icipe

African Insect Science for Food and Health

insects and africa's health

40 years at icipe

40 years Science for Africa

insects and africa's health

40 years of icipe

icipe **– African Insect Science for Food and Health**
P.O. Box 30772-00100 Nairobi, Kenya
Phone: +254 (20) 8632000
Fax: +254 (20) 8632001/2
icipe@icipe.org
www.icipe.org

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isp@icipe.org

Article compilation: Liz Ng'ang'a and Christian Borgemeister

Editorial assistance: Dolorosa Osogo

DTP, layout and cover design: Irene Ogendo

Additional support: Annah Njui, Baldwyn Torto, Brigitte Nyambo, Bruno Le Ru, Caroline Muya, Charles Midega, Everlyn Nguku, Gerphas Okuku, James Ligare, Joash Lago, John Githure, Mary Nelima, Nguya Maniania, Rajinder Saini, Sunday Ekesi, Suresh Raina, Wilber Lwande and Zeyaur Khan

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Foreword

Prof. Christian Borgemeister,
Director General, *icipe*

There is a popular saying that "life begins at forty". Its inherent meaning is that, at the age of forty, an individual will have had enough experience and accomplishments to open a new, fresh and informed chapter of their life. We believe the same argument can apply to an institution and are proud to mark this auspicious landmark. The 12 success stories featured in this publication are a retrospection of *icipe*'s achievements in the past four decades.

For many years, *icipe* has been in the frontline in the fight against malaria, guided by our steadfast belief that this menace can be alleviated through the integration of integrated vector management (IVM), tailored for specific regions and communities, into mainstream malaria control efforts. We highlight the progress we have made, in partnership with communities along coastal and western Kenya, and in Ethiopia's Ghibe Valley, in controlling mosquitoes and alleviating the malaria infection rates.

Our studies have helped to assuage the threats caused by ticks and tsetse flies, through the development of novel tools for the control of these deadly vectors that affect humans and their livestock across Africa, increasing the hardship of many smallholder farmers.

We have also contributed to improvement of the production of maize and sorghum through the development of strategies that address the constraints of these two most important cereals in Africa. Our 'push–pull' technology platform, developed in close collaboration with the Kenya Agricultural Research Institute (KARI) and Rothamsted Research (UK), simultaneously controls *Striga* and stemborers, and enhances soil fertility. In addition, *icipe* succeeded in using biological control against the complex of both indigenous African and invasive stemborer species that attack cereals in 10 countries in Africa.

Our Centre has also assisted African farmers to participate in horticultural farming for local and export markets, which has rapidly become one of the most profitable enterprises on the continent. We have made breakthroughs in the control of indigenous fruit flies. We have also kept the invasive *Bactrocera invadens* at bay, while pioneering global knowledge on this highly notorious insect, which was previously 'unknown to science'. In addition, we have been able to biologically control the destructive diamondback moth (DBM), one of the most devastating pests of cabbages. This has helped farmers in Kenya, Tanzania and Uganda to engage in prosperous cabbage farming, while reducing the risk caused to their health, those of consumers and the environment by the previous excessive use of synthetic insecticides.

Through our Commercial Insects Programme, we are proud to have succeeded where many have failed in helping communities living in harsh ecosystems break the vicious cycle of poverty. The introduction of eco-friendly technologies for sericulture and apiculture is transforming the lives and the economies of no less than 15,000 households in 24 countries in Africa and recently also in the Near East and North Africa region.

icipe's efforts towards the conservation of the Kakamega Forest of western Kenya have also had phenomenal success. For instance, the introduction of on-farm cultivation of an indigenous medicinal herb, *Ocimum kilimandscharicum,* has led to the development of a commercially branded and successful range of products known as Naturub®, which include a balm and an ointment. In turn, the lives of the communities involved in this enterprise have changed dramatically, for the better.

During the last four decades we are honoured to have nurtured hundreds of young African scientists, through our African Regional Postgraduate Programme in Insect Science (ARPPIS) and the Dissertation Research Internship Programme (DRIP), to take regional and international leadership in insect science.

As we contemplate the future, we are aware of numerous challenges, old and emerging. But we are uplifted by the achievements and the friendships and partnerships we have made in the past 40 years, with communities across Africa, and institutions and individuals all over the world, to take a determined step into the future.

Christian Borgemeister
icipe

History of *icipe*

T.R. Odhiambo was born in Mombasa, Kenya, in 1931, the first of 11 children of a telegraph clerk. Myth has it that the young Odhiambo was born holding a small microscope in his left hand, an indication of the intellectual curiosity with which he approached every aspect of life. Even from an early age, T.R. Odhiambo had a well-developed sense of wonder about the natural world. He wanted to know how things worked, what made them tick, and what effects small changes could have on large, complex systems.

The late Prof. Thomas Risley Odhiambo (fondly known as TRO), the world-renowned Kenyan scientist who founded *icipe*

As a young boy, he was fascinated by wasps, spending hours observing their intricate behaviours. In his own words, T.R. Odhiambo was educated "by missionaries and the *Encyclopaedia Britannica*". He earned a place at the Makerere University College, Uganda, where he completed a degree in botany and zoology in 1953. After graduating, he spent three years at the Tea Research Institute in Kericho, Kenya, before pursuing his fascination with African insects at the Serere and Kawanda research stations in Uganda for another three years. These assignments involved curating pests of cotton and tea. In particular, T.R. Odhiambo was responsible for the discovery of several new genera and dozens of new species of the Miridae bugs (Hemiptera) of East Africa.

In 1959, T.R. Odhiambo headed off to Cambridge University, UK, to study entomology. He spent the six years at Cambridge, completing, first, an MA in natural sciences, and then a PhD in 1965. Under the supervision of the father of insect physiology, Professor Vincent Wigglesworth, T.R. Odhiambo wrote a "phenomenally productive" thesis on the reproductive physiology of the desert locust. He produced a series of 14 papers on the topic, including one in *Nature*.

T.R. Odhiambo then returned to Kenya, where he took up a position as a lecturer in the Department of Zoology at the University of Nairobi. In 1967, he was approached by the *Science* journal to write a review on the status of science in Africa. In the article, Prof. Odhiambo argued that Africa had to embrace the scientific method to develop its own capabilities, and not just 'buy into' technologies developed in the North. He also called for the establishment of scientific 'centres of excellence' on the continent, which would help nurture and develop not only the continent's young scientists, but also its scientific capacity. He proposed that these centres should be staffed by world authorities in specific scientific disciplines who should mentor bright young postgraduate and postdoctoral fellows from Africa, to build the first generation of African scientists.

T.R. Odhiambo further argued that poor farmers were being forced into debt by being persuaded to buy insecticides from Europe and elsewhere. However, by killing beneficial insects along with the target pest species, these insecticides often had adverse effects and pest populations would soon bounce back to problematic levels.

T.R. Odhiambo's ideas got support from, among others, Carl Djerassi, a world-renowned organic chemist from Stanford University in the US. Together, Odhiambo and Djerassi set

Prof. Odhiambo pictured in May 2003 with Dr Hans Herren, who succeeded him as the Director General of *icipe*, during the inauguration of the Thomas Odhiambo Conference Hall, at the *icipe* Duduville Campus

the wheels in motion for launching the International Centre of Insect Physiology and Endocrinology (later changed to Ecology), or *icipe*, in Nairobi. Eventually, 21 national academies became sponsors of *icipe*, providing the needed external research directors and the Centre was declared open for business in 1970.

One of the objectives of *icipe* was to create motivated and highly talented 'human capital' in insect research and related areas of science, to enable Africa to sustain herself and to lead the entire pan-tropical world in this area of endeavour.

T.R. Odhiambo later remarked: "The idea was actually very simple, get the very best people and then if you have more money, put buildings and equipment around them." In the beginning money was in short supply at *icipe*, and the Centre's headquarters comprised of a number of rented wood-frame barracks perched on the hillside of Chiromo Campus at the University of Nairobi. The first postdoctoral researcher arrived to work in a garage that flooded when it rained and the budget was improvised from week to week.

At that time, there was no knowledge of how to control, on a sustainable basis, the major tropical pests. *icipe*'s initial focus, therefore, was to study and improve the traditional methods used by local farmers to control pests. These practices were then refined into low-cost technologies that could easily be adopted by African farmers.

Running *icipe* was quite an art. The elite participating institutions expected the Centre to devote itself largely to basic science, whereas the donors pushed for applications of the research. T.R. Odhiambo's charisma, intelligence, diplomacy and patience enabled him to navigate his ship successfully through these tricky waters. But both T.R. Odhiambo and the governing board understood that the ultimate proof of *icipe's* success would be its Africanisation.

After 26 years as director, T.R. Odhiambo relinquished his leadership of *icipe* in 1993. He was awarded numerous awards, among them the first Africa Prize for Leadership for the Sustainable End of Hunger, which he received in 1987 jointly with President Abdou Diouf of Senegal. But *icipe* stands as the most enduring legacy of the intellectual curiosity of this remarkable scientist.

Today, *icipe* stands as a centre of scientific excellence and training. And as T.R. Odhiambo had hoped, it is indeed staffed mainly by African scientists. The Centre currently has a staff of 288, collaborating with over 200 national systems, research institutes and universities around the world. T.R. Odhiambo's vision of 'holistic' science is today embodied in the Centre's 4Hs paradigm with its focus on human, animal, plant and environmental health issues, and insects and other arthropods as the common denominator.

Evicting Africa's unwanted tenants

A bad tenant is every landlord's worst nightmare. Bad tenants do not deal ethically or honourably; they damage property and can ruin their victim's investment and well-being. Africa has tenants like that — tsetse. Found only on the African continent, these deadly, bloodsucking insects threaten the livelihoods of an estimated 55 million people, living in 37 countries in sub-Saharan Africa, corresponding approximately to one-third of Africa's total land.

Tsetse are bloodsucking flies in the genus *Glossina*. The flies carry the trypanosome parasite that causes the dreaded sleeping sickness in people and the livestock disease known as nagana. Estimates by international organisations put monetary losses from tsetse, which include an approximate three million deaths in cattle, at over half a billion dollars annually. Nagana causes economic losses of up to US$ 1.2 million in cattle each year. Most of the tsetse-related deaths are mainly of young stock with up to a quarter of pre-weaning calves succumbing to the menace. Infected cows are also prone to miscarriage and bulls often become infertile. Crop production in Africa is also greatly affected by combined effects of tsetse; the flies are partly to blame for the fact that 80 per cent of the continent's land is tilled by hand because, in the absence of healthy cattle, there is less draught power. In addition, there is less manure to use as fertiliser. Fear of contracting sleeping sickness and nagana makes farmers avoid tsetse-infested areas, which range from the savanna to the dense riverine forests. Therefore, much of Africa's fertile landscape is lying uninhabited and unused, making it a 'green desert'.

Glossina fuscipes fuscipes, a major vector of nagana in livestock

icipe's contribution

For long, the control of tsetse has focused on the application of synthetic insecticides over vast regions. This is not only expensive but also environmentally questionable. Moreover, it is difficult to spray in hilly or densely forested areas. In addition, the frequent use of veterinary drugs for the treatment of nagana is leading to problems with resistance in trypanosomes.

icipe has been conducting research on tsetse for over three decades, with the aim of developing strategies that are based on a sound understanding of the flies' behaviour, population ecology, and tsetse–trypanosome and tsetse–host relationships. The results from the Centre have not only helped to expand the arsenal of techniques for the control of trypanosomosis but also reduced the use of trypanocides. The technologies developed by *icipe* for the control of tsetse include the NGU series of traps, named after Nguruman, an *icipe* field station in the Maasai heartland of Kenya. The NGU traps are made of several pieces of different coloured cloth: blue is used to visually attract the flies, after which they land on the black target and are then, while trying to escape, caught at the top of the trap into a plastic container where they are eventually killed by the heat of the sun. The effectiveness of the trap is enhanced by the use of volatile odour baits, for instance cattle urine and acetone (the latter present in the breath of cattle). These odours additionally attract the flies from far away. NGU traps have been successfully used in many parts of eastern Africa for monitoring and control of savanna species of tsetse.

Another of *icipe*'s tsetse technologies is a ground-breaking innovation, repellent collars, which contain either synthetic equivalents of the odours of animals that tsetse tend to avoid, for instance the waterbuck, or chemicals developed through molecular optimisation of natural repellents found in the urine of cows. Worn around the neck of cattle, these repellent collars slowly dispense the chemicals in them, thereby protecting the animals from the flies.

Community perception and involvement is crucial to the effective adoption of a technology. Development of new technologies without involving the intended users, and without an adequate understanding of their farming systems and constraints has been blamed for poor adoption of new improved technologies.

Maasai pastoralists with their cattle

Field trials in Nguruman, southwestern Kenya

In the past several years, *icipe* has conducted field trials of the NGU traps and the repellent collars with commendable success. The tests use either a 'push', 'pull' or a combination of both treatments, so labelled after the various technologies applied. The repellent collars 'push' away the flies from the cattle while the traps, with the aid of odour baits 'pull' them and then suppress their populations.

A NGU tsetse trap

The field studies were conducted in two different settings. The first was in Nguruman, in southwestern Kenya. Nguruman is in the heartland of the Maasai, whose lives revolve around cattle. The studies were conducted in collaboration with the International Livestock Research Institute (ILRI) and the Kenya Agricultural Research Institute (KARI).

The field trials started in December 2002, with the selection of three communal herds randomly selected in each of the three different locations in Nguruman, Kenya. The farmers were selected based on their willingness to participate in the trials and commitment to provide cattle. At the start of the tests, all the animals in the nine herds were block treated with a recommended veterinary drug, Diminaphen. In each locality, repellent dispensers were secured around the necks of 50 or 75% of the animals, while the rest were left unprotected as controls to the trials.

The pastoralists were kept engaged in the trials through consultative workshops where any concerns were addressed and the progress discussed. They were also trained in basic tsetse biology and ecology, how to construct, deploy and service the NGU traps, and how to maintain repellent dispensers. The results of the study showed that the synthetic repellents can provide substantial protection to cattle against trypanosomosis. The scientists then monitored the trypanosomosis infection rates in all the nine herds of cattle at monthly intervals. Overall, the mean infection rates showed significant reduction in the protected herds as compared to the unprotected herds (control).

Demonstrating how this bounty catch of the dreaded tsetse was collected into the NGU trap

At the end of the study, the pastoralists involved expressed their appreciation of the repellent collars as being simple, requiring minimum maintenance, and most importantly being mobile, which is consistent with their production practices.

Mr Juma and his daughter Katunge adjust a tsetse repellent collar on their family cow, in Shimba Hills, one of the sites where *icipe* has tested this innovative technology

Shimba Hills, coastal Kenya

The second field trial site for the *icipe* technology was in Shimba Hills, coastal Kenya, a pristine wonderland of rolling meadows and forests of giant primeval trees, an enchanting other world. Unfortunately, the tsetse violate the peace and quiet of the hills, thrust nearly 450 metres out of the coastal plains, lonely and remote, with breezes from the Indian Ocean. Shimba Hills is known to have high trypanosomosis prevalence rates. It is also known for the highest drug resistance in Kenya, yet the farmers in the area were relying on the drugs for tsetse control. So it was vital to block the treatment of all selected cows.

The *icipe* trials started with a cross-sectional study to determine the prevalence of trypanosomosis in cattle and tsetse populations in Shimba Hills. The scientists also conducted a participatory rural appraisal (PRA) to provide an understanding of the local livestock farming systems, disease constraints and farmers' decision-making processes with respect to current tsetse and trypanosomosis control. The information was used primarily to determine the suitability of the area for the 'push–pull' trials and the relevance of the strategy for the area. This bottom-top approach is useful in planning disease and vector control strategies, which take into account the end users' cultural values, socio-ethno practices and expertise. The preliminary survey showed tsetse and disease levels at 18 to 25 percent.

Based on this information, in 2005, scientists started trials funded by the International Fund for Agricultural Development (IFAD). The team held meetings with the various stakeholders, including livestock owners, the Kenya Veterinary Service, the provincial and local administrations and local NGOs. Eight sites were selected and then randomly divided into four treatment categories: (1) 'Push' — 149 cattle with synthetic repellent dispenser collars grazing in an area without traps; (2) 'pull' — 148 cattle without repellent collars in an area with 83 baited traps; (3) 'push–pull' — 120 cattle with repellent dispenser collars grazing in an area with 80 baited traps; and (4) control — 195 unprotected cattle herds without repellent dispenser collars grazing in an area without traps. In total, 130 farmers and over 600 cattle were involved in the trials.

Training in tsetse trap making to course participants

The farmers were asked to keep a daily record detailing observations of their cattle, such as the change in weight and any treatments they had made on their cattle (if any). The area veterinary officers monitored the record keeping by the farmers and helped to monitor the disease levels. Within a year, they noticed a 60 percent reduction in disease incidence in the 'push' treatment (repellent) collars and 70 percent in the push–pull repellent collars and traps. The reductions in disease infections also corresponded with improved cattle body weight, body condition, mean PCV levels and household herd size. Within weeks, the cows, which previously rose looking haggard and dull, begun to look brighter and sheened, an indication of the reduction in tsetse infection, as the disease attacks the blood and nervous system, making its victims look lethargic.

