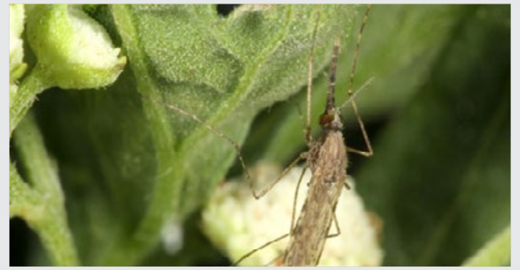
Insects for Life



Malaria mosquito,
Anopheles gambiae sensu stricto

Yellow fever mosquito, *Aedes aegypti*

Sand fly, *Phlebotomus duboscqui*

Tsetse fly, *Glossina morsitans*

Brown ear tick,
Rhipicephalus appendiculatus

Camel fly, *Hippobosca camelina*

Tomato leafminer, *Tuta absoluta*

Parasitoid wasp, *Cotesia icipe*

Honey bee, *Apis mellifera*

Mopane bee, *Plebeina hildebrandti*
(stingless bee)

Black soldier fly, *Hermetia illucens*

Long-horned grasshopper,
Ruspolia differens

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June 2020

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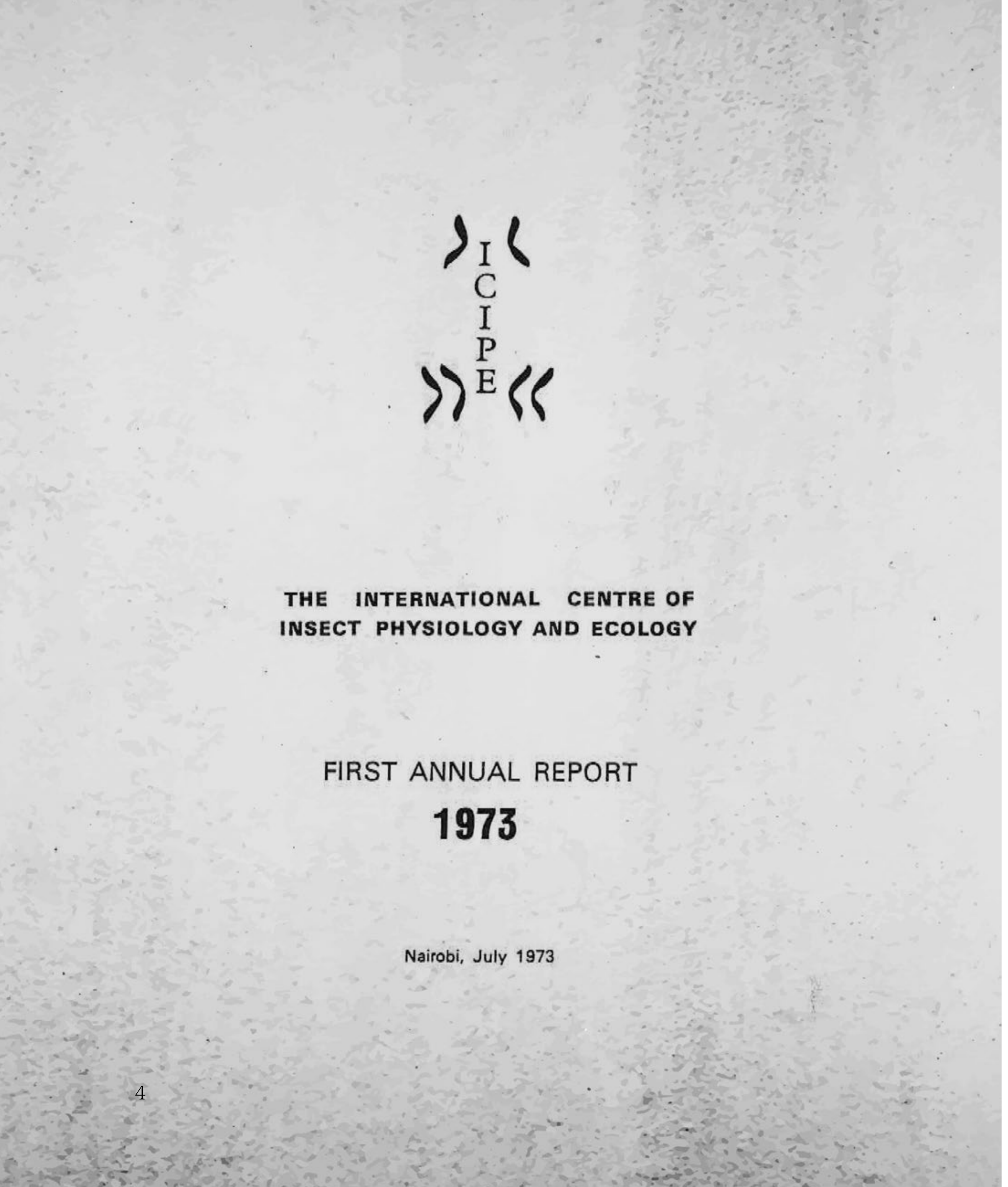

ICIPE

THE INTERNATIONAL CENTRE OF INSECT PHYSIOLOGY AND ECOLOGY

FIRST ANNUAL REPORT

1973

Nairobi, July 1973

Dedication

In the first ever *icipe* annual report, produced in 1973, the Centre's founders stated:

"This First Annual Report is largely devoted to a descriptive outline of the research activities of this young international research institute. It should be regarded as an earnest of what is yet to come."

We dedicate this special, bumper and bountiful report that marks *icipe*'s 50th anniversary to numerous individuals and institutions (past and present staff; donors and collaborators; and myriad supporters) in Africa and across the globe; to whom we owe the realisation of this prophecy.

FOREWORD

Prof. Mohamed H. A. Hassan

President, TWAS – The World Academy of Sciences; Co-chair of the InterAcademy Partnership (IAP)

I am honoured to author the Foreword for this publication that documents the institutional journey of the International Centre of Insect Physiology and Ecology (*icipe*), and the Centre's research and development accomplishments over the past 50 years.

The 50th anniversary of any entity is a momentous occasion. This is even more so in the case of *icipe*, undoubtedly one of the most unique organisations of its kind in Africa, and in the world. To understand the significance of *icipe*, it is important to locate the Centre within the historical context of its founding and evolution.

The establishment of *icipe* was mooted in 1967, at a time when Africa, then a young postcolonial continent, had very limited scientific capacity. This was due to a range of historical factors, including the fact that research on African issues, especially tropical medicine, had predominantly been conducted overseas, only being transferred to the continent around the 1920s. Moreover, during the pre-independence years, the scientific sector in Africa was dominated by expatriates, and university structures in many African countries were developed rather late.

The Centre's launch in 1970 took place against the background of a continent embarking on building its local scientific bases, endeavouring to develop indigenous research institutes and universities while 'nationalising' those set up under the colonial regime, while creating a nucleus of African scientists. These efforts led to a mode of scientific development in which the state played a central role; where scientists were largely civil servants.

icipe stood out in a number of ways – as an idea conceived by an individual scientist, and by envisioning itself, not as a national institution, but as an international organisation with a mandate for Africa and the tropical regions. Moreover, *icipe* chose to focus on a very specific area – insect science; aiming, for example, to generate knowledge in previously neglected areas like physiology, behaviour and ecology of disease vectors and crop pests. The Centre's overall vision was to push the frontiers of science, not just for the sake of it, but because of the direct relevance to major challenges affecting the continent. The foresight of undertaking advanced mission-oriented research and technology development was in contrast to traditional approaches that accorded exclusive emphasis to one aspect – either basic or applied research – at the expense of the other.

Although these goals were extremely ambitious, as demonstrated in this publication, *icipe* enjoyed early success: inspiring a regional and international movement of support; creating a budding, confident and intellectually vibrant crop of African researchers; while pioneering efforts to develop and disseminate environmentally safe and affordable integrated pest management strategies.

The 1980s were challenging for *icipe*, the result of the Centre's own growing pains and a range of regional and global economic factors. In particular, *icipe* was not left unscathed by the African Crisis and its immense and cross-cutting impact on most sectors. Indeed, the continent's emerging scientific structures, communities and outputs became seriously eroded.

Solid support from donors and partners and the government of the host country, Kenya, as well as the spirit of enthusiasm among the *icipe* scientific community ensured that the Centre not only survived, but continued to thrive. Indeed, *icipe* played a leading role in the thinking process to develop models for Africa's recovery and self-reliance. And at a time when brain drain was prime with huge numbers of African scientists joining other professionals in migration to various parts of the world, *icipe* launched one of its most important capacity building programmes; the African Regional Postgraduate Programme in Insect Science (ARPPIS). Undoubtedly, the establishment of ARPPIS was a significant landmark in the continental effort of nurturing and retaining young African talent.

In the 1990s, *icipe* introduced the 4Hs paradigm as a novel way of emphasising a holistic and integrated approach across Human Health, Animal Health, Plant Health and Environmental Health. The 4Hs became a true example of a platform for actualising the millennium development goals (MDGs). In the 2000s, *icipe* capitalised on the renewed energy resulting from the continent's rising economic growth. The Centre reached out to new donors, while also reminding the region and the world of persistent and emerging developmental challenges. The outcome was renewed focus and partnerships, for example in neglected tropical diseases, and on climate change, in specific regard to insects.

Over the last decade, the need for holistic and inclusive approaches for Africa's socio-economic transformation has become even more evident. Aligned to the need for new opportunities for vulnerable groups, like women and the youth, *icipe* has enhanced engendered approaches across all its activities. The Centre has also introduced a new dynamism towards realising the potential of the youth as a demographic dividend for Africa. In addition, *icipe* is playing a leading role in strengthening doctoral training, as well as research and innovation in applied sciences, engineering and technology, and in the creation of a bioeconomy in Africa.

Globally, academies of science are vital for scientists: they transform the idea of a scientific community into a reality; recognise and reward excellence; and serve as a hub of resources. Therefore, I would like to acknowledge the significant role played by *icipe* in development of academies of science in Africa and in the South. The Centre was instrumental in the founding of the Kenya National Academy of Sciences, and of TWAS, The World Academy of Sciences, both in 1983. Jointly with TWAS, *icipe* spearheaded the establishment of the African Academy of Sciences (AAS) in 1985. Indeed, *icipe* hosted and nurtured AAS during the Academy's formative years. In 2010, *icipe* and TWAS established a joint South–South competitive fellowship programme that enabled talented insect scientists from developing countries to undertake collaborative research at the Centre. This highly successful programme ran for a number of years.

As *icipe* moves towards the next phase of its life, it is with the solemn declaration of 'Insects for Life' – a dual expression of the interlinkage between Human, Animal, Plant and Environment Health; and the unwavering commitment of the Centre to its vision and mission. The Centre will continue to advance ongoing activities, while also acting in accordance to its *Vision and Strategy* 2021 – 2025; a document that identifies and proposes responses to a diverse set of emerging R&D challenges and opportunities.

Alongside the African, and indeed global community, I wish this exceptional institution continued success, in its mission of socio-economic transformation.

PREFACE

This report is special as it provides the first comprehensive narrative of the International Centre of Insect Physiology and Ecology (*icipe*), from inception to present, and a forecast of the organisation's future goals. The publication is segmented around five chapters, with the first four demarcated around the Centre's leadership tenures as follows:

- Chapter 1 (1970 – 1994) Founding Director: Prof. Thomas Odhiambo
- Chapter 2 (August 1994 – April 2005) Director General: Dr Hans R. Herren
- Chapter 3 (June 2005 – September 2013) Director General: Prof. Christian Borgemeister
- Chapter 4 (November 2013 – present) Director General: Dr Segenet Kelemu

This division is by no means an indication of a disjointed story. Rather, the phases are episodes in a biography that befits the title of this publication: *Insects for Life*. Indeed, this harmony is evident in the 'Introduction' sections of the first four chapters, where the Centre's leaders articulate their own visions and ideals. The 'Management and Leadership' sections are a bird's eye view of institutional milestones and vision, supported by a pictorial curation of people, faces and places that have impacted on the Centre during the various eras.

The rhythm of continuation and evolution in the two sections above is an apt preamble for the 'Research Highlights' – succinct, yet compendious accounts of *icipe*'s contribution to the global knowledge hub, and to science-led, sustainable development in Africa. The Centre's research started with five target insects: tsetse fly, tick, African armyworm, termite and the yellow fever transmitting mosquito. And this report describes how the portfolio has been transformed through internal introspection and a series of external reviews, to respond to emerging issues and changing developmental needs, aspirations and agendas in Africa and beyond. The most significant milestone was the introduction, in 1995, of the 4Hs research paradigm encompassing: Human Health, Animal Health, Plant Health and Environmental Health.

In Human Health, *icipe*'s research on malaria has been distinguished by a focus on mosquitoes – with studies adjusted in accordance to shifting trends of the disease. Using its basic science knowledge on the vectors, *icipe* has developed a range of tools and strategies, and executed highly successful integrated vector management (IVM) initiatives across Africa. Alongside, the Centre has conducted substantial research on neglected tropical diseases (NTDs). In the early years, studies on yellow fever and leishmaniasis laid the Centre's foundation on vector behaviour and ecology, parasite biology, and disease epidemiology. With the establishment of the Martin Lüscher Emerging Infectious Diseases (EID) Laboratory at *icipe* in 2011, the Centre has built on this base to intensify research on NTDs, with a growing list that now includes Rift Valley, yellow and dengue fevers; leishmaniasis, tungiasis and schistosomiasis.

The tsetse control management programme is a fascinating centrepiece of the *icipe* Animal Health Theme, whose aim is to develop vector strategies that are appropriate for smallholder livestock keepers in Africa. In the first 25 years the Centre made advances, including the development and deployment of the NGU trap, and the discovery of tsetse attractants to enhance its performance. A major milestone was the identification of a blend of odours in the waterbuck, which keep away the flies from the animal. This knowledge led to the development of a tsetse repellent collar for livestock, a technology that has been tested, optimised and refined, and is now in full-scale commercialisation and upscaling stages. *icipe*'s progressive expansion of understanding on tsetse and trypanosomes is illustrated by involvement in the genome sequencing of the *Glossina morsitans morsitans* tsetse species, completed in 2014, through a project led by the International Glossina Genome Initiative (IGGI). Also, the Centre has been unrelenting in its search for further leads for tsetse repellency and attractancy, while also appraising a variety of control options. *icipe*'s impact on the control of *Glossina fuscipes fuscipes* (which transmit human African trypanosomosis), is worth noting. Indeed, the Centre has developed a novel trapping system for this species that is notorious for its ability to evade such approaches. Moreover, *icipe* studies have revealed factors that facilitate tsetse movement and survival of trypanosomes, and divulged why only these flies transmit such parasites. As ticks are known to be resistant to most chemical acaricides, since inception, *icipe* has made it a goal to search for alternatives. This long-running quest has led to the production of effective biopesticides that are now being commercialised. *icipe* maintains research on ticks, currently through an integrated approach encompassing other hosts beyond livestock, for example wildlife, other disease vectors and pathogens, and more diverse ecosystems. Based on the experience and knowledge gained through the development of technologies for the control of tsetse flies, icipe initiated new research for the control of camel disease vectors in arid and semi-arid lands of SSA.

icipe's research has always had at its heart, the well-being of smallholder farmers, aiming to provide them with yield-improving integrated pest management (IPM) strategies that are environmentally safe, as well as economically and technically feasible. In the highly prolific Plant Health Theme, standout examples of success include two biological control programmes: one on stemborers, implemented from the 1980s to the mid-2000s; and the other on the management of the diamondback moth, a pest of cabbage, effected from 2000 to 2018. The *icipe* push–pull technology, now a phenomenal force in cereal–livestock mixed systems in Africa, has risen from modest beginnings: driven by the possibility of harnessing nature; and the wisdom in the age-old African practice of intercropping; backed by exploitation of behaviour-affecting chemicals produced by plants and insects. Meanwhile, this Theme has developed a range of packages that have supported increased yield and competitiveness of fruits and vegetables from Africa in local and export markets. Additional research has encompassed legumes, staples, indigenous vegetables and cash crops. The Theme has also been a platform to tackle a broad range of invasive pests.

