange sites for Kisumu. This evidence suggests LULC change can influence anopheline larval habitat distribution.

Keating J., Macintyre K., *Mbogo C.*, Githeko A., Regens J. L., Swalm C., Ndenga B., Steinberg L. J., Kibe L., *Githure J. I.* and *Beier J. C.* (2003) A geographic sampling strategy for studying relationships between human activity and malaria vectors in urban Africa. *American Journal of Tropical Medicine and Hygiene* 68, 357–365. **(Call No.: 03-1695)**

This paper describes a geographic sampling strategy for ecologic studies and describes the relationship between human activities and anopheline larval ecology in urban areas. Kisumu and Malindi, Kenya were mapped using global positioning systems, and a geographic information system was used to overlay a measured grid, which served as a sampling frame. Grid cells were stratified and randomly selected according to levels of planning and drainage. A cross-sectional survey was conducted in April and May 2001 to collect entomologic and human ecologic data. Multivariate regression analysis was used to test the relationship between the abundance of potential larval habitats, and house density, socioeconomic status, and planning and drainage. In Kisumu, 98 aquatic habitats were identified, 65% of which were human made and 39% were positive for anopheline larvae. In Malindi, 91 aquatic habitats were identified, of which, 93% were human made and 65% were harboring anopheline larvae. The regression model explains 82% of the variance associated with the abundance of potential larval habitats in Kisumu. In Malindi, 59% of the variance was explained. As the number of households increased, the number of larval habitats increased correspondingly to a point. Beyond a critical threshold, the density of households appeared to suppress the development of aquatic habitats. The proportion of high-income households and the planning and drainage variables tested insignificant in both locations. The integration of social and biologic sciences will allow local mosquito and malaria control groups an opportunity to assess the risk of encountering potentially infectious mosquitoes in a given area, and concentrate resources accordingly.

***Killeen G. F., Knols B. G. J., Fillinger U., Beier J. C.* and *Gouagna L. C.* (2002)** Interdisciplinary malaria vector research and training for Africa. *Trends in Parasitology* 18, 433–434.

Macintyre K., Keating J., Sosler S., Kibe L., *Mbogo C. M.*, Githeko A. K. and *Beier J. C.* (2002) Examining the determinants of mosquito avoidance practices in cities in Kenya. *Malaria Journal* 1,14.

Mathenge E. M., *Killeen G. F.*, Oulo D. O., Irungu L. W., *Ndegwa P. N.* and *Knols B. G. J.* (2002) Development of an exposure-free bednet trap for sampling Afrotropical malaria vectors. *Medical and Veterinary Entomology* 16, 67–74. **(Call No.: 02-1622)**

An exposure-free bednet trap (the 'Mbita trap') for sampling of Afrotropical malaria vectors was developed during preliminary studies of mosquito behaviour around human-occupied bednets. Its mosquito sampling efficiency was compared to the CDC miniature light-trap and human landing catches under semi-field conditions in a screen-walled greenhouse using laboratory-reared *Anopheles gambiae* Giles *sensu stricto* (Diptera: Culicidae). When compared in a competitive manner (side by side), the Mbita trap caught 4.1 ± 0.5 times as many mosquitoes as the CDC light-trap, hung beside an occupied bednet ($P < 0.0001$) and $43.2 \pm 10\%$ the number caught by human landing catches ($P <$

0.0001). The ratio of Mbita trap catches to those of the CDC light trap increased with decreasing mosquito density. Mosquito density did not affect the ratio of Mbita trap to human-landing catches. In a non-competitive comparison (each method independent of the other), the Mbita trap caught 89.7 ± 10% the number of mosquitoes caught by human landing catches ($P < 0.0001$) and 1.2 ± 0.1 times more mosquitoes than the CDC light trap ($P = 0.0008$). Differences in Mbita trap performance relative to the human landing catch under non-competitive vs. competitive conditions were explained by the rate at which each method captured mosquitoes. Such bednet traps do not expose people to potentially infectious mosquito bites and operate passively all night without the need for skilled personnel. This trap is specifically designed to catch host-seeking mosquitoes only and may be an effective, sensitive, user-friendly and economic alternative to existing methods for mosquito surveillance in Africa.

Mbogo C. M., **Mwangangi J. M., Nzovu J. G., Gu W.,** *Yan G.*, **Gunter J. T., Swalm C., Keating J., Regens J. L.,** *Shililu J. I., Githure J. I.* **and** *Beier J. C.* **(2003)** Spatial and temporal heterogeneity of *Anopheles* mosquitoes and *Plasmodium falciparum* transmission along the Kenyan coast. *American Journal of Tropical Medicine and Hygiene* 68, 734–742. **(Call No.: 03-1758)**

The seasonal dynamics and spatial distributions of *Anopheles* mosquitoes and *Plasmodium falciparum* parasites were studied for one year at 30 villages in Malindi, Kilifi and Kwale Districts along the coast of Kenya. Anopheline mosquitoes were sampled inside houses at each site once every two months and malaria parasite prevalence in local school children was determined at the end of the entomologic survey. A total of 5,476 *Anopheles gambiae s.l.* and 3,461 *An. funestus* were collected. Species in the *An. gambiae* complex, identified by a polymerase chain reaction, included 81.9% *An. gambiae s.s.*, 12.8% *An. arabiensis* and 5.3% *An. merus*. *Anopheles gambiae s.s.* contributed most to the transmission of *P. falciparum* along the coast as a whole, while *An. funestus* accounted for more than 50% of all transmission in Kwale District. Large spatial heterogeneity of transmission intensity (< 1 up to 120 infective bites per person per year) resulted in correspondingly large and significantly related variations in parasite prevalence (range = 38–83%). Thirty-two percent of the sites (7 of 22 sites) with malaria prevalences ranging from 38 to 70% had annual entomologic inoculation rates (EIR) less than five infective bites per person per year. *Anopheles gambiae s.l.* and *An. funestus* densities in Kwale were not significantly influenced by rainfall. However, both were positively correlated with rainfall one and three months previously in Malindi and Kilifi Districts, respectively. These unexpected variations in the relationship between mosquito populations and rainfall suggest environmental heterogeneity in the predominant aquatic habitats in each district. One important conclusion is that the highly non-linear relationship between EIRs and prevalence indicates that the consistent pattern of high prevalence might be governed by substantial variation in transmission intensity measured by entomologic surveys. The field-based estimate of entomologic parameters on a district level does not provide a sensitive indicator of transmission intensity in this study.

Mukabana W. R., **Takken W., Coe R. and** *Knols B. G. J.* **(2002)** Host-specific cues cause differential attractiveness of Kenyan men to the African malaria vector. *Malaria Journal* 1, 17.

Mukabana W. R., **Takken W.,** *Seda P., Killeen G. F.*, **Hawley W. A. and** *Knols B. G. J.* **(2002)** Extent of digestion affects the success of amplifying human DNA from blood meals of *Anopheles gambiae* (Diptera: Culicidae). *Bulletin of Entomological Research* 92, 233–239. **(Call No.: 02-1623)**

The success of distinguishing blood meal sources of *Anopheles gambiae* Giles through deoxyribonucleic acid (DNA) profiling was investigated by polymerase chain reaction (PCR) amplification at the TC-11 and VWA human short tandem repeats (STR) loci. Blood meal size and locus had no significant effect on the success of amplifying human DNA from blood meals digested for 0, 8, 16, 24 and 32 h ($P = 0.85$ and 0.26 respectively). However, logistic regression found a significant negative relationship between time since ingestion and the success probability of obtaining positive PCR products among meals digested for between 8 and 32 h ($P = 0.001$). Approximately 80% of fresh blood meals were successfully profiled. After 8 h, the proportion of blood meals that could be successfully profiled decreased slowly with time after ingestion, dropping to below 50% after approximately 15 h. There was no significant difference in the success of amplifying human DNA from blood meals of mosquitoes killed at time 0 and 8 h after ingestion ($P = 0.272$).

Mwangangi J. M., *Mbogo C. M.*, **Nzovu J. G.,** *Githure J. I., Yan G.* **and** *Beier J. C.* **(2003)** Blood meal analysis for anopheline mosquitoes sampled along the Kenyan coast. *Journal of the American Mosquito Control Association* 19, 371–375.

Okanda A. D., Dao A., *Njiru B.*, **Arija J., Akelo H., Toure Y.,** *Odulaja A., Beier J., Githure J., Yan G., Gouagna L., Knols B.* **and** *Killeen G.* **(2002)** Behavioural determinants of gene flow in malaria vector populations: *Anopheles gambiae* males select large females as mates. *Malaria Journal* 1, 10–13.

Okech B. A., Gouagna L. C., Killeen G. F., Knols B. G. J., **Kabiru E. W.,** *Beier J. C., Yan G.* **and** *Githure J. I.* **(2003)** Influence of sugar availability and indoor microclimate on survival of *Anopheles gambiae* (Diptera: Culicidae) under semifield conditions in western Kenya. *Journal of Medical Entomology* 40, 657–663. **(Call No.: 03-1726)**

The influence of indoor microclimate on survival of female *Anopheles gambiae sensu stricto* Giles (Diptera: Culicidae) mosquitoes fed on different nutrition sources was evaluated in a semifield experimental hut exposed to ambient climate in western Kenya. Cages of mosquitoes (n = 50 per cage) were placed in nine positions within the hut combining three different sides and three different heights. At each height and side, mosquitoes were offered either human blood (once every 2 d), glucose (6% wt: vol) or a combination of the two diets over three experiments so that each cage position received one diet source. The effect of diet on survival was significant with mean survival times of 14 d for mosquitoes fed blood alone, 29 d for sugar alone and 33 d for blood plus sugar. Sugar availability decreased the odds of mortality ≈85% compared with the blood group. Micro heterogeneities of temperature but not relative humidity also influenced survival although to a much lesser extent. The side but not height within the hut at which mosquitoes were placed, influenced survival but could not be explained by either temperature or relative humidity differences. The potential influence of seemingly minor heterogeneities of indoor microclimate upon vector longevity and vectorial capacity may merit further investigation. Also, the availability of sugar was shown to be a potentially crucial determinant of vectorial capacity. Compared with blood alone, the availability of sugar served to increase survival potential of vectors beyond ages at which they are old enough to transmit malaria.

Seyoum A., **Kabiru E. W.**, *Lwande W., Killeen G. F., Hassanali A.* **and** *Knols B. G. J.* **(2002)** Repellency of live potted plants against *Anopheles gambiae* from human baits in semi-field experimental huts. *American Journal of Tropical Medicine and Hygiene* 67, 191–195. **(Call No.: 02-1643)**

The repellency of potted plants against the malaria vector *Anopheles gambiae sensu stricto* Giles was quantified in experimental huts under semi-field conditions inside a screen-walled greenhouse. *Ocimum americanum* Linnaeus (Labiatae), *Lantana camara* L. (Verbenaceae), and *Lippia uckambensis* Spreng (Verbenaceae) repelled at an average of 39.7% (95% confidence interval [CI] = 29.6–48.4%), 32.4% (95% CI = 19.7–43.1 %), and 33.3% (95% CI = 21.5–43.3%) of the mosquitoes, respectively (P < 0.0001 for all treatments). This was determined by logistic regression, allowing for variations associated with different bait hosts, sampling huts, and replicate test nights. In contrast, *Ocimum kilimandscharicum* Guerke (Labiatae), *Ocimum suave* Willd. (Labiatae), *Corymbia citriodora* Hook (Myrtaceae), *Azadirachta indica* A. Juss (Meliaceae), *Tagetes minuta* L. (Asteraceae), and *Hyptis suaveolens* Poit. (Lamiaceae) did not significantly repel mosquitoes. The combination of *O. americanum* with either *L. camara* or *L. uckambensis* repelled 31.6% (95% CI = 19.7–41.7%) and 45.2% (95% CI = 34.7–54.0%) of the mosquitoes, respectively (P <0.0001 for both treatments). This study is the first to show that live intact plants can reduce domestic exposure to malaria vector mosquitoes. As such, they may represent a new, sustainable and readily applicable malaria vector control tool for incorporation into integrated vector management programs.

Seyoum A., **Pålsson K., Kung'a S., Kabiru E. W.**, *Lwande W., Killeen G. F., Hassanali A.* **and** *Knols B. G. J.* **(2002)** Traditional use of mosquito-repellent plants in western Kenya and their evaluation in semi-field experimental huts against *Anopheles gambiae*: Ethnobotanical studies and application by thermal expulsion and direct burning. *Transactions of the Royal Society of Tropical Medicine and Hygiene* 96, 225–231. **(Call No.: 02-1627)**

Ethnobotanical survey in 2 communities in western Kenya revealed that the most commonly known repellent plants were *Ocimum americanum* L. (64.1%), *Lantana camara* L. (17.9%), *Tagetes minuta* L. (11.3%) and *Azadirachta indica* A. Juss (8.7%) on Rusinga Island, and *Hyptis suaveolens* Poit. (49.2%), *L. camara* (30.9%) and *O. basilicum* L. (30.4%) in Rambira. Direct burning of plants is the most common method of application for *O. americanum* (68.8%), *L. camara* (100%) and *O. basilicum* (58.8%). Placing branches or whole plants inside houses is most common for *H. suaveolens* (33.3 and 57.8% for the respective locations), *A. indica* (66.7 and 100%), and *T. minuta* (54.8 and 56.0%). The repellency of plants suggested by the ethnobotanical survey and other empirical information was evaluated against the malaria vector *Anopheles gambiae s.s.* Giles in experimental huts within a screen-walled greenhouse. Thermal expulsion and direct burning were tested as alternative application methods for the selected plants *O. americanum, O. kilimandscharicum* Guerke, *O. suave* Willd., *L. camara, A. indica, H. suaveolens, Lippia uckambensis* Spreng and *Corymbia citriodora* Hook. When thermally expelled, only *H. suaveolens* failed to repel mosquitoes, whereas the leaves of *C. citriodora* (74.5%, *P* < 0.0001), leaves and seeds of *O. suave* (53.1%, *P* < 0.0001) and *O. kilimandscharicum* (52.0%, *P* < 0.0001) were the most effective. Leaves of *C. citriodora* also exhibited the highest repellency (51.3%, *P* < 0.0001) by direct burning, followed by leaves of *L. uckambensis* (33.4%, *P* = 0.0004) and leaves and seeds of *O. suave* (28.0%, *P* = 0.0255). The combination of *O. kilimandscharicum* with *L. uckambensis* repelled 54.8% of mosquitoes (*P* < 0.0001) by thermal expulsion. No combination of plants increased repellency by either method. The semi-field system described appears a promising alternative to full-field trials for screening large numbers of candidate repellents without risk of malaria exposure.

Shililu J. I., **Ghebremeskel T., Brantly E.**, *Githure J. I., Mbogo C. M., Beier J. C.*, **Fusco R. and Novak R. J. (2003)** Efficacy of *Bacillus thuringiensis israelensis, Bacillus sphaericus* and temephos for managing *Anopheles* larvae in Eritrea. *Journal of the American Mosquito Control Association* 19, 251–258. **(Call No.: 03-1741)**

We evaluated the larvicidal activity of the granular formulation of *Bacillus thuringiensis israelensis (Bti)* serotype H-14 (Vectobac® G, 200 ITU/mg) and *Bacillus sphaericus (Bsph)* serotype H5a5b (Vectolex® CG, 670 Bs ITU/mg) against *Anopheles arabiensis* and other mosquitoes in breeding habitats in 3 sites, Gash-Barka, Anseba, and Debub zones, in Eritrea. The primary objective was to determine the optimal application rate and duration of effect for *Bti* and *Bsph* in representative larval habitats as compared with the organophosphate temephos. The biolarvicides were tested at 100% (high) and 50% (low) of the maximum recommended application rate. Temephos was applied at a rate of 100 ml/ha. At least 4 replicate experiments with Vectobac G (5.6 and 11.2 kg/ha), Vectolex CG (11.2 and 22.4 kg/ha) were conducted in each study site. All 3 larvicides caused significant mortality of the main malaria vector species, *An. arabiensis*, and other mosquito species (*Anopheles cinereus, Anopheles pretoriensis, Culex quinquefasciatus*). The larvicidal activity for *Bti* and *Bsph* was variable depending upon breeding habitat, mosquito species, and general ecology of the area. Both biopesticides had a similar duration of activity (2–3 wk) and were generally as effective as temephos for these time periods. In some cases, the high and low application rates for *Bti* and *Bsph* produced equivalent control over 2–3 wk. The 2 *Bacillus* biopesticides were less effective in habitats with high algal content and in fast flowing streams primarily because of the inability to penetrate algal mats and dilution effect, respectively. The results show that application of the 2 biolarvicides bimonthly to streambed pools, rain pools, and similar habitats would maintain control of the anopheline mosquito population.

Shililu J., **Ghebremeskel T., Mengistu S., Fekadu H., Zerom M.**, *Mbogo C., Githure J.*, **Novak R., Brantly E. and** *Beier J. C.* **(2003)** High seasonal variation in entomologic inoculation rates in Eritrea, a semi-arid region of unstable malaria in Africa. *American Journal of Tropical Medicine and Hygiene* 69, 607–613. **(Call No.: 03-1735)**

Entomologic studies were conducted in eight villages to investigate the patterns of malaria transmission in different ecologic zones in Eritrea. Mosquito collections were conducted for 24 months between September 1999 and January 2002. The biting rates of *Anopheles arabiensis* were highly seasonal, with activity concentrated in the wet season between June and October in the highlands and western lowlands, and between December and March in the coastal region.

The biting rates in the western lowlands were twice as high as in the western escarpment and 20 times higher than in the coastal region. Sporozoite rates were not significantly different among villages. The risk of infection ranged from zero on the coast to 70.6 infective bites per year in the western lowlands. The number of days it would take for an individual to receive an infective bite from an infected *An. arabiensis* was variable among villages (range = 2.8–203.1 days). The data revealed the presence of only one main malaria transmission period between July and October for the highlands and western lowlands. Peak inoculation rates were recorded in August and September (range = 0.29–43.6 infective bites/person/month) at all sites over the two-year period. The annual entomologic inoculation rates (EIRs) varied greatly depending on year. The EIR profiles indicated that the risk of exposure to infected mosquitoes is highly heterogeneous and seasonal, with high inoculation rates during the rainy season, and with little or no transmission during the dry season. This study demonstrates the need to generate spatial and temporal data on transmission intensity on smaller scales to guide targeted control of malaria operations in semi-arid regions. Furthermore, EIR estimates derived in the present study provide a means of quantifying levels of exposure to infected mosquitoes in different regions of the country and could be important for evaluating the efficacy of vector control measures, since Eritrea has made significant steps in reducing the burden of malaria based on the Roll Back Malaria initiative of the World Health Organization.

***Shililu J.*, Ghebremeskel T., Seulu F., Mengitsu S., Fekadu H., Zerom M., Asmelash G., Sintasath D., Bretas G., *Mbogo C., Githure J.*, Brantly E., Novak R. and *Beier J. C.* (2003)** Larval habitat diversity and ecology of anopheline larvae in Eritrea. *Journal of Medical Entomology* 40, 921–929. **(Call No.: 03-1719)**

Studies on the spatial distribution of anopheline mosquito larvae were conducted in 302 villages over two transmission seasons in Eritrea. Additional longitudinal studies were also conducted at eight villages over a 24-mo period to determine the seasonal variation in anopheline larval densities. Eight anopheline species were identified with *Anopheles arabiensis* predominating in most of the habitats. Other species collected included: *An. cinereus, An. pretoriensis, An. d'thali, An. funestus, An. squamosus, An. adenensis*, and *An. demeilloni*. *An. arabiensis* was found in five of the six aquatic habitats found positive for anopheline larvae during the survey. *Anopheles* larvae were sampled predominantly from stream edges and streambed pools, with samples from this habitat type representing 91.2% (n = 9481) of the total anopheline larval collection in the spatial distribution survey. Other important anopheline habitats included rain pools, ponds, dams, swamps, and drainage channels at communal water supply points. Anopheline larvae were abundant in habitats that were shallow, slow flowing and had clear water. The presence of vegetation, intensity of shade, and permanence of aquatic habitats were not significant determinants of larval distribution and abundance. Larval density was positively correlated with water temperature. Larval abundance increased during the wet season and decreased in the dry season but the timing of peak densities was variable among habitat types and zones. Anopheline larvae were collected all year round with the dry season larval production restricted mainly to artificial aquatic habitats such as drainage channels at communal water supply points. This study provides important information on seasonal patterns of anopheline larval production and larval habitat diversity on a countrywide scale that will be useful in guiding larval control operations in Eritrea.

***Shililu J.*, Ghebremeskel T., Mengistu S., Fekadu H., Zerom M., *Mbogo C., Githure J.*, Gu W., Novak R. and *Beier J. C.* (2003)** Distribution of anopheline mosquitoes in Eritrea. *American Journal of Tropical Medicine and Hygiene* 69, 295–302. **(Call No.: 03-1740)**

The spatial distribution of anopheline mosquito species was studied throughout Eritrea during the 1999–2001 malaria transmission seasons from October to December for the highlands and western lowlands and February to April for the coastal region. Of the 302 villages sampled, 59 were visited in both the first and second year. Overall, 13 anopheline species were identified, with the *Anopheles gambiae* complex predominating during the first year (75.6%, n = 861) and the second year (91.9%, n = 1,262). Intrazonal variation accounted for 90% of the total variation in mosquito distribution. Polymerase chain reaction results indicated that 99% (n = 1,309) of the *An. gambiae s.l.* specimens were *An. arabiensis*, indicating that this was the only member of the *gambiae* complex present. There was a high degree of aggregation of anophelines within zones and villages, with more than 80% of the total anophelines being collected from less than 20% of the villages and from only 10% of the houses sampled. At least 80% of the anopheline mosquitoes were collected from grass-thatched Agudo-type housing. Vector abundance showed an inverse relationship with elevation, with highest densities in the low-lying western lowlands. Multiple regression analysis of log-transformed mean density of *An. arabiensis* with rainfall and the normalized difference vegetation index (NDVI) (average NDVI, minimum NDVI, and maximum NDVI) showed that these independent variables were not significantly associated with mosquito densities (R^2= 0.058). Our study contributes to the basic understanding of the ecology and distribution of malaria vectors with respect to species composition and spatial heterogeneities both that could be used to guide vector control operations in Eritrea.

***Shililu J. I., Mbogo C. M., Mutero C. M.*, Gunter J. T., Swalm C., Regens J. L., Keating J., *Yan G., Githure J. I.* and *Beier J. C.* (2003)** Spatial distribution of *Anopheles gambiae* and *Anopheles funestus* and malaria transmission in Suba district, western Kenya. *Insect Science and Its Application* 23, 187–196. **(Call No.: 03-1747)**

The study reported here evaluated the distribution, relative abundance, and malaria transmission potential of *Anopheles* mosquitoes at 30 sites representing different ecological strata in western Kenya. Seasonal variation in anopheline densities and transmission potential, as expressed by entomological inoculation rates (EIR), was investigated. Of the 6491 indoor resting anopheline mosquitoes collected at the 30 sites, 91.3 % (n = 5926) were *An. gambiae s.l.* and 8.7% (n = 565) were *An. funestus* with an average house density of 6.58 and 0.63, respectively. Analysis of the data indicated significant variation in mosquito densities between study sites, species and season. High densities of both *An. gambiae* and *An. funestus* were recorded in the northern and northeastern parts of the district, while generally low densities were recorded in the south. *Anopheles gambiae s.s.* and *An. arabiensis* comprised 60.3% (n = 3573) and 39.7% (n = 2352) of the total number of *An. gambiae s.l.* mosquitoes collected, respectively. The composition of the *An. gambiae s.l.* sibling species showed temporal and spatial variation. Entomologic inoculation rates were estimated at 1.55 and 0.12 infective bites per person per month for *An. gambiae s.l.* and *An. funestus*, respectively. This study reveals considerable seasonal and site-specific variation in vector distribution, composition and transmission potential. Application of control interventions must therefore consider seasonal variations since the vectorial system changes quite rapidly over a short period of time.

Sosler M. K., Letipila S., Lochian M., Hassig S., Omar S. and *Githure J.* (2003) A new tool for malaria prevention? Results of a trial of permethrin-impregnated bed-sheets (shukas) in an area of unstable transmission. *International Journal of Epidemiology* 32, 157–160.

Conferences and workshops attended

23rd Africa Health Sciences Congress, Kampala, Uganda, 21–27 April 2002. Attended by J. Shililu, C. Mbogo, L. Kibe, S. Kahindi and O. Spala.

51st Annual Meeting of the American Society of Tropical Medicine and Hygiene, Denver, Colorado, USA, 10–14 November, 2002. Attended by C. Mbogo.

Third Pan-African MIM meeting, Arusha, Tanzania, 17–22 November, 2002. Attended by J. Shililu and C. Mbogo.

52nd Annual Meeting of the American Society of Tropical Medicine and Hygiene, Philadelphia, USA, 3–7 December 2003. Attended by J. Shililu, C. Mbogo and J. Midega.

Workshop on the Use of Geographic Information Systems, Remote Sensing, and Spatial Statistics for Human Health Applications, Nairobi and Mombasa, Kenya, 12–25 May 2002. Attended by C. Mbogo, L. Kibe, S. Kahindi

Interdisciplinary Workshop on Biodiversity and Human Health Linkages—Dialogue and Action, Entebbe, Ugánda, 23–28 June 2002. Attended by C. Mbogo.

Workshop on Health Research Ethics and Good Clinical Practice (GCP). Pretoria, South Africa, 22–26 July 2002. Attended by C. Mbogo.

Multilateral Initiative on Malaria (MIM) Workshop on Management and Leadership for Malaria Research Leaders, Arusha, Tanzania, 6–18 October 2002. Attended by C. Mbogo.

Workshop Course on Arcpad Handheld PC, Denver, Colorado, USA, 10 November 2002. Attended by C. Mbogo.

Scope Meeting on Global Change and Human Health, Paris, France, 27 February–1 March 2003. Attended by C. Mbogo and A. Githeko.

Twelfth Annual Meeting of the NIAID International Centers for Tropical Disease Research Network and Refresher Course in ArcPad Handheld PC, Bethseda, Maryland, USA, 13–15 May 2003. Attended by C. Mbogo.

Malaria Symposium on Malaria and the Future of Africa's Children: Health, Environment and Community, Ohio University, Athens, USA, 7–8 May 2004. An invited presentation by C. Mbogo.

Regional Training Course on Bioinformatics Applied to Tropical Diseases in Africa. South African National Bioinformatics Institute, University of the Western Cape, Cape Town, South Africa, and the Human Genome and Africa Conference, Stellenbosch, South Africa. 19 March–4 April, 2003. Attended by J. Midega.

Biology of Disease Vectors (BDV) Course, National Institute for Public Health Research, Cuernavaca, Mexico. 13–26 June 2003. Attended by J. Midega.

WHO/TDR Protocol Development Workshop on the Development of a Multi Country Study on the Pupal Survey Technique for the Dengue Vector, *Aedes aegytpi*. Centers for Disease Control, Dengue Branch Laboratories. San Juan, Puerto Rico. 1–4 September 2003. Attended by J. Midega.

Conference papers

International Network for Education and Health, Eldoret, Kenya, September 2002. Paper presented: Combining health with education and income generation by the use of the neem tree (*Azadirachta indica* A. Juss): A holistic community approach in rural Kenya. F. X. Omlin.

International Pan-African Malaria Conference, Arusha, Tanzania, November 2002. Paper presented: Observations on new malaria mosquito breeding habitats and their possible implications in malaria transmission. F. X. Omlin.

Project proposals

Reducing Mosquitoes and Malaria through Environmental Management in Urban Malindi, Kenya—Funded.

InterVector Exploratory Center: Development of New International and Interdisciplinary Strategies for Controlling the Transmission of Vector-borne Diseases in Urban Environments.

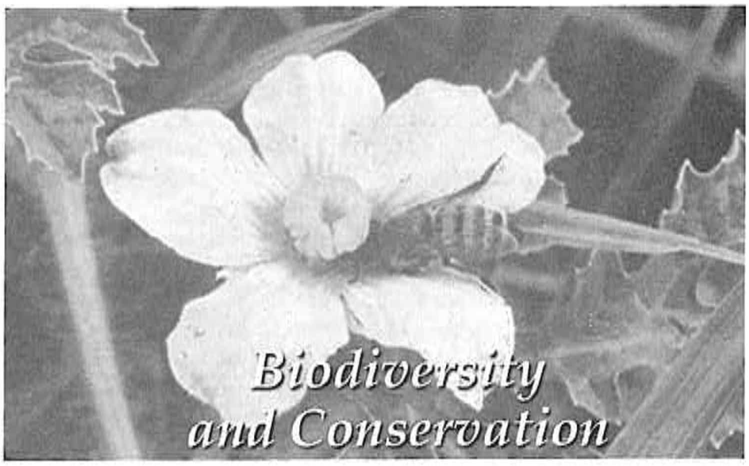
Ecological Genetics of *Anopheles funestus* in East Africa.

Mosquito Ecology in African Urban Environments.

Botanicals for malaria control: A multidisciplinary and community-participatory malaria control programme in Kenya (Kisii and Gucha Districts): Integration of botanicals including neem—Funded.

ENVIRONMENTAL HEALTH RESEARCH





AN INTEGRATED PACKAGE FOR THE CONSERVATION OF THE KAKAMEGA FOREST

BACKGROUND, APPROACH AND OBJECTIVES

Kakamega Forest is now the only surviving rainforest in Kenya. It is the eastern-most fragment of the Guineo-Çongolian rainforest, which once stretched from Kenya across Uganda, East and Central Africa to the West African coast. Situated in western Kenya, 35 km from Lake Victoria, Kakamega Forest provides a unique sanctuary for a remarkable diversity of endemic insects, plants and birds not found anywhere else. Between 10 to 20% of the animal species in the forest are unique to this forest. It is also an important watershed for some of the rivers that flow into Lake Victoria. The forest is invaluable to the people living around it, as a source of timber, fuelwood, herbal medicines, building materials, food, income and new land for agriculture and settlement.

Kakamega Forest is highly threatened, however, largely due to economic and population pressure. The exploitation of the forest has taken place in a haphazard, wasteful and uncontrollable way such that not only is the forest resource steadily diminishing, but its capacity to recover is also being destroyed. In a survey of 15,000 forest-adjacent households, 84% were found to use the forest to provide at least one basic commodity, with grazing and fuelwood collection being the most prevalent activities. The disintegration of the forest has resulted in the breakup of the main forest block into smaller separate forest islands. Only 19,000 ha remain, and there is a real danger that Kakamega Forest could disappear in the next decade at the present levels of exploitation. This situation is illustrative of the fact that forests in Kenya have shrunk to cover less than 2% of the total land area, against an international standard of 10% for ecological sustainability.

The Integrated Project on Conservation of Kakamega Forest, which began in 2000, is a consortium of several organisations, NGOs and CBOs headed by ICIPE. The project aims to contribute to the conservation of the forest by tackling some of the major factors that contribute to its destruction and loss. The following are specific objectives:

- building awareness about the importance of the forest through community-driven environmental and conservation education;
- reducing human pressure on the forest resources through promotion of alternatives to forest-derived fuelwood and fodder and fuelwood energy-saving technologies;
- promoting alternative income-generating activities, including apiculture and sericulture, cultivation of multi-purpose trees and medicinal plants, and provision of credit facilities for entrepreneurship development;
- improving on existing resource management through categorisation of land-use patterns, inventory and monitoring of selected taxa, training of parataxonomists, reforestation and enhancement of forest protection.

WORK IN PROGRESS

1. Cultivation and processing of medicinal plants

Two medicinal plants, *Ocimum kilimandscharicum* and *Mondia whytei*, which had been previously selected for development were promoted to the rural community adjacent to Kakamega forest for intensive cultivation. The Muliru Farmers Conservation Group, a community group living adjacent to the Kakamega forest, continued to plant *O. kilimandscharicum* during the review period. The community no longer required supervision. The group commissioned eight conservation groups around Kakamega forest as outgrowers. The total acreage under *O. kilimandscharicum* cultivation increased considerably to 6 ha compared to 0.2 ha at the beginning of the Project. The number of community members who participated in its cultivation also increased to 56 from 18 in the year 2000.

Hydrodistillation equipment for the extraction of *O. kilimandscharicum* was handed over to the Muliru Farmers Conservation Group on 10 March, 2002 at Isecheno, adjacent to Kakamega forest. The ceremony was presided over by the UNDP Resident Representative in Kenya and the Director General of ICIPE and attended by over 300 people including community members, Government representatives and personnel from UNDP and ICIPE. The equipment is used for extraction of the essential oil used for manufacture of Naturub products. Construction of a building for housing the extraction equipment was completed during 2003.

Several commercial products were developed from formulation to market evaluation, labelling, packaging and registration (Figure 1). Pilot and large-scale processing and manufacturing equipment was fabricated and the products were manufactured, marketed and sold (see photos). The participating farmers were paid for the harvested and processed crop of the medicinal plants.

Farmers who cultivated *O. kilimandscharicum* earned increased income from the sale of the crude essential oil, earning Kshs 52,606 (US$ 658) per hectare per year of the herb. These earnings were better than those from maize, estimated at Kshs 39,882 (US$ 500) per hectare per year. The community members earned a total of Kshs 629,300 (US$ 7870) from sale of the herb. The manufacture and sale of Naturub, the product derived from *O. kilimandscharicum* plant extract, continued to rise during 2003, with 76,287 units of Naturub products being sold in more than 62 outlets in Kenya, giving gross returns of Kshs 916,700 (US$ 11,460). Naturub is now being packaged in a 25-g bottle in addition to the 7-g and 4-g tins.

Community-based commercial cultivation of the endangered medicinal plant, *Mondia whytei* continued, with over 40,000 plants being grown in over 350 rural homes around the forest. The Project initiated the development of several commercial product lines from the roots of the plant in order to add value to the *M. whytei* plants (see Figure 1). Processing equipment was purchased for controlled air-drying of the roots. Mondia Tonic, a product from the powdered roots of the plant, has been developed by ICIPE, KEFRI and KARI and is currently sold in three large chains of supermarkets in Nairobi.

2. Improved apiculture and sericulture

Through its Commercial Insects Programme, ICIPE trained selected groups of farmers, women's and other groups, community-based extension workers and members of the Kakamega Environmental Education Programme (KEEP) (see below) in income-generating sericulture and apiculture technologies. The trained individuals and groups were subsequently helped to start these activities in their homes and to train others in the community. Over 2400 community members were exposed to efficient, modern methods of beekeeping, honey production and silkworm rearing through training and demonstrations. ICIPE

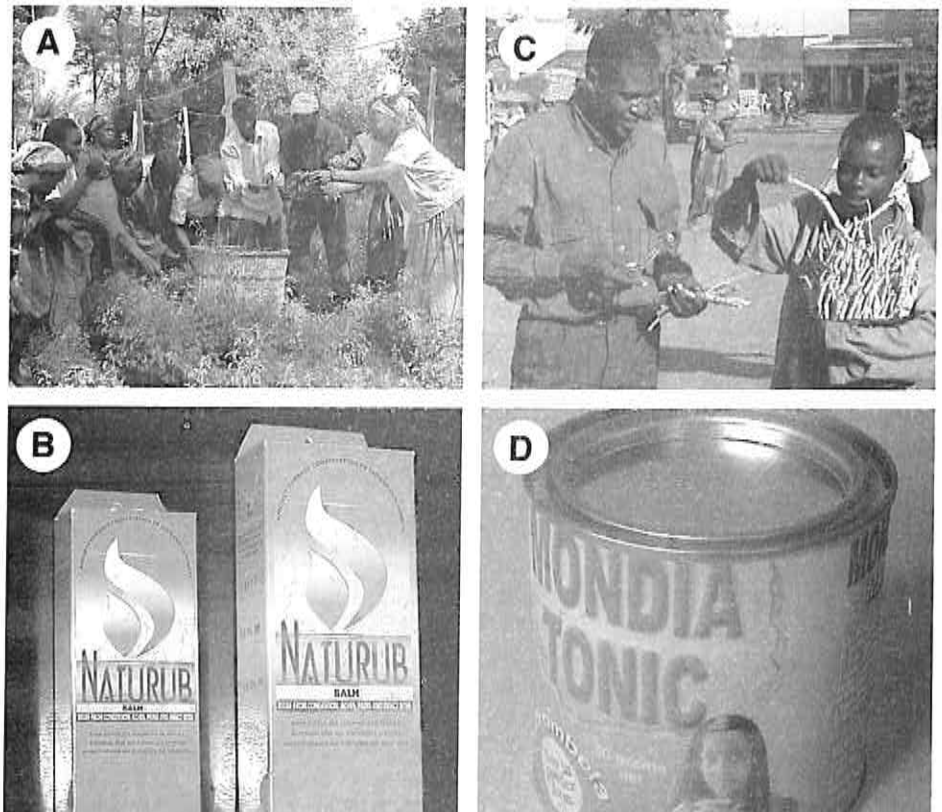


Figure 1. A, Harvesting and processing of* Ocimum kilimandscharicum *leaves by community members living around Kakamega Forest. B, Packaging developed and produced to hold Naturub products. C,* Mondia whytei *roots sold in towns in Kenya and in other African countries. D, Mondia Tonic product developed from* Mondia whytei *roots

also assisted in marketing of their apiculture and sericulture products. An additional 441 Langstroth hives were installed in rural households over the review period. Fifteen carpenters trained in the construction of the beehives have thus far sold more than 500 units.

The two women's groups based at Malava and Ileho continued to serve as models for promotion of silkworm rearing (sericulture) among the community around Kakamega forest. Model silkworm rearing huts were constructed in 2002; the Malava-based group continued to produce silkworm cocoons for trial purposes, while the Ileho group equipped its rearing hut and started to rear silkworms during 2003. Five varieties of mulberry plants (Embu, Thailand, S-36, S-41 and Thika varieties) were introduced in the area to compare leaf quality with that of the Kanva-2 variety that had previously been planted in farmers' fields. More than 200 adult community members and schoolchildren have visited the model silkworm rearing huts.

From the first trials, the Malava CBD group managed to harvest Grade A cocoons (1.5 kg) and Grade B cocoons (3.5 kg). The second trials for silkworm rearing have already been completed by Malava CBD group and the cocoons were brought to ICIPE in October 2002 by a representative of the group. She used the visit to learn about cocoon grading as well as how to maximise the harvest of silk cocoons. By the end of 2003, a total of 51 kg of cocoons had been produced by community groups.

3. Inventory and monitoring

Inventory and monitoring of species in Kakamega forest was initiated by selection of taxa of target flagship species, listing of annotated checklists of the taxa from the literature and establishment of protocols for monitoring. Annotated checklists of various species of Kakamega Forest were drawn up. The checklist for plants, butterflies and moths, snails, hoverflies, ants and mammals were completed by the end of 2003. This exercise was undertaken through consultations with experts on target taxa and in a workshop attended by the participating institutions.

Monitoring of ants was undertaken by hand, involving searching on the ground, on tree trunks, in rotten wood and under objects. Baits were also used in selected sites in the forest. Pitfall traps were used but were found to be no more effective than hand collecting methods. Malaise traps were found to be effective for trapping the winged sexual forms, while black lights were used for the flying nocturnal forms. Many litter samples were collected throughout the forest and the arthropods extracted by means of winker sacks.

More than 180 species of ants were collected and many more remain undiscovered. Of the latter, many will be true arboreal species that live exclusively in the canopy. Some of the larger ant genera (*Camponatus*, *Crematogaster* and *Pheidole*), each with several dozens of species reported from Kenya, have never been subjected to modern revisionary studies.

It was not possible to reliably attach names to most of the species collected from Kakamega forest. Most were from the genera *Monomorium* and *Tetramorium*, and these either had not been previously reported from Kenya or were undescribed new species. In one genus, *Axinidris*, there were five species, three of them undescribed.

Attempts to monitor population fluctuations were in most cases futile, mainly due to the continuing severe degradation of the forest, especially through gathering of firewood and continued illegal cutting of trees. These practices open up the undisturbed areas to colonisation by 'weedy' ants, thereby driving out the normal component of the fauna.

Selected members of the community around Kakamega forest were trained by scientists from the National Museums of Kenya in trapping, collection, sorting and preservation of specimens. The trained parataxonomists trained other members of the community, participated in inventory and monitoring in Kakamega forest and assisted schools and institutions around the forest in taxonomy.

4. Environmental education

The Project worked with the Kakamega Environmental Education Programme (KEEP), a local voluntary community-based environmental group, to support KEEP's efforts. The education covers the following areas: aspects on the importance of forest biodiversity, its conservation, consequences of its destruction and alternative activities that could reduce the pressure on the forest. The Project continued to improve KEEP's facilities and helped KEEP and the community-based Project extension workers in all the nine locations around the Forest to undertake their activities.

More than 15,644 children and 5454 adults attended lessons at the KEEP Resource Centre, visited by 306 schools, 72 university groups and 143 community groups. KEEP conducted environmental and conservation awareness activities at 70 public and eight church meetings. Over 46 demonstrations, 162 nature walks for children and adults and 166 video shows were conducted by KEEP.

5. Energy conservation

Promotion of energy-saving methods and technologies was coordinated by the Intermediate Technology Development Group (ITDG) and ICIPE. ITDG provided training to selected members of community groups, community-based Project extension workers and local leaders in acceptable fuelwood energy-saving methods of cooking and in production and installation of fuelwood energy-saving and associated devices in rural homes. The Project then facilitated the trained individuals and groups to undertake demonstrations of the techniques. In total, 53,800 people were sensitised on the various aspects of fuelwood energy-saving technologies. As a result, 14,113 cooking devices such as improved charcoal stoves and ovens and 5689 kitchen improvement devices were installed in rural homes around the forest by end-2003.

Table 1. Types and numbers of fuelwood energy-saving cooking devices installed in rural homes around Kakamega Forest in 2002 and 2003

Type of device	Description	Number 2003	Number 2002
Upesi liner	A moulded ceramic clay liner for conserving heat during cooking	1245	2630
Upesi portable	A portable *upesi* liner fixed in a cladded metal shell	70	180
Shielded fire	A traditional three-stone cooker that is improved by covering the sides leaving only one opening for firewood	38	89
Mud stove	A fuelwood energy-saving stove made out of any sort of clay	2910	5924
Jiko sanifu	Same as mud stove but has two firebox chambers and a chimney	111	276
Sawdust metal jikos	A metal device that uses only sawdust for cooking	7	18
Clay food warmers	A device attached to a mud stove or made separately to keep food warm for a long time	200	415

Some community members and groups were also trained and assisted in initiating business enterprises for the production and installation of the energy-saving devices and marketing them for income generation. The community-owned centre that was established for the Valonji Women's Group during the previous reporting period produced and sold a total of 1610 stoves.

6. Agroforestry and reforestation

Promotion of on-farm agroforestry among community members living around Kakamega Forest was coordinated by ICIPE, ICRAF and KEFRI. This involved selection and prioritisation of indigenous tree species on the basis of potential uses, ease of cultivation and acceptability by the community. Selected community groups were trained in agroforestry techniques, and these groups in turn trained and distributed seedlings for on-farm planting. A total of 486,000 seedlings of multipurpose trees were raised and planted by the local community members in their farms in 2003. This was an increase of four times compared to the number in 2001.

A deforested area in Kakamega forest was acquired for use in a model reforestation programme and seedlings of indigenous tree species selected for reforestation were raised in a nursery and planted and maintained by local community groups.

A total of 192 community groups were further facilitated to raise seedlings of their choice for distribution and sale, with 62,000 seedlings being raised. The seedlings included *Grevillea robusta*, *Eucalyptus* spp., *Markhamia lutea*, *Jacaranda mimosa*, *Calliandra calliformis* and *Sesbania sesban*. The seedlings were sold for US$ 1760 which was used for purchase of farm inputs for the group members.

7. Survey of land use patterns

Existing land use information was reviewed to obtain current land use patterns around Kakamega Forest. The land use classes were overlaid in a GIS system and periodic change detection determined. Ground truthing was undertaken and soil types, climate, population and land use and land cover data was overlaid to establish land use practices and their impact on the sustainability of forest resources. Infrastructural features were digitised, the tenure system computerised and the relationships between land use and land cover and geological and population patterns documented. The following maps were developed by the Project in collaboration with the Department of Resource Surveys and Remote Sensing (DRSRS):

- Human population density for the year 2000
- Eco-tourism trekking routes
- Soil map of Kakamega forest

These maps update existing information on the ecological status of the forest and demonstrate the human population dynamics and infrastructure in the surrounding area. More detailed interpretation of the maps indicated the following: 11 land cover classes were recognised, namely bare/quarry, built area, forest glades (bushed), forest glades (grassland), natural forest, non residential agriculture, open forest/shrubs, plantation (hardwood), plantation (softwood), residential agriculture and tea zone. Natural forest was the predominant cover, taking over 50% of the total area. Agriculture and plantations showed a definite geographical pattern in location. They were situated along the forest roads within the forest and on the western and southern edges of the forest that had dense population and a good communication network. Open forest was distributed along the edges whereas forest glades were randomly distributed within the forest.

The statistics analysed from 1975–2003 (see Table 2) showed drastic fluctuations in area of individual cover types over the years. Natural forest was the largest class throughout the years but it showed a decline of about 18% from 16,142.4 ha in 1975 to 13,995.5 ha in the year 2000.

8. Credit provision

Credit provision for communities around Kakamega Forest was coordinated and implemented by K-REP, ICIPE and community members through the establishment of community-owned and managed Financial Service Associations (FSAs) or 'Village banks'. Through the FSAs, rural communities have access to a comprehensive range of financial services, including credit (both consumptive and productive loans), savings facility, money transfers, etc.

Table 2. Changes in area of individual cover types in Kakamega Forest 1975–2000

Year	1975		1986		2000	
Cover	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Bare/quarry	15.6	0.1	12.3	0.1	10.4	0.0
Built area	–	0.0	6.4	0.0	5.3	1.8
Forest glades (bushed)	–	0.0	–	0.0	421.6	1.8
Forest glades/grassland	1491.9	6.3	1860.1	7.8	688.7	2.9
Natural forest	16,142.4	68.1	13,306.5	56.1	13,995.5	59.0
Non-residential agriculture	1368.2	5.87	3750.1	15.8	3518.8	14.8
Open forest/shrubs	1068.5	4.5	1836.9	7.7	858.3	3.6
Plantation (hardwood)	2308.4	9.7	1403.8	5.9	3165.8	13.4
Plantation (softwood)	938.5	4.0	968.1	4.1	637.0	2.7
Residential agriculture	375.0	1.6	346.1	1.5	375.0	1.6
Tea zone	–	0.0	218.0	0.9	31.7	0.1
Total	23,708.3	100.0	23,708.2	100.0	23,708.0	100.0

The Shinyalu FSA, established in the year 2000, had increased its share equity to US$ 6152 by 2002. The total savings increased to US$ 34,320 and total loans given out was US$ 17,641 in 2002 (Table 3). A second FSA is under establishment at Ikhuywa Trading Centre. Identification and equipping of the operating premises for this FSA was completed. Outreach and sensitisation of community members was also done and shareholders were recruited. These shareholders have been mobilised to elect their FSA officials, including the Board of Directors.

9. Outreach in Uganda

In 2001, a project similar to the Kakamega Forest activity on community-based commercial cultivation of *Ocimum kilimandscharicum* for alternative income generation was initiated at Budongo Forest in Uganda. During 2003, 24 farmers were already cultivating *O. kilimandscharicum*. A steam distiller was purchased and installed at Nyabyeya near Budongo Forest for extraction of the plant material for manufacture of Naturub products.

A new product line of Naturub for relief of muscular pain, arthritis and lumbago in the form of an ointment that incorporates lemongrass oil, was formulated. Design of packaging for this new product line has been done.

ICIPE continued to assist a women's conservation group at Ntungamo in western Uganda in commercial cultivation and processing of lemongrass, which also helps to promote soil conservation on terraces and contour bunds in farms. ICIPE has assisted the women's group to generate income through distillation of essential oils from the lemongrass. A hydrodistillation equipment has been purchased and installed at Ntungamo for the community group to extract the essential oil. The Project was commissioned in December 2002 by the First Lady of Uganda. The oil will be used in manufacture of various commercial cosmetic and medicinal products and food supplements, while some will be sold to manufacturing industries. *(See also the following report on the Echuya Forest and the section on bioprospecting in the Behavioural and Chemical Ecology Department report.)*

CAPACITY BUILDING

Six graduate and three technical students were trained or attached to various components of the Project. The Project trained 9 youth members of the community in handling and preparation of *O. kilimandscharicum* plant material for distillation, operation and maintenance of the hydrodistillation equipment, safety procedures and data recording and

Table 3. Progress of the Shinyalu Financial Services Association ('village bank')

Item	2003	2002	2001	2000
Share equity (US$)	5878	6152	5431	2662
Total savings (US$)	27,551	34,320	21,076	4961
Total loans given out (US$)	16,872	17,641	12,583	2287
Highest loan (US$)	592	563	324	352
Lowest loan (US$)	16	17	17	14
Number of women shareholders	104	103	93	69
Number of men shareholders	227	225	212	156
Number of community groups	56	55	48	28
Total number of shareholders	387	383	353	253
No. of institutions using the transfer service	2	1	1	1

management. The Project also continued to enable training of young Kenyans in various other aspects (Table 4). The trainees included:

- Two graduate Agricultural Economists from Egerton University.
- One graduate in Agricultural Engineering from Egerton University.
- Three technicians from local technical colleges.

MSc students

Lucas Ongeri (Kenya) Phytochemical analysis of *Mondia whytei*. Jomo Kenyatta University of Agriculture and Technology.

Paul Njihia (Kenya) Nutrition and animal feed evaluation of *Mondia whytei* products. Jomo Kenyatta University of Agriculture and Technology.

IMPACT

The Project has brought greater awareness to the forest adjacent community about the importance of the Kakamega forest and the need for its conservation with over 20,000 people contacted with environmental and conservation education. The increase in number of farmers cultivating medicinal plants is indicative of acceptance of the Project by the community largely due to the ease of cultivation of the plant, minimal farm inputs and higher income per unit area as compared to other crops cultivated. Adoption of energy-saving technologies by the locals was very high with over 14,000 devices installed. In addition, the new income-generating activities will in the long run provide alternative income and reduce the economic dependency of the community on forest resources.

Table 4. Training in agro-enterprises development and conservation in the project 'Integrated Package for Conservation of the Kakamega Forest'

Training activity	Number trained to end-2003
Cultivation of *O. kilimandscharicum* by Muliru Farmers Conservation Group	56 farmers
Outgrowers contacted by the above	8 conservation groups
Ocimum processing (hydrodistillation)	9 youth
Naturub formulation and packaging	2 technicians
Technician training	3 technicians
Postgraduate researchers	13 MSc, 3 PhD scholars
Applied business economics	2 graduate agricultural economists
Agricultural engineering applications	1 graduate agricultural engineer
Community-based project extension workers	10 high school graduates
Beekeeping and honey processing	2020 farmers from 420 groups
Hive construction	8 carpenters
Silkworm rearing	2 women's groups of 89 farmers
Parataxonomists	2 school teachers, 7 pupils, 3 adult community members
Energy-saving stoves fabrication and installation	1675 community members
Agroforestry techniques	Members of 314 community groups

OUTPUT

Books and chapters in books

Rogo L. M., Lwande W., Chapya A., Herren H. and *Miller S. E.* **(2001)** An integration conservation initiative to conserve Kakamega Forest and its biodiversity, pp. 56–60. In *Tropical Ecosystems: Structure, Diversity and Human Welfare (Supplement): Proceedings of the International Conference on Tropical Ecosystems* (Edited by K. S. Bawa and R. Uma Shaanker). ATREE, Bangalore.

Reports

Annual scientific and financial reports on the Integrated Project on Conservation of Kakamega Forest, presented to the John D. and Catherine T. MacArthur Foundation for the years 2002–2003.

Publicity

Project activities which were covered in international and national media including the following:

- CNN International television Network covered the Project's efforts to conserve medicinal plants at Kakamega forest and to promote alternative income-generating activities for the community (February 8 and 9, 2003).
- Reuters Television News Agency in their Television documentary, *Africa Journal*, covered the Project's efforts to conserve medicinal plants at Kakamega forest and to promote alternative income-generating activities for the community. The coverage was aired on various television channels in most countries in Africa including the following networks in Kenya: Nation TV (7 February, 2003) and TV Africa (2 March, 2003).
- Some aspects of the Project were covered by a World Bank television crew from Washington DC on 9–11 September, 2002.
- Okwemba A. (2002) Local impotency herb to flavour yogurt. *Daily Nation*, Kenya. October 17, 2002.
- Mwangi E. (2002) Community extraction of essential oils from a local plant in Kakamega forest, Shinyalu Location, pp. 1–5. In *UNDP/GEF-Small Grants Programme, Kenya—Promoting Forest Biodiversity*. Booklet No. 1. ICIPE Science Press, Nairobi.
- *Kakamega Environmental Education Programme (KEEP) Newsletter* (2002) Vol. 1, No. 1, ICIPE Science Press, Nairobi.
- Donisthorpe J. (2003) Saving Kakamega Forest by poverty eradication. *Travel News*, January, p. 30.

Conferences and papers presented

Presentation at the World Bank on the Kakamega Forest Conservation Project as part of a panel presentation on traditional medicine and rural development issues in Africa, Washington, DC, USA. 10 September 2002. S. Miller.

Presentation at the Second International Roundtable for Agribusiness in Natural African Plant Products (ASNAPP) on the theme: From Research and Development to Commercialization. 24–27 September 2001, Accra, Ghana. W. Lwande.

Presentation at the Symposium on Medicinal Plants, Nyabyeya Forestry College, Masindi, Uganda. 26 April 2002. W. Lwande.

Presentation to the MacArthur Foundation Board of Directors on progress of the Kakamega Forest Conservation Project, 8 October 2002, Nairobi, Kenya. W. Lwande.

Presentation at the Pan-African Malaria Conference, Arusha, Tanzania, 17–22 November 2003. W. Lwande

Presentation at the commissioning of the Ntungamo Womens's Effort to Conserve the Environment (NWESE) community-based Project on lemongrass use, presided over by the First Lady of Uganda, Ntungamo, Uganda. 3 December 2002. H. Herren.

Presentation to the First Lady of Uganda on the ICIPE activities in the promotion of community-based beekeeping, Kampala, Uganda. 17 December 2002. H. Herren.

Project proposals

Commercialisation of community-based cultivation of the medicinal plant, *Ocimum kilimandscharicum* and its products, as a means to reduction of human pressure on Budongo Forest, Uganda. Funded–First phase.

Commercialisation of lemongrass cultivation and processing as a means to sustainable control of land degradation by the community in Ntungamo District, Uganda. Funded–First phase.

Commercialisation of community-based cultivation of the medicinal plant, *Ocimum kilimandscharicum* and its products, as a means to reduction of human pressure on Kakamega rainforest in Kenya. Concept note. Funded.

Participating scientists: W. Lwande (Project Leader), S. Miller, L. Rogo, R. Bagine, K. W. Mukonyi

Assisted by: A. Chapya, L. Moreka, E. Ndenga, B. Omolo, N. Onyimbo, M. Ndwiga, D. Mbuvi, M. Nelima, M. Lumbasi

Collaborators:
Institutions: Kenya Wildlife Service (KWS); Kenya Forestry Research Institute (KEFRI); Forest Department (FD), Kenya; Smithsonian Institution (SI), (USA); Intermediate Technology Development Group of East Africa (ITDG-EA); Department of Resource Surveys and Remote Sensing (DRSRS), Kenya; National Museums of Kenya (NMK); Kenya Rural Enterprise Programme (K-REP); University of Nairobi; Kisumu Medical and Education Trust (KMET); World Agroforestry Centre (ICRAF); Kenya Ministry of Agriculture; Kenya Agricultural Research Institute (KARI)

Community-based groups: Kakamega Environmental Education Programme (KEEP); Muliru Farmers' Conservation Group (MFCG); Community-based distributors women's groups of Malava, Shamakhubu, Shikusa, Kambiri, Kuvasali, Kakamega Forest, Ileho, Sabatia, Shiru, Mang'uliro; Virhembe Youth Development Group

Donors: The John D. and Catherine T. MacArthur Foundation; the UNDP/GEF Small Grants Program; the David and Lucille Packard Foundation; the International Fund for Agricultural and Development (IFAD) and the Agricultural Research Foundation (ARF), Kenya

THE INTEGRATED PROJECT ON THE CONSERVATION OF ECHUYA FOREST RESERVE

BACKGROUND, APPROACH AND OBJECTIVES

Echuya Forest Reserve is a montane forest located in the Albertine Rift highlands in Kisoro and Kabale Districts in southwestern Uganda. This forest reserve contains a significant proportion of endemic insect plants and other animals. It is ranked first among the 65 most important forest reserves in Uganda for rarity of species, based on evaluation of their distribution in Uganda and Africa as a whole. Echuya forest contains the large and unique high altitude Muchuya swamp, which runs north-south along the centre of the reserve.

Unfortunately, Echuya forest is under high economic and population pressure. The major threats to the conservation of the forest reserve include human pressure for products and income; lack of awareness among some of the stakeholders about the need and ways by which the forest could be conserved; and inadequate resources for its management and protection.

Closely related to the threat to the forest itself is the issue of the Batwa (pygmy) population, a highly marginalised community that used to inhabit the forest and on which it depended for all the basics of life. The Batwa were excluded from the forest at the time Echuya and the other forests were made reserves in the 1960s. They own no agricultural land outside the forest and currently harvest bamboo stems for fuelwood and construction and for sale to other communities. They hunt in the forest for wild game meat and also extract fibres, water, soil and wild plants as food (Figure 1). The forest is also of cultural importance to the Batwa, who use it for religious ceremonies.

Figure 1. A group of Batwa (pygmy) living in modern style huts. They were excluded from Echuya Forest in the 1960s

The overall objective of the Project, initiated in 2002, is to contribute to the conservation of Echuya forest reserve. To achieve this goal, the Project is building the capacity of and working with local community-based groups (CBOs) and non-governmental organisations (NGOs) in undertaking the following activities:

- Promotion of alternative income-generating activities including beekeeping, provision of savings and credit facilities, butterfly eco-tourism exhibits and cultivation of medicinal plants;
- Promotion of community-driven environmental and conservation education to children and communities around the forest;
- Promotion of fuelwood energy-saving technologies and alternatives to forest-derived fuelwood;
- Training of community-based parataxonomists, and community-participatory biodiversity inventory and monitoring of selected forest taxa.