Cattle fitted with tsetse repellent collars

On a more basic level, the tsetse disturb the animals as they bite parts of the body where their tails cannot reach. Because the animals are always trying to rid themselves of the flies by twitching their skin, flicking their tails, stamping their feet with their legs, or trotting around in frustration, they are not able to graze properly. With the *icipe* technologies, the farmers noticed that the cows were able to graze steadily. This further enhanced the animals' health, and in turn, their milk yields and marketability, since healthy-looking cows are more appealing to buyers.

The farmers also reported increased peace of mind as a result of the *icipe* technologies. Previously, they would spend the equivalent of US$ 30 per month on treatment drugs for their cattle, an astronomical amount of money for many households.

In general, the farmers in Shimba Hills said they found the *icipe* strategies easy to adopt, as they required little labour and minimum maintenance. They also found the technologies environmentally friendly.

Improving the repellent collars

The prototype repellent collars used in the field trials were developed in-house by *icipe*. In 2009, *icipe* entered into a financial agreement with the European Union (EU) totalling Euros 1.5 million to support the development of affordable and more robust dispensers, and the large-scale production of the repellents. The project will also assess the socio-economic impact of the technology, as well as its integration and validation with other existing tsetse control strategies where applicable. Further, the initiative will promote the repellent collars among national agricultural research systems (NARS), and help to enhance their capacity to assist livestock keepers to take up the technology.

Unsticking the tick

Somewhere in Africa, a livestock succumbs to East Coast fever every 30 seconds. This dreadful malady, which causes symptoms that are similar to those of malaria in people, is caused by the protozoan parasite* Theileria parva*, which is transmitted by infected* Rhipicephalus appendiculatus *ticks. After the infective bites, the animal develops fever and often dies around 18–30 days later. Close to 100 percent of all cattle that contract East Coast fever are killed by it, with 1.1 million succumbing to the disease every year. The native cattle that survive East Coast fever are unthrifty for the rest of their lives. Another tick species targeted for control is* Amblyomma variegatum*, which causes major economic losses in the cattle industry.

In Africa, every livestock death signifies new hardship for the keeper and his/her family, through the loss of income, nourishment and draught power. Unlike tsetse flies, ticks are prevalent across the entire African continent. Aside from causing deaths, ticks also debilitate cattle through loss of blood and damage to hides. Ticks feeding also predisposes the cattle to other bacterial, fungal and parasitic infections.

A main strategy for controlling East Coast fever is through frequent dipping of cattle in chemicals (acaricides) to kill the ticks. However, most African farmers have neither the means nor the facilities for regular dipping. Other effective control methods are pre-infection vaccinations and chemotherapy. These control efforts impact heavily on national budgets. For instance, Tanzania and Uganda spend US$ 26 million annually on the importation of acaricides. Moreover, ticks rapidly develop resistance to these chemicals, sometimes within 18 months. At present, there is no acaricide group to which ticks are not at least partially resistant, including the recently introduced synthetic pyrethroids. Even worse, the widespread use of these synthetic pesticides contaminates the environment with toxic residues. This method of control has become less reliable over the last 30 years for many reasons, including reduced government spending on livestock and extension, the cost of acaricides, acaricide resistance, poor management of dips and spray races, and poor monitoring of the movement of cattle and quarantine of infected animals.

A Maasai herder and his son assist an *icipe* team to draw blood from one of their goats, to determine the level of risk to tick-borne diseases

For these reasons, right from its founding, *icipe* placed research on ticks high on its agenda, becoming one of the few international centres working on these important pests. *icipe*'s approach has been to develop management strategies that are effective and affordable to African farmers and which do not entail contamination of the environment. These tools are based on research on the ecology and behaviour, as well as the interactions between ticks and the animals that they are parasitic on. In addition to *Rhipicephalus appendiculatus, icipe* also incorporated the ixodid tick species, *Amblyomma variegatum*, which is a host for a microbial pathogen, the agent of heartwater in cattle, into its research.

Population dynamics

icipe has contributed to the understanding of the population dynamics of *R. appendiculatus*. These studies were grounded in knowledge on the life cycle of the tick. This cycle alternates between the ground — where the larvae hatch and the ticks return a total of three times to moult and lay eggs — and the cattle, where the ticks take three large blood meals, but in fact spend only a small proportion of their lifespan. The *icipe* studies were based on the understanding that the well-being of the tick depends on three primary factors. First, the development of the eggs and moulting stages of the ticks is dependent on the temperature on the ground. Second, the humidity in the ground also influences the survival of the unfed tick. (The moisture levels must be sufficient to keep the rate of water loss by the tick low when it is on the ground, and to replenish the tick when it returns to the soil after its sojourn in the vegetation above awaiting a host.) Third, as is commonly known, at each instar, the tick must have a suitable host to obtain a single blood meal before it can complete its development. These three factors interact with a range of others, whose effect is felt indirectly by the tick — such as the state of the vegetation, the livestock husbandry practices in the area, seasonal and climate effects and altitude. The *icipe* research was conducted at three sites in the field, and in semi-natural situations to evaluate the effects of the three primary factors more fully. In addition, the scientists also conducted ancillary studies on survival, activity and mating behaviour. The *icipe* researchers specifically contributed knowledge on the variations in stocking density, physiological manipulation and exploitation of host, and mate-seeking behaviour.

Rhipicephalus appendiculatus ticks usually attach to the ear, hence the name 'brown ear tick'

Biological control

icipe further studied the biological control agents that are effective in controlling ticks, for instance botanical extracts, predation by chickens, entomopathogenic fungi (EPF) and anti-tick vegetation. The researchers tested two EPF, *Beauveria bassiana* and *Metarhizium anisopliae* in various formulations for their potential in the control of adult *R. appendiculatus*. These products were tested on Zebu cattle (*Bos indicus*), in the field and on unfed larvae, nymphs and adults of *R. appendiculatus* and *A. variegatum* in the vegetation. When the aqueous spore formulations of both fungi were sprayed on adult *R. appendiculatus* feeding on Zebu cattle, they killed 82–85 percent of the ticks and reduced egg hatchability to between 25–60 percent. Powder spores of the two fungi also induced mortalities in adult *R. appendiculatus*. The aqueous formulations of the fungi were effective on the larval stages of both tick species. *Amblyomma* ticks respond to a number of semiochemicals including the attraction–aggregation–attachment pheromone (AAAP) emitted by feeding males and carbon dioxide exhaled from their hosts. This characteristic was exploited by *icipe*'s scientists to develop a device baited with the pheromone for effective infection of *Amblyomma* ticks with *M. anisopliae* in the field. Deployment of this technique in the field resulted in 64 percent reduction of *Amblyomma* 6 weeks after treatment. Mortality of 94 percent was observed among the ticks that were recovered from the field and maintained in the laboratory for 2 weeks while only 3 percent died from the control plots. The results of this study open up the possibility of developing an environmentally friendly and low cost application strategy to control *Amblyomma* ticks.

Parasitoids

The first report of tick parasitoids was made in 1907. Since then, seven species belonging to the genus *Ixodiphagus* have been described. In the first third of the 20th century, a few releases of tick parasitoids were done in the United States of America and Europe. In Africa, the parasitoid *Ixodiphagus hookeri* has been reported from South Africa, Nigeria, Uganda, Kenya, Côte d'Ivoire and Mozambique. A second species, *I. theilerae*, has been reported from Namibia, South Africa and Egypt. However, no parasitoid releases have been conducted anywhere on the continent classically or inundatively. Before parasitoids can be used for tick management in Africa, it is necessary to establish their geographical distribution and the identity of the existing species, and conduct studies on their biology, development in ticks, flight range, dispersal capacity and the cost-effectiveness of their use. Considerable information existed for most of these parameters on *I. hookeri*. However, further work is needed on the geographical distribution of the parasitoids on the continent, and cost-effectiveness and sustainability of their use in tick control. Investigations should be carried out on the effect of acaricides on parasitoids. It is also necessary to establish whether the use of parasitoids in an integrated control programme would be compatible with other chemical-free interventions currently being developed against ticks, such as entomopathogens, botanicals and anti-tick vaccine.

The *icipe* scientists conducted an experiment to investigate the effect of the tick parasitoid, *I. hookeri*, on tick numbers on cattle. Over a period of one year, they released 150,000 parasitoids in a field where 10 cattle infested with multiple tick species were kept. As a result, *A. variegatum* was reduced from 44 to two ticks per animal while *R. appendiculatus* increased over the time of parasitoid release. During the time of release 51 percent of the *A. variegatum* nymphs collected from the animals were parasitised. The recovery of the parasitoids after the releases were stopped was only 9 percent. The total numbers of *A. variegatum* remained low up to 1 year after the parasitoid release was stopped. The *icipe* study gave an insight into how *I. hookeri* could be used strategically for the management of *A. variegatum* on small-scale farms.

Traditional methods

icipe recognises the indigenous knowledge inherent in communities across Africa as important. But such knowledge is gradually disappearing. *icipe* has, therefore, taken the lead in evaluating traditional tick control practices as well as the socioeconomic factors that influence their adoption and sustainability.

This study included a survey, documentation and evaluation of the anti-tick ethnopractices of the Bukusu community in western Kenya, who combine arable and pastoral livelihoods. Traditionally, the Bukusu control ticks using a variety of methods, such as using ethnobotanicals, hand picking, burning pasture, livestock quarantine, grazing practices, and feeding animals on natural salty soils locally called 'silongo'.

About 141 anti-tick plant species spread over 103 genera and 48 families were suggested and documented, together with four non-botanical anti-tick ethnoagents. From the literature, 11 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 on the documented plant species, 51 plant species not evaluated previously for acaricidal properties were selected for study.

The ethnobotanicals were applied by fumigation, pouring a decoction on the animal, steaming or dusting the animal's skin, hanging plant bouquets in cattle sheds, rubbing of bolus or paste on animals, and grazing animals on identified anti-tick pasture plants.

If backed with scientific rationale, these anti-tick ethnopractices could be integrated into sustainable tick control and management. In turn, this would improve the livestock industry, and give smallscale farmers, whose livelihoods depend largely on livestock, a fresh impetus to the improvement of their livelihoods.

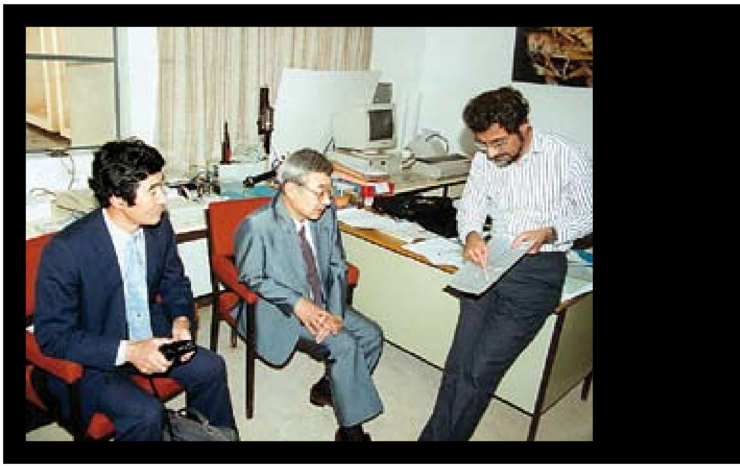
Understanding the language of locusts

For thousands of years, the desert locust,* Schistocerca gregaria, *one of about a dozen species of grasshoppers known as locusts, has caused mankind untold anguish. Unlike many other grasshoppers, desert locusts are able to change their normally solitary behaviour and aggregate into voracious hopper bands and adult swarms comprising anywhere between 40 to 80 million adults within a square kilometre. These massive adult swarms fly across thousands of kilometres, destroying crops and leaving hunger and poverty in their wake.

In Africa, the Sahel region, which stretches between the Sahara Desert in the north and the Sudanian savanna in the south, is particularly susceptible to locust outbreaks. Between 1986 and 1993, a severe locust outbreak occurred in the Sahel, destroying about 76,000 to 96,000 tonnes of sorghum in Senegal, Mauritania, Mali, Burkina Faso, Algeria, Niger, Nigeria, Chad, Sudan, Somalia, Ethiopia and Eritrea.

For a long time, many efforts to control locusts have been reactive, aimed at stopping outbreaks after they have started. These efforts include futile attempts by helpless farmers waging 'hand-to-hand combat' against the insects using hoes and brushes, and attempting to bury them alive in large ditches. On the other hand, initiatives led by international organisations attempt to control outbreaks by intoxicating the swarms with insecticides. This approach is not only extremely expensive, but also very hazardous to people, other non-target animals and the environment in general. For instance, in the 1986 to 1993 outbreak in the Sahel, over 13 million litres of insecticides were sprayed at a cost of US$ 100 million.

icipe's PAN



Prof. Ahmed Hassanali (right), a Zanzibar-born chemical ecologist who worked for many years at *icipe* on the discovery of a bio-signal that dramatically changes the swarming behaviour of the desert locust, talking to visitors from Japan in his office

For 18 years, an *icipe* team, led by Prof. Ahmed Hassanali, has been researching ways of pre-empting locust swarms. The team studied the chemical language of these insects, and identified different sets of chemical signals, which regulate their behaviour and life-style in young and adult stages. One finding caught the attention of the researchers: that young and adult locusts use different chemical communication dialects to stay together in their gregarious phases. The researchers wondered what would happen if one stage is exposed to the chemical vocabulary of the other. This question led to the discovery of a novel way of disrupting the social structure of the insect and reverting them to harmless solitarious individuals. For example, a specific adult vocabulary, phenylacetonitrile (PAN), which governs the swarming behaviour of the adults, blocks communication between young (nymphal) locusts, resulting in a total loss of communication between the young individuals.

In three separate field trials, *icipe* scientists and collaborators from Sudan demonstrated that even minute doses of PAN were effective in breaking up the social groups, or bands, that young gregarious locusts live in. The insects became highly stressed, disoriented and started to cannibalise, some losing their appetite altogether. The locusts suffered high natural mortality and the ones that survived were exposed to predators and fell prey to natural enemies like birds. Moreover, exposure to PAN made hoppers considerably more susceptible to low doses of synthetic insecticides and biopesticides.

What makes PAN particularly attractive is that the dose needed is only a fraction of the quantities of chemical or biological pesticides — typically less than 10 millilitres per hectare. This translates into substantially lower costs — 50 cents per hectare as opposed to US$ 12 for synthetic pesticides and US$ 15–20 for other bio-control agents. PAN, as a locust control agent, is environmentally friendly and cheap to develop, and can be used either on its own, or alongside other, more expensive control measures like synthetic insecticides or biopesticides but at largely reduced concentrations.

Scientists from the 2007 field trial in Sudan of PAN combined with low concentrations of the grasshopper biopesticide Green Muscle® were sponsored by FAO

A locust swarm: These voracious creatures, which move in their millions, can destroy thousands of hectares of land and crops in a matter of weeks

The Malagasy migratory locust

In addition to the desert locust, *icipe* researchers have also studied the Malagasy migratory locust, *Locusta migratoria capito*, which constitutes a major threat to agriculture in Madagascar, the world's fourth biggest island. In the 1900s, there were three major invasions of the Malagasy migratory locusts, which all required considerable chemical control. A locust plague which started in 1996 lasted four years, when only the far north of the country, was spared from invasion. In May 2010, a new locust invasion set in, and swarms of billions of insects swept across the south and the central highlands of Madagascar, destroying 120,000 hectares of crops in just one month.

Since January 2006, *icipe*, the Centre National de Recherche Appliquée au Développement (FOFIFA), and the Locust Control Centre (CAN) of Madagascar, have been conducting research towards introducing Green Muscle®, a *Metarhizium anisopliae* var. *acridum*-based biopesticide, developed in West Africa for the control of grasshoppers, for the control of migratory locusts on the island. Studies by the scientists demonstrated that under quarantine conditions, Green Muscle® was harmless to non-target insects such as bees, silkworms and butterflies. Based on these results, the biopesticide was introduced into Madagascar for efficacy trials on a large-scale. Green Muscle® was officially registered for use in the control of the Malagasy locust in July 2009.

In addition, between 2006 and 2010, two young researchers from Madagascar, Herisolo Andrianiaina Razafindraleva and Victor Razafindranaivo, were offered scholarships under the *icipe* African Regional Postgraduate Programme in Insect Science (ARPPIS) to study the chemical language of the Malagasy locust. Herisolo looked at how the adults of these insects use this chemical language to form swarms, and how the language influences the insect's juveniles in their own grouping. Victor focused on the juveniles of the Malagasy locust, studying how their chemical language can influence their maturation or development as adults.

Future work

icipe researchers are currently investigating the role of PAN in selection of mates by the females of the gregarious desert locust. The scientists are also elucidating the pathway through which the desert locust makes PAN. As part of these studies, the researchers are identifying the organs involved in the production and storage of PAN. These studies would enable safe and more cost-efficient ways of interfering with the production of PAN in the desert locust and eventually in the aggregation process of the adult locusts.