Although *icipe*'s activities have always had an accent towards protecting the environment, in 1995, the Centre introduced a Theme dedicated to this goal. Today, the Environmental Health Theme is dedicated to broadening knowledge on arthropods, their diversity and role in ecosystems; conservation and sustainable use of biodiversity; and development of strategies for climate change mitigation and adaptation. The Theme pursues specific lines of research including bee research; bioprospecting, particularly for biopesticides and medicinal products; and habitat management, which supports biodiversity, pollination ecosystem services, and alternative hosts for pests and diseases.

The four main chapters of this publication conclude with a section on Capacity Building and Institutional Development, outlining *icipe*'s remarkable devotion to nurturing Africa's leadership in producing and using insect science. Chapter 4 also presents information on new or revamped areas at *icipe*, including: the Insects for Food and Feed Programme; Social Science and Impact Assessment, and Technology Transfer units; BioInnovate Africa Programme, and the Regional Scholarship and Innovation Fund (RSIF) of The Partnership for Skills in Applied Sciences, Engineering and Technology (PASET), both being managed by the Centre.

The report concludes with a brief chapter titled: *icipe* Beyond 50, which re-emphasises the validity of the founding mission of *icipe*; that of a centre of excellence devoted to insect science as a basis for enhanced agricultural production, better health, and better livelihoods. This chapter also outlines the Centre's future that in the next five years will be guided by the *icipe* Vision and Strategy 2021 – 2025.

1

A centre of excellence is born

INTRODUCTION

The International Centre of Insect Physiology and Ecology *(icipe)* stands as the enduring legacy of the late internationally renowned Kenyan scientist, Prof. Thomas Risley Odhiambo.

Educated in Cambridge University, United Kingdom, Prof. Odhiambo completed a PhD in 1965 under the supervision of the guru of insect physiology, Prof. Vincent Wigglesworth, producing a ‘phenomenally productive’ thesis on the reproductive physiology of the desert locust, with a series of 14 papers on the topic.

Upon his return to Kenya, Prof. Odhiambo 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 observed that scientific research was urgently required in the then postcolonial Africa, to develop environmentally safe strategies to increase agricultural production and to address prevalent tropical and vector-borne diseases. He stressed that the science conducted in Africa should have at its heart the elevation of the livelihoods of smallholder farmers.

At the same time, Prof. Odhiambo noted, the indigenous scientific community in Africa was ‘woefully small’, and the continent was hardly equipped, from a financial and infrastructural point of view, to tackle the challenges at hand. Therefore, he proposed that Africa’s best long-term solution towards conducting useful research was to concentrate efforts in a few centres of excellence.

As an example, Prof. Odhiambo recommended the locating of Africa’s insect research in one centre that would have the best equipment put to the best advantage. Such a centre would have permanent staff; it would also train young researchers from Africa and offer opportunities to other scientists from across the globe looking for ‘periodical renovation’. In Prof. Odhiambo’s words, the insect science centre of excellence would become “a powerhouse for the initiated and those wishing to be initiated into research”.

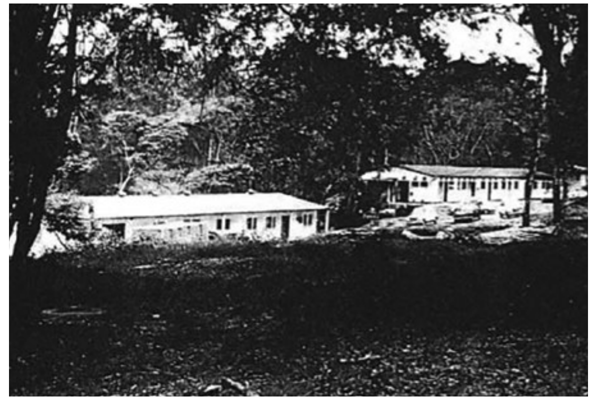
Prof. Odhiambo’s ideas obtained support from, among others, Prof. Carl Djerassi, a world-renowned American scientist. Together, Odhiambo and Djerassi set the wheels in motion for the establishment of *icipe*. Eventually, they gained the support of 21 national academies of science across the globe who became the first sponsors of *icipe*.

icipe was declared open for business in 1970, one of its objectives being the creation of motivated and talented ‘human capital’ in insect science and related areas of research, to enable Africa to sustain itself.

“The idea was actually very simple: Get the very best people and then if you have more money, put buildings and equipment around them.”

***icipe* Founding Director,**

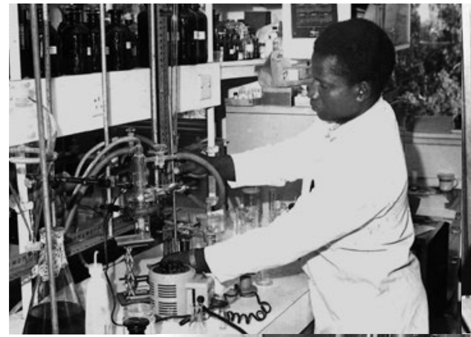
Prof. Thomas Risley Odhiambo



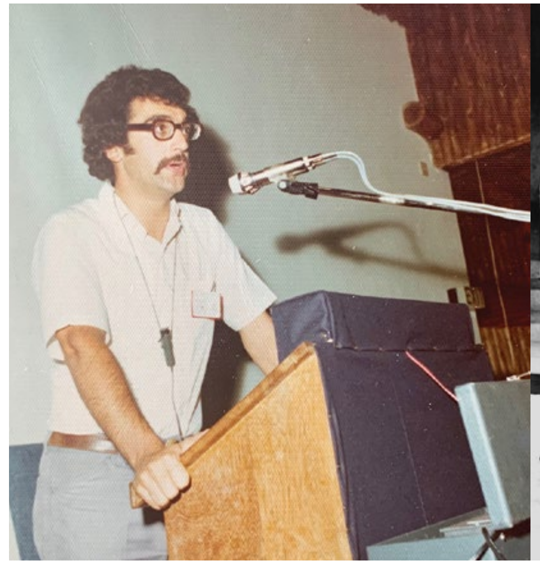
icipe was officially registered by the government of Kenya, its host country, in 1970. The Centre was granted full international status in 1977, and it was converted into an intergovernmental organisation through a Charter in 1986. *icipe* began its life in a one-room garage at the University of Nairobi, Chiromo campus (top left), moving, in December 1972, to the Northern Star Building on Chiromo Campus (top right). The Centre also established its Coastal Research Station in Mombasa, on the Kenyan coast. In 1990, *icipe* relocated to its international headquarters, known as Duduville Campus, in Kasarani, Nairobi (bottom left). ‘Dudu’ is Kiswahili for insect. A field station was inaugurated in 1986 at Mbita Point, on the shores of Lake Victoria (bottom right), and field sites were established around Kenya and in neighbouring countries.

MANAGEMENT & LEADERSHIP

The International Centre of Insect Physiology and Ecology (*icipe*) was established in 1970 as a unique institution linking the world's leading scientists in a quest for new knowledge that may permit the design and development of species-specific, non-toxic, non-persistent means of insect pest control.










At its founding, *icipe* committed to conduct research on selected insects and arthropods on their identity, abundance distribution, ecology, behaviour, physiology, pathology and genetics. This knowledge would then be translated into integrated pest and vector management approaches, and into strategies for the exploitation of beneficial insects "with special reference to Africa and other tropical regions of the world".

In effect, what set *icipe* apart was the philosophy of pushing the frontiers of insect science, not merely for its own sake, but because of its direct relevance to the significant tropical pest problems that had continued to defy effective management. The core of this vision was the linkage between advanced mission-oriented research and technology development. This balance was in contrast to traditional approaches of science in Africa over the eras, which accorded exclusive emphasis to one aspect – either basic or applied research – at the expense of the other.

Therefore, the young *icipe* may be described as an experiment in itself – a study in the intellectual communion of Africa's emerging scientific communities and advanced research institutions in the developing world, to solve the continent's priority problems. From the onset, the founders of *icipe* recognised that they had set themselves an 'awesome' challenge that required intensive global support.

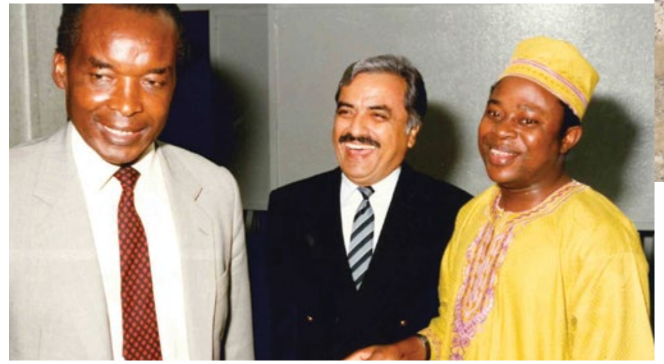
One of *icipe*'s governance organs was an international committee composed of representatives of academies of science and various scientific institutions from Australia, Czechoslovakia, Denmark, East Africa, Finland, France, Germany, Hungary, Israel, Japan, Netherlands, Norway, Sweden, Switzerland, UK and USA. These institutions provided the Centre's first Directors of Research; world-renowned scientists who visited *icipe* two or three times a year to set up respective programmes and to guide the Centre's activities.

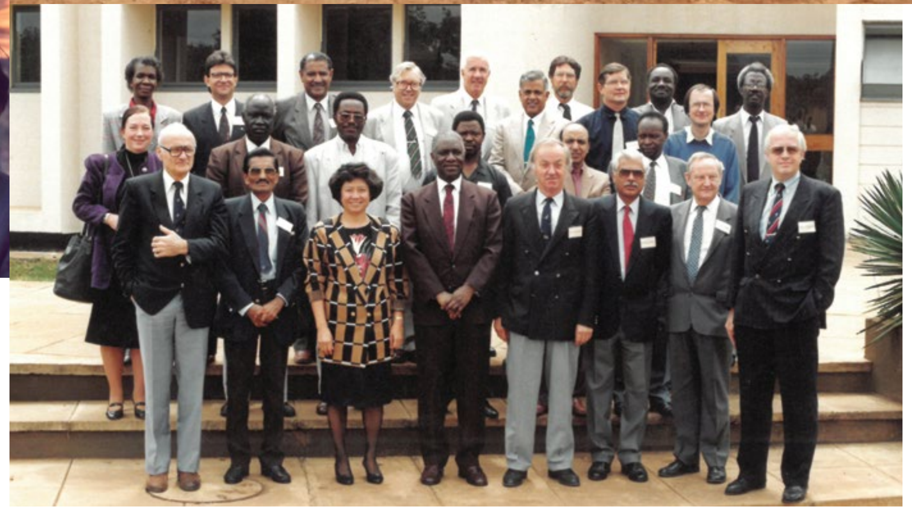
The *icipe* Governing Board initially consisted of senior scientists, from Africa and beyond, elected on a personal basis. In 1977, the composition of the Board shifted to encompass personalities experienced in science policy, institutional management, and international donorship. The *icipe* African Committee complemented these two organs. In 1977, an Inter-Agency Conference on the Development of *icipe* was convened in Nairobi, on a joint initiative by United Nations Development Programme (UNDP) and United Nations Environment Programme (UNEP). This was the first time that *icipe*'s current and potential donors, as well as supporting agencies and private foundations, had come together to discuss the Centre's objectives, programmes and needs.

In 1977, the *icipe* Governing Board recommended the creation of an advisory body – the *icipe* Foundation – which was subsequently established and headquartered at the Royal Swedish Academy of Sciences. The Foundation aimed to support *icipe* from a knowledge production perspective and to strengthen the Centre's communication with the international scientific community. In 1980, partly stemming from the worldwide economic recession, *icipe* experienced the most acute financial situation since the Centre's establishment. In response, the Centre's traditional donors launched a consortium, the Sponsoring Group of *icipe* (SGI), to seek ways to ensure the Centre's survival.

To build a research team, *icipe*'s approach was to advertise internationally for young scientists at postdoctoral level, and then select the brightest talents, whether from Africa or elsewhere, on a global scale of scientific quality. These budding researchers worked under the general supervision of Directors of Research. By the mid-1970s, the *icipe* research community was a hive of activity; a highly stimulating intellectual environment. In the 1980s, this group had adequate confidence in its own *in situ* programme leadership, such that, in 1978, when a Visiting Group on Administration and Finance proposed that the Directors of Research scheme be phased out, it was feasible for *icipe* to appoint Programme Leaders from its cadre of senior scientists.

At its founding, on the recommendation of its Governing Board, *icipe* selected five target insects: tsetse fly, tick, African armyworm, termite, and the yellow fever transmitting mosquito. The Centre's scientific programme garnered critical mass supported by a diversity of disciplinary expertise in organic chemistry, biochemistry, physiology, experimental biology, electrophysiology, fine structure and ecology. *icipe* also received technical support in electronics, photographic services, field travel facilities, and laboratory services. The Centre gained more than a hundred essential biological and chemical texts and subscriptions to several important journals, enabling the setting up of a Library. The Insectary was the first scientific support service to be set up in 1970, to provide standardised insect material as required.





The *icipe* research portfolio evolved through a series of independent international reviews, starting in 1974 when a new programme on the sorghum shoot fly was introduced. The first significant shift was in 1977, a year that marked the start of the consolidation of the *icipe* programmes.

The *icipe* Strategic Research Plans, developed in early 1979, were a landmark. This document was retrospective and restated categorically that the most crucial target of *icipe*'s research effort was provision of effective support to resource-poor farmers in Africa and other tropical regions. In 1982, the *icipe* Governing Board requested the SGI to conduct an external review of the Centre.

The process reassessed activities to ensure that the Centre's goals corresponded with the needs of farmers and that the research training would indeed strengthen Africa's capacity. This exercise was vital as it contributed to the grouping of *icipe*'s activities into the core programmes and research units outlined below:

Programmes
- Bases of plant resistance to insect attack
- Crop borers research
- Insect pathology and pest management
- Livestock ticks research
- Tsetse research
- Medical vectors research

Research units
- Chemistry and bioassay
- Histology and fine structure
- Sensory physiology

By 1986, it was evident that a robust contextual framework was in place for *icipe* to initiate the third component of its mandate: the establishment of an interactive research and development process with national programmes in the tropical developing regions of the world. Guided by dialogue with policy and decision-makers in eastern and southern Africa, *icipe* established the Pest Management Research and Development Network (PESTNET). Soon after, the Centre set up the Social Science Interface Research Unit (SSIRU).

The *icipe Vision and Strategic Framework* for the 1990s had an accent towards the maintenance of the status of a centre of excellence serving various constituencies, and as a marketplace for implementable ideas and technologies. The Strategy stressed the long-range goal of *icipe* as the development of a firm foundation of a new-age innovative pest management approach.