WORK IN PROGRESS

1. Community mobilisation

The Project enhanced the capacity of Africa 2000 Network (A2N) to mobilise the community around Echuya Forest to undertake the Project activities, and in training in leadership and management skills and group dynamics. Funds for facilities and additional staff recruited from among the local community were provided by the Project.

Work began with communities living adjacent to Echuya Forest Reserve in the Kanaba and Murora sub-counties in Kisoro district, to sensitise them about the goal and objectives of the Project, its potential benefits to them, their expected contribution and the importance of forming community groups. The meetings were undertaken through the local councils and churches. A total of 359 members from 9 communities comprised of 73 women and 286 men from 327 households attended the meetings. By December 2003, the membership of the groups had grown to a total of 881, comprised of 399 women and 482 men from 544 households.

Prior to this Project, no 'formal' community groups existed adjacent to Echuya Forest Reserve, apart from the Local Ambulance (or Ingobyi) Group (which is present among all the communities in the Districts) and small groups consisting of 5–10 individual members who pooled money together for sharing out after an agreed period. Now that the communities have been sensitised about the new project, they are coming out in large numbers to be trained in various activities, and participation of women is improving.

2. Resource centre

A provisional resource centre was established during the reporting period. The Uganda Forest Department (FD) availed the Project with a four-bedroomed house at the edge of Echuya Forest at Kanaba Gap (Figure 2). Since there is no electricity in the area, the Project installed a solar system for lighting and powering electrical appliances. The resource centre will act

Figure 2. The provisional resource centre near Kanaba Gap, Echuya Forest

as a central point for community activities such as meetings, training, information dissemination and as a library and field office.

3. Environmental education

As a first step towards promotion of community-based environmental and conservation education around Echuya forest, the Project provided audiovisual equipment, including a colour television, a video cassette recorder/player, power generator (1.7 KVA), public address system, a computer with monitor and UPS (Figure 3). The aim is to build awareness among adults and children about the importance of biodiversity and its conservation, and ways by which it can be conserved.

4. Apiculture

The Project initiated the establishment of a new improved beekeeping enterprise for the highly marginalised Batwa (pygmy) community as part of the alternative income-generating component. In a survey conducted among the community groups, the Batwa selected beekeeping as their first priority among all the proposed activities. Some of the proceeds from the enterprise will be used to improve the livelihoods of this group, and some to purchase land for them. The Uganda Forest Department has agreed to set aside a section of land in the forest where the Batwa will install beehives.

Figure 3. Handing over of some of the audio-visual equipment to representatives of the community living adjacent to Echuya Forest

The Project will train selected members in modern beekeeping technologies and facilitate the establishment of a honey processing and packaging unit. This specialised honey will be marketed both locally and internationally.

5. Credit provision

The Project groups have began credit and savings schemes plans to facilitate the upgrading of these credit schemes into community-owned and managed Financial Service Associations (FSAs) or 'Village Banks' near the forest. The schemes involve pooling of money for provision of credit to the group members, however later the FSAs will operate as shareholding financial enterprises that will be directly linked to formal financial institutions in a commercially sustainable manner. Through the FSAs, rural communities will have access to a comprehensive range of financial services.

6. Energy conservation

The Project initiated the fuelwood energy-saving technology component through training of community members in construction of fuelwood energy-saving stoves (Figure 4). These stoves are cooking devices that use much less fuelwood compared to the traditional three-stone fires used to hold the cooking pot. A total of 70 community members comprised of 18 women and 52 men from 60 households participated in the training exercise in early 2003. The trained community members were encouraged to construct these stoves in their homes and also in those of their fellow members, and to train other members in the skill.

Promotion of fuelwood energy-saving methods and alternative energy technologies will contribute to conservation of Echuya Forest through reduction in the amount of fuelwood collected from the forest.

Figure 4. A typical fuelwood energy-saving stove

It will also improve the quality of life by reducing the amount of time spent on collecting fuelwood, an exercise carried out largely by women and children.

CAPACITY BUILDING

The community groups formed were trained to enable them to manage their planned project activities, including management and leadership skills, group dynamics and constitution-making. These training sessions were attended by 350 members (124 women and 266 men) from 302 households. Constitutions were then formulated to guide the management of their Project activities. Training in record keeping was also initiated, benefiting 37 community members from 34 households.

FUTURE OUTLOOK

Surveys are underway to select suitable medicinal plant species for domestication and promotion of butterfly eco-tourism exhibits. Training of the community-based parataxonomists and community-participatory biodiversity inventory and monitoring of selected forest taxa will be initiated when the capacity of the community groups has been built appropriately to undertake these activities.

The project is initiating a model activity to address the serious problem of the highly marginalised Batwa (pygmy) tribe.

OUTPUT

Proposals

Integrated Project on the Conservation of Echuya Forest Reserve, Uganda. Funded.

Establishment of a beekeeping enterprise for the Batwa (pygmy) community, and information and activity centres for the forest-adjacent community as strategies for conservation of Echuya Forest.

Participating scientists: W. Lwande (Project Coordinator), I. Gordon, S. K. Raina

Assisted by: E. Ndenga, L. Moreka, D. Mbuvi, M. Nelima

Collaborators: Africa 2000 Network, Uganda; UNDP/GEF-Small Grants Programme; Forest Department; Nature Uganda; Royal Society for the Protection of Birds

Donors: The John D. and Catherine T. MacArthur Foundation; UNDP/GEF-Small Grants Programme

COWPEA GENE FLOW AND IMPACT ASSESSMENT OF GENETICALLY MODIFIED CROPS

BACKGROUND, APPROACH AND OBJECTIVES

Transgenic crops are increasingly becoming a dominant feature of the agricultural landscape, and genetically modified crops (GMCs) hold potential for increasing food security in Africa, where traditional farming is based on mixed cropping with low agricultural inputs. However, the potential release of GMCs in Africa raises several concerns, such as toxicity of GMCs to non-target organisms, development of insect populations resistant to the toxins expressed in the GM plants, and more importantly in the case of crops with wild relatives, gene flow from cultivated to wild and weedy plants. As emphasised by Richard Cowan in an interview to *Fortune Magazine* (21st February 2000), "the most serious environment risk is the possibility that implanted genes will escape from cultivated crops into wild relatives, resulting in the production of superweeds. It is not clear that escaped genes would remain in wild relatives and cause adverse ecological effects. Only extensive field tests will give us answers on this".

Beyond extending basic knowledge on the relationships between an important African crop, the cowpea (*Vigna unguiculata*), and its wild progenitor, the ultimate goal is to provide reliable information in the areas of ecology and population genetics in order to allow for well-planned deployment of genetically modified (GM) cowpea in Africa, where insect-resistant varieties are desperately needed. Since wild relatives of cultivated cowpea are widespread in Africa, and in some places very common, the current research on gene flow between cultivated and wild cowpea is fully justified.

However, studying gene flow in cowpea is not restricted to the pollen flow from cultivated to wild plants. Although pollen flow is an important component, post-fertilisation events also need to be taken into consideration. Moreover, one needs to keep in mind that pollen flow in both directions can lead to hybrid plants able to backcross with other plants. Therefore, pollen competitivity, fitness of hybrids and of the hybrid progenies, as well as seed predation and seed flow, are phenomena that need attention. Indeed, every link in the chain, from flowering of the cultivated plant to the seed predation of a BC2 introgressed wild plant, need to be studied.

Although one element seems very positive so far for a possible GM cowpea deployment, i.e. the pollinator behaviour and the low pollen flow, no single element alone will provide a zero-risk clearance for the release of GM cowpea. Each step of the process leading to gene establishment in a wild population needs to be examined in order to be sure no major problem remains which would hamper the release of GM cowpea or make it environmentally risky.

WORK IN PROGRESS

1. Pollen flow

The first phase of the project showed that gene flow, and especially pollen flow, is low or at least lower than expected, considering that the focus of this study was on the area most suitable for gene-flow, i.e. coastal East Africa where the floral morphology suggests a more outcrossed breeding system. The study of natural wild populations of cowpea shows that gene flow is low, especially between populations ($Nm < 0.5$ between neighbouring populations), and outcrossing rates are not that high. Wild populations show a heterozygote deficit, a sign of a predominantly inbred mating system, and a source of sink trials failed to prove pollen flow beyond 50 m.

This situation was shown to be a direct consequence of floral biology and pollinator behaviour. Pollen matures at least one and a half days before flower opening, and the same is true for the stigma if the stigma cuticle is artificially ruptured. In nature, as in coastal Kenya, the anthers release pollen during the late evening before 2200 hrs and the stigma cuticle is ruptured between 2200 and 0200 hrs. Therefore, when the anthers are not far from the stigmatic surface, as is the case with the domesticated and most of the wild populations, the fertilisation process starts long before sunrise and flower opening. When flowers open, self-pollen is already rushing towards the ovules. Therefore deposit of a pollen load during the first hour after sunrise allows only 1 to 20% (according to the lines involved) of hybrid formation. Even fertilising a domesticated cowpea with wild line 219, whose pollen is faster when competition is fair, does not yield more than 15% of hybrids.

In addition to the above, pollinator behaviour worsens the situation for foreign pollen. First of all, effective pollinators are not so numerous. Most insects seen on cowpea flowers (especially honey bees) are too light to move flower parts and get into contact with both the pollen and the stigmatic surface. In coastal Kenya, only seven species can be considered as pollinators, and two carpenter bees (*Xylocopa caffra* and *X. flavorufa*) account for more than 90% of the flower visits (Figure 1). They mainly forage during

Figure 1. **Xylocopa caffra** ***pollinating a cowpea flower***

the first half hour after sunrise (90% of the flowers are visited after 30 min), unfortunately at a time when self-pollen is already at work for at least an hour. In addition, while tripping a flower, the bee brings to the stigmatic surface more self-pollen than foreign pollen. That means that even if a bee is observed moving from a domesticated flower to a wild selfing flower, obtaining a hybrid progeny is far from assured.

Pollinators are attracted to flower patches by aroma, which means that while large and dense flower stands are thoroughly visited, isolated flowers and plants are usually ignored. Most of the pollinator movements are less than a few metres within flower patches and many of these are between different flowers of the same wild plant. They are not faithful to cowpea flowers and they can visit *Vigna reticulata* flowers if the flower patch includes both species. Within a flower patch, pollinators mainly look for nectar and they reject the empty flowers that have just been visited by another bee or manually emptied.

2. Fitness of hybrids and progenies

All these data above show that cowpea gene flow and especially pollen flow is low. This low amount of gene flow could clear the way to GM cowpea deployment, if GM cowpea were to be cultivated only by large-scale farmers in relatively controlled conditions. However, this is not the goal, as GM cowpea research is undertaken for the benefit of low-income African farmers. The plots from these farmers often includes wild cowpea, especially in West Africa where weedy (wild) cowpea provides a fodder as good as the one from domesticated cowpea.

For the above reasons, this study also compared the fitness of hybrids and hybrid progenies with the fitness of the wild plants. Results show that F1 hybrids are more vigorous than wild plants, especially the hybrids from domesticated plants fertilised by wild pollen (biomass after 45 days is 10-fold higher with hybrids from wild mother plants and 50-fold higher with hybrids from domesticated mother plants). However, if we consider longevity (wild cowpea is pluriennual in coastal East Africa), seed dormancy and number of seed produced, hybrids are less fit than wild plants, which also explains why hybrids or intermediate plants are so rare in natural populations. Regarding the number of seed produced, wild plants clearly out-perform hybrids from wild mother plants, while hybrids from domesticated mother plants produce slightly more seeds than wild plants. However, giving insect protection (through weekly insecticide spraying) usually leads to an increase in seed production, as much as 100% with some hybrid combinations.

Work on seed predation and grazing is continuing in order to ascertain if the additional production of seeds can be destroyed by predators other than insects targeted by the transgene.

(See also the report of the Molecular Biology and Biochemistry Department.)

CAPACITY BUILDING

PhD students

Yonas Feleke (Ethiopia) Cowpea *(Vigna unguiculata)* cpDNA polymorphism as a tool to assess gene-flow directions between cultivated and wild cowpea.

Alfred Ochieng (Kenya) Cowpea *(Vigna unguiculata)* pollination and risk assessment linked to the future release of genetically transformed cowpea breeding lines. University of Nairobi.

MSc students

Ismael Yusuf Rabi (Kenya) Molecular estimation of breeding system and gene flow of wild cowpea [*Vigna unguiculata* (L.) Walp] from coastal Kenya. Kenyatta University.

Consolata Atieno Ager (Kenya) Chemical composition of volatiles and nectar of cowpea flowers. Kenyatta University.

OUTPUT

(See ICIPE Publications List for other publications related to this work by project staff)

Participating scientist: R. S. Pasquet

Assisted by: B. Elesani, A. M. Gunia

Collaborators: University of California at Davis, Purdue University, Ohio State University at Columbia (USA); University of Nairobi, Kenya; INERA, CREAF de Kamboinsé, Ouagadougou, Burkina Faso

Donors: Rockefeller Foundation, USAID

ENVIRONMENTAL HEALTH

SERICULTURE AND APICULTURE TECHNOLOGIES AS INCOME-GENERATING OPTIONS FOR RURAL COMMUNITIES IN AFRICA—TRIALS AND VALIDATION

BACKGROUND, APPROACH AND OBJECTIVES

Poverty reduction in rural areas in Africa can only be achieved by increasing the assets and income in the hands of the poor themselves. The answer to their poverty is growth and development of their livelihood systems.

The overall strategy of the Commercial Insects Programme has been to develop innovative technologies such as **apiculture** (beekeeping) and **sericulture** (silkworm rearing) as rural micro-enterprises for the resource-poor farming communities of Africa and to create off-farm employment and income generation in harsh agroecosystems where food production is marginal and the risk of crop failure is high. The present project has focused on three phases: Phase I—development of technologies and training of staff from NARS and NGOs; Phase II—validation trials and marketplace development with initial market studies; Phase III—development of marketing linkages and product research for sustainability.

In Phase I of the project, ICIPE conducted strategic research that provided the underpinning for developing the relevant technologies in apiculture and sericulture so as to modernise and introduce them to the rural communities. Several thousands of African farmers were trained along with NARS and NGOs in the art of beekeeping and silk farming. In Phase II, from 2001–2003, the Project has validated these technologies in the farmers' fields with participation of the communities and NARS. As a result, four marketplaces have been established in Kenya and Uganda for silk and honey. This approach to diverse, management-intensive, environmentally sound honey and silk production systems will enhance farmers' share of the profits. However, farmers' success in apiculture and sericulture ventures largely depends on having the right product in the right quantity at the right price and at the right time.

The specific objectives of this Phase II of the Programme are to:

- develop silkmoth and honey bee smallholder microenterprise production facilities adapted to local conditions;
- collect data and undertake an analysis addressing location-specific production and adoption issues for both apiculture and sericulture on socio-economic, institutional and biophysical aspects;
- define product-quality requirements of the markets;
- provide technical backstopping and trouble-shooting in sericulture and apiculture;
- provide training for farmers and farmers' groups in appropriate technology for apiculture and sericulture;
- increase scientific capacity by means of graduate and postgraduate training and scholarships, in order to provide a solid scientific base for practitioners throughout Africa;
- promote further the dissemination of the apiculture and sericulture technologies developed under Phase I of the Programme;
- continue the support for demonstration groups established under Phase I, including development of marketing strategies, identification of marketing constraints and identification of relevant market linkages with private traders.

The Programme consists of the seven components, with each corresponding to an expected Programme output: validation of production modules; establishment of grainages for the production of silkmoth eggs; honey bee line-breeding; assessment of location-specific constraints; assessment of pollination; capacity-building and development of a marketing strategy.

The Programme has identified several bottlenecks affecting the growth of sericulture as an agro-based cottage industry in Africa. The national and global markets demand higher standards of goods. Various methods are being developed to enhance the aesthetic value of newly introduced mulberry silk. Among these are the introduction of African designs, use of ecofriendly natural dyes to enhance the organic value of silk fibre and fabric, and application of strict quality control measures to meet international standards. In the case of wild species of silkmoths, the programme has focused on conservation of biodiversity through scientifically training local people. Various methods are being developed to minimise predators, pests and disease problems in wild silk farming to enhance yield and help rural communities. The Programme is also involved in the protection and preservation of genetic diversity of silkmoth species. One of the promising wild silkmoths, *Gonometa* sp., has been explored for commercial silk production. An exit strategy for silk fabric in Africa is being introduced through creation of marketplaces in different localities. Very few quality testing labs and marketplaces have been created through project assistance, however more marketplaces are required to sustain these cottage-based industries in Africa.

In apiculture, the main constraints are diseases in North African apiaries; missing knowledge on colony multiplication through queen rearing; delay in introduction of frame hives and lack of product processing and packaging technologies. The project has resolved three of the foregoing constraints in various geographic locations in Africa: diseases, queen rearing and processing.

A. Marketplace Development

WORK IN PROGRESS

1. Site selection for apiculture and sericulture validation trials

In the present Phase II, ICIPE has focused on understanding the level of poverty in the rural regions in East Africa before selecting the sites for validation trials. First, the Project explored ways by which the poor earn and use their income. Second, the barriers to progress were assessed, especially in terms of adequate health, absence from schooling due to limited cash income and constraints that exist in implementing sericulture and apiculture and other income-generating options within existing subsistence farming systems. In each case, observations indicated that these characteristics differed across regions. Generally the poorest of the rural poor live either in remote areas or in densely populated areas, particularly near capital cities in East Africa. But mostly they are found in areas of low agricultural potential in the arid or semi-arid zones.

The Project therefore has selected these high poverty zones in East Africa for validation of the sericulture and apiculture modules developed in Phase I. Often such areas are neglected in terms of market access, health care and roads. Poverty is intensified by further discrimination or exclusion; for instance banks will not offer credit without a guarantee and the rural poor lack assets such as quality land. Land size is often too small to ensure the nutritional well-being of the household. Thus, indigenous populations in these regions face barriers to progress owing to both discrimination and their geographic location.

The final results of the Phase II third project year (2003) are given for Uganda and Kenya only. The validation trials in Tanzania were initiated in Sakila and Mara for honey and silk products; however these have not reached the operational level due to socioeconomic and cultural constraints, which the Project is addressing.

The rationale for marketplace development is based on the fact that the demand for honey- and silk-based products is increasing in East Africa as markets become aware of the assured availability of good quality products. An emerging problem is becoming one of supply rather than the initial problem of demand. The market for quality honey already exists, but is difficult for small farmers to access. This is what the present Project seeks to overcome. The result of value adding and capacity building of the target community to process the silk- and honey-based products provides an important mechanism and leverage for marketplace development. Low-tech approaches have been developed and combined with social and market support to produce economically viable activities that are easily adaptable to local circumstances and hence can find ready uptake in different areas throughout East Africa. Through appropriate technology and training, communities are being empowered to maintain their own business activities, reducing the role of the middleman and allowing silk farmers and beekeepers to improve their livelihoods. The economics of honey and silk-based marketplaces are given in Figure 1.

Marketplaces for silk- and honey-based products can succeed only if local communities understand biodiversity and its value, however. Communities should realise how the biodiversity of silkworms and honey bees is important in their lives and should know how to manage indigenous bioregions to meet their needs without damage.

2. Operational honey marketplaces: Mwingi, Kenya

Mwingi is a dry land and woodland forest reserve (14,550 ha) in the semi-arid eastern part of the country at an altitude of 560–1000 masl. The Mwingi area has a low potential for agriculture and therefore much of the local population derive their income from forest resources. Beekeeping has been one of the important activities for income generation and Mwingi is one of the districts in Kenya that has the capacity to produce high amounts of honey and other beehive products. Before the intervention by ICIPE, beekeeping in Mwingi was practised traditionally using logwood hives, and employing smoke and fire for honey harvesting. The harvested combs were crushed in a bucket, making the honey unpalatable

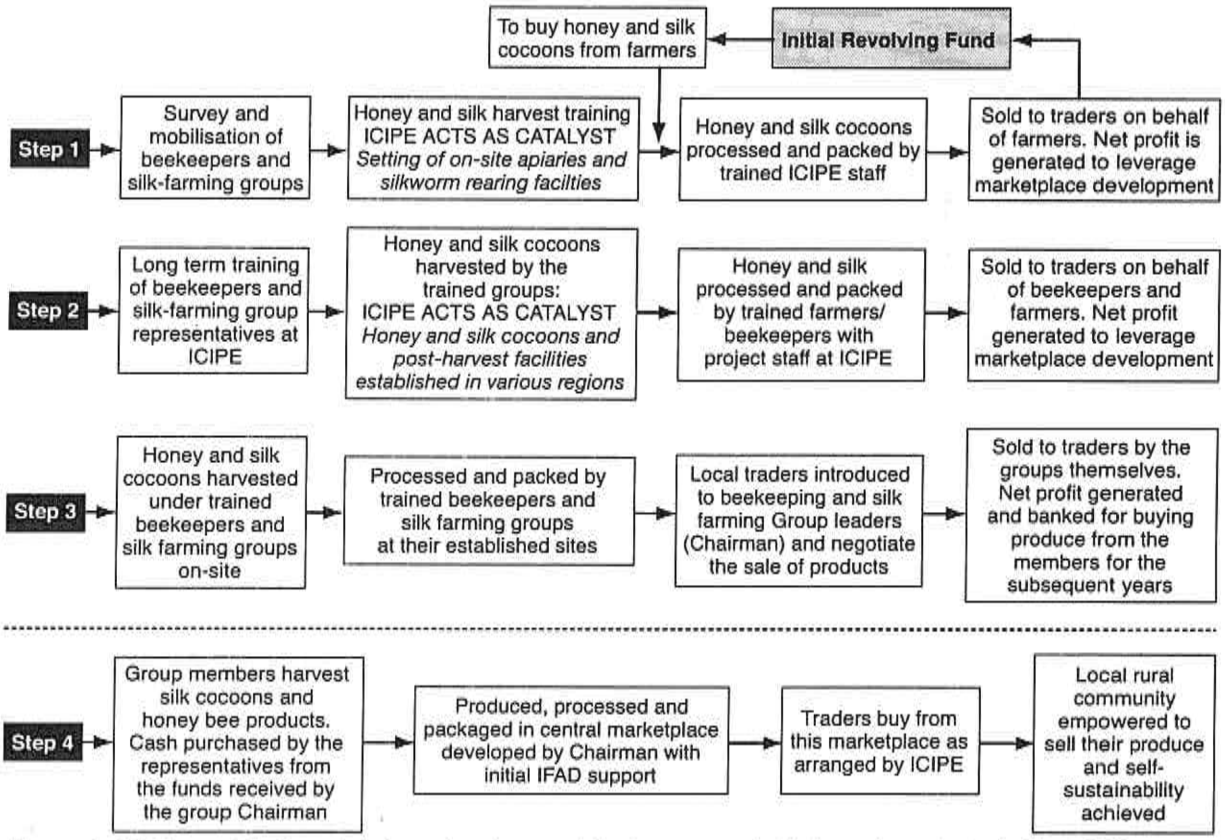


Figure 1. ICIPE model of marketplace development for honey- and silk-based products in East Africa

for human consumption and hence the honey was sold mainly for beer making. This has kept the beekeeping industry in an infant stage, mainly due to poor management practices and lack of knowledge of queen-rearing methods for colony multiplication, as well as lack of processing and packaging of honey and hive products for the competitive market.

Mainstreaming of the communities and implementation of the model

In 1996, ICIPE surveyed the potential areas for honey production, and by 1998 beekeepers were grouped under one umbrella called the Mwingi District Joint Beekeepers Self Help Group (MDJBSHG). Data was gathered and analysed to design a suitable model for the district. ICIPE introduced modern beekeeping technology using Langstroth hives as well as modified traditional beekeeping methods for better harvesting of honey. Beekeepers were trained at ICIPE and on-site on hive management, harvesting and processing of the honey. A total of 13 beekeepers' groups were registered by end-2003 under one umbrella with a membership of more than 1000 communities. Each group elected a representative, who together elected a Chairman and management committee for one fiscal year.

The Chairman and committee members purchase the harvested honey from beekeepers and process and pack it for sale in the marketplace established by the group. ICIPE assisted in training, improving post-harvest facilities and introducing the group to honey traders. The initial capital for honey purchase (from ICIPE) and the profits obtained through the sale of honey after processing was deposited in a bank account operated by the Chairman and two elected committee members. This has generated a revolving fund to buy honey in subsequent harvests. A self-sustainable honey marketplace has now been established which gives hard cash to the honey producers, thus strengthening rural development and empowering the villagers to control their produce and market with no middlemen. The group has plans to eventually register as a cooperative society.

Marketplace construction and government support

The construction of the marketplace premises was a joint effort by various project partners. The Ministry of Agriculture and Rural Development agreed to allot land for the construction of a Honey Marketplace and various government departments authorised the proposal. Construction started in September 2002 and Mwingi Honey Marketplace, located in Mwingi town, was inaugurated on 13th November 2002. The Ambassador of Switzerland and the Deputy High Commissioner, British High Commission (BHC) to Kenya performed the inauguration ceremony. About 400 farmers from the bee farming communities within Mwingi District attended the ceremony. Also in attendance were Kenya Government officials, diplomats and NGOs (Figure 2).

In order to assist beekeepers during harvesting season in Mwingi, locational honey stores have been constructed at six sites in the district. The beekeepers contributed the bricks, sand, stones and water while

Figure 2. Mwingi Honey Marketplace inauguration, November 2002

the donors provided the other materials. To assist in marketing, ICIPE initially purchased honey from beekeepers and sold it on their behalf to the local traders at fixed prices for comb and liquid honey. The number of groups is expected to increase in most of these centres and one or two more centres for honey collection may be opened, depending on production and establishment of new self-help groups.

The timetable for honey collection is set by ICIPE with the beekeepers, depending on the onset of the rains. The calendar of the honey harvest in the district therefore differs considerably from one year to the next. Each batch of honey processed is tested for quality at the ICIPE quality control laboratory. The honey is examined for moisture, free acid, pH, simple sugars and enzyme content. The sugar content and the floral source of the bee nectar are indicated on the label. The honey is bottled in glass jars of 470 g or is sold in bulk in liquid or comb form. The value of honey and other hive products is influenced both by production and market factors. Consumer demand is affected by honey quality, price, competition and consumer income. The Group's managers exert a positive influence on profit by maintaining a high quality product.

Domestic honey prices are closely correlated with export (large quantity) market prices. When setting the price of honey for sale in the marketplace, a number of parameters were considered, which include labour, start-up and running costs, product transport costs and demand. Table 1 gives the actual honey production in 2002 and projected potential in 2004 of the groups.

3. Hoima district honey marketplace, Uganda

Hoima is located in the western part of Uganda at an altitude of 1250 masl. The poverty level is high and the sources of cash income are extremely low compared to other parts of the country. The community draws its income from nearby forest resources, which are being degraded at an alarming rate, reducing the biodiversity of flora and fauna including honey bees. Beekeeping is traditionally practised and offers only a meagre source of income to the poorest households. Through ICIPE's intervention, beekeeping has been modernised by setting up a demonstration apiary, training and capacity building. The beekeepers have organised themselves under one umbrella called the Hoima Honey Beekeepers Association, having more than 1000 registered beekeepers. An MOU was signed between Hoima Beekeepers Association, Hoima Local Government, ICIPE, Viking House Limited, Kenya and Ministry of Agriculture and Animal Industry and Fisheries (MAAIF), Uganda.

In Phase II, ICIPE trained the farmers and the MAAIF staff on apiculture technology. Equipment and beekeeping tools were purchased and used for conducting the validation trials in Hoima District. ICIPE staff conducted on-site training in Hoima to establish the honey processing unit and to impart practical training to the beekeepers in the district. The training included colony management, queen breeding, royal jelly production, honey harvesting, extraction, processing and packaging. An operational Hoima Honey Marketplace has been established and is serving the local bee farming community in Uganda (Figure 3).

Table 1. Honey production by established market sub-centres in Mwingi district, 2002 and projections to 2004

Name of centre	Beekeepers self-help groups bringing honey to this centre	Number of beekeepers	Honey production 2002 (kg/annum)	Projected honey production 2004 (kg/annum)
Nuu Market	i. Nuu ii. Mikuyuni	250	3255	5000
Nguni Market	i. Imba ii. Mathyakani	120	1220	3500
Kamuwongo Market	i. Katuuni ii. Itiva Nzou	200	4560	7000
Kathiani Village Market	i. Kathiani ii. Musosya	100	2194	5500
Endau Market	i. Endau	85	5110	8000
Ngomeni Market	i. Ngomeni ii. Mitamisyi	110	969	3000
Malalani Market	i. Malalani	40	6887	1500

Figure 3. Hoima Honey Marketplace, Uganda

4. Bushenyi silk marketplace, Uganda

Bushenyi in Uganda is situated at an altitude of 2300 masl. The site was selected for developing the first silk marketplace because of its favourable climate conditions, increasing unemployment, abundant rural labour and availability of mulberry leaves. These factors make sericulture an ideal enterprise for smallholders in Uganda. Sericulture was introduced in 1992 and quality bivoltine silk cocoons of 2A grade were produced through the efforts of the Government of Uganda and EU Silk Sector Development Project. Uganda had also managed to export dry cocoons to Japan, but due to uneconomic transportation of the voluminous cocoons, the export market collapsed in 1997 (Table 2). When the export market collapsed, farmers were burying their cocoons in the field and uprooting mulberry plantations out of frustration at lack of an outlet. ICIPE intervened and purchased cocoons in 1997 and established the first reeling machine in 1998.

The Government of Uganda approached ICIPE for assistance to save the collapsing silk industry. Reeling machines with re-reeling facilities were established in Kawanda campus, Kampala for the silkgrowers and ICIPE also assisted in long-term training of three extension staff of the Ugandan Silk Programme in silk reeling, fibre processing and packaging. ICIPE concentrated in setting up a complete post-harvest unit with high production capacity for internal and external market outlets. The validation trials were based on the ICIPE strategy for mulberry silk farming *(See previous ICIPE Annual Reports).*

Silk growers and extension staff of the former silk project initiated a new company called NOBWE (North, Buganda, West and East) and reactivated the silk project and exported raw silk to South Africa and Egypt from 2002. Uganda has now also established contacts with Zimbabwe and Ghana for trade in silk. The silk growers were brought together under the umbrella of the Bushenyi Silk Farmers Association. More than 1000 farmers who democratically elect their chairperson, secretary and treasurer are members of the association.

Silk machines with high production capacity were imported in 2001 from RK Industries, India for conducting validation trials in Uganda and Kenya and a marketplace plan was designed for implementation. In the first week of July 2002 all machines (60 multiend reeling and closed type re-reeling with boiler and steam drying arrangement, 60 spindle capacity winding machines, 60 spindle capacity doubling machines and 240 spindle capacity twisting machine, one twist reeling machine, powerloom with Jacquard, power warp and rewinding rids, steaming chamber, bleaching, degumming and dyeing material, accessories) were tested before shipment. ICIPE organised a team of 10 technical persons including the RK Industries manager, engineers, and ICIPE scientific and technical project staff to travel to Uganda for the installation, testing of production performance and teaching operational and mechanical maintenance training at Bushenyi.

Table 2. Ugandan fresh bivoltine silk cocoon production 1992–1999 and dry cocoon exports, 1993–1997 (SDCD data) and 1998–2003 (ICIPE data)

Cocoon production		Dry cocoon exports		
Year	Quantity (kg)	Quantity (kg)	FOB (US$)	Grade
1992	432	0	0	–
1993	8332	1660	15,243	2A
1994	8679	3332	27,498	2A
1995	8302	1800	14,850	2A
1996	9451	0	0	–
1997	10,705	1700	15,300	2A
1998	14,085	0	0	–
1999	8390	0	0	–
2000	1325	0	0	–
2001	3317	0	0	–
2002	3420	0	0	–
2003	6340 (projected)			

The ICIPE Programme Leader and staff evaluated the marketplace in February 2003. Positive changes in the silk growers' lives were noticed and 22 silk-farming members were employed. From September 2002 to date, the marketplace has produced 1100 kg of raw silk with high denier to fulfill the market demand from Egypt. It has also produced 200 kg of fine raw silk of 20/22 denier and prepared twist yarn of 44 denier (Figure 4a–d). Local handloom weavers have also been supplied with the local silk yarn for their designs.

ICIPE staff have trained the women members in degumming and dyeing of the yarn and fabric, to produce Uganda's first silk cloth. About 50 m of polyester silk and 100 m of pure silk have been produced (Figure 5 a, b). ICIPE has also trained staff in finishing and packaging of the silk cloth, and in tie dying and screen-printing to add more value to the silk products. Through these efforts, an internal market for silk cloth has been created with links to designers, merchants and traders from Kenya. However, the silk marketplace still requires more monitoring and evaluation to make it completely operational with a high-quality product.

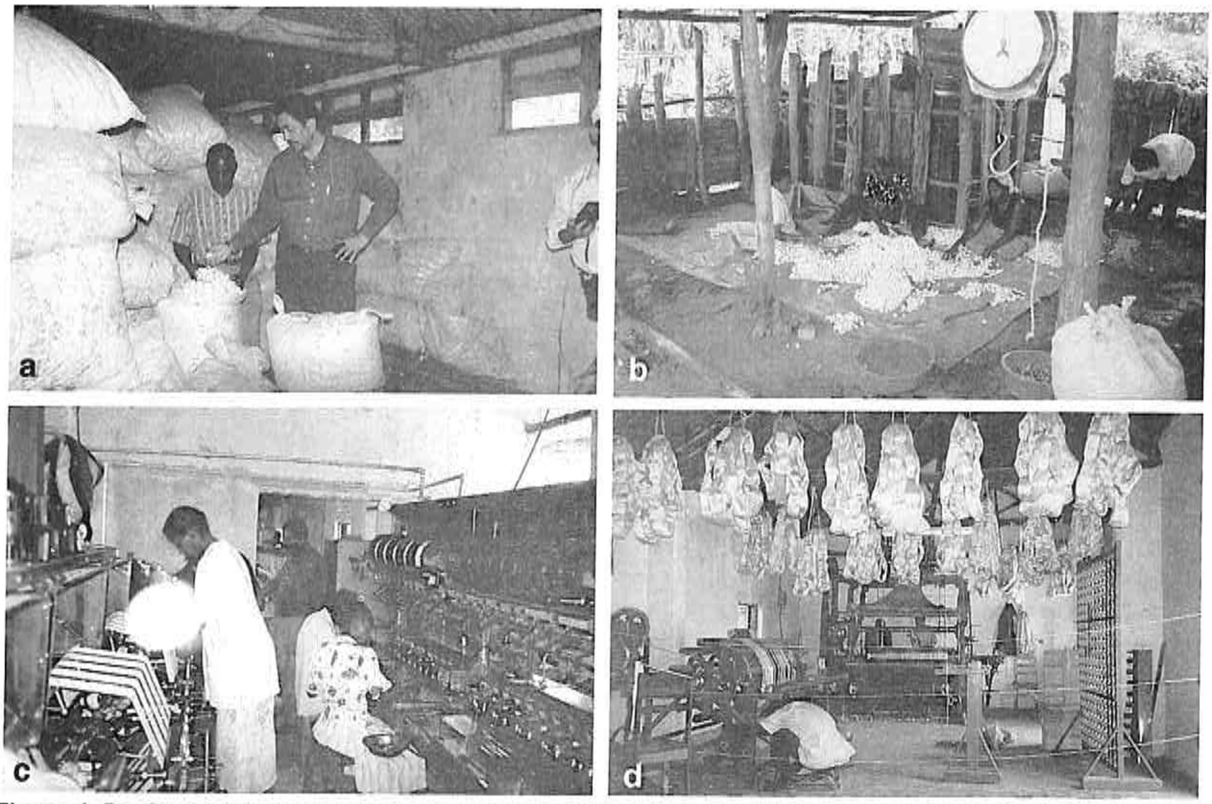


Figure 4. Bushenyi Silk Marketplace, Uganda: (a) Programme Leader inspecting dried silk cocoons in the store; (b) Bushenyi Silk Farmers Association (BSFA) members sorting/deflossing the cocoons; (c) BSFA farmers operating reeling and re-reeling machines; (d) preparation of power warp for weaving operation, reeled silk displayed (hanging in bags)

Figure 5. Post-cocoon operations at Bushenyi Silk Marketplace, Uganda: (a) a trained weaver develops silk warp for weaving; (b) BSFA farmers unfolding silk cloth from the beam

Marketplace sustainability

This marketplace required initial seed money for purchase of cocoons and machine operation and maintenance. The funds were set for silk cocoon purchase as a revolving fund (operated by the elected chairperson and representative) and are released during the purchase of cocoons. After the sale of finished products the revolving funds are put back into the account. This will sustain the operation of Bushenyi marketplace.

Impact on the Bushenyi silk sector and farmers

The capacity of silk growers to build strong and long lasting sericulture skills improved. The area under mulberry plantation has increased, and farmers have started using mulberry as alternative fodder for livestock. One hectare (2.5 acre) of mulberry generates employment for 4 people year-round. By end-2003, 2000 farmers in Uganda had planted mulberry and 300 farmers are actively involved in silkworm rearing. Rearing of silkworms has increased, and the quantity and quality of silk cocoons has improved. On average, farmers produce 625–750 kg cocoons per ha (250–300 kg per acre) of mulberry if they rear 5–6 cycles / annum which brings around US$ 1200–1500 per annum. Silk fibre and fabric are produced as per market demand. Employment has been generated, household incomes increased and natural resources conserved. By-products of the industry (silkworm pupae, mulberry leaves, etc.) provide alternative fodder for livestock, a protein source for poultry and fish culture, bringing sustainability at the community level.

5. Othoro silk marketplace, Kenya

Othoro is situated in western Kenya in Rachuonyo District at an altitude of 1160 masl with annual rainfall of about 1000–1500 mm. The Kamiro Women's Group, a self-help group, initiated the sericulture venture in 1999 with 150 members. A Memorandum of Understanding was developed between ICIPE, the Ministry of Agriculture and Rural Development, Kamiro Women's Group (KWG) and the Kenya Silk Textile Industries Limited (KSTIL).

The Kamiro Group received mulberry seedlings from ICIPE'S Mbita Point Field Station and from Uganda for plantation of 20 ha (50 acres) of land. ICIPE assisted the farmers with training and technology transfer in sericulture from mulberry planting through silkworm rearing to post-harvest technology. With the help of donors, construction of additional rearing houses and purchase of planting material was possible. This Group initiated cocoon production in 2000 and reached the 0.5 tonne-level in a few months' time. Based on the progress and response from the Group and favourable climatic conditions, this site was selected for marketplace development.

The marketplace was first established on private land donated to the Group by a social worker, while the Group awaits the allotment of government land. One full set of post-harvest machines (10 multiend reeling machines with re-reeling facilities, 20 spindle capacity winding machines, doubling machine and single and double twist machine with twist reeling facilities, steaming chamber, power warp, creel, and powerloom with accessories and spares) was supplied and delivered to the Othoro Marketplace site on 5 July 2002. A team of six members from RK Industries, India, erected and tested the machines on-site and imparted operational training to the silk growers at Othoro. Being a remote rural area, the Group initially faced problems with the supply of electricity and water, and lack of cocoon storage and drying facilities. However, these initial difficulties were overcome and the marketplace established. Although initial seed money for cocoon and yarn purchase was not available from the government or private sector, ICIPE and donors assisted with revolving funds as was done in Bushenyi (see previous section).

B. Sericulture Research and Development

WORK IN PROGRESS

6. Grainage establishment for silkmoth eggs production

One of the constraints facing the upcoming sericulture sector in Africa is the dependancy on Asian partners for regular supply of eggs. Delays in shipping can also result in the spoilage of eggs and a gap in the cocoon production cycle. ICIPE has gauged the situation and developed a strategy for establishing an Africa-based grainage which will cater for the needs of sericulture farmers by supplying silkmoth eggs economically and improving the sericulture industry in Africa.

The grainages produce hybrid seeds for the production of commercial cocoons. The hybrids have a shorter larval duration, better survival rate and are richer in silk content than the pure races. Eggs are either prepared in loose form or packed in egg boxes and shipped to the destination. Each box contains about 20,000 eggs and 1 g contains 1800 eggs. One kilogramme of bivoltine cocoons yields about 55,000 silkworm eggs.

First African grainage for silkworm seed production

To establish the first grainage in Africa for silkworm (*Bombyx mori*) seed production, a conceptual model drawn by the Project is being implemented. The main objective of the grainage is to produce quality disease-free eggs at reasonable cost. In this model, the basic silkworm seeds of *Bombyx mori* races are evolved at the P3 stations in Government sericulture farms of China and India. These races are tested and multiplied in their respective P2 farms. P1 seeds produced are supplied to ICIPE and are multiplied and tested in Kenyan P1 farms under different agro-ecological conditions. The best races are multiplied at ICIPE laboratories and the disease-free P1 seeds produced are supplied to laboratories in Uganda and Kenya for mass multiplication through selected and trained P1 seed cocoon growers. Seed organisations in these countries receive P1 cocoons from various growers and ensure the production of parent seed cocoons with vigour. In their respective grainages, hybrid seeds (F_1) are produced which are supplied to the industrial cocoon growers in Africa.

The ICIPE grainage maintains the original P1 seeds and also produces industrial seeds for other African countries (Figure 6a–c). The industrial cocoon growers sell their cocoons at the cocoon marketplace established by the farmers through ICIPE initiatives in their respective districts. The respective representatives then send cocoons to the post-harvest units for further processing and fabric making in Othoro, Kenya and Bushenyi, Uganda. Sericulture farmers are issued an official receipt on the basis of their cocoon grades. Farmers receive their money through the banks in their respective districts on production of the official receipt.

The mini-grainage at ICIPE produced 112 boxes of disease-free silkworm eggs in 2001 and 179 boxes during 2002. Each box contains 20,000 eggs. The Project supplied eggs to silkgrowers in Kenya, Uganda, Zambia, Zimbabwe, Ghana and South Africa.

Silkworm breeding laboratory

Recent trends in silkworm breeding have concentrated more on improving silk quality to international standards, by developing bivoltine silkworm breeds

Figure 6. Steps in bivoltine silkworm egg production: (a) bivoltine **Bombyx mori** *seed cocoons; (b) moths of* **Bombyx mori** *mating; (c) disease-free layings of* **Bombyx mori**

with high economic potential. Crossing of two genetically distinct strains results in more vigorous offspring than pure parental strains. The F_1 hybrids are intermediate between parents in quantitative traits and hybrid vigour, and is expressed as higher survival rates, disease resistance, weight gain, denier of the fibre, filament length, etc. A study on the comparative performance of newly evolved bivoltine races of silkworm *Bombyx mori* L. and various bivoltine hybrids with regard to quantitative traits of economic importance is presently being undertaken. Only healthy broods which have the highest characters are selected for breeding and stock maintenance.

ICIPE has established its own silkworm-breeding laboratory for evolving and screening silkworm races adaptable to African conditions. Various races/hybrids are collected from China, Japan, Bulgaria and India and the cocoon assessment done for pure line breeding. After the screening, suitable silkworm breeds are identified and various cross breeds prepared and then tested in farmers' fields under various agroclimatic conditions. Pure-line breeding programmes are undertaken for self-sustainability, and post-harvest parameters are studied thoroughly to ensure the highest performance.

The seed crop rearing of ICIPE I, ICIPE II, Q x B, Q x H, S x M, 75 x IN x 7532, C x Z, S x R, Indian hybrid silkworm races was conducted as per standard rearing methods. Nine races reared during 2001 and 2002 (short rains, long rains and dry season) showed good performance. The lowest larval duration of 28 days was noticed in ICIPE I and ICIPE II whereas in the others it was 29 days in January. In August–September it was about 29 in I–I and I–II, whereas the other races showed a 30-day duration. A good survival rate of 90% or higher was observed in all the races. Overall higher cocoon weight, shell weight and filament length were observed in ICIPE2, followed by C x Z and Japanese S x R. An average fecundity > 500 eggs/moth was found in ICIPE2 and C x Z, while the other races showed fecundity > 450 eggs/moth.

A breeding programme was initiated in Kawanda in 2002 with ICIPE's assistance and several races were maintained. Previously Uganda relied on China, Japan and Bulgaria for its egg supply. Experiments are being conducted on high-yielding, locally adapted silkworm races/hybrids. In Uganda bivoltine pure lines and hybrids performed well and produced good shell percentage and Grade A silk fibre. Some of the farmers produced 30 kg per box, exhibiting high performance in this climate. As per ICIPE's grainage strategy, emphasis is given to stable cocoon production and satisfying all the economic characters. Japanese hybrids performed well and showed a larval duration of 27 days with average cocoon weight of 1.80 g and average filament length of 1100 m; evaluation of other races is continuing. All the hybrids are being evaluated in highland, midland and mid-low altitudes.

7. Wild silk farming

An attempt has been made to initiate wild silk farming in the East Africa region using different host plants (wattle or *Acacia mearnsii* and *A. hockii*). The biology of a potential silkmoth was studied to set up commercial-scale farming in the field in Kamaguti (Eldoret), Uasin Gishu District, Kenya.

In this region the wild silkmoth identified for farming, *Gonometa* sp., showed very distinct sexual dimorphism. The females were larger than the males, with a longer mean wing length of 8.93 ± 0.32 cm ($P < 0.05$). This was significantly different than that of the males (5.04 ± 0.21 cm) ($P = 0.039$). The sexual dimorphism exhibited in the adult stage can be used precisely for identification and separation of the sexes during the breeding period.

Plastic containers and net-sleeves were set to test fecundity and infertility of moths in different environments. The mean fecundity for female moths kept enclosed in a plastic container was 293 ± 22.28 eggs while the mean fecundity for the female moths kept in a net sleeve was 338.65 ± 24.28. The results show a high infertility of 51.65% of the moths enclosed in plastic containers in the second season. This was probably due to the small size of the plastic containers used, which do not allow free mating. Since the results indicated high fecundity in net-sleeve set-up, this could be manipulated for indoor egg production.

Natural enemies

The eggs and cocoons collected from the field were kept under laboratory conditions to determine the emergence of parasitoids. These were identified and the percentage parasitism determined. In the cage, all insects and other arthropods within the vicinity of the silkworms were observed and recorded. Other mortality factors were determined by releasing fourth instar larvae on two host plants (*A. mearnsii* and *A. hockii*). Each host plant had four replicates with a sample size of 50 larvae for each replicate. The replicates were single host plants with enough forage

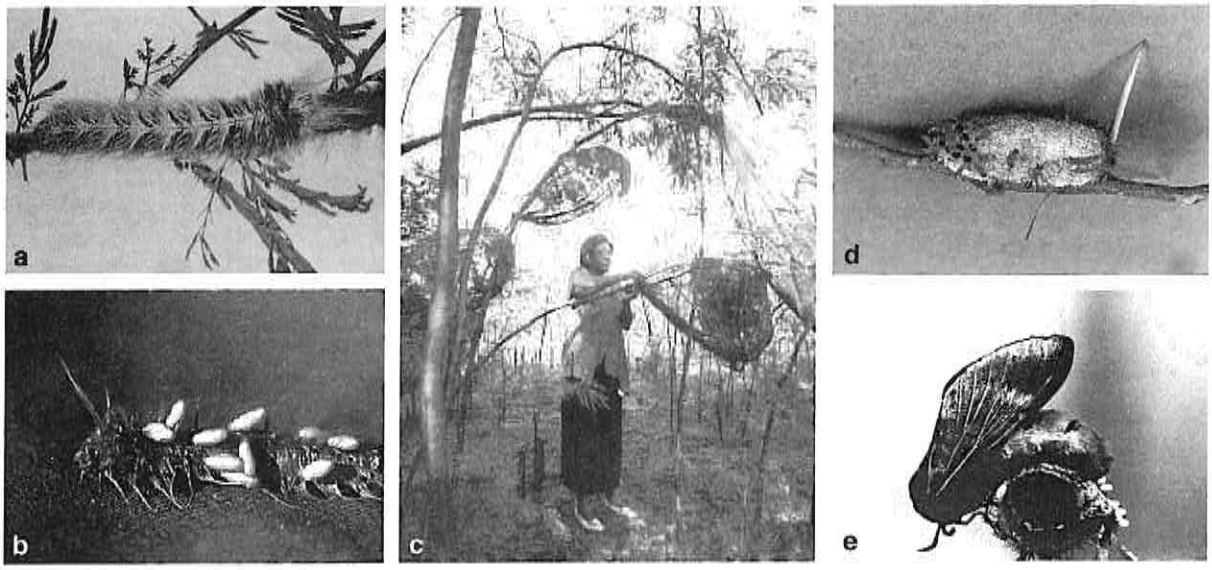


Figure 7. Wild silk farming in Kamaguti, Uasin Gishu district, Kenya: (a) healthy **Gonometa sp.** *larva; (b) parasitised larva with unidentified parasitic shells; (c) a farmer releasing young instars in the cage; (d) infested cocoon and (e) female* **Gonometa** *laying eggs over the cocoon*

to host 50 of the larvae. Counts of the surviving larvae on each host plant were made after seven days. Close observation on the possible causes of mortality was made on a daily basis (Figure 7). There was no egg parasitism. Mortality of larvae was caused by birds, *Macrorphaphis spurcata* (A. Walker) and carpenter ants, *Camponotus* sp. Cocoons were parasitised by *Compilura* (Tachinidae) and *Coccygomimus* (Ichneumonidae).

8. Quality testing of bivoltine mulberry silk for better fibre and fabric production

A single silk filament is the product of a series of stages derived from the cultivation of mulberry for feed, to the breeding of the domesticated silkworm, *Bombyx mori*. At the culmination of the larval phase of the domesticated silkworm, the worm wraps itself in a liquid protein, which it secretes and hardens upon exposure to air. The silkworm internally adds layer after layer to complete this protective covering. The resulting cocoon is in essence a silk fibre obtainable through the reeling process. The objectives of this study were to determine the cocoon quality in different silkworm strains; to study the reeling performance of selected silkworm strains and to verify the silk filament quality.

A laboratory (Figure 8) for this purpose has been established at ICIPE. The laboratory for quality control of silk was established by SRICAAS China under the consultancy of Dr Li Long, Chief Sericulture scientist. Raw silk needs to be examined following rigorous quality control tests before packing into skeins for the market or processed further for fabric making.

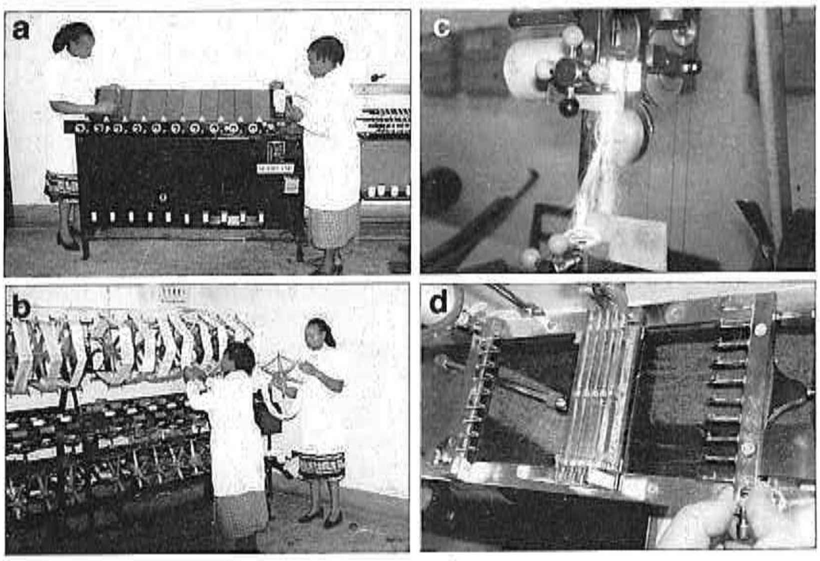


Figure 8. Testing of raw silk at the ICIPE Quality Control Laboratory; (a) technician filling the black board with raw silk for testing the neatness and eveness; (b) winding machine for testing winding breaks in raw silk; (c) tensile strength measurement machine and (d) twist testing machine

Table 3. Quality performance of various *Bombyx mori* races in 2002

Parameters/strains	ICIPE I	C x Z	Q x B	Q x H	S x M	ICIPE II
Cocoon weight (g)	2.055	1.7185	1.5185	1.5015	1.5685	2.195
Cocoon layer ratio (%)	20.3	20.36	19.09	21.25	24.04	21.0
Cocoon fibre weight (g)	0.381	0.323	0.251	0.29	0.302	0.405
Filament length (m)	1103.6	1042.7	964.3	976.9	995.6	1256.0
Cleanliness (%)	96	94	93	90	94	98
Av. neatness (%)	93	89	88	89	87	95
Winding (breaks)	5	8	8	12	10	2
Elongation	20	18	18	18	17	22
Cohesion	70	70	70	70	70	70

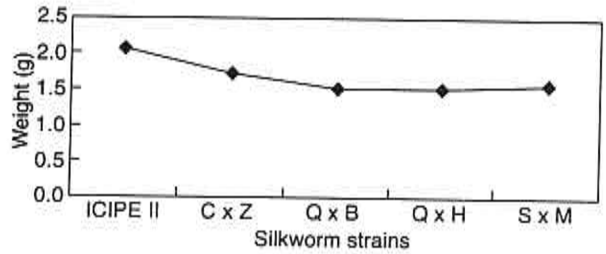


Figure 9. Comparison of cocoon weight (g) of* Bombyx mori *strains developed at ICIPE

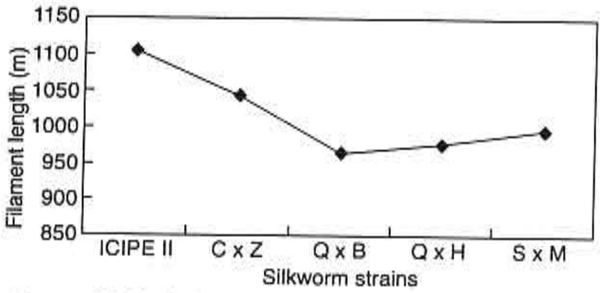


Figure 10. Variation of cocoon filament length (m) in* Bombyx mori *strains

Figure 11. Tie-dyeing creates unique designs on silk fabric

The cocoon weight of *Bombyx mori* strains was compared and ICIPE II was found to be superior to other races (Figure 9). In winding breaks, all races performed differently with ICIPE II the best, followed by C x Z. In cohesion tests, the performance of all races was equally good. The quality performance on the seriplane was highest in ICIPE II followed by C x Z. The filament length shows drastic variation. The longest filament was observed in ICIPE II followed by C x Z and S x M. The other two races did not reach the standard level (Figure 10). A summary of overall performance is shown in Table 3.

9. Natural dyeing of African silk

Dyes play a vital role in contributing to the aesthetic appeal of the fabric or fibre (Figure 11). Since ancient times natural dyes from flowers, seeds, nuts and other parts of plants have been used for dyeing local native handicrafts. Silk has greater affinity for dyes than any other textile fibre and natural dyes are particularly excellent for animal fibres. In Africa there is a good array of natural dyes over a diversity of climates and geographical conditions. The present study has been undertaken to assess the performance of natural dyes with mordants on bivoltine silk fabric.

Selection of natural dyes

Fresh plants of black jack (*Bidens pilosa*), *Ocimum* and *Acacia* bark were collected from the ICIPE beeyard; bixa (*Bixa orellana*) seeds were obtained from Muhaka Research Station on the south coast of Kenya. The crude turmeric (*Curcuma longa*), Harda, custard apples, passion fruits, catechu and henna powder were obtained from the local market.

During this study the flowers, leaves and roots of black jack were separated and the roots were washed thoroughly. Bixa seeds and crude turmeric and other dye extracts were prepared in tap water by boiling about 100 g of each material (leaf/flower/root) in 1000 ml of water in aluminium containers. The extracts were then filtered and used for dyeing. Degummed and bleached and plain-woven bivoltine silk fabric of 120 ends per inch was used for dyeing. The chemicals used for the mordant were aluminium sulfate (Al_2SO_4) and stannus chloride ($SnCl_2 . 2H_2O$).

The silk fabric when treated with black jack flowers, leaves and roots exhibited shades of yellow. Bixa seeds exhibited an orange colour of different shades in untreated and mordant-treated groups. In the case of turmeric (*Curcuma longa* L.), a bright yellow colour was obtained in untreated samples and an orange colour in treated samples. Custard apple (*Anona reticulata*) produced an ash colour (untreated) or purple-blue (treated), Harada (*Terminalia chebula*) gave golden yellow and orange-yellow colours, while ocimum (*Ocimum kilimandscharicum*) showed a greyish-brown colour. Catechu (*Acacia catechue*) showed yellowish-brown and shades of brown colours, whereas *Acacia nilotica* gave a golden brown to light brown shade.

Almost all the samples treated with mordants showed remarkable colour-fastness to washing with light detergent, crocking, bleeding and hot ironing. The untreated samples showed 9–10% noticeable change only in detergent washing, while other tests showed negligible change.

This preliminary study on various natural dyes with eco-friendly mordants showed a good performance on natural bivoltine silk fibre and fabric. Considering the increasing trend towards organic eco-friendly products in the textile industry, natural dyes can play an important role. It can help local dyers by increasing their income. More emphasis should be given to organic dyeing, and research is in progress.

C. Apiculture Research and Development

WORK IN PROGRESS

10. Queen breeding

ICIPE has developed and adapted queen-rearing techniques for African honey bee races and the technologies have been disseminated to local beekeepers (*See previous ICIPE Annual Reports*). However, even if the best queen rearing techniques are applied on genetically inferior queens, maximum production cannot be achieved. Selection and breeding from genetically superior queens is a major step towards development of high quality bee strains for improved hive production. ICIPE is currently carrying out a breeding programme using local honey bee races to develop better bee strains adapted to local environmental conditions. Apiaries have been established in Kenya in Mwingi, Mbita (Rusinga Island), Muka Mukuu, Kinangop and ICIPE headquarters at Duduville for this purpose. The breeding programme involves the following four major steps: (i) colony evaluation—targeted selection characteristics are honey production, stinging behaviour, swarming tendencies, nursing ability of young worker bees (hence royal jelly production) and reproductive rates (colony population build-up); (ii) queen rearing; (iii) drone rearing; and (iv) mating of queens—complete mating control has been attained through artificial insemination. The results of breeding research will be evaluated and presented in a later report.