Beyond PAN, the scientists realise that a lot of research still remains to be done on the desert locust. One of the areas that need further investigation is the effect of exposing adults to the chemical vocabulary that governs the grouping behaviour of the juveniles. The *icipe* researchers have a hypothesis that a certain juvenile chemical vocabulary might work in a manner similar to PAN.

Participants in the photograph include a FAO consultant, locust control operators and technicians from the Plant Protection Directorate in Sudan, representatives from AGRHYMET regional centre (Centre Régional de Formation et d'Application en Agrométérologie et Hydrologie Opérationnelle) in Niger, the National Centre for Locust Control (CNLA) and Mauritanian Desert Locust Centre both in Mauritania, and the Commission for Controlling the Desert Locust in the Central Region (CRC-EMPRES) (Emergency Prevention System for Transboundary Animal and Plant Pests and Diseases). The CRC participants at this trial were from Sudan, Ethiopia, Egypt, Yemen and Iraq

The identity of the chemical signal that governs mass egg-laying by gregarious desert locust females has only partially been elucidated by *icipe* scientists. Therefore, another area of research that also needs further investigation is the full identity of this chemical signal. The identification of this signal would allow *icipe* scientists to develop a lure-and-kill strategy for females of this locust using biopesticides or limited amounts of insecticides as the killing agent.

In addition, there is still not enough knowledge on the identity of the chemical vocabulary that brings together the opposite sexes of the desert locust when it is in the harmless solitary phase for mating. An understanding of the relationship between this locust phase and the plants that it feeds on and shelters in, in its recession and breeding areas is also warranted.

Further, there is also need for a better understanding as to why these locusts undergo a temporary dormant stage (diapause) at certain times of their development when no reproduction occurs. Moreover, the signals that terminate the dormancy to allow for mating and egg laying will also need to be investigated.

Locusts mating: More knowledge is needed on the chemical vocabulary that brings together the opposite sexes of the desert locust when it is in the harmless solitary phase for mating

The researchers believe that such knowledge, combined with the relationship between the desert locust, weather and vegetation patterns, would provide the groundwork for developing population and gregarisation models, and predicting potential outbreaks of these highly destructive insects.

Saving the cabbage

Between 2001 and 2008, icipe implemented a highly successful biocontrol project of diamondback moth (DBM) in all key brassica growing areas in Kenya, Tanzania, Uganda, Ethiopia and Cameroon. The project resulted in a significant reduction of DBM populations and damage to target vegetables, with over 30 percent reduction in pesticide application on cabbage and kale and 20 percent less in pesticide-related health symptoms.

Crucifers are among the most important vegetables for home consumption and local markets in eastern and southern Africa. In Kenya, for instance, cabbages are grown in all the country's eight provinces, occupying over 18,000 hectares of land within small- and medium-scale holdings. In Ethiopia, kale is part of almost every meal while in Mozambique and Zimbabwe the vegetable is an important smallholder subsistence crop. In East Africa, limited amounts of cabbage and Brussels sprouts are also exported to Europe. Overall, cabbages and kales have the potential to transform African economies and to contribute to poverty reduction. The vegetables provide employment mostly for women and youth, who are largely involved in their production and also provide a positive spillover effect upon a range of other industries, such as transport and trade.

For a long time, however, farmers have not earned as much as they should from the cultivation of cabbages and kales. The average yield and income of the vegetables has remained low due to various factors, the most important being insect pest damage. One of cabbage's major devastating pests is the diamondback moth (DBM) (*Plutella xylostella*), a small greyish-brown insect which gets its name from 3 pale triangular markings which form a diamond pattern on its back, seen when its wings are closed at rest. Despite its small size — 8 millimetres in length when fully grown with a wingspan of about 15 millimetres

— the DBM causes damage that is often sufficient to ruin cabbage heads to a level where they are no longer marketable. Plant damage is caused by larval feeding. DBM attacks cabbage and other host plants such as cauliflower, broccoli, radish and turnip. Feeding by the DBM larvae damages leaves, making them appear skeletonised. The pest also contaminates the cabbage heads with larvae or faecal waste. Control of the pest, which is so cosmopolitan that it tolerates tropical, subtropical and temperate climates, has remained elusive for a long time, due to its notorious pesticide resistance. The use of synthetic pesticides often leads to serious environmental problems, besides affecting the health of farmers and consumers. In addition, pesticides eliminate the natural enemies of DBM, thereby creating the need for more pesticides and causing the build-up of considerable residue levels in subsequent cabbage production. This in turn increases the production cost and development of resistance. Ironically, to overcome the pest's resistance to insecticides, farmers resort to applying higher and more frequent doses of insecticide cocktails, making control of the pest even more complicated. However, intensive studies carried out around the world have found biological control — the use of a living organism to control pests — to be an effective, safe and sustainable way to control DBM.

The diamondback moth (DBM)

Introducing *Diadegma semiclausum*

An analysis of the research on plant protection on crucifers in the national research institutions of eastern and southern Africa, conducted by *icipe* scientists (between 1980 and 1995), showed that the emphasis on DBM control had been on pesticide screening. The study also revealed that, due to the limited resources in horticultural research, sustainable control of DBM could only be effected through regional cooperation and networking, to make optimal use of available manpower and finances.

The parasitic wasp, *Diadegma semiclausum*. (Photo courtesy of G. Goergen of IITA).

In 2000, *icipe* embarked on a research project towards the biological control of DBM. The project commenced with a survey in the major cabbage growing areas in Kenya, Uganda and Tanzania, which showed that existing natural enemies were not providing a big enough impact in control of DBM. *icipe*, therefore, decided to import a parasitic wasp (*Diadegma semiclausum)*, which was already being used in a number of countries in South East Asia (Taiwan, Indonesia) and in Mainland China and New Zealand. The wasps sting the DBM larvae,

Farmer Simon Mwacharo pictured in his flourishing cabbage farm with David Onano, an agricultural extension officer in Wundanyi, Taita–Taveta District

lay their eggs in them which hatch into larvae, which then feed on the internal organs of the DBM causing death. When a wasp's larva pupates, the DBM turns brown and hard and remains stuck to the leaves. The adult parasitic wasp then emerges from the DBM cadaver in a few days.

Prior to the first field releases, which were granted through permits by the governments of Kenya and Tanzania in 2002, *icipe* scientists carried out thorough laboratory studies on the biology, behaviour and efficacy of the little wasp. Four pilot sites, three in Kenya and one in Tanzania were selected. As most of the cabbage and other brassicas in East Africa are grown in the highlands, all these sites were at high altitudes. The researchers visited the release sites every fortnight and collected data to find out if the natural enemy was getting established. The results from these surveys showed a reduction in the number of DBM in the fields, as well as its damage on crops. A parasitisation rate of up to 60 percent was recorded in one of the sites in Kenya. In Tanzania, within eight months, the natural enemy spread widely with an average of 30 percent parasitism, though some fields recorded as high as 80 percent parasitism. By the end of the first year, the wasp was providing phenomenal control of DBM. Since then *icipe*, together with its partners, has scaled up operations to cover all brassica growing areas of Kenya, Tanzania and Uganda. More than 10 districts in Kenya benefited from the release of *D. semiclausum*. Because the effect of other pests in lowering brassica yield cannot be overlooked, *icipe* worked with farmers in the adaptation of several other safer control methods. Based on interviews, it was clear that most farmers use pesticides more than necessary, generally applying recommended pesticides on the basis of a schedule, or as an insurance against the risk of crop loss caused by pests without assessing if the application is needed or not. The *icipe* partners worked with farmers on how to apply scouting methods to determine the need for pesticide application. The process involves counting of the DBM on several crops. A system was introduced where spraying would only be done if there was an average of more than three larvae on the scouted crops in the dry season, and more than five in the wet season. As a result DBM damage to cruciferous vegetable crops has declined. In addition, the quality of the produce has improved, due to the reduced pesticide sprays against the pest. In most areas, spraying for DBM control went down from 12 sprays per cropping season to zero. Use of IPM-compatible insecticides for the control of other brassica insect pests, including aphids, has become a common practice

Farmer training in Tanzania

among sensitised farmers. In an effort to expand DBM biocontrol to other African countries, *D. semiclausum* was field released in Cameroon and Ethiopia in 2007 and 2008, respectively.

Farmer cadre trainers learning about pest damage symptoms

Cotesia plutellae

Based on the need for another parasitoid for the lowland and semi-arid regions, where kale is an important subsistence crop, the *icipe* scientists and collaborators selected *Cotesia plutellae,* and specifically a strain of the parasitoid from South Africa. The parasitoid was first released in central Uganda in November 2003 and in eastern Kenya in 2005. Post-release surveys conducted in 2005 in central and eastern Uganda indicated that the parasitoid had established and was co-existing with the indigenous DBM parasitoids. The level of parasitism was as high as 100 percent in some fields. In February 2006, *C. plutellae* was recorded for the first time in western Kenya, having migrated from Uganda. By October 2007, the parasitoid's parasitism rate in the region had increased from 5.9 to 36.6 percent. Moreover, by that time, the parasitoid had also moved further south close to the Tanzanian border, an indication that it was still spreading and colonising new areas.

In Kenya, the first field release of *C. plutellae* was done in June 2005 and then repeated in 2006. However, the establishment and impact of the parasitoid on DBM in eastern Kenya has not been assessed.

Economic impact

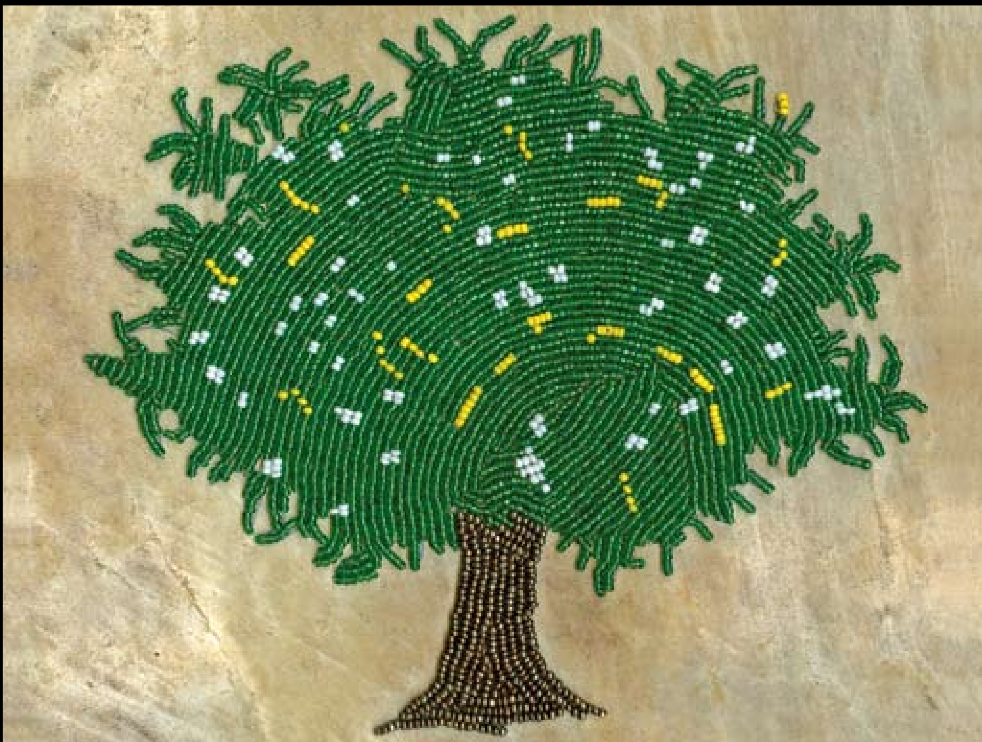
An economic impact of the *icipe* DBM biological control strategy commenced in 2005. Surveys were carried out in the Central Province of Kenya and the Northern Zone of Tanzania. Farmers producing cabbage in areas where the *D. semiclasum* is present were found to use significantly less pesticides, in comparison to those where the parasitoid was absent. The survey further showed that in areas with the wasp, farmers showed 20 percent less pesticide-related health symptoms than in areas without the wasp, holding all other factors constant. Baseline information on *C. plutellae* was collected in Eastern Province and western Kenya. This involved 250 commercial kale farmers.

Farmers in Nyeri, Central Kenya, observe DBM's natural enemy before its release into their farms.

Collaboration and capacity building

The DBM biocontrol project became a platform for North–South collaboration between *icipe* and German universities. This resulted in three master of science degrees, four doctoral degrees and two post-doctoral fellowships.

In addition, the partnership with national agricultural research institutes (NARIs) helped to build their capacity. For instance, staff of national biocontrol units received hands-on training on mass rearing, field release and impact assessment of the parasitoids and DBM. The project also provided refresher courses for national extension staff, to conduct research and disseminate results to end-users. The NARIs staff participated in project planning, implementation and reviews, which contributed to their capacity to develop and manage projects. The process also involved the training of farmers and farm input suppliers. The experiences, lessons learned and the network of collaborators accumulated by *icipe* in the course of implementing this project are invaluable. More specifically, the experience will be extremely useful in the management of other invasive exotic insect pest species in the region.



Battling a tiny but tenacious enemy

A two-hour drive south of the Kenyan capital, Nairobi, lies the Maasailand division of Magadi, a vast arid plain characterised by baking salts and rocky soils. Amidst this landscape sits the Nguruman irrigation scheme, which brings an unexpected flush of life to Magadi. Fed by streams flowing from the Nguruman Escarpment, the irrigation scheme nourishes 5000 hectares of arable land. Yet, for years, the Maasai community — Kenya's most renowned pastoralists — did not venture into agriculture, remaining faithful to keeping cattle, their undisputed symbol of status and wealth. The Maasai would herd their livestock in the drier parts of Nguruman, renting the irrigated land to other farming communities. In turn, these 'incoming' farmers concentrated on cultivating subsistence crops, such as maize and beans.

However, in the recent past several changes have affected the practices of both the farming residents and the Maasai herders in Nguruman. As in many developing regions, in Kenya, horticultural farming for local and export markets has rapidly become one of the most profitable agricultural enterprises. Efforts by organisations such as the World Health Organization (WHO) of the United Nations to emphasise the need for balanced nutrition in the otherwise maize-based diet of the rural and urban poor, have elevated the role, and encouraged the cultivation of fruits and vegetables. In addition, in recent years, a lucrative market for vegetables and fruits has steadily grown in Europe. Horticultural farming provides income and employment, and better livelihoods for smallholder farmers and an array of people, especially women and youth, are involved in the production chain. The Nguruman farmers have been quick to recognise this potential, and focused their attention on fruits and

Adult *Ceratitis cosyra* (Photo by M.K. Billah)

vegetables. On the other hand, the growing impact of climate change has had a dramatic effect on the Maasai. For instance, severe droughts brought on by climate change have in some instances wiped out entire herds of cattle, leaving the herders desperate for back-up sources of livelihood. In doing so, the Maasai pastoralists have begun to appreciate the value of farming and horticultural crops.

And this is how the humble mango has found its place of pride in Nguruman. Reputed to be the most commonly eaten fresh fruit worldwide, mango ranks high, alongside avocado and citrus, among export fruits from Africa. For the Nguruman community, the cultivation of mangoes has become popular, as the crop requires little labour, water or farm inputs. In addition, the fruit is highly-profitable, with proceeds as high as US$ 570 per farmer per month, which is enough to buy as many as four cows.

An encounter with Ceratitis cosyra

However, the transition towards cultivating mangoes has not been easy for the Nguruman community. Breaking long-established pastoralist and farming traditions is one thing, but the farmers have had to contend with a tiny but tenacious enemy — the fruit fly. Fruit flies attack fruits by puncturing the skin and laying their eggs. These eggs then hatch into maggots that feed on the decaying flesh. Infested fruits quickly become rotten and inedible, eventually dropping to the ground, and are thus completely lost to the growers.

For over a decade, from the mid 1980s to 1990s, the Nguruman farmers did their best to contend with the flies, with little success. They would often lose up to 70% of their fruits.

In 1994, the Kenya Ministry of Agriculture approached *icipe* for assistance on behalf of the Nguruman farmers. The scientists took up the challenge wholeheartedly, but when they visited Nguruman they found a devastating situation; the fruit flies had reduced most of the orchards to carpets of rotting mangoes.

Adult *Bactrocera invadens* (Photo by M.K. Billah)

Undeterred, the *icipe* scientists begun an exploratory survey to profile the prevalent fruit fly species. These studies determined *Ceratitis cosyra* as the most destructive fruit fly species in Nguruman. The scientists then developed a control package using a two-pronged approach: a baiting technique that both attracts and kills the flies and a soil application of an entomopathogenic fungus that destroys the maggots entering the soil to rest. Through laboratory studies, the researchers established that brewers' yeast, a locally available inexpensive waste material (as bait substrate), and the insect killing fungus were the most effective products. The scientists supported these two strategies with orchard sanitation (the collecting and destroying of all rotting mangoes on the ground to prevent the pests from completing their life cycle thus further suppressing their populations).

Mr Binito Atonya, a Divisional Agricultural Officer in Nguruman, Rift Valley, Kenya is assisted by Martin Wanyonyi, an *icipe* technician in releasing the fruit fly egg parasitoid *Fopius arisanus* for management of *Bactrocera invadens* on mango

Understanding Bactrocera invadens

By 2002, *icipe* appeared to be winning the war against fruit flies in Nguruman, as the strategies had brought the pest population down by 70 percent. The researchers continued to apply the integrated pest management packages while monitoring populations of the fruit flies.