Awards and honours (1970 – 1994)

Centrewide honours

Award title	Awarded by
International Saint Francis Prize for the Environment (received in 1992)	Franciscan Centre of Environmental Studies, Assisi, Italy
Alan Shawn Feinstein World Hunger Award (received in 1986)	Brown University, Rhode Island, USA

Individual recognitions

Category	Staff member	Details
Awards	Thomas R. Odhiambo (Founding Director)	Silver Jubilee Medal, awarded in 1999, by the Organization of African Unity (OAU)
		Distinguished Scientist Award, received in 1998, from the World Bank-International Monetary Fund-Africa Club
		Albert Einstein Gold Medal, awarded in 1991, by the United Nations Educational, Scientific and Cultural Organization (UNESCO)
		Africa Prize for Leadership for the Sustainable End of Hunger, received in 1987, co-jointly with Abdou Diouf, who was at the time the President of Senegal. The award was conferred by The Hunger Project, New York, USA
		Gold Medal Award, awarded in 1983, by the International Congress of Plant Protection
		Gold Mercury International Award for development, social, cultural and economic cooperation, awarded in 1982, by Gold Mercury International, London, England
	Francis Omeno Onyango (Associate Scientific Officer)	*icipe* Medal for Innovative Research, awarded in 1992, for pioneering research on successful colonisation and rearing of the maize and sorghum stemborer, *Busseola fusca*, on a semi-synthetic diet
	Wilber Lwande (Scientist)	*icipe* Medal for Innovative Research, awarded in 1988, for studies on airborne volatile compounds of sorghum and cowpea
	Leonard H. Otieno (Scientist)	*icipe* Medal for Innovative Research, awarded in 1988, for research on rearing the *Glossina pallidipes* tsetse species
	Mary L. A. Owaga (Scientist)	*icipe* Medal for Innovative Research, awarded in 1986, for studies on attractiveness of animal odours to the tsetse fly
	Mutuku John Mutinga (Scientist)	*icipe* Medal for Innovative Research, awarded in 1985, for discovery of a new type of leishmaniasis in Baringo, Kenya
	Rajinder Saini (Scientist)	*icipe* Medal for Innovative Research, awarded in 1985, for research on a novel method for screening chemicals for attractancy in the tsetse fly

Awards and honours (1970 – 1994)

Category	Staff member	Details
Awards	Abdul Mongi (Scientist)	Annual Award for Innovative Research, received in May 1990, for studies leading to the development of a tick resistance antigenic indicator (TRAI), during the 20th Annual Research Conference, organised by *icipe* as one of the activities to mark the Centre's 20th anniversary
Special recognitions	Thomas R. Odhiambo	Doctor of Laws from Notre Dame University, Indiana, USA, awarded in 1991
		Doctor of Humane Letters from Johns Hopkins University, Maryland, USA, awarded in 1991
		Honorary Degree of Doctor of Science, from University of Nigeria, Nsukka, awarded in 1991
		Honorary Degree of Doctor of Science from the University of Massachusetts, USA, awarded in 1990
		Honorary Doctorate from University of Oslo, Norway, awarded in 1986
		Freedom of the City of Tuskegee, Alabama, USA, in 1980
Fellowships	Thomas R. Odhiambo	Foreign Member, Russian Academy of Agricultural Sciences, appointed in 1992
		Fellow, World Academy of Art and Science, Minnesota, USA, appointed in 1989
		Fellow, Puerto Rico Academy of Science, appointed in 1987
		Fellow, Norwegian Academy of Science and Letters, Oslo, Norway, appointed in 1986
		Founding Fellow, African Academy of Sciences, in 1985
		Founding Fellow, TWAS, in 1983
		Founding Fellow, Kenya National Academy of Sciences, in 1983
		Member, Pontifical Academy of Sciences, chosen by Pope John Paul II, in 1981, becoming the first African ever to be appointed to the Academy
		Fellow, Accademia Nazionale delle Scienze detta dei XL (National Academy of the Sciences), Italy, appointed in 1979
		Foreign Fellow, Indian National Science Academy, appointed in 1977
Appointments	Thomas R. Odhiambo	President, African Academy of Sciences (1986 – 1999)
		Vice President, TWAS (1983 – 1999)
		Chairman, Kenya National Academy of Sciences (1983 – 1994)
	Baldwyn Torto	African Association of Insect Scientists (AAIS)

Communication

From its founding, *icipe* was a media darling. The charisma and high profile of the Centre's Founding Director, Prof. Thomas Odhiambo; the Centre's unique mandate and novel breakthroughs; its budding and intellectually vibrant crop of African researchers; made for regular press coverage.

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Peer-reviewed journal articles were published between April 1970 and October 1994.

Core donors

Food and Agriculture Organization of the United Nations (FAO)
Government of Australia
Government of Belgium
Government of Denmark
Government of France
Government of Kenya
Government of Norway
Government of the Federal Republic of Germany
Government of the Netherlands
Government of the United Kingdom
International Fund for Agricultural Development (IFAD)
Organization of the Petroleum Exporting Countries Fund for International Development
Swedish International Development Cooperation Agency (Sida), Sweden
Swiss Agency for Development and Cooperation (SDC), Switzerland
United Nations Development Programme (UNDP)
United States Agency for International Development (USAID)
World Bank

Sponsoring academies

Academy of Finland
American Academy of Arts and Sciences
Australian Academy of Science
Austrian Academy of Sciences
East African Academy
Finnish Academy of Science and Letters
Finnish Scientific Society
Hungarian Academy of Sciences
Israel Academy of Sciences and Humanities
National Academy of Sciences, USA
Norwegian Academy of Science and Letters
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RESEARCH HIGHLIGHTS

Termite Research

icipe's research on termites was based on the desire to unravel the rare complexity of social organisation attained by these insects in Africa. The Centre believed that termites, with their intricate social system and dependence on the maintenance of a stable domestic environment, offered excellent experimental materials for investigating other insect problems.

Johanna P.E.C. Darlington (UK), was the Director of Research who set up the termite research programme at *icipe*. She is pictured briefing the team ahead of field activities.

Milcah Gitau (seated, headscarf) was one of the first *icipe* technicians, primarily attached to the Centre's (now defunct) Kajiado Field Station, in Kenya's Rift Valley, where most of the termite research was conducted. Milcah has remained on the *icipe* team, and as of 2020, she oversees the Centre's Animal Rearing and Containment Unit.

These insects formed a major experimental basis for elucidation of the chemical communication system of insects. Also, although known to be great, the economic importance of termites resulting from their feeding on crops and forest products had been inaccurately computed.

Moreover, it was important to understand the crucial role of termites on soil productivity and landscape architecture. For example, grass feeding termites remove considerable quantities of vegetation to the detriment of livestock.

The Centre's studies revolved around the effect of termites on soil development and nutrient availability. This is because termites transport enormous amounts of soil and organic matter to mounds and other structures, which are then redistributed through erosion and decomposition. The influence of the insects on soil properties (such as texture, structure, porosity, infiltration, water holding capacity, chemical characteristics and plant diversification) was also investigated.

Crop Pests Research Programme

The primary goal was to contribute to a sustainable increase in food production in Africa, by reducing damage by key insect pests. The research aimed to develop integrated pest management (IPM) strategies that were environmentally safe (as well as economically and technically feasible) for small-scale farmers.

William Overholt (second left), who was Coordinator of the *icipe* biological control of stemborers project, pictured during an event to release a wasp known as *Cotesia flavipes*, a natural enemy of stemborers. Looking on: W. Malinga (second right), who was at the time Director, KARI; P. Pats (right), Swedish University of Agricultural Sciences and K. Gitonge (left), an *icipe* technician.

The Centre and partners envisioned an IPM package consisting of pest resistant and tolerant cultivars; intercropping and other cultural practices; biocontrol agents (parasitoids, predators and pathogens of target pests); population surveillance and forecasting; and use of low-cost, natural and non-polluting botanicals and pheromones as pest control agents. Assessment of crop losses due to insect pests and determination of economic injury levels and control thresholds were also key foci.

The programme focused on the management of major insect pests of maize (stemborers – *Chilo partellus*, *Busseola fusca*, *Sesamia calamistis* and *Eldana saccharina*); sorghum shoot fly (*Atherigona soccata*); cowpea pod borer (*Maruca vitrata);* bean flower thrips (*Megalurothrips sjostedti*); banana weevil (*Cosmopolites sordidus)*; nematodes (*Pratylenchus* sp.); cassava green spider mite (*Mononychellus* sp.); and rice pests.

All research was conducted at the Mbita Point Field Station, with trials in farmers' fields. *icipe* collaborated with international agricultural research centres such as International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), International Maize and Wheat Improvement Center (CIMMYT), International Institute of Tropical Agriculture (IITA), International Rice Research Institute (IRRI), and West Africa Rice Development Association (WARDA), and with national agricultural systems.

Kailash N. Saxena (India, left), who was Leader of the *icipe* Crop Pests Research Programme from 1983, and Deputy Director of Research from 1993, pictured with Timothy Epidi (Nigeria), who was a PhD scholar at the time. During this period, studies were initiated to understand the potential of intercropping as a strategy for insect suppression. The findings obtained through trials, as shown in the picture on the right, formed the basis for the introduction of the now phenomenal push–pull technology.

A tiny wasp, *Cotesia flavipes*, was shown to be an effective parasitoid of the highly destructive stemborer *C. partellus*. *icipe* also tested the behavioural manipulation of the sorghum shoot fly as a way of managing the pest. Trials on intercropping confirmed sorghum–cowpea combination to be effective in managing stemborer populations. *icipe* also conducted studies on optimal patterns of strip cropping as a way of reducing stemborer infestation. Insect pathogens, like bacteria, fungi, nematodes and protozoans, also showed effectiveness against stemborers.

The outcomes included identification and testing of sorghum and maize lines and hybrids with high levels of resistance to stemborer attack, and improved grain yields. The researchers also found that thrips infestation in cowpea could be successfully controlled through the application of neem seed extract, with yields rivalling those from plots treated with commercial insecticides.

Rice varieties and breeding lines were developed, and early-maturing ones were identified. Banana cultivars were assembled and evaluated, and those resistant to the banana weevil and root lesion nematodes were identified.

Livestock Pests Research Programme

The research focused on two vectors: tsetse flies and ticks, which are major constraints to livestock production in Africa. Historically, these two vectors that transmit devastating livestock diseases have been the subject of intensive study. However, most investigations have been directed towards understanding diagnosis, disease pathology and epidemiology. In many cases resulting in the development of high-end management tools that are unsuitable for smallholder farmers. *icipe* aimed to create appropriate and sustainable strategies for African livestock keepers. As a foundation, the Centre embarked on completing major gaps in knowledge on the physiology of the two vectors: their feeding and developmental biology, and their reproductive and sensory physiology.

Livestock remains one of the most important resources in many households across Africa. In the years surrounding the founding of *icipe* (1970s and 1980s), there was significant decline in livestock productivity, with diseases among the responsible factors.

Ticks research

Ticks – small, blood-sucking arachnids— are external parasites and are among the most important disease vectors of livestock. Although about 160 tick species exist in Africa, the two most important are *Rhipicephalus appendiculatus* (the brown ear tick), and *Amblyomma variegatum* (the variegated tick).

icipe aimed to develop alternative, environmentally sound technologies to suppress tick populations below harmful levels, guided by research on the ecology and behaviour, as well as the interactions between ticks and the animals that they parasitise. The Centre also conducted studies on survival, activity, mating behaviour, and pheromones in the ticks.

The *R. appendiculatus* species transmit *Theileria parva*, parasites that cause East Coast fever, a devastating disease of cattle. Most cows that contract the ailment succumb to it and those that survive are unthrifty for the rest of their lives.

icipe contributed to understanding the population dynamics of *R. appendiculatus*. These studies were grounded in knowledge on the life cycle of the tick, which 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 large blood meals but spend only a small proportion of their lifespan).

The *A. variegatum* ticks are also important as they cause heartwater, a rickettsial disease of livestock. Aside from leading to mortalities, ticks also debilitate livestock through loss of blood and damage to hides, predisposing the animals to bacterial, fungal and parasitic infections.

The *icipe* studies were based on the perception that the well-being of the tick depends on various factors in the ground. In turn, these aspects 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 influences, climatic effects and altitude.

Several leads for non-chemical control of *R. appendiculatus* were revealed, including habitat manipulation and controlled livestock stocking. Biological control agents were also identified, including botanical extracts, nematodes and anti-tick vegetation. The researchers tested and found potential in two entomogenous fungi, *Beauveria bassiana* and *Metarhizium anisopliae* for the management of *R. appendiculatus*.

Participants of a Tick Study Workshop held at *icipe* in October 1977. Among them was Rachel Galun (third left) a Director of Research from Hebrew University of Jerusalem, who started the programme.

Researchers had known for long that *Ixodiphagus* wasp species are parasitoids of ticks. Indeed *Ixodiphagus hookeri* and *Ixodiphagus theilerae* had been reported in Africa. However, no releases of the wasp had been conducted on the continent.

icipe advanced knowledge on *I. hookeri* to understand its geographical distribution in Africa, cost-effectiveness and sustainability in tick control, as part of an integrated approach with other chemical-free interventions. The studies confirmed that this tiny wasp could penetrate the seemingly impervious leathery sack of the tick body. Indeed this little parasitoid was found to be a mighty natural enemy of ticks, capable of mortalities in *A. variegatum* of up to 80%.

In appreciation of the wealth of indigenous knowledge inherent in communities across Africa, the Centre evaluated and documented anti-tick ethnopractices, as well as the socioeconomic factors that influence their adoption and sustainability.

Tsetse research

From the onset, the *icipe* tsetse research programme aimed to develop environmentally safe tsetse control tools. In the first 25 years, *icipe* implemented three projects. First, studies were conducted on tsetse reproductive physiology, aimed at better understanding of the mechanisms that play an important role in the increase of the fly's populations. Second was ecology and epidemiology research geared to unravel the population dynamics and behaviour of tsetse, the relationship between tsetse physiology and trypanosomes, and the mode of action of factors involved in the vectorial capacity of the flies. Third, population sampling techniques were explored, to develop a methodology to relate fly catches to true population size and structure, and to find a means to exclude ultra-low population densities.

A NGU trap: The blue colour attracts tsetse flies. After landing on the blue coloured cloth, the flies move on to the black target, and while trying to escape, they are captured at the top in a plastic container, where the heat of the sun kills them.

DAILY NATION, WEDNESDAY, MARCH 11, 1992

FEATURE

Discovery that opened a new chapter in tsetse fly control

BY JEMIMAH MWAKISHA

The walls of her office are patched by graphs of her work, glass cupboards containing eight species of the tsetse fly and pictures of the biconnical trap, which she has helped make successful through the discovery she made some years back.

A computer screen is placed on one end while books, papers and a neat table are in other parts of the room.

Mary Owaga, is not a person you are likely to meet in social gatherings or in women's meeting.

She would probably be in the laboratory testing this or that theory when her womenfolk are meeting or chatting.

Mary is the woman who five years ago made an outstanding contribution to the control of tsetse which infests over 10 million square kilometres or one quarter of the African continent.

She identified the compound that makes tsetse attracted to the buffalo – the animal's urine.

Further test revealed that a cow's urine has similar compounds to that of the buffalo which keep the fly glued to it, and therefore dangerous to its life.

This meant that urine from either buffalo or cow could be used to trap the insect and therefore control it.

Her findings were specifically applicable with one species – *Glossina pallidipes* – most wide-spread in Eastern and Southern Africa.

Parts of Western Kenya, Lambwe Valley, areas bordering Lake Magadi, and some coastal areas are infested with the fly.

Her achievement in 1986 had however taken years to attain and had demanded sacrifice, patience and hard work. She had been working on the tsetse since 1978 and five years later she started on the olfactory (smell) process.

"We thought of chemical free traps in order to maximise the efficiency of the traps," a jovial but busy Mary told me recently.

The trap, which has been in use since the turn of the century to control trypanosomiasis has been little used because of the introduction of pesticides.

Scientists had already found out that tsetse are attracted to certain colours, namely black and blue.

"But we also found out that the contrast of colour – white, royal blue (as opposed to sky blue), black and vegetation makes the insects even more attracted to the trap," she adds.

But why did she think of the buffalo in the first place?

"We were trying to find out some process which could complement the visual attraction, so then I thought of their best hosts."

Her earlier experience with animals offered part of the solution.

She had worked on the feeding habits of wild animals, particularly grazers and this made her relate easily to the buffalo.

Testing and analysis of the fly blood indicated that they fed mostly on buffaloes, warthog and

'Mary Owaga identified important compounds in buffalo urine.'

She set out to find what really attracts them to these animals.

She went to the animal orphanage where she got the buffalo's urine, dung and body wash.

She then went to test it in the field at Nguruman, near Lake Magadi, an area infested by the *pallidipes* fly and where the Maasais have lost lots of cows due to *nagana*.

The urine emerged most effective. That was in 1984.

She then tried the cow's urine which also proved fairly good.

Chemists in the ICIPE laboratories identified the chemicals responsible for the attraction of the urine. These were the phenolic compounds in the urine – the paracresol and meta propyphenal.