11. Hive product research

Royal jelly

ICIPE is currently carrying out research on the potential of local East African honey bee races for royal jelly production to help bee farmers generate additional income. Since the 1950s, royal jelly has become a commercial hive product with a current world annual production of about 1 million tonnes. Farmers have been trained on the art of queen rearing and the basics of royal jelly production. The objective of this study was to establish a royal jelly production system.

There are significant differences in the brood food fed to worker larvae and that fed to queen larvae. The food fed to the queen is popularly called *gelee royal* or royal jelly. However, since royal jelly is fed directly to the developing larvae and is not stored, it is not a traditional hive product. As it is only feasible to harvest royal jelly during the peak queen rearing seasons, and since natural queen rearing is erratic and produces minimal amounts of queen cells (and thus royal jelly), it is not commercially viable to depend on the natural process. Instead, honey bee colonies are manipulated to induce conditions similar to those of swarming and emergency replacement of queens. Royal jelly production relies on artificial queen rearing techniques, and since most beekeeping in East Africa relies on annual catching of swarms for colony multiplication, royal jelly production for economic purposes has not been practised previously. ICIPE is thus helping African farmers develop this potential income-generating activity.

Selection of bee races

Results from these studies show that there are no significant differences in royal jelly yields between *Apis mellifera scutellata* and *Apis mellifera monticolla*. Colonies produced from 4–11 g per harvest with cell reception of 69–73% (Table 4). It is hoped that with good floral resources and good colony management practices, it will be posible to harvest 500–1000 g of royal jelly per colony in a productive season of 8 months. Research is being directed towards this goal. Colony organisation for royal jelly production using three systems is being investigated.

Studies have established that larvae grafted at the age of 18–24 h gave the highest royal jelly yields

Table 4. Comparison of royal jelly yields of *Apis mellifera scutellata* and *A. m. monticolla* honey bee races in East Africa

Honey bee race	% queen cup reception	Royal jelly yields per queen cup (mg)
A. m. scutellata	69 a	334.5 a
A. m. monticolla	73 a	331.0 a

Means followed by the same letter in the same column are not significantly different ($P < 0.05$) by Tukey's Test.

Table 5. Mean acceptance rates and average royal jelly yields of *Apis mellifera scutellata*

Age of larvae (h)	Number of grafted cells	Mean cell reception (%) ± SE	Mean royal jelly yield/cup (mg)
24	560	74.5 ± 4.9 a	419.5 ± 0.51 a
36	560	58.5 ± 4.9 b	356.8 ± 0.51 ba
48	560	42.5 ± 4.9 c	284.5 ± 0.51 c
60	560	35.0 ± 4.9 c	181.5 ± 0.51 c

Means followed by the same letter in the same column are not significantly different (P < 0.05) by Tukey's Test.

Table 6. Effects of harvesting time after grafting on royal jelly yields from *Apis mellifera scutellata*

Harvesting time after grafting	No. of harvested cell cups	Royal jelly/ cell cup (mg)	Total royal jelly weight (g)
2 days	2130 a	236.3 a	503.4 a
3 days	1414 b	349.5 b	494.2 a

Means followed by the same letter in the same column are not significantly different (P < 0.05) by Tukey's Test.

(Table 5). At this age the larvae are small and floating on a bed of royal jelly and clearly visible, thus easily grafted with minimal chances of injury.

The traditional practice in royal jelly production is to harvest 3 days (72 hrs) after grafting. It was hypothesised that harvesting after 2 days would lead to more harvests and hence higher yields of royal jelly. Results show that 30 harvests were achieved in 60 days when harvesting 2 days after grafting, while 20 harvests were achieved when harvesting 3 days after grafting. The 2-day cycle produced more royal jelly but the results were not significantly different. However, the 3-day cycle had significantly more royal jelly amounts per queen cup (Table 6). The 2-day cycle is labour intensive and suitable with a high number of colonies to compensate for the lower yields per queen cup. The 3-day cycle is ideal with fewer colonies, is less labour intensive, and results in fewer colony disturbances and is thus suitable with defensive honey bee strains. The chemical composition of royal jelly produced by the local honey bee races has been analysed.

Economics of the royal jelly production system have been established. Royal jelly is harvested (350–400 g per colony) and lypholysed. Using local honey bee races, an average of 400–600 mg of royal jelly per queen cup has been achieved. By conventional standards 250 mg/cup is acceptable. Various colony organisations are being evaluated in a bid to increase the number of accepted cells. With good nectar flow, acceptances of 20 queen cups per colony in one graft have been achieved. This translates to 12 g per colony per graft. Thus one colony is capable of producing 350–400 g royal jelly in one season. Attempts are being made to increase this to 500–1000 g per season.

These results show that royal jelly production for commercial purposes using the local East African honey bee races is feasible. However, instead of selling the royal jelly in its raw form, it would be more rewarding financially to sell it in a 'value-added' form. One honey bee colony produces 350 g of royal jelly annually, worth US$ 35. If a farmer has five colonies, the annual earning is US$ 175 (35 x 5). Honey production will add up to 100 kg (20 kg x 5) worth US$ 120. The total income per farm family is US$ 295. If royal jelly is added to the honey (value adding), the cost per 500 g bottle would increase from US$ 2.30 to US$ 5.80. A farm family can earn in one year US$ 1160 for 100 kg of royal jelly honey (200 bottles) as compared to a previous earning of US$ 295 for plain honey.

Royal jelly capsule production

During the review period, steps were undertaken to develop the first royal jelly (RJ) capsules using African races of *Apis mellifera* in Kenya. Capsules (250 mg) of lypholysed powder with honey and soya bean powder base have been produced (Figure 12a – e).

12. Microsatellite investigations of effective mating frequencies in honey bees *(A. mellifera)* from different locations in Kenya

The patrilinear distribution and effective mating frequency of 29 honey bee colonies from five geographic locations in Kenya with altitudes ranging from 128 to 2760 masl were determined by A76 and AI queen mates at random with access to a large gene pool. The average effective mating frequencies for each location ranged from 20.61 to 36.12. No significant difference in colony effective mating frequency was observed between any of the sampling locations (Mann-Whitney U-test, P > 0.05). The large variation in effective mating frequency within a location between colonies suggests that the number of matings may be influenced by local abiotic factors rather than being the result of genetic adaptation to certain climate types. The genetic differentiation of bees between sampling locations (Fst values) were low, and varied between 0.0099–0.0329, suggesting that no distinct populations of bees were sampled.

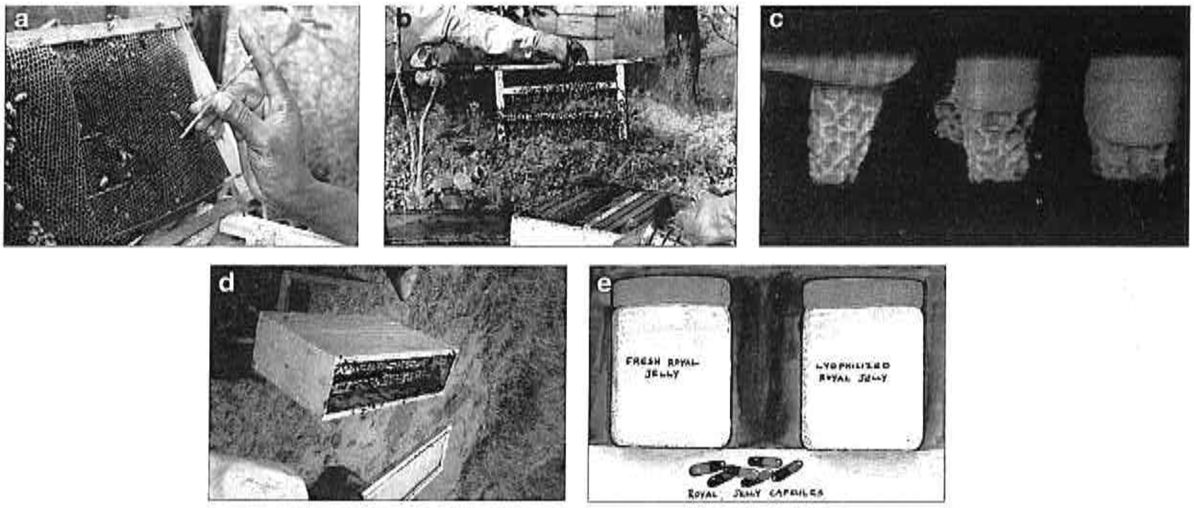


Figure 12. Step-wise process of royal jelly capsule production: (a) grafting process, (b) grafted cells with nurse bees; (c) developing queen cells; (d) nucleus colony and (e) royal jelly capsules for health

13. Honey quality control

Major importers and packers will only buy high quality honey. In Kenya, honey was collected from two provinces, Eastern Province and the Rift Valley Province, and analysed for quality. Sixty-two samples of honey were tested from the two provinces, and all but two honey samples contained less than 21% water. All honey samples contained a higher amount of proline than the minimum limit required. In respect to free acid, six honey samples from the Rift Valley Province and 11 samples from Eastern province contained a level of free acid outside the accepted limit. Of the 62 samples tested, only one sample of honey from the Eastern Province had an unacceptable level of HMF (hydroxymethylfurfural), an indication of over-heating during processing. All honey samples had more invertase enzyme activity than the minimum 50 U/kg. Three samples of honey from Eastern Province and one from Rift Valley had less diastase enzyme than acceptable. All 62 contained more than the minimum limit of fructose and glucose required. In addition, the level of sucrose in these honey samples was acceptable, and less than the maximum limit of 5%.

In summary, more than 90% of the honey produced in two provinces in Kenya meet the European Union quality standard for table honey. Only in respect to free acid level did a few samples of honey contain a higher level than that allowable for export. The reasons for this need to be determined and the problem addressed. However, the remaining biochemical indices suggest that with proper bee management, Kenya is capable of producing a high quality of honey.

D. Pollinators and Pollination Studies

WORK IN PROGRESS

14. Honey bees as pollinators

Food crops and pollination

The majority of commercially important crops depend on insects for pollination, for the quantity and/or quality of their yield, and for propagation or hybrid seed production. The importance of pollination to the yield of most crops grown in temperate climates is known, at least partially, but there is relatively little information about pollination of tropical crops. In Africa and other tropical regions, many studies of crop pollination have been preliminary.

Changes in land use and biodiversity-destroying agricultural and apicultural practices are resulting in declining populations of indigenous wild and managed bee populations at a time when greater crop diversification and consumer demand for high quality produce and variety of food, particularly fruits and vegetables, requires more insect pollinators. The honey bee, *Apis mellifera* L., is an important general pollinator. The practice of using honey bees, the only insects that can successfully be moved from farm to farm, to pollinate crops deserves much consideration.

Multiple use of insecticides and expansion of single cropping, both of which have been conducive to the development of modern agriculture, have also led to the decrease of natural pollinator populations. Cultivation in greenhouses, where no rain, wind, or natural pollinators can be expected, is growing in response to the rising demand for fruits and vegetables. These agricultural conditions have stimulated demand for efficient, manageable pollinators for greenhouse crops.

The assumption that when bees are foraging on a crop then they are also pollinating it sufficiently is not necessarily valid. Information about the behaviour of bees on flowers and how this affects pollination efficiency and crop yields is therefore essential. The problems of world food production, relative to the growth of the human population, are increasing daily and a solution would enhance the value of readily available and easily managed honey bees, but more importantly, it would increase food production.

Plant volatiles (semiochemicals) have an important role in the chemical ecology of the honey bee and are suspected to facilitate flower recognition, thereby increasing foraging and pollinator efficiency. The honey bee is extraordinarily responsive to semiochemical odorants that are produced by flowers and this plays a major role in the synonomy that induces them to visit a large array of blossoms in search of pollen and nectar. Few studies to date include such information.

This study seeks to assess to what extent the production of field crops increases due to adequate pollination, then to use and disseminate this information to farmers and develop strategies to conserve key pollinators. The Programme also explores the role of floral volatiles of specific species to enhance pollination and thus increase yield.

Floral volatiles and foraging bees on Cucurbitaceae

The role of floral volatiles of specific Cucurbitaceae species in their attraction to foraging worker, *A. mellifera* was studied as a model system. The use of a volatile blend to enhance pollination and therefore increase yield was also investigated. Optimisation of volatile collection methods has been done. Comparison was made of the suitability of the use of different adsorbents (Porapak Q, activated charcoal and Reverse Phase silica gel) to trap volatile emissions from whole flowers of the cucumber, *Cucumis sativus* L. var. Market Master. The different profiles (Figure 13) obtained were compared to determine the best adsorbent for each kind of compound emitted. Separation and identification of the constituents of the volatiles collected are now in progress.

Preliminary field evaluation of pollination of local crops is being studied in experiments conducted in Mbeere District in Eastern Province of Kenya. Experimental plots were prepared and planted with two varieties each of cucurbits as follows: watermelon [Sugar Baby (SB) and Charleston Gray (CG)] and cucumber [Ashley (A) and Market Master (MM)].

Initial yield data on fruit weight and seed numbers were obtained when the honey bee colonies had not yet been manipulated. This experiment has also been set up at ICIPE-Mbita Point Research and Training Centre in Suba District of Nyanza Province in western Kenya. Results from this study will enable the comparison of yield from different geographical regions.

15. Pollination through stingless bees *Hypotrigona* spp. (Fam: Apidae, Sub-Fam: Meliponinae, Tribe: Trigonini)

Stingless bees exist in many parts of the world and are an untapped resource for people working toward self-reliance. Stingless bees produce a sweet honey that is highly valued for its medicinal properties, and which fetches better prices (about 5–15 times more than *Apis mellifera* honey). Stingless bees are important pollinators, especially of native plants, including crops. For instance, stingless bees have been used for pollination of macadamia nuts and strawberries.

Stingless bees are potentially promising pollinators for the following reasons: they do not sting and thus are not a hazard to humans or animals; they collect and utilise considerable nectar and pollen throughout most of the year, therefore visiting numerous flowers which are pollinated; they can be manipulated in hives like honey bees; their hives are small, easily handled and relatively inexpensive; and the colony is unlikely to become hopelessly queenless (Figure 14 a, b). In addition, stingless bees are polylectic, foraging over a wide range of crops for pollen. The size of the bees is very important for the kind of plant they visit. Many species of stingless bees are less than 5 mm in length and therefore are able to search for food in very small flowers arranged in a large inflorescence.

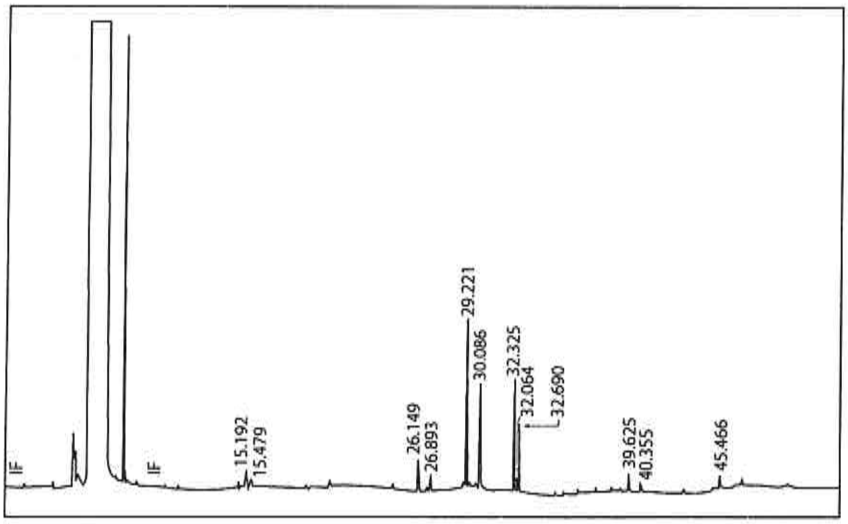


Figure 13. Gas chromatogram of volatiles released from whole flowers of* Cucumis sativus *L. var. Market Master

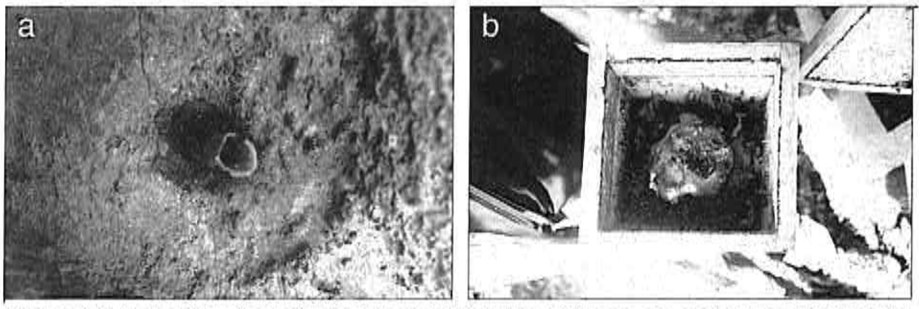


Figure 14. Stingless bee domestication: (a) **Hypotrigona** *sp. colony entrance; (b)* **Hypotrigona** *sp. colony in hive*

The following steps are being undertaken to achieve commercialisation of *Hypotrigona* spp. cultures: determine the species diversity and distribution of indigenous stingless bees species; study the effects of agricultural practices and land degradation on populations of stingless bees; promote meliponiculture as a means of income generation while conserving stingless bees species; develop a colony management system for the stingless bees in artificial hives; and evaluate their pollination potential and pollinator efficiency on various fruits and vegetables of commercial value.

This study began end of 2003, and the expected outcomes include: native bees species diversity and distribution determined and appropriate measures for their conservation established; honey production using stingless bees for income generation established; biology and ecology of native bees studied and methods for increasing colony numbers through colony divisions established; artificial hives for native bees developed for commercialisation of meliponiculture; and pollination potential of stingless bees on various crops of commercial value evaluated.

FUTURE OUTLOOK

ICIPE has developed several training programmes for rural people to assist them in establishing a central marketplace for their agro-industry products. This was confirmed through monitoring supply and demand of apiculture and sericulture products in the region. Such background work will be translated into business opportunities by bringing together potential trading partners in a buyers and sellers meeting covering one particular product such as honey or silk or product groups. This will create a template to transact business and establish marketplaces for the rural communities. By demonstrating the existence of promising trade opportunities within East Africa for commercial insects products and by bringing together entrepreneurs, ICIPE is harnessing a 'bottom-up' contribution to the long-term process of developing regional marketplace opportunities, generating off-farm employment and conserving the resource base. These efforts will further be promoted through on-site training, workshops and trade fairs. This process will develop a self-sustainable revolving fund, empowering local communities to put producers on a sound footing and with leverage in the marketplace.

CAPACITY BUILDING

Training courses for beekeepers, non-governmental organisations (NGOs) and government officers were undertaken. Arrangements were made for strengthening the capacity of scientific staff to undertake local and regional research and to backstop the adoption of technology packages developed under the Programme. The technology has been disseminated through one international workshop and training of national agricultural research systems (NARS) staff.

Three PhD students were registered (60% were women); two were awarded. One Masters level student was registered and one was awarded.

PhD students

Eluid M. Maundu (Kenya) Breeding of the honey bee (*Apis mellifera* L.) and their potential for royal jelly production in Kenya. Kenyatta University.

Evelyn Nguku (Kenya) A study on the quality of silk fibre and fabric of the bivoltine silkworm *Bombyx mori* L. Kenyatta University.

Gershom Mugeroi (Uganda) Grainage development and race performance testing in Uganda. Makerere University.

MSc student

Boniface M. Ngoka (Kenya) A study on the biology and impact of natural enemies on the African wild silkmoth, *Gonometa* sp. at Kamaguti, Uasin Gishu District, Kenya. MSc, Kenyatta University (2003). Supervisors: Prof. J. M. Mueke (Kenyatta University) and Dr E. Kioko, Prof. S. K. Raina (ICIPE).

Summary of training activities

Year 2002

Visits: Scientists (114), farmers (494), students (221)

Training: Attachment students (7), apiculture (60), sericulture, rearing (13); sericulture post-harvest (2)

Year 2003

Visits: Scientists (120), farmers (550), students (243)

Training: Attachment students (2), sericulture (38), apiculture (10)

Sericulture and apiculture training materials

Audio/visual cassettes prepared and released to the training institutes in Africa.

Handouts on sericulture and apiculture technologies were distributed to more than 6000 African farmers in Africa in English, Arabic, Kiswahili, French, Luganda, Kamba, Luo, Kikuyu and Woloff (Senegal).

OUTPUT

Journal articles

Fries I. and *Raina S.* (2003) American foulbrood and African honey bees (Hymenoptera: Apidae). *Journal of Economic Entomology* 96, 1641–1646. **(Call No.: 03-1715)**

We have taken samples of honey from individual beekeepers ($N = 64$), and of domestic ($N = 35$) and imported honey ($N = 15$) retailed in supermarkets in several sub-Saharan countries and cultivated these samples for *Paenibacillus larvae* subsp. *larvae* Heyndrickx et al. causing American foulbrood in honey bee colonies. The results are compared with samples of similar backgrounds and treated the same way but collected in Sweden ($N = 35$). No *P. larvae* subsp. *larvae* spores were found in any honey produced in Africa south of the Sahara although honey imported into this region frequently contains the pathogen. Swedish honey frequently contains *P. larvae* subsp. *larvae* spores although the general level of visibly infected bee colonies is low (roughly 0.5%). The results suggest that large parts of Africa may be free from American foulbrood. Behavioral studies (hygienic behavior) on *Apis mellifera* subsp. *scutellata* Lepeletier in Zimbabwe suggest that hygienic behavior of African bees could influence the apparent low level, or even absence, of American foulbrood in large parts of Africa.

Books

***Raina S. K.* (2003)** A Practical Guide for Raising and Utilising Silkmoths and Honey Bees in Africa (Edited by K. Overholt) 273 pp. ISBN 92 9064 136 3. [French translation by Randriamananoro J. J.; Spanish translation by Egea L. P. and De Shah M. M.; Kiswahili translation by Chimtawi A. M.; and Luganda translation by Kiggundu A.]. IBRA, Cardiff, CF10 3DT UK. (In press).

Raina S. K., Kimbu D., Kioko E., Adolkar V.* and *Herren H. R. (2003) Products of ICIPE's R&D: Integrating apiculture and sericulture technologies with regional development operations—Wilderness to marketplace partnerships: Development of global marketing facilities for honeybee and silkmoth products, pp. 9-19. In *Integrating Sericulture and Apiculture Technologies with Regional Development Operations.* Proceedings of the Trainers Course and Third International Workshop on the Conservation and Utilisation of Commercial Insects. 13 November–8 December 2000, Nairobi, Kenya. (Edited by S. K. Raina, E. K. Nguku and S. W. Mwanycky). ISBN: 92 9064 141 X. ICIPE Science Press, Nairobi. (Temporary document).

***Raina S. K., Nguku E. K.* and *Mwanycky S. W.* (Eds.) (2003)** *Integrating Sericulture and Apiculture Technologies with Regional Development Operations.* Proceeding of the Trainers Course and Third International Workshop on the Conservation and Utilization of Commercial Insects. 13 November–8 December 2000, Nairobi, Kenya. ISBN 92 9064 141 X. 274 pp. (Temporary document). ICIPE Science Press, Nairobi.

Proceedings

***Kioko E. N.* (2002)** Insects for food and income generation: An overview with reference to wild silkmoths in Africa, pp. 103–106. In *Indigenous Knowledge for Biodiversity and Development.* Proceedings of a National Workshop in Indigenous Knowledge, 1–3 July 1996, National Museums of Kenya, Nairobi (Edited by C. H. S. Kabuye). National Museums of Kenya. ISBN 9966-955-12-7. **(Call No. RE-1315)**

Technical reports

***Raina S.K.* (2003)** Final Technical Report IFAD Phase II on Sericulture and Apiculture Validation Trial. 150 pp.
Final technical reports, Phase I on Commercial Insects.
First technical reports, Phase II on Commercial Insects.

Conferences/workshops attended

African Pollinators Initiative. 18–22 February 2002, ICIPE, Nairobi, Kenya. V. Adolkar, E. Kioko, E. Muli and E. Nguku.
3rd Global BioNet—International Workshop held in Pretoria, South Africa, 8–12 July 2002. E. Kioko.

15th Biennial Congress of the African Association of Insect Scientists (AAIS) and Silver Jubilee Celebrations jointly organised by the Entomological Society of Kenya (ESK), 9–13 June 2003, ICIPE, Nairobi, Kenya. S. Raina, E. Kioko, V. Adolkar, E. Nguku, E. Muli.

Strategic Action Planning in Forest Sector Stakeholder Workshop, 22–24 July 2003, Nakuru, Kenya. V. Adolkar, E. Kioko, E. Muli.

Trees On Farm Network (TOFNET) Stakeholders Workshop and Steering Committee Meeting, 19–22 November 2003, ICRAF, Headquarters, Nairobi, Kenya. V. Adolkar.

Commercial Insects Strategy in World Summit on Sustainable Development (WSSD) exhibition, South Africa, August 2002.

Research proposals

British High Commission (BHC): 2002 Mwingi District Beekeepers Joint Self Help Group–SGS Project Number SGS/40.

UNDP-TUP (Trickle-Up Programme), Finnish Embassy, US Embassy Ambassador's fund: Community based apiculture/sericulture micro-enterprise development programme. Small grant support programme since 2001. Small grants for apiculture/sericulture development among rural communities.

German Development Services (DED): 2003–2004 Introducing modern apiculture technologies for income generation in West Pokot District, Kenya.

German Development Services (DED): 2003–2004 Community-based silk micro-enterprise development as an income generating source for rural and semiurban communities. SISIBO, Self Help Group, Eldoret, Kenya.

German Development Services (DED): 2003–2004 Prisoners' rehabilitation programme by introducing sericulture and apiculture technologies at Kamiti Maximum Security Prison and Langata Women's Prison, Nairobi, Kenya.

United Nations Development Programme (UNDP): In the pipeline—Introducing beekeeping technologies to the Batwa (Pygmy community of Uganda for additional income generation.

Awards

The project was awarded the finalist plaque by the World Bank, Washington in the Development Marketplace Innovation Competition 2002.

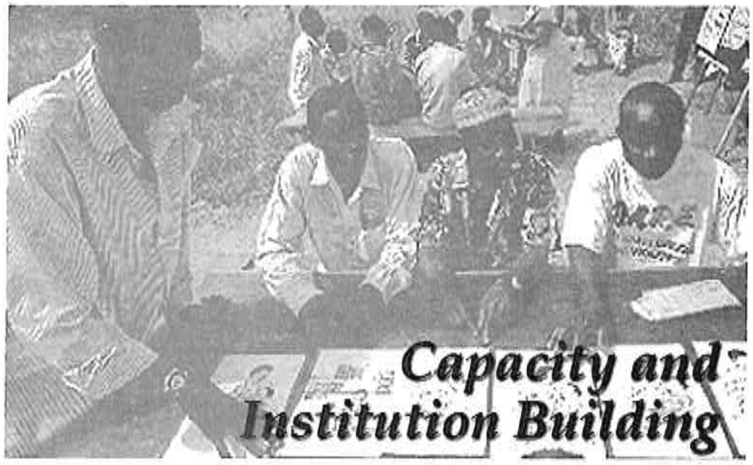
Participating scientists: S. K. Raina (Project Leader), E. N. Kioko,V. V. Adolkar

Assisted by: B. Nyagode, A. Ochieng, E. Muli, E. Nguku, B. Ngoka, J. Macharia, D. M. Kimbu, H. G. Muiru, J. Auma, R. Waruiu, D. Ogolla, G. Owino, G. Kamau, E. Kuria, D. Muia, R. Macharia, F. Kiilu, J. Nganga

Collaborators: Ministries of Agriculture and Livestock in Nigeria, Benin, Côte d'Ivoire, Zambia, Malawi, Uganda, Tanzania, Ethiopia, Rwanda, Libya, Burkina Faso and Senegal; Kenya Agricultural Research Institute (KARI); International Bee Research Association (IBRA), UK; New South Wales (NSW), Australia; Chinese Academy of Agricultural Sciences (CAAS); World Agroforestry Centre (ICRAF), Nairobi; Central Silk Board (CSB), India; Sericulture Research Institute (SRI), China; Centre for Sericulture and Biological Pest Management Research (CSBR), India; Food and Agriculture Organisation of the UN (FAO), Rome; University of Nairobi, Kenyatta University (Kenya); Uppsala University, Sweden; private sector and farmers; beekeepers, coffee growers, local and international traders, beekeeping stations in East Africa, honey processors, sericulture farming community, silk industries and regional textile traders, International Sericulture Associations (ITC Geneva, International Silk Association, France); wild silk research laboratories in Japan, China and India

Donors: IFAD, British High Commission (BHC), UNDP/TUP (Trickle-Up Programme), German Development Service (DED), US Embassy, Nairobi

CAPACITY AND INSTITUTION BUILDING, RESEARCH DEPARTMENTS AND UNITS



CAPACITY AND INSTITUTION BUILDING IN THE BIOSCIENCES

BACKGROUND, APPROACH AND OBJECTIVES

The major objective of ICIPE's capacity and institution building programmes is to build human resource capacity in insect science and related areas of the biosciences. The goal is to produce well trained, highly motivated and capable persons able to respond to the arthropod-related development needs of ICIPE's pan-African constituency. Additionally, ICIPE's approach has been to acclimatise researchers such that they can function and perform within the African context, yet remain competitive in the global research and development marketplace. The Centre's capacity building effort is intricately built into the R&D programmes. These span the continuum, from basic strategic research to technology development and validation, and finally community-based adaptation.

One of the key elements of ICIPE's training programmes is the emphasis on 'hands-on' experience and regular contact with the target communities, be it through training of farmers or training of trainers (ToT) and extension workers. ICIPE believes that this contact is pivotal in ensuring that the training remains relevant and that the trainees are aware of the pressing on-the-ground problems of technology implementation and adaptation in Africa.

ICIPE's capacity building programme is complemented by collaborative arrangements with university and research institutions in developed countries. The training programme is structured along the following major thrusts:

- *Higher degree training* for leadership in scientific research and policy formulation. This postgraduate training is offered at PhD and MSc levels through the African Regional Postgraduate Programme in Insect Science (ARPPIS) and the Dissertation Research Internship Programme (DRIP);
- *Non-degree training* is mainly targeted to practitioners in the national agricultural and health research and extension systems;
- *Professional development schemes*, where postdoctoral fellows, research associates and visiting scientists come to ICIPE to develop and share expertise; and
- *Interactive on-site training*, as collaborative research work is carried out with ICIPE's national partners.

WORK IN PROGRESS

A. POSTGRADUATE TRAINING

1. African Regional Postgraduate Programme in Insect Science (ARPPIS)

In 2002–2003, the 'Human Resource Development for Scientific and Technology Capability in Arthropod Science in Africa' project was in its second and third phases. The Project has made significant progress in building the human and institutional capacity to help Africa solve the many arthropod-related development issues that plague the continent. These include the loss of standing field and horticultural crops and stored agricultural products from plant pests; transference of plant diseases by insect vectors; loss of livestock and/or reduction in animal productivity due to ticks, tsetse and other disease vectors; loss of human life and working productivity from vector-borne diseases such as malaria and sleeping sickness; and reduction in agricultural productivity and natural resources arising from degradation of the environment, loss of biodiversity and unsustainable agricultural practices. *(See the publications lists at the end of this report for details of students' theses titles, registering universities and ICIPE supervisors.)*

By 2003, a total of 167 PhD scholars from over 25 countries in Africa had been enrolled in the ARRPIS programme, of which 121 had been awarded their degrees from the 27 African universities participating in the programme. Table 1 lists the training information on ARPPIS students in training in 2002–2003. Another 122 students have enrolled for Masters degrees in insect science at three ARPPIS Sub-Regional Centres at the Universities of Ghana (Legon), Zimbabwe and Addis Ababa (Ethiopia), of whom over 90 have received their degrees.

Table 1. Information on ARPPIS PhD students in training at ICIPE in 2002–2003

Name/Country	Class	Title of Thesis	ICIPE supervisors	University supervisors	Registering university
Mr Mohamed Hassan (Somalia)	1998	Stemborers host plants interactions in striga infested/uninfested hosts and their semiochemical basis	Dr Z. R. Khan	Prof. Jones Mueke	Kenyatta University
Ms Laila Uweso Abubakar (Kenya)	1998	Molecular characterisation of the factors involved in the development of trypanosomes in the tsetse midgut	Dr E. Osir	Dr F. Mulaa	University of Nairobi
Ms D. Wanyama-Masinde (Kenya)	1998	Impact of farmer participation technology adoption and diffusion: An assessment of a collaborative project in Trans Nzoia, Kenya on the use of fodder host plants for the control of stemborers in maize	Dr Z. R. Khan Dr J. Ssennyonga	Dr A. Chitere	University of Nairobi
Mr Ibrahima Sarr (Senegal)	1998	Studies on bioecology and environmentally sound control of red spider mites on tomatoes in Kenya	Dr M. Knapp	Dr C. K. Ogol	Kenyatta University
Mr Maxwell Billah (Ghana)	1999	Biosystematics of *Psytallia* species complex (Hym: Braconide), parasitoids of Tephritidae	Dr S. Kimani-Njogu Dr W. Overholt	Prof. D. Wilson	University of Ghana
Mr Peter Chinwada (Zimbabwe)	1999	Partial niche partitioning and complementarity of stemborer parasitism by *Cotesia sesamiae* and mechanisms of seasonal carryover in unimodal rainfall climatic zones as typified by Zimbabwe	Dr C. Omwega Dr W. Overholt	Prof. Jones Mueke	Kenyatta University
Mr Pontiano Nemeye (Uganda)	1999	Distribution and macro-ecology of two indigenous African fruit flies *Ceratitis cosyra* and *C. rosa* in Kenya, Tanzania and Uganda and their implications for strategies and tactics of fruit fly management in Africa	Dr S. A. Lux	Prof. J. Kaddu	Makerere University
Ms Susan Dimbi (Zimbabwe)	1999	Exploration for and assessment of the local pathogens of indigenous African fruit flies, *C. cosyra* and *C. rosa* and prospects for their use to manage immature and adult stages of fruit flies	Dr S. A. Lux	Prof. Jones Mueke	Kenyatta University
Mr Washington Ayiemba (Kenya)	1999	Ecological monitoring and sustainable utilisation of butterflies at Arabuko-Sokoke forest, Kenya	Dr L. Rogo Dr I. Gordon	Prof. Okello	Kenyatta University
Mr Cherif M. H. Kane (Mauritania)	1999	Optimisation of use of phenylacetonitrile in enhancing susceptibility of gregarious nymphal desert locust, *Schistocerca gregaria* (Forsk) to insecticides and pathogens	Prof. A. Hassanali Dr P. Njagi	Dr C. K. Ogol	Kenyatta University
Mr Benard Okech (Kenya)	1999	Vector competence of African malaria vectors	Dr J. Githure	Dr Kabiru	Kenyatta University
Mr Sidi Ould Ely (Mauritania)	1999	Relative oviposition preferences of solitarious desert locusts on different *Heliotropium* spp. and their semiochemicals basis	Prof. A. Hassanali Dr P. Njagi	Prof. M. Bashir	University of Khartoum
Mr Alfred Ochieng (Kenya)	1999	Cowpea *(Vigna unguiculata)* pollination and risk assessment linked to the future release of genetically transformed cowpea breeding lines	Dr R. Pasquet	Dr B. Gemmill	University of Nairobi
Mr Yonas Feleke (Ethiopia)	2000	Cowpea *(Vigna unguiculata)* cpDNA polymorphism as a tool to assess gene-flow directions between cultivated and wild	Dr R. Pasquet	Dr Munuvi	Kenyatta University
Ms Leunita Sumba (Kenya)	2000	Pre-oviposition behaviour of the African malaria mosquito, *Anopheles gambiae*	Dr J. Githure Prof. A. Hassanali	Dr Arop Leek Deng	Egerton University
Dr Frederick Baliraine (Uganda)	2000	Analysis of genetic diversity of fruit fly populations in Africa for improved management	Dr E. Osir Dr S. A. Lux	Dr F. Mulaa	University of Nairobi

Table 1 continued

Name/Country	Class	Title of Thesis	ICIPE supervisors	University supervisors	Registering university
Mr Gashawbeza Ayalew (Ethiopia)	2000	Population ecology of DBM and its parasitoids in Ethiopia	Dr B. Löhr	Dr C. K. Ogol	Kenyatta University
Ms Aruna Manrakhan (Mauritius)	2000	Food attractants for management of fruit flies: Biological mechanism of their activity and methods of their production from locally available materials	Dr S. A. Lux	Prof. I. Fagoonee	University of Mauritius
Ms Rudo Sithole (Zimbabwe)	2000	Studies on comparative fitness of African parasitoids of DBM	Dr B. Löhr	Dr A. Mabveni	University of Zimbabwe
Mr Aklilu Seyoum (Ethiopia)	2000	Evaluation of mosquito repellent and insecticidal plants and plant products for control of mosquitoes	Prof. A. Hassanali	Dr E. Kairu	Kenyatta University
Mr Mathew.Bett (Kenya)	2000	Integrated use of synthetic and natural repellents for tsetse management	Dr R. K. Saini		Moi University
Mr Charles Aura Midega (Kenya)	2001	Impact of habitat management on abundance and activity of maize stemborer natural enemies and biodiversity of arthropods and soil fauna in Africa	Dr Z. R. Khan	Dr C. K. Ogol	Kenyatta University
Mr Andrew Kalyebi (Uganda)	2001	Assessment of some performance attributes of selected indigenous *Trichogramma* species (Hymenoptera: Trichogrammatidae) for biocontrol of African bollworm *(Helicoverpa armigera)* (Lepidoptera: Noctuidae) in Kenya	Dr S. Sithanantham	Prof. Jones Mueke	Kenyatta University
Ms Janet T. Midega (Kenya)	2001	Distribution patterns, gene flow and dispersal capabilities of anopheline mosquito species at three ecological zones along the Kenyan Coast	Dr J. Githure Dr C. Mbogo	Prof. D. Wilson	University of Ghana
Mr Melaku Wale (Ethiopia)	2002	Ecology and biologically based management of cereal stemborers on maize and sorghum in the Amhara state of Ethiopia	Dr C. Omwega	Dr E. Kairu	Kenyatta University
Ms Catherine Gitau (Kenya)	2002	Geographical variation in the developmental success of *Cotesia sesamiae* Cameron (Hymenoptera: Braconidae) on *Busseola fusca* Fuller (Lepidoptera: Noctuidae) in Kenya	Dr Adele Ngi-Song Dr F. Schulthess	Prof. Jones Mueke	Kenyatta University
Ms Teddy Kauma (Uganda)	2002	Role of wild host plants in population dynamics of cereal stemborers and associated natural enemies in Uganda	Dr C. Omwega Dr F. Schulthess	Prof. Jones Mueke	Kenyatta University
Mr Domingos Cugala (Mozambique)	2002	Impact assessment of natural enemies on stemborer populations and maize yield in Mozambique	Dr C. Omwega	Dr C. K. Ogol	Kenyatta University
Ms Ester Innocent (Tanzania)	2002	Bio-prospecting for botanical larvicides and repellents for the control of the malaria vectors	Prof. Hassanali	Prof. Nkunya	University of Dar es Salaam
Ms Hortance Manda (Cameroon)	2002	Plant-feeding behaviour and effect of plant diets on the African malaria vector *Anopheles gambiae* fitness	Dr J. Githure Dr L. Gouagna	Dr E. Kabiru	Kenyatta University
Mr Daniel Ndem Amin (Cameroon)	2002	Functional analysis of the midgut lectin gene of *Glossina austeni*	Dr E. Osir	Dr G. Munuvi Prof. J. Machoka	Kenyatta University
Mr Fiaboe Kouma Mokpokpo (Togo)	2002	Studies of potential predators of tomato red spider mite *Tetranychus evansi* (Baker and Pritchard) for possible introduction as biocontrol agents in Africa	Dr M. Knapp	Dr C. K. Ogol	Kenyatta University

Contd.

Table 1 continued

Name/Country	Class	Title of Thesis	ICIPE supervisors	University supervisors	Registering university
Mr Charles Kihampa (Tanzania)	2003	Characterisation and assessment of anti-mosquito natural products from Tanzanian botanicals	Prof. A. Hassanali	Prof. Nkunya	University of Dar es Salaam
Mr Anderson Kipkoech (Kenya)	2003	The socio-economic impact assessment of biological control of cereal stemborers in maize growing belts of eastern and southern Africa	Dr F. Schulthess	Prof. H. Maritim Dr W. Nyaban	Moi University
Ms Salome Guchu (Kenya)	2003	Allelochemical mechanisms of *Striga* suppression by *Desmodium*	Prof. A. Hassanali	Dr A. Yenesew	University of Nairobi
Mr Ohaga Spala Oduor (Kenya)	2003	Host location behaviour of *Glossina swynnertoni* and development of baits	Dr R. Saini	Prof. E. D. Kokwaro	Kenyatta University
Mr Bruce Anani Yaovi (Togo)	2003	The importance of indigenous egg parasitoids in the population dynamics of cereal stemborers in East Africa and its implication for the release of the western egg parasitoid species *Telenomus isis* Polaszek (Hymenoptera: Scelionidae)	Dr F. Schulthess Dr A. Ngi-Song	Prof. Jones Mueke	Kenyatta University
Ms Esther Mwihaki Njuguna (Kenya)	2003	Economics of habitat management strategies in maize and livestock production by controlling stemborers and striga weed in mixed farming systems	Dr Z. R. Khan		University of Nairobi

During the reporting period, the University of Gulu in Northern Uganda joined the ARPPIS network by signing a Memorandum of Understanding in October 2003. Negotiations are continuing with other universities in the region who have expressed interest in joining the network, especially Maseno University in Kenya, which signed a general agreement with ICIPE in September 2003.

2. Dissertation Research Internship Programme (DRIP)

Twenty-four doctoral students and 54 masters scholars were enrolled during 2002–2003, with some receiving full or partial support under the DRIP Programme (Tables 2 and 3). The thesis topics represent the entire range of ICIPE's R&D interests in the multi-disciplinary field of insect science, ranging from studies on molecular biology, behavioural and chemical ecology to environmental health and the use of food attractants made from locally available materials for the control of fruit flies.

3. Networking

The programme hosted the second planning workshop, 11–13 July 2001, on a new network for biotechnology among African universities, named BiONET-AFRICA for bioscience specialists. The network consists of national universities in eastern and southern Africa. *(See also report of Molecular Biology and Biotechnology Department.)*

B. Professional Development Schemes

Eight African scientists from four countries received funding from the programme under the 'Re-entry Research Grants' to encourage them to initiate and remain in research in their home countries. Eight former ARPPIS scholars who are now employed in their home countries have travelled on a scientific exchange programme to visit and work with other ARPPIS alumni or other scientists on projects of mutual interest. To encourage collaboration, 15 ARPPIS alumni have been awarded short-term research internship fellowships tenable at ICIPE. This support helps promote intra-Africa cooperation and networking, and serves as a stimulus to keep young scientists in the continent.

During 2002 and 2003, ICIPE hosted 28 and 16 visiting scientists, respectively. These visits were made based on mutual benefit to ICIPE and the home institute of the scientists.

C. Non-degree training

Practitioners of arthropod pest and vector management were trained in the special short courses offered by the programme. Seven courses were offered, on

Table 2. Information on DRIP Doctoral (PhD) scholars in training at ICIPE in 2002–2003

Name and country	Duration	Sponsor	Title of thesis project	Registering university	ICIPE Supervisor
Mr Emmanuel Niyibigira (Uganda)	4 years 1.9.1998–30.6.2002	DGIS/WAU/DSO	Genetic variability in *Cotesia flavipes* Cameron and its significance for population establishment in the biological control of lepidopteran stemborers	Wageningen Agricultural University	Dr W. Overholt
Mr I. Ogwayo (Kenya)	4 years 15.9.99–15.8.2003	Kenyatta University	An instrumental method for the determination of the quality of Kenyan coffee flavour	Kenyatta University	Prof. A. Hassanali
Ms Lucy Kamau (Kenya)	2 years 1.3.1999–28.2.2002	DAAD (R)	The role of skin bacteria in the production of volatiles that attract malaria mosquitoes	Kenyatta University	Dr B. Knols
Mr Richard Mukabana (Kenya)	3 years 1.4.1999–31.5.2002	WHO/TDR (R)	Characterisation of human odour causing differential attractiveness of humans to malaria mosquitoes	Wageningen Agricultural University	Dr B. Knols
Ms Emmah Omulokoli (Kenya)	5 years 2.6.1999–31.5.2003	Dupont Aid to Education	Isolation of anti-arthropod pest natural products derived from soil microorganisms	Jomo Kenyatta University of Agriculture and Technology	Dr W. Lwande
Mr Evan Mathenge (Kenya)	3 years 01.6.1999–31.12.2003	WHO/TDR (R/S)	Development of an exposure-free bednet trap for afrotropical malaria mosquitoes	University of Nairobi	Dr J. Githure Dr L. Gouagna
Ms Monicah Waiganjo (Kenya)	3 years 1.9.1999–31.8.2002	USAID/DSO(R)	Studies on ecology and preventive management strategies on onion thrips *Thrips tabaci* (Thysanoptera: Thripidae)	Kenyatta University	Dr S. Sithanantham
Mr Paul Wachana (Kenya)	3 years 1.9.2000–30.8.2003	ICIPE/Self	The community-managed tsetse and trypanosomosis technology in Lambwe Valley	Moi University	Dr S. Ssennyonga
Ms Intisar E. Elteraifi (Sudan)	3 years 2.6.2000–31.8.2003	TWAS (S) ICIPE (R)	Ecological viability in neem growth, oil and limonoids in Sudan	Gezira University	Prof. A. Hassanali
Ms Grace Njoroge (Kenya)	3 years 01.12.2000–30.11.2004	Biovision (S/R)	Anthecological and systematic studies of four Cucurbitaceae species at Yatta (Kenya)	Jomo Kenyatta University of Agriculture and Technology	Dr S. Raina
Ms Barbara Wagener (Germany)	3 years 01.11.2000–30.4.2004	DBM (R/S)	Molecular taxonomic studies of *Diadegma semiclausum* and other important parasitoids of the diamondback moth in Africa	University of Hohenheim	Dr B. Löhr
Ms Evelyn Nguku (Kenya)	3 years 01.9.2001–31.8.2004	IFAD (R)	A study of the quality of silk fabric using bivoltine silkworm races, *Bombyx mori* L.	Kenyatta University	Dr S. Raina
Mr Elliud Maundu (Kenya)	3 years 01.4.2001–31.3.2004	IFAD (R)	Breeding of the honey bee *Apis mellifera* L races and their potential for royal jelly production in Kenya	Kenyatta University	Dr S. Raina
Mr Joseph Odhiambo (Kenya)	3 years 01.8.2001–31.7.2004	NIH/ABC (S/R)	Immune disruption of protein digestion in *Anopheles gambiae* midgut based on digestive enzyme cDNA immunisation	Kenyatta University	Dr J. Githure Dr E. Osir
Mr Paul Mireji (Kenya)	3 years 01.8.2001–31.7.2004	NIH/ABC (S/R)	Response of mosquitoes to urban environmental contaminants	Kenyatta University	Dr J. Githure Dr E. Osir

Contd.

Table 2 continued

Name and country	Duration	Sponsor	Title of thesis project	Registering university	ICIPE Supervisor
Mr Wilfred Injera (Kenya)	3 years 01.8.2001–31.7.2004	NIH/ABC (S/R)	Characterisation of anti-mosquito immune responses in mice immunised with plasmid containing *Anopheles gambiae* mucin (AgMuc1) cDNA	Kenyatta University	Dr J. Githure Dr E. Osir
Mr Brandon Ogbuganofor (USA)	1 year 01.8.2002–31.7.2003	Fulbright (S/R)	Characterisation of novel antiviral therapeutic agents	Yale University, USA	Prof. A. Hassanali
Ms Tereza Megalhaes (Brazil)	1 year 01.1.2003–31.7.2004	University of Miami (S/R)	DNA vaccination against the malaria vector *Anopheles gambiae*	University of Miami	Dr J. Githure
Mr Joseph Baya (Kenya)	3 years 01.9.2001–30.9.2004	USAID. IPM (S/R)	Characterisation of inter-and intra-species diversity and habitat association of native trichogrammatid species occurring on *Helicoverpa armigera* Hübner (Lepidoptera: Noctuidae) in eastern Africa	Jomo Kenyatta University of Agriculture and Technology	Dr S. Sithanatham
Mr Benjamin Jacobs (USA)	3 months 15.7.2002–14.10.2002	NIH (S/R)	*Anopheles* larval habitats	Tulane University	Dr J. Githure
Mr John Carlson (USA)	1 year 01.6.2002–30.6.2003	NIH-ICIDIR (S/R)	Predators of mosquito larvae	Tulane University	Dr J. Githure Prof. F. Omlin
Mr Steven Barasa (Kenya)	3 years 01.10.2001–30.9.2004	NIH/ABC (R/S)	Chemical ecology of oviposition site selection of the major malaria vector, *Anopheles gambiae*	Jomo Kenyatta University of Agriculture and Technology	Prof. A. Hassanali Dr J. Githure
Mr Radoslaw Brzezowski (Poland)	2 years 01.6.2002–31.5.2004	JIRCAS (S/R)	Study of ecology and behaviour of parasitoid flies that are potential biological control agents on major crop pests in E. Africa	Jagiellonian University	Dr T. Yoshida Prof. A. Hassanali
Mr Maurice Omollo (Kenya)	3 years 01.2.2002–31.1.2005	WHO (R/S)	The isolation, identification and synthesis of behaviourally active semiochemicals from human foot odour as attractants for African malaria vectors	Kenyatta University	Prof. A. Hassanali

S = Scholarship; R = Research.

Table 3. Training information on DRIP Masters (MSc) scholars in training at ICIPE in 2002–2003

Name and country	Duration	Sponsor	Title of thesis project	Registering university	ICIPE Supervisor
Ms Zipporah B. Osiemo (Kenya)	2 years 2.4.2000–31.3.2002	DSO (R/S)	Naturally occurring *Trichogramma* egg parasitoids	Jomo Kenyatta University of Agriculture and Technology	Dr S. Sithanantham
Mr Boniface Ngoka (Kenya)	2 years 2.5.2000–30.4.2002	IFAD C. Insects (R)	Research on technologies for wild silk mass production in Kenya	Kenyatta University	Dr S. Raina
Mr Barasa M. Maniafu (Kenya)	1 year 01.4.2001–31.3.2002	ICIPE WHO/MIM (R)	1,4-naphthoquinones and related compounds from *Plumbago* spp. assessment of the activity on *Anopheles gambiae*	Kenyatta University	Dr W. Lwande
Mr Silas K. Simuyu (Kenya)	1 year 01.9.2001–31.8.2002	WHO/MIM (R)	Bioprospecting on the mosquito repellents/insecticides	Kenyatta University	Dr W. Lwande
Ms Fidelis N. Samita (Kenya)	1 year 01.9.2001–31.8.2002	WHO/MIM (R)	Bioprospecting for phytochemicals for *Anopheles gambiae* control	Kenyatta University	Dr W. Lwande
Mr Fred M. Okanda (Kenya)	1 year 01.10.2001–30.9.2002	NIH (R/S)	The mating behaviour of *Anopheles gambiae*	University of Nairobi	Dr B. Knols
Mr Geoffrey M. Mahanga (Kenya)	1 year 01.4.2001–31.3.2002	WHO/MIM (R)	Synthesis and structure activity tests of 2-hydroxy-4-methoxybenzaldehyde and derivatives as mosquito larvicides	Kenyatta University	Dr W. Lwande
Ms Jacqueline Makatiani (Kenya)	1 year 01.5.2001–30.4.2002	USAID (R)	Role of companion crops in managing DBM on cabbage/kale	Kenyatta University	Dr S. Sithanantham
Mr John N. Kuria (Kenya)	8 months 01.9.2001–30.4.2002	IDRC/IWMI (R)	An economic assessment of rice production systems in Mwea Irrigation Scheme	University of Nairobi	Dr C. M. Mutero
Mr Joseph Mwangagi (Kenya)	2 years 04.9.2000–03.9.2002	NIH (R)	Larval ecology of malaria vectors at the Kenyan coast	Kenyatta University	Dr C. Mbogo Dr J. Githure
Mr Josiah O. Odalo (Kenya)	1 year 01.5.2001–31.5.2002	WHO/MIM (R)	Bio-examination for phytochemicals active against *Anopheles gambiae* from eastern and coastal Kenya flora	Kenyatta University	Dr W. Lwande
Mr John Bwire (Kenya)	2 years 01.5.2002–31.7.2003	ICIPE (S) Dupont Aid to Education (R)	Bioprospecting for insecticidal scorpion venom and identification of active toxins for potential development of pest control products	Jomo Kenyatta University of Agriculture and Technology	Dr W. Lwande
Mr Elijah K. Gituanjah (Kenya)	8 months 01.7.2001–29.2.2002	IDRC/IWMI (R)	Assessment of crops/livestock interactions and nutrient cycling in a rice-based Mwea irrigation scheme	Kenyatta University	Dr C. M. Mutero Dr J. Githure
Ms Lucy Musyoka (Kenya)	Nine months 01.5.2001–28.2.2002	IDRC/IWMI (R)	Treatment-seeking behaviour for malaria in a rice irrigation scheme	Kenyatta University	Dr C. M. Mutero Dr J. Githure
Mr Ohaga S. Oduor (Kenya)	1 year 01.5.2001–30.4.2002	WHO/MIM (R)	Field evaluation of mosquito larvicidal plants	Kenyatta University	Dr W. Lwande
Ms Samita K. Nekesa (Kenya)	1 year 01.5.2001–28.2.2002	WHO/MIM (R)	Bioprospecting for phytochemicals for *Anopheles gambiae* control	Kenyatta University	Prof. A. Hassanali Dr W. Lwande

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Table 3 continued

Name and country	Duration	Sponsor	Title of thesis project	Registering university	ICIPE Supervisor
Mr Simon M. Karuka (Kenya)	1 year 02.5.2001–30.4.2002	Self	Biostatistics	Kenyatta University	Dr A. Odulaja
Mr Harrison Kibogo (Kenya)	2 years 01.3.2002–31.3.2004	USAID (R)	Population genetics of *C. anonae*: Comparison of two geographically isolated populations in Kenya	Jomo Kenyatta University of Agriculture and Technology	Dr E. Osir Dr D. Masiga
Ms Marion Warigia (Kenya)	1 year 01.8.2002–31.7.2003	BioNet-Africa	Molecular characterisation of *Anopheles gambiae* and *Culex* and habitat selection of *Anopheles gambiae*	Kenyatta University	Dr E. Osir
Mr Samuel K. Muiruri (Kenya)	1 year 19.7.2002–18.7.2003	Malaria Programme	Research on larval ecology	Kenyatta University	Dr C. M. Mbogo Dr J. Githure
Mr Frederick Musieba (Kenya)	6 months 01.8.2001–28.2.2002	Self	Valuation of the adult gregarisation pheromone	University of Nairobi	Prof. A. Hassanali Dr P. Arama
Mr Steven B. Obuya (Kenya)	3 years 01.1.2001–31.12.2003	Rockefeller Foundation (R)	The population structure of *Vigna unguiculata*: An assessment of the impact of gene flow between crops and wild plants	Kenyatta University	Dr R. Pasquet
Ms Christine Ngei (Kenya)	1 year 01.7.2001–30.6.2002	ICSC-WL (R)	Research in the biotechnology area	Kenyatta University	Dr E. Osir Dr P. Arama
Ms Jackline Makatiani (Kenya)	1 year 01.5.01–30.4.02	Self	Studies on the potential of companion crops in managing the diamondback moth, *Plutella xylostella* (L.) in cabbage/kale cropping systems in Kenya	Kenyatta University	Dr S. Sithanantham
Mr Musa O. Nga'yo (Kenya)	1 year 01.7.2001–30.6.2002	ICSC-WL (R)	Molecular characterisation of trypanosomes in small ruminants and pigs from western Kenya	Kenyatta University	Dr E. Osir
Mr Dennis Okinyo (Kenya)	1 year 01.5.2001–30.6.2002	WHO/MIM	Bio-prospecting for phytochemicals for *Anopheles gambiae* larval control	Kenyatta University	Dr Lwande
Ms Gladys B. Bichang'a (Kenya)	1 year 01.7.2001–30.6.2002	ICSC-WL (R)	Characterisation of cell cycle regulator genes in mature *in-vitro Plasmodium falciparum* gametocytes	University of Nairobi	Dr E. Osir
Ms Dolphine Amenya (Kenya)	1 year 01.1.2001–28.2.2002	ICSC-WL (R)	Lectin expression associated with plasmodium infections in *Anopheles* spp.	University of Nairobi	Dr E. Osir
Mr Caleb M. Momanyi (Kenya)	2 years 01.8.2002–31.9.2004	ICIPE Core (R) DSO	Biological impact assessment of *Diagema semiclausum* on *Plutella xylostella* and its local natural enemies in Kenya	Jomo Kenyatta University of Agriculture and Technology	Dr B. Löhr
Ms Fathiya Mbarak (Kenya)	1 year 01.1.2002–28.2.2003	ICSC-WL (R)	Studies on biochemical changes associated with the transfer of gregarious phase of offspring in the desert locust, *Schistocerca gregaria*	Jomo Kenyatta University of Agriculture and Technology	Dr E. Osir Prof. A. Hassanali
Mr George M. Keere (Kenya)	1 year 1.12.2002–31.1.2003	Self	Study on the potential integration of trichogrammatid biocontrol agents with pesticides for the management of African bollworm *Helicoverpa armigera* (Hübner) in tomatoes	Jomo Kenyatta University of Agriculture and Technology	Dr S. Sithanantham

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Table 3 continued

Name and country	Duration	Sponsor	Title of thesis project	Registering university	ICIPE Supervisor
Mr Ibrahim Macharia (Kenya)	1 year 01.1.2002–31.12.2002	DBM (R)	Ex-ante economic impact assessment of classical biological control of diamondback moth on cabbage and kales by use of exotic parasitiod *Diadegma semiclausum* in Kenya	Jomo Kenyatta University of Agriculture and Technology	Dr B. Löhr
Mr Evans Okoth (Kenya)	2 years 15.10.2002–14.10.2004	WAU (R/S)	Research on cereal stemborers	Kenyatta University	Dr M. Setamou Dr C. Omwega
Mr Vincent Mahiva (Kenya)	1 year 01.10.2002–30.9.03	Co-BIOTA Co.	Study on dung beetles in the Kakamega Forest region	University of Nairobi	Dr I. Gordon
Mr John J. Muturi (Kenya)	1 year 01.6.2002–31.5.2003	WAU	Assessment of potential effects of *Xanthopimpla stemmator* (Hymenoptera: Ichneumonidae) on target and non-target Lepidoptera and pupal parasitoids in grasses	Kenyatta University	Dr E. Osir Dr A. Ngi-Song
Mr James I. Kanya (Kenya)	1 year 01.3.2002–28.2.2003	USAID	Quantification and qualification of vegetation in the proximity of maize fields in Trans Nzoia District, Kenya	Jomo Kenyatta University of Agriculture and Technology	Dr E. Osir Dr A. Ngi-Song
Mr Gerald Juma (Kenya)	1 year 01.4.2003–31.3.2004	IRD	Chemical cues from host plants influencing the oviposition behaviour of the stemborer *Busseola fusca* Fuller (Lepidoptera: Noctuidae)	Kenyatta University	Dr P.-A. Calatayud
Ms Peninah Munyua (Kenya)	1 year 01.5.2003–30.4.2004	IFAD (R)	Toxicological effects of a repellent on livestock	University of Nairobi	Dr R. Saini
Mr Wycliffe Wanzala (Kenya)	1 year 6 months 01.6.2003–31.12.2004	IFS (R)	Evaluation of anti-tick natural products used in livestock health management by the Bukusu in Bungoma District, Kenya	Wageningen Agricultural University	Prof. A. Hassanali
Ms Lucy Murungi (Kenya)	2 years 01.6.2003–31.5.2005	RSM (R/S)	The host plant preference of the red spider mite *Tetranychus evansi*	Jomo Kenyatta University of Agriculture and Technology	Dr M. Knapp
Mr Allen N. Mueke (Kenya)	1 year 01.6.2003–31.5. 2004	USAID	Management of root-knot nematodes in okra	University of Nairobi	Dr A. A. Seif
Ms Franscisca Malenge (Kenya)	1 year 01.6.2003–31.5.2004	USAID	Management of aphids in okra	University of Nairobi	Dr A. A. Seif
Mr Mark Otieno (Kenya)	1 year 01.5.2003–30.4.2004	TBA (R/S)	Spatial and temporal distribution and dynamics of male-killers (spiroplasm) in the butterfly *Danaus chrysippus*	University of Nairobi	Dr I. Gordon
Ms Lydia Kibe (Kenya)	2 years 01.10.2003–30.9.2005	NIH-ABC	Community participation in mosquito control activity in Malindi, Kenya	Kenyatta University	Dr J. Githure Dr C. Mbogo
Ms Rose Irungu (Kenya)	1 year 01.3.2002–31.12.2003	IITA	Identification of sustainable sites for the release of Neozygitaceae for the control of the cassava green mite *Mononychellus tanajoa* (Acari: Tetranychidae)	University of Nairobi	Dr N. Maniania

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Table 3 continued

Name and country	Duration	Sponsor	Title of thesis project	Registering university	ICIPE Supervisor
Mr Joseph Thaimuta (Kenya)	1 year 15.9.2002–16.9.2003	WHO	Bioprospecting for natural botanicals with insecticidal action for adult mosquitoes	Kenyatta University	Prof. A. Hassanali
Mr Joseph O. Odero (Kenya)	1 year 17.2.2003–16.1.2004	MIM/TDR	Isolation and characterisation of anti-mosquito compounds	Jomo Kenyatta University of Agriculture and Technology	Prof. A. Hassanali Dr M. Ndung'u
Mr Timothy Rimu (Kenya)	1 year 17.2.2003–16.1.2004	MIM/TDR	Isolation and characterisation of anti-mosquito compounds from *Turraea mombasana*	Jomo Kenyatta University of Agriculture and Technology	Prof. A. Hassanali Dr M. Ndung'u
Ms Lorna Migiro (Kenya)	2 years 1.5.2001–30.6.2003	ICIPE (S/R) DSO	Development of improved mass production methods for *Trichogramma* sp. as a native biocontrol agent for African bollworm *(Helicoverpa armigera)* in Kenya	Jomo Kenyatta University of Agriculture and Technology	Dr S. Sithanantham
Mr Samuel M. Karenga (Kenya)	1 year 11.8.2003–10.8.2004	WHO/MIM	Research in the area of anti-mosquito compounds	Kenyatta University	Prof. A. Hassanali
Dennis W. Ochieno (Kenya)	1 year 01.3.2002–28.2.2003	USAID	Effect of *Bt*-maize tissues and pollen on stemborer parasitoids and selected non-target Lepidoptera in Kenya	Kenyatta University	Dr E. Osir Dr A. Ngi-Song
Mr Elijah K. Lelmen (Kenya)	1 year 01.3.2002–28.2.2003	USAID	Effect of *Bt* toxins on selected soil communities	Kenyatta University	Dr E. Osir
Mr Ismael Rabii (Kenya)	01.6.2002–31.3.2004	Rockefeller Foundation (R)	Population genetic studies of wild cowpea populations from Kenya	Kenyatta University	Dr R. Pasquet
Ms Consolata Ager (Kenya)	1 year 01.8.2002–31.12.2003	Rockefeller Foundation	Volatile composition of some selected cowpea varieties: Assessment of chances of cross pollination and gene flow	Kenyatta University	Dr R. Pasquet

S = Scholarship; R = Research.

themes ranging from management of livestock ticks, tsetse, vegetable pests and fruit flies to use of *Bt* as a microbial pest control agent and new methods for managing malaria. Over 167 practitioners have benefited from these courses. More than 7000 farmers have received training through ICIPE's facilitation. Thus far, over 750 undergraduate students from local universities and polytechnics have also benefited from short-term industrial attachments to ICIPE's programmes.