Unfortunately, in October 2003, the situation took a downturn. During their routine seasonal population studies, the *icipe* scientists recorded, for the first time in Africa, the presence of *Bactrocera invadens*, a notorious, highly invasive fruit fly species from Asia.

Since several *Bactrocera* species are well documented as notorious pests and are ranked high on quarantine lists worldwide, the *icipe* scientists knew that the arrival of *B. invadens* spelt trouble for all stakeholders in the fruit industry in Africa. Within a span of one year of it being reported in Kenya, *B. invadens* had moved to 10 other countries within the continent, spreading first to Tanzania and Uganda, and then to several Central and West African countries. By 2010, the pest had been reported in 28 African countries, including the Comoros Islands and the Republic of Cape Verde.

The scientists, therefore, incorporated *B. invadens* into the ongoing fruit fly management project, expanding their studies beyond Kenya, to Uganda, Tanzania and Benin. They speculated that *B. invadens* would cause competitive displacement of native fruit fly species. Therefore, for three years, from October 2005 to October 2008, the *icipe* researchers monitored seasonal and annual adult fruit fly populations in the Nguruman area, during the off and the main mango seasons. It was clear that *B. invadens* was becoming the predominant species, and within four years, the invasive pest had displaced the native *C. cosyra,* constituting 80 percent of the fruit fly population in the traps.

One reason why *B. invadens* was able to displace the native species was because the invasive pest has a higher reproductive capacity than the indigenous species. In addition, *B. invadens* is a mobile insect, which means that it tends to arrive first at host resources, giving it competitive superiority to *C. cosyra*. Importantly, in its new environment, *B. invadens* also stands a chance to thrive better as it is no longer under threat from its co-evolved natural enemies.

icipe technicians demonstrating the use of an augmentorium for fruit fly parasitoid conservation

The *icipe* study also contributed further knowledge on the bioecology of *B. invadens*. For instance, the speed at which the pest displaced *C. cosyra* suggests that *B. invadens* has adapted to using the mango as host fruit over a long period. The research also provided baseline information necessary for a successful fruit fly suppression programme, through IPM and classical biological control. The trend of the three-year annual population dynamics distinctly showed peak abundance of both fruit flies to be between the months of October to December, which indicates when management based on baiting technique and application of entomopathogens should commence.

The *icipe* study also showed that *B. invadens* was capable of year-round breeding, indicating that alternative host plants around a mango orchard were playing a part in the survival and thriving of *B. invadens*. Based on this inkling, between June 2006 to January 2009, the *icipe* researchers conducted a host plant survey for *B. invadens* in Kenya, Benin and Tanzania, which suggested further that the pest may be emerging as a polyphagous species.

To obtain more knowledge on the insect, the *icipe* scientists also conducted complementary laboratory based experiments. In April 2007, the scientists started rearing *B. invadens* colonies on artificial diet, using adult flies from rotten mangoes collected at local markets in Nairobi. This project led the *icipe* scientists into areas of *B. invadens* research that had so far received little attention, for instance the effect of environmental variables such as temperature and relative humidity on fruit fly species, characterising molecular markers to better understand its identity as well as delving into its molecular ecology to understand its invasion history and spread. Such information is important for understanding the insect, from various aspects including the temporal and geographic patterns of *B. invadens* and how the pest can be suppressed and prevented from spreading to other localities/countries. The knowledge is also valuable in guiding the release of natural enemies, as well as understanding the relationship between the pest and other native fruit flies.

In the meantime, the researchers were also investigating the native natural enemies in Kenya, Tanzania and Benin, to see if there were any that could attack *B. invadens*. Although the scientists had collected information regarding the parasitoid complex in the mango regions in Kenya in previous studies, they needed to further characterise them, to assess the rate of parasitism, and find out if any of the parasitoids would make new associations with the invasive species.

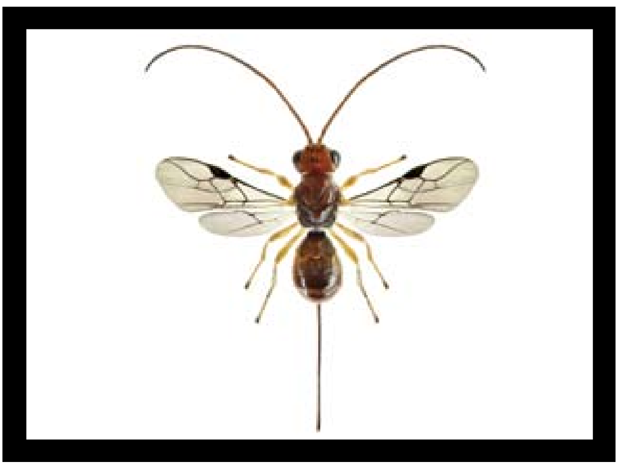
The team also needed baseline information to predict potential competitive or complementary interaction between the indigenous and exotic parasitoid species. After carrying out tests on two indigenous parasitoid genera, *Psyttalia* and *Tetrastichus*, the scientists concluded that none of them could be used for classical biological control of the pest because the immune system of *B. invadens* was stronger than that of the parasitoids, and the parasitoid eggs were encapsulated by the fruit fly. Importantly, through the results of this study, they learned that in addition to the destructive nature of *B. invadens*, it also has the potential to act as an ecological sink for some of the indigenous generalist parasitoids, and may even cause their extinction.

Biodegradable bait station devices for fruit fly suppression

As such, they took the search for natural enemies of *B. invadens* to the pest's putative aboriginal home, Sri Lanka, with the assistance of the country's Department of Agriculture's, Horticultural Crop Research and Development Institute (HORDI). Although three natural enemy species were detected, their parasitism rates on *B. invadens* were low in all the fruits collected and in the laboratory suitability and acceptability test.

This meant that a second trip was necessary, which commenced in July 2007. The exploration work was more intense and incorporated a wide range of activities on the pest as had been done in Kenya, Uganda, Tanzania and Benin. From the population studies, although *B. invadens* was found in all agroecological zones of Sri Lanka, the pest seemed to prefer the low and intermediate areas, which reaffirmed results from Kenya that it is a lowland resident pest. From the range of natural enemies that were collected, it became clear that a large diversity of natural enemies of the *Bactrocera* species exists in Sri Lanka.

The scientists also obtained clear evidence that colonies of *B. invadens, B. zonata* and *B. kandiensis,* which are the dominant fruit fly species in Sri Lanka, could easily be established. They also succeeded in establishing colonies of the major parasitoid species, and identified *Fopius arisanus* and *Diachasmimorpha longicaudata* as the most attractive ones for future studies. In addition, they encountered some major alternative host plants such as *Terminalia catappa* (tropical almond), *Syzygium jambos* (rose apple) and *Solanum mauritianum* (bugweed) that could be good sources of natural enemies in future explorations.



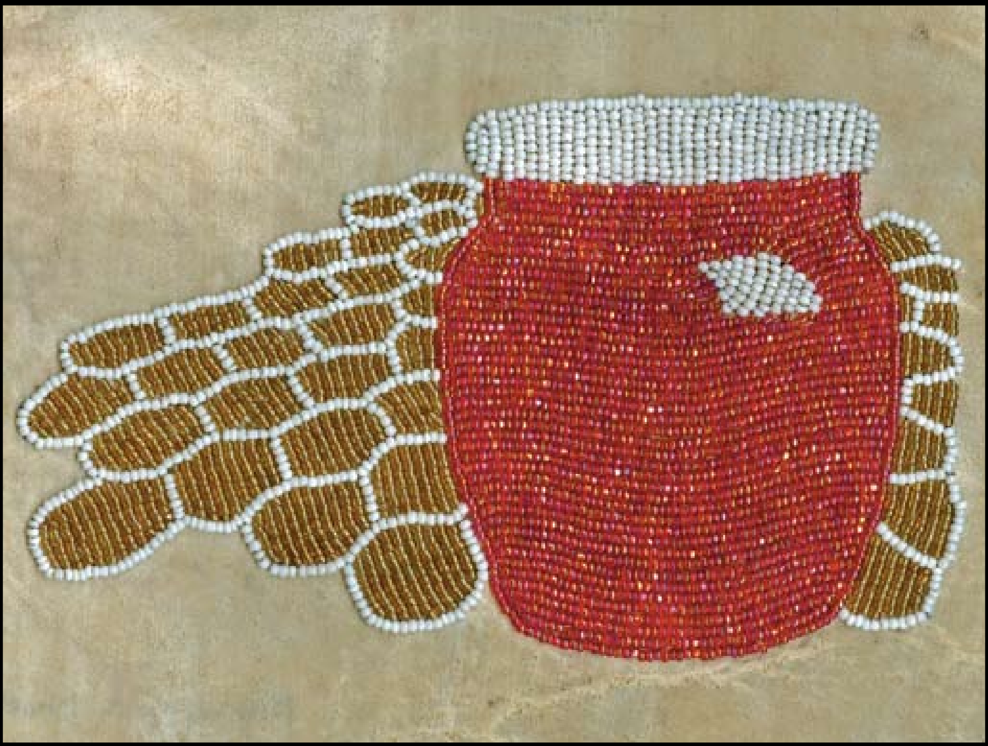
Adult *Fopius arisanus*, a natural enemy of fruit flies (Photo by G. Goergen, IITA)

Unfortunately, the *icipe* scientists were unable to import the promising parasitoid species from Sri Lanka to Africa to suppress *B. invadens*, as the restrictions of the Convention on Biological Diversity (CBD) related to movement of biological control agents made it difficult to obtain the necessary permits.

However, in parallel to the exploratory activities in Sri Lanka, the *icipe* researchers sought parasitoids from other established laboratories worldwide. They succeeded in obtaining *F. arisanus* and *D. longicaudata* from the

USDA-ARS laboratory in Hawaii for introduction and testing against *B. invadens* in Africa. After encouraging laboratory results on the effectiveness of *F. arisanus* against *B. invadens*, the scientists submitted applications for import permits to the Kenya Plant Health Inspectorate Service (KEPHIS), Tanzania Ministry of Agriculture and Cooperatives, and Service de Protection des Végétaux, Ministry of Agriculture of Benin, to conduct experimental field biological control. This enabled them to commence pilot releases at the beginning of the 2008/2009 mango fruiting season in both Kenya and Tanzania and in March 2009 in Benin. Already, the scientists have recovered *F. arisanus* from field populations of *B. invadens*, which indicates success although it is too early to declare establishment of the parasitoid.

This classical biological approach with *F. arisanus,* if complemented with IPM packages such as baiting technique, soil inoculation with entomopathogenic fungus, male annihilation (removal of a large number of males using male attractant and a killing agent) and orchard sanitation using a tentlike structure called 'augmentorium' (it keeps fruit flies inside but allows beneficial parasitoids to escape), can result in over 80% suppression of *B. invadens* leading to production of quality fruits for domestic and export markets.



Breaking the vicious cycle of poverty, step by step

In general, the poorest communities in the rural areas of Africa live mostly in the arid and semi-arid zones. The lives of these communities are marked by a constant contest between the harsh ecosystems that they live in and the people's efforts for survival. The adverse climate — unreliable rainfall and recurrent droughts — in these areas makes agriculture unviable. To make a living, community members turn to activities such as charcoal burning, as a way of earning income. This undermines efforts to conserve the environment, further exposing the regions to more unfavourable weather. Without a proper economic base, many households cannot afford proper education, nutrition or healthcare, resulting in a vicious cycle of poverty.

Many development organisations rightly recognise that the vicious cycle of poverty can be broken through innovative, off-farm income-generating activities for the communities. Unfortunately, while numerous attempts have been made by various local and international organisations towards such endeavours, the successes have been limited.

However, over the past one decade, *icipe* has made considerable progress in addressing this challenging situation by simultaneously tackling yet another problem — The under-utilisation and the threats facing Africa's rich and abundant resource, the beneficial arthropods. This has been through the introduction of eco-friendly technologies for sericulture and apiculture that are transforming the lives and the economies of no less than 15,000 households in 24 countries in Africa and recently, in the Near East and North Africa (NENA) region, to modernise the traditional apiculture practices and introduce a new culture of silk farming.

Ms Nados Bekele (on behalf of Ms Elizabeth Lwanga, UNDP Representative to Kenya), and *icipe* Director General, Prof. Christian Borgemeister, unveil the plaque for the inauguration of the Mwingi Silk Marketplace in 2006. In the background is the late Dr Alan Rodgers, a former UNDP-GEF Regional Director for Africa, who provided the overall guidance in the planning and implementation of *icipe*'s GEF project research in commercial insects

Three key factors have contributed to *icipe*'s success in these ventures. They include a stage-by-stage, as opposed to a 'master-plan', project approach; proper research on marketing constraints and opportunities, and focused attribution of the ownership of the initiatives to the respective communities. Accordingly, the *icipe* Commercial Insects Programme has been implemented in three phases.

Phase 1: Strategic research

At the beginning of the commercial insects project, *icipe* scientists identified the lack of research and training as the main hindrance to previous attempts to provide alternatives to marginalised communities. They therefore started their activities with strategic studies, which in turn provided the basis for modern technologies in sericulture and apiculture.

The scientists carried out research to identify specialised breeds of silkmoths and honeybees in various African ecosystems, so as to select potential races for commercial production of silk and honey-based commodities. This work included the survey of existing wild silkmoth species in Kenya and Uganda and establishing their abundance and potential for silk production. The research also extended to morphological studies on different stages of the silkmoths and designing of breeding techniques for the species in their natural habitats.

On the other hand, research on the domesticated silkworm, *Bombyx mori,* entailed breeding of a new silkworm hybrid suitable for the African climate. *icipe* further identified and investigated solutions for major silkworm diseases. The researchers also screened the cultivars of *Morus alba* mulberry against silkworm diseases and established the necessary preventive measures.

The major breakthrough in *icipe* research was the establishment of the breeding of the queen bee, which was the major obstacle in modernising beekeeping in Africa. *icipe*'s basic research in beekeeping has resolved many critical issues, such as the selection of potential bee races, development of a floral calendar for the production of honey and beehive products (such as wax, royal jelly, propolis, bee venom, pollen) and pollination services.

First mulberry silk cocoon harvest in Kakamega

After the strategic research, the scientists proceeded to identify four potential sites for silk and honey production, in Kenya and Uganda. The Mwingi District, a dryland and woodland area in the semi-arid eastern part of Kenya was among the selected regions because of its high potential for honey production. Communities in this poor agricultural area had been practising beekeeping for many years, but the industry had remained in its infancy for a long time, constrained by poor production and harvesting methods.

Silk cocoons being cleaned and processed in Bushenyi, Uganda

The scientists found the Hoima District in western Uganda also to be an ideal area for honey production. This region has a high poverty level, forcing communities to over-rely on the nearby forest resources, which are consequently being degraded at an alarming level. Traditional beekeeping in Hoima provided meagre income as well.

Bushenyi, another region of Uganda and Othoro in western Kenya were selected as ideal sericulture enterprise regions because of their favourable climate, high unemployment, abundant rural labour and availability of mulberry plants.

With the pilot sites in place, the scientists set off to tackle the second key challenge that organisations working in the development of marginalised areas face: the lack of proper entry points, through organised groupings or organisations, and the need for a sense of ownership of the projects by the local communities. Therefore, the various communities involved grouped themselves under four umbrella bodies respectively: The Mwingi District Joint Beekeepers Self Help Group, Hoima Honey Beekeepers Association, Kabondo Silk Group and Bushenyi Silk Farmers Association.

Phase 2: Implementation

Wild silk cloth production at the Mwingi Silk Marketplace

Like in any other enterprise, *icipe* recognised that the success of the apiculture and sericulture ventures largely depended on having the right product in the right quantity at the right place and at the right time. *icipe*, therefore, moved on to validate its research technologies by fostering smallholder silkmoth and beekeeping micro-enterprises, adapted to local conditions and the various communities.

In the four pilot sites, the scientists focused on promoting the technologies developed in

Hive inspection

Phase 1 through the training of farmers and farmers' groups, to identify marketing constraints, define product-quality requirements of these markets and provide technical backstopping and troubleshooting as required. They started by collecting data and undertaking an analysis to identify the location-specific production and adoption issues that needed to be considered, based on socio-economic, institutional and biophysical aspects.

In Mwingi, for instance, data gathered was used to design a suitable model for the entire district. *icipe* then introduced modern beekeeping technology using Langstroth hives as well as modified traditional beekeeping methods for better harvesting of honey.

Members of the Hoima Beekeepers Association were trained in various technologies, including colony management, queen breeding, royal jelly production, and honey harvesting, extraction, processing and packaging. They were also provided with equipment and beekeeping tools to establish on-site honey processing.

In Bushenyi, where *icipe* was trying to re-start the previous, but by then stalled silk industry, the Centre assisted in the long-term training of three extension staff of the Ugandan Silk Programme in silk reeling, fibre processing and packaging. *icipe* then concentrated in setting up a complete post-harvest unit with high production capacity for internal and external market outlets. Cocoon production in Othoro was initiated in 2000.