"But the cow's urine was not as effective so we used another compound acetone to make it as strong as the buffalo's urine," Mary explains.

Both the urine and acetone were then kept outside the trap to attract the fly.

They would further be attracted by colour into the trap and in an effort to look for light, they would get into a plastic tolet and exposed to beams sunlight which would eventually kill them.

"We used the chemistry of attraction through smell and vision to make the procedure more effective."

The results were outstandi[ng] and within seven

per cent and the Maasais were able to do it for themselves.

How did you feel?

"I don't know," she says thoughtfully.

"One feels pleased to come up with some finding after many years of working."

Mary is the second recipient of the ICOPE Award for Innovative Research. She is now carrying out more research on the tsetse found in the Coast Province.

The species found there do not respond to the odour bait, she explains.

She is a mother of three children aged 16, 12 and seven.

Says Dr Leonard Otieno, the tsetse programme leader: "Our interest here is to find long-term solutions for tsetse fly and trypanchomiasis."

He says the trap method had advantages over the pesticides because it is cheap, no risks involved in form of side effects or enviromental contamination.

He says DDT which is still in use here has been banned from Europe and the USA.

"We thought we should re-appraise and re-examine methods of managing tsetse flies."

Trapping was their target. He says although what they came up with was very unique, trapping dates as far back as 1906 when a Portuguese farm manager found out that tse tse flies were attracted to the black workers by sticking on their backs as they worked.

He then gave each of them a piece of cloth on their backs and made them walk around the farm.

"That would attract many tsetse flies and that way, they were able to control them in the farm.

Then DDT came into being in the Second World War but trapping was reactivated by French workers who in the end of 60's developed a conical-shaped trap.

Zimbabwe workers picked this up and made a box one.

"We looked at these and made a blend of both of them." The trap made up of three colours of cloth, white, royal blue and black has been very effective with one species of the tsetse, namely

Owaga's discovery has enhanced efforts to control the devastation caused by the tsetse fly. The Maasai community in Nguruman has been using the trap continuously, having learnt the methods of doing it on their own.

"It is simple and cheap since they get the cow urine just from their own cows," he says.

Otieno, along with other colleagues, also tested the method in south-east Rwanda where there are three species of the fly.

He says the method had not offered a permanent solution because it did not seem effective with two of the three species.

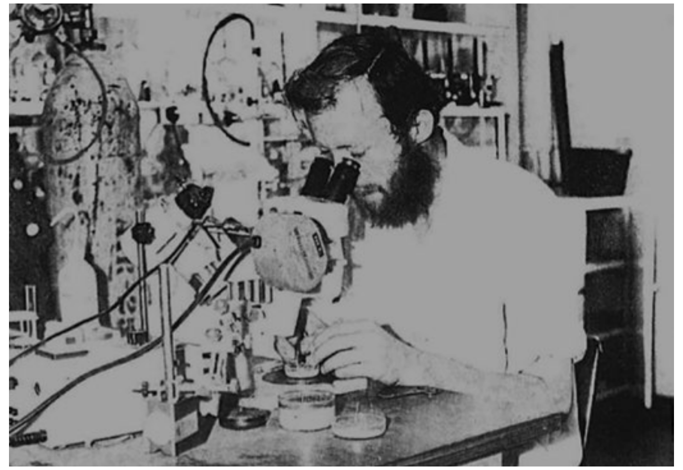
ICIPE scientists are also tr[ying] it in Eth[iopia]

Mary Owaga: Made great contribution to research on the tsetse fly control.

One of the major milestones was the development of the NGU trap, arising from *icipe*'s landmark Nguruman Tsetse Project, implemented in Kajiado, Rift Valley, Kenya, between 1983 and 1986. At the time, the biconical trap (developed in West Africa in the 1970s), was the most widely used tsetse sampling technique in Africa. *icipe* aimed to determine the effective use of this technology and various modifications to make it more affordable and efficient. The studies were conducted in collaboration with various research institutes, and the Maasai community in Nguruman. The trap was named after the *icipe* Nguruman Field Station.

In the 1980s, to improve the efficiency of the NGU trap, *icipe* researchers started conducting studies on scent lures that attract tsetse to their hosts. The intention was to use such chemicals as 'artificial livestock' placed in the proximity of the traps. Investigations were conducted on animals that are known to be preferred hosts of tsetse, for example goats, cattle and warthogs. The studies identified chemicals in the urine of bovines (like cattle and water buffalo) to be attractive to *Glossina pallidipes* and *G. morsitans*.

The Centre also undertook research to find repellents that would drive tsetse flies away from livestock. In this case, the analysis targeted animals found in tsetse habitats, but which are rarely fed on by the insects. These studies led to identification of chemical odours in waterbuck, a large antelope found in sub-Saharan Africa. These two sets of findings inspired the possibility of developing a push–pull tsetse control strategy, combining the repellents blend applied on livestock, and the NGU traps enhanced with the tsetse attractants.



Pictured in 1973: One of the earliest postdoctoral researchers at *icipe* conducting research on reproductive physiology of tsetse flies.

Pictured in 1977: Ahmed Hassanali (front) (Zanzibar, Tanzania), one of *icipe*'s first African talents, and pioneer chemical ecologist, showing Bradford Morse, Administrator, UNDP, a sample of tsetse sex pheromone synthesised at the Centre.

During their life cycle in tsetse, trypanosomes, the parasites that cause, trypanosomosis, must undergo several transformations, each of which can result in high mortalities for the parasites. In different phases, most tsetse flies are able to detect and efficiently clear trypanosome infections. Indeed, only less than 5% of these vectors end up transmitting trypanosomes. For example, when bloodstream form trypanosomes originating from the vertebrate host enter into the insect's midgut, they must transform into forms better suited for survival in the harsh environment created by the vector host.

Very few parasites (less than 1%) survive this step. A crucial event for the transformation of trypanosomes is the ability to become established in the tsetse midgut. Therefore, *icipe*'s early studies focused on understanding the factors that promote trypanosomes in tsetse midgut. This research led to the identification of trypsin and lectin enzymes as key factors in the survival of the parasites. The information formed the basis for future *icipe* studies, especially on the susceptibility of tsetse flies to trypanosome infections.

icipe also made a breakthrough in the identification of new odours with great promise for the control of riverine tsetse, the group that carries human sleeping sickness, and which has proven difficult to manage with baits. The Centre demonstrated for the first time that tsetse species (such as *Glossina fuscipes*) locate their preferred hosts (monitor lizards) through previously unknown odour cues.

Yellow fever research

At the founding of the Centre, yellow fever was selected as one of the focal topics, based on the importance of the disease in Africa. Besides, the Centre considered the *Aedes aegypti* mosquito, the yellow fever vector, a target insect species for exploring possibilities of insect genetic engineering as a control technique. By this time, although there was general knowledge on the ecology of the insect, critical gaps existed. Therefore, *icipe* focused on advancing understanding and on characterising the population genetics, dynamics, and behaviour of the various strains of *A. aegypti*. Additional studies examined the ecological and environmental drivers favouring the distribution of this mosquito to predict its response to seasonal changes and control operations.

Malaria research

icipe research concentrated on ecological and behavioural studies on the *Anopheles gambiae* species complex, which includes two of the world's most efficient malaria vectors. At the time, malaria control focused on diagnosis and treatment. Vector control only played a minor role, and the understanding of vector behaviour was limited. Also, the emergence of chloroquine-resistant *Plasmodium falciparum* malaria in eastern Africa in 1978 underlined the urgency to intensify new management strategies for the disease, targeting the vectors as transmission drivers of the disease.

Participants of an *icipe* International Group Training Course in Pest and Vector Management while on a visit to the Mwea Irrigation Settlement Scheme, where *icipe* was conducting studies.

Through studies conducted at the *icipe* Coastal Field Station, the Centre's attention was on several interrelated but underresearched topics. These included identification of the local sibling species of the *An. gambiae* species complex, their egg-laying behaviour, and aquatic population regulation of freshwater species. These findings paved the way for the development of methods to intercept female mosquitoes as they lay eggs.

The findings enabled a better understanding of local vector systems and species distribution, as well as information on their survival and biting rates. By combining various scientific techniques and disciplinary approaches, *icipe* pioneered knowledge on the identity of the local Gambiae species like *An. gambiae sensu stricto*, *An. arabiensis* and *An. merus*.

George Craig, Professor of Biology, University of Notre Dame, USA, a mosquito geneticist was a Director of Research at *icipe*, who worked primarily on *Aedes* spp., especially on *Aedes aegypti*, the yellow fever mosquito. He led the search for genetic means to control mosquitoes. In the picture is a fellow Director of Research, Jan De Wilde, Wageningen Agricultural University, Wageningen, the Netherlands, an insect physiologist, who initiated research on biological control of stemborers.

icipe identified a larvivorous fish, *Tilapia zilli*, as being able to significantly reduce mosquito larvae, highlighting the fish as a mosquito control agent, and as a rich source of high-quality protein.

Leishmaniasis research

Leishmaniasis is transmitted by sand flies, tiny blood-sucking insects. The disease occurs in three forms: the visceral form, kala-azar, which affects the spleen and liver; the cutaneous type that affects the skin leading to permanent scarring and disfigurement; and mucocutaneous leishmaniasis, which produces lesions that spread to the mucous membranes of the nose, mouth and pharynx causing severe disfigurement and suffering. Leishmaniasis is expensive to treat, and medications are not always available for its treatment.

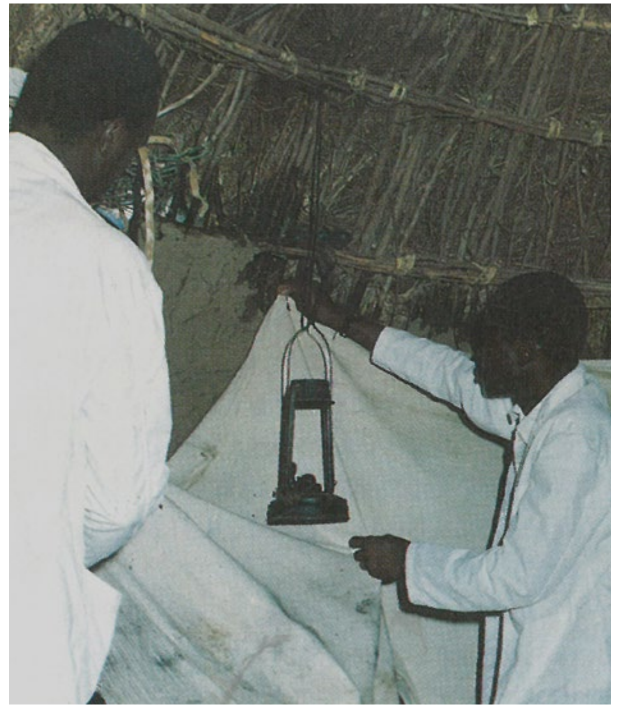
icipe researchers collecting sand flies using the '*icipe* sticky trap', mounted on a house.

A rational approach for the prevention of leishmaniasis is through the control of its vectors. During the early years, *icipe* focused on obtaining basic understanding of the behaviour and ecology of sand flies. As a result, the Centre developed a new sticky trap that enabled more effective catches of sand flies (and mosquitoes), thereby facilitating better monitoring.

icipe researchers identified the breeding sites of most sand fly species. They also undertook studies on domestic and wild animals that are reservoirs of *Leishmania* parasites. Factors influencing the vector potential of sand flies were investigated and *Leishmania* parasites identified and characterised. A significant finding at the time was that *Leishmania* parasites found in reptiles had adapted themselves to human hosts. Microorganisms, including bacteria and fungi that affect the establishment of *Leishmania* in the sand fly gut, were also examined.

The mbu cloth technology

The mbu cloth was a technology developed by *icipe* that proved effective in controlling both sand flies and mosquitoes. The cloth was impregnated with WHO-recommended pyrethroid insecticide and used as wall lining in houses, with efficacy lasting for up to six months. (At the time mosquito resistance to pyrethroids had not been detected).



Capacity Building and Institutional Development Programme

One of *icipe*'s founding goals was to strengthen Africa's capacity in insect science. In its first decade, *icipe* evolved this objective into a series of programmes, the most important being the Group Training Courses in Pest and Vector Management Systems. A joint initiative between the Centre and the United Nations Environment Programme (UNEP), was an annual Science Bursary Scheme for internships at *icipe*, awarded to selected Kenyan high school graduates who planned to proceed to study science at university. The hope was that this exposure would lead the young scholars to include entomology and research for development in their courses.

Rajinder Saini (photo 1, extreme right); Clifford Mutero (photo 2, top-left) and Peter Njagi (photo 3, extreme right), were among the first Kenyan students to be trained through *icipe*. They continued their careers at the Centre, making significant contributions in human and animal health.

icipe also offered research associateships to developing country scientists involved in pest management research. A key feature was cooperation with institutions in Africa. The Centre had agreements with the University of Nairobi, Kenya; University of Ibadan, Nigeria; University of Ghana; Makerere University, Uganda and Dar es Salaam University, Tanzania; and also trained staff from research institutions in Zambia. Postdoctoral fellowships tenable at *icipe* were granted to gifted young scientists worldwide on a competitive basis.

The *icipe* Directors of Research also offered training facilities for *icipe* staff in laboratories in their home countries. Many *icipe* scientists undertook further training in Australia, Canada, Italy, Japan, the Philippines, Sweden, the United Kingdom, and the United States of America. The Centre's technical staff were able to upgrade their skills at the Kenya Polytechnic and in laboratories abroad. Meanwhile, *icipe* management staff received advanced training in research management.

Establishment of ARPPIS

In the mid-1970s, the *icipe* training activities underwent several independent reviews – in tandem with the centrewide re-evaluations. The culmination of this process was in 1983 when a workshop convened at the Rockefeller Foundation Bellagio Center, Bellagio, Italy, recommended the rationalisation of *icipe*'s postgraduate training to meet the needs of the region in high-level research and training in insect pest management.

This proposal led to the establishment of the African Regional Postgraduate Programme in Insect Science (ARPPIS). The programme was envisioned as a collaborative project between *icipe*, as the executing agency, and African institutions, particularly universities. The ARPPIS scholars would conduct research at *icipe* and elsewhere on the continent, receiving a scientific and technological base, while the universities would provide theoretical instructions and award degrees.


The pioneer ARPPIS scholars went on to have impressive careers. For example: (top, l–r): Hassane Mahamat Hassane (Chad – class of 1987), served as Director-General Laboratoire de Recherches Veterinaires et Zootechniques de Farcha, Chad; and Elianeny Mose Minja (Tanzania – class of 1986), a well-reputed IPM practitioner. (Bottom, l–r) Richard Bagine (Kenya – class of 1983) held senior national and regional positions in biodiversity conservation; J. B. Okeyo-Owuor (Kenya – class of 1983) held positions in the academic sector; and Dona Dakouo (Burkina Faso – class of 1990), held the position of Director, Research at the Institut de l'Environnement et de Recherches Agricoles (INERA), Burkina Faso.



The launch of ARPPIS, on 1 March 1983, was undoubtedly the most significant landmark in the history of *icipe* capacity building. The first ARPPIS class consisted of seven students from four countries in Africa: Richard Bagine, S.H. Okech and J.B. Okeyo-Owuor (Kenya); Suliman Forawi and Latif A. Ibrahim (Sudan); Barnabas Njau (Tanzania); and J.H.P. Nyeko (Uganda).

ARPPIS scholars conducted research on such areas as the ecology of arthropods of economic importance in agriculture and rural health; insect endocrinology; developmental and pheromonal biology; parasitology; insect pathology; bases of plant resistance to insect attack; insect behaviour, morphology and anatomy; biochemistry and natural products chemistry; toxicology; insect nutrition and mass-rearing; development of specialised bioassay techniques; among others.

Beyond ARPPIS, *icipe* consolidated the rest of its training programmes into 5 training projects: the Postdoctoral Research Fellowship Programme; the Financial and Administrative Management of Research Projects in Eastern and Southern Africa; the International Group Training Course for Ecologically Sound Pest and Vector Management Systems; the International Training Course in Insect Growth, Development and Behaviour; and the Staff Development Programme.