A farmers' workshop for training in sericulture and apiculture and commercial insect conservation was sponsored by the Programme.

The Programme has continued to sponsor the publication by ICIPE of much-needed resource materials for farmers, such as manuals on the use of IPM (integrated pest management) for tomatoes, brassicas and Frenchbeans, and a practical guide for raising and utilising silkmoths and honeybees in Africa (in press), as well as the Proceedings from the ARPPIS Symposia.

IMPACT

The success of ICIPE's training programmes was commended by the external ICIPE Strategic Review of 2002 as: "...[the] unique accomplishments associated with ICIPE's role in capacity building on the African continent in insect sciences and the fact that the majority of scientists thus trained remain active on the continent, sets ICIPE apart... there is a high and improving quality of education associated with ICIPE" (Strategic Review Report 2002).

FUTURE OUTLOOK

1. Retooling the capacity building programme and enhancing partnership with African universities: The African Biosciences Initiative

The success of the innovative ARPPIS programme is predominantly due to the fact that it combines the excellence of ICIPE's research and development agenda with the academic experience of its partner African universities. With very few exceptions, ICIPE's graduates have remained to work in Africa. A number of graduates have risen to policy-influencing positions within their governments and have maintained linkages with ICIPE through their alumni association, the ARPPIS Scholars Association (ASA). These advances have been achieved despite the continent's loss of human resource capability through 'brain drain', particularly in the sciences and technology. The success of ARPPIS has resulted in an annual increase in demand for postgraduate training with requests coming from all over Africa. Following recommendations of stakeholders during the 2002 Strategic Review, ICIPE has begun to restructure its capacity building programme.

In response to the growing demand, ICIPE is working with a number of development partners to assist in the long-term revitalisation of university capability to offer quality higher education, especially in the area of biosciences. This will be achieved by modernising the teaching of biosciences with a strong bias on insect science by integrating the newer approaches and scientific discoveries into the curricula. This new initiative is also designed to initially focus on building research and training capability of the universities in the network by providing key institutional support to upgrade research and training facilities, staff development, and communication capacity. The programme will significantly contribute high-level trained brainpower, which will in turn undertake further training and hence sustain quality postgraduate training. The programme will serve as a model that can be replicated in the other collaborating universities within the region. Efforts are being made to enhance linkages with institutions of higher learning and laboratories in the South within the framework of South–South cooperation.

As a first step in this regard, the new initiative will address capacity limitations of the universities, especially in terms of ready access to scientific information, in particular journals. ICIPE is working to facilitate the provision of online journal access to the universities participating in its training networks, as a way of building institutional capacity to undertake research, and hence contribute to solving critical national and regional problems. Since availing of information online is only a part of the solution, ICIPE intends to address the need for reliable and affordable technology infrastructure through the establishment of a virtual campus based on a linkage of V-Sat stations. It is through the virtual campus that partnerships with international programmes that promote free information access including FAO's Access to Global Online Research in Agriculture (AGORA) and the WHO-sponsored Health InterNetwork Access to Research Initiative (HINARI) is being established. When fully functional, the virtual campus infrastructure will enable the universities to gain access over the worldwide web to a research collection of key journals in agriculture and related biological, environmental sciences comparable to that available to their counterparts in the developed world. The New Partnership for Africa's Development (NEPAD) is being requested to fund this initiative.

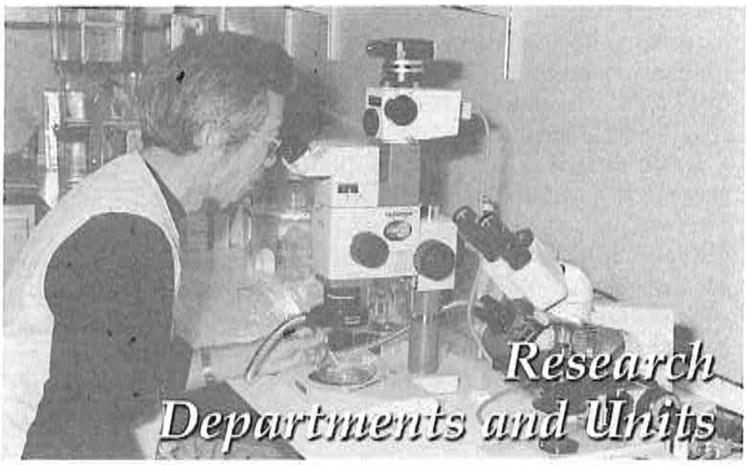
Within the framework of ARPPIS, participating African universities have played largely administrative and facilitative roles in the past. The ARPPIS programme has now been revised to enable the partner universities be active participants in the conception of student research projects and student supervision, as well as in providing facilities for a substantial part of student research activities at the universities. The participating universities will be recruited on the basis of past successful involvement in ARPPIS, representative regional distribution, and capability to fit and complement the areas of ICIPE's research programmes. Twinning arrangements with advanced research laboratories will be sought to give the students exposure to new analytical methodologies and approaches.

While the main thrust of ICIPE's capacity building programmes is geared at ensuring technology transfer by integrating the training of scientists, technologists and farmers in all of ICIPE research projects, student thesis research is being refocused to ensure maximum impact. New linkages will be developed, especially through postdoctoral research fellowships and invitation to visiting scientists to enrich research at ICIPE. The Masters degree training is set to be strengthened largely through fund-raising for scholarships, increased supervision of students, focus on training of field advisors and building up of the host institutions to be effective sub-regional centres.

Participating staff: O. K. ole-MoiYoi (Supervisor), J. P. R. Ochieng-Odero, V. O. Musewe (2002), L. Chongoti (2002), ICIPE research scientists

Collaborators: 27 African universities

Donors: The Netherlands Ministry of Foreign Affairs, German Academic Exchange Service (DAAD), Dupont Aid to Education, European Union, FAO, Gatsby Charitable Trust, GTZ, IFAD, IFS, McArthur Foundation, NIH, Singeberg Foundation, Switzerland; Rockefeller Foundation, WHO-MIM/TDR and WOTRO



BEHAVIOURAL AND CHEMICAL ECOLOGY DEPARTMENT

The Department continued to contribute to research in all the 4H areas, through studies on the chemical signals mediating arthropod behaviour, the underlying basis of striga parasitism and suppression, and exploration, identification and characterisation of insect-active plants through bioprospecting.

PLANT HEALTH

1. Desmodium allelopathy on striga

Previously, *Striga* suppression by *Desmodium* spp. in maize–*Desmodium* intercrops was shown to be due to a novel allelopathic effect of the root exudates of the legume. This is manifested in the stimulation of germination of *Striga* seeds and subsequent inhibition of the growth of the germinated seeds, resulting in few successful attachments on host plants. Chromatographic (HPLC) examination of the exudates showed a complex blend of constituents. Three new isoflavanones and a previously known isoflavanone (genistein) have so far been isolated and characterised spectroscopically. One of the new isoflavanones (uncinanone-B) is a striga germination stimulant, and another (uncinanone-C) moderately inhibits radical growth of the germinated striga seeds. Uncinanone-A is inactive as a germination stimulant or as a post-germination growth inhibitor. Isolation and assays of other constituents are expected to clarify the precise biochemical traits associated with *Desmodium* effects on *Striga* and to assess their biotechnological potential. *(See also the report under Staple Food Crops research under Plant Health.)*

2. Desert locust research

Interesting insights have been garnered on the behaviour and ecology of solitarious desert locusts. One relates to the mating behaviour of solitaria. Comparison of the responses of males that had not experienced crowding (i.e. were physiologically solitarious) and those that had (i.e. gregarising) showed that the latter were more strongly attracted to solitarious females than their solitarious counterparts. This may constitute an important mechanism for recruiting solitaria into the gregarising nuclei of adults at early stages of gregarisation. The study provides a useful basis for the characterisation of the sex pheromone emitted by solitarious females.

A series of validation/optimisation trials in boomas on mass-reared gregarious nymphs treated with the major component of the adult aggregation-maturation pheromone (PAN) and bio- and chemo-pesticides, have confirmed that the pheromone component predisposes hoppers to enhanced mortality from only fractional doses of the pesticides to those normally required.

The physiological basis of the behaviour of gregarious nymphs exposed to PAN, the major component of the adult pheromone, has been elucidated. PAN was found to significantly reduce the nymphs' ability to perceive their own aggregation pheromone and to raise the level of total haemocyte counts. These effects account for the enhanced susceptibility of exposed gregarious nymphs to mortality factors. Related effects of the nymphal pheromone blend (NPB) on adults also have been demonstrated.

An artificial diet for the desert locust that can sustain several generations of the gregarious phase has been developed. Rearing temperature has been shown to affect egg development and maturation. On the hypothesis that the balance of ingredients in the diet affects the development of locusts, a comparison experiment has been conducted using two different artificial diets (powdered grass harvested in spring and in autumn). Some differences in the development rate during the nymphal stage were observed. *(See also the Locusts and Migratory Pests reports under Plant Health.)*

ANIMAL HEALTH

1. Tsetse semiochemical research

Comparison of the body odours of tsetse hosts (ox and buffalo) and a tsetse-refractory 'host' (waterbuck) by gas chromatography (GC) and electroantennographic detector linked to gas chromatography (GC-EAD) led to the identification of two sets of potentially useful candidate blends: (i) a blend of 15 constituents made up of 2-ketones, phenols, fatty acids and δ-octalactone specific to waterbuck (putative repellent), and (ii) a series of C_7–C_{12} aldehydes (putative attractant) present in greater diversity in the preferred hosts. These blends have been tested behaviourally in the laboratory and their repellency or attractancy confirmed. Latin square experiments in the field with different blends have shown that 4–6 of these compounds are critical for repellency. *(See also the Tsetse research reports under Animal Health.)*

HUMAN HEALTH

1. Bioprospecting for anti-mosquito phytochemicals

In a project designed to promote networking between institutions in East Africa (ICIPE, Kenyatta University, Jomo Kenyatta University, University of Dar-es-Salaam, Makerere University, Addis Ababa University), and to enhance capacity to undertake research and postgraduate training on natural products with potential for control of malaria vectors, over 250 African plants were screened for repellency and larvicidal properties. Five plants have shown promising repellency in thermal fumigation experiments, and three were effective as live potted plants. Essential oils of six plants were found to have potent repellency and fumigant toxicity. Five individual compounds have shown potential for personal protection for 8 h or more against malaria vectors. Ten plants have shown promising larvicidal properties as crude botanicals. Participating in the project were 13 MSc and 2 PhD students from the network institutions.

2. Behavioural and chemical ecology of *Anopheles gambiae*

Aspects of host location, oviposition and plant feeding behaviours of *An. gambiae* were studied with the objective of characterising the mediating chemical signals. Comparison of the foot odour collections of 16 individuals in a screenhouse at the ICIPE-Mbita campus showed consistently large differences in their attractivity and in their chromatographic profiles. Attraction of gravid females to oviposition sites was found to be mediated, on the one hand, by volatiles associated with microbial activity (attraction) and on the other, by signals associated with culicine egg rafts (repulsion). The presence of conspecific larvae was also found to regulate the oviposition behaviour of gravid females. Sugar feeding on plants is a vital activity of mosquitoes. Large variations have been found to occur in the amount of sugars in different plant species potentially available to mosquitoes and in the selection of appropriate plants by the insects. The studies are laying down the groundwork for the identification of the mediating signals and, eventually, the exploitation of these in the development of intervention tactics. *(See also the reports under Human Health research.)*

ENVIRONMENTAL HEALTH

1. Bioprospecting

Bioprospecting, the discovery, development and commercialisation of naturally derived products, can play a role in conservation of arthropods and related biodiversity if revenue from this commercialisation is shared with rural communities who live side-by-side with threatened biodiversity areas. The Bioprospecting Programme has been initiating model projects that involve development of commercial products from multipurpose plants. These plants can be cultivated and processed by such communities as an alternative income-generating activity that does not rely on exploitation of forest resources.

One such plant is *Ocimum kilimandscharicum*, an indigenous medicinal plant that has been shown at ICIPE to have potential for repelling mosquitoes in rural homesteads through thermal fumigation of the leaves using traditional cooking stoves. The plant has also been shown to have potential for use in protecting grain against stored product pests. *Ocimum kilimandscharicum* is also very attractive to bees and a good source of nectar. Members of the rural community living near the highly threatened Kakamega Forest Reserve in Kenya and Budongo Forest Reserve in Uganda have been mobilised by ICIPE and partner institutions to cultivate *O. kilimandscharicum* on a commercial basis. An extract from the plant material is used by ICIPE and the University of Nairobi in the manufacture of Naturub, a commercial product developed by the two institutions for alleviation of congestion, colds, flu, insect bites, aches and pains. Members of the rural community who cultivate *O. kilimandscharicum* continued to earn income from their harvested plant material during the period. *(See reports under Biodiversity and Conservation under Environmental Health research and the report above on search for anti-mosquito compounds.)*

2. Oil and limonoids in neem trees in Sudan

A PhD scholar from Gezira University supported by the Third World Organisation for Women in Science (TWOWS) has been looking at phytochemical variations in the seed kernels of neem trees growing in different agroecological sites in Sudan. Interestingly, whereas the amount of neem oil was more or less the same, there were significant variations in the contents of limonoids (azadirachtin, nimbin, salanin). The relative amount of azadirachtin—the most important anti-insect constituent in neem—showed an interesting parabolic relation with rainfall, with the optimum falling in the range 500–1000 mm.

OUTPUT

Journal articles

Akol A. M., Njagi P. G. N., Sithananthan S. and **Mueke J. M. (2003)** Effects of two neem insecticide formulations on the attractiveness, acceptability, and suitability of diamondback moth larvae to the parasitoid, *Diadegma mollipla* (Holmgren) (Hym.: Ichneumonidae). *Journal of Applied Entomology* 127, 325–331. **(Call No.: 03-1684)**

Akol A. M., Sithananthan S., Njagi P. G. N., Varela A. and **Mueke J. M. (2002)** Relative safety of sprays of two neem insecticides to *Diadegma mollipla* (Holmgren), a parasitoid of the diamondback moth: Effects on adult longevity and foraging behaviour. *Crop Protection* 21, 853–859. **(Call No.: 02-1666)**

Barasa S. S., **Ndiege I. O.**, *Lwande W.* and *Hassanali A.* **(2002)** Repellent activities of stereoisomers of *p*-menthane-3, 8-diols against *Anopheles gambiae* (Diptera: Culicidae). *Journal of Medical Entomology* 39, 736–741. **(Call No.: 02-1640)**

> Four stereoisomers of *p*-menthane-3,8-diol, which make up the natural product obtained from *Eucalyptus citriodora*, were synthesized through stereoselective procedures. Repellency assays showed that all the four were equally active against *Anopheles gambiae* s.s. Racemic blends and the diastereoisomeric mixture of all the four isomers were also equally repellent. 1-α-terpeneol, with a single hydroxyl function at C-8 and unsaturation at C-8, and menthol, with a single hydroxyl function at C-3, were not repellent. The practical implication of these results is discussed.

Demas F. A., Mwangi E. N., Hassanali A., **Kunjeku E. C. and Mabveni A. R. (2002)** Visual evaluation and recognition of hosts by the tick parasitoid, *Ixodiphagus hookeri* (Hymenoptera: Encyrtidae). *Journal of Insect Behaviour* 15, 477–494. **(Call No.: 02-1657)**

Gikonyo N. K., Hassanali A., Njagi P. G. N., **Gitu P. M. and Midiwo J. O. (2002)** Odor composition of preferred (buffalo and ox) and nonpreferred (waterbuck) hosts of some savanna tsetse flies. *Journal of Chemical Ecology* 28, 969–981. **(Call No.: 02-1626)**

Gikonyo N. K., Hassanali A., Njagi P. G. N. and *Saini R. K.* **(2003)** Responses of *Glossina morsitans morsitans* to blends of electroa ntennographically active compounds in the odors of its preferred (buffalo and ox) and nonpreferred (waterbuck) hosts. *Journal of Chemical Ecology* 29, 2331–2345. **(Call No.: 03-1705)**

Khan Z. R., Hassanali A., Overholt W. A., Tsanuo K. M., **Hooper A. M., Pickett J. A., Wadhams L. J. and Woodcock C. M. (2002)** Control of witchweed *Striga hermonthica* by intercropping with *Desmodium* spp., and the mechanism defined as allelopathic. *Journal of Chemical Ecology* 28, 1871–1885. **(Call No.: 02-1649)**

Maranga R. O., *Hassanali A., Kaaya G. P.* and **Mueke J. M. (2003)** Attraction of *Amblyomma variegatum* (ticks) to the attraction-aggregation-attachment pheromone with or without carbon dioxide. *Experimental and Applied Acarology* 29, 121–130. **(Call No.: 03-1696)**

Ndung'u M., Hassanali A., **Hooper A. M., Chhabra S., Miller T. A., Paul R. L.** and *Torto B.* **(2003)** Ring A-seco mosquito larvicidal limonoids from *Turrea wakefieldii*. *Phytochemistry* 64, 817–823. **(Call No.: 03-1723)**

> Five novel limonoids were isolated from the root bark of *Turraea wakefieldii* and were characterized as tecleaninoid derivatives. This is the first report of the natural occurrence of tecleanin-type limonoids with a five-membered-ring A-seco structure for which we propose the name neotecleanins. The relative stereochemical structures of the compounds were established on the basis of NMR spectroscopy. The absolute stereochemical structure of one compound was confirmed by X-ray diffraction methods. In mosquito larvicidal assays, three compounds showed dose-dependent larvicidal activity against larvae of *Anopheles gambiae s.s.*

Njagi P. G. N. and *Torto B.* **(2002)** Evidence for a compound in the Comstock-Kellog glands modulating premating behavior in male desert locust, *Schistocerca gregaria*. *Journal of Chemical Ecology* 28, 1065–1074. **(Call No.: 02-1654)**

Seyoum A., **Kabiru E. W.**, *Lwande W., Killeen G. F., Hassanali A.* and *Knols B. G. J.* **(2002)** Repellency of live potted plants against *Anopheles gambiae* from human baits in semi-field experimental huts. *American Journal of Tropical Medicine and Hygiene* 67, 191–195. **(Call No.: 02-1643)**

Seyoum A., Killeen G. F., **Kabiru E. W.**, *Knols B. G. J.* and *Hassanali A.* **(2003)** Field efficacy of thermally expelled or live potted repellent plants against African malaria vectors in western Kenya. *Tropical Medicine and International Health* 8, 1005–1011. **(Call No.: 03-1704)**

Seyoum A., **Pålsson K., Kung'a S., Kabiru E. W.**, *Lwande W., Killeen G. F., Hassanali A.* and *Knols B. G. J.* **(2002)** Traditional use of mosquito repellent plants in western Kenya and their evaluation in semi-field experimental huts against *Anopheles gambiae*: Ethnobotanical studies and application by thermal expulsion and direct burning. *Transactions of the Royal Society of Tropical Medicine and Hygiene* 96, 225–231. **(Call No.: 02-1627)**

Takasu K., Takano S.-I., Sasaki M., *Yagi M. S.* and *Nakamura S.* **(2003)** Host recognition by the tick parasitoid *Ixodiphagus hookeri* (Hymenoptera: Encyrtidae). *Environmental Entomology* 32, 614–617. **(Call No.: 03-1750)**

Tsanuo M. K., Hassanali A., **Hooper A. M.**, *Khan Z.*, **Kaberia F., Pickett J. A. and Wadhams L. J. (2003)** Isoflavanones from the allelopathic aqueous root exudates of *Desmodium uncinatum*. *Phytochemistry* 64, 265–273. **(Call No.: 03-1751)**

(For abstracts of these papers, see under the relevant thematic sections of this report.)

Conference papers presented

14th European Conference of the Society for Vector Ecology, Bellinzona, Switzerland, 3–6 September 2003. Paper presented: Avoidane of refractory 'hosts' by tsetse and identification of the mediating semiochemicals. N. Gikonyo, M. Bett, P. Njagi, R. Saini and A. Hassanali.

CAPACITY BUILDING

(For students supervised, see under the relevant thematic sections of this report.)

Participating scientists: A. Hassanali (Head of Department), W. Lwande (Bioprospecting Programme Leader), Y. Takao (Project Coordinator, JIRCAS), P. Njagi, M. O. Bashir (Port Sudan)

Assisted by: L. Moreka, E. Nyandat, D. M. Mbesi, B. O. K. Wanyama, M. W. Gitau, B. N. Njiru

Collaborators:

Desert locust research
EMPRES/FAO (Emergency Prevention System); GTZ; Plant Protection Directorate, Sudan; Japan Society for the Promotion of Science (JSPS); JIRCAS; Desert Locust Control Organisation for Eastern Africa (DLCO-EA), Nairobi; Ministre de l'Agriculture (MINAGRI), Madagascar; Malagasy Research Centre (FOFIFA), Madagascar; Kazakh Scientific Research Institute for Plant Protection, Republic of Kazakhstan; Locust/USDA Project, Port Sudan; Chinese Agricultural University (CAU)

Stemborers/striga
Institute of Arable Crops Research (IACR), Rothamsted, UK

Neem
University of Gezira, Sudan

Bioprospecting
Addis Ababa University, Ethiopia; Kenyatta University, Nairobi; Makerere University, Uganda; University of Dar es Salaam, Tanzania; Kenya Wildlife Service (KWS); UNDP/GEF-Small Grants Programme; Forest Department, Uganda; Nature Uganda; Intermediate Technology Development Group of East Africa (ITDG-EA); National Museums of Kenya (NMK); Kenya Rural Enterprise Programme (K-REP); Kisumu Medical and Education Trust (KMET); World Agroforestry Centre (ICRAF); Kenya Ministry of Agriculture; Kenya Forestry Research Institute (KEFRI); Smithsonian Institution, USA; Dupont Corp, USA; Diversa Corp, USA

Capacity building
Egerton University, Njoro, Kenya; University of Nairobi, Kenya; Kenyatta University, Kenya; Jomo Kenyatta University of Agriculture and Technology (JKUAT)

Donors: UNDP/World Bank/WHO Special Programme for Research Training in Tropical Diseases (TDR), Geneva; WHO Multilateral Initiative on Malaria (WHO/MIM/TDR); NIH, International Collaborations in Infectious Diseases Research (NIH/ICIDR); FAO, Rome; USAID Africa Emergency Locust and Grasshopper Assistance (USAID/AELGA)

MOLECULAR BIOLOGY AND BIOCHEMISTRY/ BIOTECHNOLOGY DEPARTMENT

The Department conducts goal-oriented research in the areas of molecular biology, biochemistry, genomics and bioinformatics in support of ICIPE's programmes. Current research focus is on development of molecular tools for species identification and characterisation of population genetic structures; molecular studies on parasite-vector interactions; and assessment of ecological impacts of genetically-modified crops. Additionally, the Department offers specialised services in bloodmeal identification as well as electron microscopy (scanning and transmission).

Recently, the department spearheaded the formation of BiONET-Africa, an interactive capacity building network in biochemistry and biotechnology with support from the ICSC-World Laboratory. The goal of the network is to enhance the capacity of African universities to undertake research and teaching in biotechnology-related subjects (namely, molecular biology, genomics and bioinformatics). In addition, the network seeks to promote North-South collaboration in order to promote transfer of appropriate technology. Current partners include eight universities in six countries. To date, a total of eight MSc fellowships have been awarded, mainly to female students. Three PhD students spent a total of two years carrying out research in Pavia (Italy) and seven young lecturers have carried out collaborative research at ICIPE over the last three years.

A. Current Activities Supporting the 4H Research Divisions

PLANT HEALTH

1. Invasive fruit fly species: Development of molecular markers for species diagnosis and analysis of genetic diversity

The project goal was to develop molecular markers for accurate, life stage-independent fruit fly species identification and to undertake genetic analysis of African fruit fly populations, with the objective of contributing to the array of tools and data for improving on the existing fruit fly management capacity in Africa. PCR amplification, cloning and sequencing of *Ceratitis capitata*-based microsatellite loci 1–34 was carried out in *C. rosa*, *C. fasciventris* and *C. cosyra*. Sequence results showed that the same loci were amplified per primer set for all the species, confirming that the microsatellites are locus-specific. SSR length polymorphisms were detected within and between species. Some loci were not detectable in some species. For example, locus 4 was non-detectable in *C. cosyra* and *C. rosa*, while it was detectable in *C. fasciventris* and *C. capitata*. Locus 9 was discriminative against *C. cosyra*, *C. fasciventris* and *C. rosa*, being only amplified in *C. capitata*.

A comprehensive table of informative molecular markers has been compiled. It has been confirmed that it is possible to adapt medfly microsatellite markers for effective genetic analysis of natural populations of *Ceratitis rosa*, *C. fasciventris* and *C. cosyra*. In addition, it was found that it may be possible to distinguish among the above species, including the medfly, using a combination of medfly microsatellite primers. A population genetic structure analysis of natural populations of *C. rosa*, *C. fasciventris* and *C. capitata* from various parts of Africa, using a set of 10 medfly-derived microsatellite markers was successfully carried out.

The data suggest that East Africa is the native home for these three pest species. This implies that East Africa should be the priority region for any search for biological control agents (natural enemies). In addition, the microsatellite variability data reveal (i) a high degree of genetic variability and (ii) little or no differentiation, with (iii) substantial levels of gene flow among the populations of each of the above three species in the Africa region. The implication of this for control is that the same management strategies should effectively work across the entire Africa region for each of these species.

Participating scientists: D. Masiga, E. Osir

Assisted by: H. Kibogo

Collaborators: University of Florida, University of Pennsylvania

Donor: US Department of Agriculture (USDA)

2. Biochemical changes in developing embryos of *Schistocerca gregaria* induced by pheromone produced by ovipositing gregarious females

The goal of this project was to assess induced biochemical events associated with the onset and subsequent stages of phase transition (solitaria to gregaria) of locust eggs exposed to the gregarising primer pheromone associated with egg laying by gregarising/ gregarious ovipositing females. The objectives are to compare the different embryonic proteins expressed at the onset and subsequent stages of phase transition, and to compare RNA expression during the process. Analysis of protein profiles by 2-D gel electrophoresis showed that in the early embryonic stages, the eggs derived from the two phases were essentially similar, and that phase-related differentiation was discernable in the later stages and at hatching following exposure to the pheromone. The 'pheromone-induced gregariousness' of the solitary eggs was dose-dependent, that is, the higher the dose the more they tended to shift towards the gregarious phase.

Participating scientists: E. Osir, A. Hassanali

Assisted by: F. Mbarak

Collaborators: Jomo Kenyatta University of Agriculture and Technology

Donors: ICSC-World Laboratory and ICIPE core funds

ANIMAL HEALTH

3. Cloning of tsetse fly midgut molecules involved in differentiation of African trypanosomes

The goal of the project was to define the specific interaction between tsetse flies and trypanosomes at the molecular level. The objectives were to prepare a tsetse fly midgut cDNA expression library; clone and sequence the lectin and trypsin cDNA from tsetse midgut cDNA library; characterise the cloned lectin-trypsin cDNA; and assess the role of the molecule in trypanosome differentiation. A bloodmeal-induced gene with both lectin and trypsin activities was isolated by antibody screening of the tsetse midgut cDNA library. The cDNA (933 bp) encoded a mature protein of 274 amino acids containing the highly conserved trypsin residues. The recombinant protein (M_r~ 32,500) compared favourably with the predicted molecular weight (M_r~ 29,179). The expressed protein had affinity for D-glucosamine and induced the transformation of bloodstream trypanosomes to procyclic (midgut) forms. The rate of transformation by the protein was not significantly different from the transformation rate observed with *cis*-aconitate-supplemented procyclic medium.

Participating scientists: E. Osir, F. Mulaa

Assisted by: L. Abubakar

Collaborators: University of Nairobi

Donor: WHO/TDR, ICSC-WL

4. Expression of *Glossina* proteolytic lectin (*Gpl*) gene in tsetse flies and other haematophagous arthropods

The overall goal of this project was to study the expression of *Gpl* in tsetse flies and other haematophagous arthropods. The objectives were to screen for presence of *Gpl* gene in other haematophagous arthropods following a bloodmeal; to determine the expression levels of the *Gpl* gene in tsetse flies at different intervals post-bloodmeal, and to determine the expression of *Gpl* gene in tsetse flies following trypanosome infections. Screening for the *Gpl* gene in other haematophagous arthropods revealed that this gene was only expressed in *Glossina*. The gene was not expressed in other haematophagous arthropods such as ticks, biting flies and sandflies.

Participating scientists: E. Osir, L. Abubakar

Assisted by: M. W. Burugu

Collaborators: Kenyatta University

Donor: WHO-TDR, ICSC-World Laboratory

5. The role of sheep, goats, and pigs in the epidemiology of nagana and sleeping sickness in western Kenya

The objectives of this collaborative project with KETRI was to investigate the prevalence of trypanosomes in small ruminants and pigs in western Kenya, and the potential of these livestock to serve as reservoirs of human-infective trypanosomes. The study was undertaken in five villages to address two key questions: (i) are small ruminants and pigs important in the transmission dynamics of trypanosomes?, and (ii) do they harbour potentially human infective trypanosomes? Answers to these questions are important in developing strategies for the control of both livestock and human trypanosomosis.

Seventy-six animals, representing 18.9% of the 402 sampled in the five villages, were detected as positive by PCR using species and sub-species-specific primers. These were categorised as 23 (5.7%) infections of *T. vivax*, 22 (5.5%) of *T. simiae*, 20 (5.2%) of the *T. congolense* clade and 20 (5.2%) of *T. brucei* ssp. Sheep were more susceptible to trypanosome infection as compared to goats and pigs. The 20 *T. brucei*-positive samples were evaluated by PCR for the presence of the Serum Resistance Associated (SRA) gene, which has been linked to human infectivity in *T. b. rhodesiense*. Three samples (one pig, one sheep and one goat) were found to have the SRA gene. These results suggest that sheep, goats and pigs which are kept alongside cattle may harbour human-infective trypanosomes. Hence, they may be important reservoirs of *T. b. rhodesiense*, and therefore contribute to the maintenance of the endemic status in this locality.

Participating scientists: D. Masiga, E. Kenya, G. Muluvi, E. Osir

Assisted by: Z. Njiru, J. Kabii

Collaborators: Kenya Trypanosomiasis Research Institute (KETRI), Kenyatta University

Donor: International Foundation for Science (IFS)

6. Expression of surface antigens of *Trypanosoma brucei rhodesiense* in insect larvae for diagnosis and disease staging

The aim of this project is to develop a diagnostic tool for sleeping sickness in eastern Africa, exploiting ICIPE's insect resources as tools for large-scale production of diagnostic proteins. Genotyping of a panel of isolates has been undertaken. Preparation of clones and the complete cycle of infection (mammalian and tsetse fly hosts) were carried out for two of these. Experiments are underway using a laboratory primate model to mimic human infections.

Participating scientists: D. Masiga, E. Osir

Assisted by: V. Chepchumba

Collaborators: Kenya Trypanosomiasis Research Institute (KETRI); Kenyatta University; University of Glasgow, Scotland; LIRI, Uganda

Donor: WHO/TDR

7. Use of ELISA for identification of bloodmeals in haematophagous arthropods

A reliable bloodmeal identification service (based on ELISA) has been developed and validated for tsetse flies. Identification services have been offered to a number of outside collaborators, including the Natural Resources Institute, the University of Addis Ababa and ILRI.

Participating scientists: E. Osir

Assisted by: J. Kabii

Donor: Paid-for service

HUMAN HEALTH

8. Lectin expression associated with *Plasmodium* infections in *Anopheles* spp.

A mannose-specific lectin in the mosquito *Anopheles stephensi*, has been shown to be associated with the transmission of *Plasmodium*. Blocking of the lectin reduces transmission of the parasites. The goal of the study is to assess the role of lectin during malaria infections of the mosquito and the variations of the lectin gene sequence in *Anopheles gambiae* populations. The specific objectives were to:

- amplify and sequence mannose-binding protein (MBP) from genomic DNA of individual mosquitoes (*A. gambiae s.s., A. arabiensis* and *A. funestus*);
- analyse the sequence variations between individual mosquitoes and thereby describe the heterogeneity of the gene in populations of *Anopheles;*
- identify by semi-quantitative RT-PCR the expression of the gene in midguts of mosquitoes infected with oocysts of *P. falciparum;*
- identify by semi-quantitative RT-PCR the expression of the gene in the midgut of mosquitoes following a gametocytaemic bloodmeal.

Single strand conformation polymorphism (SSCP) data from *Anopheles* clones showed a high level of polymorphism based on the migration pattern of the DNA strands. These results provided evidence for variation of the MBP gene in mosquitoes. A large number of clones was obtained from the various *Anopheles* spp., suggesting that MBP is an abundant molecule and could be involved in mosquito-parasite interaction. Multiplex titration RT-PCR analysis showed that MBP was differently expressed with respect to bloodmeal status of the mosquitoes. Hence altered expression of MBP may contribute to the risk of disease transmission by the *Plasmodium*. MBP levels decreased with time post-infection. These changes may disturb normal MBP levels and create a favourable condition for parasite establishment within the mosquito midgut. The differences observed in RT-PCR of the cDNA prepared from the Mbita (Kenya) and Ifakara (Tanzania) *A. gambiae s.s.* may be due to geographical differences.

Participating scientists: E. O. Osir, P. Billingsley, H. Ochanda

Assisted by: J. Kabii

Collaborators: University of Nairobi, Kenya; University of Aberdeen, Scotland

Donor: ICSC-World Laboratory

9. PCR identification of malaria vectors

Species identification of field-collected *Anopheles gambiae* samples, and screening of natural populations of anophelines for densoviruses were the goals of this collaborative project. Densoviruses are potential vehicles for the expression of foreign genes in mosquitoes. Species identification of over 10,000 specimens from Mbita and Kilifi in Kenya and from Eritrea were identified. In Kenya, three species were identified (A. *gambiae s.s*, *A. arabiensis* from both Mbita and the coast and *A. merus* in the coast). About 2000 specimens from the various field samples were screened for densovirus and a few positive identifications made.

Participating scientists: E. O. Osir, J. Githure

Assisted by: P. Seda

Collaborators: Kenya Medical Research Institute (KEMRI), Colorado State University (USA)

Donor: National Institute of Health (NIH) (USA)

10. Rapid assessment tool for mosquito bloodmeal sources

The goal of this project was to develop a bloodmeal analysis technique that can rapidly identify mosquito bloodmeal sources. The technique (dip-stick ELISA) was developed and used to identify 1200 samples.

Participating scientists: E. O. Osir, J. Githure

Assisted by: P. Seda

Collaborators: Kenya Medical Research Institute (KEMRI)

Donor: NIH (USA)

ENVIRONMENTAL HEALTH

11. Biodiversity of extremophiles and screening for useful pharmaceutical, agricultural and industrial products

As part of the ICIPE's bioprospecting activities, the Department is collecting environmental samples containing heterogeneous populations of uncultured microbes from diverse ecosystems in Kenya, and screening for new pharmaceutical, agricultural and industrial products. *(See also the bioprospecting activities under the Behavioural and Chemical Ecology Department and the Arthropod Pathology report.)*

B. Research on Environmental Impact of GE Crops Expressing *Bt* Toxins

12. The effect of *Bacillus thuringiensis (Bt)* toxins on the symbiosis between arbuscular mycorrhizal fungi (AMF) and sorghum

The colonisation of AMF in soil has been proposed as an important indicator of plant and soil ecosystem health. For example, AMF diversity has been reported to be sensitive to heavy metal contamination, organic pollutants and atmospheric deposition. This study was carried out to assess whether the *Bacillus thuringiensis (Bt)* δ-endotoxin has any effect on the germination of AMF spores and its symbiosis in sorghum. Sorghum seedlings mixed with a culture of AMF were grown in black cotton soil in the presence of increasing toxin concentrations. Data collected included mycorrhizal colonisation, root lengths, shoot and root weights. In addition, the effect of *Bt* on spore germination and hyphal spread was examined.

The results showed a progressive increase in mycorrhizal colonisation from the first (2 weeks) to the fourth and final (12 weeks) harvests in all treatments. The total root length, fresh shoot and root weights did not differ significantly among the treatments, and the abundance and species composition of spores extracted from the soil at the fourth harvest also showed no significant difference. In another experiment, the effect of toxin on spore germination and hyphal spread was examined. In this case toxin concentrations below 10 μg/ml had no effect on fungal germination and hyphal spread. However, at 100 μg/ml the number of germinating spores was reduced by about 53%, while the radius of hyphal spread was reduced to 3.60 mm compared to 11.82 mm in controls. Taken together, these findings suggest that the presence of the *Bt* toxin in soil at concentrations expected in the soil does not appear to affect either AMF spore germination or its symbiotic association with plants. However, the viability of the spores is affected at high toxin concentrations.

Participating scientists: E. O. Osir, J. Jefwa

Collaborators: Jomo Kenyatta University of Agriculture and Technology; National Museums of Kenya

Donor: USAID

13. Effect of feeding of the plant-parasitic nematode, *Meloidogyne javanica,* on GM maize in a greenhouse trial

The effects of reproduction of the root-knot nematode, *Meloidogyne javanica*, on *Bt*-maize genotypes Phb 33v08 *Bt* and SNK2340 *Bt* were evaluated in a greenhouse trial and compared to the untransformed genotypes Phb3394 and SNK2340, respectively and a negative (resistant) control (inbred line 1). Both these GM maize hybrids contained the event MON810. *Meloidogyne javanica* was maintained in the greenhouse on tomatoes (Moneymaker cv). Infested tomato roots were washed free of soil and cut into 1-cm pieces. Eggs were extracted by the NaOCl-method. The trial was conducted at a 19–26 °C night/day temperature regime and a 14 L: 10 D photoperiod. A complete randomised block design replicated six times was used.

Plastic pots (20-cm diameter) were filled with 4 dm^3 methylbromide fumigated (1 020 g/m^2) sandy loam soil with a clay content of 10%. Five seeds of each maize genotype were planted per pot and thinned to one seedling 16 days after emergence, and soil nutrients added according to nutrient analyses. Plants were watered 3 times per week. Inoculation was done by pipetting 10 ml water suspension containing 10,000 eggs on the roots of the seedlings. Root systems were removed 56 days after inoculation and washed free of excess soil and debris. Eggs and larvae of *M. javanica* were extracted from the roots of the maize genotypes using the NaOCl-method and counted under a stereomicroscope.

There were no significant differences between the total number of nematodes recovered from the different *Bt* and non-*Bt* cultivars after 56 days. Similarly, the population growth of the nematode population on the respective cultivars did not differ significantly between *Bt* and non-*Bt* hybrids after 56 days. However, the resistant control treatment, inbred line 1, had a significantly lower number of larvae per root system and 1 g of roots, and a negative population growth.

Participating scientists: J. van den Berg, E. O. Osir, M. A. Okech

Assisted by: M. Kimondo, J. Nono

Collaborator: Agricultural Research Council (ARC), South Africa

Donor: USAID

14. Effect of *Bt* on non-target arthropod populations

Effect of Bt *on larval and pupal stemborer parasitoids*

Tritrophic experiments were conducted to investigate the effect of host-ingested *Bt* toxin on two parasitoids. The toxin was incorporated into the artificial diet at two concentrations (0.005 μg/ml and 0.01 μg/ml). *Chilo partellus* larvae were reared to the 3rd or 4th instar on the toxin-containing diet and parasitised by *Cotesia flavipes*; the pupae were parasitised by *Xanthopimpla stemmator*.

The effects of the toxin on *C. flavipes* included reduction in size of their hosts exhibiting higher parasitism; small brood sizes; longer development time; higher mortality of immatures; oviposition of fewer eggs; smaller egg loads; low longevity; and small adult size. The effects on *X. stemmator* were not serious, except for the lower levels of acceptance of pupae by the ovipositing parasitoids. The larval parasitoids were more vulnerable to the toxins since they have to synchronise their development with that of the host (hosts must be alive for the parasitoid to develop). The pupal parasitoids were not adversely affected, since they required a quiescent stage, in which synchronisation is not a factor.

Effects of Bt *toxins on non-target Lepidoptera*

This study was carried out to assess the effects of *Bt* pollen on larvae of the butterfly, *Acraea* spp. Non-*Bt* maize was planted in pots. During anthesis, the host plants were arranged at different distances in four directions to trap drifting pollen. The pollen densities (grains/cm^2) on the leaves were then estimated using a small wire quadrant. Maximum densities of 492 grains/cm^2 were obtained. The pollen density was converted to toxin quantity in micrograms, by simulating it with toxin levels in equivalent density of pollen in MON810 *Bt* maize. Two toxin concentrations of 0.31 μg/ml and 0.15 μg/ml that would spread on a 2.54 cm^2 leaf disc to give an equivalence of 492 grains/cm^2 and 246 grains/cm^2 were prepared. The toxin concentrations were spread on leaf discs of *Waltheria*, and fed to 2nd and 4th instar caterpillars.

Both toxin concentrations caused mortality of larvae within 10 days. *Bt* pollen at densities as low as 246 grains/cm^2 may be harmful to the butterfly species.

Participating scientists: W. Overholt, A. Ngi-Song, E. O. Osir, M. Setamou

Assisted by: J. Obonyo

Collaborator: University of Nairobi, Kenya

Donor: USAID

15. Toxicity of *Bt* toxin to stemborers and resistance development

This study was carried out to assess the toxicity of *Bt* toxins (*Cry1Ab*) to the key maize stemborer species found in Kenya, namely *Chilo partellus, Busseola fusca, Eldana saccharina* and *Sesamia calamistis*. The second objective was therefore to study resistance development in *C. partellus*. First instar larvae were placed on diets containing the toxin (0, 0.025, 0.05, 0.1, 0.5, 1.0, and 5.0 μg/ml of diet). Larval mortality was recorded after 7 days.

The LC_{50} values were 1.67 μg/ml (*C. partellus*); 0.50 μg/ml (*E. saccharina*); 0.35 μg/ml (*S. calamistis*). However, *B. fusca* larvae were observed to avoid eating the diet-toxin mixture. Test results on *B. fusca* were inconsistent and so instead of LC_{50} determination, the effect of toxin on its development was examined, as this can also indicate whether the toxin will control the insect. The results showed that lower concentrations (0.025, 0.05, 0.1, 0.5, 1 μg/ml) had no significant effect on *B. fusca* development. A concentration of 5 μg/ml was tolerated by the insect since it could survive for more than 14 days before dying (Table 1).

Field-collected *C. partellus* were used for resistance studies. Based on previous data, a single toxin dose (0.05 μg/ml) was used. The F_1 generation obtained from the field insects was left in the diet-toxin for 7 days. The surviving larvae were transferred to fresh diet without toxin and incubated at 25–28 °C to complete their development. Eight hundred (800) individual larvae were tested. The adult surviving F_1 were mated to produce the F_2 generation which were used to generate the F_3 generation. The results

Table 1. Effects of *Bacillus thuringiensis* toxin on *Busseola fusca* development

Concentration (μg/ml)	Larval weight (g)	Larval duration (days)	Pupal duration (days)
0	0.35 ± 0.07 a	41.12 ± 1.2 a	14.0 ± 1.0 a
0.025	0.23 ± 0.02 ab	44.14 ± 1.0 a	14.4 ± 1.2 a
0.050	0.188 ± 0.03 ab	42.62 ± 1.1 a	13.8 ± 0.5 a
0.100	0.207 ± 0.06 ab	43.0 ± 1.4 a	14.8 ± 0.037 a
0.500	0.157 ± 0.01 b	43.3 ± 2.6 a	15.4 ± 0.7 a
1.00	0.064 ± 0.03 b	47.6 ± 2.3 a	13 ± 0.3 a
5.00	0.052 ± 0.03 b	–	Not pupated

Means ± SE. Means in a column followed by the same letter are not significantly different (P> 0.004). Larval weight was taken at 14 days.

Table 2. Comparative development of F_1 and F_2 generations of *Chilo partellus* fed with a diet containing *Bt* toxin

Treatments	Larval duration (days)	Pupal weight (g)	Pupal duration (days)
Control F_1	34.077 ± 0.62 c	0.104 ± 0.016 a	8.1 ± 0.4 a
Treated F_1	45.0 ± 0.409 a	0.079 ± 0.001 b	7.553 ± 0.10 a
Control F_1	29.22 ± 0.71 c	0.072 ± 0.004 b	7.92 ± 0.33 a
Treated F_2	41.93 ± 0.38b	0.085 ± 0.001 b	7.561 ± 0.18 a

Means in a column followed by the same letter are not significantly different.

(larval duration, pupal weight and pupal duration) were analysed using the t-test (Table 2). From the two generations examined, no conclusions could be made about resistance development in this population. However, a reduction in larval duration between F_1 and F_2 was evident. Similarly, an increase in pupal weight was noted, but was not significantly different from that of the F_2 generation. Future studies on resistance development should be carried out using *Bt* maize plants.

16. Quantification of potential alternative refuge of maize stemborers in Trans Nzoia district of Kenya

The objective of this study was to estimate the amount and temporal arrangement of maize and other host plants (native grasses and sedges) in Trans Nzoia district, a major maize-growing area in Kenya. Data collection was carried out using the line intercept method. Transects of 1 km long were made at randomly selected locations within the district and the sampling carried out during cropping and non-cropping seasons in order to examine temporal aspects of habitat stability. All plants encountered along the sampling line were identified and a species list compiled.

The family Gramineae showed the highest landcover of 43%, followed by the Compositae (21.5%) and Cyperacea (5.7%). The proportion of refugia (potential wild hosts) of 9.6% relative to maize during the maize growing period was below the recommended proportion of 25–50%, suggesting that using the observed proportion alone, natural refugia may be inadequate to delay resistance development in stemborers (Figure 1). However, the abundance of the proposed refugia varied with the agroecological zones (AEZ) as indicated by Shannon's diversity indices.

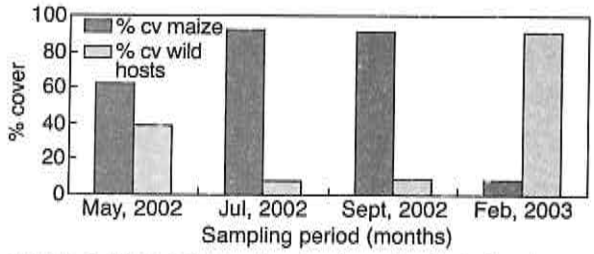


Figure 1. Proportion of maize to potential stemborer wild host plants during the maize-growing period in Trans Nzoia, Kenya

The results suggest that with the introduction of *Bt* maize, stemborers in the higher agroecological zones (with low refuge cover) may develop resistance faster than those in lower elevations (with high refuge cover). Future studies should focus on determining stemborer preference levels for each host plant species, as well as identification of the edaphic factors associated with growth and development of the host plants and estimation of the appropriate size of refugia in Africa.

(See also the report on field studies of gene flow in cowpea under the Environmental Health section.)

Participating scientists: W. Overholt, A. Ngi-Song, E. O. Osir, M. Setamou, J. Ochora

Assisted by: S. Mathenge

Collaborators: Jomo Kenyatta University of Agriculture and Technology; University of Nairobi, Kenya

Donor: USAID

FUTURE OUTLOOK: NEW INITIATIVES IN FUNCTIONAL GENOMICS AND BIOTECHNOLOGY

Initiative on applications of genomics for improved vector management in Africa

Arthropod vectors transmit diseases (e.g. malaria, dengue, yellow fever, encephalitis, filariasis, and human and animal trypanosomosis) to millions of Africans resulting in an estimated four million deaths each year (WHO reports). Current strategies for the management of these disease vectors rely largely on chemical pesticides. However, growing concerns about the high cost of synthetic pesticides, the negative environmental effects associated with their heavy use, and the development of resistance in target organisms has provided impetus for the search for new management approaches.

The major aim of this new project initiative is to develop molecular techniques that will contribute to and advance an integrated approach for the management of mosquitoes and tsetse flies in Africa. It is important to understand how pathogenic parasites circulate within disease hot spots where several parasites and vectors are present, and to determine the most dangerous parasite-vector combinations. Such information will be invaluable to public health personnel and will assist them to accurately target and monitor their control campaigns. The project applies cutting edge science, including emerging techniques in genomics and bioinformatics to the development of novel management tactics or the improvement of existing ones. To this end, the multi-faceted approach involves the following activities:

- molecular analysis of vector competence in natural populations;
- analysis of population genetic structures of mosquitoes (*Anopheles gambiae*) and tsetse (*Glossina* spp.) in selected disease-endemic African countries;
- analysis of single nucleotide polymorphisms in genes of known importance in vector competence and of interest for transgenic purposes;
- assessment of the relationships between these profiles and vector competence;
- analysis of polymorphisms in the parasites transmitted by these vectors;
- use of data to develop models predicting the potential failure points, bottlenecks and strategic implications that molecular changes have upon current and future control strategies;
- build capacity at all levels in important areas such as vector genomics, bioinformatics and modelling of disease vectors, with particular emphasis on the applications of these approaches towards a better understanding of vector-parasite relationships and ultimately, disease control.

Initiative on studies of the molecular basis for olfaction in disease vectors

Identification of the molecular basis of olfaction and mechanosensory transduction is an area of great interest in vector management. Although insect olfaction is not yet well understood at the molecular level, the recent identification of a family of 48 putative olfactory receptor proteins in *Drosophila* promises rapid progress. *Drosophila*'s mechanoreceptor repertoire includes proprioception, touch and hearing, which are mediated by sensory bristles and other organelles that allow the fly to determine its position in space, coordinate its movements, and feel and hear. Mechanosensory transduction ion channels have been identified in the fruit fly, which raises the possibility of adding repulsive or attractive sounds to the repertoire of fly control programmes.

It is likely that expressed sequence tags (ESTs)' from tsetse olfactory organs and mechanosensory transduction ion channels should provide an early opportunity for comparison between the two flies. Comparative genomics of the coding sequences from the organisms that have already been completed, including several bacteria, *Caenorhabditis elegans*, *Drosophila* and the human genome has provided evidence that evolution to more complex forms of life does not principally depend on a substantial increase in the number of genes, but rather on the generation of new combinations of functional protein domains and novel interactions amongst them. With sequence information and functional genomics, it is quite likely that tsetse-specific expansion of certain families of proteins to suit its novel adaptations to survive its haematophagous life and the definition of vectorial capacity at the molecular (pathways) level can be revealed.

Functional and comparative genomics also has the capacity for allowing the identification of gene products that modulate particular types of tsetse behaviour and providing explanations for some observations from field studies. For instance, what governs the selection of preferred/unpreferred animals for feeding? Why do riverine tsetse prefer feeding on reptilian hosts compared to their savanna fly relatives? What triggers tsetse to switch from feeding on wild animals and cattle to human beings?

Once the determinants of tsetse behaviour are understood, the information will be useful in developing more potent attractants and repellants for use to enhance the efficiency of baits. This is an area in which ICIPE has been in the forefront for the last two decades. Such functional genomics information may also allow for the potency of the current repellents for tsetse to be enhanced *(see under tsetse research)*. The pay-off of such work will be the manipulation of the behaviour of the vectors so as to prevent tsetse from transmitting disease to animals and human beings. This will allow smallholder farmers greater access to tsetse-infested areas.

Initiative on expression of useful biomolecules in insect larvae using baculovirus vector expression system (BEVS)

The baculovirus vector expression system (BEVS) is a eukaryotic expression that has been successfully used to express a large variety of proteins. Depending upon the level of expression obtained for a particular protein, quantities ranging from 100's of micrograms to 10's of mg can be readily produced. The advantages of this system include:

- high protein expression levels achieved (1–30 mg/l;
- authentic post-translational modifications achieved (signal sequence processing; proper protein localisation within cells; glycosylation);
- ability to express multiple genes simultaneously.

The goal of this project will be to establish an ICIPE Recombinant Protein Expression Laboratory (IRPEL) that uses silkworm as 'bioreactors' to produce a wide variety of useful biomolecules such as vaccines and diagnostic antigens. Proposed activities include production of:

- recombinant variant surface glycoproteins (VSGs) and other gene products for use in diagnosis of African trypanosomosis;
- diagnostic agents for human and animal diseases (TB, Rift Valley fever, and possibly yellow fever);
- vaccines for animal diseases;
- anti-tick vaccines;
- tsetse proteins to be used in studies of vector-parasite interactions.

Initiative on development and use of bioengineered baculoviruses for pest control

Nuclear polyhedrosis viruses (NPVs) of the family Baculoviridae hold great promise as biopesticides due to their specificity to arthropods. However, they have a number of limitations, including narrow range of activity, lack of contact action and slow action. A major research focus on insect viruses involves engineering the viruses to express foreign genes that code for acute insecticidal proteins or disrupt normal physiological functions. For example, genes for scorpion and mite venoms have been engineered into the baculovirus from *Autographa californica*. Similarly, genes for juvenile hormone esterase and diuretic hormone have been expressed in other baculoviruses. The engineered viruses can be applied like classical insecticides and they do not recycle in the environment, present no residue problems, and are active on insects resistant to classical pesticides.