Phase 3: Development of marketplaces

A great deal of marketing research has been necessary in the *icipe* Commercial Insects Programme. For instance, while local and international markets for quality honey already exist, it had been continuously difficult for small-scale farmers to access them. The constraints faced by the farmers ranged from infrastructural challenges, such as remoteness from major commercial centres, bad roads, inadequate transport and storage facilities, to difficulties in accessing reliable information on products and prices. These hitches leave the farmers at the mercy of a few powerful buyers (known as brokers) of their products. It was therefore important to establish proper market linkages both locally and globally.

The Mwingi Honey Marketplace in Kenya

So far, two marketplaces have been constructed in Mwingi, as well as in other pilot regions in Kenya, Madagascar, Southern Sudan and Tanzania.

The marketplaces, which are fully owned by the communities, bring all the farmers together, and play a role beyond mere infrastructural facilities. They empower the farmers to negotiate for their products, to learn from each other, and to bond and unite in the fight against poverty while protecting their environment. A further aspect of the marketing process is the value addition to the honey and silk products produced by the communities, for instance through organic certification.

Results

The *icipe* Commercial Insects Programme is changing the economic landscape for communities in arid and semi-arid areas. As an example, when the *icipe* project started, there were only six beekeeper groups with a total of 180 members in Mwingi. Today, there are over 50 groups with more than 2000 participants practising apiculture in Mwingi. The Mwingi beekeepers were also the first in Kenya to receive organic certification of their hive products. With assistance from *icipe* and support from the United Nations Development Programme (UNDP), honey production in the district increased from 2 tonnes in 1997 to 40 tonnes in 2009.

icipe hopes that the programme will develop a full package of practices for the rural poor, not only raising their incomes, but also empowering them to participate in new trade opportunities. *icipe*'s vision is to do this within the scope of opportunities, constraints and even threats posed by globalisation. The Centre is also acting as a nucleus for research on the basic problems in silk- and honey-based production systems. *icipe* maintains that sustainable development in the marginalised areas is a journey that requires mechanisms to power it, set the pace, explore paths, check progress, and learn and adapt for government, civil society, business and donors alike. Therefore, *icipe* will continue to emphasise a step-by-step system as opposed to a 'master-plan'.

Effective partnerships in the fight against malaria

Africa is a continent of fascinating and charming landscapes. Unfortunately, within its highlands, plains and valleys abounds one of the greatest threats to mankind — malaria. Every year, millions of people in sub-Saharan Africa succumb to the disease, which is caused by a protozoan parasite of the genus *Plasmodium*, and transmitted by the female *Anopheles* mosquito. This menace, which kills a child every five seconds in Africa, poses astronomical costs for the continent, in its impact on human life and productivity, and on the healthcare system.

For many years, *icipe* has been in the forefront in the fight against malaria. The Centre recognises the interrelation between poor health and the cycle of poverty. Further, *icipe* realises that although many people are aware of the need to improve and protect their health, a majority of them, especially in the rural areas, lack the necessary information. *icipe*'s work in malaria control has been guided by the steadfast belief that the menace can be alleviated through an integrated vector management (IVM) approach, tailored for specific regions and communities. In three different environments, *icipe* has established effective partnerships with communities in the fight against malaria.

Malindi, coastal Kenya

Located on the shores of the Indian Ocean, the town of Malindi is a seaside resort that is grounded in great history. Although quite small, being only Kenya's tenth largest urban centre, Malindi rivals many tourist destinations worldwide as a seaside paradise, a reputation that not even the proximity to tourism giant, Mombasa City, has managed to oust it from. Unfortunately, in recent years, the town has seen an upsurge in mosquito-borne diseases, with outbreaks of malaria and filariasis becoming gradually prevalent. In addition, a recent Rift Valley fever outbreak (RVF) has caused untold problems in the town.

A female *Anopheles gambiae*. Worldwide, this mosquito species is one of the most important vectors of the malaria parasite, which alone causes more than 1 million deaths a year in Africa, particularly among children under five and pregnant women. During the day the mosquito rests indoors, and bites humans at night while they are asleep. In the course of its lifespan of approximately one month, such a female can infect up to five humans with the deadly disease. Many economists nowadays believe that malaria-transmitting mosquitoes are among the prime factors responsible for the slow economic development of sub-Saharan Africa (Photo courtesy of G. Goergen of IITA).

In 2001, *icipe*, in collaboration with the Kenya Medical Research Institute (KEMRI) started a programme towards alleviating the mosquito problem in Malindi. The project's aim is to prevent the emergence and resurgence of malaria and other mosquito-borne diseases, through the development of novel tools and methods, which incorporate the town's wider socio-economic factors. These include tourism, rapid urbanisation and the related infrastructural constraints as well as rising poverty levels.

A preliminary survey by the scientists at the start of the project showed that more than 90 percent of the mosquito larval habitats in Malindi were man-made. The study identified three main culprits that contribute to the larval habitats, the foremost being tourism. While the town's many hotels and cottages are fully booked between August and March, which is the tourist peak season, they are almost deserted during the rainy months of April to June. Since the swimming pools in these facilities are hardly in use during the latter period, rainwater accumulates in them, creating ideal breeding sites for mosquitoes. The second factor is Malindi's rapid population expansion, which has brought on unplanned, crowded, poorly constructed settlements that lack basic amenities such as running water, proper drainage and sanitation facilities. Inadequate infrastructural services, such as garbage collection or proper road maintenance, were revealed as a third cause of the increase in mosquito breeding sites in Malindi. While trying to deal with the inadequate water supplies, residents dig up wells or construct other water storage facilities. Eventually, malfunctioning sanitation facilities, stagnant water from open wells and tanks, clogged sewage canals and even potholes in the streets, all form good breeding sites for mosquitoes. These man-made factors are enhanced by Malindi's warm temperatures, which range between 22 and 30°C, average relative humidity of 65% and the town's clay soils which are susceptible to flooding,

Sampling mosquito larvae in a disused pool

CDC light trap

to make a thriving environment for mosquitoes.

From the onset, the *icipe* and KEMRI scientists realised that the eradication of malaria in Malindi would only be achieved with the full involvement, partnership and participation of the town's diverse communities, from local authorities, hotel and business owners down to individual households. The researchers felt that the key to the project's success was the empowerment of the communities to select and design control systems that are ecologically, economically and socially acceptable and feasible. They therefore adopted a "learning-by-doing" approach, geared towards enabling community members to develop, plan and implement an evidence-based IVM strategy, using a range of available interventions selectively.

The process started with the building of information on mosquito control, through the 'training of trainers' approach, who then each trained at least 30 more community members. Beyond this level, the researchers saw the need of nurturing 'community-owned' resource people, who would assist the residents in identifying mosquito problems and offer guidance towards solutions. This led to a novel idea, in 2005, of mosquito scouts. These individuals are nominated by community groups, and approved by the researchers on various criteria, for instance good communication skills, interest, commitment and a promising aptitude towards various technologies used in the project, such as CDC light traps. The selected nominees receive intensive training from *icipe* and KEMRI scientists, starting with introductory theory on mosquitoes and malaria control. They also learn how to identify and map mosquito breeding areas. These lessons are then followed by practicals and hands-on instructions where the scouts are paired with research teams.

After the training, the scouts are assigned a one-by-one kilometre cell, with a two-point mandate: to monitor adult mosquitoes in people's homes using CDC light traps; and carry out mosquito larval surveys, keeping a clear record of the types of habitat, their locations and the presence or absence of larvae.

The information collected by the mosquito scouts from the field is handed over to the research team. The trapped mosquitoes are taken to the laboratory for sorting and further observation, while the information on the larvae is analysed and verified. Based on the findings from the cells, the community members discuss among themselves the appropriate actions that they

Mosquito scouts

need to take so as to prevent the breeding of mosquitoes. The scouts then present a set of options, which are assessed for the practicability of say, filling and/or draining the main larval habitats, or treating them with an environmentally safe biopesticide, *Bacillus thuringiensis israelensis*, (Bti), which decimates the vectors in the larval stage.

An *icipe* scientist sampling mosquito larval stages. Controlling mosquitoes in their larval stages prevents the emergence of the disease-transmitting adults

The mosquito scouts have helped to identify hundreds of active and potential larval habitats in Malindi, with drainages topping the list, followed by wells and septic tanks. The scouts have also helped to flag neighbourhoods in terms of larval habitats. The work of mosquito scouts has helped in creating a positive response among household owners. Many of them are now taking responsibility in filling or draining the mosquito breeding areas in their compounds.

In addition, the mosquito scouts also help to distribute and monitor the usage of insecticide treated nets (ITNs) to the high-risk community members — pregnant women and children under five years of age. These nets are provided by the *icipe* and KEMRI team at a highly subsidised cost.

The results of the partnership between *icipe*, KEMRI and the Malindi community are already evident. Between 2008 and 2009, reports from health facilities around the district indicated that the cases of malaria had substantially decreased in the areas where the IVM strategies are in place.

Nyabondo, western Kenya

The western highlands of Kenya are littered with abandoned brick-making pits that are prime breeding sites for mosquitoes. Simple participatory environmental management interventions and larviciding with biopesticides can substantially reduce the malaria burden for the communities

Based on the success from the Malindi project, *icipe* scientists started a similar IVM project in Nyabondo, a scenic plateau near Lake Victoria. One of only two plateaus in Kenya, Nyabondo lies 1560 metres above sea level, and was formerly a wetland, which, due to a well-functioning drainage system was malaria-free for a long time. However, in recent years, the plateau has seen many serious outbreaks of malaria with 7000 to 8000 cases reported at local hospitals annually.

icipe scientists who started working in Nyabondo in 2002 implicated brick-making as the

icipe's collaborators from the Ministry of Health screening for malaria parasites in children, who are among the most vulnerable groups to malaria infections

major cause for this unfortunate trend. The plateau's heavy clay soil is ideal for making bricks, and over time, this activity has become the main source of income for a vast section of the 35,000 people who live in the region. The brick makers cut into the earth to dig out mud for making bricks. Once the activity is complete, these pits are abandoned, and for a long time, no-one had considered these hollows to be anymore than eyesores. That is until studies by *icipe* scientists in 2004 revealed these abandoned pits, which quickly fill up with water, as the major breeding sites for mosquitoes. Samples taken by the *icipe* scientists showed that there were far more *Anopheles* mosquito larvae in the puddles created by the abandoned brick-making pits than there were in the larger ponds. With thousands of abandoned brick-making pits littering the Nyabondo plateau, malaria spreads quickly through the settlements that are located close to the breeding sites.

With support from the Swiss Biovision Foundation, *icipe* has focused on strengthening the involvement of the Nyabondo community in the fight against malaria through two avenues. The first is the network of community based organisations (CBOs) against malaria and the formation of school health clubs. The network, which comprises 10 groups and has its own constitution, was registered with the Ministry of Social Services in 2010, with assistance from *icipe*. It facilitates meetings between stakeholders, where detailed workplans are discussed and prepared. The school health clubs create awareness in the control and environmental management of malaria through 'learning-by-doing'. So far, a total of 27 schools have formed science and health clubs, which are already actively involved in issues of malaria and mosquito education, and water management in their schools. As an example, the clubs have dug trenches extending over 2400 metres to enhance the drainage of stagnant water, especially in areas prone to flooding during the rainy seasons. The clubs have also been organising general clean up campaigns under the banner, 'shine the village', in marketplaces with the help of *icipe*. The patrons of the clubs have formed a steering committee that coordinates activities. Researchers from the *icipe* project visit the clubs regularly to build their capacity on malaria and mosquito control and prevention.

Many communities in Africa are vulnerable to malaria and lack the necessary information to protect themselves against it. Awareness creation, initiated by *icipe* and their collaborators, is often eagerly taken up by the community members, as illustrated by this woman proudly presenting a banner developed for an anti-malaria *baraza* in Malindi in 2005

The *icipe* researchers have also focused on building partnerships, for instance by strengthening collaboration with the Kenya Ministry of Public Health and Sanitation. This partnership has been remarkable. Recently, the Ministry chose Nyabondo as one of the venues for the commemoration of the annual World Malaria Day in the country.

The results of the project are already emerging, with a substantial reduction of mosquito larval population being observed between May 2008 and June 2010.

Ghibe Valley, Ethiopia

In the past decade, several groups of people relocated from the drought-threatened highlands of Ethiopia to the country's sparsely-populated fertile lowlands, along the Ghibe Valley. Unfortunately, the bright future promised by this resettlement was threatened by tsetse flies and mosquitoes, which are rife in the area. Through past efforts of *icipe*, the problem of tsetse flies has been successfully tackled. Now, the *icipe* scientists are building on this work, while incorporating lessons learned in Kenya to control malaria.

icipe and Biovision trained 'mosquito scouts' from Tolay within the Ghibe Valley, Ethiopia, pose for a photo before heading off to work

The malaria control project in Ethiopia follows the same principles that were developed and maximised in Malindi and Nyabondo. It includes sensitising people to the danger presented by malaria-transmitting mosquitoes, the relation between mosquitoes and malaria, as well as guidance on environmental management and correct use of bednets. Through community work, mosquito breeding sites are dried out and blocked water channels are cleared. Where this is not possible, stagnant bodies of water are treated with *Bti*. Mosquito scouts are also involved in ensuring the long-term success of the project. Eventually, the *icipe* project in Ethiopia will benefit 12,000 people.

Outwitting a cryptic feeder

Literally translated, the word maize means, "that which sustains life". In Africa, this denotation of maize is hardly an exaggeration. Indeed, it is difficult to imagine a life without this cereal, which was introduced into the continent from Central America approximately 500 years ago. Since then, maize has become the most important food in many African households, where it is eaten boiled, roasted or pounded into a thick paste as *fufu* ***or*** *ugali****, or as porridge. Most of the continent's population, especially the poor, relies on maize for half of their basic calories. For this reason, many smallholder farmers allocate a significant portion of their land to maize farming. Unfortunately, the level of maize production in Africa is less than desirable.***

One of the key constraints to maize production in Africa is a complex of indigenous African and invasive borer species that attack cereals, which together cause yield losses of 20–40 percent. This grain could feed millions of people. Moreover, the damage caused by these stemborers to the maize when it is in the field renders the grain susceptible to growth of moulds that produce toxic by-products such as aflatoxins, which are responsible for the high liver cancer rates in Africa. Aflatoxins also cause immune suppression making people susceptible to infectious diseases like malaria and HIV. For almost 20 years, *icipe* has been researching ways to control maize stemborers.

In sub-Saharan Africa, maize is grown across various ecozones and altitudes, ranging from the tropical lowlands to the cool highlands, each characterised by different stemborer complexes. In addition, most of the maize production takes place on small-scale farms, with African women contributing more than 80 percent to the continent's maize harvest, the majority of whom cannot afford expensive synthetic pesticides. *icipe*'s research on the control of stemborers, therefore, focuses on the development of region-specific, affordable, environmentally-friendly and sustainable, biological strategies.

The spotted stemborer in eastern and southern Africa

In eastern and southern Africa (ESA), one of the most important of these pests is the spotted stemborer *Chilo partellus*, an exotic invasive stemborer pest accidentally introduced to Africa, from Asia, some 80 years ago. The pest has since spread rapidly over the lowlands and mid-altitudes in the region. Climate modelling shows that it is only a matter of time before it spreads to Central and West Africa.

Cotesia flavipes, the natural enemy of the invasive spotted stemborer, *Chilo partellus*, that was successfully introduced by *icipe* scientists from Asia into Africa (Photo courtesy of G. Goergen of IITA)

The *icipe* researchers considered the spotted stemborer a suitable candidate for classical biological control. This approach involves going back to the area of origin of the pest to search for effective and specific natural enemies, which are then brought to the region newly invaded by the pest. The reuniting of the pest and its natural enemy often helps to keep pest populations under check, making it a sustainable and environmentally friendly approach for pest control. The advantage of biological control is that it has minimal cost and labour implications for farmers. Unlike pesticides, which require blanket application and may kill beneficial insects, biological control is selective and self-perpetuating. Moreover, insecticides bear the added disadvantage of chemical residues left on the crop and in the environment.

In the early 1990s, *icipe* imported the parasitic wasp *Cotesia flavipes*, from India and Pakistan to Kenya, and initially reared it in its quarantine facilities. The first releases were carried out in 1993 along the Kenyan coast. Since 2002, the parasitoid has been released in farmers' maize fields seasonally in selected regions across the country. As a result, the pest populations have decreased significantly.

icipe researchers release *Cotesia flavipes*, a natural enemy of the spotted stemborer, *Chilo partellus*, in one of the field sites in Kenya

After this success in Kenya, between 1998 and 2005 the wasp was released and got established in Ethiopia, Somalia, Malawi, Mozambique, Uganda, Tanzania mainland and Zanzibar, Zambia and Zimbabwe. In all countries populations of the spotted stemborer are now in serious decline.