2

The 4Hs: A framework for transformation

INTRODUCTION

My appointment as the Director General of *icipe* came 15 years into what was a chance sojourn in Africa. In 1979, after completing a postdoctoral fellowship at the University of California, Berkeley, USA, focusing on biological control, I answered an advertisement for an entomologist in a maize programme at IITA in Nigeria. However, because of my experience, I was offered a position in the biocontrol of the cassava mealybug and green spider mite. This assignment provided me with the opportunity to implement my 'book-knowledge' on biological control not only in natural settings but in a sustainable way that few people had considered before. We reared millions of ladybugs and parasitic wasps and then shot them from aeroplanes over cassava fields. This way, we were able to control the cassava mealybug, a highly destructive pest, saving millions of people from starvation.

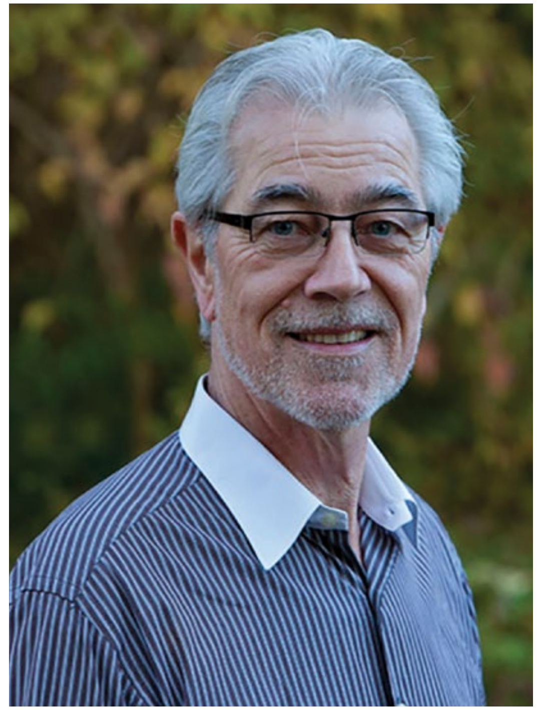
In 1994, I received a phone call from Dr William Mashler, who was at the time the Chairman of the *icipe* Governing Council, inviting me to apply for the position of Director General. At that time, I was contemplating a move from IITA to the United States. Still, the opportunity to lead *icipe* into its new phase sounded too exciting to pass, even though I knew that the transition would be challenging.

At the Centre, I found a strong team and an even larger platform for sustainable development. I developed the 4Hs paradigm as the framework for the 'new *icipe*'. I came to this idea from the experience I had gained both at IITA and from having studied the failures of many development projects. I realised that to be successful, projects needed a holistic and integrated approach that would facilitate sustainable development for farmers and rural communities in general.

The 4Hs paradigm represents Human Health, Animal Health, Plant Health and Environmental Health. Concerning human health, some of the continent's most devastating diseases, including malaria, dengue fever and sleeping sickness, are transmitted by insects. These diseases not only put a strain on the already fragile health care systems but also cost the continent vast amounts of money, in terms of loss of life and human resources.

In animal health, every year several millions of cattle are lost in Africa due to the fatal disease nagana, which is transmitted by the tsetse fly. If we can control these pests, we increase the production of milk and meat and, importantly, draught animal power for tilling the land. Insect pests also constrain the production of most major crops in Africa. However, efforts to combat these pests should not just focus on how to increase yield, but also on how to do it sustainably. This means better water and soil management and integrative production systems that maintain diversity and provide the needed ecosystem services. For all these tasks we need more well-trained people in Africa who can deal with the problems on their own and in their environment.

The main idea was to link the 4Hs, which had a common thread – the insects – to create momentum and positive synergies, along an upward spinning spiral, which would cater for the different development problems encountered by farmers and rural communities. I am proud to have left the 4Hs as a legacy of my tenure at *icipe*, and that the best example of this research paradigm, the push–pull technology, continues to thrive.



"I think that my team and I managed, against many odds, to rebuild icipe as Prof. Odhiambo had imagined it: a centre of excellence in insect science, and a pearl in the African science landscape. The fact that there are many leaders in agriculture and the environment, from government, academia, regional and international research and development and the private sector today in Africa that have a connection to icipe, is a sign of this excellence."

Dr Hans R. Herren
Director General (1995 – 2005)

icipe Duduville campus, Kasarani, Nairobi (above) and Thomas Odhiambo campus, Mbita, on the shores of Lake Victoria (below) during this period.

MANAGEMENT & LEADERSHIP

This was a critical period of transition for *icipe* marked by a significant decline in donor funding and departure of the Centre's Founding Director, Prof. Thomas Odhiambo. The Management sought to revitalise *icipe* through staff rationalisation, recruitment of younger scientists and streamlining of operations.

Completion of negotiations with the government of Kenya pivoted *icipe*'s international status, leading to the signing of an agreement to regulate the Centre's headquarters in Nairobi, Kenya. And as *icipe* celebrated its 25th anniversary, it was with a strong and highly publicised expression of support for the Centre and its mission from its host government.

The Centre expounded its research agenda in the *Vision and Strategic Framework Towards 2020* (published in 1997), aimed at continuing research in the 'classical' areas of insect ecology, behaviour, biology, taxonomy and diversity. But, *icipe* also re-articulated its goal of finding solutions for insect challenges against growing advocacy for strategies that the Centre's Management considered to have direct and indirect detrimental effects on human and environmental health.

As a result, *icipe* aimed to venture into the applied aspects of insect science. The Centre also purposed to mainstream efforts to explore the potential of insect biodiversity for income generation, while also protecting its invaluable ecosystem services. During this period, the Centre was extremely vocal in advocacy activities against harmful and ultra-expensive pesticides like dichlorodiphenyltrichloroethane, commonly known as DDT.

These aspects and insights led to the introduction of the 4Hs approach as a new research paradigm for the Centre, emphasising a holistic and integrated approach across human health, animal health, plant health and environmental health.

In accordance, in 1997, further restructuring of *icipe* programmes took place, resulting in eight megaprojects: Horticultural Crop Pests; Food and Perennial Crop Pests; Locusts and Migrant Pests; Tsetse; Livestock Ticks; Malaria Vectors; Commercial Insects, and Biodiversity and Conservation.

In 2004, *icipe* launched a new Strategic Vision, at a time when the global community was expressing concern that the millennium development goals (MDGs), launched in 2000, were way off the set targets. *icipe* introspected its contribution to the MDGs, noting that the Centre was addressing the five key priorities (Water, Energy, Health, Agriculture, and Biodiversity, collectively known as the WEHAB initiative) outlined in 2002 by the then United Nations Secretary General, Kofi Annan. This scenario highlighted *icipe*'s uniqueness among international research and capacity building organisations, in terms of critical competencies in the most crucial areas of development identified by the international community.

To honour the legacy of the Founding Director, Prof. Odhiambo, the Management renamed the Centre's conference hall at the headquarters in Duduville, Kasarani, Nairobi; and the Mbita Point Field Station on the shores of Lake Victoria after him.

At this juncture, the Centre had a well-established reputation for developing natural control methods for arthropods. However, the aspect of insect conservation was still in its infancy. During this period, the Management boosted such start-up ideas through the creation of a Biodiversity Programme, under the leadership of Scott Miller, who was on a 'loan' to the Centre from the Smithsonian Institution, Washington DC.

The Centre's Management considered the survival of *icipe*, after more than a quarter of a century of intense basic research, to be dependent on the ability to commercialise its research results. As such, *icipe* launched a TechnoPark to undertake large-scale production and marketing of the Centre's technologies, tools and strategies entirely as a business venture. This idea laid the foundation for the commercialisation of *icipe* technologies, which has since been advanced by subsequent Management.

The Plant Health Theme was elevated significantly. The stemborer biocontrol started under the Founding Director was advanced. The launch of the push–pull programme became a game-changer in the control of key constraints of cereal production. The serious diversification into control of pests of fruits and vegetables also augmented the activities of the Theme.

Having a steady supply of arthropods for research, in adequate quantities and quality, is vital for an institution like *icipe*. Indeed, the Animal Rearing and Quarantine Unit (ARQU) was the first support facility to be established at *icipe* at the Centre's founding. Over the years, the ARQU had developed its potential as a regional and international resource and advisory centre in insect rearing technology. The Unit raised several species of tsetse, ticks, stemborers, gregarious and solitary phase locusts, as well as beneficial insects.

In 1997, the ARQU was upgraded to provide a biologically secure laboratory facility built and equipped under the Wageningen Agricultural University/*icipe* collaborative project on the biological control of cereal stemborers. This quarantine facility enabled *icipe* to import a variety of arthropod species, and potential plant and animal microorganisms, and maintain their cultures under biologically secure conditions that exclude possible escape. The Unit also continued to conduct research on new techniques of arthropod rearing and mass production, and in the breeding and handling of small laboratory mammals. The Centre also established a new facility for rearing mosquitoes at the *icipe* Mbita Campus.

icipe resolved to engage even more in global partnerships for research and capacity and institution building. During this period, the Centre had over 80 formal memoranda of understanding or agreements and numerous additional informal collaborative agreements.

Awards and honours (1994 – 2005)

Recognition to programmes and projects

Award	Awarded to	Awarded by	Details
Top scientific programme award (received in 2004)	Push–pull technology	Kenya Agricultural Research Institute (KARI), during the organisation's Biennial Scientific Conference	Recognised for increasing food productivity and security
Special mentions and recognitions (in 1998)	'Building awareness and promoting the use of neem for improving the living environment and mitigating rural and urban poverty in sub-Saharan Africa' project	Dubai International Award for Best Practices to Improve the Living Environment	The Award is given to institutions that have a demonstrable and tangible impact on improving people's quality of life
		Rolex Awards for Enterprise	The project was featured for environmental impact in the book: 'Spirit of Enterprise: The 1996 Rolex Awards'
Top award (received in 1997)	Educational play entitled "Mosquito Mask" jointly authored by *icipe* researchers and teachers from Sindo Girls School, Homa Bay, Kenya	Kenya District Secondary Schools Drama Festival	Based on the prevailing malaria situation in Africa, the play helped to create awareness on the role of mosquitoes in the transmission of the disease. It also highlighted methods available for mosquito and malaria control

Individual recognitions

Category	Staff member	Details	Awarded by
Awards	Hans R. Herren (Director General)	Tyler Prize for Environmental Achievement, awarded in 2003, for outstanding contributions to environmental health	Tyler Prize Foundation, Los Angeles, USA
		Excellent Performance Award, awarded in 2002	Organisers of the International Pest Management Conference, initiated by the Integrated Pest Management Collaborative Research Support Program, held in Kampala, Uganda on 8 – 12 September 2002
		Brandenberger Prize, awarded in 2002, for guiding contributions and improvement of the living standards of rural populations in Africa through development of agricultural production methods in harmony with the environment	Dr J. E. Brandenberger Foundation, Zurich, Switzerland

Category	Staff member	Details	Awarded by
Awards	Hans R. Herren (Director General)	Award for outstanding contribution to improved health, agricultural production and environmental protection in Africa, received in 1996	African Association of Insect Scientists
		World Food Prize, awarded in 1995, for having advanced human development by improving the quality, quantity and availability of the world's food supply	World Food Prize Foundation, Iowa, USA
		Kilby International Award, received in 1995, for extraordinary contribution to society through science, technology, innovation, invention, and education	Kilby Award Foundation, Texas, USA
	Onesmo ole-MoiYoi (Director of Research and Partnerships)	Kilby International Award received in 2003	Kilby Award Foundation, Texas, USA
	Thomas R. Odhiambo (Founding Director)	International Scientific Council for Trypanosomiasis Research and Control (ISCTRC) Silver Jubilee Award, received in 2000	Organisation of African Unity (OAU)
	Rajinder Saini (Scientist)	Silver Medal, awarded in 1999, for significant contributions to the understanding and control of African trypanosomes and their vectors	Secretary General of OAU, on behalf of 37 African countries affected by tsetse flies
	Ramesh C. Saxena (Scientist)	Distinguished Achievement Award, received in 1998, for outstanding contribution and valuable service in the field of pest management	Organisers of the International Pest and Pesticide Management Conference for Sustainable Agriculture, held in Kanpur, India, on 11 December 1998
Special recognitions	Hans R. Herren	Honorary Doctorate, awarded in 2004	Kenyatta University, Kenya
		Honorary Professor, accorded in 2004	Hubei University, Wuhan, People's Republic of China
	Thomas R. Odhiambo	Doctor of Science, awarded in 2003	Jomo Kenyatta University of Agriculture and Technology, Kenya
		Doctor of Science, awarded in 2002	University of Eastern Africa at Baraton, Eldoret, Kenya
Fellowships	Hans R. Herren	Member, TWAS, The World Academy of Sciences, appointed in 2005	
		Foreign Associate, US National Academy of Sciences (NAS), appointed in 1999	

Awards and honours (1994 – 2005)

Category	Staff member	Details	Awarded by
Fellowships	Sunday Ekesi	Rothamsted International Fellow, awarded in 2003	Rothamsted Research, UK
	Baldwyn Torto	Rothamsted International Fellow, awarded in 2000	Rothamsted Research, UK
Appointments	Hans R. Herren	President of the Board (2004 – present), Biovision Foundation, Zurich, Switzerland	
		Member (2005 – 2011), Scientific Advisory Council, Swiss Institute of Technology, Lausanne	
		Member (2005 – 2010), Science Council, CGIAR	
		Co-chairman (2005 – 2007), International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD)	
		President (1999 – 2007), International Association of Plant Protection Sciences	
		Editor-in-Chief (1994 – 2005) *Insect Science and Its Application* journal, *icipe*	
		Co-Founder, Biovision Foundation for Ecological Development, Switzerland, in 1998	
		Member, Entomological Society of America (appointed in 1998)	
		Member, American Association for the Advancement of Science	
		Founding member, Monsanto Tribunal Foundation	
		Member, International Panel of Experts on Sustainable Food Systems (IPES-Food)	
	Onesmo ole-MoiYoi	Vice Chairman and Chairman (1988 – 2010), Kenyatta University Council, Kenya	
		Member (2004 – 2007), Science Council, CGIAR	

Communication

The recognition of the Centre's Director General, Dr Hans Herren, as the World Food Prize winner in 1995 generated plenty of national, regional and global publicity for *icipe*. Moreover, Dr Herren's vocal standpoint on issues such as malaria, anti-DDT campaign, and sustainable development, kept the Centre in the limelight. *icipe*'s Silver Jubilee and the support by the government of Kenya articulated publicly by no less by the then President, Daniel arap Moi, raised the Centre's profile. Additionally, the launch of the push–pull programme caught media attention.

465

Peer-reviewed journal articles were published between 1995 and October 2005.