For ICIPE, baculoviruses can be targeted at several pests, including *Helicoverpa*, *Plutella xylostella* and *Spodoptera exempta*. Proposed activities include:

- bioengineering of local strains of NPVs (against *Helicoverpa* and *Spodoptera*) and granuloviruses (GVs) (against *Plutella xylostella*), in collaboration with partners;
- bioassays against the target pests (at ICIPE);
- mass production at ICIPE for field trials;
- test for compatibility with parasitoids.

CAPACITY BUILDING

PhD students

F. N. Baliraine (Uganda) Development of molecular markers for species diagnosis and analysis of genetic diversity in African fruitfly populations. University of Nairobi.

Alioune Toure (Senegal) The assessment of the use of botanical extracts and pheromones for the off-host and on-host control of *Amblyomma variegatum* tick. Kenyatta University.

Daniel Amin (Cameroon) Functional analysis of the mid-gut lectin gene of *Glossina austeni*. Kenyatta University.

MSc students

D. Amenya (Kenya) Lectin expression associated with *Plasmodium* infection in *Anopheles* species. University of Nairobi.

M. Ng'ayo (Kenya) Molecular characterisation of trypanosomes in small ruminants and pigs from western Kenya. Kenyatta University.

Marion Wariga Burugu (Kenya) Expression of the lectin-trypsin gene in tsetse flies and other haematophagus arthropods. Kenyatta University.

Elijah Lelmen (Kenya) Effect of *Bacillus thuringiensis* δ-endotoxins on the diversity and function of Glomalean fungi forming arbuscular mycorrhizae with maize *(Zea mays)* and sorghum *(Sorghum bicolor)*. Jomo Kenyatta University of Agriculture and Technology (JKUAT).

Fathiya Mbarak (Kenya) Studies on biochemical changes associated with pheromone induced maternal transfer of gregarious phase to offspring in the desert locust, *Schistocerca gregaria*. JKUAT.

Harrison Mbogo (Kenya) Population genetics of *Ceratitis anonae*: Comparison of two geographically isolated populations in Kenya. JKUAT.

C. N. Ngei (Kenya) Responses of *Chilo partellus* populations in Kenya to *Bacillus thuringiensis* formulations. University of Nairobi.

Dennis Wanyama Ochieno (Kenya) Effects of *Bt* toxins on non-target arthropods. University of Nairobi.

G. Bosibori (Kenya) Characterisation of cell cycle regulator genes in mature *in vitro Plasmodium falciparum* gametocytes. University of Nairobi.

OUTPUT

Journal articles

Abubakar L. U., **Zimba G., Wells C., Mulaa F. and** *Osir E. O.* **(2003)** Evidence for the involvement of a tsetse midgut lectin-trypsin complex in differentiation of bloodstream-form trypanosomes. *Insect Science and Its Application* 23, 197–205. **(Call No.: 03-1748)**

Baliraine F. N., Bonizzoni M., *Osir E. O., Lux S. A.*, **Mulaa F. J., Zheng L., Gomulski L. M., Gasperi G. and Malacrida A. R. (2003)** Comparative analysis of microsatellite loci in four fruit fly species of the genus *Ceratitis* (Diptera: Tephritidae). *Bulletin of Entomological Research* 93, 1–10. **(Call No.: 03-1636)**

Kinyua J. K., *Osir E. O.*, **Ogoyi D. O. and Nguu E. K. (2002)** Characterization of protective antigens from the midgut of *Amblyomma variegatum* ticks. *Experimental and Applied Acarology* 26, 101–113. **(Call No.: 02-1648)**

Kongoro J. A., Osir E. O., **Imbuga M. O. and Oguge N. O. (2002)** Comparison of midgut trypsin/lectin activities and trypanosome infection rates in three *Glossina* species. *Insect Science and Its Application* 22, 295–301. **(Call No.: 02-1671)**

Book chapters

Somers D. A., Andow D.A., Amugune N., Aragao F. M., Ghosh K., Magiri E., Moar W. and *Osir E.* Transgene expression and locus structure of *Bt* maize, Chapter 4 Environmental Risk Assessment of Genetically Modified Organisms, Volume 1: A Case Study of *Bt* Maize in Kenya. CABI Bioscience. In press.

Gary F., Andow D., Moar Y. C. W., Schuler T., Omoto C., Kanya J., *Okech M., Arama P.* **and** *Maniania N. K.* Resistance risks and management associated with *Bt* maize in Kenya. Chapter 7 *Environmental Risk Assessment of Genetically Modified Organisms, Volume 1: A Case Study of* Bt *Maize in Kenya.* CABI Bioscience. In press.

Masiga D. K. **and Turner C. M. R.** Amplified (restriction) fragment length polymorphism (AFLP) analysis. In Parasite Genomics Protocols (Edited by S. E. Melville). Humana Press Inc., Totowa New Jersey, USA. In press.

POPULATION ECOLOGY AND ECOSYSTEM SCIENCE DEPARTMENT

The Department coordinates research and implementation work on the levels of population, communities and ecosystems. It thereby considers the hierarchical organisation of nature as a basic presumption and treats populations as basic units of ecosystems. The Population Ecology and Ecosystem Science (PEES) Department oversees the development and use of mathematical models in the different research divisions. Of particular importance is the development (with partners) of generic models that are being integrated in ICIPE's research activities with ICIPE scientists.

The development of generic models and their implementation is done in the areas of:

- Temporal dynamics of single-species populations
- Spatio-temporal dynamics of single-species populations
- Population interactions
- Multi-species interactions
- Ecosystem structure and function

The work relies on close collaboration with international collaborators, including an advisory panel and several task forces formed and supervised by the Department Head. These task forces consist of ICIPE scientists and external collaborators. For research and decision-support system development, the Department participated in the establishment of the CASAS (Centre of Analysis of Sustainable Agricultural Systems) Foundation, USA.

WORK IN PROGRESS

Below are summaries of the main areas of work.

1. Development of generic models of population systems

- *Temporal population dynamics:* Improved parameter estimation procedures for stochastic population models. Stochastic cohort development of poikilotherms can be described by delay models that require estimation of three parameters, i.e. the thermal threshold, the thermal constant and the variability parameter. These parameters are estimated from stage-frequency matrices. Models on structured single species populations were further developed. They will be applied in the proposed project on *Helicoverpa armigera*. A participative adaptive tsetse population management system was developed and implemented in the Gurage area of Ethiopia. The system relies on information obtained from monitoring traps, information used in a *decision-support system* based on kriging/mapping, and optimum deployment of control traps. The model is being applied also to diamondback moth and spider mite population dynamics in ICIPE's Plant Health areas.
- *Population interactions:* The introduction of scale considerations in functional response models. Functional response models were reviewed and completed with both behavioural and physiological elements. The model will be applied to the *Trichogramma* studies undertaken in ICIPE's Plant Health Division.
- *The clarification of scale and hierarchy theory elements into ecological/agricultural research* on integrated pest management.
- *The extension of integrated pest management (IPM) into biological, spatial, temporal and institutional dimensions* for human health improvement in Africa.
- *Introduction of adaptive population and ecosystem management schemes into ICIPE's R&D agenda.* Managing ecosystems to improve human health and alleviate poverty.

The existing knowledge on specific ecological systems is particularly limited in developing countries. Moreover, being in a state of change, concepts of resilience, of managing with uncertainty or even managing uncertainty itself, may be appropriate. Approaches that attempt to deal explicitly with uncertainty in ecological system management are of particular relevance for developing countries. The adaptive management approach is particularly useful in helping to make fast decisions where data are incomplete and uncertainty is great. All techniques are accessible at a moderate cost, and some are very cheap.

Adaptive populations management

The first case study is control of tsetse fly (*Glossina* spp.) populations through mass trapping in Ethiopia's Luke area. In an area about 7 x 7 km, data from monitoring traps are regularly collected, subjected to kriging analyses and mapped to guide community-participatory control trap deployment during tsetse presence on a biweekly basis. *(See the full report under Tsetse Research under Animal Health.)*

Adaptive ecosystems management

The second case study refers to adaptive ecosystem management schemes under development in Ethiopia. The purpose for managing a rural (BioVillage) and a periurban (Biofarm) farming system is to enhance human health and alleviate poverty.

2. Ecosystems structure, function and management

A book on resource management technologies and approaches and their use in a national development agenda was prepared for Ethiopia. Concepts of hierarchy and scale were reviewed and published. The demographic approach to agroecosystem study and management was prepared and has been accepted for publication. A comprehensive review on applied ecosystem management was prepared. In particular, participative management of ecosystems guided by sustainability and ecosystem service criteria were identified as key elements. Adaptive management procedures are applied to keep the system on a trajectory leading to improved human health.

OUTPUT

Journal articles

Baumgärtner J., Schulthess F. **and** *Yunlong X.* **(2003)** (Mini review) Integrated arthropod pest management systems for human health improvement in Africa. *Insect Science and Its Application* 23, 85–98. **(Call No.: 03-1694)**

> In a sub-Saharan African context, limited natural resources, infectious diseases, including those transmitted by arthropod vectors, and chronic exposure to food contaminated with mycotoxin-producing fungi which, among others, are vectored by insects, are among the major constraints to human health. Thus, pest control should be an important component in human health improvement projects. It appears that the advantages of preventive over curative methods are rarely recognised in Africa, with more emphasis being given to the search for the 'silver bullet' than to integrated control approaches. Integrated pest management (IPM) systems can be assigned to different decision-making levels as well as to different integration levels, combining ecological (individual pest species, species communities, species assemblages) and management (crop, cropping systems, farms, communities) levels with the respective control systems. These levels produce a highly structured environment for decision-making, in which the use of modern information technology is important. Case studies show that IPM systems are developed and implemented at four integration levels, whereby most work is done on the lowest integration level, addressing a single pest or pest complex attacking a particular crop, group of livestock or human population, and the respective control measures undertaken. Coordinated efforts to develop and implement supplementary IPM systems at higher levels are concluded to be important elements in integrated pest management and a further contribution to human health improvement and poverty alleviation.

Maniania N. K., Sithanantham S., Ekesi K., Ampong-Nyarko K., Baumgärtner J., Löhr B. **and** *Matoka C. M.* **(2003)** A field trial of the entomogenous fungus *Metarhizium anisopliae* for control of onion thrips, *Thrips tabaci*. *Crop Protection* 22, 553–559. **(Call No.: 03-1675)**

Severini M., *Baumgärtner J.* **and Limonta L. (2003)** Parameter estimation for distributed delay-based population models from laboratory data: Egg hatching of *Oulema duftschmidi* Redthenbacher (Coleoptera, Chrysomelidae) as an example. *Ecological Modelling* 167, 233–246.

Sileshi G., Baumgärtner J., Sithanantham S. **and Ogol C. K. P. O. (2002)** Spatial distribution and sampling plans for *Mesoplatys ochroptera* (Coleoptera: Chrysomelidae) on sesbania. *Journal of Economic Entomology* 95, 499–506. **(Call No.: 02-1642)**

Books and book chapters

Baumgärtner J. **and Gessler J. (2002)** Pest population monitoring, pp. 587–589. In *Encyclopedia of Pest Management* (Edited by D. Pimentel). Marcel Dekker, New York. **(Call No.: 02-1638)**

Baumgärtner J., Getachew T., **Gilioli G. and Bieri M. (2003)** Managing ecosystems to improve human health and alleviate poverty, pp. 179–186. In *Resource Management for Poverty Reduction Approaches and Technologies* (Edited by A. Aseffa, T. Getachew and J. Baumgärtner). Ethiopian Social Rehabilitation and Development Fund, Addis Ababa, Ethiopia. **(Call No.: 03-1742)**

Conference papers

Baumgärtner J. **(2002)** Resource management for poverty alleviation: Ecological paradigms and implications for IPM. Euro-Mediterranean Forum "Feeding Minds—Fighting Hunger", Centre for Agro-food Research, Calabria, Lamezia, Italy, November 8–10.

Baumgärtner J., **Gilioli G., Schneider D. and Severini M. (2002)** The management of populations in hierarchically organised systems. La gestione delle popolazioni in sistemi con organizzazione gerarchica. Giornate di Studio 'metodi numerici, statistici e informatici nella difesa dele colture agarie e delle foreste: ricerca ed applicazioni. Pisa, May 20–23, 2002.

Baumgärtner J., Tikubet G., **Gilioli G. and Bieri M. (2002)** The design and implementation of integrated disease and resource management schemes for human health improvement in sub-Saharan Africa. In *Proceedings of Ethio-Forum 2002*, Government of Ethiopia. Addis Ababa, Ethiopia, January, 2002.

Sciarretta A., ***Baumgärtner J.*** **and Trematerra P. (2002)** L'analise geostatistica nella pianificazione di un sistema di protezione integrata: sua utilità nella gestione, a livello locale, delle popolazioni di *Cidia funebrana* (Treitschke). Giornate di Studio metodi numerici, statistici e informatici nella difesa dele colture agarie e delle foreste: ricerca ed applicazioni. Pisa, May 20–23, 2002.

Project proposals

Disease burden and poverty explanation.

(See also the report of the adaptive management of tsetse in Ethiopia under Animal Health.)

Participating scientist: J. Baumgärtner (Head of Department)

Collaborators: University of Reggio di Calabria, Reggio di Calabria (Italy); Molise University, Campobasso (Italy); University of California, Berkeley (USA); University of Oxford (UK); Italian Research Council (CNR, Italy)

Donors: ICIPE core fund donors (Denmark, Sweden, Switzerland, Norway, Finland, Kenya, France, Japan), Swiss Development Corporation, Ethiopian Social Rehabilitation and Development Fund

ARTHROPOD PATHOLOGY UNIT

The Arthropod Pathology Unit is engaged in research into pathogens such as bacteria, fungi, viruses, protozoa and nematodes as biological control agents, or biopesticides as they are often called. Over the review period, entomopathogens have been tested against grasshoppers and locusts, diamondback moth *(Plutella xylostella)*, the tobacco red spider mite *(Tetranychus evansi)*, tephritid fruit flies, the African armyworm *(Spodoptera exempta)*, termites and onion and flower thrips among others. *(See report under Plant Health.)*

Of particular interest is the testing and use of *Bacillus thuringiensis (Bt)* against a variety of crop pests and for mosquito larvae control. The Unit is helping to manage the newly commissioned Bt factory constructed in 2003 on the ICIPE campus with technical and financial support of the government of the Peoples Republic of China. The first of its kind in Africa, the factory will be able to produce *Bt, Bti* and *Bacillus sphaericus* for large-scale testing in crop pest and disease vector management.

The APU also operates a gene bank for pathogens, described below.

WORK IN PROGRESS

1. Development of biopesticides for grasshopper and locust control in sub-Saharan Africa

Integrated pest management (IPM) interventions do not yet exist for control of locusts and grasshoppers in sub-Saharan Africa. Available alternative locust control methods are a crucial limiting factor to IPM programmes. Therefore, the variety of techniques comprising an IPM 'toolbox' is lacking. Both large-scale and local or village grasshopper or locust control programmes have relied almost exclusively on chemical insecticides. Effective, economical, and safe alternative methods are needed to control acridids.

Because entomopathogens can be applied using the same application technology as the chemicals that currently form the basis for control, they are suitable focus for generating alternative control measures. The specific objective of the Project is to increase efficacy of entomopathogens used as biopesticides by increasing virulence and environmental persistence sufficiently to become marketable products.

2. ICIPE pathogen germplasm centre

The ICIPE Germplasm Centre (IGC) is a repository for African arthropod pathogens (fungi, viruses, bacteria, and protozoa) and makes them available to investigators. Activities include training, isolation, culture, identification, and preservation. The Unit also makes available a catalog of all pathogen samples through the Internet. During the years 2002–2003 the IGC isolated 84 isolates of *Bacillus thuringiensis (Bt)* and 5 isolates of *Metarhizium* sp., which are now stored in liquid nitrogen and silica gel at -70 °C. During the reporting period, the Centre received 14 isolates of *M. anisopliae* from Senegal for preservation, and a request from the University of Nairobi for fungal isolates for the screening against the sweet potato weevil.

CAPACITY BUILDING

PhD students

S. Dimbi (Zimbabwe) Evaluation of the potential of entomopathogenic fungi for the management of African Tephritidae fruit flies in Kenya. PhD, Kenyatta University, Kenya (2003). Supervisors: N. K. Maniania, S. A. Lux (ICIPE), J. K. Mueke (Kenyatta University).

E. A. Ndhine (Kenya) Evaluation of *Bacillus thuringiensis* and botanical extracts for the IPM of African armyworm, *Spodoptera exempta*. Makerere University, Uganda.

MSc Students

D. Thumbi (Kenya) Evaluation of native isolates of *Bacillus thuringiensis* and *Metarhizium anisopliae* for the control of *Plutella xylostella* (L.) (Lepidoptera: Plutellidae). MSc, Kenyatta University (2002). Supervisors: N. K. Maniania, S. Sithanantham (ICIPE), N. M. Gitonga, P. O. Owino (Kenyatta University).

V. W. Wekesa (Kenya) Evaluation of pathogenic fungi *Beauveria bassiana* and *Metarhizium anisopliae* for the control of tobacco spider mite, *Tetranychus evansi* Baker & Pritchard (Acarina: Tetranychidae). Jomo Kenyatta University of Agriculture and Technology.

R. W. Irungu (Kenya) Identification of suitable sites for the release of the fungal pathogen *Neozygites tanajoae* for the control of cassava green mite in eastern Africa. University of Nairobi.

OUTPUT

Journal articles

***Dimbi S., Maniania N. K., Lux S. A., Ekesi S.* and Mueke J. K. (2003)** Pathogenicity of *Metarhizium anisopliae* (Metsch.) Sorokin and *Beauveria bassiana* (Balsamo) Vuillemin, to three adult fruit fly species: *Ceratitis capitata* (Weidemann), *C. rosa* var. *fasciventris* Karsch and *C. cosyra* (Walker) (Diptera: Tephritidae). *Mycopathologia* 156, 375–382. **(Call No.: 03-1712)**

Dimbi S., Maniania N. K., Lux S. A., Ekesi S. **and Mueke J. K. (2003)** Host species, age and sex as factors affecting the susceptibility of the African Tephritid fruit fly species, *Ceratitis capitata, C. cosyra* and *C. fasciventris* to infection by *Metarhizium anisopliae*. *Journal of Pest Science* 76, 113–117. **(Call No.: 03-1752)**

The effect of host age and sex on the susceptibility of 3 tephritid fruit fly species, *Ceratitis capitata* (Wiedemann), *C. cosyra* (Walker) and *C. fasciventris* (Bezzi) to the entomopathogenic fungus *Metarhizium anisopliae* (Metchnikoff) Sorokin was studied in the laboratory. Three adult host ages, 0 (<1 day-old); 7-day-old and 14-day-old, were used. All 3 species were susceptible to fungal infection, although there were differences in the levels of susceptibility among the hosts. Age accounted for the largest variability in mortality followed by species, while sex had the lowest variability. Of the 3 host ages tested, the 0- and 7-day-old flies were more susceptible to fungal infection than the 14-day-old flies. Male and female *C. fasciventris* flies generally succumbed earlier to fungal infection than the other two species. Female flies of *C. cosyra* and *C. fasciventris* were also generally more susceptible to fungal infection than the males, although differences were apparent at 3 and 4 days after treatment but not 5 days after treatment. Age accounted for the largest variability in lethal time mortality values (LTs). Mean LT-values generally indicated that the speed of kill was faster among younger flies than the older flies. LT_{95} ranged between 3.9–4.9 days in the 0-day-old flies, 4.3–6.1 days in the 7-day-old flies and 4.6–6.1 days in 14-day-old flies in the different species and sexes. The implication of this study for the management of fruit flies is discussed.

Dimbi S., Maniania N. K., Lux S. A. **and Mueke J. K.** Effect of constant temperatures on germination, radial growth and virulence of *Metarhizium anisopliae* to three species of African tephritid fruit flies. *BioControl* (in press).

Ekesi S., Maniania N. K. **and** *Lux S. A.* **(2003)** Effect of soil temperature and moisture on survival and infectivity of *Metarhizium anosopliae* to four tephritid fruit fly puparia. *Journal of Invertebrate Pathology* 83, 157–167. **(Call No.: 03-1700)**

Ekesi S., Maniania N. K. **and** *Lux S. A.* **(2002)** Mortality in three economically important African tephritid fruit fly puparia and adults caused by the entomopathogenic fungi, *Metarhizium anisopliae* and *Beauveria bassiana*. *Biocontrol Science and Technology* 12, 7–17. **(Call No.: 02-1628)**

Maniania N. K. **(2002)** A low-cost contamination device for infecting adult tsetse flies, *Glossina* spp. with the entomopathogenic fungus *Metarhizium anisopliae* in the field. *Biocontrol Science and Technology* 12, 59–66. **(Call No.: 02-1620)**

A low-cost device for infecting adult tsetse fly, *Glossina fuscipes fuscipes*, with the entomopathogenic fungus *Metarhizium anisopliae* was designed and tested in the field. Tsetse flies that are attracted to the trap entered the contamination device and ultimately became infected with the fungus. Traps exposed to the sun attracted more flies than did the ones placed in the shade. The time spent by single flies in the contamination device varied between 5–189 s, and the subsequent number of conidia collected varied between 1.6×10^5 conidia and 40.5×10^5 conidia per fly, and largely depended on the behavior of individual flies. Dry conidia of *M. anisopliae* in the device retained their viability for 31 days in the field, and efficacy against *G. fuscipes* was not affected.

Maniania N. K., Ekesi S. **and** *Songa J. M.* **(2002)** Managing termites in maize with the entomopathogenic fungus *Metarhizium anisopliae*. *Insect Science and Its Application* 22, 41–46. **(Call No.: 02-1637)**

Field experiments were conducted for two seasons to assess the efficacy of the entomopathogenic fungus *Metarhizium anisopliae* in the control of termites in maize. Application of the fungus at planting was found to significantly reduce maize lodging and increase grain yield in both seasons. However, data from treatment application at tasselling were not consistent. Our results suggest that a granular formulation of *M. anisopliae* might be a useful option for the management of termites in the maize agroecosystem.

Maniania N. K., Sithanantham S., Ekesi S., Ampong-Nyarko K., Baumgärtner J., Löhr B. **and** *Matoka C. M.* **(2003)** A field trial of the entomogenous fungus *Metarhizium anisopliae* for control of onion thrips, *Thris tabaci*. *Crop Protection* 22, 553–559. **(Call No.: 03-1675)**

In Kenya, *Thrips tabaci* Lind., is an important constraint to onion production. The current strategy to use synthetic pesticides is inadequate and unsustainable. An isolate of *Metarhizium anisopliae* (Metsch.) Sorok. with high pathogenicity to legume thrips, *Megalurothrips sjostedti*, and western flower thrips, *Frankliniella occidentalis*, was tested in field trials as a potential alternative for control of onion thrips. Weekly and bi-weekly applications of the fungus *M. anisopliae* and bi-weekly spray of the chemical insecticide dimethoate (Rogor® 50) were compared for 3 seasons. *M. anisopliae* was applied at the rate of 1×10^{11} conidia ha^{-1} and dimethoate was applied at the recommended rate of 17.5 g a.i. ha^{-1}. In all the trials, thrips density and damage were significantly lower in the fungal and chemical insecticide treatments compared with the untreated control. Onion bulb yield did not differ significantly among the treatments during the first season trial. However, in the second season trial, dimethoate-treated plots provided the greatest bulb yield (17 metric tons ha^{-1}) and in the third season trial, *M. anisopliae* applied weekly recorded the highest yield (24 metric tons ha^{-1}). With the exception of spiders, densities of nontarget organisms were higher in plots treated with *M. anisopliae* than in dimethoate-treated plots. The results indicate the potential of using *M. anisopliae* for the control of *T. tabaci* while protecting biodiversity in the onion agroecosystem.

(See also abstracts under the respective programme areas)

Book chapters

Ekesi S. **and** *Maniania N. K.* **(2002)** *Metarhizium anisopliae*: An effective biological control agent for the management of thrips in horti- and floriculture in Africa. *op. cit.*, pp. 164–180. **(Call No.: 02-1670)**

Maniania N. K., **Laveissière C.**, *Odulaja A.*, *Ekesi S.* **and** *Herren H.R.* **(2002)** Entomopathogenic fungi as potential biocontrol agents for tsetse flies, pp. 145–163. In *Advances in Microbial Control of Insect Pests* (Edited by R. K. Upadhyay). Kluwer Academic Publishers, Dordrecht, The Netherlands/Plenum Publishers, New York. ISBN 0-306-47491-3. **(Call No.: 02-1669)**

Langewald J., Michell J. D., ***Maniania N. K.*** **and Kooyman C. (2003)** Microbial control of termites in Africa, pp. 227–242. In *Biological Control in IPM Systems in Africa* (Edited by P. Neuenschwander, C. Borgemeister and J. Langewald). CABI Publishing, Wallingford. **(Call No.: 03-1709)**

Tamò M., ***Ekesi S., Maniania N. K.*** **and Cherry A. (2003)** Biological control, a non-obvious component of IPM for cowpea *op. cit.*, pp. 295–309. CABI Publishing, Wallingford. **(Call No.: 03-1681)**

Conferences attended

Maniania N. K. (2002) Biology and management of termites in structures and agriculture. UNEP/WHO Sub-regional Workshop on the Reduction/Elimination and Management of Pesticides in the Context of the Stockholm and Basel Conventions and Related Activities of WHO's Regional Office for Africa, 4–8 November, 2002, Pretoria, South Africa.

Cherry A., Maniania N. K. and Oduor G. (2003) Microbial control in Africa: Current status and future. Bi-annual meeting of the Association of Insect Scientists (AAIS), Nairobi, 9–13 June 2003, Kenya.

Wafula W. V., Maniania N. K., Markus K. and Boga H. (2003) Pathogenic fungi as potential control agents for tobacco red mite *Tetranycus evansi*. Bi-annual meeting of the Association of Insect Scientists (AAIS), Nairobi, 9–13 June 2003, Kenya.

Maniania N. K., Vaughan L. J., Osir E. O. and Ouna E. O. (2003) Virulence and development of the microsporidium *Johenrea locustae* in two locust species: *Schistocerca gregaria* and *Locusta migratoria*. 36th Annual Meeting of the Society for Invertebrate Pathology, Burlington, 26–30 July 2003, USA.

Maniania N. K. (2003) Biology and management of termites in structures and agriculture. UNEP/WHO Sub-regional Workshop on the Reduction/Elimination and Management of Pesticides in the Context of the Stockholm Convention on Persistent Organic Pollutants and Related Activities of WHO, 6–9 October 2003, Tunis, Tunisia.

Maniania N. K. (2003) Integrated vector management: Tsetse fly as a case study. UNEP/WHO Sub-regional Workshop on the Reduction/Elimination and Management of Pesticides in the Context of the Stockholm Convention on Persistent Organic Pollutants and Related Activities of WHO, 6–9 October 2003, Tunis, Tunisia.

Maniania N. K., and Löhr B. (2003) Biopesticides and pest management system: Recent development and future needs in Africa. International Symposium on Biopesticdes for Developing Countries, 28–30 October 2003, Turrialba, Costa Rica.

Maniania N. K., and Varela A. (2003) Production of biopesticides in Africa. International Symposium on Biopesticides for Developing Countries, 28–30 October 2003, Turrialba, Costa Rica.

Maniania N. K., Ekesi S. and Lwande W. (2003) Tritrophic interactions: Plant-insect-entomopathogenic fungus. Annual Meeting of the Entomological Society of Ontario, 28–30 November 2003, Guelph, Canada.

Participating scientists: N. K. Maniania (Head of Unit), P. Arama, S. Ekesi

Assisted by: E. O. Ouna, R. Rotich, E. Wesonga

Collaborators: Virginia Polytechnic Institute and State University (USA), USDA, Insect Biological Control Laboratory (France), Locustox (FAO), DLCO (East Africa), INRA (France), Département de protection des végétaux (DPV) (Sénégal), DPV (Madagascar), FOFIFA (Madagascar), Centre National Antiacridien (CNA) (Madagascar)

Donors: USAID/Africa Bureau

BIOSTATISTICS UNIT

INTRODUCTION

A new team in the Biostatistics Unit started to work on 1st September 2002. Over the review period, the Unit provided scientific support to all projects and departments at ICIPE. This included assisting staff and students in design of experiments, data analysis (in particular, restoration of values of parameters of various non-linear mathematical models of population dynamics), results verification and interpretation, statistical software installation and upgrading, and exploring available databases statistically for detailed information contributing to the general objectives of the different projects. The Unit also contributed essential statistical and modelling ideas to various research project proposals during this period.

In the area of capacity building, the Head of Unit was involved in teaching and review of theses and manuscripts. Short courses are offered yearly for 5 weeks in biostatistics with computer training for the new classes of ICIPE's PhD and Masters students *(see also Capacity Building report)*. The main topics of the course are manual/computer calculations and solution of various statistical problems; use of modern software (Excel, SAS, Statistica) and solving various typical entomological problems with modern statistical methods. The lectures on biostatistics were transformed into a textbook with typical agricultural/entomological examples. The book is available for students in electronic form, and will soon be published as a print edition. The Unit also accepts students on attachment from local institutions for training in statistics, computing and modelling.

Other main activities of the Biostatistics Unit are the constructing and analysis of mathematical models of population/ecosystem dynamics and their application to the description of real biological processes. This includes the solution of various methodological problems of ecological modelling (population dynamics with overlapping and non-overlapping generations, parasite-host system dynamics, time lag in reaction of intra-population self-regulative mechanisms, etc.), and development of ecological theories of insect population dynamics, among others. Some of these basic results are presented in a scientific monograph, 'Mathematical Models in Phenomenological Theory of Insect Population Dynamics' (in press at ICIPE Science Press). *(See also Information and Publications Unit report.)*

WORK IN PROGRESS

The following are the highlights of the Biostatistics Unit's research achievements from September 2002–December 2003.

1. Resource-phytophagous insect-pathogen system dynamics

Analysis of the model of resource-phytophagous insect-pathogen system dynamics:

$$\frac{dx}{dt} = \alpha x - \beta x(x+y) - \gamma_1 xy,$$
$$\frac{dy}{dt} = \gamma_1 xy - \beta_1 y(x+y) - \alpha_1 y,$$
$$\frac{dP}{dt} = P_0 - \alpha_2 P - \gamma_2 P(x+\delta y), \quad (1)$$

where $x(t)$ is a number of 'healthy' individuals in the population, $y(t)$ is a number of 'sick' individuals and $P(t)$ is the volume of suitable food in a system at moment t (all parameters in system (1) are positive) allowed us to obtain the following result: even in a situation when P_0=*const*>0 (i.e. insects do not have an influence on the food flow into the system), the combined influence of two factors can lead to a trigger dynamic regime (fixed outbreak in the Isaev-Khlebopros classification of insect population dynamic regimes). One of the possible dynamic regimes is presented in Figure 1. Regimes of this type can be realised in nature for various species of insect pests.

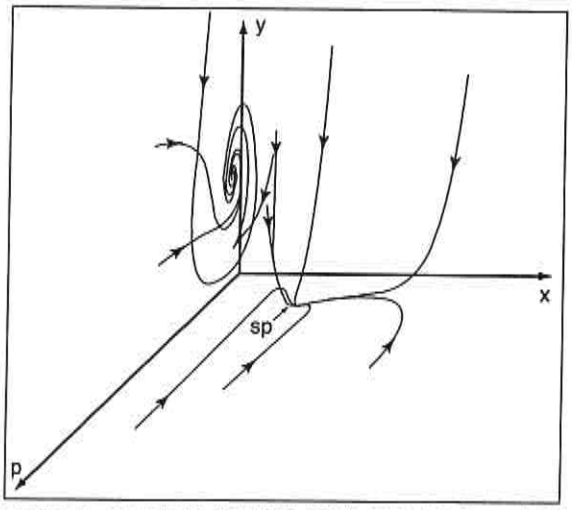


Figure 1. Dynamic regime with one of the stable points (sp) on a coordinate plane (analogous to a fixed outbreak regime)

2. Influence of harvesting on population dynamics

Within the framework of a model of insect population dynamics with overlapping generations, it is assumed there exists moments $\{t_k\}$ which correspond to "moments (fixed time) of harvesting", then

$$x_k = x(t_k) = px(t_k - 0), \quad (2)$$

where the coefficient of survival is $0<p<1$, $x(t_k-0)$ is the number of individuals before harvesting, and $x(t_k)$ is the number of individuals surviving after the harvesting impact. The value of p depends on the food supply for the population between selected times t_k. Over time interval $[t_k, t_{k+1})$,

$$\frac{dx}{dt} = xR(x), \quad (3)$$

where $R(x)$ satisfies the conditions:

$$R(0)>0,\ \exists K: R(K)=0, \frac{dR}{dx}<0,\ R(\infty)=-\infty. \qquad (4)$$

If $p = const$ in model (2)–(3) under conditions (4), there are regimes of monotonous stabilisation of $\{x_k\}$ only. However regimes with several stationary states can exist; periodic impacts on population size can lead to the occurence of fixed outbreaks. If equation (3) represents the Verhulst (1838) model, and p is an exponentially decreasing function with respect to the average population size, then chaotic regimes can occur.

3. Modification of the Verhulst model

If the death rate of individuals in a population corresponds to Verhulst's (1838) law:

$$\frac{dx}{dt}=-\alpha x-\beta x^2, \qquad (5)$$

where $x(t)$ is the population size at time t, α is the intensity of the death rate and β is the coefficient of self-regulation, and the birth rate depends on population size $x(t-\tau)$ where $t-\tau$ = constant > 0 (more precisely, it depends on the number of individuals which existed at moment $t-\tau$ and survived following law (5) to moment t) we have the following modification of the Verhulst model:

$$\frac{dx}{dt}=ax(t-\tau)e^{-\alpha\tau-\beta\int_{t-\tau}^{t}x(s)ds}-\alpha x-\beta x^2 \qquad (6)$$

where a is the productivity of surviving individuals, with the initial conditions $x(t)=\phi(t)>0$ at $t\in[-\tau,0]$, $\phi(t)\in C_{[-\tau,0]}$. Let $A=a\tau$ and $B=\alpha\tau$. The following theorem is obtained:

Theorem

1. All solutions of equation (6) are non-negative and bounded.
2. If $A\le Be^{B}$ the population becomes extinct at all initial conditions.
3. If $A>Be^{B}$ the population size stabilises at a unique, none-zero level.

4. Modification of the Lotka-Volterra model of predator-prey system dynamics

The Lotka-Volterra model of predator-prey system dynamics can be presented in the following form (with respective initial conditions) when considering situations pertaining to model (6):

$$\frac{dx}{dt}=ax(t-\tau)e^{-\alpha\tau-\beta\int_{t-\tau}^{t}x(s)ds}-\alpha x-\beta x^2-\gamma xz$$
$$\frac{dz}{dt}=-\alpha_1 z+\gamma_1 xz. \qquad (7)$$

After transformation of variables in (7) and introduction of a new variable,

$$t=\tau t',\ \beta\tau x=u,\ \gamma\tau z=v,\ I=B+\int_{t-1}^{t}(u+v)ds,$$

we have the following system of ordinary differential equations with time lag:

$$\frac{du}{dt}=Au(t-1)e^{-I}-Bu-u^2-uv,$$
$$\frac{dv}{dt}=-Cv+Duv,$$
$$\frac{dI}{dt}=u+v-u(t-1)-v(t-1), \qquad (8)$$

where $A=a\tau,\ B=\alpha\tau,\ C=\alpha_1\tau,\ D=\gamma_1\tau.$

Initial conditions for (8) are the following: $u(t)=\rho_u(t)>0,\ v(t)=\rho_v(t)>0$ at $t\in[-1,0]$, then

$$\rho_u(t),\ \rho_v(t)\in C_{[-1,0]},\ I(0)=B+\int_{t-1}^{t}(\rho_u(s)+\rho_v(s))ds$$

and the following theorem can be obtained;

Theorem

1. All solutions of system (8) are non-negative and bounded.
2. If $A\le Be^{B}$ all solutions converge to the origin.
3. If $A>Be^{B}$ there exists an equilibrium on Ou line which is stable asymptotically at

$$Be^{B}<A<\left(B+\frac{C}{D}\right)e^{\left(B+\frac{C}{D}\right)},$$

4. If this inequality is realised:

$$A>\left(B+\frac{C}{D}\right)e^{\left(B+\frac{C}{D}\right)},\ \text{then}$$

on a plane Ouv, there exists a non-trivial stationary state which is stable asymptotically at all possible values of the model parameters.

5. Chaos in models of a bisexual population (with non-overlapping generations) dynamics

Let t_k, k = 0,1,2..., be the times of appearance of individuals of new generations, $t_{k+1}-t_k\equiv const=h>0$. Assume that on the time intervals $[t_k, t_{k+1})$ there is a monotonous decrease in individuals of both sexes (as a result of natural death and influence of self-regulation). This process in the most simple case that can be described by the following system of equations:

$$\frac{dx}{dy}=-\alpha_1 x-\beta_1 x(x+\gamma y),$$
$$\frac{dy}{dt}=-\alpha_2 y-\beta_2 y(x+\gamma y), \qquad (9)$$

where $x(t)$ is the number of males, $x(t)$ is the number of females at the moment t; α_i are the coefficients of natural death rates, β_i are the coefficients of self-regulation, $\alpha_i, \beta_i, \gamma > 0$. Coefficient γ corresponds to the non-equivalence of contribution of males and females to the process of self-regulation.

Let $x(t_k - 0)$ and $y(t_k - 0)$ be the numbers of individuals of respective sexes which have survived to the moment of appearance of a new generation, and f be the number of impregnated females. In the simplest case, function f satisfies the following ratio:

$$f = \min\{y(t_i - 0), \varepsilon x(t_i - 0)\},$$

where ε is the 'coefficient of male activity' which reflects not only their potential opportunities for mating but also characterises the interaction of individuals of the two sexes. In particular, if all individuals are strictly paired off, this parameter is equal to one, $\varepsilon = 1$.

Let m_1, m_2 be the average numbers of males and females accordingly which are the progeny of one impregnated female, $m_1, m_2 = const > 0$. At the time of appearance of individuals of the new generation, the equations have the following forms:

$$x(t_i) = m_1 f,$$
$$y(t_i) = m_2 f. \qquad (10)$$

It is necessary to assume that the numbers of individuals of both sexes at the initial time are positive, $x(t_0) = x_0 > 0$, $y(t_0) = y_0 > 0$. In general, it is possible to consider the case $\varepsilon = 1$ and $h = 1$.

(1) Taking into account that the following conditions are realised:

$$\left.\frac{dx}{dt}\right|_{x=0} = 0, \left.\frac{dy}{dt}\right|_{y=0} = 0,$$

and coefficients $m_1, m_2 > 0$, then solutions of system (9)–(10) are non-negative.

(2) There exists a stable invariant compact,

$$\Delta = \Delta_1 \times \Delta_2 = \left[0, \frac{\alpha_1(m_1 - e^{\alpha_1})}{\beta_1(e^{\alpha_1} - 1)}\right] \times \left[0, \frac{\alpha_2(m_2 - e^{\alpha_2})}{\beta_2\gamma(e^{\alpha_2} - 1)}\right].$$

If one of the inequalities

$$m_1 > e^{\alpha_1}, m_2 > e^{\alpha_2} \qquad (11)$$

does not pertain (resp., Δ does not exist) the population becomes extinct.

(3) The origin is the stationary state of the system (9)–(10). If the conditions (11) are fulfilled then this point is not stable; otherwise it is stable.

Let

$$B = \frac{\beta_1}{\beta_2}.$$

(4) If the conditions (11) pertain, the system (9)–(10) has one non-trivial state $(\bar{x}, \bar{y})$.

(5) If $\frac{1}{2} \le \frac{1}{B} \le 2$

then $(\bar{x}, \bar{y})$ is a global stable equilibrium. There are no cycles (periodic population fluctuations) in this case.

(6) If $\frac{1}{B} > 2$ or $\frac{1}{B} > \frac{1}{2}$

then if parameter m_2 increases (at constant ratio m_1/m_2) the point $(\bar{x}, \bar{y})$ loses stability and with further increases in m_2, the cyclic and chaotic regimes can be observed in the system.

Thus, analysis of models of the dynamics of isolated populations with both sexes are present shows that even in the simplest cases, when mortality of individuals in a population follows Verhulst's (1838) Law, and fecundity is constant, there exist values of the model's parameters at which there are chaotic regimes of population dynamics. It is important to note that the cyclic and chaotic dynamic conditions can arise only when the difference in action of self-regulating mechanisms for the two sexes achieves a defined critical value. If this critical value is not reached, then the unique global stable equilibrium is observed in the system.

OUTPUT

Journal articles

Nedorezov L. V. and Ut'yupin Yu. V. (2003) About a predator-prey dynamic model with time lag. *Siberian Journal of Industrial Mathematics*, V. 6, N 4, 67–75 (in Russian).

Nedorezov L. V. and Ut'yupin Yu. V. (2003) Discrete-continuous model of bisexual population pynamics. *Siberian Mathematical Journal*, V. 44, N 3, 650–659. (in Russian) English version reprinted by Kluwer.

Nedorezov L. V. and Karlyuk A. Yu. About a model of resource-phytophagous insect-pathogen system dynamics. *Eurasian Entomological Journal*. (In press)

Nedorezov L. V. **and Sadykov A. M.** Isolated population dynamics with periodic disturbances. *Eurasian Entomological Journal*. (In press).

Books

Nedorezov L. V. Mathematical Models in Phenomenological Theory of Insect Population Dynamics. ICIPE Science Press, Nairobi. (In press)

Conferences/workshops attended

Ut'yupin Yu. V. and Nedorezov L. V. (2003) Model of Isolated Population Dynamics with Time Lag. Int. Conference on Mathematics in the 21 century, Novosibirsk, Russia. (pdf-file at: http://www-sbras.nsc.ru/ws/show abstract.dhtml?ru+59+17).

Ut'yupin Yu. V. and Nedorezov L. V. (2003) Model of Predator-Prey System Dynamics with Time Lag. Int. Conference "Mathematics in 21 Century", Novosibirsk, Russia. (pdf-file at: http://www-sbras.nsc.ru/ws/show abstract.dhtml?ru+59+18).

Participating scientist: L. Nedorezov

Assisted by: A. Wanjoya

Collaborators: Ministry of Agriculture, Kazakhstan; Kazakh Scientific Research Institute for Plant Protection; Novosibirsk State University, Novosibirsk, Russia; Institute of Molecular Biology and Biophysics, Novosibirsk; Institute of Systematics and Animal Ecology, Novosibirsk; V.N. Sukachev Forest Institute, Krasnoyarsk, Russia

Donor: ICIPE Core Fund donors, ARPPIS programme

INFORMATION TECHNOLOGY AND BIOINFORMATICS

The Information Technology and Bioinformatics Unit was established in January 2002 to provide better ICT and Bioinformatics infrastructure and services and to integrate all ICT-related research, development and training activities for the Centre. Below are highlights of the Unit's work over the review period.

WORK IN PROGRESS

1. Improvement of IT and bioinformatics infrastructure

ICIPE has joined the KENET (Kenya Education Network, a project funded by USAID) since January 2002. With this membership, ICIPE is entitled to connect to the Kenya Internet gateway, the JamboNet directly and at half of the commercial ISP rate. Therefore, ICIPE acquired the Internet connectivity via JamboNet from April 2002 at a bandwidth of 128K BPS. With the extension of the TelecomKenya's fibre optical cable to our campus, ICIPE has applied to upgrade our Internet connectivity to T1 level (1024 KBPS). This will improve the Internet connectivity substantially and make all web-based applications perform better. High-speed Internet connectivity is a critical requirement for Bioinformatics applications.

The ICIPE Mbita Point Field Station has been connected to the Internet via the MIMCom satellite solution since June 2001. ICIPE plans to set up a VPN (virtual private network) between the headquarters and its ICIPE Mbita Campus via VSAT. This will eventually replace the Internet connection provided by the MIMCom RedWing satellite solution. The establishment of the VPN will enable us to share resources and enjoy free video-conferencing between the campuses.

Discussions in the Beijing Genome Institute (BGI) to establish an African Regional Bioinformatics Research and Training centre has been initiated, which will be part of the proposed China-Africa Bioscience Innovation Centre, to be supported by the Chinese government. The Chinese Embassy to Kenya and the Chinese Academy of Sciences have expressed their interest in this project.

A Bioinformatics Lab is being established to allow staff and students to conduct bioinformatics and functional genomics applications. It will also be used for training activities.

2. Insect informatics R&D

ICIPE has been carrying out following activities in Insect Informatics:

- The Africa IPM Forum project has developed a web-based product, IPMAfrica (http://informatics.icipe.org/IPMAfrica/). The IPMAfrica supports unlimited users, unlimited discussion forums/topics and unlimited messages/posts. Powered by Active Server Pages (ASP) and written in server side Java, IPMAfrica features many handy functions, such as rich HTML message (supporting picture, sound, video and links); threaded or linear messages; file attachment; automatic-Cookie login; email integration; full search; and private messages.
- Upgrading of the Africa Remote Sensing Data Bank (http://informatics.icipe.org/databank/). Apart from the availability of 20 years of WMO ground observation data for more than 1000 stations in Africa, the 40-years-average climatic data from Australian National University, together with many other data sets and digital maps for most African countries were added to the data bank. The GIS shape files for all African countries also have been made available recently. This data facility has been downloaded over 2.5 million times since its launching in 1998.
- The proposal of 'Combatting Malaria with Natural Herbal Medicine: Mapping Growth Suitability of *Artemisia annua* L. in Africa using Remote Sensing and Satellite Imagery' has received initial funding support. A literature review of all previous and related research being done in China and other parts of the world have been done by the Unit.
- Upgrading of the ICIPE Insect Informatics Initiative home page (http://informatics.icipe.org/IPMAfrica/) to provide news and information to end-users.
- The web-based intelligent insect management information system is under development, which is the prioritised Insect Informatics activity for the post-PC Era.
- The Web-based ICIPE Management Information System (WIMIS) is under development, as a cross-platform tool for managing all ICIPE in-house data via a browser from anywhere in the world, therefore enabling tele-working and closer links with the Governing Council and donor community. A web-based proposal and project management protocol has been developed. Other modules will be developed step-by-step according to in-house priority and available resources.
- CD-ROM products development: Insect Informatics Initiative assisted the ICIPE African Fruit Fly Initiative (AFFI) in the development of a CD-ROM product titled 'Courtship Behaviour of the Mediterranean Fruitfly (Medfly): Worldwide Comparisons'. Both IBM and Macintosh-compatible versions of the CD-ROM are available. The Unit also helped AFFI in developing the AFFI home page (http://informatics.icipe.org/fruitfly/).

3. Progress in implementing ICIPE's eWorking strategy

A Jason VoIP (voice over IP) gateway has been procured and a Web-based interface for the ICIPE email system has been installed. Two modules of the Web-based ICIPE Management Information System (WIMIS) have been developed: (i) Web-based 'ICIPE Project Reporting and Disbursement

Schedule management System' has been developed by the IT team, and (ii) Web-based 'ICIPE Proposal Management System'. Other modules of the WIMIS are in the process of development.

- Upgrading of Internet connectivity to a faster VSAT link, which requires in-house LAN upgrade (replacement of old Switches/Hubs).
- Free or low-cost voice- and fax-over TCP/IP, which will reduce communication costs to the Centre.
- Providing Web-based interface for the ICIPE email system.
- VPN (virtual private network) between Duduville and Mbita, which will integrate the two LANs and reduce the cost of operating Mbita (configuring Mbita phones as extensions of Duduville PBX, Direct link of SunSystems, remote administration of LAN from Duduville...)
  - Web-based procurement system, which provides on-line requisition, on-line bidding and real-time supply functions.
  - Web-based R&D management system, which allows authorised users to log in from anywhere to get information on various donors, databases, e.g. on conceptual notes, proposals, projects, photos, presentations, etc.
  - Web-based access of financial and human resources systems.

OUTPUT

Project proposals

Strengthening ICIPE's Information Technology and Bioinformatics Infrastructure for Enhanced Regional Research and Training Capacity.

Combating Malaria with Natural Herbal Medicine: (i) Mapping Growth Suitability of *Artemisia annua* L. in Africa using Remote Sensing and Satellite Imagery; (ii) Studying Malaria Resistance Development against *Artemisia annua* L. and Clinical Trials.

Africa IPM Portal (http://www.ipmafrica.org): *An Integrated Approach for Information Sharing and Exchange.*

IPM Education Promotes Development and Democracy in Africa: Establishment of an IPM Virtual Campus.

Information and Modern Technologies Empower Rural Ethiopian Communities: Developing Multi-purpose Tele-centres and Relevant Information Products for Improved Health, Productivity and Poverty Reduction.

Remote Sensing and Strategic Planning for Better Agriculture Production in Africa: Development of Web-based Data Bank and Intelligent Geographical Management Information Systems.

Participating staff: Y. Xia (Head of Unit), G. Sequeira, J. Mwangi, A. Kamau, F. Orwa

Collaborators: NSF Centre for IPM, North Carolina State University, USA; Virginia Polytechnic Institute and Stae University (Virginia Tech), USA; Centre for Pest Information Technology and Transfer (C-PITT), The University of Queensland, Australia; IITA (CGIAR SP-IPM); Africa IPMlink; IPMNet/CICP; IPM/CRSP; IPM Europe; IPM Forum; IPM Globe Facility; Beijing Genome Institute

Donor: ICIPE Core Fund (Denmark, Sweden, Switzerland, Norway, Finland, Kenya, France, Japan), Swiss Development Corporation (SDC), USAID

BIOSYSTEMATICS SUPPORT UNIT

The Biosystematics Support Unit (BSU) activities were reduced from April 2003 after the departure of the head of unit and the death of the technician early in the year. However, a taxonomic expert attached to the 'Grasses' project *(see under Plant Health)* has undertaken some of the vital identification services, followed by the recruitment of a new laboratory technician.

Below are highlights of the BSU activities and services. Details can be found under the project reports.

WORK IN PROGRESS

1. Taxonomic backstopping services

The demand for identification of arthropods among ICIPE scientists arises from two perspectives, namely, for pest and vector management and for assessment of biodiversity. Table 1 shows some of the clients of taxonomic services. Two new clients will be provided with services in 2004: the KARI group working on the vectors of maize streak virus and the ICIPE-Malaria team working on the aquatic predators against mosquito wrigglers in irrigated rice ecosystems.

The Biosystematics Unit is presently also heavily involved with the UNEP/GEF-funded project on 'Conservation of Gramineae and Associated Arthropods for Sustainable Agricultural Development in Africa'. Taxonomic backstopping provides identification of the stemborer complex and their parasitoids all emanating from grasses. These are:

- Order Coleoptera: Families Anthribidae, Cerambycidae, Curculionidae, Languriidae, Mordellidae and Tenebrionidae.
- Order Diptera: Families Chloropidae, Diopsidae, Muscidae, Phoridae and Tachinidae
- Order Lepidoptera: Families Cossidae, Noctuidae, Pyralidae and Tortricidae
- Order Hymenoptera: Families Bethylidae, Braconidae, Ceraphronidae, Encyrtidae, Eulophidae, Ichneumonidae, Mymaridae, Pteromalidae and Scelionidae

2. Voucher collection of parasitoids

With numerous collections coming in from different working groups, it is anticipated to build up the collections of arthropods (insects, spiders, mites, etc.) in the Unit. Table 2 shows the new additions to the voucher collection and the new records for Kenya.

3. Training in taxonomy

Around 20 project staff of the Stemborer Biological Control Project were provided with training in stemborer identification of larvae and moths at ICIPE in October 2003. A PhD scholar working on the *Diadegma* complex was also given training in insect morphology in order to understand the important body parts in recognising the different species.

FUTURE OUTLOOK

Within the Grasses Project *(see under Plant Health)*, a guide to the identification of wild grass stemborers and their associated natural enemies will be developed by end-2004. Proposals will also be written for funding to

Table 1. Clientele of BSU provided with services

Institution/ Agency/Group	Origin of specimens	Arthropods submitted	Crops
ICIPE–AFFI	Kenya, Tanzania, Zanzibar	Diptera and Araneae	Coffee and Mango
ICIPE–Biological Control of Stemborers	Kenya, Somalia, Tanzania, Uganda, Zambia	Diptera and Hymenoptera	Maize, sorghum and grass
ICIPE–GTZ Project	Kenya	Coleoptera and Diptera	Cabbage and mango
ICIPE–Biodiversity/ Commercial Insects	Kenya	Hymenoptera	Cabbage
JIRCAS	Kenya	Diptera	Pigeon peas
EARO/DZARC	Ethiopia	Diptera and Hymenoptera	Barley, maize and wheat

Table 2. New additions to the parasitoid voucher collection

Taxa	No. of specimens	Host(s)	Distribution record
Hymenoptera: Scelonidae			
• *Telenomus isis* Polaszek	165FF	*Busseola fusca* (Fuller)	Kenya (new record)
	65MM	*Sesmia calamistis* Hampson	Kenya (new record)
• *Telenomus soudanensis* (Risbec)	5FF/3MM	*Busseola fusca* (Fuller)	Kenya (new record)
		Sesamia calamistis Hampson	Kenya (new record)
Hymenoptera: Trichogrammatidae			
• *Trichogramma* sp. n.	12FF/1M	*Busseola fusca* (Fuller)	Kenya (new record)

support 'Biosystematics as a Tool in Understanding the Arthropod Biodiversity Surrounding the Agricultural Landscape in Africa'. A second proposal on 'Farmer Empowerment in Understanding Diversity of Crops and Arthropods to Improve Their Livelihood' will be conceptualised and submitted for funding.

CAPACITY BUILDING

PhD student

Maxwell Billah (Ghana) The revision of *Psyttalia* species (Hymenoptera: Braconidae), parasitoids of fruit infesting flies (Diptera: Tephritidae) in Africa. PhD, University of Ghana, Legon, 2003. Supervisors: S. Kimani-Njogu, W. A. Overholt (ICIPE) and Prof. D. Wilson and Ms. Cobbleh (University of Ghana).

OUTPUT

Journal article

Lux S. A., Copeland R. S., White I. M., Manrakhan A. and Billah M. K. (2003) (Short communication) A new invasive fruit fly species from the *Bactrocera dorsalis* (Hendel) group detected in East Africa. *Insect Science and Its Application* 23, 355–361. **(Call No.: 03-1733)**

A new fruit fly species suspected to be from the *Bactrocera dorsalis* (Hendel) group (originating from Asia), was detected during routine field surveys in the Coast Province of Kenya. Since most species in this group are of tremendous quarantine concern when introduced, and considering the fact that it has never before been detected or reported in continental Africa, surveys were immediately initiated covering a distance of over 3000 km across major fruit-growing and trading localities within Kenya, to determine the extent of spread of the new invasive species. We report on the detection of the flies, preliminary results of the survey, and discuss the potential effects of these flies on the horticulture industry in East Africa.

Participating scientists: S. Kimani-Njogu (to April 2003), A. Barrion

Assisted by: M. Wandago, M. Watiti, H. Mwadime, T. Ondiek

Collaborators: National Museums of Kenya, Natural History Museum (UK), PPRI (Pretoria), Royal Museum of Central Africa, Tervuren

Donors: ICIPE Core Fund donors and projects

SOCIAL SCIENCE AND TECHNOLOGY DELIVERY DEPARTMENT

Although social science research is a component of most ICIPE projects *(see for instance under the habitat management project in Plant Health and under Ticks Research in Animal Health)*, the Department staff were greatly reduced over the review period until the end of 2003, when plans were made to revive the unit. This step followed on from the recommendations of an external review conducted in 2002.

The new Social Science and Technology Delivery Department (SSTDD) at ICIPE has developed as a direct response to ICIPE's strategic goal of deploying science and technology in support of local communities to go beyond emergencies, stem recurrent and seasonal threats of hunger, and ensure sustainable food and income security. The Centre's basic goal is to develop pest and vector management technologies appropriate for the production systems and economic and social circumstances of potential users of such technologies, who largely consist of smallholder agricultural producers and pastoralists. It is now widely recognised that the efficacy and sustainability of new pest and vector management technologies can be made more robust and their adoption and impact greatly enhanced when socioeconomic analysis is effectively integrated in the research and development process. This socioeconomic research must be integrated in the R&D process from the very inception of a research activity to the final evaluation and use of the resulting technologies. Substantive collaboration and partnership between biological and social scientists is a key element in this process.

The SSTDD is mandated to undertake basic and operational research to facilitate the design and development of technology, taking full account of the conditions, needs and demands of resource-limited farmers in the tropics. It is also expected to elucidate the socioeconomic dimensions of research in insect science and its application by participating in priority and policy setting, and by contributing to ICIPE's capacity building and training programmes, such as the African Regional Postgraduate Programme in Insect Science (ARPPIS), short-term attachments, supervision of students and farmers' training courses.

Substantive areas of research include:

- indigenous knowledge and technology;
- characterisation of production, environmental and health systems of local communities and end-users;
- determination of economic viability (costs, benefits and affordability) of the technology;
- user-participatory research;
- assessment of technology adoption potential;
- assessment of technology adoption paths;
- Assessment of marketing outlets of pest and vector management technologies;
- facilitating integration of technology components at the community level to address food and income security and health issues;
- ex-ante and ex-post impact assessment in economic, social and environmental terms.

Over the next review period, substantial effort will be devoted to re-building the Department's human and financial resources to enable it to carry out its full mandate. Simultaneously, the Department will work in partnership with bioscientists, extensionists, NGOs and community-based organisations in all phases of technology development. It will build on community resources, capacities and priorities and work to link communities with opportunities and technological advances in agricultural health and environmental sciences. The staff will collaborate with social and biological scientists in national agricultural and extension systems, national universities and international agricultural research centres to accomplish the above objectives.

CAPACITY BUILDING

PhD students

D. Wanyama-Masinde (Kenya) Impact of farmer participation technology adoption and diffusion: An assessment of a collaborative project in Trans Nzoia, Kenya on the use of fodder host plants for the control of stemborers in maize. PhD, University of Nairobi (2003). Supervisors: Z. R. Khan, J. Ssenyonga (ICIPE), A. Chitere (University of Nairobi).