Natural enemy exchange

While the wasp imported from Asia has improved the situation regarding the exotic spotted stemborer, the indigenous African

The natural enemy, *Cotesia flavipes* on a *Chilo partellus* larva

stemborers still remain a major problem for the farmers. One of the most important is *Busseola fusca*, which is an especially serious pest in the cooler areas of ESA. Yet, in West Africa, it is only common in the dry savannas, where it attacks sorghum. In Central Africa, *B. fusca* is the main maize pest across all altitudes, from the humid forests to the mountain areas. *icipe*'s research attributed these differences to the different geographic races of the pest, that vary in their climatic requirements, and to the occurrence of their natural enemy. This knowledge opened up avenues for 'redistribution' — the expansion of the geographic range of a natural enemy to areas where it previously did not exist. For instance, a comparison of natural enemies between the ESA and West Africa showed that the indigenous larval parasitoid *Cotesia sesamiae*, which is effectively controlling the African maize stemborer in lowland ESA, is very rarely found in western and Central Africa. Therefore, various races of the parasitoid were imported from Kenya and released in farmers' fields in the highlands and the humid forest zone of Cameroon between 2006 and 2008. Acclimatisation and establishment was confirmed in 2009 in the humid forest zone after molecular analyses made in the Institute de Recherche pour le Développement/Centre National de la Recherche Scientifique (IRD/CNRS) in France confirmed the Kenyan origin of the recovered *C. sesamiae*. Studies are ongoing to confirm possible effects on the *B. fusca* dynamics in farmers' fields.

Advancing knowledge on stemborers

The *icipe* researchers acknowledge that solving the stemborer problem is a momentous task. Their experience so far has taught them that if they are methodical and patient, and gain a good understanding of the ecosystems within which maize is grown, they can outwit these pests.

Moreover, the scientists' understanding of interactions between pest and natural enemies is evolving very fast. For instance, a recent study done in collaboration with IRD, demonstrates a clear case where an apparently broad generalist parasitoid species, *C. sesamiae*, is actually composed of a collection of cryptic specialist populations. In particular, studies on the virulence — the ability of the parasitoid to circumvent the defences of the stemborer hosts — revealed that in all the morphologically identified *C.*

icipe entomologist, Dr Rose Ndemah and colleagues inspecting a maize field in the forest zone of Cameroon. The maize fields are monitored regularly for stemborer damage and the presence of the newly introduced natural enemies *sesamiae*, there exists at least eight distinct evolutionary lineages. This high intraspecific diversity in virulence ability may be useful for optimising the management of the pest. Indeed, parasitoid strains can be identified through specific genotyping for targeting the most suitable parasitoid populations to rear thereby improving efficiency of biological control in this system. Based on this knowledge, the scientists believe it is correct to assume that previous failures in biological control strategies may be due to the absence of studies on intraspecific variation of parasitoids, particularly for virulence factors. A better knowledge of such variation would increase the efficacy of biological control agents and reduce potential harmful effects on non-target species.

Since the majority of the small-scale maize farmers cannot afford expensive synthetic pesticides, *icipe*'s research focuses on the development of affordable, environmentally friendly, sustainable, biological control strategies

Capacity building at *icipe*

As the only international institution in Africa working primarily on arthropods, icipe considers building the capacity of individual researchers, institutions and communities in Africa an integral part of its research and development activities. icipe's capacity building efforts have always been intricately built into its 4-Hs research paradigm. These span the whole continuum, from basic strategic research to technology development and validation, and finally to community-based adaptation.

ARPPIS and DRIP

The major activity of the *icipe* Capacity Building and Institutional Development Programme is the provision of doctoral and masters level training, through the African Regional Postgraduate Programme in Insect Science (ARPPIS) and the Dissertation Research Internship Programme (DRIP). These two programmes are designed to nurture young African scientists to take regional and international leadership roles in insect science, to meet the needs of the continent as well as the challenges of a rapidly changing global environment. At any one time ARPPIS and DRIP have at least 20, and at times up to 40, students at various stages of their research.

ARPPIS was founded in 1983, through a partnership between *icipe* and leading universities in Africa. Since then ARPPIS has earned a well-deserved reputation of 'an incubator of some of Africa's finest young scientists'. In collaboration with 35 African universities, the programme has trained close to 300 African PhD-level and 170 MSc-level scientists. DRIP is a sandwich form of study, where scholars spend half their academic tenure at *icipe* and the other half at their respective universities. Over 250 scholars, mostly from Africa, have been trained at *icipe* through the DRIP programme.

One of the main reasons for the success of the ARPPIS and DRIP programmes is because they combine *icipe*'s unique 4Hs research paradigm, denoting research on human, plant, animal and environmental health, with the academic experience of its partner universities. *icipe* provides the students with a thesis project, research facilities and supervision, in addition to a training fellowship covering university fees, research costs and a maintenance stipend. A full ARPPIS scholarship amounts to approximately US$ 30,000 per year. Through research training undertaken at the Centre's laboratories and field sites located in various agroecological zones, *icipe* is able to expose the upcoming scientists to modern scientific approaches and techniques under the supervision of an internationally reputable group of scientists backed by their counterparts in African universities. Students are registered at any ARPPIS participating university, whose responsibility it is to provide additional research supervision, so as to ensure that the work of the scholars meets international standards. The university also examines and awards degrees to the students.

Herisolo Razafindraleva from Madagascar, who recently completed his PhD research on the Malagasy locust, in an *icipe* insectary

Over the years, ARPPIS and DRIP students have been instrumental in providing some unique insights and scientific discoveries at *icipe*. Research undertaken as a thesis requirement for doctoral or masters training has helped to explore and answer many scientific questions, and assisted in shaping the direction and focus of *icipe* programmes at their infancy, giving vital clues as the projects mature, aiding in refining the methodological approaches, and provided the much needed socio-economic impact assessment of the technological packages that are eventually adopted by the target communities.

For instance, *icipe* has been a pioneer in the development of community-based trapping technology for tsetse flies. Over the last two decades, a total of 22 students from Africa have been involved in key aspects of research within the programme. For instance, Charles Kyorku from Ghana joined a team of *icipe* researchers in 1985 developing the NGU trap for savanna species of tsetse. His pioneering work at determining the efficacy of the trap was later on expounded by Jean-Berkmans Muhigwa from the Democratic Republic of Congo, who together with Mwangelwa I. Mwangelwa of Zambia developed baits for the riverine species that transmits human sleeping sickness. Parallel to the development of traps, was the discovery of potent repellents that could be used in the management of the flies. In 2003, a Kenyan student, Nicholas Gikonyo was instrumental in the

Jean-Berkmans Muhigwa from the Democratic Republic of Congo (left) and Nicholas Gikonyo from Kenya (right)

Joseph J. Randriamananoro from Madagascar (left) and Lefulesele Lebesa from Lesotho (right)

identification of the active tsetse repellent blend from the waterbuck. Gikonyo's work and that of other subsequent students has provided the basis of a bio-based product that is currently being evaluated for commercial development.

In the *icipe*'s Habitat Management Programme, a significant level of contribution has been realised from the 14 doctoral-level students that have been involved. Joseph J. Randriamananoro from Madagascar joined the programme in 1993, becoming the first PhD-level student to be trained under the 'push–pull' project. His research was key in evaluating several wild grasses for their suitability to the stemborer *Busseola fusca*. Joining a year later, Mohammed Hassan Mohamoud from Somalia investigated the suitability of different wild grasses for the development of the other economically important stemborer, *Chilo partellus*. The results obtained by Joseph Randriamananoro and Hassan Mohamoud formed the basis for selecting grasses for testing in the 'push–pull' strategy. These pioneering contributions have been complemented by the work of other students. Linnet Gohole, working within a partnership doctoral programme between Moi University (Kenya), the Wageningen Agricultural University (the Netherlands) and *icipe,* demonstrated the altitude specificity of nonatriene, an SOS volatile chemical produced by molasses grass. This work is important in understanding the biochemical mechanism of the push–pull interaction.

The ARPPIS and DRIP students have also contributed valuable socio-economic perspectives on *icipe*'s research. For instance, Esther Njuguna's ongoing work on the evaluation of determinants of the farmer technology choice in stemborer and/or striga management in maize in western Kenya is important. When completed, this work will broaden our understanding on how farmers choose a technology and what criteria they look for before adopting it. Other ongoing student work contributing to the 'push-pull' portfolio includes that of Lefulesele Lebesa from Lesotho who is conducting research on blister beetles that attack the useful desmodium plant. Also, the results from screening trials in Sudan by Khogali Idris are aimed at identifying drought-tolerant desmodium species and designing push–pull strategies for sorghum and millet in drier areas of Africa.

Most ARPPIS alumni have remained in Africa, where they are actively involved in research and development projects. A number of them have risen to policy-influencing positions within their governments. Others have taken up major international positions,

Baldwyn Torto, a former ARPPIS scholar, with some of the students he is now mentoring under the same programme thus making valid contributions to insect science worldwide. In addition, through re-entry grant assistance and South–South cooperation schemes operated through ARPPIS, graduates returning to their home institutions are able to establish a research career in Africa and collaborate with one another.

Farmers in Vihiga, western Kenya, enthusiastically take part in a push–pull farmers' school session

Beyond the insect science capacity-strengthening mandate, the ARPPIS and DRIP programmes have touched their graduates in many unique ways. For some, these programmes have been a journey of self-discovery and self-realisation. For others, they have been a second chance, and for others still, especially those from strive-torn countries, a life line.

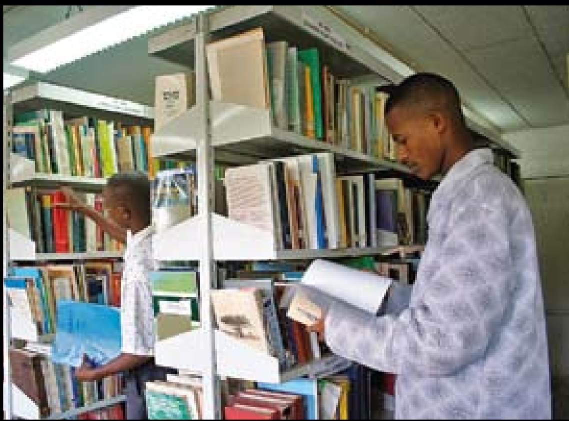
Informal training

icipe's capacity building programmes place emphasis on ensuring that the technologies developed through the Centre's research enhance the capabilities of decision makers and local communities. Towards this end, *icipe* considers partnerships with national research and extension organisations and workers particularly critical. For this reason, the Centre regularly sponsors and hosts various group training courses and workshops for technologists and practitioners from national programmes. The ultimate aim is to enable the beneficiaries of the courses to become trainers of trainers (TOT), who will then pass on the information to end-user communities. The Centre recognises that it does not have the capacity to train large numbers of end-users. Therefore, to ensure wider and rapid dissemination of the technologies, *icipe* relies on the extension staff in the national systems. Therefore, *icipe* has had a vibrant programme for on-site, interactive training of extensionists, technicians and end-users, in specific research techniques or pest control technologies at country and sub-regional levels.

ARPPIS Silver Jubilee logo

Turning point

In 2007, *icipe* underwent an external strategic review process of its research and capacity building programmes. Further, during the commemoration of the ARPPIS Silver Jubilee held in November 2008, the ARPPIS alumni and *icipe*'s Governing Council reflected on the mandate, programme design and achievements of ARPPIS, as well as the role of ARPPIS in the future in terms of strategic implications, opportunities and challenges. *icipe* has strived to implement



The Information Resource Centre (IRC) based at the *icipe* headquarters in Nairobi

the recommendations of the these two deliberation processes in three significant ways discussed below.

Science cooperation

Based on the competitive nature of resources for higher education training, the two reviews highlighted the need for *icipe* to continually identify strategic partners to utilise investments more efficiently. An example of *icipe*'s accomplishment in this area was the signing of a partnership, in early 2010, with TWAS, the Academy of Sciences for the Developing World, which is the world's pre-eminent academy of sciences dedicated to the promotion of science in the South. This alliance boosts the role of *icipe* in promoting insect science for food security and health in Africa, and in other developing regions.

As part of the agreement, *icipe* joins the TWAS–UNESCO Associateship Scheme, a network of over 100 scientific centres of excellence from developing countries. Started in 1994, the scheme aims to counteract brain drain by alleviating the isolation of scientists in the South and to strengthen the research programmes of the collaborating centres. Under the initiative, *icipe* will host associates — talented and promising researchers from developing countries, appointed through a highly competitive and merit-based process, for a fixed period of three years — at its facilities. The associates are entitled to visit the Centre twice during their appointment, for durations of two to three months each time, to pursue their own research interests and/or collaborate with the researchers at *icipe* in programmes of common interest.

In addition, *icipe* becomes the first partner in Africa of the TWAS South–South Fellowship Programme, which enables young scientists from developing countries to carry out postgraduate or postdoctoral research in developing countries other than their own, and allows more experienced scientists from developing countries to visit participating research centres as 'visiting scholars'.

Information access and scientific exchange

Access to scientific publications and other information is one of the major constraints to researchers in Africa. *icipe*'s Information Resource Centre (IRC) has long served as a regional resource for information and publications on insect science. This is mainly through the Centre's library, which houses about 12,000 books and over 20 journal titles. *icipe* is making efforts to ensure that the IRC plays an even greater role in future as a central repository of information.

Research management training

The *icipe* and ARPPIS reviews also stressed the need for a regional approach, to effectively address issues such as climate change, and local and invasive alien species that threaten the production of staple food crops, high value non-staple crops, as well as livestock. The transboundary nature of these problems requires the strategic building of human, knowledge and technical capacity. In this regard, *icipe* is developing joint research and training activities with a number of national and regional institutions. These include the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA), the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM), the African Population and Health Research Centre (APHRC), and the Consortium for National Health Research (CNHR), among others.

Innovation

The *icipe* review process noted the shifting agenda within the international research context, where the global emphasis is on increasing food productivity, as well as on explicit attempts to reduce poverty and protect the environment. This means that the *icipe* capacity development has to be more concerned with strengthening the systems that interface between research and society and which can promote learning and innovation. *icipe*'s integrated pest management approach is more relevant than ever. The Centre has in recent years undertaken projects as part of multi-centre consortia. One example of this approach is an arbovirus surveillance and research project supported by Google.org, which includes veterinary and health ministries, and national and international research institutions (http://avid.icipe.org/). The Centre is also a partner in the Wellcome Trust-supported THRiVE network for capacity building in health research (www.thrive.or.ug). *icipe* is also taking part in a project for capacity building for research in neglected vector-borne tropical diseases that is due to start, funded by the Consortium for National Health Research (www.cnhrkenya.org).

Looking forward

Future capacity building plans include increased collaboration with partners like the Association of African Universities (AAU), the United Nations Educational, Scientific and Cultural Organisation (UNESCO), African Network of Scientific and Technical Institutions (ANSTI), ACP-EU Cooperation Programme in Higher Education (EDULINK) etc., which will increase synergies and opportunities for more collaboration and increased funding for fellowships and scholarships. In addition, the Centre hopes to explore opportunities to collaborate with the Association of African Agricultural Professionals in the Diaspora (AAAPD). This is a premier resource network of African agricultural professionals living in the United States and Canada with the mission of promoting sustainable livelihood for Africa's smallholder farmers and the rural sector by improving food security, economic growth and environmental quality and quality of life.

Naturub®

Kakamega Forest, the easternmost fragment of the Guineo-Congolian rainforest, is world-famous for its unique biodiversity, which includes a variety of flora and fauna. Sitting on the fringes of this forest in western Kenya is the village of Virhembe, a contrastingly nondescript neighbourhood for such a famous site. In the past 10 years, icipe and partners, has led a conservation effort for the forest, while bringing prosperity to Virhembe.

Kakamega forest has always been a researcher's haven, attracting a constant stream of visitors from all over the world. However, the people of Virhembe have on their part remained confined within their boundaries, too constrained by poverty to venture yonder.

The fortunes of this community, however, changed in 2000, when *icipe,* in partnership with the University of Nairobi (UoN), the Kenya Wildlife Service (KWS), the World Agroforestry Centre (ICRAF) and Kenya Forestry Research Institute (KEFRI), initiated several projects on forest conservation. The researchers selected Kakamega Forest as one of the sites.

"Kakamega Forest is an invaluable resource for the people who live around it. They have depended on it for firewood, timber, herbal medicine, food and new land for agriculture and settlement. However, increasing human pressure has led to haphazard and unsustainable harvesting of forest products. Our aim was to ease pressure on the forest while improving the livelihoods of the people living around it," explains *icipe* scientist, Wilber Lwande.

icipe and partners found a ready entry point for their proposed project, through the Muliru Farmers' Conservation Group (MFCG), which had been started in the 1990s by a group of 30 community members from Virhembe Village. The aim of the group was to conserve the forest by planting tree seedlings, which they would then re-sell to other community members.