Core donors

Danish International Development Agency, Denmark

Government of Finland

Government of France

Government of Kenya

Government of Norway

Japan International Research Center for Agricultural Sciences (JIRCAS)

Japanese Society for the Promotion of Science (JSPS)

Norwegian Agency for Development Cooperation (Norad)

Organization of Petroleum Exporting Countries (OPEC) Fund for International Development

New donors

Arab Organisation for Agricultural Development (AOAD)

Centre for Agriculture and Bioscience International (CABI)

Conservation International, USA

Critical Ecosystem Partnership Fund of Conservation International, USA

David and Lucile Packard Foundation

Department for International Development (DFID), UK

Diversa Corporation, USA

DuPont Corporation, USA

Dutch Programme for Cooperation with International Institutions (Netherlands-SII)

Electronic Publishing Trust and Bioline Publications, UK

Farm Africa

Fresh Produce Exporters Association of Kenya (FPEAK)

Australian Centre for International Agricultural Research (ACIAR)

Austrian Development Cooperation (ADC)

Belgian Administration for Development Cooperation (ABOS)

Bionet International

Biotechnology and Biological Sciences Research Council

Biovision Foundation for Ecological Development, Switzerland

German Development Service

Global Biodiversity Institute

Government of France

Government of Japan

International Centre for Scientific Culture (ICSC) -World Laboratory

International Committee of the Red Cross (ICRC)

International Foundation for Science (IFS)

International Labour Organisation (ILO)

International Union for Conservation of Nature (IUCN)

Johnson Wax, USA

Kirkhouse Trust, UK

MacArthur Foundation, USA

National Institutes of Health (NIH), USA

National Library of Medicine, USA

National Museums of Kenya

National Science Foundation (NSF), USA

Royce Fellowship Program

Smithsonian Institution, USA

Stanley-Johanson Foundation

Texas A&M Research Foundation, USA

Third World Academy of Sciences (TWAS)

Toyota Environmental Education Foundation, Japan

United States Department of Agriculture (USDA)

Watson Scholars Program

World Resources Institute (WRI), USA

Continuing donors

African Development Bank (AfDB)

Arab Fund for Economic and Social Development (AFESD)

Directorate General for International Cooperation, The Netherlands

Directorate of Non-Governmental Organisations (NGO), International Education and Research Programme (DPO), The Netherlands

European Union

Food and Agriculture Organization of the United Nations (FAO)

Ford Foundation, USA

Gatsby Charitable Foundation, UK

German Academic Exchange Service (DAAD)

German Federal Ministry of Economic Cooperation and Development (BMZ)

International Bank for Reconstruction and Development – World Bank

International Fund for Agricultural Development (IFAD)

International Development Research Centre (IDRC), Canada

Natural Resources Institute (NRI), UK

Swedish Agency for Research Cooperation with Developing Countries (SAREC)

Toyota Foundation, Japan

United Nations Children's Fund (UNICEF)

United Nations Development Programme (UNDP)

United Nations Educational, Scientific and Cultural Organization (UNESCO)

United Nations Environment Programme (UNEP)

United Nations High Commissioner for Refugees (UNHCR)

United States Agency for International Development (USAID)

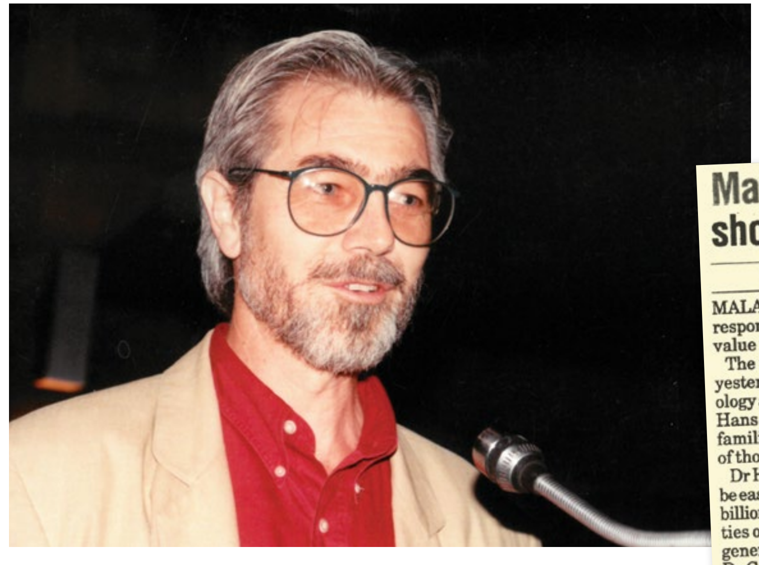
World Health Organization (WHO)

RESEARCH HIGHLIGHTS

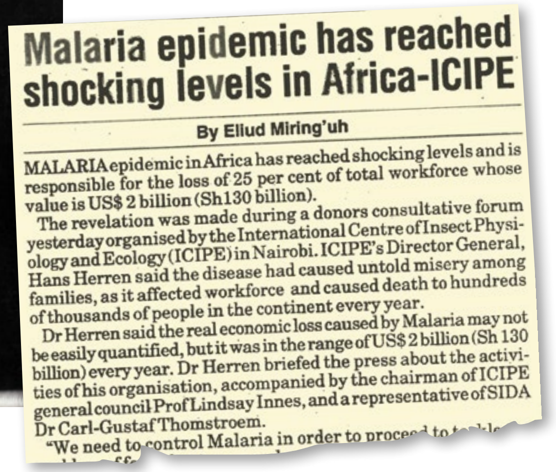
Human Health Theme

Malaria–mosquito research

icipe continued studies to understand the larval ecology of African malaria vectors. Progress was made in knowledge of environmental and climatic factors affecting the development of these mosquitoes in natural aquatic habitats across the continent. Other advances made by *icipe* at this time included identification of mosquito species and subspecies, the parasites they transmit, egg-laying behaviour and bloodmeal sources necessary for the development of eggs.



Hans Herren, who was *icipe* Director General at the time, was a keen advocate of malaria elimination in Africa.



Malaria epidemic has reached shocking levels in Africa-ICIPE

By Ellud Miring'uh

MALARIA epidemic in Africa has reached shocking levels and is responsible for the loss of 25 per cent of total workforce whose value is US$ 2 billion (Sh130 billion).

The revelation was made during a donors consultative forum yesterday organised by the International Centre of Insect Physiology and Ecology (ICIPE) in Nairobi. ICIPE's Director General, Hans Herren said the disease had caused untold misery among families, as it affected workforce and caused death to hundreds of thousands of people in the continent every year.

Dr Herren said the real economic loss caused by Malaria may not be easily quantified, but it was in the range of US$ 2 billion (Sh 130 billion) every year. Dr Herren briefed the press about the activities of his organisation, accompanied by the chairman of ICIPE general council Prof Lindsay Innes, and a representative of SIDA Dr Carl-Gustaf Thomstroem.

"We need to control Malaria in order to proce[illegible]

The Centre also intensified research to identify semiochemicals in *Anopheles gambiae* mosquito species that could be exploited to develop novel tools to interrupt contact between these mosquitoes and people. This research led to an exciting milestone: *icipe* researchers made the first report, outside laboratory trials, that human foot odour attracts *A. gambiae*. While this attractiveness had been reported before, confirmation studies under field conditions had largely remained unsuccessful. The *icipe* findings were widely hailed and formed one more step towards the ever-elusive goal of effective trapping of mosquitoes.

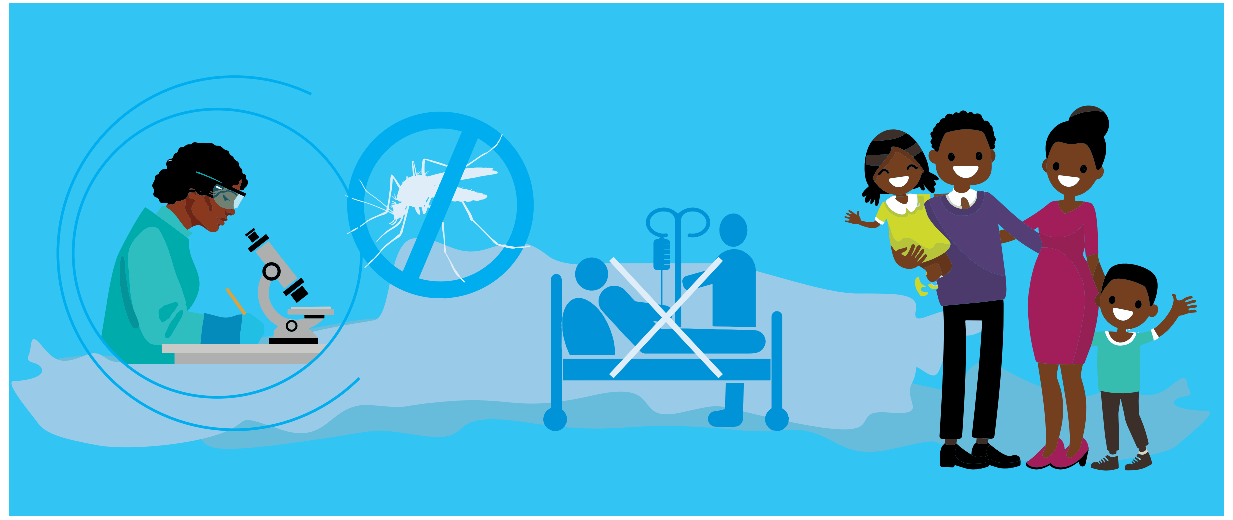
During this period, *icipe* developed a commendable range of affordable mosquito control tools, including botanicals, mosquitocides, larvicides, ovicides and repellents. In fact, at the core of *icipe*'s activities was the concerted goal to push for the replacement of harmful pesticides like DDT with more affordable and benign control agents, such as the soil-dwelling bacterium, *Bacillus thuringiensis (Bt)*, and products derived from neem (*Azadirachta indica)*, a tree known for its pesticidal and insecticidal properties. The Centre also investigated the potential of insect growth regulators and other biological control agents in mosquito control.

icipe developed a proof-of-concept, with encouraging results, on improved development of a malaria drug from sweet wormwood (*Artemisia annua*). This research was based on the recommendation, in 2004, by the World Health Organisation (WHO), for the adoption of Coartem, an artemisinin-based combination therapy (ACT), as the first-line treatment for malaria in Africa. *icipe* was concerned that the use of purified artemisinin could lead to resistance. Moreover, the Centre hoped that commercial cultivation of *A. annua*, and the establishment of extraction companies in East Africa, would open up enterprise opportunities, and make the drug more easily accessible and affordable in the continent.

Integrated vector management

icipe's basic science outcomes up to this period formed the basis for the Centre to embark in earnest on an integrated vector management (IVM) approach. Defined as a rational decision-making process for the optimal use of resources for vector control, this approach seeks to improve the efficacy, cost-effectiveness, ecological soundness and sustainability of disease-vector control. The ultimate goal of IVM is to overcome challenges of conventional, single-intervention approaches to vector control, and to enable multi-sectoral approaches to human health. *icipe*'s aim was to develop IVM approaches specific to different ecological settings in Africa. The Centre employed its own tools and strategies in combination with conventional preventive methods, such as impregnated bednets, which had proven unsuccessful on their own.

In undertaking these activities, *icipe* exposed a growing, and previously largely unexamined trend. Investigations by the Centre revealed a connection between socio-economic activities, and rising dramatic changes in land use in Africa, and increased, as well geographical diversification of malaria incidences. In other words, man-made activities were progressively becoming a chief contributor of malaria. In accordance, the Centre initiated IVM activities in a number of selected sites, which were completed in the subsequent phases.



IVM in Eritrea

In Eritrea, malaria is a significant public health problem. During this period, estimates showed that two-thirds of the country's population was at risk of infection, and cases diagnosed as malaria accounted for 32% of outpatient visits and 24% of hospital admissions in government health facilities. All levels of malaria endemicity existed in the country, with occasional severe epidemics; for example, one in 1998 that resulted in approximately 150,000 cases across the country.

Between 1999 – 2001, *icipe* provided technical assistance to the Eritrean National Malaria Control Programme. The Plan articulated several specific objectives, priorities, cross-cutting themes, interventions and strategies. It also described an integrated approach combining the use of available interventions (case management, chemoprophylaxis, bednets and vector control) with efforts to improve surveillance, programme management, operational research and community awareness and mobilisation.

Tourism and malaria

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 beach paradise. At the time, the town was witnessing an upsurge in mosquito-borne diseases with outbreaks of malaria, filariasis and Rift Valley fever becoming gradually prevalent.

In 2001, *icipe* in collaboration with the Kenya Medical Research Institute (KEMRI), started a programme to alleviate the mosquito problem in Malindi. The aim was to apply novel tools and methods, in consideration of the town's wider socio-economic factors.

Surveys showed that more than 90% of the mosquito larval habitats in Malindi were man-made. Three main culprits were identified, the foremost being tourism. During tourism off-peak seasons, a period coinciding with the rainy months (April – June), many of the town's tourist accommodations are deserted. Rainwater accumulates in the disused swimming pools, creating ideal breeding sites for mosquitoes. In addition, rapid population expansion in Malindi had brought on unplanned settlements, and insufficient access to basic amenities, such as running water, proper drainage and sanitation facilities.

The *icipe*–KEMRI IVM initiative led to the formation of the Punguza Mbu Malindi (PUMMA, Kiswahili for 'eliminate mosquitoes in Malindi'), a highly effective umbrella body for community participation, including spearheading public awareness campaigns.

Inadequate infrastructural services, such as garbage collection and proper road maintenance (with potholes collecting rain water), were also cited as causes of the increase in mosquito breeding sites in Malindi. These man-made factors were being enhanced by Malindi's warm temperatures, which range between 22°C and 30°C; average relative humidity of 65% and the town's clay soils, which are susceptible to flooding, to make a thriving environment for mosquitoes.

icipe and KEMRI researchers recognised that the eradication of mosquitoes and 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, to individual households. The researchers considered it critical to the project's success and the empowerment of communities in the selection and design of ecological, economical, socially acceptable and feasible control systems. One of the accomplishments during this phase was the development of a 'learning by doing' approach, to enable community members develop, plan and implement an evidence-based IVM strategy.

Brickmaking and malaria

From the 1990s, the incidence of malaria and the frequency of epidemics in the western Kenya highlands had increased, with at least four severe outbreaks during the decade. Various possible causes of this unfortunate trend had been proposed, including: climate change favouring vector and parasite survival; reduced efficiency of medication; intrinsic vector population dynamics responsible for mosquito fluctuations; as well as lack of community awareness, preparedness, communication and personal protection. *icipe* launched intense surveys to obtain a clearer understanding.

One of the sites selected was Nyabondo, a scenic plateau near Lake Victoria. Lying 1560 metres above sea level, this plateau was formerly a wetland that, due to a well-functioning drainage system, had historically been malaria-free.

The *icipe* IVM activities in Nyabondo included creating awareness among community members on the linkage between brickmaking and malaria in the region.

The *icipe* research in Nyabondo, which started in 2002, implicated brickmaking as the major cause for the malaria incidences. 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 people. Brickmakers bore into the earth to dig out mud for making bricks. Once the activity is complete, these pits are abandoned. Previously, these hollows had not been considered to be anything more than eyesores.

icipe research revealed these abandoned pits, which quickly fill up with water, as the major mosquito breeding sites in the area. With thousands of abandoned brickmaking pits littering the Nyabondo plateau, malaria was spreading quickly through adjacent settlements. Therefore, *icipe* and partners launched an IVM strategy to tackle these habitats.

Rice, irrigation and malaria

Rice fields generally constitute an important source of vector mosquitoes, resulting in a corresponding increase in the prevalence of malaria and other vector- and water-borne diseases. In accordance, right from its founding, the Centre commenced studies to combat mosquito-borne diseases in the Mwea Irrigation Scheme, the largest such entity in Kenya, located 100 kilometres northeast of Nairobi city.

The cultivation of soya beans as a way of tackling mosquito challenges in Mwea Irrigation Scheme had numerous socio-economic benefits, including improved nutrition and additional incomes.

The Centre's activities were conducted over a long period, first from 1984 –1997; and then from 1999 – 2012. These initiatives were highly interdisciplinary, and they were implemented in close partnership with key stakeholders. The goal was to comprehensively address a range of interlinked problems. At the heart of these efforts was the highly successful socio-mobilisation on control of mosquitoes and malaria, including use of insecticide-treated bednets and environmental management.

Improved water management was introduced by changing flooding schedules in the rice paddies, and rotation of rice cropping with dryland crops like soya beans. In addition, to reducing mosquito breeding sites, cultivation of soya beans boosted incomes and household nutrition, and improved soil texture and fertility. These efforts led to reductions in mosquito breeding sites, and dramatic reduction in malaria parasite reservoirs. Indeed, in many ways, the success of *icipe* and partners in tackling malaria in the region remains an untold story.

Translating tsetse knowledge breakthroughs into technologies

icipe's main focus was the advancement, development and dissemination of technologies based on the major breakthroughs made during the previous period. Significantly, the Centre laid emphasis on continuous involvement of beneficiary communities, while also striving to understand their farming systems and aspirations, for effective tsetse and trypanosomosis control.