Anderson Kipkoech (Kenya) The socio-economic impact assessment of biological control of cereal stemborers in maize growing belts of eastern and southern Africa. Moi University.

Esther M. Njuguna (Kenya) Economics of habitat management strategies in maize and livestock production by controlling stemborers and striga weed in mixed farming systems. University of Nairobi.

Paul Wachana (Kenya) The community-managed tsetse and trypanosomosis technology in Lambwe Valley. PhD, Moi University. Supervisor: S. Ssenyonnga (ICIPE).

MSc students

Wycliffe Wanzala (Kenya) Evaluation of anti-tick natural products used in livestock health management by the Bukusus in Bungoma district, Kenya. Wageningen University, the Netherlands.

(See also the lists of PhD and MSc students under the Capacity Building Report.)

Participating scientists: J. Ssennyonga (2002), A. Pala (from end-2003)

Collaborators: Kenya Agricultural Research Institute (KARI, Kenya)

TECHNOLOGY TRANSFER UNIT

This report focuses on the Technology Transfer Unit's (TTU) efforts to establish demand-driven outreach activities mainly in Suba, Maragua and Mbeere districts of Kenya and also in Ethiopia's Biovillage Project. *(See also the Population Ecology and Ecosystem Science Department report.)* Training to facilitate uptake and sustainability of these technologies was also carried out. The training unit is based at Duduville for it to function as a national, regional and international programme. TTU moved to its new offices at Mbita Point Field Station on 7 February 2002.

To integrate the ICIPE 4Hs (human, animal, plant and environmental health), enhance ownership, reduce the dependency syndrome at community level, and to facilitate collaboration, it has become necessary to work with farmer groups using FFS (Farmers Field Schools) approaches. To achieve this, the coordinator spent the first three weeks of March 2002 conducting hands-on-training for the two eco-trainers at MPFS. The training was meant to equip them with basic FFS skills, develop training curriculum with farmer groups and integrate the group programmes in their overall (mega) work-plan. The idea is to target women groups, the 4K clubs (school children), youth groups and farmer (mixed) groups and to develop need-based training programmes.

There has been some progress in the amount and quality of work with farmer groups in Suba district. By end 2002, there were activities with eight groups (three women groups, four farmers groups and one 4K club. Some of the activities started in 2003 include:

- Organic kitchen gardens to improve household nutrition in Suba district
- Maragwa Ridge Organic Mango Pilot Project
- Mwingi bee-keepers: Training in coping strategies for the larger grain borer (LGB)
- Bee-keeping training for Muli Children Family Home for income generation
- Community-based tsetse control in Mwea area (funds available since 2003).

WORK IN PROGRESS

1. Outreach for farmers groups and other projects in other parts of Kenya

Maragua Ridge Organic Mango Group

Due to increased pest pressure, spraying costs, reduced production and income from mango production, the Maragua Ridge Organic Mango Group, approached ICIPE for training in mango IPM through the Kenya Institute of Organic Farming (KIOF) in 2002. Following the request, a training needs assessment for the group was carried out late in 2002.

The project was implemented in collaboration with the AFFI project, the ICIPE Plant Health Division, KIOF and the Maragua Ridge Organic Mango Growers. The initiative addressed all the major pests and agronomic problems limiting quality mango production through a season long hands-on training programme in mid June 2003. A total of 14 nominated farmers participated in the training.

A baseline study on knowledge, practice, production and marketing, was conducted in January–May 2003, before the training course started. The bulk of the information for the mango IPM training module was collected. This information has to be collated and processed for further field use. Some of the early adopters are already practising some of the IPM options in their own orchards and the results are encouraging.

The group organised and held field days on 22 july and 16 November 2003 to share information about mango IPM and organic approaches with other farmers within the community. The Field Days, facilitated by the trainees, were well attended and the farmers were enthusiastic about some of the interventions. Information on mango post-harvest technology, will be collected early 2004.

Due to the importance of mangos in East Africa, the information and experience generated from this pilot site will be used to develop a regional project to reach more farmers.

Mwingi Beekeepers Self-help Group

The Mwingi bee-keepers group in Eastern Province, a semi-arid area of Kenya, requested assistance on how to cope with an outbreak of *Prostephanus truncatus*, the larger grain borer, which is a new pest of cereals in granaries in the area. In response to this, the project organised for a consultant from Tanzania with experience in on-farm strategies to conduct a ToT for group representatives in February 2003, as a short-term strategy to improve food security in the area. The information gained in Tanzania, where the LGB was first reported, can be adapted and fine-tuned for use by farmers in LGB-affected areas in Kenya. In the long term, there may be a need to develop LGB-resistant maize varieties and effective biocontrol of the pest in the wild. The course facilitator was assisted by Matilda Ouma (eco-trainer at MPFS).

The training in coping strategies for the larger grain borer course was conducted from 26 January to 7 February 2003 at Mwingi town and was organised in close collaboration with the ICIPE Commercial Insects Programme (Plant Health Division), the Tanzania Ministry of Agriculture and Food Security and the Mwingi District Agricultural and Livestock Development Office. The course combined field visits, group work and discussions. The trainees conducted their practical sessions with farmer groups in Kiomo location, Mwingi district.

Twelve nominated farmers from various parts of the district and five extension workers under Mwingi district Ministry of Agriculture and Livestock Development completed the course. These will be the nucleus for further dissemination of the coping strategies to other farmers in the district.

Muli Children Family Home Beekeeping Project

The Muli Children Family Home (MCFH) located in Ndalani location, Matuu division, Machakos district, Eastern province, is home for 500 to 600 children (orphans, rehabilitated street children and children from destitute families). Part of the land still maintains the indigenous acacia tree species that are known to attract a wide range of honey bees.

The main objective of this project was to introduce modern apiculture for income generation and for providing the institute school leavers with beekeeping skills through a cost sharing approach. The Institution provided labour to make hives and hive stands, hang up the hives, and carried out regular maintenance of the apiary including labour for fencing the apiary. TTU provided all the necessary logistical support and technical know-how for proper establishment of an apiary.

This is a joint activity between the ICIPE Commercial Insects Programme and the Technology Transfer Unit (TTU). The project is run under the umbrella of TTU. The training was hands-on to ensure full participation and continuity. Established colonies were used for demonstration (teaching aids) and practical lessons.

An intensive residential one-week training at ICIPE apiary for the club patron has been organised to take place in January 2004 to facilitate regular on-site technical support to the bee club members. Draft beekeeping teaching materials have been prepared for school children. These will be tested in 2004.

Mwea National Reserve Community-Based Tsetse Control

The Mwea National Reserve, covering an area of 68 km² is located in Mbeere district, Eastern Province. The Reserve is jointly managed by the Mbeere County Council and the Kenya Wildlife Service (KWS). Due to the proximity of the Reserve to human settlements, tsetse flies breeding on wild ungulates within the reserve have continued to be a source of conflict to effective conservation efforts. For sustainability, it was deemed necessary to develop a community-based tsetse control programme to reduce the conflict. A three-year project that aims to introduce community-based environmentally acceptable tsetse control technology was initiated in March 2003. The project combines tsetse control using the ICIPE NGU tsetse trapping technology and promotion of conservation related and compatible income-generating activities to support and encourage sustainable community participation and contribution in the management and conservation of biodiversity in the Mwea National Reserve.

The initiative targeted all the villages bordering the Mwea National Reserve as these are the most affected by the tsetse population emanating from the Reserve. A combination of awareness group meetings and joint planning with affected communities was used to enlist community participation. As a result, nominated members of the community were trained on how to construct the NGU trap, trap deployment, servicing and maintenance in July 2003 (Figure 1). A total of 54 trainees (37 men and 17 women) participated in a hands-on training of trainers (ToT) course on deployment and servicing of the ICIPE NGU tsetse trap that took place on 7 to 9 July 2003.

Figure 1. Course participants nominated from the Mwea National Reserve community learning trap deployment on the ToT course held on 7 July 2003

By the end of July 2003, the course graduates, in collaboration with members of the community, KWS and ICIPE, had deployed 326 traps within the Reserve. Furthermore, 161 barrier traps were deployed around the reserve to prevent escaping flies reaching homesteads in all the villages bordering the MNR.

Overall, there has been appreciable reduction in tsetse flies within the reserve and its environs. However, incidence of trypanosomosis infection in cattle around the reserve was confirmed during a survey conducted in December 2003. The infection level was 7 to 18% in all the cattle sampled.

In recognition of the need for continued tsetse control beyond the project phase, the community has formed a tsetse control management group whose major responsibility is overseeing sustainability of the initiative.

Baseline information on the socioeconomic status of the community was conducted in 2003 and the information is available as a report. The project is being implemented in close collaboration with KWS, the Mbeere County Council and the communities.

Visit to Ethiopia

The objectives of the visit to Ethiopia were to clarify the role and function of the Technology Transfer Unit; to discuss, identify and prepare a concept for funding and to familiarise with the Biovillage community training initiative.

The familiarisation tour took the form of discussions, observations, reading project reports and field visits to the biofarm and the biovillage. The biovillage is a modified farmer field school that is catering for the needs of the Gurage farming system. To operate on the farmer field schools model, training should focus on demand-driven technologies. This change will require regular dialogue and planning with the beneficiaries to make the interventions demand driven.

2. Initiatives at Mbita Point Field Station

Beekeeping

The programme at MPFS continued to support modern beekeeping among interested farmers in close collaboration with the Commercial Insects Programme, the IFAD-Trickle Up Project and Honey Care International.

Ruma Park Honey Makers Self Help Group (RPHM) registered 14 beekeeping groups. The initiative was implemented in several steps. First, the beekeeping status among the individual groups was established. Then a 3-day training on improved bee-keeping techniques was held for 30 farmers (bee-keeping promoters), two from each of the 15 groups.

Beekeeping was promoted through training and technical support to groups under the umbrella group of Ruma Park Honey Makers (RPHM). The emphasis was on the ICIPE Commercial Insect Programme-developed modern beekeeping technologies based on the Langstroth hives. Through this group, it is possible to reach about 174 other farmers with a total of 127 beehives.

Striga management

Promotion of the use of KSTP-94 maize variety with tolerance to striga attack among the contact farmer groups was done in close collaboration with KARI-Kakamega. KSTP-94, developed by KARI-Kakamega, is a composite high yielding drought tolerant maize variety that is also tolerant to striga infestation. Being a composite variety, farmers can select for planting seed at harvest and it is therefore ideal for resource limited farmers.

Farmers were very happy with the performance of the variety. KSTP-94 gave a grain yield of 16 (90 kg) bags compared to 6–8 (90 kg) bags obtained from local white and local yellow varieties. KSTP-94, a maize variety tolerant to striga attack, was given to six farmers of the Seredo Women Group on credit who established it on one and 0.2 ha plots for bulking. Due to the prolonged dry period, the variety did not perform as expected; but the group members appreciated its attributes compared to the traditional hybrid varieties now grown in the area.

During 2003, 100 kg of breeder seeds was soured from KARI-Kakamega by the project and sold to interested farmers for planting during the long rains. Farmers from Seredo and Victor Musoga groups planted a total of 72 kg of KSTP-94 breeder seeds. The overall yield performance was good especially for farmers who planted early and weeded twice.

The participating farmers were impressed by the good yields achieved under heavy striga infestation and the degree of tolerance to drought. They are willing to adopt KSTP-94 and are willing to purchase KSTP-94 seed maize from farmers who bulked enough to plant in the subsequent long rains.

Cassava

Cassava mosaic disease resistant varieties were promoted among some groups in Suba district, in collaboration with the ICIPE/IITA/KARI project, as a strategy to improve food security among the community. Unfortunately, cassava is not a popular crop and therefore its uptake is rather slow.

Five farmers from the Seredo Women Group got the mosaic virus free (MVF) cassava cuttings for bulking but the dry spell affected the establishment. The group organised a field day in collaboration with TTU, AEP, MOARD and invited Nyatoto village members (non-member) and the local administration on 31 May 2002. The day was a success. Villagers are now requesting for the cassava mosaic-free planting material. Cassava mosaic free cassava cuttings were provided to three additional farmers for bulking to ensure availability of adequate planting material during the next long rainy season to the group members.

Overall, there is an increasing awareness and interest in cassava among other farmers in District where the crop was not traditionally grown. The project has been requested by farmers to continue assisting in sourcing for improved planting materials.

Rain water harvesting and school gardens

TTU is working closely with the Rural Youth Officer Suba district to develop the Osodo Primary 4K club in Gembe Central, Mbita Divison. The group requested to be given training in tomato and kale production. TTU is doing this training in close collaboration with MOARD.

Water availability for vegetable production during the dry season is a major constraint for the school. The rain-water harvesting project was started with sponsorship from a private donor on cost sharing basis. (The Osodo community provided unskilled labour and some locally available materials.) The construction work for the water storage facility started in December 2002. The facility, based on roof-catchment, was completed in September 2003 at Osodo Primary School to facilitate access to potable water by the school children. The 4-K Club organic vegetable garden is being irrigated using this water. The club grows both exotic and indigenous vegetables.

Neem nursery

Seedlings raised were sold to interested farm groups and individuals at Kshs 20 each. Unfortunately, despite the fact that many of the neem trees in Suba district are at fruit bearing age, birds eat many of the seeds. As a result, seeds for the nursery have to be bought from the Coast.

Poultry keeping

A survey of poultry keeping status was conducted for the Bungkwach Seed Growers Association (BUSGA) within the village. A savings and credit scheme was started in 2002. Thirty-two farmers attended a 4-day course on improved local poultry keeping in the same year. As a follow-up to improved poultry keeping training, a 2-day vaccination campaign against Newcastle disease was organised within the village. A total of 800 birds were vaccinated. As a result of the training on improved poultry keeping, three farmers have constructed improved poultry houses while one farmer has started keeping exotic layers.

Tsetse control

The explosion of the tsetse populations in the district, which has led to massive loss of draught power, was voiced strongly during a one-day collaborators' meeting held on 7 March 2002. After consultation with ICIPE scientists, the DC Suba district and the Ministry of Agriculture and Livestock Development Suba district, it was strongly suggested that short and long term strategies be initiated to address the issue. The need for a team approach, which should involve the communities, KWS, KETRI, the DC's office, and the Ministry of Agriculture and Livestock Development was emphasised. It was thus agreed that the Kisabe community, which has been involved in routine tsetse trapping for the last 10 years, be reviewed as a special case study to draw on their experiences. The lessons from the Kisabe community would be used in planning future strategies for tsetse management in the district.

Identification and sensitisation of communities around the Ruma National Park for purposes of further planning of community-based action plan was carried out late in 2002.

Kuja River Cow Improvement Project

The project continued well despite persisting drought during the year. The Kuja River Site Cow Improvement Project is under the management of the MPFS station manager. A total of 31 bull services were provided for December 2001 to June 2002. The service to the community is done on cost sharing basis. For each service, a farmer pays Kshs 100. The cows started calving in May 2002. To date, six of the cows have calved.

3. Technology outreach in Suba District, Kenya

January–March 2002 was spent on introducing new working modalities to enhance the ICIPE outreach programme in Suba district. The focus was on the following (i) establishing working protocol and modality for the Unit; (ii) provision of hands-on training to the eco-trainers to work with established groups as opposed to villages, and how to work with farmer groups ; (iii) identification of collaborators to facilitate uptake of information and technologies from ICIPE and other relevant institutions; (iv) establishing working relationship with ICIPE research programmes and (v) identification of pioneer farmer groups in Suba district for training the eco-trainers.

Technologies promoted during 2002 through contact farmer groups include:

- Push-pull strategy for the control of striga weed and stemborers in cereal-based cropping systems.
- Tsetse traps (NGU trap) awareness creation.
- Planting of neem.
- Organic farming (conservation farming) approaches
- Improved ICIPE bee keeping (American 10-frame Langstroth hives and other modern beekeeping) technologies.
- Mosaic virus free (MVF) cassava varieties particularly SS4 and Migyera
- Indigenous vegetable farming.
- Improved local poultry keeping methods
- KSTP-94 striga-tolerant maize variety to complement the push-pull strategy for stemborer/striga control.
- Introduction of credit system through the Agriculture and Environment Programme (AEP) of the Homa Bay Diocese.
- Cost sharing through seed loans.

The emphasis was on hands-on learning with existing farmer groups on demand-driven interventions. Collaboration with the Ministry of Agriculture and Rural Development, the District Commissioner, NGOs and community-based organisations (CBO) was sought.

Different participatory technology dissemination approaches were used. A combination of traditional and modern (field visits, needs assessment ToTs, group meetings, field days, exchange visits, participatory evaluation and assessment of results) extension methods were used depending on the problem, available interventions and resources. Time was also devoted to strengthening small working groups, farmers groups and to building farmers' confidence.

Suba district organic kitchen gardens

The goal of this project has been to improve the nutritional status of children and women in Suba District through improved vegetable and fruit production and availability. The project, which started in 2002, worked with five women/farmer groups in the District to: (i) create awareness about conservation farming and organic kitchen gardening; (ii) train group members to establish organic kitchen vegetables and fruit gardens; (ii) promote the use and conservation of indigenous vegetable seeds at households levels.

An internal impact assessment was carried out in January–June 2003. The results indicated that members of the five farmer groups trained in conservation organic kitchen gardening continued to be role models for other farmers in the district. As a result, the Suba district National Agriculture and Livestock Extension Programme (NALEP) is intending to scale up the technology to reach many more farmers.

Vegetable availability and farm gate prices in the neighbourhood of practising farmers remained stable throughout 2003 including during the dry season. Fruit production and availability is still minimal as the trees are not yet at bearing age.

A summary of the major achievements indicates the following:

- The popular indigenous vegetables including 'osuga', 'dek', 'mtoo', 'boo' and pumpkins, were promoted within the community by TTU through the seed loan (seed-for-seed) initiative started in 2002.
- An improved 'osuga' known as Nya-ICIPE, is very popular with farmers in terms of acreage being grown and its utilisation at household level because it is high yielding, drought tolerant, tasty, easy to cook and manage.

The communities identified the following as challenges to adoption of the conservation-based kitchen gardens:

- The options promoted by KIOF, particularly double dug bed, deep dug and fertility trench, for soil and water conservation, are labour-intensive.
- The demand for planting indigenous vegetable seed could not be met because of inadequate supply from the seed loan initiative. The range of vegetables available was also limiting.
- Most farmers did not have enough cash to purchase exotic vegetables from reliable stockists.
- The production of exotic vegetables is a new innovation in the district and so agro-businesses do not see the justification to stock seeds.

The following are the general trends:

- Vegetable production and supply among the group members remained stable throughout the reporting period including during the dry seasons. There was no seasonality gap in vegetable production. Thus, there was continuity in consumption and sales of different varieties of vegetables (both indigenous and exotic) in varying quantities throughout the reporting period.
- Conservation farming significantly increased vegetable yields and availability among practising members over the reporting period. The results of the market study and focused discussions for income usage conducted over the period have shown that the technology had a significant impact on households' monetary income. At least each farmer with a conservation-based organic kitchen garden was able to earn Kshs 40 per day from the sale of surplus vegetables during the dry period for the first time.
- Due to improved vegetable production and availability both at groups and household levels, the farm gate prices as at September 2003 were lower (e.g. 4 leaves of kale/ Kshs 1) compared to prices over the same period (1–2 leaves/ Kshs 1) in the year 2002.
- Six other new groups (Sigulu, St Margarita, Koito, Sawanka, Aringo and Ruma pap) adopted the technology. As a result, more vegetable varieties have been introduced.
- The acreage under conservation-based organic kitchen gardens at the nucleus groups has increased. In 2002, the acreage under conservation kitchen gardens was approximately 0.64 ha but this has increased to approximately 0.96 ha by the end of 2003 (Table 1).

Table 1. Impact of conservation-based organic kitchen gardens in Suba District, Kenya, 2002 to 2003

Year (No. of groups)	Active members	New/ impact groups	Active members in the new groups	Acreage under conservation-based organic kitchen gardens	Vegetables introduced[1]	Vegetable availability	Price fluctuations	Seeds loan recovered from groups
2002 (7)	111	3	16	Approx. 0.64 ha	'Osuga', Nya-Luo, 'Dek' 'Mtoo', 'Boo' Nya-ICIPE Pumpkin, 'Apoth'	Some seasonal gaps in supply observed	1–2 leaves of kales per Kshs 1	800 g
2003 (5)	223	6	92	Approx. 0.96 ha	'Osuga' Nya-ICIPE[2] Others[3]	No seasonal gaps in supply observed	4 leaves of kales per Kshs 1	5800 g

[1]Only traditional vegetables were introduced to the groups.
[2]These were mostly sourced from outside the District and bulked by the eco-trainers at MPFS before distribution to farmers. The vegetables included 'osuga' Nya-Luo (*Solananum nigrum*), 'dek', 'mtoo' (*Crotalaria* spp.)-mild, 'boo' (cowpea) Nya-ICIPE, pumpkin, and 'apoth'.
[3]Apart from 'osuga' Nya-Luo/ICIPE which were introduced to farmers by the project, farmers have introduced different types/races of the original types: 'osuga' Nya-Kisii/Kakamega, 'mtoo'-bitter type, 'boo'-different races of local type.

Table 2. Type and quantity of indigenous seeds recovered per group during 2003 through the seed loan (seed-for-seed) initiative to farmers' groups in Suba District, Kenya

Group	Vegetable					
	'Osuga'	'Dek'	'Mtoo'	Cowpea 'boo'	Pumpkin	Total
Ndiru	350 g	50 g	400 g	500 g	50 g	1350 g
Victor	100 g	50 g	100 g	250 g	30 g	530 g
Bonde	150 g	50 g	100 g	250 g	50 g	600 g
Seredo	250 g	250 g	200 g	250 g	40 g	990 g
BUSGA	150 g	80 g	100 g	250 g	30 g	610 g
Total	1000 g	480 g	900 g	1500 g	200 g	4080 g

- The effort to promote production and consumption of indigenous vegetables in the district through a seed-loan system has been successful (Table 2).
- Fruit tree growing is also promoted under the conservation-based organic kitchen garden initiative. As a result, all participating groups raised fruit tree nurseries with the help of the KIOF students on attachment and technical backup from the eco-trainers. To date, pawpaws (*Carica papaya*) and purple passion (*Passiflora edulis*) have started fruiting. Most of these are at the individual garden level for household use.

This project is being implemented in collaboration with KIOF, the Ministry of Agriculture and Livestock Development Suba district and farmer groups.

Osodo Farmers' Development group activities:

- Twenty farmers got seed of the promoted indigenous vegetables on loan.
- A field day was held on 31 July 2002 at one farmer's shamba. Fifty-two farmers attended the event.
- Indigenous seeds were recovered from the farmers. These recovered seeds were loaned to other farmers on condition that they too would give some seeds back at harvest to facilitate continuous availability and so reduce loss of the material.
- The group organised a seed day for farmers to exchange indigenous vegetable seeds and other new crop varieties among themselves.
- Two sessions to raise awareness on the importance of organic and conservation farming were organised.

Ndiru Women Group activities:

- A 2-day session on the introduction to organic (conservation) farming was held.
- A farmers field school focusing on organic vegetable growing and kitchen gardening (189 m^2 plots of kales and 180 m^2 plots of tomatoes on double dug beds) was established.
- Hands-on training of group members on vegetable nursery establishment, transplanting and conservation farming (double digging, mulching etc.) was completed.
- Indigenous vegetables were introduced and about one kg loan seeds were given to the group.
- 189 m^2 plots of kales, 180 m^2 plots of tomatoes and 99 m^2 of indigenous vegetables were established under double dug beds.
- Kitchen gardening using basket compost, movable gardens, double dug beds and trench compost techniques was promoted to group members.
- A demonstration on proper use of neemros 0.3% for cutworms and crickets (the major insect pests of vegetable nurseries and new transplants in the area) was held.

Victor Musoga Farmers Group activities:

- Organic (conservation) farming concept (three sessions) was introduced to the group members.
- A farmer's field school focusing on organic vegetable growing and kitchen gardening was held. Group demonstration plots (270 m^2 plot of kales, 180 m^2 plots of tomatoes, 180 m^2 plots of indigenous vegetables) were established.
- Use of neemros 0.3% for the control of cutworms and crickets in vegetable nurseries and new transplants were promoted.
- Hands-on training of group members on vegetable nursery establishment, transplanting, double digging and mulching was conducted.
- Organic kitchen gardening was promoted. Six farmers have already established kitchen gardens in their homes. These will be used for further training of other farmers in the area.
- Use of neem powder for pest control was demonstrated.

Bonde Women Group activities:

- A two-day awareness session on organic farming concept was held.
- Use of neemros 0.3% for controlling soil insect pests in vegetable gardens was demonstrated to the group.
- A Farmer Field School (FFS) was started.
- Hands-on training session on vegetable nursery establishment, transplanting and mulching was conducted.

Bungkwach Seed Growers Association (BUSGA):

- Two sessions on the importance of organic (conservation) farming were conducted.

FUTURE OUTLOOK

- The indigenous vegetables initiative is very popular with the groups, creating a lot of enthusiasm among members. More accessions need to be identified and bulked for further on-farm bulking and sharing among farmers. In addition, farmers should be trained on how to conserve and preserve seeds for future use to ensure continuity and availability of planting material particularly after prolonged dry spells. This should be linked with conservation farming and kitchen gardens to ensure sustainability.
- The loan seed scheme initiated under the indigenous vegetable activity has shown that farmers can be entrusted and empowered to propagate technologies as long as there is demand within the community.
- Local poultry keeping appears to be another entry point to group development. The case of BUSGA is very encouraging and can form a basis for extending this initiative to other groups. Areas of intervention include improved housing and equipment, feeds and feeding, hatching and brooding management, flock management, upgrading of the flock, disease control and commercial poultry keeping.
- Using successful farmer responsive entry points (demand-driven technologies/initiatives), it is possible to build up community study groups and to focus on different technologies simultaneously, e.g. push-pull strategy, beekeeping, local poultry keeping, organic vegetable growing and organic kitchen gardening, thus addressing different interests within a particular group.
- Preliminary baseline information on current beekeeping in the Mwea National Reserve area was collected in August 2003. The traditional log type of hive is predominant in the project area and therefore women may not be actively involved in bee keeping. Future plans should promote modern beekeeping that will enable women take an active role in the industry and facilitate production of quality honey in the area.
- To facilitate uptake and sustainability, additional training approaches, e.g. group exchange visits, networking among groups, newsletters, relevant organised visits to research institutions and provision of new information (information update) would be invaluable to existing groups.

CAPACITY BUILDING

Students on attachment

Ms Franziska Schwab was on attachment to the programme from November 2001 to March 2002, from Biovision, Switzerland.

Dr Claudia Friedl from Biovision headquarters in Switzerland was on attachment to the programme from 1 August 2002. She was based at the ICIPE Mbita Point Field Station.

Two interns from the USA and 10 students from local polytechnics and agricultural institutes spent 4–6 weeks on the project, as well as one anthropology student from the University of Nairobi

Table 3. Training of trainers (ToT) courses conducted in 2002

Date	Beneficiaries	Collaborators	ICIPE programme	Number trained
5th to 10th Aug	Kenya Frenchbean small scale growers	Kenya Ministry of Agriculture and Rural Development (MOARD), Winrock International, East African Growers, KIOF, HCDA, Kerio Green	ICIPE/USAID French bean project	12
12th to 16th Aug	Smallscale vegetable growers in Kiambu, Muranga, Maragua and Nyeri districts, Central Province, Kenya	Kenya MOARD, FAO-Kenya office	Horticulture Sub-division, Plant Health Division	21
26th to 31st Aug	Kale and cabbage growers in Kenya and Tanzania	Kenya MOARD and Tanzania Ministry of Agriculture and Food Security (MOAFS)	DBM Project under the Plant Health Division	17
23rd to 27th Sept	Suba district community	KIOF and farmer groups in Mbita, Central and Ogongo division	TTU	10
8th to 11th Oct	Magana Flowers	Flower Label Programme (FLP) and Magana Flowers	Horticulture Sub-division, Plant Health Division	15
22nd to 25th Oct	Sofia Roses	FLP and Sofia Roses	Horticulture Sub-division, Plant Health Division	15
4th to 7th Nov	Stoni Athi	FLP and Stoni Athi	Horticulture Sub-division, Plant Health Division	15
25th to 28th Nov	Smallscale Frenchbean growers	Indu Farm and Muli Children Family Home (MCFH)	Horticulture Sub-division, Plant Health Division	20

Table 4. Training of Trainers (ToT) courses conducted in 2003

Venue/Date	Project/Sponsor	Number of participants
Arusha, Tanzania 20th to 25th January	DBM biocontrol programme/ Tanzania Ministry of Agriculture and Food Security	14 (5 women and 9 men)
ICIPE-Duduville 9th to 20th June	Smallholder Irrigation Improvement Component, Tanzania Ministry of Agriculture and Food Security/EU-KARI	5 (1 woman and 4 men)
Arusha, Tanzania 21st to 25th July	Sunripe (Serengeti Fresh) Export crops/PIP	13 (1 woman and 12 men)
Laikipia, Kenya 5th to 8th August	PIP/Sunripe Export crops	3 men
Ruiru Kenya	FLP/Redland Roses, cutflowers	10 men
Ol Donyo Sabuk, Kenya 30th Sept to 19th Dec	ICIPE/USAID support to smallholder export vegetable growers for compliance with EU regulations on MRLs and hygiene standards in French bean production	37 (7 women and 30 men)
ICIPE/Duduville 22nd to 24 October	ICIPE/USAID support to smallholder export vegetable growers for compliance with EU regulations on MRLs and hygiene standards in okra production	10 (2 women and 8 men)
ICIPE/Duduville 2nd to 15th November	ICIPE/CPP: Private service providers for the Horticulture industry in Kenya with funding from DFID	19 (6 women and 13 men)
Kampala, Uganda 23rd to 29th November	DBM biocontrol/ NARO with funding from Biovision	19 (4 women and 15 men)
TOTAL		130 (26 women and 104 men)

Training courses organised

Several specialised ToT courses were organised in collaboration with the Plant Health Division (ICIPE). These covered the following topics: French beans IPM for small scale farmers (USAID Kenya support to ICIPE); biological control of the diamondback moth in highland areas (sponsored by the DBM project); technical support to the FAO/FFS facilitators in the Central province of Kenya (sponsored by FAO Kenya) and targeted extension workers only.

Training of Trainers (ToT) courses conducted in 2002 and 2003 are shown (Tables 3 and 4). All the eco-training courses during 2003 were conducted in collaboration with the ICIPE Horticulture Unit.

OUTPUT

Internal reports

Macharia I. and *Nyambo B.* (2003) Impact of integrated crop management training on Maragua ridge mango production: Baseline data on knowledge, practice, marketing, and production economics. TTU Internal report, May 2003, unpublished.

***Nyambo B.*, Ouma M. A. and Ndong'a H. (2003)** Suba District Organic Vegetable Kitchen Gardens Project: Impact Assessment, January/June 2003.

Publicity

SF-DRS filming of BioVision activities, 5 to 15 February 2002 was successfully implemented as planned.
TTU prepared a poster for the MPFS field day on 21 June 2002.

Workshops attended

TTU Eco-trainer participated as an observer during a one-week capacity building training session organised by UNDP for BUSGA group (TTU contact group).

TTU Eco-trainer facilitated two weeks PRA exercises held at focal areas of Lambwe and Mbita Divisions organised by MOALD-NALEP (National Agriculture and Livestock Extension Programme).

Workshops organised

The first planning workshop was held on 6 to 10 May 2002 at Mbita Point Field Station.

Project proposals

In 2002, the Unit was actively involved in the development of joint technology transfer project proposals with the Plant Health Division (ICIPE), FAO, ApproTech and East African Growers.
Proposal on an Eco-Training Centre.
Improved local poultry keeping
Promotion of Cassava Mosaic disease tolerant cultivars to enhance food security.
Organic vegetable growing and kitchen gardening.
Enhancing maize production through the dissemination of new information, e.g. PPS- Napier/demodulation, KSTP-94 striga tolerant variety, early maturing seed varieties, Lagrotech early maturing varieties and better post-harvest storage facilities and technologies
Modern beekeeping promotion
Promotion of neem tree planting and utilisation.

Consultancy services

Technology Transfer Unit carried out a number of consultancies in close collaboration with the Plant Health Division, the FAO (Kenya office) and the private sector (mostly flower and vegetable exporters in Kenya).
A 19-day consultancy to Tanzania sponsored by AGPF-FAO and Tanzania Ministry of Agriculture and Food Security to assess the status of the elegant grasshopper in Kondoa district, Dodoma Region, Tanzania, was carried out from 31 August to 17 September 2003.

Participating staff: B. Nyambo (Unit Head)

Assisted by: M. A. Ouma, H. Ndong'a

Collaborators: MOARD; AEP; KIM; District Commissioner, Suba District; Kenya Wildlife Service (KWS); Division of Veterinary Services (DVS); Ruma National Park; World Vision; KIOF; KARI; farming communities in Suba, Maragua and Mbeere districts of Kenya

Donor: Biovision Foundation, Switzerland

ANIMAL REARING AND CONTAINMENT UNIT

BACKGROUND, APPROACH AND OBJECTIVES

The Animal Rearing and Quarantine Unit (ARQU) was renamed Animal Rearing and Containment Unit (ARCU) in order to better reflect the nature of operations. In 2002–2003, ARCU provided cost-effective insectaries, animal breeding and containment services for research and capacity building at ICIPE in Duduville and Mbita Point Research and Training Centre. Some services were provided to NARES and universities, among others. In-house attachment training was also provided to a number of students and interns. Containment services for introduced exotic organisms were provided through the Biologically Secure Laboratory Facility (BSLF). Insects and laboratory animals were monitored regularly to ensure that only those that met the stringent quality criteria were supplied for research.

WORK IN PROGRESS

1. Insectary services

Cereal stemborers

Four cereal stemborer species were reared and supplied for research and training. In Duduville, *Chilo partellus*, *Busseola fusca*, *Sesamia calamistis* and *Eldana saccharina* were cultured. At Mbita Point Research and Training Centre, small colonies of *C. partellus*, *B. fusca* and *S. calamistis* were maintained to cater for local demand. *Sesamia calamistis* rearing was introduced at Mbita in May 2003. Crops were cultivated at Mbita and the leaves processed into powders for artificial diets for rearing all stemborer species at Mbita and Duduville.

The level of production of cereal stemborers increased by 21% from 143,428 in 2002 to 182,448 in 2003. Quantities of *C. partellus*, *B. fusca* and *S. calamistis* produced increased by 13, 44 and 38%, respectively. However, the level of production of *E. saccharina* declined by 35% from 15,353 in 2002 to 9944 in 2003.

A total of 832,102 stemborer eggs, larvae, pupae and adults (Table 1) were supplied in 2003 compared to 720,012 in 2002, indicating a 14% increase in the quantities supplied. Quantities of *C. partellus* supplied in 2003 declined by 35% from 503,024 in 2002 to 325,893 in 2003, despite the 13% increase in production. However, quantities of *S. calamistis* supplied increased by 79% from 14,175 in 2002 to 66,778 in 2003 while that of *B. fusca* increased by 54% from 201,619 in 2002 to 439,431 in 2003. There was hardly any demand for *E. saccharina* in both years.

Chilo partellus: To establish the quality of the laboratory-reared stemborers, random samples of fourth instar larvae (L4) and pupae were taken over five successive generations. The results (Figure 1), indicated that the mean weights were not significantly different in any of the generations, indicating no trends in the genetic drift or loss of performance based on the standard operating procedures (SOPs) followed.

A total of 325,893 *C. partellus* eggs, larvae, pupae and adults were supplied to different research projects in 2003 compared to 503,024 in 2002, reflecting a 35% decrease in the quantity supplied. The demand for eggs decreased in 2003, while demand for larvae, pupae and adults doubled compared to that in 2002. The demand for laboratory-reared stemborers was evenly distributed throughout the year.

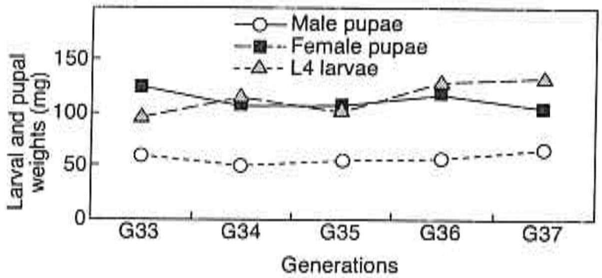


Figure 1. Larval and pupal weights (mg) over 5 successive generations of* Chilo partellus *reared on artificial diet

Sesamia calamistis: A total of 66,778 eggs, larvae, pupae and adults of *S. calamistis* were supplied for research in 2003 compared to 14,175 in 2002, translating to 79 % or a 5-fold increase in the quantities supplied. However, a serious problem thought to be associated with a viral infection, caused severe stunting and general lethargy to the larvae. The cause of the problem was not confirmed. In September 2003, the colony was replaced with wild material and also boosted with pupae obtained from the Mbita insectary.

Table 1. Quantities of cereal stemborers produced and supplied in 2003 compared to 2002

	Number of pupae produced			Number of insects supplied[+]		
Stemborer species	2002	2003	Change (%)	2002	2003	Change (%)
Chilo partellus	86,293	99,688	13	503,024	325,893	-35
Busseola fusca	29,573	53,111	44	201,619	439,431	54
Sesamia calamistis	12,209	19,704	38	14,175	66,778	79
Eldana saccharina	15,353	9944	-35	294	0	-100
Total	145,428	182,448	21	720,012	832,102	14

[+]Insects supplied included eggs, larvae, pupae and adults.

Table 2. Quantities of artificial diets produced and supplied in 2003 compared to 2002

Diet type	Quantity produced (litres) 2002	2003	Increase (%)	Quantity supplied (litres) 2002	2003	Increase (%)
Chilo partellus	2540	3710	32	15	38	61
Busseola fusca	1753	3020	42	254	594	57
Total	4293	6730	36	269	632	57

Busseola fusca: The quantity of *B. fusca* supplied in 2003 doubled that of 2002. A total of 439,431 eggs were supplied from the stemborer rearing facility compared to 201,619 the previous year. In 2003, a total of 53,111 pupae were produced compared to 29,573 in 2002.

Eldana saccharina: There were few requests for *E. saccharina* in 2003. Similarly, in 2002, the demand for *E. saccharina* was low with only 294 assorted stages being requested and supplied. During the review period, 15,353 and 9944 pupae were produced, respectively.

Artificial diet: In 2003, a total of 6730 litres of artificial diets (Table 2) for rearing cereal stemborers were prepared and about 10% supplied to users. The remaining diet was used for rearing the stemborers. In 2002, 4293 litres of the diets were prepared and 6% supplied.

Locusts

There was a reduction in the quantities of locusts produced and supplied in 2003 due to diminished demand. Gregarious (crowded) and solitary (isolated) phases of desert locust, *Schistocerca gregaria*, were reared. A total of 17,650 (63%) gregarious individuals were produced and 5901 eggs, nymphs, and adults supplied. Similarly, a total of 1756 (6%) solitary individuals were produced and 412 eggs, nymphs, and adults supplied.

In the same year, 8610 individuals of *Locusta migratoria* (Figure 2) were produced and 437 nymphs and adults supplied. In total, 28,016 locusts were produced in 2003 and 6338 nymphs and adults of both species supplied.

In 2002, a total of 70,341 *S. gregaria* were produced, comprising 60,370 (82%) gregarious nymphs and 9971 (18%) solitary individuals. During the year, 18,488 gregarious eggs, nymphs and adults were supplied. Similarly, 475 solitary eggs, nymphs and adults were supplied for research and training purposes. In the same year, a total of 15,230 individuals of *L. migratoria* were produced and 2170 nymphs supplied. In total, 85,571 locusts were produced in 2002 and 21,133 eggs, nymphs, and adults of both species supplied.

In 2003, the production and supply of locusts was deliberately reduced by 70% compared to 2002 due to funding constraints.

In April 2003, a small colony of *Locusta migratoria manilensis* introduced from China was maintained. *(See also the report on Locusts and Migratory Pests research.)*

Mosquitoes

Mosquito larvae were reared using water from a spring in Zimmerman Estate, Nairobi, in the immediate environs of ICIPE at Duduville. This water was found to be as adequate as distilled water in perpetuating mosquito colonies in the laboratory. In addition, rainwater catchment tanks were installed and are envisaged to reduce the mosquito rearing costs once in use.

In 2002, two strains of the malaria-causing *Anopheles gambiae* (ex-Ifakara and ex-Mbita) were maintained at the Duduville insectaries. A total of 1,414,066 pupae (Figure 3) were produced, 36% being the ex-Ifakara and 64% being the ex-Mbita. In the same year, a total of 315,551 *A. gambiae* eggs were supplied, comprised of 20 and 80% of the ex-Ifakara and the ex-Mbita strains, respectively.

In May 2003, the filariasis-causing *Culex quinquefasciatus* was introduced into the insectary. Of the 1,292,042 mosquitoes supplied, 40% were *C. quinquefasciatus*. In 2003, a total of 2,781,225 pupae of both species were produced, 70% being *A. gambiae*. A total of 777,750 *A. gambiae* were supplied, comprising 6 and 94% ex-Ifakara and ex-Mbita strains, respectively.

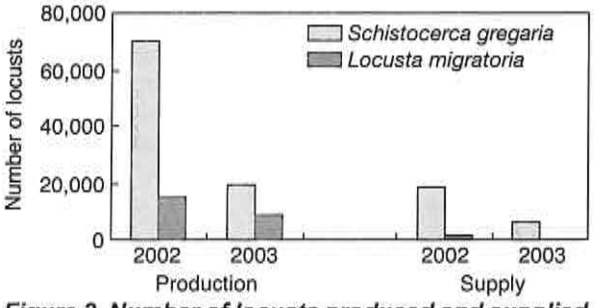


Figure 2. Number of locusts produced and supplied in 2002 and 2003

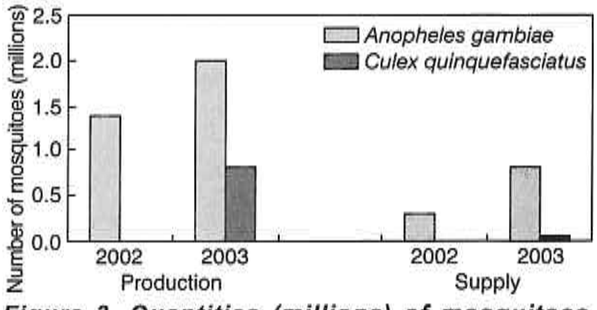


Figure 3. Quantities (millions) of mosquitoes produced and supplied in 2002 and 2003

Tsetse flies

In 2002, limited colonies of *Glossina fuscipes* and *G. austeni* were maintained on pig blood from a local abattoir and using silicon membranes. The level of production was deliberately reduced due to the low demand from users. A total of 5792 pupae of both the species were produced (90% being *G. austeni*) and 616 tenerals supplied. In 2003, only *G. austeni* was maintained.

Ticks

Approximately 160,000 ticks were maintained during the 2002/2003 period. These were *Rhipicephalus appendiculatus*, *Boophilus decoloratus*, *Amblyomma gemma*, *A. variegatum* and *Hyalomma truncatum*. About 5%, comprising *A. variegatum* and *R. appendiculatus*, were supplied for ticks research. The rest were maintained for incidental requests.

Greater wax moth

A small culture of the greater wax moth, *Galleria mellonella*, was maintained during the 2002/2003 reporting period. The demand was extremely low in 2002, and virtually zero in 2003. A total of 3254 pupae were produced in 2002 and 1830 larvae supplied, while 1333 pupae were produced in 2003 and none supplied.

2. Animal breeding services

Only small laboratory mammals were maintained during the period. There were 120 rabbits weaned in 2002 compared to 150 in 2003 and all were supplied for research. Similarly, 90 rats were weaned and 19 supplied. Use of Balb-c mice increased during 2003 with 360 being weaned and 298 being supplied mainly for malaria research.

3. Biologically Secure Laboratory Facility (BSLF)

Exotic insect species used in biological control were imported by ICIPE between 1991 and 2002 and contained in the Biologically Secure Laboratory Facility (BSLF) included *Psyttalia concolor* (from Italy), *Xanthopimpla stemmator* (from South Africa and India), *Sturmiopsis parasitica* (from Zimbabwe), *Cotesia flavipes* isolines (from India), *Diadegma semiclausum* (from Taiwan) and *Diadegma mollipla* (from South Africa). In 2003, another shipment of *D. mollipla* was received as well as *Telenomus isis* (from Benin), and *Cotesia plutellae* (from Taiwan and South Africa).

Rearing of *P. concolor* was terminated in March 2003 while the culture of *Sturmiopsis inferens* (from South Africa) did not establish in the laboratory due to protracted problems associated with mating and emergence.

4. Recharges on animal rearing and containment services

Income accruing from recharges during 2002 amounted to about US$ 65,000 with an average of about US$ 5000 per month. In 2003, the revenue collected was US$ 127,000, being double that of 2002 and averaging about US$ 10,000 per month. Arthropods are charged for at modest rates.

CAPACITY BUILDING

A student from the Kenya Polytechnic acquired skills necessary for laboratory rearing of cereal stemborers and the desert locust for 3 months in 2002. His project was on 'Rapid diagnosis of *Malamoeba locustae* in the laboratory-reared desert locust, *Schistocerca gregaria*'.

A young woman on attachment from Murang'a College of Technology, acquired skills on rearing and handling cereal stemborers, locusts, mosquitoes, ticks, and tsetse in early 2002.

Ms Mariana Jaarsveld and Ms Leoni Pretorious of the Plant Protection Research Institute of the Agricultural Research Council (ARC-PPRI), Republic of South Africa visited ICIPE to acquaint themselves with advances in techniques for rearing cereal stemborers, especially the maize stemborer, *Busseola fusca*, in October 2003.

IMPACT

- Provided insects and small laboratory mammals for experiments to ICIPE research projects and local universities, thereby enhancing their research activities.
- Trained scientists, scholars, and technicians in insect and animal rearing/handling techniques.
- Guided ICIPE staff on importation and exportation protocols for biological organisms.
- Supplied schools, colleges and local universities with learning and examination specimens.

FUTURE PLANS

The Unit will continue to enhance R&D activities at ICIPE, NARES, and national universities by providing quality experimental insects and animals as required, as well as training scientists, scholars and technicians in insect and animal rearing procedures. As a research unit as well as a service provider, the Unit will continue developing appropriate and cost-effective insect and animal rearing procedures, and in giving guidance on importation protocol for biological organisms. Support to learning institutions with teaching and examination specimens will also continue.

OUTPUT

Conferences and workshops attended

F. O. Onyango and *J. P. R. Ochieng'-Odero* (2002) Techniques for rearing cereal stemborers for biological control. Paper presented at the Workshop and Group Training Course on Biological Control of Cereal Stemborers in Eastern and Southern Africa, 4–8 March 2002, ICIPE, Duduville, Nairobi, Kenya.

F. O. Onyango and *J. P. R. Ochieng'-Odero* (2003) Development of a low-cost, high quality artificial diet for rearing the spotted sorghum stemborer, *Chilo partellus*. Paper presented at the 15th Biennial Congress of the African Association of Insect Scientists (AAIS) and the Entomological Society of Kenya (ESK), 9–13 June 2003, Duduville, Nairobi, Kenya.

F. O. Onyango and *J. P. R. Ochieng'-Odero* (2003) Cost-effective methods of rearing cereal stemborers for mass production of parasitoids for field releases. Paper presented at the Cereal Stemborer Taxonomy and Training Workshop, 20–30 October 2003, ICIPE, Duduville, Nairobi, Kenya.

Participating scientist: J. P. R. Ochieng'-Odero

Assisted by: F. O. Onyango, J. H. Ongudha, J. W. Otsieno, R. O. Agan, M. M. Miti, J. M. Onyango, A. Majanje, P. O. Wagara, A. G. Nyangwara, M. W. Gitau, M. G. Kimondo, J. O. Ochieng'

Collaborators: Kenya Agricultural Research Institute (KARI), Kenya Medical Research Institute (KEMRI), Kenya Trypanosomiasis Research Institute (KETRI), National Museums of Kenya (NMK), International Livestock Research Institute (ILRI), University of Nairobi (UoN), Desert Locust Control Organisation for East Africa (DLCO-EA), International Red Locust Control Organisation for Central and Southern Africa (IRLCO-CSA), International Maize and Wheat Improvement Centre (CIMMYT), National Beekeeping Station (Kenya), Ministry of Agriculture (Kenya)

Donors: ICIPE core fund donors (Finland, Switzerland, Sweden, Norway, Denmark, France, Kenya and Japan), Netherlands Government, IFAD, Gatsby Charitable Trust, Austrian Development Cooperation (ADC)

INFORMATION AND PUBLICATIONS UNIT

This Unit is responsible for writing, compiling, publishing and printing information about ICIPE and its projects, in both printed and electronic formats. This includes writing, editing, design and layout of official documents such as annual reports, business plans, vision and strategy documents, brochures, and many proceedings. In these activities, the Unit liaises closely with the Public Relations Office and the Information Technology services of ICIPE.

The Information and Publications Unit (IPU) includes the following five sections:

- Editorial and Information Services;
- *Insect Science and Its Application*;
- ICIPE Science Press and Printing Services;
- Publications;
- Information Resources Centre (Library).

WORK IN PROGRESS

1. Editorial and Information Services

The editorial services provided by the Information and Publications Unit include writing and compiling information about ICIPE's projects and activities, and providing advice to staff about publishing. The editors also ensure that scientific manuscripts of ICIPE researchers undergo preliminary editing and internal peer review before they are submitted to international journals, and frequently edit ICIPE project proposals and donor reports. This section also produces content for ICIPE's webpage and contributes to public relations materials, as well as serving as a focus for providing general information about ICIPE to the public, media and scientific collaborators. A Graphics section produces posters, PowerPoint presentations and other materials.

Editing and production of documents and publications

Over the review period, several important Centre documents were produced, including *Meeting the Needs of a Changing World: ICIPE's Vision and Strategy 2003–2012*, and case studies of ICIPE's approach described in *Paths to Development: Operationalising ICIPE's Vision and Strategy 2003–2012*. The previous biennial *ICIPE Annual Scientific Report Summaries 2000–2001* was also produced. Important reference books written by ICIPE scientists and edited for production were two manuals of the use of integrated pest management (IPM) for brassicas and tomatoes production. *(See the list of ICIPE Science Press publications in the general ICIPE Publications List.)*

The nucleus of about 34 ICIPE fulltime scientists published 44 articles in refereed journals in 2002 and 46 in 2003. Twenty-eight book chapters were written and published, and 10 other important scientific publications (books and manuals) published over the two years.

Public relations and information activities

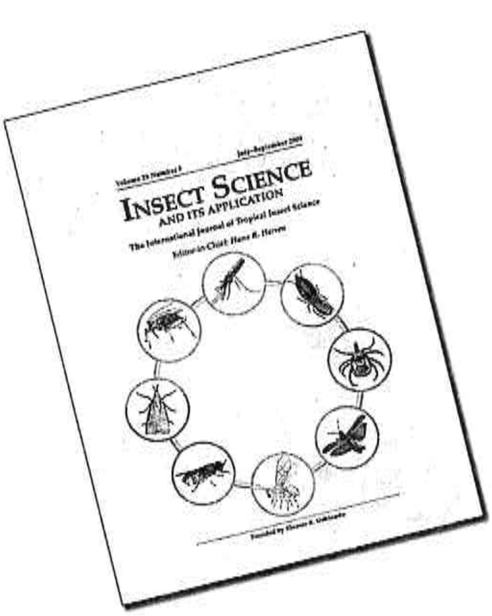
During the review period, over 50 articles were written and/or edited for the media, including the announcement of the receipt of the Brandenberger Prize in 2002 by Hans Herren, ICIPE Director General, the Tyler Prize by Hans Herren in 2003, and the Kilby Award in 2003 by Onesmo ole-MoiYoi, Director of Research and Partnerships. The Unit also helped the Public Relations Office with the organisation and publicity surrounding the dedication of the Thomas R. Odhiambo Conference Centre on the ICIPE Duduville, Kasarani campus and later, in June 2003, in providing information and documentation for the funeral ceremony of ICIPE's Founding Director. The monthly ICIPE Newsletter distributed to donors and collaborators, *ICIPE Update*, was edited and distributed via email by the PR Office. Much of the public relations writing and liaison will soon be taken over by a Press Officer, to be hired in early 2004.

Efforts are being made to update and improve the ICIPE webpage, a process begun in late 2003, by a consultant web-editor. This activity will be given emphasis in 2004.

2. Insect Science and Its Application

Insect Science and Its Application, was founded in 1980 under the aegis of ICIPE and the African Association of Insect Scientists (AAIS) as an international peer-reviewed journal and a forum for original research findings on tropical insects and related arthropods and their sustainable management, conservation and utilisation. The journal was supported financially and technically by ICIPE for its first 23 volumes. However, from 2004 under a collaborative agreement between CABI Publishing (UK), CABI will publish and distribute the journal on behalf of ICIPE. This arrangement aims to take advantage of CABI's specialised publishing services and its expansive distribution network. ICIPE will continue to host the Secretariat, and perform the screening of manuscripts, appointment of peer reviewers, selection of peer reviewers, and the science editing, as well as liaising with the international Editorial Board who determine the journal's policies (independently of ICIPE). The journal will be made available online via the CABI website at http://www.cabi-publishing.org/ijt, and a profile of the journal and its table of contents will be available on the ICIPE website, at http://www.icipe.org/isa. The new journal will also be accessed via the Ingenta website and may be available to third world countries under the AGORA scheme.

Hans Herren served as the Editor-in-Chief, while Ahmed Hassanali, William A. Overholt and Cliff Gold served as the Associate Editors for Volumes 22 (2002) and 23(2003). A special issue on 'Novel Approaches to Tick and Mite Management in Africa' was published as Volume 23(1), while another special issue on 'African Pollinators' is planned for the maiden issue of the new title *International Journal of Tropical Insect Science*. During the review period, *Insect Science and Its Application* was also published on Bioline and the INASP-AJOL (Africa Journals On-Line) websites, acquiring more than 2700 hits in September 2003.



3. ICIPE Science Press (ISP) and printing services

ICIPE Science Press (ISP) was started in 1988 to promote scientific writing and publishing in Africa. ISP is an active member of the publishing fraternity in East Africa. For the past 3 years, ISP has operated on a cost-recovery basis. The Press publishes work for the Centre's core departments, project-related activities and third party clients. These include official documents such as *Focus on the Future: Strategic Planning Review of ICIPE, Report of the Review Team and ICIPE's Response* (in English with French Summary), the IPM manuals cited above, textbooks and reference books, brochures, calendars and stationery. Over the review period, ISP has helped launch a new African journal, the *Journal of Tropical Microbiology*, one of several new journals for which ISP has published their maiden issue.

4. Information Resources Centre

The Information Resources Centre (Library) serves as a regional resource on information and publications on all areas of insect science, including agriculture, medical entomology and ecology. Interlibrary loan services are operational with local institutions and through the British Lending Library, among others. The library is intensively used by the 50–60 ARPPIS (African Regional Postgraduate Programme in Insect Science) and other scholars usually in residence. The library is located on the Duduville campus with a small informal branch at the Mbita Point Research and Training Centre. It serves not only ICIPE staff but users from research centres, universities, national research and extension systems, and other organisations in the eastern and southern Africa region. Over the review period, about 7000 users annually and 600 literature requests were served. About 70 literature searches are conducted annually at a small fee for both staff and outside clients.

The library houses about 12,000 books, and 26 current journal titles (150 titles in total), and a small CD collection. Many are specialised publications not found in other libraries in the region. Several databases on CD-ROM (e.g. AGRIS, CABCD, Current Contents) make up part of the collection. Journals and reference materials are currently being received in both print and on-line versions.

As well as handling in-house user requests, the library staff also order books and other reference materials for staff and interested parties; maintain an archive of ICIPE publications, student theses, reprints and photographs; operate a photocopying service; perform computer-based literature searches for clients; and organise for interlibrary loans. The library is now on-line and searches can be done on the Internet. Part of the library catalogue has been published on the ICIPE website (http://www.icipe.org) and may be accessed by both internal and external users.

The library also helps to produce and provide information. The staff scan all recent publications in the areas of ICIPE's research interests and enter it into a Pest Management Database (PMD) accessible to all library users. This important resource is shared with other research centres and organisations. ICIPE also regularly provides input into the AGRIS database of FAO via *Insect Science and Its Application*.

5. Capacity building

Capacity building and stimulating scholarly publishing in the region are important mandates of this Unit. This is done through assisting ICIPE scientists in writing up papers and reports for publication in journals and books, and publication of original research papers by tropical insect scientists in the ICIPE-hosted *Insect Science and Its Application*. Capacity building in printing and publishing and information sciences is also achieved through training of staff and student interns and attachment students from both local and regional institutions. Lectures and papers at meetings of editors and publishers are often presented by the Head of Unit and Science Editor.

Participating staff: A. N. Mengech (Managing Editor and Head of IPU), D. Ouya (Journal Science Editor)

Assisted by: D. Osogo, I. Ogendo, J. Malombe, A. Ndungu, J. Kisini, C. Sanginga (2003), E. Wasike, J. Lago, W. Ambaka, M. Kageche

Collaborators: Electronic Publishing Trust (UK), INASP/AJOL, Bioline International, Ingenta, CASAS

Donors: ICIPE Core Fund donors, CTA, 3rd party clients (AAS, AAIS, UNEP, KARI, COMESA, etc.)