One of the efforts by *icipe* and partners was the introduction of on-farm cultivation of medicinal plants. Among the species that they selected was *Ocimum kilimandscharicum*, an indigenous medicinal herb of the mint family, known locally as 'mwonyi', which was used traditionally to treat colds and flu, coughs, sore eyes, diarrhoea, abdominal pain and measles. The scientists proposed that, instead of harvesting *O. kilimandscharicum* from the wild, the community members could grow the plant on their farms. Through the MFCG, the idea not only caught on, but has become a new enterprise. Using the essential oil from these leaves, *icipe*, together with the University of Nairobi, developed a commercially branded range of products known as Naturub®, which includes a balm and an ointment. With assistance from *icipe and its partners,* and funding from the UNDP/GEF-Small Grants Programme, the Ford Foundation, the Swiss-based Biovision Foundation and MacArthur Foundation, the farmers have been able to put up a hydrodistillation facility in their village. The 'wet' leaves from the herb generate three times the income that farmers previously obtained from maize cultivation. The group members have also mastered the technology of extracting essential oil from the leaves of the plant. Importantly, MFCG now has all the necessary enterprise development capacity to contract other farmers adjacent to Kakamega Forest in western Kenya and to manufacture Naturub® range of products and make them available in leading outlets across the country. In short, the farmers are now running a commercially viable, profit-making venture, without any detriment to the forest.

Household smallholder farm of *Ocimum*

Awards

The phenomenal success of the Kakamega Forest conservation project by *icipe* and partners has been recognised globally.

In September 2010, during the United Nations General Assembly and MDG Review Summit held in New York, the MFCG was presented the prestigious Equator Prize. The Equator Prize is awarded by the Equator Initiative, a partnership that brings together the

James Ligare receiving the Equator Award during the United Nations General Assembly and MDG Review Summit in New York, September 2010

Muliru Farmers' Conservation Group at the *Ocimum* processing facility in Virhembe

United Nations, governments, civil society, businesses and grassroots organisations to build the capacity and raise the profile of local efforts to reduce poverty through the conservation and sustainable use of biodiversity.

The group was one of 25 winners selected from nearly 300 nominations from 66 different countries in Africa, Asia and the Pacific, Latin America and the Caribbean.

In 2010, the MFCG was selected as one of 30 innovative start-up ventures to be awarded the SEED Awards for Entrepreneurship in Sustainable Development. This annual global awards scheme is designed to find the most promising, innovative and locally led start-up social and environmental entrepreneurs in countries with developing and emerging economies. An international jury of experts selects enterprises that have the potential to make real improvements in poverty eradication and environmental sustainability while contributing to a greener economy.

Overall, the *icipe*-led project has completely transformed the landscape of Virhembe. The project has given the community members status. A lot of them have learned new skills and many find jobs within the enterprise chain. Using the income from the project, the farmers have been able to upgrade their lives; for instance, by replacing previously predominant thatched houses with more permanent structures. Below are two testimonials.

James' story

James Ligare recalls that while growing up in Virhembe, even the possibility of visiting Kisumu, a city just 100 kilometres away seemed like a dream. After graduating with average 'O' level grades, James "just hung around at home". He thought of starting a 'project', but his peasant parents who had more children to put through school could not afford to fund any of the ideas that James had. In the 1990s, James heard about the MFCG, which was then just coming up. He was impressed by the initiative and asked if he could help out voluntarily. For this reason, he happened to be in the right place at the right time when the *icipe* researchers came calling.

James Ligare (right) with Ted Turner (centre) and another participant

James recalls: "We had always harvested the plants from the wild, so when the *icipe* scientists suggested planting the medicinal plants in our gardens, most of us thought it was a big joke. But the chairman of the group decided to give it a try. After six months, *icipe* researchers purchased the leaves. That is when more people started planting the medicinal plants."

James Ligare

The growth of the project has not only been a lifeline for James; it has also broadened his horizons. For instance, in 2005, James was invited by the Ford Foundation to travel to South Africa on an exchange programme, to share insights learned by the Virhembe community in conservation entrepreneurship. Since 2007 James has been based at *icipe* where he has undergone hands-on training in the management of the enterprise operations. But the crowning moment of it all was when James travelled to New York to accept the Equator Award on behalf of the MFCG. James says: "Never in my wildest dreams, would I have imagined that I could ever travel to the great city of New York and that I would ever be part of such a high level ceremony or that I would ever be in the same space as Heads of State and world famous celebrities. I also had the rare opportunity to attend one of the sessions of the United Nations General Assembly. I was overwhelmed with the experiences throughout the trip".

Ezina's story

Like many women in Virhembe, Ezina's life has changed dramatically for the better in the past decade since the launch of the *icipe* project. Nine years ago, she was a peasant farmer, trying to eke a living from her quarter acre plot of land, to fend for her family of eight.

Mrs Ezina Ayuma, a farmer from Virhembe, a small village on the periphery of the Kakamega Forest, is pictured posing proudly in her thriving *Ocimum kilimandscharicum* farm

The accomplishments of the project rely largely on the persistence of individual members of the MFCG, such as Ezina. She is a member of the procurement committee, which is involved in the administration of new initiatives for continued improvement and expansion of the *O. kilimandscharicum* enterprise facility. Through her determination, many women have taken up cultivation of *Ocimum* and other medicinal plants introduced by *icipe* and partners. Recently, Ezina offered her family home as the base of a community-based library recently founded by the MFCG to support its conservation initiatives. One of her daughters has volunteered to serve as the librarian. Ezina is also passionately involved in other environmental conservation initiatives and serves on the boards of several local community based organisations, where she shares her experience from the *icipe*-led project. She also participates in training other farmers on the importance of conserving the biodiversity of Kakamega Forest. Most of the members participating in the enterprise are women, like Ezina, whose lives have changed for the better as a result. Many of them have learned the technical and scientific skills required in the processing and production of Naturub®. They have also acquired entrepreneurial skills including sales, marketing and business management. The women participate in the project as owners, managers and leaders.

Push–pull technology

In the past 17 years, icipe, in collaboration with the Kenya Agricultural Research Institute (KARI), other national partners, NGOs and Rothamsted Research (UK), has discovered and implemented a phenomenally successful technology known as 'push–pull'. The technology, which simultaneously addresses the major constraints of cereal-based farming systems such as striga weeds, stemborers and poor soil fertility, has been hailed as "the single most effective and efficient low-cost technology for removing the major constraints faced by the majority of smallholders in eastern Africa resulting in an overall and significant improvement of their food security and livelihoods".

Background

Cereals — maize, sorghum, millet and rice — are the main staple and cash crops for millions of small-scale farmers in most of sub-Saharan Africa (SSA). However, the continent also has the lowest yield of cereals in the world, averaging less than one tonne per hectare. This low cereal productivity is due to a range of biotic constraints, which include insect pests, (notably stemborers) and the parasitic weed *Striga*, and abiotic constraints, signified by land degradation and poor soil fertility. By ruining cereal yields, these factors keep the food security and livelihoods of millions of people in the region in constant risk.

In 1993, *icipe,* in collaboration with the Kenya Agricultural Research Institute (KARI), Rothamsted Research (UK) and other partners in eastern Africa, commenced efforts to simultaneously address these biotic and abiotic problems. The outcome was a novel habitat management approach, known as 'push–pull'. The strategy involves intercropping cereals with a repellent plant such as desmodium, and planting an attractive trap plant, such

A push–pull intercrop, with newly planted maize and desmodium, and thriving Napier grass around the border

as Napier grass, as a border crop around this intercrop. Stemborers are repelled or deterred away from the target food crop (push) while, at the same time, they are attracted to the trap crop (pull), leaving the food crop protected. In addition, desmodium stimulates the germination of *Striga* seeds and inhibits its growth after it germinates. The technology also provides high quality animal fodder. Furthermore, since both companion plant species are perennial, 'push–pull' conserves soil moisture and improves soil health and beneficial biodiversity.

Finding the 'pull'

Push–pull relies on an in-depth understanding of chemical ecology, agrobiodiversity and plant–plant and insect–plant interactions. From the onset, the researchers already knew that some wild grasses acted as 'trap plants', enticing egg-laying borer females but depriving the larvae of a suitable environment. In 1994, with funding from the Gatsby Charitable Trust, the researchers studied more than 400 species of wild grasses for efficacy in these dual roles. The results revealed more than 30 grass species with the potential of being used as trap crops to draw the borers away from the maize while reducing their populations. The scientists then consulted farmers and identified Napier grass (*Pennisetum purpureum*) and Sudan grass (*Sorghum sudanense*) as the two species that would be most useful as cattle fodder, and which would therefore be ideal from a socio-economic perspective. From a scientific point of view, Napier grass has a particularly ingenious way of defending itself: When the larvae bore into the stem, the grass secretes a sticky gum, physically trapping the borers and preventing most larvae from completing their life cycle. Sudan grass is an attractive habitat for the parasitic wasp *Cotesia sesamiae*. These tiny insects inject their eggs into the stemborer larvae and, when the eggs hatch, the wasp larvae eat the stemborers. Both grasses attract additional stemborer predators, such as ants, earwigs and spiders. Because intercropping grasses planted among the maize plants would provide too much competition for the cereals, the researchers opted to plant grass border rows around maize fields. The grasses would provide a 'pull' and an effective defence mechanism against stemborer attack. In 1997, the scientists began on-farm trials to evaluate the benefits of Napier grass, a perennial plant that is already grown widely for livestock fodder. Working with farmers, they identified 'bana', a smooth, broad-leafed variety as the best option. Besides increasing their

Farmers inspecting progress in a maturing 'push–pull' intercrop maize yields, the farmers planting Napier border rows benefited from a ready supply of grass to feed their livestock or sell to other farmers.

Prof. Zeyaur Khan is pictured in a 'push–pull' farm, explaining the merits of desmodium to Dr Bashir Juma, the director of the Soil Health Programme of the Alliance for a Green Revolution in Africa (AGRA)

Finding the 'push'

For the 'push' part of the technology, the team focused on screening grasses and legumes that could repel stemborer moths. The molasses grass, *Melinis minutiflora*, caught the attention of the researchers. After conducting trials on the species, the scientists confirmed that the strong, sweet smell of this grass did indeed have a repellent effect on stemborers. Furthermore, the researchers discovered that the molasses grass also attracts *C. sesamiae*, parasite of stemborers. Their colleagues at Rothamsted Research helped to piece the puzzle together, by investigating the nature of the semiochemicals that attract or repel stemborer moths, and to find out why molasses grass repels stemborers but attracts their natural enemies. They identified a compound that is produced by maize plants, as a key stimulus, a 'feeding stress' chemical, when they come under attack from the stemborer. The scientists concluded that molasses grass has evolved an ingenious defence strategy through the release of volatile chemicals that mimic those of damaged plants. In this way, the grass defends itself against the stemborer attack by constitutively releasing a 'cry for help' comprising volatile cues that have dual effects: repelling the moths but also attracting the pest's natural enemies.

With this unique property, molasses grass was the first plant to be used by the *icipe* scientists as a 'push' plant. The scientists recognised that one of the reasons why the grass was accepted by farmers as a 'push' intercrop, was because it provides fodder for cattle. The scientists were therefore keen to find additional plants that would add a further dimension to the habitat management system. They focused their attention on legumes, which would potentially improve soil fertility because of their nitrogen-fixing qualities. In this regard, they shortlisted *Desmodium,* as a possible 'push' intercrop. After evaluation, the silverleaf desmodium and the greenleaf desmodium were found to repel stemborers. The scientists proceeded to test these species on maize on-station at the *icipe* research station in Mbita Point, around Lake Victoria. As it happened, all the experimental plots were infested with striga. But to the amazement of the scientists, they found that the maize plots with a desmodium intercrop not only had little stemborer damage but also became virtually free of striga after only two seasons. This

A farmer admires his healthy sorghum on a push–pull farm result brought a new dimension to the push–pull technology, as it meant that desmodium could be used to control stemborers and striga, in addition to fixing nitrogen and providing fodder. The crop was, therefore, incorporated as a 'push' plant.

A push–pull farmer teacher during a visit to one of the farmers under her jurisdiction

'Push–pull' in farmers' fields

In 1997, *icipe* and partners integrated 'push–pull' in maize, and later sorghum-based cropping systems in Kenya and in eastern Uganda. Today, 'push–pull' technology is widely recognised, and is currently being practised by over 35,000 farmers in eastern Africa. This impressive accomplishment was realised through an effective collaboration between the scientists and the national research and extension systems and non-governmental organisations. Together, the teams developed a range of innovative transfer dissemination methods to create awareness and increase the adoption of the 'push–pull' technology.

One of the dissemination strategies used is the 'farmer-to-farmer' approach, based on the influence that farmers have on their peers in the adoption of new technologies and practices. Farmers are trained through the national agricultural research institutes (NARIs) and non-governmental organisations (NGOs) participating in the 'push–pull' project. They are provided with information regarding the technology as well as technical backstopping.

The *icipe* scientists also found the use of 'farmer teachers' — farmers who are particularly knowledgeable about the push–pull technology — to be an effective method. These farmers were trained, provided with dissemination materials, bicycles for moving around the farms and technology backstopping support. *icipe*'s research in western Kenya has endorsed the farmer teachers' approach, showing that one single farmer teacher is able to teach on average 17 farmers, who successfully adopt the technology. Each of these farmers in turn teaches at least two additional farmers, giving a total of 34 farmers adopting the technology per single farmer teacher. The farmer teachers also help to foster collaborations among farmers, scientists and extension personnel.

A push–pull intercrop incorporating beans

The scientists also conduct field days every cropping season. These occasions are hosted by farmers already practising 'push–pull'. The field days provide an opportunity for farmers to evaluate the performance of the technology based on the host's experience and to make recommendations on areas of improvement. The participants also acquire new skills and knowledge through sharing information and experiences. The events also create awareness among community members as well as interest and demand for the technology.

The researchers also use print materials such as brochures, manuals and posters in the dissemination of the 'push–pull' technology, to provide farmers with accurate and reliable information. 'Push–pull' print materials are designed to be effective references of technical details, for instance, planting details and illustrated instructions of how to manage the technology.

Desmodium left to flower and pod in a push–pull farm after a maize harvest

Moving 'push–pull' forward

In SSA, smallholder farming systems are characterised by intercropping cereals with edible legumes. Therefore, as the 'push–pull' project progressed, the need to incorporate edible beans into 'push–pull' plots became important. In consultation with the farmers, the *icipe* scientists, therefore, conducted further laboratory studies and field trials on the effects of integrating beans in the maize–desmodium intercrops. They found that integration of beans in the maize–desmodium intercrops, guaranteed farmers a protein source without compromising the striga and stemborer control efficacy of desmodium. In addition, the researchers and the farmers have been able to work out ways of varying the number of Napier grass rows surrounding the cereal fields according to the fodder demand.

Between 2007 and 2008 *icipe* scientists evaluated the potential of *Desmodium intortum*, a drought-tolerant desmodium species, for 'push–pull' application in finger millet in western Kenya. Finger millet has outstanding attributes as a subsistence food and fodder crop, and has superior nutritional qualities in the drier areas of Africa. The results of the study showed that the desmodium species offered an effective control of both striga and stemborers for finger millet.

In recent years, Napier stunt disease (NSD) started to threaten Napier grass in the 'push–pull' regions and beyond. The *icipe* scientists immediately embarked on studies, which confirmed that the leafhopper *Recilia banda* is the vector of the Napier stunt phytoplasma in western Kenya. The studies also indicated that the species might be the key vector of NSD in the region. The scientists are advancing studies on Napier grass cultivars that might be resistant to NSD, as well as integrated pest management strategies for its control.

Desmodium seed, packaged and ready for sale to farmers

The effect of climate change is likely to affect the effectiveness

A farmer threshing desmodium

of the push–pull strategy especially on some desmodium species, which require sufficient moisture to establish, and during planting and after harvesting of the cereal crops. In response to this challenge, *icipe* initiated a study in Sudan to identify drought-tolerant species of Desmodium.

Making desmodium seed available

One of the limiting factors for the 'push–pull' technology has been the lack of sufficient quantities of desmodium seeds. *icipe* and partners have undertaken a three-pronged approach to resolve this issue. The first is through commercialisation, whereby, in collaboration with Western Seed Company Ltd, one of the main private seed producers in East Africa, commercial quantities of desmodium seed are produced through a network of farmers and farmer groups. The company sub-contracts farmers to produce quality seeds on its behalf. It then buys, cleans, controls seed quality and obtains certification from the Kenya Plant Health Inspectorate Service (KEPHIS) for germination and viability. The company then packs and distributes certified seed through its network of agro-stockists.

The second approach to ensure availability of desmodium seed is through farmer groups, who have been trained in its production, processing and marketing, using phytosanitary guidelines. This approach is aimed at boosting the production of desmodium seeds, while improving its access and affordability.

Third, farmers have been trained to establish desmodium through vegetative propagation of the vines.

Impact assessment

In 2009, *icipe* commissioned an independent impact assessment of 'push–pull' to establish its effect on the livelihoods of smallholder farmers and their perceptions towards the technology.

The study found that 19 percent of the farmers in the villages under assessment had adopted 'push–pull', citing the technology's ability to address the major cereal production constraints concurrently as the main attraction. The farmers also mentioned the low cost of implementing 'push–pull', and the use of Napier grass and desmodium as fodder as other motivating factors for adopting the technology.

Based on the impact assessment, the 'push–pull' technology has contributed significantly to reducing the vulnerability of farm families by ensuring higher and better yields. Of the assessed farmers, 75 percent indicated maize yield increases of between three- to fourfold. For instance, farmers using 'push–pull' were able to harvest more than five tonnes of maize per hectare from plots that previously yielded below one tonne per hectare. In addition, 'push–pull' has become a 'springboard' for diversifying the farming system, especially incorporating dairy operations using Napier and desmodium as fodder.