Trials of the NGU traps, enhanced with the attractants identified through *icipe* research in bovines, continued in Kenya. Through collaborative efforts with the Kenya Wildlife Service (KWS), the technology was employed in the Mwea Game Reserve, in the eastern part of the country. Heavy tsetse infestation emanating from the Reserve had created conflict, pitting community members on the one side, and wildlife conservation efforts on the other.

The NGU trap technology was also expanded to Ethiopia, initially to Wolayita Zone, Southern Nations, Nationalities, and Peoples' Region. Here, thousands of NGU traps were deployed leading to significant reduction in tsetse and trypanosomosis. As a result, *icipe* was requested to scale-out tsetse management activities to Tolay, Ghibe Valley, southwest Ethiopia, where several groups of people had been relocated from drought-threatened highlands of Ethiopia. Unfortunately, the bright future promised by this resettlement was threatened by factors, including tsetse flies and mosquitoes. *icipe*'s efforts led to successful management of tsetse flies.

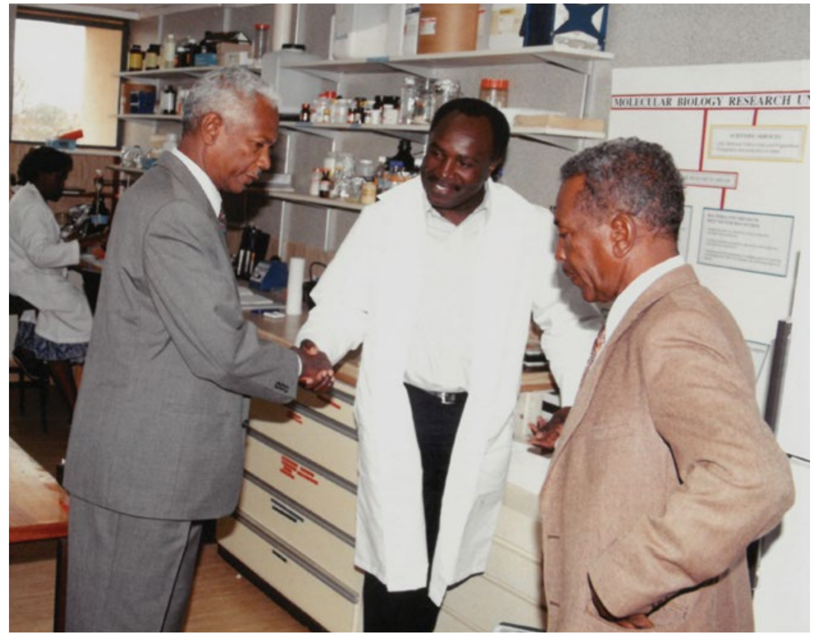
A cow wearing one of the earliest prototype *icipe* tsetse repellent collars.

A major accomplishment by *icipe* during this period was in regard to translating the repellent blends that the Centre had previously discovered from waterbuck, into a solution for tsetse management. The researchers envisioned a technology that would be worn around the neck of cattle, steadily emitting the chemicals, thus driving away the flies from the animals. In effect, the Centre aimed to develop a tsetse repellent collar for livestock. Prototype dispensers of the repellent were developed and tested with communities around Shimba Hills, coastal Kenya. *icipe* also started testing a 'push–pull' strategy; using the collars to 'push' away the flies from the animals, and the attractants to 'pull' them to the NGU traps.

Shimba Hils was an ideal site for these trials. Situated about 45 kilometres from Mombasa city, the region is, at first glance, a pristine wonderland of rolling meadows and forests of giant primeval trees. Thrust nearly 450 metres out of the coastal plains, the area is an enchanting other world; remote from the heat below with breezes from the Indian Ocean. But for long, the tsetse menace has violated the peace and quiet of the hills. In fact, Shimba Hills is an apt demonstration of the manner that these flies lead to 'green deserts' which are stretches of fertile landscape.

Knowledge on tsetse and trypanosomes

Previously, *icipe* had made a breakthrough in studies on how enzymes in the tsetse midgut affect the survival of trypanosomes, the parasites that cause human and animal trypanosomosis. This research had identified two enzymes, lectin and trypsin, as factors in the survival of the parasites. During this period, *icipe* developed a molecular tool to identify blood meal residues in the guts of tsetse, and then conducted rigorous studies to address the hypothesis that lectin and trypsin were in fact the same molecule. The findings revealed that the lectin–trypsin complex positively influences development and transformation of the parasites to a form where they can escape the midgut to move to the tsetse's salivary glands as infective forms, ready to transmit the parasites to other vertebrate hosts. These discoveries were groundbreaking as they unravelled the mystery of how tsetse flies, the only definitive biological vectors of trypanosomes, are able to successfully transmit the parasites. Mechanical transmitters of animal African trypanosomosis (such as *Stomoxys calcitrans*) lack the lectin–trypsin complex, thus the parasites do not transform in them.



Ellie Osir (lab coat) headed the *icipe* Molecular Biology and Biotechnology Unit, which in 2003, was awarded the Institute for Genomics Research (TIGR) international award for research on the factors involved in the transmission of trypanosomes by tsetse.

In the Lake Victoria region, monitor lizards are the major source of blood meals for *Glossina fuscipes fuscipes*, the main vector of trypanosome parasites that cause human and animal trypanosomosis. But monitor lizards are poor hosts of the parasites, because of extreme fluctuations in the temperature of these cold-blooded reptiles. They warm up when the sun comes out by basking on the rocky shores; however, this is also the peak feeding time for tsetse flies, which explains the high likelihood of finding monitor lizard blood in their guts. Naturally, the reptile was the subject of early successful exploratory studies at *icipe,* aimed at discovering baits for *G. fuscipes fuscipes* tsetse species, which has historically defied trapping strategies.

Such investigations continued during this period. Using the chemicals in monitor lizards identified and characterised in earlier studies for their potential to attract tsetse, odour baits were developed. Preliminary field evaluations on Rusinga Island, Lake Victoria, Kenya, and in Ethiopia, demonstrated some potential of the baits in increasing the catches of *G. fuscipes fuscipes*.

The Centre also explored the possibility of using the lethal insect technique (LIT) on tsetse. At the time, LIT was a novel strategy, aimed at turning the table on pests and vectors. The technique involves the employment of biological control in a manner whereby insects destroy each other by passing on a microbiological disease, with which they have been deliberately contaminated. *icipe*'s goal was to mass rear and infect tsetse flies with pathogens like *M. anisopliae* and *B. bassiana* fungi, so that the insects could then spread these pathogens to other tsetse flies.

Tick control

icipe studies showed oil-based formulations of the fungi *B. bassiana* and *M. anisopliae*, combined with natural tick attractants like pheromones and carbon dioxide, to be effective in controlling immature stages of the ticks *A. variegatum* (vector of heartwater) and *R. appendiculatus* (vector of East Coast fever). Neem oil applied directly to the skin of animals was also found to repel *A. variegatum*.

Esther Mwangi (Kenya, right), was one of the first ARPPIS scholars to conduct doctoral research on the ecology of the non-parasitic phase of ticks, the most critical phase in the life cycle of these pests. She also investigated predators, parasitoids, pathogens and climatic factors in the regulation of ticks.

Maize and other cereals

When translated, the word maize means "that which sustains life". In Africa, this denotation of maize is hardly an exaggeration. Indeed, it is not easy 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 households, where people eat it boiled, roasted or pounded into a thick paste as *fufu* or *ugali* or as a porridge. Most of the continent's population rely on maize for half of their basic calories. Indeed, many smallholder farmers allocate a significant portion of their land to maize farming. As discussed in the previous chapter, increasing the yield of maize (alongside other cereals) was a substantial focus of *icipe* since its founding.

During this period, the Centre made significant progress towards this goal, specifically by addressing one of the key constraints to maize production in Africa – a complex of indigenous African and invasive borer species that attack cereals, which together causes yield losses of 20–40%.

The damage caused by stemborers to maize in the field renders the grain susceptible to the growth of moulds that produce toxic by-products such as aflatoxins, implicated in liver cancer. Aflatoxins also cause immune suppression making people susceptible to infectious diseases.

Introducing push–pull

In 1995, *icipe* made a significant breakthrough towards improving cereal production in Africa through the launch of the push–pull technology. The Centre conceptualised the approach around two complementary sets of knowledge. First is the understanding that it is possible to harness nature to control crop pests; for example, by managing the natural habitat surrounding farmlands. The wild grasses and other plants often ploughed under in modern monocropping practice harbour a wide spectrum of natural enemies of pests. Second is the wisdom in the age-old African tradition of intercropping, which helps restore balance in nature. It is important to note that the push–pull technology was grounded in knowledge and evidence obtained in the efforts to manage stemborers, as reported in the previous chapter.

A push–pull plot using Napier grass as the pull plant and silverleaf desmodium (*Desmodium uncinatum*) as the push plant.

In partnership with Rothamsted Research, UK, and Kenya Agricultural Research Institute (KARI), *icipe* sought to introduce nature's in-built checks and balances into cereal fields by exploiting behaviour-affecting chemicals produced by both the plants and insects.

icipe's specific target pest was stemborers. While these insects naturally feed on wild grasses, over time, they have turned to cereals like maize and sorghum, based on their predominant cultivation across Africa. Lack of defence mechanisms in such crops has enabled stemborer populations to flourish and become a problem of economic importance.

The goal was to develop a 'stimulo-deterrent' approach using rigorously selected companion crops planted around and among maize plants to attract crop pests to a highly susceptible trap plant (the 'pull') and to drive them away from the main crop using a repellent plant as an intercrop (the 'push').

The researchers were sensitive to the fact that the push–pull crops would have to make sense to smallholder farmers who often own minute land parcels. Through participatory research involving farmers, Napier grass, an important cattle fodder, was selected as the 'pull' plant. Legumes were considered the best option for the 'push' due to their nutritional benefits and soil fertility improvement qualities. Ultimately silverleaf desmodium (*Desmodium uncinatum*) was selected.

Push–pull farmer teachers in western Kenya all set for action.

icipe used a popular radio programme *Tembea na Majira* (Walk with the Seasons) to promote the push–pull technology in Kenya.

In the first instance, *icipe* tested push–pull in more than 600 farmers' fields in western Kenya, with a quick demonstration of the effectiveness of the technology in controlling stemborers.

And there was a surprising outcome: The researchers noted that maize plots with a *Desmodium* intercrop not only had little stemborer damage but were also free of the devastating effects of the parasitic weed *Striga*. Eliminating this weed had an even more significant impact on increasing maize yields than controlling the stemborers.

After the first season, most trial farmers were keen to expand their push–pull plots, and *icipe* embarked on a dissemination strategy involving farmers as teachers where each trained farmer taught five new farmers a year. Field days and informal contacts were also used to create additional interest in the technology.

The uniqueness of the push–pull technology became rapidly evident, especially in regard to its development process: from basic science to technology transfer; to farmer uptake and spontaneous technology transfer between farmers.

Based on the success in Kenya, *icipe* started to expand the push–pull technology into Uganda and Tanzania. Moreover, through a partnership with Sasakawa Global 2000, efforts were commenced to advance the approach into Ethiopia and Mozambique.

Women farmers uprooting *Striga* weed from a field. The push–pull technology has pre-empted the need for this grim and futile task.

By the end of 2005, a total of 10,000 farmers were using the push–pull technology.

The farmers had at least doubled their maize yields and increased milk production by 50%.

Fodder produced by push–pull farmers contributed to the production of one million litres of milk annually.

A total of 500 small-scale farmers were producing *Desmodium* seed for income generation, linked to a private seed company.

Extra income from push–pull had enabled more than 300 farmers to send at least one child to secondary school.

At least three tonnes of *Desmodium* seed was being produced annually by 1000 small-scale farmers.

Stemborer research

In 2001, a team of researchers based at *icipe* from the French Institut de Recherche pour le Developpement (IRD), initiated a project focusing on assessing the genetic variation in the stemborer species *Busseola fusca, Sesamia calamistis, Sesamia nonagrioides* and related genera. The studies also concentrated on *Cotesia sesamiae*, the parasitoid of *B. fusca*.

The goal was to develop evolutionary scenarios explaining the present-day interaction between host plants, herbivores and parasitoids. In turn, this would enable prediction of how global changes (global warming) or human activities (use of genetically modified organisms, as well as deforestation and displacements of wild habitats) may modify these interactions.

The researchers also aimed to gain a better understanding of the population dynamics and necessary improvement of existing strategies to manage stemborers on crops. Further, the team generated knowledge on the carry-over effects of wild habitats in biological control by introduced and indigenous natural enemies.

Biological control of stemborers

The spotted stemborer, *Chilo partellus*, an exotic invasive stemborer accidentally introduced to Africa from Asia almost 100 years ago is one of the most important pests of maize. Since its arrival, the pest has spread over the lowlands and mid-altitudes of eastern and southern Africa.

From the onset, *icipe* researchers considered the spotted stemborer a suitable candidate for classical biological control. This approach involves going back to the area of origin of a pest to search for effective and specific natural enemies, which are then introduced in the region newly invaded by the pest. As reported in the previous chapter, in the early 1990s, *icipe* imported from Asia, a wasp known as *Cotesia flavipes*, which is parasitic to the spotted stemborer.

Chilo partellus larva.

During this period, *icipe* continued to monitor the performance of the wasp along the Kenyan coast where it had been introduced. Studies showed that the wasp had reduced stemborer populations dramatically. The reuniting of a pest and its natural enemy often helps to keep pest populations perpetually in control, making it a sustainable and environmentally-friendly approach for pest control.

An economic impact study in Kenya calculated a benefit: cost ratio of 19:1, amounting to US$ 183 million following the first release of the natural enemy. Other benefits included the increase in caloric intake by households as a result of better maize production, reduction in food poisoning resulting from reduced aflatoxin contaminations of cobs damaged by stemborers and conservation of biodiversity.

After this success in Kenya, between 1998 and 2005, *icipe* and partners released the wasp in Ethiopia, Malawi, Mozambique, Somalia, Tanzania, Uganda, Zambia, Tanzania (mainland and Zanzibar), and Zimbabwe. In all these countries, populations of the spotted stemborer declined.

A second parasitoid, *Xanthopimpla stemmator*, was imported into Kenya and was observed to successfully parasitise four of the major stemborer species found in eastern and southern Africa.

Fruit fly IPM

In many parts of Africa, numerous households depend on fruit cultivation as a source of nutrition and income. Such produce is sold in local markets, and also has export potential. However, the continent's fruit production is way below potential. This is mainly due to fruit flies, which not only increase production costs, but also seriously reduce the quality as well as quantity of marketable mangoes. During this period, *icipe* incorporated fruit flies as a subject of particular concern. For example, the pests were causing yield losses amounting to 70%, resulting in low profits and loss of competitiveness of produce in local markets. Moreover, in 2001, the European Union introduced maximum residue levels (MRLs) guidelines, and strict quarantine and stringent regulations, compounding the situation for African farmers.

In response to requests from fruit growers, *icipe* commenced efforts to develop an IPM for fruit flies. The Centre assembled its own team and established an extensive network of stakeholders from African countries, as well as research and technical institutions from USA, Central America and Europe.

Using mango as a model crop, the Centre conducted extensive studies in several African countries. Progress was made in determining socioeconomic aspects of fruit production; profiles, distribution and seasonality of African fruit fly species; and investigations of the most destructive species and their natural enemies. Other achievements included identification of fruit fly lures from locally available materials, which were tested and found to be more effective and affordable than imported options.

Sunday Ekesi, a former ARPPIS scholar, undertook postdoctoral training at *icipe* on fruit fly IPM. In later years, he capably led the Programme and is today the Centre's Director of Research and Partnerships.

Until this time, the main constraint to the production of mangoes had been a plethora of indigenous African fruit flies, the most notorious being the *Ceratitis cosyra* species. Indeed, by 2001, the researchers had succeeded in developing a control package for *C. cosyra*, which included baiting and trapping techniques, use of insect killing fungus, and sanitation of orchards to rid them of fallen fruits. This package was being applied with commendable success in selected sites in Kenya.