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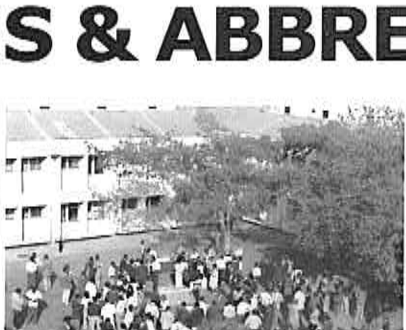
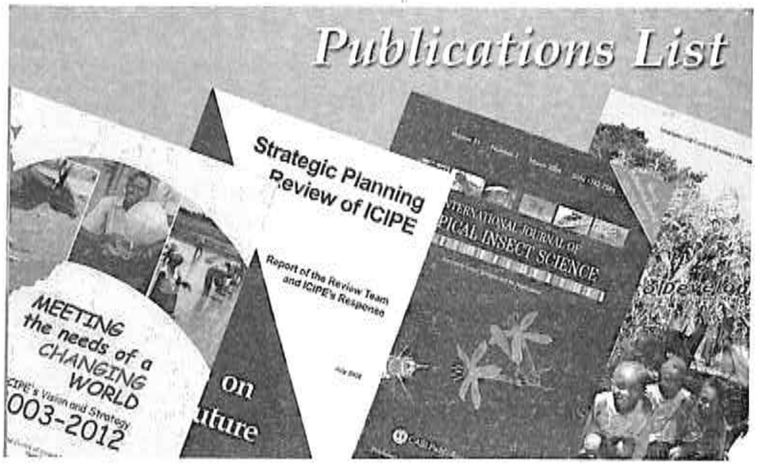
GOVERNING COUNCIL

COLLABORATORS

FINANCIAL STATEMENT

ACRONYMS & ABBREVIATIONS





ICIPE PUBLICATIONS FOR 2002

A. ARTICLES PUBLISHED IN REFEREED JOURNALS

*(ICIPE staff, visiting scientists, scholars and technicians' names are italicised. Publications with a 2001 date that have not previously been reported in the ICIPE Publications List are also included here. Reprints of articles with a call number at the end of the citation can be ordered from the Documentalist, ICIPE. *These articles were in press in the 2001 list.)*

***Abera T. H.*, Hassan S. A., Ogol C. K. P. O., *Baumgärtner J.*, *Sithanantham S.*, Monje J. C. and Zebitz C. P. W. (2002)** Temperature-dependent development of four egg parasitoid *Trichogramma* species (Hymenoptera: Trichogrammatidae). *Biocontrol Science and Technology* 12, 555–567. 02-1646

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***Barasa S. S.*, Ndiege I. O., *Lwande W.* and *Hassanali A.* (2002)** Repellent activities of stereoisomers of p-menthane-3, 8-diols against *Anopheles gambiae* (Diptera: Culicidae). *Journal of Medical Entomology* 39, 736–741. 02-1640*

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***Ekesi S.*, Adamu R. S. and *Maniania N. K.* (2002)** Ovicidal activity of entomopathogenic hyphomycetes to the legume pod borer, *Maruca vitrata* and the pod sucking bug, *Clavigralla tomentosicollis*. Crop Protection 21, 589–595. 02-1645

***Ekesi S.*, *Maniania N. K.* and *Lux S. A.* (2002)** Mortality in three African tephritid fruit fly puparia and adults caused by the entomopathogenic fungi, *Metarhizium anisopliae* and *Beauveria bassiana*. Biocontrol Science and Technology 12, 7–17. 02-1628*

***Emana G. D.*, *Overholt W. A.*, Kairu E., *MacOpiyo L.* and *Zhou G.* (2002)** Predicting the distribution of *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae) and *Cotesia flavipes* Cameron (Hymenoptera: Braconidae) in Ethiopia using step-wise regression and geographic information systems. *Insect Science and Its Application* 22, 123–129. 02-1685

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Baliraine F. N. **(2003)** Development of molecular markers for species diagnosis and analysis of genetic diversity in African fruit fly populations. (ARPPIS). University of Nairobi. ICIPE Supervisor(s): Dr E. Osir. TH 577.21: 595.773.4 BAL

Chinwada P. **(2002)** Stemborer parasitism by *Cotesia sesamiae* and *Sturmiopsis parasitica* and an assessment of the need to introduce *Cotesia flavipes* into Zimbabwe. (ARPPIS). Kenyatta University, Kenya. ICIPE Supervisor(s): Dr C. Omwega. TH 632.937 (689.1) CHI

Dimbi S. **(2003)** Evaluation of the potential of hyphomycetes fungi for the management of the African tephritid fruit flies *Ceratitis capitata* (Wiedeman), *Ceratitis cosyra* (Walker) and *Ceratitis fasciventris* (Brezzi) in Kenya. (ARPPIS). Kenyatta University, Kenya. ICIPE Supervisor(s): Dr N. K. Maniania, S. Lux. TH 632.9 DIM

Ely S. O. **(2003)** Reproductive behaviour of the solitarious desert locusts, *Schistocerca gregaria* (Forskal), in relation to semiochemical attributes of desert plants. (ARPPIS). University of Khartoum, Sudan. ICIPE Supervisor(s): Prof. A. Hassanali, Dr P. G. N. Njagi. TH 595.728 ELY

Ndung'u M. W. **(2003)** Isolation and characterisation of antimosquito compounds from selected E. African Meliaceae plants. (DRIP). Jomo Kenyatta University of Agriculture and Technology, Kenya. ICIPE Supervisor(s): Prof. A. Hassanali.

Sarr I. **(2003)** Bioecology and population dynamics of red spider mites (Acari: Tetranychidae) on tomato in small-scale production systems in Kenya. (ARPPIS). Kenyatta University, Kenya. ICIPE Supervisor(s): Dr M. Knapp. TH 632.7(676.2) SAR

Seyoum A. **(2003)** Evaluation of mosquito repellent and insecticidal plants and plant products for control of mosquitoes. (ARPPIS). Kenyatta University, Kenya. ICIPE Supervisor(s): Prof. A. Hassanali.

Sithole R. **(2003)** Studies of the bionomics of *Diadegma mollipla* (Holmgren) (Hymenoptera: Ichneumonidae: Campopleginae), indigenous parasitoid of the diamondback moth, *Plutella xylostella* (Lepidoptera: Plutellidae) in East Africa. (ARPPIS). University of Harare, Zimbabwe. ICIPE Supervisor(s): Dr B. Löhr.

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Gatama J. **(2003)** Evaluation of efficacy of selected Zimbabwean repellent plant species against laboratory-reared female *Aedes aegypti* (Wied.) mosquitoes (Diptera: Culicidae). (ARPPIS). University of Zimbabwe.

Kanya J. I. **(2003)** Quantification and qualification of vegetation in the proximity of maize fields in Trans-Nzoia District. (DRIP). Jomo Kenyatta University of Agriculture and Technology (JKUAT). ICIPE Supervisor(s): Dr A. Ngi-Song.

Macharia I. **(2003)** Ex-ante economic impact assessment of classical biological control of diamondback moth in cabbage production by use of the exotic parasitoid, *Diadegma semiclausum* (Hellen). (ARPPIS). Jomo Kenyatta University of Agriculture and Technology (JKUAT). ICIPE Supervisor(s): Dr B. Löhr.

Mahanga G. M. **(2003)** Synthesis and structure activity tests of 2-hydroxy-4-methoxybenzaldehyde and derivatives as mosquito larvicides. (DRIP). Kenyatta University. ICIPE Supervisor(s): Dr W. Lwande.

Maniafu B. M. **(2003)** 1,4-naphthoquinones and related compounds from *Plumbago* spp.: Assessment of the activity on *Anopheles gambiae*. (DRIP). Kenyatta University. ICIPE Supervisor(s): Dr W. Lwande.

Mburu D. W. **(2003)** The effects of temperature on development, survival, body size, gonotrophic cycle and fecundity of *Anopheles arabiensis* (Diptera: Culicidae) and Aedes aegypti (Diptera: Culicidae). (ARPPIS). University of Zimbabwe. TH 595.77 MBU

Muturi J. J. **(2003)** Efficacy of *Xanthopimpla stemmator* against major and minor lepidopteran pests and its interaction with pupal endoparasitoid *Pediobius furvus* in graminaceous plants in Kenya. (DRIP). Kenyatta University, Nairobi. ICIPE Supervisor(s): Dr A. Ngi-Song.

Nagawa F. **(2003)** Incidence of diamondback moth, *Plutella xylostella* L. and its parasitoids on cabbage in Uganda. (ARPPIS). Makerere University, Kampala, Uganda. ICIPE Supervisor(s): Dr B. Löhr.

Nekesa S. F. **(2003)** Bio-evaluation of larvicidal plants from the coastal parts of Kenya. (DRIP). Kenyatta University, Nairobi. ICIPE Supervisor(s): Prof. A. Hassanali, Dr W. Lwande.

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Nyambega B. **(2003)** Mechanisms of trypanolysin mediated lysis of *Trypanosoma brucei brucei* (Kinetoplastida: Trypanomastidae). (DRIP). Jomo Kenyatta University of Agriculture and Technology (JKUAT). ICIPE Supervisor(s): Dr E. Osir.

Ogembo G. **(2003)** Comparative biological and biochemical studies of two isolates of nucleopolyhedrovirus infecting *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae). (ARPPIS). University of Zimbabwe. TH 632.9 OGE

Romushana I. **(2003)** Impact of introduced *Cotesia flavipes* (Hymenoptera: Braconidae) on non co-evolved Lepidoptera in eastern Uganda. (Rockefeller Fellowship managed by Makerere University). Makerere University, Uganda. ICIPE Supervisor(s): Dr A. Ngi-Song.

Wekesa V. W. **(2003)** Evaluation of pathogenic fungi *Beauveria bassiana* and *Metarhizium anisopliae* for the control of tobacco spider mite, *Tetranychus evansi* Baker & Pritchard (Acarina: Tetranychidae). (DRIP). Jomo Kenyatta University of Agriculture and Technology (JKUAT), Kenya. ICIPE Supervisor(s): N. K. Maniania, M. Knapp.

ARPPIS, African Regional Postgraduate Programme in Insect Science; DRIP, Dissertation Research Internship Programme

Other Publications by ICIPE Scientists

(Publications by ICIPE staff on work not directly related to ICIPE.)

Ako M., ***Schulthess F.,*** **Gumedzoe M. Y. D. and Cardwell K. F. (2003)** The effect of *Fusarium verticillioides* Sacc. (Nirenberg) on oviposition behaviour and bionomics of lepidopteran and coleopteran pests attacking the stem and cobs of maize in West Africa. *Entomologia Experimentalis et Applicata* 106, 201–210.

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Nedorezov L. V. **and Ut'yupin Yu. V. (2003)** Discrete-continuous model of bisexual population dynamics. *Siberian Mathematical Journal* 44, 650–659 [in Russian]. Reprinted by Kluwer.

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Spangler P. J. **and** ***Steiner W. E. Jr*** **(2003)** A new species of water scavenger beetle, *Coelostoma* (s. str.) *tina* (Coleoptera: Hydrophilidae: Sphaeridiinae), from Kenya, eastern Africa. *Proceedings of the Entomological Society of Washington* 105, 1–8. RE-1379**

White I. M., ***Copeland R. S.*** **and Hancock D. L. (2003)** Revision of the afrotropical genus *Trirhithrum* Bezzi (Diptera: Tephritidae). *Cimbebasia* 18, 71–137.

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Anjili C. O., Mbati P. A., Robert L. L., Odongo S., Ogaja P., Tonui W. and ***Githure J.*** Leishmania major infection in *Phlebotomus duboscqi* fed on murine models immunized with *L. major* subcelluar antigens and sandfly gut antigens. *Acta Tropica*.

Anjili C. O., Mwangi R. W., Mbati P. A., Olobo J. O., ***Githure J. I.*** **and Koech D. K.** Inflammatory reactions of hamsters skin after bites of uninfected and Leishmania major-infected *Phlebotomus duboscqi*. *Journal of Medical Entomology*.

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Beier J. C. **and** ***Killeen G. F.*** Relationship between the force of malaria parasite transmission by mosquitoes and the public health burden of malaria in communities. In *Malaria and Human Affairs* (Edited by A. Spielman).

Bonnet S., ***Gouagna L. C.,*** **Paul R. E. I., Safeukui I., Meunier J.-Y. and Boudin C.** Estimation of malaria transmission

from man to mosquito in two neighbouring villages of South Cameroon: Evaluation and comparison of several parameters. *Transactions of the Royal Society of Tropical Medicine and Hygiene.*

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Killeen G. F., **Foy B. D., Frohn R. F., Impoinvil D., Williams A. and** ***Beier J. C.*** Limitations of phage display for generating antibody panels against mosquito tissues: Enrichment of a single clone from a high diversity naïve human library by panning with Anopheles gambiae midgut homogenate. *Bulletin of Entomological Research.*

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Killeen G. F., **McKenzie F. E., Foy B. D. and** ***Beier J. C.*** The exposure of potential host populations as a determinant of vector population dynamics and pathogen transmission intensity: Bloodmeal choice by African malaria vectors as an example. *Transactions of the Royal Society of Tropical Medicine and Hygiene.*

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Robert L. L., Perich M., Schlein Y., Jacobson R. L., Wirtz R. A., Lawyer P. G. and ***Githure J. I.*** Phlebotomine sandfly control using bait-fed adults to carry the larvicide *Bacillus sphaericus* to the larval habitat. *Journal of Medical and Veterinary Entomology.*

Tonui W. K., Mbati P. A., Anjili C. O., Orago A. S., Turco S. J., ***Githure J. I.*** **and Koech D. K.** Use of Leishmania major 63kD glycoprotein lipophosphoglycan and whole parasite antigens as candidate transmission blocking vaccines against *L. major* in Balb/c mice. *East African Medical Journal.*

ANNEX 1: ARTICLES SUBMITTED FOR PUBLICATION BUT STILL UNDER REVIEW (AS AT 15 MARCH 2004)

Arpaia S., Birch A. N. E., Lövei G. L., ***Sétamou M., Sithanantham S.,*** **Wheatley R., Hilbeck A. and Andow D. A.** Selection procedure to study ecological impact of GM plants: A case study of B. t.-maize in Kenya. *Biocontrol.*

Gilioli G., ***Baumgärtner J.*** **and Vacante V.** Temperature influences on the functional response of *Coenosia attenuata* Stein (Diptera, Muscidae) individuals. *Journal of Economic Entomology.*

Gitau C. W., Ngi-Song A. J., Overholt W. A. **and Otieno S. A.** Acceptance and suitability of four gramineous stem borers (Lepidoptera: Crambidae, Noctuidae, Pyralidae) for the development of the pupal parasitoid *Xanthopimpla stemmator* Thunberg (Hymenoptera: Ichneumonidae). *Biological Control.*

Gitau C. W., Ngi-Song A. J., Overholt W. A. **and Otieno S. A.** Pupal parasitoids of sub-Saharan African cereal stemborers and the potential for introduction of an exotic species—*Xanthopimpla stemmator* Thunberg (Hymenoptera: Ichneumonidae). *African Crop Science Journal.*

Lushai G., ***Gordon I. J.*** **and Smith D. A. S.** Evidence from mitochondrial DNA supports earlier records of African queen butterflies (*Danaus chrysippus*) migrating in Kenya. *Journal of East African Natural History.*

Lushai G., Smith D. A. S., ***Gordon I. J.,*** **Goulson D., Allen J. A. and Maclean N.** Mitochondrial and nuclear sequences from the butterfly *Danaus chrysippus* (L.) reveal ancient paraphyletic lineages that hybridise extensively in Africa. *Heredity.*

Mohamed S. A., Overholt W. A., Lux S. A., **Wharton R. A. and Eltoum E. M.** Host acceptability and suitability of six fruit fly (Diptera: Tephritidae) for oviposition and development of the parasitoid *Psyttalia* cf. *concolor* (Hymenoptera: Braconidae). *Bulletin of Entomological Research.*

Ochieng-Odero J. P. R. **and** ***Onyango F.*** Development of cost-effective methodologies for mass production of cereal stemborers. *International Journal of Pest Management.*

Ogwal-Okeng J., Odyek O., ***Nyandat E., Lwande W.*** **and Ndiege I. O.** Sanguinolentin: A new antimalarial 10-N-hydroxycryptolepine hydrohalide from *Cryptolepis sanguinolenta* (Lindl) Schletcher. (incomplete information).

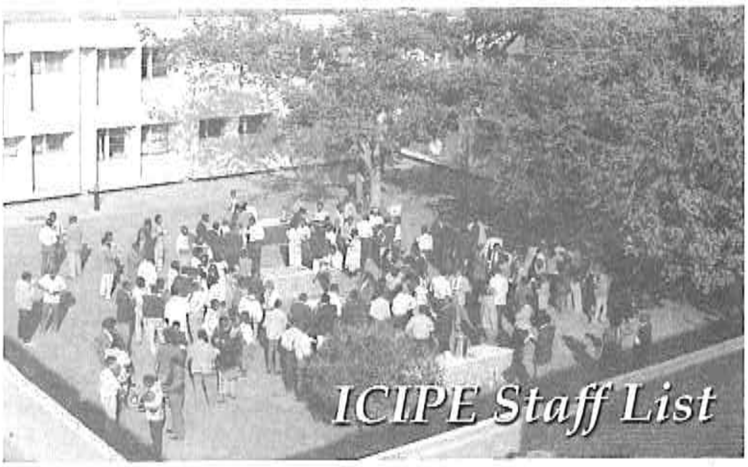
Rossbach A., Löhr B. L. **and Vidal S.** Response of the larval parasitoid *Diadegma mollipla* to a host shift of the diamondback moth, *Plutella xylostella*, to peas. *Biological Control.*

Sarr I., Baumgärtner J., Knapp M. **and Ogol C. K. P.** Within-field spatial distribution and preliminary sampling plans for the two-spotted spider mite (*Tetranychus urticae* Koch) on tomato plants (*Lycopersicon esculentum* Mill.). *International Journal of Tropical Insect Science.*

Sarr I., Knapp M., **Ogol C. K. P. O. and** ***Baumgärtner J.*** Observations on predators of Tetranychus evansi Baker & Pritchard populations and on spider mite damage in Kenyan field tomatoes (Lycopersicon esculentum Mill.) *African Crop Science Journal.*

Sithanantham S., Matoka C. M., **Nyarko K. A., Reddy K. V. S.,** ***Sileshi G.,*** **Olubayo F. and Seme G. N.** Occurrence of insect pests and associated yield loss on some African indigenous vegetable crops in Kenya. *African Crop Science Journal.*

Waiganjo M., Sithanantham S., **Mueke J. M. and Gitonga L.** Species composition of thrips occurring on onion in Kenya. *African Crop Science Journal.*



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Machakos District-based
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Suba District-based
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Mwea-based
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SCIENCE DEPARTMENTS

Population Ecology and Ecosystems Science Department

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Lev V. Nedorezov, *Senior Scientist & Head, Biostatistics Unit*
Jurgen Greiling, *Programme Leader, Biovillage Project, Ethiopia*
Joseph Wokulira Ssennyonga, *Senior Scientist**
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Markus Bieri, *Visiting Scientist*
Getachew Tikubet, *Visiting Scientist & Country Coordinator, Ethiopia Country Office*
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Behavioural and Chemical Ecology Department

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Wilber Lwande, *Senior Scientist & Head of Laboratory Management Unit*
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Satoshi Nakamura, *Senior Scientist, JIRCAS*
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Edward Nyandat, *Research Assistant*
Lamberts Moreka, *Technician*
David Mbuvi Mbesi, *Technical Assistant*
Ben Sylvester Olukohe, *Technical Assistant*
Jeremiah Ojude, *Technical Assistant*
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Mbita Point-based
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RESEARCH SUPPORT UNITS AND SERVICES

Molecular Biology and Biotechnology Unit

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Beatrice Onyango, *Visiting Scientist*
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James Gitari Kabii, *Research Assistant*
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Entomopathology Unit

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Information Technology and Bioinformatics

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Animal Rearing and Quarantine Unit

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Paul Odawo Wagara, *Technical Assistant*

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Annalee Ng'eny-Mengech, *Principal Science Editor & Head*
Daisy Wairimu Ouya, *Science Editor*
Irene Akinyi Ogendo, *Graphic Artist*
Dolorosa Osogo, *Journal Proofreader*
Joseph Mwanthi Malombe, *Printing Technician*
Joshua Mbithi Kisini, *Clerical Assistant*
Gilbert Mwaura Kageche, *Driver/Messenger*
Annclaire Muthoni Ndungu, *Secretary*

Information Resources Centre (IRC)

Eddah Wasike, *Library Assistant*
Joash Ada Lago, *Library Assistant*
Wellington Ambaka, *Clerical Assistant*

AFRICAN REGIONAL POSTGRADUATE PROGRAMME IN INSECT SCIENCE (ARPPIS) SCHOLARS

PhD Scholars

Daniel Ndem Amin, Hortance Manda (Cameroon); Aklilu Seyoum, Gashawbeza Ayalew, Yonas Feleke (Ethiopia); Maxwel Billah (Ghana); Alfred Ochieng, Bernard Okech, Betty Nyagode, Janet T. Midega, Laila Abubakar, Leunita Sumba, Matthew Bett, Washington Ayiemba (Kenya); Cherif M. H. Kane, Sidi Ould Ely (Mauritania); Aruna Manrakhan (Mauritius); Alioune Toure, Ibrahim Sarr, Serigne Kandji (Senegal); Samira Mohamed (Sudan); Mohamed Hassan (Somalia); Ester Innocent (Tanzania); Andrew Kalyebi, Anne Akol, Emmanuel Niyibigira, Pontiano Nemeye (Uganda); Ivy Gertrude Nzuma, Peter Chinwada, Rudo Sithole, Susan Dimbi (Zimbabwe)

MSc Scholars

Daniel Gebeyehu, Gebeyehu Feleke (Ethiopia); Bonaventure Aman Omondi, Constance Muholo, David Mwangi, Javier Gordon Ogembo, John Ogecha, Joseph Gatama, Kennedy Gachoka, Mary Ndila Mbola, Stephen Ger Nyanjom (Kenya); Gadzama Usman-Ngamarju, Mailafiya Duna Madu, Okoye Nkem, Patricia Atijegbe, Stanley Dimkp Obumneke (Nigeria); Hellen Namusana, Stephen Sabiiti (Uganda); Sukholole Khumalo (Zimbabwe)

DISSERTATION RESEARCH INTERNSHIP PROGRAMME (DRIP) SCHOLARS

PhD Scholars

Ishida Takahide (Japan); Edwardina Ndhine, Eliud Maundu, Emmah Omulokoli, Evan Mathenge, Evelyn Nguku, Grace Njoroge, Isaac Ogwayo, Joseph Baya, Joseph Odhiambo, Linnet Gohole, Maurice Omolo, Monica Waiganjo, Paul Mireji, Richard Mukabana, Steven Barasa, Wilfred Injera, (Kenya); Radoslaw Brzezowski (Poland); Intisar Elnour Elteraifi (Sudan); Benjamin Jacob, Brandon Ogbunugafor, Christopher Stone, John Carlson (USA)

MSc Scholars

Barasa Maniafu, Boniface Ngoka, Caleb Momanyi, Charles Aura Midega, Fidelis Samita, Geoffrey Mahanga, George Keere, Gladys Kithusi, James Kanya, James Mutunga, Jaqueline Makatiani, John Muturi, Joseph Mwangagi, Josiah Odalo, Justin Mabeya, Lorna Migiro, Lucy Mackenzie, Vincent Mahiva (Kenya)

[Note that postgraduate students are not officially ICIPE staff but are major contributors to ICIPE's R&D effort.]

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Cyrus Kimani Watuku, *Systems Analyst*
Peter Nyakeri Onsongo, *Management Accountant*
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Eustace Njuma Mbuthia, *Treasury Accountant*
Peter Ossmy Ngugi, *Assistant Accountant*
George Muchuku Kiondo, *Assistant Project Accountant*
Nancy Wangui, *Accounts Assistant*
Alphonse Bubusi, *Mail Clerk*

Mbita Point-based

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John Muhia Kibera, *Accounts Assistant*

Procurement

Peter Dickson Kamau Ndirangu, *Procurement Supervisor*
Daniel Oduor Owino Olalo, *Storekeeper*

Mbita Point-based

John Odongo Gombe, *Purchasing Officer*

ADMINISTRATION

Human Resources

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Lucy Wangari Macharia, *Specialist, Compensation Benefits*
Purity Ngima Kaweru, *Recruitment Specialist*
Titus Musyoki Kaviti, *Clerical Assistant*
Simprose Oyola Oyugi, *Switchboard Supervisor*
Dominic O. Mogeni, *Telephonist/Switchboard Operator*
Josephine A. Opiyo, *Telephonist/Switchboard Operator*
Elijah Asami, *Mail Clerk*
Syprine Amolo Abongo, *Office Assistant*
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Elias Ondeyo, *Office Attendant*
Lucy Wanjiru Mwaura, *Office Attendant*
Phoebe Siva, *Office Attendant*
Richard Musyoki Masaka, *Office Attendant*
Anne Wanjiru Karanja, *Cleaner*

Muhaka-based

Douglas Charo Kalume, *Office Attendant*

Nguruman-based

Joseph Naata Tanchu, *Security Guard*
Joseph Saningo ole Soinkei, *Camp Attendant*

Security
Anthony Ochieng Owala, *Security Supervisor*

Transport Unit
Kamau Gitonga, *Fleet/Transport Supervisor*
David Marangu M. Kimotho, *Transport Assistant*
Richard Muiruri Mugi, *Artisan Assistant*
Ibrahim Umar, *Artisan Assistant*
Henry Njoroge Njachi, *Driver*
John Mutunga Mweu, *Driver*
Joseph Raphael Makumi, *Driver Mechanic*
Donald Mwachoni Nyambu, *Mechanic*
Anastasia Kabura Macharia, *Mechanic*
Walter Kariuki Warui, *Mechanic*

Workshops Services
Abdul Abdalla Razaq, *Workshop Manager*
Patroba Onkoba Nyacheo, *Senior Artisan*
John Musyoka Mutua, *Electrician*
Andrew Makheti Wanyama, *Artisan/Plumber*
John Pancras Nyongesa, *Artisan/Carpenter*
Dick Mutisya Kakuku, *Artisan/Metal Fabricator*
John Njeri Waweru, *Artisan*
Christopher Bernard Wasike, *Artisan*

Special Services
Kurt Benjamin Iten, *General Manager, Guest Centres*

Duduville International Guest Centre
Simon Maitethia Aritho, *Assistant Accountant*
George M. Ongoncho, *Accounts Assistant*
Petronila Achieng Ocholla, *Executive Housekeeper*
Ruth Molly Wekesa, *Senior Receptionist*
Simon M. Mkamba, *Receptionist*
Silas Owiti Ojwang', *Storekeeper*
Naomi Ifire, *Barman/Waiter*
David Orinda Otieno, *Barman/Waiter*
Patrick Mungithia, *Barman/Waiter*
Patrick Omollo, *Barman/Waiter*
Tabitha Akeyo Ogongo, *Room Steward*
Lawrence M. Mulae, *Room Steward*
Joan Auma Awich, *Laundry Assistant*
John Nalisi Kipserem, *Laundry Assistant*
Kenneth Kwemoi Omari, *Kitchen Assistant*
Moses Kasembeli Wepukhulu, *Kitchen Assistant*
Marystella Mutasta Wanjala, *Kitchen Assistant*
Mary Nyeusi Etuku, *Kitchen Assistant*
Benson M. Lihanda, *Kitchen Assistant*
Kenneth K. Omari, *Kitchen Assistant*
David Nyaribo, *Cleaner*
Naomi Mwendwa Stephen, *Cleaner*
Jane Adisa Asaba, *Cleaner*

International Guest Centre-Mbita Point
George Gichuru, *Chef*
Johnstone Okal Koyaa, *Catering Officer*
Mary A. Nalo, *Catering Officer*
Hellen A. Ouma, *Receptionist*
Rosemary Manyara, *Receptionist/Clerk*
Susan Akinyi Akelo, *Clerical Assistant*
Patrick Edward Otieno, *Artisan/Panel Beater*
Charles Odera Nyagaya, *Room Steward*
Francis Namoyo Omutsebi, *Laundry Assistant*
Wilson Mahindu Esirenyi, *Kitchen Assistant*
Susan Adhiambo Otila, *Cleaner*

FIELD STATIONS

Mbita Point Field Station
Bart Geert Jan Knols, *Senior Scientist & Station Manager*
Charles Waweru Mwendia, *Station Administrator*
Patrick O. Sawa, *Medical Officer*
George Khaemba Khisa, *Telephonist/Receptionist*
Peter William K. Nyongesa, *Farm Supervisor*
Zedekia Boaz Ooko, *Technical Assistant*
Kennedy Otieno Onyango, *Driver*
Eric Omondi Ogutu, *Tractor Operator*
Tony Linus Ngutu, *Mechanic*
William Nagenda Omino, *Transport Assistant*
Peter Otieno Kisaria, *Security Guard*
George Okaka Aunga, *Security Guard*
Samuel Ojako Okumu, *Security Guard*
Robert Mutunga Nzioka, *Artisan Assistant*
Dominic Owinyo Wanjara, *Artisan Assistant*
Eliud Oguok Ndiao, *Artisan Assistant*
Samwel Mwaura Karanja, *Generator Operator*
Hilda Awiti Abade, *Secretary*

Port Sudan Field Station
Magzoub Omer Bashir, *Visiting Scientist & Scientist-in-Charge*

Ethiopia Country Office
Getachew Tikubet, *Visiting Scientist & Country Coordinator*

**Left in year 2002*
***Joined in 2002.*

JKUAT = *Jomo Kenyatta University of Agriculture and Technology*
KARI = *Kenya Agricultural Research Institute*
KEMRI = *Kenya Medical Research Institute*
OCEAC = *Organisation de Coordination pour la lutte contre les Endémies en Afrique Centrale (Organisation for Control of Endemic Diseases in Central Africa)*

GOVERNING COUNCIL MEMBERS, 2002

Dr Dunstan Spencer
Chairman, ICIPE Governing Council and Chairman, Executive Board
Dunstan Spencer and Associates
(Sierra Leone)

Dr Michael Porter Collinson
Vice-Chairman, ICIPE Governing Council
(UK)

Prof. Dr Niklaus A. Weiss
Head of Department of Medical Parasitology
Swiss Tropical Institute
(Switzerland)

Dr Walter N. Masiga
Chairman, Nominating Committee
Director
InterAfrican Bureau for Animal Resources,
Organisation of African Unity (OAU)
(Kenya)

Dr Jorge Soberon
Chairman, Programme Committee
Secreatrio Ejectivo
CONABIO
(Mexico)

Dr Paul Kipkorir arap Konuche
Vice Chairman, Programme Committee
Director
Kenya Forestry Research Institute (KEFRI)
(Kenya)

Ms Nancy Andrews
Chair, Audit Committee
President, Low Income Housing Fund
(USA)

Prof. Peter Esbjerg
Professor, Agricultural Entomology
Royal Veterinary and Agricultural University
(Denmark)

Dr Gabrielle J. Persley
Ausbiotech Alliance
(Australia)

Dr Hiroyasu Aizawa
President
Hiro Research Consultancy Inc.
(Japan)

Dr Sylvia Blümel
BFL, Institute of Phytomedicine
(Austria)

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Dr Shantanu Mathur
Chief Economist
International Fund for Agricultural Development (IFAD)
(Italy)

Professor W. K. Kilama
AMANET Managing Trustee
Chairman cum Coordinator
African Malaria Network Trust
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RESEARCH DIVISIONS

Plant Health

Bernhard Löhr, *Principal Scientist & Division Head*

Staple Food Crops

Fritz Schulthess, *Principal Scientist & Coordinator, Biological Control of Cereal Stemborers in Eastern and Southern Africa Project*
Zeyaur Rahman Khan, *Principal Scientist & Push-pull Habitat Management Programmes Leader*
Charles Omambia Omwega, *Senior Scientist & Regional Coordinator, Biological Control of Cereal Stemborers in Eastern and Southern Africa Project*
Adele Josee Ngi-Song, *Scientist*
Nanqin Jiang, *Postdoctoral Fellow*
Glenn Mark Sequeira, *Webmaster*
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Gerphas Okuku Ogola, *Technical Assistant*
Peter Omolo Owuor, *Technical Assistant*
Hellen Heya Mwadime, *Technical Assistant*
Julius Obonyo Ochieng, *Technical Assistant*
Carolyne Akal, *Secretary*

Horticultural Crops

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Slawomir Antoni Lux, *Principal Scientist & African Fruit Fly Initiative Programme Leader*
Srinivasan Sithanantham, *Senior Scientist & African Bollworm Egg Parasitoid Project Leader*
Markus Knapp, *Scientist & Tomato Red Spider Mite Project Leader*
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Ruth Nyaga, *Research Assistant*
Ibrahim Macharia, *Research Assistant*
Peterson Wachira Nderitu, *Research Assistant*
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Bernard Musembi Muia, *Technician*
Gideon Jira Chigunda, *Technician*
John Mbatha Kiilu, *Technical Assistant*
Peris Karimi Machera, *Technical Assistant*
Kity Nyale Nguya, *Technical Assistant*
Stanely Opiyo Maramba, *Technical Assistant*
Dan Otieno Ageng'o, *Technical Assistant*
Andrew Wanyonyi, *Technical Assistant*
Judith Mumo Kiluvu, *Technical Assistant*
Raphael Mukiti, *Technical Assistant*
Carlos Maweu, *Technical Assistant*
Lydia Vutsigwa Masambu, *Technical Assistant/Survey Data Processing and Documentation*
Joseph Mucheru Gachugu, *Lab/Technical Assistant (headquarters and JKUAT)*
Charles Muchina Kanyi, *Driver/Mechanic*
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Rose Atieno Ogolla, *Secretary*
Beatrice Muthoni Gikaria, *Secretary*

Mbita Point-based

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Mutunga Kithokoi, *Technician*
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Muhaka-based

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Locusts and Migratory Pests

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Mbita Point-based

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Animal Health

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Nguruman-based

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Human Health

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Charles Mbogo, *Visiting Scientist-KEMRI*
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Ulrike Fillinger, *Visiting Scientist*
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Guiyun Yan, *Visiting Scientist-State University of New York, USA*
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Lawrence Omukuba, *Technical Assistant*

Environmental Health

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Scott E. Miller, *Visiting Scientist*
Frank Thorsten Krell, *Visiting Scientist*
Viola Clausnitzer, *Visiting Scientist*
Jay M. Short, *Visiting Scientist-Diversa Corporation*
Dirk Schmitt Wagner, *Visiting Scientist*
Thomas Bergsdolf, *Visiting Scientist*
James C. Register, *Visiting Scientist*
Rafael Hermman, *Visiting Scientist*
Bill McCutchen, *Visiting Scientist*
Ronald Flannagan, *Visiting Scientist*
Martin Keller, *Visiting Scientist*
James Pesnail, *Visiting Scientist*
Eric Jan Mathur, *Visiting Scientist*
Guy D'Ieteren, *Visiting Scientist*
Leif Pierce Christoffersen, *Visiting Scientist*
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Kavaka W. Mukonyi, *Visiting Scientist*
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Nina Farwig, *Visiting Scientist*
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George Kamau Nyakiringa, *Technical Assistant*
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Boaz Kimanzi Musyoka, *Technical Assistant*
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CAPACITY BUILDING

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SCIENCE DEPARTMENTS

Population Ecology and Ecosystems Science Department

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Lev V. Nedorezov, *Senior Scientist & Head, Biostatistics Unit*
Markus Bieri, *Visiting Scientist*
Getachew Tikubet, *Consultant & Country Coordinator, Ethiopia Country Office*
Anthony Kibira Wanjoya, *Senior Research Assistant*

Behavioural and Chemical Ecology Department

Ahmed Hassanali, *Principal Scientist & Department Head*
Zeyaur Rahman Khan, *Principal Scientist & Habitat Management Programme Leader*
Wilber Lwande, *Senior Scientist*
Magzoub Omer Bashir, *Consultant*

Peter Njagi, *Consultant*
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Nicholas Gikonyo, *Visiting Scientist-University of Nairobi*
Keiji Takasu, *Visiting Scientist*
Muniru Tsanuo Khamis, *Visiting Scientist-JKUAT*
Mary W. Ndung'u, *Visiting Scientist-JKUAT*
Isaiah Ndiege, *Visiting Scientist-Kenyatta University, Nairobi*
Shi Wangpeng, *Visiting Scientist*
Esther Njuguna, *Visiting Scientist-KARI*
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Edward Nyandat, *Research Assistant*
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Ben Sylvester Olukohe, *Technical Assistant*
Charity Waruinu Mwangi, *Secretary*

Mbita Point-based
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Samuel Ezekiel Mokaya, *Technical Assistant/Driver*
Elisha Kongere, *Technical Assistant/Driver*
Philip Salim Juma, *Field Attendant/Driver*

RESEARCH SUPPORT UNITS AND SERVICES

Molecular Biology and Biotechnology Unit

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Daniel Masiga, *Visiting Scientist*
Huang Zhiyuan, *Visiting Scientist, Bt Project*
Sun Changbing, *Visiting Scientist, Bt Project*
Wei Hanru, *Visiting Scientist, Bt Project*
Xiang Xie, *Visiting Scientist, Bt Project*
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Mathayo Mangwe Chimtawi, *Research Assistant*
James Gitari Kabii, *Research Assistant*
Elizabeth Awuor Ouna, *Research Assistant*
Mark Gacau Kimondo, *Research Assistant*
Rosekellen N. Njiru, *Data Input Clerk*

Muhaka-based
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Beatrice Elesani, *Field Assistant*

Arthropod Pathology Unit

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Sunday Ekesi, *Postdoctoral Fellow*

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John Mureithi Mwangi, *Network Administrator*
Allan Anthony Kamau, *Programmer/Web Developer*

Mbita Point-based
Fredrick Ochieng Orwa, *EDP Specialist*

Animal Rearing and Containment Unit

James Patrick Ochieng'-Odero, *Senior Scientist & Unit Head*
Francis Omeno Onyango, *Senior Research Assistant*
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James Henry Ongudha, *Technician*
Matthew Mugweru Miti, *Technical Assistant*
Alphonse Majanje, *Technical Assistant*
Paul Odawo Wagara, *Technical Assistant*
Raphael Odhiambo Agan, *Technical Assistant*

Mbita Point-based
Amos Gadi Nyangwara, *Technical Assistant*

Technology Transfer Unit

Brigitte Nyambo, *Senior Scientist & Head, Technology Transfer Unit*
Janet Nguna Maundu, *Research Assistant*
Bernard Mulwa Musee, *Driver/Mechanic (Biovision Project)*

Information and Publications Unit

Annalee Ng'eny-Mengech, *Principal Science Editor & Unit Head; Managing Editor, Insect Science and Its Application and ICIPE Science Press*
Daisy W. Ouya, *Consultant Science Editor, Insect Science and Its Application*
Irene A. Ogendo, *Graphics Artist*
Dolorosa Osogo, *Editorial Assistant*
Joseph Mwanthi Malombe, *Printing Technician*
Joshua Mbithi Kisini, *Clerical Assistant*
Gilbert Mwaura Kageche, *Driver*
Annclaire Muthoni Ndungu, *Secretary*

INFORMATION RESOURCES CENTRE

Eddah Wasike, *Library Assistant*
Joash Ada Lago, *Library Assistant*
Wellington Ambaka, *Clerical Assistant*

AFRICAN REGIONAL POSTGRADUATE PROGRAMME IN INSECT SCIENCE (ARPPIS) SCHOLARS

PhD Scholars

Amin Daniel Ndem, Hortance Manda (Cameroon); Abeyonas Feleke, Ferede Melaku Wale, Gashawbeza Ayalew (Ethiopia); Maxwell Billah (Ghana); Anderson Kipkoech, Catherine Wanjiku Gitau, Charles Aura Midega, Esther Mwihaki Njuguna, Janet Theresa Midega, Joseph Mwangangi, Leunita Asande Sumba, Matthews Kipchumba Bett, Salome Guchu, Spala Ohaga Oduor, Steven Ger Nyanjom (Kenya); Cugala Domingos (Mozambique); Aruna Manrakhan (Mauritius); Alioune Toure (Senegal); Charles Kihampa, Innocent Ester (Tanzania); Bruce Yaoni Anani, Fiaboe Komi Mokpokpo (Togo); Andrew Kalyebi, Frederick Ndhoga Baliraine, Teddy Kauma Matama (Uganda); Rudo Sithole (Zimbabwe)

MSc Scholars

Olivia Achuonduh (Cameroon); Charo Samuel Kahindi, Jacinter Atieno O. Odhiambo (Kenya); Audu Abdullahi, Zakka Usman (Nigeria)

DISSERTATION RESEARCH INTERNSHIP PROGRAMME (DRIP) SCHOLARS

PhD Scholars

Barbara Wagener (Germany); Elliud Maundu Muli, Evelyn Kamene Nguku, Grace Njeri Njoroge, Maurice Vincent Omolo, Monica Waiganjo, Msanzu Baya, Stephen Super Barasa (Kenya); Radoslaw T. Brzezowski (Poland)

MSc Scholars

Caleb Mose Momanyi, Consolata Atieno Ager, Dennis Wanyama Ochieno, Elijah Kipkorir Lelmen, James Ireri Kanya, James Mutuku Mutunga, Jamleck John Muturi, John Bwire Ocholla, Joseph Odero Owino, Joseph K. Thamuta, Lucy Kanani Murungi, Lucy Kibe, Lucy Mwende Mackenzie, Marion Wariga Burugu, Philip Wafula Mayeku, Priscillar Mumo Mutungi, Samuel Karenga, Samuel K. Muiruri, Stephen Makali Musyoka, Timothy Maina Rimu, Vitalis Wafula Wekesa (Kenya)

[Note that postgraduate students are not officially ICIPE staff but are major contributors to ICIPE's R&D effort.]

ADMINISTRATION AND FINANCE

Christopher Geoffrey Hill, *Director, Finance & Administration*

Finance

ACCOUNTING

Dinah Wairimu Njoroge, *Financial Controller*
Patrick Ngahu Ndiangui, *Project Accountant*
Cyrus Kimani Watuku, *Systems Analyst*
Peter Nyakeri Onsongo, *Management Accountant*
Eustace Njuma Mbuthia, *Treasury Accountant*
George Muchuku Kiondo, *Assistant Project Accountant*
Peter Ossmy Ngugi, *Assistant Accountant*
Nancy Wangui Mwangi, *Accounts Assistant*
Alphonse Bubusi, *Mail Clerk*

Mbita Point-based

Henry Victor Ligedere, *Assistant Accountant*
John Muhia Kibera, *Accounts Assistant*

PROCUREMENT

Peter Dickson Kamau Ndirangu, *Procurement Supervisor*
Daniel Oduor Owino Olalo, *Storekeeper*
Tobias Odongo Oloo, *Purchasing Officer*
Patrick Matheri Munyui, *Administrative Assistant*

Mbita Point-based

John Odongo Gombe, *Purchasing Officer*

ADMINISTRATION

Human Resources

Duduville-based

Willis Harrison Awori, *Human Resources Manager*
Lucy Wangari Macharia, *Specialist/Benefits Compensation*
Purity Ngima Kaweru, *Recruitment Specialist*
Titus Musyoki Kaviti, *Clerical Assistant*
Simprose Oyola Oyugi, *Telephonist/Receptionist*
Dominic Ogembo Mogeni, *Telephonist/Switchboard Operator*
Josephine Akoth Opiyo, *Telephonist/Switchboard Operator*
Elijah Asami, *Mail Clerk*
Esinas Jeptum Tirop, *Office Attendant*
George S. K. Kariuki, *Office Attendant*
Benard Mita Okech, *Office Attendant*
Elias Ondeyo, *Office Attendant*
Lucy Wanjiru Mwaura, *Office Attendant*
Phoebe Siva, *Office Attendant*
Richard Musyoki Masaka, *Office Attendant*
Anne Wanjiku Karanja, *Office Attendant*
Syprine Amolo Abongo, *Office Attendant*

Mbita Point-based

Samuel Ojako Okumu, *Security Guard*

Nguruman-based

Joseph Naata Tanchu, *Camp Security Guard*
Joseph Saningo ole Soinkei, *Camp Attendant*

Muhaka-based

Douglas Charo Kalume, *Office Attendant*

Transport Unit

Zakayo Kimathi Mungania, *Fleet Supervisor*
David Marangu Mbui Kimotho, *Transport Assistant*
John Musyoka Mutua, *Electrician*
Richard Muiruri Mugi, *Artisan Assistant*
Umar Ibrahim, *Artisan Assistant*
Donald Mwachoni Nyambu, *Mechanic*
Anastasia Kabura Macharia, *Mechanic*
Walter Kariuki Warui, *Mechanic*
Joseph Raphael Makumi, *Driver/Mechanic*
Henry Njoroge Njachi, *Driver*
John Mweu Mutunga, *Driver*

Workshops Services

Abdul Razaq Abdalla, *Workshops Manager*
Patroba Nyachieo, *Senior Artisan*
Andrew Makheti Wanyama, *Artisan/Plumber*
John Pancras Nyongesa, *Artisan/Carpenter*
Dick Mutisya Kakuku, *Artisan/Metal, Plastic Fabricator*
John Njeri Waweru, *Artisan*
Christopher Bernard Wasike, *Artisan*

Mbita Point-based
Tony Linus Ngutu, *Mechanic*
Robert Mutunga Nzioka, *Artisan Assistant*
Eliud Oguok Ndiao, *Artisan Assistant*
Dominic Owinyo Wanjara, *Artisan/Woodwork*

Special Services

Kurt Benjamin Iten, *General Manager, Guest Centres*

Duduville International Guest Centre
Simon Maitethia Aritho, *Assistant Accountant*
Joseph Omari Mukhobi, *Chef*
Ruth Molly Wekesa, *Executive Receptionist*
Petronila Achieng Ocholla, *Executive Housekeeper*
Silas Owiti Ojwang', *Storekeeper*
David Nyaribo, *Receptionist*
Marystella Mutasta Wanjala, *Pastry Cook*
Mary Nyeusi Etuku, *Pastry Cook*
David Otieno Orinda, *Barman/Waiter*
Naomi Mwendwa Stephen, *Waitress*
Tabitha Akeyo Ogongo, *Room Stewardess*
Joan Auma Awich, *Room Stewardess*
Jane Adisa Asaba, *Room Stewardess*
John Nalisi Kipserem, *Laundry Assistant*
Naomi Ifire, *Laundry Assistant*
Moses Kasembeli Wepukhulu, *Kitchen Assistant*

International Guest Centre-Mbita Point
Wilson Mahindu Esirenyi, *Head Cook*
George Gichuru, *Chef*
Johnstone Okal Koyaa, *Catering Officer*
Francis Namoyo Omutsebi, *Laundry Assistant*
Charles Odera Nyagaya, *Room Steward*

FIELD STATIONS

ICIPE-Mbita (Mbita Point Research and Training Centre)

Charles Mwendia, *Station Administrator*
Patrick O. Sawa, *Medical Officer*
Peter William K. Nyongesa, *Farm Supervisor*
John Mongare Motaari, *Security Supervisor*
William Nagenda Omino, *Transport Assistant*
Zedekia Boaz Ooko, *Technical Assistant*
Barack Odhiambo Okudo, *Assistant Electrician*
Mohamed Onyango Auma, *Assistant Generator Operator*
Benedict Onyango Juombo, *Tractor Operator*
George Khaemba Khisa, *Telephonist/Receptionist*
Susan Akinyi Akelo, *Clerical Assistant*
Susan Adhiambo Otila, *Cleaner*
Peter Otieno Kisaria, *Security Guard*

Port Sudan Field Station

Magzoub Omer Bashir, *Scientist-in-Charge*

Ethiopia Country Office

Getachew Tikubet, *Consultant & Country Coordinator*

Republic of Chad

Hassane Mahamat, *Visiting Scientist & Country Representative*

ICIPE GOVERNING COUNCIL, 2003

Dr Dunstan Spencer (Sierra Leone)
Chairman, ICIPE Governing Council and Chairman, Executive Board
Dunstan Spencer and Associates

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Vice-Chairman, ICIPE Governing Council

Prof. Dr Niklaus A. Weiss (Switzerland)
Head of Department of Medical Parasitology
Swiss Tropical Institute

Dr Walter N. Masiga (Kenya)
Chairman, Nominating Committee
Director
InterAfrican Bureau for Animal Resources,
Organisation of African Unity (OAU)

Dr Jorge Soberon (Mexico)
Chairman, Programme Committee
Secreatrio Ejectivo
CONABIO

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Vice Chairman, Programme Committee
Director
Kenya Forestry Research Institute (KEFRI)

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Chair, Audit Committee
President, Low Income Housing Fund

Prof. Peter Esbjerg (Denmark)
Professor, Agricultural Entomology
Royal Veterinary and Agricultural University

Dr Gabrielle J. Persley (Australia)
Ausbiotech Alliance

Dr Hiroyasu Aizawa (Japan)
President
Hiro Research Consultancy Inc.

Dr Sylvia Blümel (Austria)
BFL, Institute of Phytomedicine

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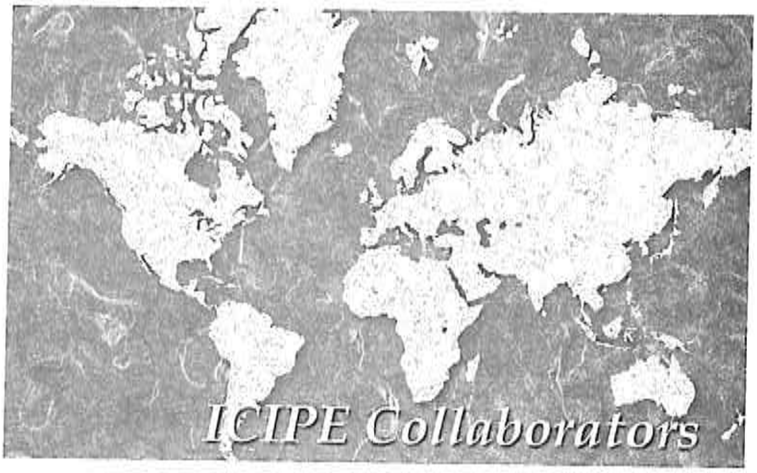
University of Zimbabwe

Dr Shantanu Mathur (Italy)
Chief Economist
International Fund for Agricultural Development (IFAD)

Professor W. K. Kilama (Tanzania)
AMANET Managing Trustee
Chairman cum Coordinator
African Malaria Network Trust

Dr Hans Herren (Switzerland)
Ex-Officio Member
Director General, ICIPE



LIST OF ICIPE COLLABORATORS BY COUNTRY (2002–2003)

ALGERIA
Ministry of Agriculture and Livestock, Algeria
Environmental Health Division-Sericulture

ANGOLA
Instituto de Investigaçao Agronomica -Departmento de Botanica e Melhoramento de Plantas, Programa de Investigaçao dos Cereais, Luanda, Angola
Plant Health Division-Biological Control of Cereal Stemborers

ARGENTINA
Instituto de Investigaciones en Ingenieria Genetica y Biologia Molecular, Argentina
Molecular Biology and Biotechnology Unit-Trypanosomosis (2003)
University of Buenos Aires, Argentina
Plant Health Division-The African Fruit Fly Initiative (2002)

AUSTRALIA
Centre for Pest Information Technology and Transfer (C-PITT), The University of Queensland, Australia
Insect Informatics Unit
Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia
Entomopathology Unit
New South Wales (NWS), Australia
Environmental Health Division-Apiculture

AUSTRIA
Joint FAO/IAEA Laboratories, Austria
Plant Health Division-The African Fruit Fly Initiative (2002)

BELGIUM
Royal Museum of Central Africa, Tervuren, Belgium
Environmental Health Division-Biodiversity; Plant Health Division-The African Fruit Fly Initiative (2002); Biosystematics Unit
Faculte des Sciences Agronomiques, Gembloux, Belgium
Molecular Biology and Biotechnology Unit-Gene Flow and Transgenic Risk Assessment

BENIN
IITA/CABI-Lutte Biologique Contre les Locustes et les Sauteriaux (LUBILOSA), Benin
Plant Health Division-Staple Food Crops; Plant Health Division-Sweet Potato IPM Project (2002)
International Institute of Tropical Agriculture (IITA), Cotonou, Benin
Population Ecology and Ecosystem Science Department; Plant Health Division-Staple Food Crops; Entomopathology Unit; Plant Health Division-Habitat Management of Cereal Stemborers and Striga (2003); Capacity Building Programme (2003); Institutional Collaboration (2003)

BOTSWANA, REPUBLIC OF
Ministry of Agriculture-Department of Agricultural Research, Gaborone, Republic of Botswana
Plant Health Division-Biological Control of Cereal Stemborers

BRAZIL
Escola Superior de Agricultura 'Luiz de Queiroz' (ESALQ), University of São Paulo, Piracicaba, Brazil
Plant Health Division-Red Spider Mites in Smallholder Tomato Production
Empresa Brasiliera de Pesquisa Agropecuária (EMBRAPA) (Brazilian Agricultural Research Corporation), Brazil
Population Ecology and Ecosystem Science Department-Resource Management, Universidade Federal Rural de Pernambuco, Recife, Brazil. Plant Health Division-Red Spider Mites in Smallholder Tomato Production (2003)
Universidade Regional do Cariri, Crato, Brazil
Plant Health Division-Red Spider Mites in Smallholder Tomato Production

BURKINA FASO
Centre International de recherche et de développement sur l'élevage en zone subhumide (CIRDES)
Animal Health Division-Epidemiological Studies (Tsetse)
Directorate of Veterinary Services, Burkina Faso
Molecular Biology and Biotechnology Unit- Control of Livestock Ticks; Molecular Biology and Biotechnology Unit-Capacity Building; Animal Health Division-Ticks
Institut de l'Environnement et de Recherches Agricoles (INERA), Ouagadougou, Burkina Faso
Environmental Health Division-Exchange of Information and Scientific Technologies (2003)
Ministry of Agriculture and Livestock, Burkina Faso
Environmental Health Division-Sericulture

CAMEROON
Universite de Dschang, Cameroon
Capacity Building Programme
Interafrican Phytosanitary Council (IAPSC)/OAU
Plant Health Division-The African Fruit Fly Initiative (2002)

CANADA
International Development Research Centre (IDRC), Canada
Human Health Division-Malaria Epidemiology

University of Victoria, Victoria
Molecular Biology and Biotechnology Unit-Tsetse

CHAD

Ministry of Livestock, N'djamena, Chad
Animal Health Division-Developmental Issues (2003)

CHINA

B.t. Research and Development Centre (BtRDC), Hubei, China
Plant Health Division-Horticultural Crops (2002)

Chinese Academy of Agricultural Sciences (CAAS), China
Environmental Health Division-Apiculture; Environmental Health Division-Sericulture; Plant Health Division-African Bollworm Egg Parasitoid Project

Chinese Agricultural University (CAU), China
Plant Health Division-Desert Locust (2003)

Shanshi Seritech, China
Environmental Health Division-Sericulture

Wild Silk Research Station, China
Environmental Health Division-Sericulture

COLOMBIA

Centro Internacional de Agricultura Tropical (CIAT), Colombia
Plant Health Division-Horticultural Crops (2002)

COSTA RICA

University of Costa Rica, Costa Rica
Plant Health Division-The African Fruit Fly Initiative (2002)

CÔTE D'IVOIRE

Centre National de Recherche Agronomique (CNRA), Abidjan, Côte d'Ivoire
Plant Health Division-The African Fruit Fly Initiative (2002)

Ministry of Agriculture and Livestock, Côte d'Ivoire
Environmental Health Division-Sericulture

CZECHOSLOVAKIA

Czech Academy of Sciences, Czechoslovakia
Environmental Health Division-Biodiversity

DENMARK

University of Copenhagen, Denmark
Plant Health Division-Horticultural Crops (2002)

EGYPT

Assiut University, Egypt
Capacity Building Programme

ERITREA

Ministry of Agriculture and Livestock, Eritrea
Environmental Health Division-Sericulture

Ministry of Health, Eritrea
Human Health Division-Bioprospecting for Useful Plants for Cultivation; Human Health Division-Capacity Building

University of Asmara, Eritrea
Plant Health Division-Biological Control of Cereal Stemborers; Plant Health Division-Habitat Management of Cereal Stemborers and Striga (2003)

ETHIOPIA

Addis Ababa University, Ethiopia-[1]The National Herbarium, Addis Ababa, Ethiopia
[1]Plant Health Division-Global Environment Facility (GEF) Grass Project (2003); Capacity Building Programme; Population Ecology and Ecosystem Science Department-Apiculture (2002); Animal Health Division-Tsetse; Environmental Health Division-Biodiversity; Behavioural and Chemical Ecology Department-Bioprospecting; Human Health Division-Bioprospecting for Mosquito Repellent and Insecticidal Plants; Human Health Division-Capacity Building

Alemaya University of Agriculture, Ethiopia
Capacity Building Programme

Ethiopian Agricultural Research Organisation (EARO), Ethiopia-[1]Melkessa Agricultural Research Centre, Nazareth; [2]Plant Protection Research Centre, Ambo
[1]Plant Health Division-Biological Control of Cereal Stemborers; [1]Plant Health Division- Diamondback Moth Biocontrol Project; [1]Plant Health Division-Global Environment Facility (GEF) Grass Project;[2]Plant Health Division-African Bollworm Egg Parasitoid Project; Capacity Building Programme; Population Ecology and Ecosystem Science Department-Apiculture (2002); Animal Health Division/ Population Ecology and Ecosystem Science Department-Population Management (Tsetse Flies); Plant Health Division/ Population Ecology and Ecosystem Science Department-(Pachnoda, Maize Stemborers and Weeds) As Well As Fodder Tree Establishment; Behavioural and Chemical Ecology Department-Sorghum Chafer; Plant Health Division-Habitat Management of Cereal Stemborers and Striga

Ethiopian Health and Nutrition Research Institute, Ethiopia
Population Ecology and Ecosystem Science Department-Human Health & Nutrition; Human Health Division-Bioprospecting for Useful Plants for Cultivation

Ethiopian Science and Technology Commission
Animal Health Division-Epidemiological Studies (Tsetse)

Ethiopian Social Rehabilitation and Development Fund (ESRDF)
Biovillage Project-Ecosystem Management for Human Health Improvement and Poverty Alleviation (2002)

GTZ-LUPO, Ethiopia
Population Ecology and Ecosystem Science Department-Resource Management, Apiculture (2002)

Institute of Biodiversity Conservation and Research (IBCR), Addis Ababa, Ethiopia
Plant Health Division-Global Environment Facility (GEF) Grass Project (2003)

International Livestock Research Institute (ILRI), Ethiopia
Animal Health Division-Animal Health & Animal Disease Vectors

Ministry of Agriculture and Livestock, Ethiopia
Environmental Health Division-Sericulture; Plant Health Division-Global Environment Facility (GEF) Grass Project

National Herbarium, Addis Ababa, Ethiopia
Plant Health Division-Global Environment Facility (GEF) Grass Project (2003)