These benefits have contributed to the increased well-being at household and village levels. By selling their surplus grain, milk and fodder, 'push–pull' farmers earn extra income, which they use to pay school fees for children, purchase household items, and improve their housing, overall nutrition and health. The study thus suggests 'push–pull' as "probably the single most effective and efficient low-cost technology for removing major constraints faced by the majority of smallholder farmers in the region, resulting in an overall and significant improvement of their food security and livelihoods".

A farmer conducts a peer-to-peer, push–pull impact assessment evaluation

On a national scale, the economic benefit of 'push–pull' is estimated at US$ 2–3 million annually. In addition, the technology contributes to national food security, rural employment, better education and increased farming knowledge. Furthermore, 'push–pull' is an environmentally friendly technology that is likely to increase agrobiodiversity and contribute to provision of ecosystem services.

Pushing forward

'Push–pull' responds directly to the rising uncertainties in Africa's rain-fed agriculture due to the continent's vulnerability to climate change as it addresses both abiotic and biotic constraints, resulting in improved farm productivity, incomes and food security.

icipe and partners hope to build on their phenomenal 17-year 'push–pull' experience, aiming to extend the benefits to 1 million smallholder farmers in SSA by 2020. The researchers also hope to spread the technology to regions with harsher climate conditions. There is a great deal of scope for further expansion, as the technology has not been extended to millions of farmers within and beyond East Africa, who could benefit from it. Moreover, with the rising uncertainties in the region's rain-fed agriculture due to the continent's vulnerability to climate change, there is a demand for the more robust cropping system provided by the technology and for its further adaptation to withstand the increasingly adverse and changeable conditions.

In sum, the full potential of 'push–pull' to enhance the food security and prosperity of millions of smallholders in Africa could be realised by:

- Extending the technology and integrating it with livestock development enterprises to areas of similar agroecologies to those where it is currently practised.
- Ensuring accessibility and availability of companion planting materials in the target areas.
- Adapting the technology to the increasingly dry and hot conditions with less predictable rainfall associated with climate change.

Lethal missiles

In a word, fungi can be described as 'weird'. This strange group, which includes thousands of large and conspicuous organisms such as mushrooms and toadstools, and also includes microscopic organisms such as moulds and yeasts, is found in a range of forms; colourful and jelly-like, brown and slimy, green and dusty, or just white. Fungi can be found nearly everywhere, from forests to homes. icipe has contributed significantly towards the understanding of the roles played by fungi specific to insects, known as entomopathogenic fungi, which act as parasites of insects and are capable of killing or seriously disabling them.

Tsetse control

In 1992, *icipe* obtained funding from the European Union (EU) to undertake a project on the development and application of cost-effective, environmentally sustainable and culturally acceptable strategies for the management of tsetse. One of the objectives of the initiative was to evaluate the potential of certain biological agents, such as DNA viruses, the soil-dwelling bacterium, *Bacillus thuringiensis* (*Bt*) and the fungus *Beauveria bassiana*, in controlling tsetse flies.

Although entomopathogens have been known to infect tsetse flies under both natural and laboratory conditions, no attempt had been made to apply them in the control of these insects that transmit sleeping sickness in people and the nagana disease in animals. For example, the DNA virus causes the enlargement of the flies' salivary glands and could make the pests sterile. Strains of entomopathogenic fungi and *Bt* have been shown to be deadly to tsetse in laboratory bioassays. However, it has been difficult to use these pathogens, as they are difficult to apply under field conditions. The major constraint is putting the pathogen in contact with the adult tsetse fly.

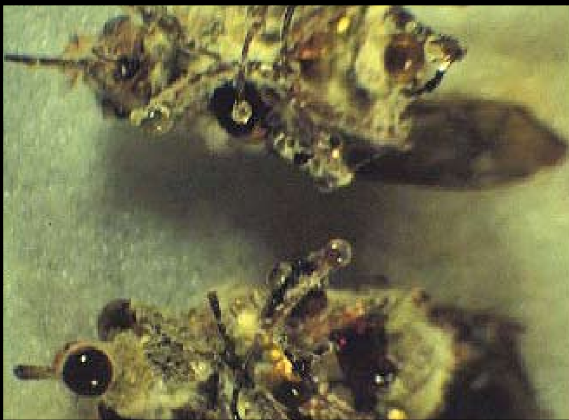
Metarhizium anisopliae spores (conidia)

Under the EU-funded project, the *icipe* scientists were given the challenge of developing a system that could be used to deliver the pathogen to the pests under field conditions. The researchers exploited the unique characteristic of entomopathogenic fungi, which infect their hosts through the cuticle, as compared to viruses, *Bt* and DNA virus, which need to be ingested to be effective. In addition, these fungi can be transmitted horizontally from infected to healthy insects. This work resulted in the design and fabrication in 1998 of a contamination device (Cd), which allowed tsetse flies to get contaminated with fungal spores while exiting the Cd. In this way, the contaminated flies could pass on spores to healthy ones during mating. Three adult tsetse fly species, *Glossina pallidipes, G. fuscipes* and *G. longipes* successfully entered the Cd and got contaminated with fungal spores.

The strategy developed by *icipe* attracted the attention of the late Dr David Nadel, a former tsetse-rearing specialist at the International Atomic Energy Agency (IAEA). Dr Nadel compared the approach to a "guided missile", and he decided to name it the lethal insect technique (LIT). As a result, a project entitled "Sustainable Management of Trypanosomosis and Tsetse Flies through a New Concept: The Lethal Insect Technique" was developed and submitted to the Austrian Development Cooperation for funding. It had two objectives; to develop an improved and cost-effective tsetse mass rearing system, and to introduce and validate the LIT technology. The *icipe* scientists considered two methodological approaches. The first involved the use of traps mounted with the Cd containing fungal spores in the treatment area. The second strategy relied on the cheap mass-production of the appropriate tsetse species and their contamination just prior to field release.


Maniania's contamination device placed on top of a tsetse trap

The initial contamination devices were made of Plexiglas®, and were complex and costly to fabricate. This prevented their broader production and wide-scale adoption. Therefore, a simple low-cost contamination device was subsequently developed and named Maniania's Cd. The scientists proved skeptics wrong by demonstrating the feasibility of this technique on Mfangano Island in Lake Victoria, from March 1999 to March 2000



Tsetse killed by *Metarhizium anisopliae*

(Maniania *et al.*, 2006). The fly population in this heavily invested tsetse region was reduced to 82.4 percent in the fungus-treated island (Mfangano) and 95.8 percent in the island where the conventional mass trapping technology was used during the experimental period. Compared to the fungus-treated island, the number of flies increased considerably in the island where mass trapping was deployed five months after the treatments were removed. The incidence of the fungus in fly populations was low during the 12 weeks following the initiation of the experiment but increased afterward up to the termination of the treatment. The fungus was still present in fly populations three months after the end of the treatment although the incidence was low. The results of this study have showed that fungus used in a Cd can give a control comparable to the mass trapping technology with added advantage of the ability of the fungus to persist in the field.

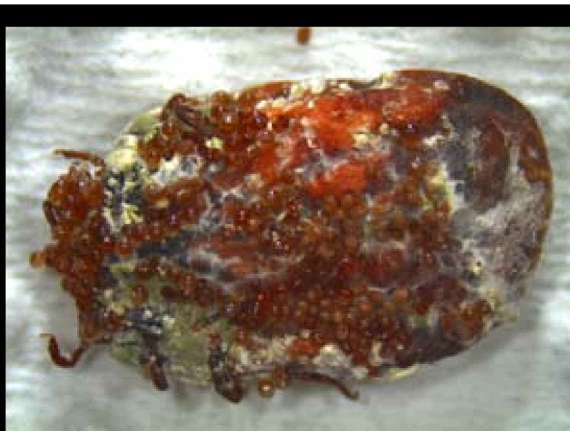
Consequently, IAEA included *icipe*'s work in the Coordinated Research Project (CRP) "Improving SIT for Tsetse Flies through Research on Their Symbionts and Pathogens" as one of the tools in reducing tsetse populations before the release of sterile males.

Additional achievements

Some of the achievements made by *icipe* include prompting the research on control of mosquitoes with entomopathogenic fungi by the Wageningen University and Research Centre (WUR) group. Based on the Centre's work, the concept of auto-dissemination has been extended to other arthropod pests and disease vectors such as ticks, leafmining flies, thrips and fruit flies, which are attracted to pheromones or kairomones, or use visual cues.

Crop protection

In Africa, the protection of crops from pests relies mostly on imported synthetic pesticides that damage the environment and have adverse effects on the health of farmers and consumers. In the long run, residues from these chemicals upset the natural balance in the agroecosystems. Globally, the replacement of synthetic pesticides with biological alternatives is seen as an ideal strategy towards sustainable



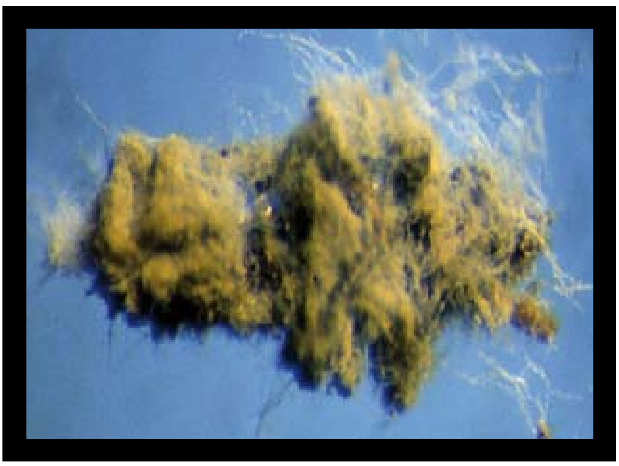
A female tick, *Rhipicephalus appendiculatus*, showing mycosis by *Metarhizium anisopliae*, laying eggs agriculture and the conservation of biological diversity. Among other microorganisms such as bacteria, viruses, nematodes and protozoa, fungi are known to contribute to the natural regulation of pest populations. In the last four decades these microorganisms have all been extensively studied and have been developed into microbial insecticides or biopesticides.

icipe has contributed to this quest by bioprospecting for discovery of novel arthropod pathogens, especially entomopathogenic fungi and bacteria, and their conservation in its Germplasm Centre. The Centre also conducts laboratory screening of the pathogens against target insect pests and disease vectors, and training.

icipe's studies on entomopathogens show promise in the quest for environmentally safe control options for fruit fly species, locusts, leafmining flies, western flower thrips (WFT), termites, and the red spider mite. In addition, *icipe*'s studies show that entomopathogens can also be used in the control of sandflies and ticks, either on their own or in auto-dissemination approach in combination with the respective pheromones.

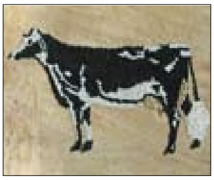
Metathripol: "No Mercy for Thrips"

Thrips are economically important pests on vegetable and flower crops worldwide. Their infestation can cause total crop failure and some transmit plant viruses. The most damaging species in Africa include the legume flower thrips *Megalurothrips sjostedti* on cowpeas and beans (20–100 percent yield loss); western flower thrips *Frankliniella occidentali,* on a variety of crops (10–80 percent yield loss), and onion thrips *Thrips tabaci* on onions and cucumbers (10–80 percent yield loss). Control of thrips in Africa relies mainly on the use of chemical insecticides. In recent years, however, growing concerns over environmental quality and human health, demand for contaminant-free food and the threat posed by synthetic chemical insecticide resistance have fostered the need to identify safer, non-chemical management options. The use of entomopathogenic fungi is an attractive option. At *icipe*, an isolate of *Metarhizium anisopliae* ICIPE 69 ('Metathripol'), has been found highly pathogenic to these three species of thrips. Field trials conducted in partnership with the horticultural industry have shown that Metathripol can effectively control thrips in a variety of crops. In addition, its safety towards non-target organisms has been demonstrated. *icipe* has entered into a partnership with Real IPM, Kenya, a commercial biopesticide firm, to mass produce and commercialise the *M. anisopliae* isolate for the control of thrips.



Thrips killed by fungus

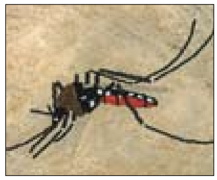
The 12 photos on the front cover depict 12 success stories of *icipe* across the last four decades. The beadwork was made by women from West Pokot, a drought-prone and poor region in Kenya's North Rift. *icipe* assists these women by, among others, promoting the sale of their artwork.



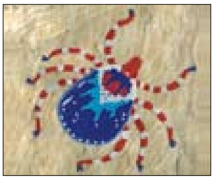
Machemtai Kangole
(Dairy cow)

Cattle are important in Africa, where they are a source of milk and draught power. They are also a symbol of wealth. By helping control the tsetse menace, *icipe* is helping these livestock regain their rightful place in African society.

The *Anopheles* mosquito is one of the deadliest insects on earth. For years, *icipe* has been studying the vector's ecology and morphology, and sharing this knowledge with communities vulnerable to it.



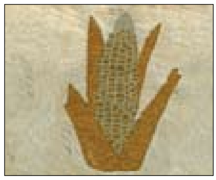
Machenang'at Yara
(Mosquito)



Macheyech Lomullo
(Tick)

Ticks are small bloodsucking arthropods, which cause great economic losses to livestock keepers. *icipe* pioneered research on ticks in Africa.

Maize is the most important cereal crop in Africa, on which most people depend for their starch. *icipe* has made progress in controlling the stemborers that attack this cereal through biological control.



Macheruto Losil
(Maize cob)

Machepkiach Domongiro
(Locust)

Locusts, in their gregarious swarming phase, can be extremely destructive. *icipe* has been studying the signals that cause the insects to change from a solitary to a gregarious phase, and interventions for controlling them.

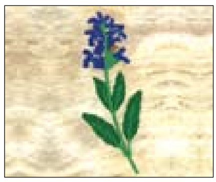
The building of indigenous scientific capacity is integral in every aspect of *icipe*'s work. Close to 200 scientists from across Africa have been trained through *icipe*.

Machemtai Longuranyang
(Microscope)

Macheptoo Paulo
(Healthy cabbage)

Cabbage is part of almost every meal in many parts of Africa. It is also a source of income. *icipe* has helped to control one of this vegetable's most damaging pests.

Ocimum kilimandscharicum, an indigenous medicinal herb of the mint family, is used traditionally to treat a myriad of diseases. Farmers in an *icipe*-led project near Kakamega Forest grow the plant on their farms, instead of harvesting it from the forest.



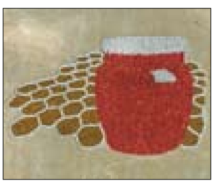
Machemwok Ritakapel
(*Ocimum* plant)

Mapkiror Ngoria Muna
(Mango tree)

The mango tree provides shade, nutrition and income in many African homesteads. *icipe* is helping farmers to reap the full fruits from this valuable tree.

icipe's innovative and successful 'push–pull' technology has led to the introduction of dairy goat keeping in western Kenya, diversifying the source of milk and nutrients, and providing income for farmers.

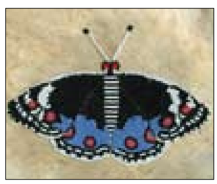
Machemwok Yapolima
(Healthy goat)



Machepkiaech Cherelmot
(Honey jar on honeycomb)

The *icipe* Commercial Insects Programme is enabling the communities in marginalised parts of Africa to produce high quality honey for local and international markets.

Africa has some of the most unusual and beautiful butterflies. *icipe* helped to pioneer the 'butterfly effect' in Africa, which has given a stake to forest-adjacent communities in the conservation of the important biodiversity that they live next to.



Macheptoo Kedingura
(Butterfly)

icipe – Working in Africa for Africa…

Many of Africa's problems are associated with a lack of energy for growth and development. Arthropods (insects, ticks, mites, spiders and others), contribute greatly to the continent's lack of sustainable growth, because of their ability to severely reduce the output of humans, animals and plants. However, they also harbour great potential for Africa's development.

icipe was established in 1970 in direct response to the need for alternative and environmentally friendly pest and vector management strategies. Headquartered in Nairobi, Kenya, *icipe* conducts research and develops methods that are effective, selective, non-polluting, non-resistance inducing, and which are affordable to resource-limited rural and urban communities. *icipe*'s mandate further extends to the conservation and utilisation of the rich insect biodiversity found in Africa.

icipe focuses on sustainable development, using human health as the basis for development and the environment as the foundation for sustainability. Working in a holistic and integrated approach through the 4-Hs paradigm — human, animal, plant and environmental health — *icipe* aims at improving the overall health of communities in tropical Africa by addressing the interlinked problems of poverty, poor health, low agricultural productivity and degradation of the environment.

icipe is the only international institution in Africa working primarily on arthropods. Therefore, capacity building of individual researchers and institutions in Africa is an integral part of all research and development activities at *icipe*; to empower women, harness the youth and build capacity to use, transfer and teach *icipe*'s technologies. In this way, *icipe* will continue to work 'in Africa, for Africa'.

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