Organisation of African Unity (OAU), Ethiopia-[1]The Inter-Africa Bureau for Animal Resources (OAU-IBAR), Ethiopia; [2]International Steering Committee for Trypanosomiasis Research and Control (OAU-ISCTRC), Ethiopia; [3]Farming in Tsetse Controlled Areas (EU) Project of OAU-IBAR
[1, 2]Animal Health Division-Epidemiological Studies (Tsetse); [3]Animal Health Division-Training of Farmers, Tsetse Control and Socioeconomic Studies; Social Science Unit

University of Addis Ababa, Ethiopia
Behavioural and Chemical Ecology Department (2002)

FRANCE

Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD), France
Plant Health Division-The African Fruit Fly Initiative (2002)

Centre for Biology and Management of Populations (CBGP), Montpellier, France
Plant Health Division-Red Spider Mites in Smallholder Tomato Production

Ecole Nationale Supérieure Agronomique (ENSAM), Montpellier, France
Plant Health Division-Red Spider Mites in Smallholder Tomato Production

Insect Biological Control Laboratory, France
Plant Health Division-Staple Food Crops; Entomopathology Unit-Locust and Grasshopper Biocontrol (2002)

Institut de la Recherche Agronomique, France
Plant Health Division-Staple Food Crops
Institut de Recherche pour le Développement, France
Molecular Biology and Biotechnology Unit-Gene Flow and Transgenic Risk Assessment; Environmental Health Division-Biodiversity (Stemborer Diversity)
INRA, France
Plant Health Division-Staple Food Crops; Entomopathology Unit-Locust and Grasshopper Biocontrol (2002)
ISC & ISA, France
Environmental Health Division-Sericulture
United States Department of Agriculture/Agricultural Research Station (USDA/ARS), Montpellier, France
Plant Health Division-Diamondback Moth Biocontrol Project/ Locust Biocontrol Project

GAMBIA, THE

The International Trypanotolerance Centre (ITC), Banjul, The Gambia
Animal Health Division-Epidemiological Studies (Tsetse)

GERMANY

Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ), Germany
Plant Health Division-Desert Locust (2003)
Federal Biological Research Centre for Agriculture and Forestry, Germany-[1]Institute for Biological Control, Darmstadt
[1]Entomopathology Unit; [1]Plant Health Division-African Bollworm Egg Parasitoid Project; Social Science Unit
German Centre for Documentation and Information in Agriculture (ZADI), Bonn, Germany
Insect Informatics Unit
Institute for Systematic Zoology at the Museum of Natural History of Humboldt, University of Berlin, Germany
Environmental Health Division-Biodiversity
Museum Koenig, Bonn, Germany
Environmental Health Division-Biodiversity
University of Bayreuth, Germany
Behavioural and Chemical Ecology Department
University of Bonn, Germany
Environmental Health Division-Biodiversity
University of Constance, Germany
Capacity Building Programme
University of Gottingen, Germany-Institute of Plant Pathology, Germany
Capacity Building Programme (2003)
University of Hohenheim, Stuttgart, Germany-[1]Institut für Phytomedizin
[1]Plant Health Division-Diamondback Moth Biocontrol Project; Population Ecology and Ecosystem Science Department-Socioeconomics, Apiculture, Nutrition; Plant Health Division-African Bollworm Egg Parasitoid Project; Plant Health Division-African Fruit Fly Initiative (2002)
University of Jena, Germany
Capacity Building Programme

GHANA

Ministry of Agriculture and Livestock, Ghana
Environmental Health Division-Sericulture
University of Cape Coast, Ghana
Capacity Building Programme; Behavioural and Chemical Ecology Department
University of Ghana, Legon
Capacity Building Programme

GREECE

University of Crete, Heraklion, Greece
Plant Health Division-The African Fruit Fly Initiative (2002)

GUATEMALA

USDA-APHIS-PPQ Methods Station, Guatemala
Plant Health Division-The African Fruit Fly Initiative (2002)

INDIA

Central Silk Board (CSB), India
Environmental Health Division-Sericulture
Centre of Sericulture and Biological Pest Management Research (CSBR), India
Environmental Health Division-Sericulture
Indian Agricultural Research Institute (IARI), New Delhi
Plant Health Division-African Bollworm Egg Parasitoid Project
Indian Council of Agricultural Research (ICAR)
Plant Health Division-African Bollworm Egg Parasitoid Project
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Hyderabad, India
Plant Health Division-Biological Control of Cereal Stemborers
National Project Directorate for Biological Control (PDBC), Bangalore
Plant Health Division-Augmentation Biocontrol
Tamil Nadu Agricultural University (TNAU), Coimbatore
Plant Health Division-African Bollworm Egg Parasitoid Project
Wild Silk Research Station, India
Environmental Health Division-Sericulture

ISRAEL

Kimron Veterinary Institute (KVI), Israel
Molecular Biology and Biotechnology Unit-Control of Livestock Ticks; Animal Health Division-Ticks
Tel Aviv University, Israel
Plant Health Division-Armyworm
The Agricultural Research Organisation (ARO), Israel-Department of Nematology
Animal Health Division-Ticks
The Hebrew University, Israel
Plant Health Division-The African Fruit Fly Initiative (2002)
The Volcani Centre, Israel
Animal Health Division-Ticks
University of Haifa, Israel
Plant Health Division-Armyworm; Plant Health Division-Habitat Management of Cereal Stemborers and Striga

ITALY

ENEA (Italian Agency for New Technology, Energy and Environment), La Spezia, Italy
Population Ecology and Ecosystem Science Department-Ecosystem Modelling
Food and Agriculture Organisation of the UN (FAO), Italy-[1]Food and Agriculture Organisation / Emergency Prevention System (FAO-EMPRES); [2]IPM Global Facility; [3]Inter-Governmental Sub-Group on Tropical Fruits (IGG-TF), Commodity and Trade Division
[1]Plant Health Division-Semiochemical Research for Management and Control of the Desert Locust; [2]Insect Informatics Unit; [3]Plant Health Division-The African Fruit Fly Initiative (2002); Environmental Health Division-Sericulture; Animal Health Division-Tsetse and Trypanosomosis
University of Molise, Italy
Population Ecology and Ecosystem Science Department-Spatio-temporal Population Dynamics and Ecosystem Modelling
University of Parvia, Italy
Capacity Building Programme (2003); Molecular Biology and Biotechnology Unit-Invasive Species (2003); Plant Health Division-The African Fruit Fly Initiative (2002)
University of Reggio di Calabria, Italy
Population Ecology and Ecosystem Science Department-Spatio-temporal Population Dynamics and Ecosystem Modelling
University of Rome, Italy
Population Ecology and Ecosystem Science Department-Spatio-temporal Population Dynamics

JAPAN

Wild Silk Research Station, Japan
Environmental Health Division-Sericulture

Japan International Research Centre for Agricultural Sciences (JIRCAS)
Plant Health Division-Desert Locust IPM; Animal Health Division-Tick Parasitoids
Japanese Society for the Promotion of Science (JSPS)
Plant Health Division-Desert Locust IPM

KAZAKHSTAN, REPUBLIC OF

Ministry of Agriculture, Kazakhstan-Agriculture and Plant Growing Unit; Department of Science; Plant Protection and Quarantine Department
Biostatistics Unit (2003)
National Academy of Sciences, Kazakhstan
Biostatistics Unit (2003)
The Kazakh Scientific Research Institute for Plant Protection
Plant Health Division-Desert Locust; Biostatistics Unit

KENYA

Abcon Ltd, Kenya
TechnoPark for Commercialisation-Potential for Bacillus thuringiensis *(Bt) Distribution and Water Purification (2003)*
African Butterfly Research Institute, Kenya
Environmental Health Division-Biodiversity
African Centre for Technology Studies (ACTS), Kenya
Policy Issues (2003)
African Technology Policy Studies Network (ATPS), Kenya
Policy and Advocacy (2003)
Agriculture and Environmental Programme, Homa Bay Diocese, Kenya
Technology Transfer Unit (2003); Plant Health Division-Habitat Management of Cereal Stemborers and Striga (2003)
Arabuko-Sokoke Forest Management Team, Kenya
Environmental Health Division-Biodiversity (2003)
Biocontrol AG, Kenya
TechnoPark for Commercialisation-Potential Partner for Export with Biop (2003)
BirdLife International (Africa Division), Duduville, Kenya
Environmental Health Division-Biodiversity (2003)
Centre for Applied Biosciences International (CABI), Kenya
Plant Health Division-Desert Locust; Entomopathology Unit
Coffee Research Foundation (CRF), Kenya
Biosystematics Unit
Coffee Research Institute, Kenya
Plant Health Division-The African Fruit Fly Initiative (2002)
Department of Resource Surveys and Remote Sensing (DRSRS), Kenya
Environmental Health Division-Kakamega Forest Conservation Project
Desert Locust Control Organisation for Eastern Africa (DLCO-EA)
Plant Health Division-Desert Locust; Animal Rearing and Containment Unit; Entomopathology Unit-Locust and Grasshopper Biocontrol (2002)
Dudutech Limited, Nanyuki, Kenya
Plant Health Division-Biological Control Products
East African Wildlife Society, Kenya
Environmental Health Division-Kakamega Forest Conservation Project
Egerton University, Njoro, Kenya
Capacity Building Programme; Behavioural and Chemical Ecology Department-Capacity Building; Molecular Biology and Biotechnology Unit-Capacity Building; Plant Health Division-Habitat Management of Cereal Stemborers and Striga (2002)
Environment Liaison Centre International (ELCI), Nairobi, Kenya
Plant Health Division-Global Environment Facility (GEF) Grass Project (2003)
Export Promotion Zones (EPZ) Authority, Kenya
TechnoPark and Commercialisation of Innovations (2003)
Finlay Flowers, Kericho, Kenya
Plant Health Division-Horticultural Crops
Flower Label Programme Kenya
Plant Health Division (2003)
International Centre for Research in Agroforestry (ICRAF), Nairobi, Kenya
Plant Health Division-Armyworm; Environmental Health Division-Sericulture; Environmental Health Division-Biodiversity; Capacity Building Programme; Biostatistics Unit; Plant Health Division-Habitat Management of Cereal Stemborers and Striga (2003); Plant Health Division-Sweet Potato IPM Project (2002)
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Kenya
Entomopathology Unit; Plant Health Division-African Bollworm Egg Parasitoid Project
International Development Research Centre (IDRC) Acacia Initiative, Kenya
Information and Publications Unit-Production of Content for Rural Telecentres in Uganda, E. Africa (Pilot Study)
International Livestock Research Institute (ILRI), Nairobi, Kenya
Animal Health Division-Ticks; Animal Health Division-Validation of Repellent Technologies (Tsetse); Animal Health Division-Genomics (2003); Animal Rearing and Containment Unit; Biostatistics Unit; Molecular Biology and Biotechnology Unit-Tsetse (2003)
International Plant Genetic Resources Institute (IPGRI), Nairobi, Kenya
Plant Health Division-Global Environment Facility (GEF) Grass Project (2003)
Intermediate Technology Development Group (ITDG), Kenya
Environmental Health Division-Kakamega Forest Conservation Project
Jestan Herbal Health Clinic Inc., Kenya
Environmental Health Division-Biodiversity; Human Health Division-Bioprospecting for Mosquito Repellent and Insecticidal Plants
Jomo Kenyatta University of Agriculture and Technology (JKUAT), Kenya
Capacity Building Programme; Animal Health Division-Tsetse; Environmental Health Division-Biodiversity; Behavioural and Chemical Ecology Department-Capacity Building; Human Health Division-Bioprospecting for Mosquito Repellent and Insecticidal Plants; Human Health Division-Bioprospecting for Useful Plants for Cultivation; Human Health Division-Capacity Building; Plant Health Division-Red Spider Mites in Smallholder Tomato Production; Plant Health Division-Striga Allelochemicals; Molecular Biology and Biotechnology Unit-Capacity Building
Kakamega Environmental Education Programme (KEEP), Kenya
Environmental Health Division-Kakamega Forest Conservation Project (2003)
Kakuzi Farm, Thika, Kenya
Environmental Health Division-Apiculture
Kenya Agricultural Research Institute (KARI)-[1]Coast Regional Agricultural Research Centre, Kikambala; [2]Katumani National Dryland Research Centre, Machakos; [3]National Agricultural Research Laboratories, Muguga; [4]Regional Agricultural Research Centre, Kisii; [5]National Biological Control Centre, Muguga; [6]National Research Centre (NRC), Biocontrol Programme; [7]National Agricultural Research Centre, Kitale; [8]Crop Plant Genetics Research Centre, National Gene Bank, Muguga; [9]National Veterinary Research Centre (NVRC)
[1,2]*Plant Health Division-Biological Control of Cereal Stemborers;* [3]*Plant Health Division-The African Fruit Fly Initiative (2002);* [3]*Social Science Unit;* [3]*Biosystematics Unit;* [3]*Plant Health Division-Red Spider Mites in Smallholder Tomato Production;* [4,5]*Plant Health Division-Diamondback Moth Biocontrol Project;* [6]*Plant Health Division-African Bollworm Egg Parasitoid Project;* [7]*Plant Health Division-Habitat Management of Cereal Stemborers and Striga;* [8]*Plant Health Division-Global Environment Facility (GEF) Grass Project (2003);* [9]*Molecular Biology and Biotechnology Unit-Control of Livestock Ticks;* [9]*Animal Health Division-Ticks;* [9]*Animal Health Division-Epidemiological Studies (Tsetse) (2003); Environmental Health Division-Sericulture; Capacity Building Programme; Animal Rearing and Containment Unit; Entomopathology Unit; Technology Transfer Unit (2003); Plant Health Division-Sweet*

Potato IPM Project (2002)

Kenya Institute of Organic Farming

Technology Transfer Unit (2003)

Kenya Forestry Research Institute (KEFRI)

Human Health Division-Bioprospecting for Useful Plants for Cultivation; Environmental Health Division-Kakamega Forest Conservation Project

Kenya Industrial Property Institute (KIPI)

TechnoPark for Commercialisation-Patents (2003)

Kenya Industrial Research and Development Institute (KIRDI)

TechnoPark for Commercialisation (2003)

Kenya Medical Research Institute (KEMRI)

Animal Rearing and Containment Unit; Human Health Division-Bioprospecting for Useful Plants for Cultivation; Human Health Division-Vector Competence, Larval Ecology, Antimalarials; Human Health Division-Urban Malaria; Human Health Division-Bacillus thuringiensis (Bt) for Malaria Control; Entomopathology Unit

Kenya Rural Enterprise Programme (K-REP)-[1]K-REP Bank, Kenya

[1]TechnoPark for Commercialisation-Supporting Micro Financing (2003); Environmental Health Division-Kakamega Forest Conservation Project

Kenya Trypanosomiasis Research Institute (KETRI)

Animal Rearing and Containment Unit; Molecular Biology and Biotechnology Unit; Animal Health Division-Epidemiological Studies (Tsetse)

Kenya Wildlife Service

Molecular Biology and Biotechnology Unit; Environmental Health Division-Kakamega Forest Conservation Project; Environmental Health Division-Microbial, Toxin and Plant Discovery (2003); Environmental Health Division-Microbial Enzymes and Antibiotics Discovery and Development (2003); Animal Health Division-Animal Health Issues in the Boundaries of National Parks and Reserves; Technology Transfer Unit (2003)

Kenyatta University, Nairobi, Kenya

Capacity Building Programme; Environmental Health Division-Biodiversity; Environmental Health Division-Sericulture; Behavioural and Chemical Ecology Department-Bioprospecting, Capacity Building; Animal Health Division-Ticks; Human Health Division-Bioprospecting for Mosquito Repellent and Insecticidal Plants; Human Health Division-Bioprospecting for Useful Plants for Cultivation; Human Health Division-Capacity Building; Plant Health Division-Biological Control of Cereal Stemborers; Biostatistics Unit; Molecular Biology and Biotechnology Unit-Capacity Building

Kilifi Plantations Ltd

TechnoPark for Commercialisation-Neem Tree Growing (2003)

Ministry of Agriculture and Rural Development (MOARD) (formerly MOALDM), Kenya-[1]Department of Veterinary Services; [2]InterAfrican Bureau of Animal Resources (IBAR); [3]District Agricultural Office, Taita/Taveta District

[1]Animal Health Division-Epidemiological Studies (Tsetse); [2]Social Science Unit; [3]Plant Health Division-Diamondback Moth Biocontrol; Plant Health Division-Habitat Management of Cereal Stemborers and Striga; Animal Rearing and Containment Unit; Technology Transfer Unit (2003); Plant Health Division-Sweet Potato IPM Project (2002)

Ministry of Environment and Natural Resources, Kenya-The Forest Department

Environmental Health Division-Kakamega Forest Conservation Project (2003)

Ministry of Health, Kenya-Division of Vector Borne Diseases (DVBD)

Human Health Division-Vector Competence (Malaria Mosquitoes)

Ministry of Natural Resources, Kenya-The Forest Department

Environmental Health Division-Kakamega Forest Conservation Project (2002)

Ministry of Trade and Industry, Kenya-Department of Industry

TechnoPark for Commercialisation (2003)

Moi University, Kenya

Capacity Building Programme; Molecular Biology and Biotechnology Unit-Capacity Building

Mpala Research Centre, Kenya

Environmental Health Division-Biodiversity

Municipal Council of Kisumu

Human Health Division-Urban Malaria

Municipal Council of Malindi

Human Health Division-Urban Malaria

National Council for Science and Technology, Kenya

Human Health Division-Bioprospecting for Useful Plants for Commercial Cultivation

National Environment Management Council, Kenya

Environmental Policy (2003)

National Irrigation Board, Kenya

Human Health Division-Malaria Epidemiology

National Museums of Kenya-[1]Invertebrate Section, [2]East African Herbarium

[1, 2]Plant Health Division-Global Environment Facility (GEF) Grass Project; Capacity Building Programme; Biosystematics Unit; Animal Rearing and Containment Unit; Environmental Health Division-Kakamega Forest Conservation Project; Plant Health Division-Biological Control of Cereal Stemborers; Molecular Biology and Biotechnology Unit-Impact Assessment Studies (GE crops) (2003); Plant Health Division-The African Fruit Fly Initiative (2002)

Nature Kenya

Environmental Health Division-Biodiversity (2003)

NGO Council of Kenya

Environmental Health Division-Sericulture

Ol Jogi Ranch, Nanyuki, Kenya

Molecular Biology and Biotechnology Unit

Oxfam (Kenya)

TechnoPark for Commercialisation-Neem Leaf Harvesting (2003)

Regional Land Management Unit/Swedish International Development Agency

Technology Transfer Unit (2003)

Rift Valley Products Ltd, Kenya

TechnoPark for Commercialisation-Cotton Products, Vegetable Oil Extraction (2003)

Taita Hills Biodiversity Project, Kenya

Environmental Health Division-Biodiversity

Tropical Soil Biology and Fertility Programme (TSBF), Kenya

Environmental Health Division-Biodiversity; Plant Health Division-Habitat Management of Cereal Stemborers and Striga (2003)

University of Nairobi, Kenya-[1]Department of Botany; [2]Department of Biochemistry; [3]Department of Crop Science

[1]Molecular Biology and Biotechnology Unit-Impact Assessment Studies (Genetically Engineered Crops); [2]Molecular Biology and Biotechnology Unit-Invasive Species (2003); [2]Molecular Biology and Biotechnology Unit-Tsetse; [2]Molecular Biology and Biotechnology Unit-Mosquito–Plasmodium Interactions; [2]Molecular Biology and Biotechnology Unit-Diversity of Trypanosomes in Small Ruminants and Pigs in a Sleeping Sickness Endemic Area of Western Kenya; [2]Molecular Biology and Biotechnology Unit-Population Genetics of Fruit Flies (2002); [3]Plant Health Division-Red Spider Mites in Smallholder Tomato Production (2003); Capacity Building Programme; Animal Health Division-Tsetse; Animal Health Division-Ticks; Human Health Division-Bioprospecting for Mosquito Repellent and Insecticidal Plants; Human Health Division-Bioprospecting for Useful Plants for Cultivation; Human Health Division-Capacity Building; Environmental Health Division-Biodiversity; Environmental Health Division-Sericulture; Behavioural and Chemical Ecology Department-Capacity Building; Population Ecology and Ecosystem Science Department; Molecular Biology and Biotechnology Unit-Capacity Building; Animal Rearing and Containment Unit; Biostatistics Unit

Western Seed Company, Kenya

Plant Health Division-Habitat Management of Cereal Stemborers and Striga

Winrock International
Plant Health Division (2003); Technology Transfer Unit (2003)
Yoder Farm, Embu, Kenya
Plant Health Division-Horticultural Crops

LESOTHO
National University of Lesotho, Roma
Plant Health Division-Biological Control of Cereal Stemborers

LIBYA
Ministry of Agriculture and Livestock, Libya
Environmental Health Division-Sericulture

MADAGASCAR
Centre National Antiacridien (CNA), Madagascar
Entomopathology Unit-Locust and Grasshopper Biocontrol (2002)
Département de la Protection des Végétaux, Madagascar
Entomopathology Unit-Locust and Grasshopper Biocontrol (2002)
Institut de Pasteur, Madagascar
Human Health Division-Vector Competence (Malaria Mosquitoes)
Malagasy Research Centre (FOFIFA)
Plant Health Division-Desert Locust; Entomopathology Unit-Locust and Grasshopper Biocontrol (2002)
Ministre de l'Agriculture (MINAGRI), Madagascar
Plant Health Division-Desert Locust; Environmental Health Division-Sericulture

MALAWI
Ministry of Agriculture and Livestock, Malawi-[1]Chitidze Research Station; [2]Bvumbwe Agricultural Research Station
[1,2]*Plant Health Division-Biological Control of Cereal Stemborers;* [1,2]*Plant Health Division-Habitat Management of Cereal Stemborers and Striga; Environmental Health Division-Sericulture*
University of Malawi, Malawi
Capacity Building Programme

MALAYSIA
Tropical Fruit Network (TFNet), Kuala Lumpur, Malaysia
Plant Health Division-The African Fruit Fly Initiative (2002)

MALI
Institut d'Economie Rural [The Institute for Rural Economy], Bamako, Mali-Equippe Systeme de Production et de Gestion des Resources Naturelles, Mopti, Mali; Centre Regional de Recherché Agronomique de Sikasso, Sikasso, Mali
Plant Health Division-Global Environment Facility (GEF) Grass Project
Malaria Research and Training Centre, Bamako, Mali
Human Health Division-Bioprospecting for Useful Plants for Cultivation; Human Health Division-Behavioural Ecology (Malaria Mosquitoes); Human Health Division-Capacity Building

MAURITIUS
University of Mauritius, Mauritius
Capacity Building Programme (2003)

MEXICO
Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT) (International Maize and Wheat Improvement Centre), Mexico
Animal Rearing and Containment Unit; Plant Health Division-Habitat Management of Cereal Stemborers and Striga (2003); Plant Health Division-Sweet Potato-IPM Project (2002)
El Colegio de la Frontera Sur (ECOSUR), Tapachula, Mexico
Plant Health Division-The African Fruit Fly Initiative (2002)

MOROCCO
Ministry of Agriculture and Livestock, Morocco
Environmental Health Division-Sericulture

MOZAMBIQUE
Eduardo Mondlane University, Mozambique
Plant Health Division-Biological Control of Cereal Stemborers
Food for Hungry International, Mozambique
Plant Health Division-Biological Control of Cereal Stemborers
Instituto Nacional de Investigaçao Veterinaria (INIVE), Mozambique
Molecular Biology and Biotechnology Unit- Control of Livestock Ticks; Molecular Biology and Biotechnology Unit-Capacity Building; Animal Health Division-Ticks
Ministry of Agriculture and Rural Development, Maputo, Mozambique
Plant Health Division-Biological Control of Cereal Stemborers
Sasakawa Global 2000, Mozambique
Plant Health Division-Biological Control of Cereal Stemborers
World Vision, Mozambique
Plant Health Division-Biological Control of Cereal Stemborers

NAMIBIA
University of Namibia, Namibia
Animal Health Division-Ticks

NETHERLANDS, THE
Netherlands Institute of Cooperative Entrepreneurship, Nijenrode University, the Netherlands
Animal Health Division-Tsetse
University of Nijmegen, the Netherlands
Human Health Division-Vector Competence (Malaria Mosquitoes)
Wageningen Agricultural University, the Netherlands
Capacity Building Programme; Plant Health Division-Biological Control of Cereal Stemborers; Human Health Division-Behavioural Ecology (Malaria Mosquitoes); Biosystematics Unit

NIGERIA
Ahmadu Bello University, Nigeria
Capacity Building Programme
Enugu State University, Nigeria
Capacity Building Programme
International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria
Biosystematics Unit; Insect Informatics Unit; Biostatistics Unit; Plant Health Division-Habitat Management of Cereal Stemborers and Striga (2003); Capacity Building Programme (2003); Plant Health Division-Sweet Potato IPM Project (2002)
Ministry of Agriculture and Livestock, Nigeria
Environmental Health Division-Sericulture
Nnamdi Azikiwe University, Nigeria
Capacity Building Programme
Ogun State University, Nigeria
Capacity Building Programme
Rivers State University of Science and Technology, Nigeria
Capacity Building Programme
University of Agriculture, Makurdi, Nigeria
Capacity Building Programme
University of Ibadan, Nigeria
Capacity Building Programme; Biostatistics Unit

PAPUA NEW GUINEA
Bishop Museum, Papua New Guinea
Environmental Health Division-Biodiversity
University of Papua New Guinea, Papua New Guinea
Environmental Health Division-Biodiversity

REUNION
CIRAD-FLHOR, Reunion
Plant Health Division-The African Fruit Fly Initiative (2002)

Station de Bassivi Martin, Reunion
Plant Health Division-The African Fruit Fly Initiative (2002)
Laboratorie d'Entomologie, Reunion
Plant Health Division-The African Fruit Fly Initiative (2002)

RUSSIAN FEDERATION

Novosibirsk State University, Novosibirsk, Russian Federation
Biostatistics Unit (2003)
Russian Academy of Medical Sciences-Institute of Molecular Biology and Biophysics, Novosibirsk, Russian Federation
Biostatistics Unit (2003)
Russian Academy of Sciences-Institute of Systematics and Animal Ecology, Novosibirsk, Russian Federation
Biostatistics Unit (2003)

RWANDA

Universite Nationale du Rwanda
Capacity Building Programme

SENEGAL

Direction de la Protection des Végétaux, Senegal
Plant Health Division-Staple Food Crops; Entomopathology Unit-Locust and Grasshopper Biocontrol (2002)
Institut de Recherches pour le Développement (IRD), Dakar, Senegal
Environmental Health Division-Biodiversity
Foundation CERESLOCUSTOX, Senegal
Plant Health Division-Staple Food Crops
Ministry of Agriculture and Livestock, Senegal
Environmental Health Division-Sericulture
Senegalese Institute for Agricultural Research (ISRA), Senegal
Molecular Biology and Biotechnology Unit- Control of Livestock Ticks; Animal Health Division-Ticks

SIERRA LEONE

Rice Research Station, Sierra Leone
Capacity Building Programme

SOUTH AFRICA, REPUBLIC OF

Agricultural Research Council (ARC), Republic of South Africa-[1]Grain Crops Institute, Potchefstroom, Republic of South Africa; [2]Plant Protection Research Institute, Pretoria, Republic of South Africa; [3]Institute for Tropical and Subtropical Fruits, Nelspruit, Republic of South Africa
[1]Plant Health Division-Biological Control of Cereal Stemborers; [1]Plant Health Division-Habitat Management of Cereal Stemborers and Striga; [1]Molecular Biology and Biotechnology Unit-Impact Assessment Studies (Genetically Engineered Crops): [1]Capacity Building Programme (2003); [2]Plant Health Division-Red Spider Mites in Smallholder Tomato Production; [2]Biosystematics Unit; [2]Plant Health Division-Diamondback Moth Biocontrol Project; [2,3]Plant Health Division-The African Fruit Fly Initiative (2002); Environmental Health Division-Biodiversity
Centre for Advanced Study of African Society (CASAS), Cape Town, Republic of South Africa
Information and Publications Unit-Production of Content for Rural Telecentres in Uganda, E. Africa (Pilot Study)
International Service for the Acquisition of AgriBiotechnology Application (ISAAA), Republic of South Africa
Plant Health Division-Staple Food Crops
Natal Museum, Pietermaritzburg, Republic of South Africa
Plant Health Division-The African Fruit Fly Initiative (2002)
Onderstepoort Veterinary Institute (OVI), Republic of South Africa
Animal Health Division-Ticks
South Africa Museum, Cape Town, Republic of South Africa
Biosystematics Unit
University of Cape Town, Republic of South Africa
Plant Health Division-Staple Food Crops
University of Fort Hare, Republic of South Africa
Plant Health Division-Biological Control of Cereal Stemborers; Plant Health Division-Habitat Management of Cereal Stemborers (2002)
University of Natal, Republic of South Africa
Environmental Health Division-Capacity Building
University of Pretoria, Republic of South Africa
Capacity Building Programme
University of the Western Cape, Republic of South Africa-South African National Bioinformatics Institute (SANBI)
Molecular Biology and Biotechnology Unit- Bioinformatics (2003)

SRI LANKA

International Water Management Institute (IWMI), Colombo-[1]CGIAR Systemwide Initiative on Malaria and Agriculture (SIMA), Sri Lanka
[1]Human Health Division-Malaria Epidemiology; Plant Health Division-African Bollworm Egg Parasitoid Project

SUDAN

Agricultural Research Corporation, Sudan
Plant Health Division-The African Fruit Fly Initiative (2002)
Arab Organisation for Agricultural Development (AOAD), Khartoum, Sudan
Population Ecology and Ecosystem Science Department; Behavioural and Chemical Ecology Department (2003); Plant Health Division-Desert Locust, Red Palm Weevil
Concern Worldwide International, Sudan
Plant Health Division-Habitat Management of Cereal Stemborers and Striga (2003)
Ministry of Agriculture and Livestock, Sudan
Environmental Health Division-Sericulture
Plant Protection Directorate, Sudan
Plant Health Division-Desert Locust (2003)
Sudanese Department of Plant Protection, Sudan
Plant Health Division-Staple Food Crops
University of Gezira, Sudan
Capacity Building Programme; Plant Health Division-Neem, Capacity Building; Behavioural and Chemical Ecology Department-Neem (2003); Plant Health Division-The African Fruit Fly Initiative (2002)
University of Khartoum, Sudan
Capacity Building Programme

SWAZILAND

Ministry of Agriculture and Cooperatives-Malkerns Research Station, Malkerns, Swaziland
Plant Health Division-Biological Control of Cereal Stemborers
University of Swaziland, Kwaluseni
Plant Health Division-Biological Control of Cereal Stemborers

SWEDEN

Swedish Agricultural University, Sweden
Environmental Health Division-Biodiversity
Swedish University of Agricultural Sciences, Uppsala
Capacity Building Programme; Plant Health Division-Diamondback Moth Biocontrol Project (2003)
University of Sweden, Sweden
Human Health Division-Vector Competence (Malaria Mosquitoes)

SWITZERLAND

Claro, Switzerland
Environmental Health Division-Sericulture
ETH (Swiss Federal Institute of Technology) Zürich, Switzerland
Population Ecology and Ecosystem Science Department-Resource Management; Behavioural and Chemical Ecology Department
University of Bern, Switzerland
Animal Health Division-Tsetse; Molecular Biology and Biotechnology Unit-Tsetse
World Health Organisation, Geneva, Switzerland
Human Health Division-Malaria Epidemiology; Animal Health Division-Tsetse and Trypanosomosis; Molecular Biology and Biotechnology Unit-Trypanosomosis (2003)

TAIWAN

Asian Vegetable Research and Development Centre (AVRDC), Taiwan
Plant Health Division-Red Spider Mites in Smallholder Tomato Production; Plant Health Division-Diamondback Moth Biocontrol Project

TANZANIA

Eastern Zone Agricultural Research Institute, Ilonga, Tanzania
Plant Health Division-Habitat Management of Cereal Stemborers and Striga (2003)

Ministry of Agriculture and Livestock, Tanzania-[1]IFAD Integrated Rural Development in Kagera Region; [2]GTZ-IPM Project, Tanzania; [3]National Biological Control Programme, Kibaha Biocontrol Station; [4]Plant Protection Division, Zanzibar; [5]Agricultural Research Institute, Mikocheni, Dar es Salaam; [6]Plant Protection Department; [7]Horticultural Research and Training Institute (HORTI), Arusha, Tanzania
[1, 2, 3, 4]*Plant Health Division-Biological Control of Cereal Stemborers;* [1, 2, 3, 4]*Plant Health Division-Habitat Management of Cereal Stemborers and Striga;* [4, 5]*Plant Health Division-The African Fruit Fly Initiative (2002);* [2, 3, 5, 6]*Plant Health Division-Diamondback Moth Biocontrol Project;* [3]*Plant Health Division-African Bollworm Egg Parasitoid Project;* [7]*Plant Health Division-Red Spider Mites in Smallholder Tomato Production Environmental Health Division-Sericulture*

National Institute for Medical Research, Tanzania
Human Health Division-Larval Ecology (Malaria Mosquitoes); Human Health Division-Behavioural Ecology (Malaria Mosquitoes)

Selian Agricultural Research Institute, Tanzania
Plant Health Division-Horticultural Crops

Sokoine University of Agriculture, Tanzania
Capacity Building Programme

Tropical Pesticides Research Institute (TPRI), Arusha, Tanzania
Animal Health Division-Epidemiological Studies (Tsetse); Population Ecology and Ecosystem Science Department-Animal Health and Animal Disease Vectors; Human Health Division-Bioprospecting for Useful Plants for Cultivation

Tropical Products Research Institute, Arusha, Tanzania
Plant Health Division-African Bollworm Egg Parasitoid Project

University of Dar es Salaam, Tanzania
Behavioural and Chemical Ecology Department-Bioprospecting; Environmental Health Division-Biodiversity; Human Health Division-Bioprospecting for Mosquito Repellent and Insecticidal Plants; Plant Health Division-Biological Control of Cereal Stemborers

TUNISIA

Ministry of Agriculture and Livestock, Tunisia
Environmental Health Division-Sericulture

UGANDA

Africa Network 2000 (A2N), Uganda
Environmental Health Division-Echuya Forest Conservation Project (2003)

Forestry Research Institute (FORRI), Uganda
Environmental Health Division-Echuya Forest Conservation Project (2003)

International Institute of Tropical Agriculture (IITA), Uganda
Plant Health Division-Horticultural Crops; Molecular Biology and Biotechnology Unit; Social Sciences Unit; Plant Health Division-Banana Weevil

Livestock Health Research Institute (LIRI), Uganda
Animal Health Division-Ticks

Makerere University, Uganda
Capacity Building Programme; Behavioural and Chemical Ecology Department-Bioprospecting; Environmental Health Division-Biodiversity; Human Health Division-Bioprospecting for Mosquito Repellent and Insecticidal Plants; Human Health Division-Capacity Building; Plant Health Division-Biological Control of Cereal Stemborers; Plant Health Division-Diamondback Moth Biocontrol Project (2003)

Ministry of Agriculture Livestock Development and Fisheries, Uganda
Environmental Health Division-Sericulture; Social Science Unit

Ministry of Water, Land and Environment, Uganda-Uganda Forest Department
Environmental Health Division-Echuya Forest Conservation Project (2003)

National Agricultural Research Organisation (NARO), Uganda-[1]Namulonge Agricultural and Animal Research Institute; [2]Uganda National Banana Research Programme; [3]National Biocontrol Programme, Namulonge; [4]Kawanda Agricultural Research Institute, Kampala
[1]*Plant Health Division-Biological Control of Cereal Stemborers;* [1]*Plant Health Division-Diamondback Moth Biocontrol Project;* [1]*Plant Health Division-Habitat Management of Cereal Stemborers and Striga;* [2]*Social Science Unit;* [3]*Plant Health Division-African Bollworm Egg Parasitoid Project;* [4]*Plant Health Division-The African Fruit Fly Initiative (2002); Entomopathology Unit; Environmental Health Division-Echuya Forest Conservation Project (2003)*

Nature Uganda, Uganda
Environmental Health Division-Echuya Forest Conservation Project (2003)

The Coordinating Office for the Control of Trypanosomiasis in Uganda (COCTU), Uganda
Animal Health Division-Epidemiological Studies (Tsetse)

The United Nations Development Programme (UNDP)/ Global Environment Facility (GEF)-Small Grants Programme, Uganda
Environmental Health Division-Echuya Forest Conservation Project (2003)

Uganda Forest Department, Uganda
Environmental Health Division-Echuya Forest Conservation Project (2003)

Uganda Trypanosomiasis Research Council (ESTC), Uganda
Animal Health Division-Epidemiological Studies (Tsetse)

USAID-CRSP Project, Uganda
Plant Health Division-Biological Control of Cereal Stemborers

UNITED KINGDOM

Bionet International, UK
Environmental Health Division-Biodiversity

CAB International, London, UK
Biosystematics Unit

Institute for Arable Crops Research (IACR), Rothamsted, UK - [1]Research
[1]*Plant Health Division-Habitat Management of Cereal Stemborers and Striga; Behavioural and Chemical Ecology Department-Stemborers, Striga; Environmental Health Division-Sericulture; Capacity Building Programme (2003)*

International Bee Research Association (IBRA), UK
Environmental Health Division-Apiculture

IPM Europe, UK
Insect Informatics Unit

John Innes Centre, UK
Plant Health Division-Staple Food Crops; Plant Health Division-Horticultural Crops

Natural History Museum, London, UK
Biosystematics Unit; Environmental Health Division-Biodiversity; Plant Health Division-Global Environment Facility (GEF) Grass Project (2003); Plant Health Division-The African Fruit Fly Initiative (2002)

Natural Resources Institute (NRI), UK
Plant Health Division-African Bollworm Egg Parasitoid Project; Technology Transfer Unit (2003)

Royal Botanic Gardens, Edinburgh, UK
Environmental Health Division-Biodiversity

University of Aberdeen, Scotland, UK
Molecular Biology and Biotechnology Unit- Mosquito–Plasmodium Interactions

University of Bristol, UK
Capacity Building Programme

University of Edinburgh, UK
Human Health Division-Vector Competence (Malaria Mosquitoes) (2003)
University of Glasgow, UK
Animal Health Division-Tsetse (2003)
University of Oxford

USA

California State University at Stanislaus
Biovillage Project-Ecosystem Management, Poverty Alleviation and Human Health Programmes (2002)
Carnegie Museum of Natural History, Pennsylvania, USA
Environmental Health Division-Biodiversity
Diversa Corporation, California, USA
Environmental Health Division-Microbial Enzymes and Antibiotics Discovery and Development (2003)
Ecological Society of America, USA
Environmental Health Division-Biodiversity
Entomological Information Services, USA
Environmental Health Division-Biodiversity
Global Biodiversity Institute (GBDI), USA
Environmental Health Division-Biodiversity
Illinois Natural History Survey, USA
Human Health Division-Bacillus thuringiensis (Bt) for Malaria Control (2003); Human Health Division-Larval Ecology (Malaria Mosquitoes) (2003)
Harvard University, USA
Human Health-Larval Ecology (2002)
International Organisation of Chemical Sciences in Development (IOCD), USA
Behavioural and Chemical Ecology Department; Environmental Health Division-Biodiversity
Michigan State University, USA
Human Health Division-Behavioural Ecology (Malaria Mosquitoes)
Montana State University, Bozeman, USA
Plant Health Division-Horticultural Crops (2003)
National Institutes of Health (USA)
Human Health-Botanicals for Malaria Control (2002)
Natural History Museum of Los Angeles County, USA
Environmental Health Division-Biodiversity
North Carolina State University, USA-[1]IPMNet/CICP; [2]NSF Centre for IPM
[1,2]Insect Informatics Unit; Molecular Biology and Biotechnology Unit-Impacts Assessment Studies (Genetically Engineered Crops)
Ohio State University, Columbus, USA
Molecular Biology and Biotechnology Unit-Gene Flow and Transgenic Risk Assessment
Pennsylvania State University, Pennsylvania, USA
Molecular Biology and Biotechnology Unit-Invasive Species (2003)
Purdue University, USA
Molecular Biology and Biotechnology Unit-Gene Flow and Transgenic Risk Assessment
San Diego Supercomputer Center, USA
Environmental Health Division-Biodiversity
Smithsonian Institution, USA
Environmental Health Division-Biodiversity; Environmental Health Division-Echuya Forest Conservation Project (2003)
State University of New York (SUNY, Buffalo), USA
Molecular Biology and Biotechnology Unit; Human Health Division-Population Genetics (Malaria Mosquitoes)
Texas A&M Research Foundation, USA
Molecular Biology and Biotechnology Unit-Invasive Species (2003)
Texas A&M University, USA
Biosystematics Unit; Plant Health Division-Biological Control of Cereal Stemborers; Plant Health Division-The African Fruit Fly Initiative (2002); Molecular Biology and Biotechnology Unit-Invasive Species (2002)
The Institute for Genomics Research (TIGR), Rockville, Maryland, USA
Plant Health Division-Polydnaviruses in Stemborers (2003); Molecular Biology and Biotechnology Unit-Molecular Biology (2003)
Tulane University, USA
Human Health Division-Ecology and Behaviour of Mosquitoes; Human Health Division-Urban Malaria (2003); Capacity Building Programme (2003)
United States Department of Agriculture (USDA), USA-[1]Pacific Basin Agricultural Research Center, Hilo, Hawaii; [2]Agricultural Research Center, Gainesville, Florida, USA; [3]Plant Protection Research Unit, US Plant, Soil and Nutrition Laboratory
[1]Plant Health Division-The African Fruit Fly Initiative (2002); [2]Entomopathology Unit-Collection of Entomopathogenic Fungal Cultures (2002); [3]Entomopathology Unit-Locust and Grasshopper Biocontrol (2002) Plant Health Division- Staple Food Crops
United States National Center for Ecological Synthesis and Analysis, USA
Environmental Health Division-Biodiversity (2003)
United States Pacific Basin Agricultural Research Centre, Hawaii, USA
Capacity Building Programme (2003)
University Experimental Station, Kauai, Hawaii, USA
Plant Health Division-Horticultural Crops
University of California at Berkeley, USA
Population Ecology and Ecosystem Science Department-Modelling Temporal Dynamics of Populations
University of California, Davis, USA
Molecular Biology and Biotechnology Unit-Gene Flow and Transgenic Risk Assessment; Capacity Building Programme (2003)
University of Florida, USA
Plant Health Division-The African Fruit Fly Initiative (2002)
University of Hawaii, USA
Plant Health Division-The African Fruit Fly Initiative (2002)
University of Illinois, USA
Human Health-Larval Ecology (Malaria Mosquitoes) (2002)
University of Miami, USA
Human Health Division-Ecology and Behaviour of Malaria Mosquitoes (2003); Capacity Building Programme (2003)
University of Vermont, USA
Plant Health Division-Armyworm
University of Washington, Seattle, USA
Human Health Division-Larval Ecology (Malaria Mosquitoes)
US National Center for Ecological Synthesis and Analysis, USA
Environmental Health Division-Biodiversity (2002)
Virginia Polytechnic Institute and State University (Virginia Tech), USA
Insect Informatics Unit; Plant Health Division-Locust Biocontrol Project; Molecular Biology and Biotechnology Unit/ Entomopathology Unit-Locust and Grasshopper Biocontrol (2002)
Xerces Society, USA
Environmental Health Division-Biodiversity
Yale University, USA
Animal Health Division-Tsetse; Capacity Building Programme (2003)

ZAMBIA

International Red Locust Control Organisation for Central and Southern Africa (IRLCO-CSA), Zambia
Animal Rearing and Containment Unit
Ministry of Agriculture and Livestock, Zambia-[1]Mt Makulu Research Station, Lusaka; [2]Mochipapa Research Station; [3]National Irrigation Research Station, Mazabuka
[1,2]Plant Health Division-Biological Control of Cereal Stemborers; [3]Plant Health Division-Red Spider Mites in Smallholder Tomato Production; Environmental Health Division-Sericulture
University of Zambia, Zambia
Capacity Building Programme

ZIMBABWE

Agricultural Research and Extension Services (AREX) (formerly Agritex), Harare, Zimbabwe-[1]Horticultural Research Centre, Marondera, Zimbabwe; [2]Plant Protection Research Institute, Harare, Zimbabwe

[1,2]*Plant Health Division-Red Spider Mites in Smallholder Tomato Production;* [2]*Capacity Building Programme;* [2]*Plant Health Division-Biological Control of Cereal Stemborers;* [2]*Plant Health Division-Diamondback Moth Biocontrol Project*

Ministry of Agriculture and Livestock, Zimbabwe

Environmental Health Division-Sericulture; Plant Health Division-Red Spider Mites in Smallholder Tomato Production

Ministry of Home Affairs, Zimbabwe-The National Museums and Monuments

Plant Health Division-Diamondback Moth Biocontrol Project

Regional Tsetse and Trypanosomiasis Control Programme (RTTCP), Zimbabwe

Animal Health Division-Epidemiological Studies (Tsetse)

University of Zimbabwe

Capacity Building Programme; Environmental Health Division-Sericulture

KEY:
Organisation
Division, Department, Unit or Programme-Area of collaboration

INCOME AND EXPENDITURE ACCOUNT

FOR THE YEAR ENDED 31 DECEMBER 2003

	2003 US $	2002 US $
INCOME		
Unrestricted Core Grants	**3,310,546**	2,771,320
Restricted Projects Grants	**6,090,954**	6,705,119
Miscellaneous Income	**430,894**	473,658
Currency Translation Gain	**111,760**	106,593
Total Income	**9,944,154**	10,056,690
EXPENDITURE		
Project and Support costs		
Centre Management	**695,329**	657,123
Research & NRES Strengthening	**7,062,992**	7,487,504
Administration & Finance	**655,525**	664,716
Other Support Units	**534,013**	471,111
Utilities	**651,886**	603,903
Overhead Recovery	**(443,021)**	(464,964)
Total Project & Support Expenses	**9,156,724**	9,419,393
Purchase of Fixed Assets		
Scientific Equipment	**22,085**	54,588
Office Equipment & Furniture	**51,789**	64,285
Vehicles	**10,832**	93,962
Others	**745**	1,625
Total	**85,451**	214,460
Total Expenditure	**9,242,175**	9,633,853
SURPLUS FOR THE YEAR	**701,979**	422,837

BALANCE SHEET

AS AT 31 DECEMBER 2003

	2003 US $	2002 US $
NON-CURRENT ASSETS		
Fixed assets	**509,374**	493,595
Joint Venture Project	**95,359**	–
Total non-current assets	**604,733**	493,595
CURRENT ASSETS		
Consumable Stores	**75,717**	78,862
Grants Receivable	**1,076,553**	918,192
Debtors & Prepayments	**1,344,706**	1,374,462
Bank and Cash Balances	**1,081,413**	1,228,062
Total Current Assets	**3,578,389**	3,599,578
TOTAL ASSETS	**4,183,122**	4,093,173
CURRENT LIABILITIES		
Creditors and Accruals	**2,144,490**	2,199,871
Unexpended Operating Grants	**2,128,991**	2,480,929
Total Current Liabilities	**4,273,481**	4,680,800
LONG TERM LIABILITIES		
Provision for Staff Separation Pay and Relocation Pay	**454,005**	658,716
TOTAL LIABILITIES	**4,727,486**	5,339,516
TOTAL ASSETS LESS TOTAL LIABILITIES	**(544,364)**	(1,246,343)
FINANCED BY:		
Accumulated deficit	**(544,364)**	(1,246,343)

SCHEDULE OF GRANTS (2002)

	Income for the Year 2002 US $
UNRESTRICTED	
Danish International Development Agency (DANIDA)	597,886
Danish International Development Agency (DANIDA)	531,606
Finnish Government	144,928
French Government	47,700
Japanese Society for the Promotion of Science (JSPS)	6,000
Kenya Government	12,338
Norwegian Government	533,533
Swedish International Development Agency (SIDA)	788,925
Swiss Government	706,290
TOTAL UNRESTRICTED	2,771,320
RESTRICTED	
Australian Centre for International Agricultural Research (ACIAR)	5,114
Austrian Government	5,467
Biovision Switzerland	307,820
Department for International Development (DFID), UK	77,753
Diversa Corporation	56,812
DuPont Corporation	94,955
European Union	1,013
Finnish Government	92,604
Food and Agriculture Organisation of the United Nations (FAO)	36,461
Gatsby Charitable Foundation	244,443
German Academic Exchange Service (DAAD)	131,039
German Federal Ministry of Economic Co-operation, German Technical Cooperation (BMZ)	872,057
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)	1,912
International Development Research Centre (IDRC)	67,058
International Fund for Agricultural Development (IFAD)	302,523
International Fund for Agricultural Development (IFAD)-ICIPE/ILRI/KETRI Collaborative Tsetse Project	191,981
International Institute of Tropical Agriculture (IITA)	16,365
International Labour Organisation (ILO)	11,274
International Water Management Institute (IWMI)	5,621
Japan International Research Centre for Agricultural Sciences (JIRCAS)	190,674
MacArthur Foundation	178,673
National Institutes of Health (NIH), USA	507,532
National Library of Medicine, USA	4,208
National Science Foundation (NSF), USA	35,657
Netherlands Government, Directorate for NGO, International Education and Research Programme (DPO)	1,643,113
Packard Foundation	761
Rockefeller Foundation	284,889
Smithsonian Institution, USA	5,527
Sundry Grants	172,720
Swiss Government Special Grant	99,836
Texas A&M Research Foundation	7,844
Third World Academy of Sciences	3,016
United Nations Development Programme (UNDP)	44,768
United Nations Environment Programme (UNEP)	301,103
United States Agency for International Development (USAID)	365,969
United States Department of Agriculture (USDA)	105,002
University of Hawaii/ Florida, USA	137
World Health Organisation (WHO)	182,771
World Laboratory	48,647
TOTAL RESTRICTED	6,705,119
Total operating grants received during the year	**9,476,439**

SCHEDULE OF GRANTS (2003)

	Income for the Year 2003 US $
UNRESTRICTED	
Danish International Development Agency (DANIDA)	597,886
Finnish Government	181,476
French Government	38,025
Japanese Society for the Promotion of Science (JSPS)	6,000
Kenya Government	14,870
Norwegian Government	579,198
Swedish International Development Agency (SIDA)	951,074
Swiss Government	942,017
TOTAL UNRESTRICTED	3,310,546
RESTRICTED	
Biovision Switzerland	194,601
CABI International	470
Conservation International	38,716
Danish International Development Agency	2,291
Department for International Development (DFID), UK	186,073
Diversa Corporation	42,413
DuPont Corporation	80,284
Finnish Government	53,830
Food and Agriculture Organisation of the United Nations (FAO)	50,844
Gatsby Charitable Foundation	375,723
German Academic Exchange Service (DAAD)	123,629
German Federal Ministry of Economic Co-operation, German Technical Cooperation (BMZ)	705,135
International Fund for Agricultural Development (IFAD)	162,950
International Fund for Agricultural Development (IFAD)-ICIPE/ILRI/ KETRI Collaborative Tsetse Project	314,411
International Institute of Tropical Agriculture (IITA)	3,099
International Water Management Institute (IWMI)	15,975
Japan International Research Centre for Agricultural Sciences (JIRCAS)	150,558
MacArthur Foundation	159,649
National Institutes of Health (NIH), USA	496,572
National Science Foundation (NSF), USA	50,492
Netherlands Government, Directorate for NGO, International Education and Research Programme (DPO)	1,583,733
Packard Foundation	795
Rockfeller Foundation	123,907
Sundry Grants	193,306
Swiss Government Special Grant	75,552
Texas A&M Research Foundation	2,077
Third World Academy of Sciences	7,858
United Nations Development Programme (UNDP)	38,406
United Nations Environment Programme (UNEP)	229,191
United States Agency for International Development (USAID)	327,971
United States Department of Agriculture (USDA)	151,700
World Health Organisation (WHO)	132,082
World Laboratory	16,660
TOTAL RESTRICTED GRANTS	6,090,954
Total operating grants received during the year	**9,401,500**

ACRONYMS AND ABBREVIATIONS

AAAP	attraction-aggregation-attachment pheromone
AAIS	African Association of Insect Scientists
ADC	Austrian Development Cooperation
AEP	Agriculture and Environment Programme of Homa Bay Diocese
AEZ	agro-ecological zones
AFFI	African Fruit Fly Initiative
AGORA	Access to Global Online Research in Agriculture
AMF	arbuscular mycorrhizal fungi
ARPPIS	African Regional Postgraduate Programme in Insect Science (ICIPE)
ASA	ARRPIS Scholars Association
ASARECA	Association for Strengthening Agriculture Research in East and Central Africa
AVRDC	Asian Vegetable Research and Development Centre (Taiwan, China)
BiONET	Capacity Building Network in Biotechnology and Biosafety for African Universities (ICIPE)
BSC	biological species concept
BSLF	Biologically Secure Laboratory Facility
Bt	*Bacillus thuringiensis*
CBD	community-based development groups
CBOs	community based organisations
CIMMYT	Centro Internacional de Mejoramiento de Maiz y Trigo (Mexico DF, Mexico)
CGIAR	Consultative Group on International Agricultural Research (Washington DC, USA)
CIAT	Centro Internacional de Agricultura Tropical (Colombia)
CMD	cassava mosaic diseases
DAAD	German Academic Exchange Service
DBM	diamondback moth
DC	District Commissioner
DFID	Department for International Development
DGIS	Directorate General for International Cooperation (The Netherlands)
DLCO-EA	Desert Locust Control Organisation for Eastern Africa
DPPOs	District Plant Protection Officers
DRIP	Dissertation Research Internship Programme (ICIPE)
DSO	Direct Support to Training Institutions in Developing Countries Programme
ECF	East coast fever
EMPRES	FAO's Emergency Prevention System (Rome)
EUREPGAP	European Retailers Programme on Good Agricultural Practices
FAO/TCP	Food and Agriculture Organisation/Technical Coordinated Program
FFS	Farmers Field Schools
FLP	German Flower Label Programme
FOFIFA	Centre national de recherche appliquée au développement rural (Madagascar)
FPEAK	Fresh Produce Exporters Association of Kenya
FSAs	Financial Service Organisations
GEF	Global Environment Facility
GIS	geographic information system
GMOs	genetically modified organisms
GMCs	genetically modified crops
GPS	global positioning system
GTZ	Gesellschaft für Technische Zusammenarbeit (Eschborn, Germany)
GV	granulosis viruses
HAT	human African trypanosmosis
HCDA	Horticultural Crops Development Authority (Kenya)
HINARI	Health InterNetwork Access to Research Initiative
IARCs	international agricultural research centres
IAEA	International Atomic Energy Agency (Austria)
ICIDR	NIH's International Collaborations in Infectious Diseases Research
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics (India)
ICSC-WL	International Centre for Scientific Culture-World Laboratory (Lausanne)
ICT	information and communication technology
IDRC	International Development Research Centre (Canada)
IFAD	International Fund for Agricultural Development (Rome)
IFS	International Foundation for Science
IGC	ICIPE Germplasm Centre
IITA	International Institute of Tropical Agriculture
ILRI	International Livestock Research Institute
INERA	Institut de l'envirotudes de recherches agricoles, station de recherches agronomique (Bobo Dioulasso)
IPGRI	International Plant Genetic Resources Institute
IPM	Integrated pest management
IPSFM	integrated pest and soil fertility management approach
IRD	Institut de Recherche pour le Développement (Montpellier, France)
IRLCO-CSA	International Red Locust Control Organisation for Central and Southern Africa
IRS	indoor residual spraying
IVM	integrated vector management
IWMI	International Water Management Institute (Colombo)

JIRCAS	Japan International Research Centre for Agricultural Sciences
KARI	Kenya Agricultural Research Institute
KEFRI	Kenya Forestry Research Institute
KENET	Kenya Education Network
KEPHIS	Kenya Plant Health Inspectorate Service
KETRI	Kenya Trypanosomiasis Research Institute
KIOF	Kenya Institute of Organic Farming
KISABE	Organisation for Community-Managed Tsetse in Lambwe Valley
KWS	Kenya Wildlife Service
LANs	local area networks
LGB	larger grain borer
MAT	male annihilation technique
MBP	mannose-binding protein
MEWS	malaria early warning system
MIM	Multilateral Initiative on Malaria Research in Africa
MNR	Mwea National Reserve
MOAFS	Ministry of Agriculture and Food Security (Tanzania)
MOARD	Ministry of Agriculture and Rural Development (Kenya)
MOU	Memorandum of Understanding
MPFS	ICIPE Mbita Point Field Station
MRLs	maximum/minimum residue limits
MRR	mark-release-recapture
MROMG	Maragua Ridge Organic Mango Growers
NALEP	National Agriculture and Livestock Extension Programme
NARO	Uganda National Research Organisation
NARES	national agricultural research and extension systems
NEPAD	New Partnership for Africa's Development
NGOs	non-governmental organisations
NGU	ICIPE Nguruman supertrap
NIH	National Institutes of Health (USA)
NPB	nymphal pheromone blend
NPVs	nuclear polyhedrosis viruses
OTR	ovipositor/tibia ratio
PAN	phenylacetonitrile
PCV	packed cell volume
PIP	Pesticide Initiative Programme of COLEACP
PPRI	Plant Protection Research Institute (Zimbabwe)
PRA	participatory rural appraisals
RBM	WHO's Roll Back Malaria initiative
R&D	research and development
RSM	red spider mite
SDC	Swiss Development Corporation
SRA	serum resistance associated gene
SSCP	single strand conformation polymorphism
STR	sheath/tibia ratio
TDR	Tropical Diseases Research
TOTs	Training of Trainers
TSBF	Tropical Soil Biology and Fertility Programme (Kenya)
TTU	Technology Transfer Unit
TWAS	Third World Academy of Sciences
TWOWS	Third World Organization for Women in Science
UNEP	United Nations Environment Programme
UNDP	United Nations Development Programme
USAID/AELGA	United States of America Agency for International Development/Africa Emergency Locust and Grasshopper Assistance
USDA	United States Department of Agriculture
VEOs	Village Extension Officers
VPN	virtual private network
WAU	Wageningen Agricultural University (the Netherlands)
WHO	World Health Organisation
WIMIS	Web-based ICIPE Management Information System
WMO	World Meteorological Organisation
WOTRO	Netherlands Foundation for Tropical Science

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