In October 2003, during their routine seasonal population studies in Kenya, *icipe* scientists recorded for the first time in Africa, an invasive *Bactrocera* fruit fly. This species is well documented as a notorious pest, and is ranked high on quarantine lists. This news caused great concern to stakeholders in the fruit industry, as the highly invasive and polyphagous species was anticipated to cause even more damage than the native African fruit flies. Within a span of one year, the new species had spread to 10 African countries. Therefore, *icipe* researchers incorporated the pest into ongoing fruit fly management activities, expanding their studies beyond Kenya, to Uganda, Tanzania and Benin. Among the first steps was the assessment of the abundance, distribution, pest status, seasonality and host plants, and the identification of areas where additional information on the pest was required. It is important to note that at the time, there was lack of clarity on the identity of the *Bactrocera* species, which was being described as a "new pest" to science.

Wasp versus moth: Managing DBM

Crucifers are among the most important vegetables for home consumption and local markets in eastern and southern Africa. One of the major devastating pests of these crops is the diamondback moth (DBM, *Plutella xylostella*), a small greyish-brown moth that gets its name from three pale triangular markings that form a diamond pattern on its back, seen when its wings are closed, at rest. Despite its small size — eight 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. Control of the pest, which is so cosmopolitan that it tolerates tropical, subtropical and temperate climates, is difficult, due to its notorious resistance to pesticides.

A thriving cabbage plot in Coast Province, Kenya, in one of the first trial sites of the *icipe* DBM control project. Participating farmers reported improved cabbage yield, in terms of quality and quantity, and lower production costs.

Previous research by *icipe* (conducted between 1980 and 1995), showed emphasis on DBM control in Africa to be pesticide based. The study also revealed that sustainable control of DBM could only be effected through regional cooperation and networking, to make optimal use of available resources.

Guided by this knowledge, in 2000, *icipe* embarked on a research project towards 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 enough control of DBM. Therefore, *icipe* opted to import a parasitic wasp known as *Diadegma semiclausum*, which was already being used in a number of countries in Southeast Asia, and in China and New Zealand.

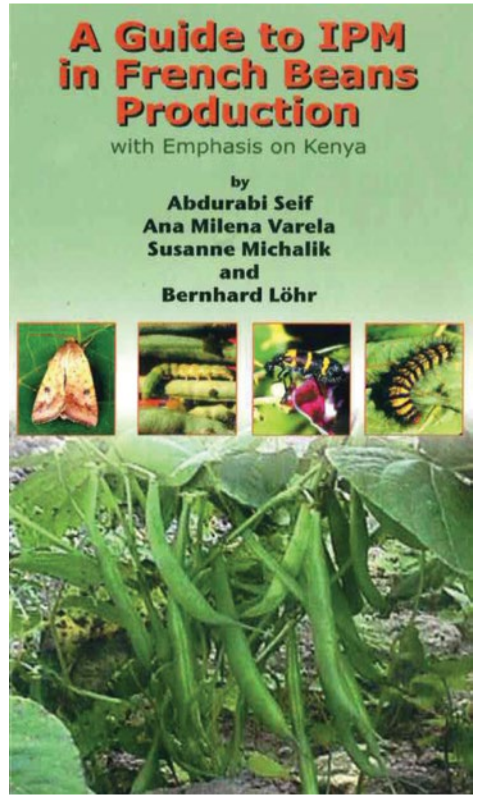
The pest was released in eastern Africa, in the highlands, where most of the region's cabbage and other brassicas are grown. The performance of the wasp, and a reduction in DBM populations, was rapidly evident. For example, in Tanzania, within eight months, the natural enemy spread widely with a parasitism rate as high as 80%. By the end of the first year, the wasp was providing phenomenal control of DBM. This spurred *icipe* and partners to scale-up the project to all brassica-growing areas of Kenya, Tanzania and Uganda. The *icipe* DBM biocontrol was also introduced in Cameroon and Ethiopia.

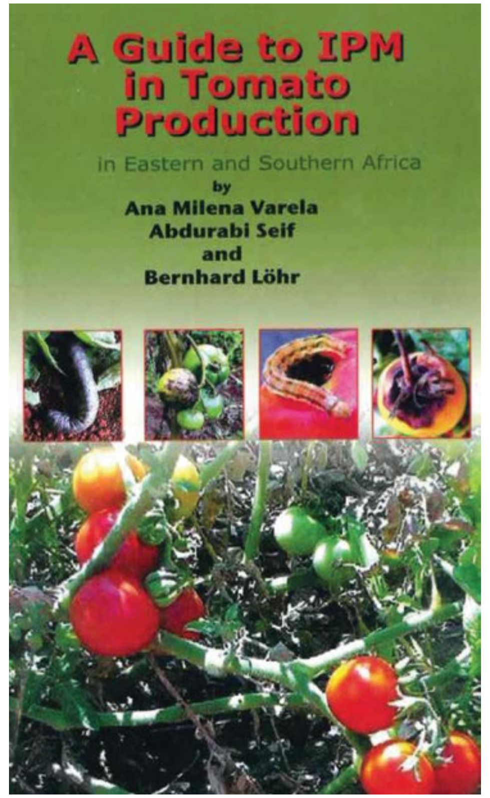
Kale, a cousin of cabbage, is an important crop, especially in East Africa. In fact, it is for a good reason that it is known as 'sukuma wiki', the vegetable that helps people get through the week. Kale is one of the most affordable and highly nutritious foods. The *icipe* DBM control activities greatly impacted on the production of this vegetable.

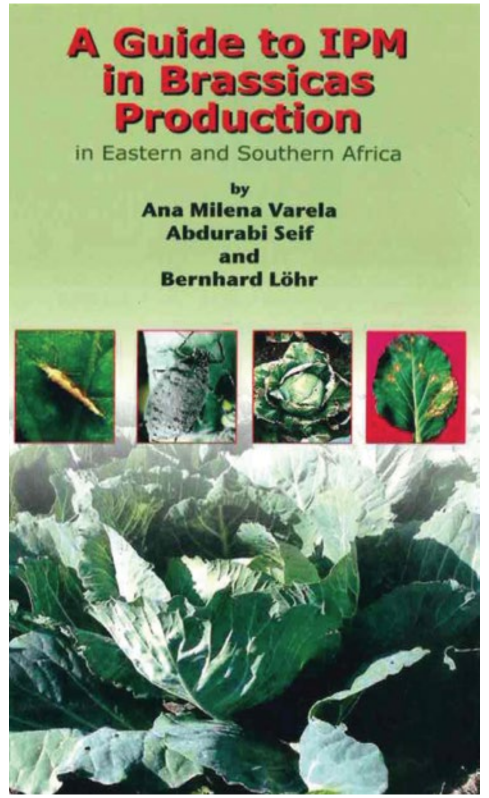
In tandem, *icipe* also worked with farmers in the adaptation of other safe pest control methods, for example, scouting, a process that involves counting the number of pests on crops, to determine the need for pesticide application. A system was introduced for the DBM population threshold that warranted spraying. In addition, IPM-compatible insecticides were introduced for the control of other brassica insect pests.

Based on the need for another parasitoid for the lowland and semi-arid regions, where kale is an important subsistence crop, *icipe* and collaborators identified a wasp known as *Cotesia plutellae*. The parasitoid was first released in central Uganda in November 2003 and in eastern Kenya in 2005. Post-release surveys conducted in 2005 indicated that the parasitoid had established and was co-existing with the indigenous DBM parasitoids.

An economic impact of the *icipe* DBM biological control strategy commenced in 2005. Surveys were carried out in Kenya and Tanzania. Farmers were found to use significantly less pesticides, in comparison to those where the parasitoid was absent.







In view of the EU MRLs guidance on fresh agricultural produce, *icipe* recognised that Africa's export industry would have difficulties balancing compliance on safe plant protection measures and profitable yield. Therefore, the Centre started the development of IPM packages for various vegetables consisting of the use of parasitic wasps, Bt, as well as fungi and neem.

Among those developed was an IPM system for French beans, an important export crop, targeting its main pests red spider mites, nematodes, fruitworms, whiteflies, leafminers, thrips, and diseases (early and late blights, bacterial wilt, Fusarium wilt and bacterial canker). The system had two major principles. First, to delay the application of foliar pesticides for as long as possible, to give natural control agents a chance to keep pest populations at low levels. Second, to avoid the application of any pesticide after the onset of pod formation.

icipe also developed a tomato IPM to manage spider mites, the most important pest of the crop and others belonging to the Solanaceae family (potato, eggplant, tobacco and wild plants like black nightshade, bitter apple and wild gooseberry). In addition, the Centre also developed strategies for the management of leafminers, aphids and whiteflies, which attack a range of vegetables.

Locust control

For thousands of years, the desert locust, *Schistocerca gregaria*, one of about a dozen species of grasshoppers, 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 (in their early, wingless stages), and adult swarms. The latter can consist of anywhere between 40 to 80 million locusts within a square kilometre. These massive swarms fly across thousands of kilometres, destroying crops, leaving hunger and poverty in their wake. For a long time, many efforts to control locusts have been reactive, aimed at stopping outbreaks after they have started. Such efforts range from helpless farmers waging 'hand-to-hand combat' against the insects using any manner of tools, or attempting to bury them alive in ditches. Initiatives led by governments and international organisations attempt to control outbreaks by intoxicating the swarms with insecticides. This approach is not only extremely expensive, but also hazardous to people, other non-target animals and the environment in general.

Locusts consume leaves and the tender tissues of plants. Large swarms of locusts can completely strip the foliage and stems of plants. Indeed, as shown in this picture taken in Kenya during the locust invasion in 2020, locusts are tenacious enough to even colonise an acacia, undeterred by the tree's sharp thorns.

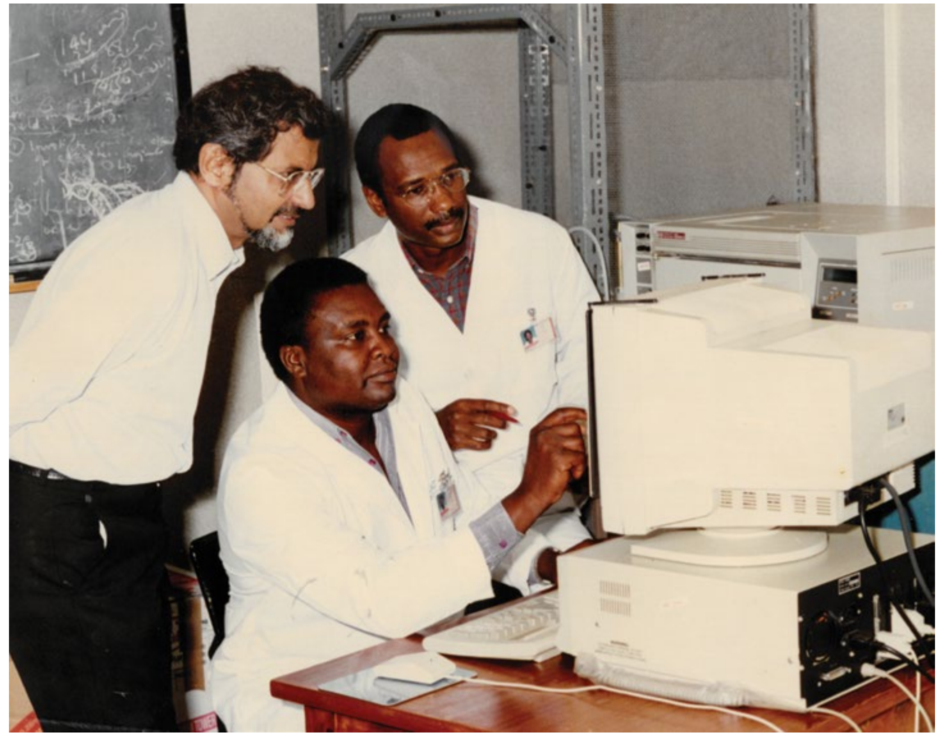
Understanding the language of locusts

icipe's research on locusts was initiated in the 1990s during the tenure of the Centre's Founding Director, Prof. Thomas Odhiambo, himself an expert in this field. For 18 years, research focused on ways of pre-empting locust swarms. The team studied the chemical language of these insects, and identified different sets of signals that regulate their behaviour and lifestyle in young and adult stages.

A breakthrough was the finding that young and adult locusts use different chemical communication dialects to stay together in their respective gregarious phases. The researchers wondered what would happen if one locust stage were to be exposed to the chemical vocabulary of the other. This question led to the discovery of a novel way of disrupting the social structure of locusts, reverting the insects to harmless solitarious individuals. For example, a specific adult vocabulary, phenylacetonitrile (PAN), governs the swarming behaviour of the adults, and blocks communication between young (nymphal) locusts, resulting in a total loss of communication between the individuals.

PAN success

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, of young locusts. The insects became highly stressed, disoriented and started to cannibalise each other, with 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.



The three *icipe* locust whisperers: Ahmed Hassanali (Zanzibar, Tanzania), Peter Njagi (Kenya) and Baldwyn Torto (Ghana); the core team that made the groundbreaking discovery of PAN, a chemical signal that governs the swarming behaviour of adult locusts.

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 biocontrol 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.

Commercial insects

In 1995, *icipe* introduced the Commercial Insects Programme to develop sustainable apiculture and sericulture value chains as livelihood alternatives for rural communities in Africa, especially those living in fragile or natural resource-rich ecosystems. *icipe* was aware of previous attempts by international and national players to establish such income-generating options. These efforts had been constrained by lack of research and training. Therefore, *icipe* aimed to build on the Centre's success in basic sciences, with four main activities: queen bee rearing and breeding; honey bee disease control; training of beekeepers and technology diffusion; and quality control and marketing of honey bee products.

One of the first silk processing plants, set up by *icipe* in Bushenyi District, Uganda.

The *icipe* package included: value added bee and silk products through quality control in processing and packaging to meet national and international standards; empowerment of communities through ownership and operation of marketplaces, to eliminate middlemen, and, overall, strengthen value chains for more effective marketing and income generation.

A network known as the Sericulture, Apiculture Research and Development Network in Africa (SARDNet Africa) was established to validate *icipe* technologies in beekeeping, wild and domesticated silkworm rearing, and conservation and utilisation of these commercial insects and their habitats.

icipe helped to initiate community-driven income-generating integrated use of commercial insects in vulnerable regions of Kenya, Uganda, Egypt, Sudan and Yemen.

Biodiversity and conservation

icipe commenced biodiversity and conservation efforts focused on compiling inventories, while also monitoring arthropod and other biodiversity changes in selected ecosystems. The aim was also to assess and build awareness about the role of arthropods, while also promoting conservation.

Panoramic view of Kakamega forest

One of the key projects initiated by the Centre and partners was an integrated project on the conservation of arthropods and other related biodiversity in the unique Kakamega Forest in western Kenya. This tropical rainforest is the easternmost outlier of the Congo Basin forests, and the vastness and uniqueness of its species has led to its recognition as a UNESCO heritage site. However, the forest is threatened by unsustainable consumption of its natural resources, due to economic and population pressure.

icipe activities led to the production of an inventory and annotated checklists for selected arthropods in the forest. Community members were also trained as parataxonomists, to enable their contribution in recognising, sampling and monitoring activities.

Bioprospecting

icipe commenced bioprospecting research, aimed to discover, develop and commercialise natural products for pest and vector management that would be appropriate for use by rural communities. Central to this vision was the provision of new avenues for income generation by communities living adjacent to biodiversity-rich areas.

Mrs Marita Lumiti, a member of Muliru Farmers' Conservation Group (MFCG) pictured with her family harvesting *Ocimum kilimandscharicum*. She said: "My life has changed significantly. I now allocate half of my land to *Ocimum*. I used to harvest less than one bag of maize, which was not even enough to feed my family. Using the proceedings from the cultivation of *Ocimum*, I have been able to educate our children. As a woman, it is good to have some financial independence."

One of the major successes was a partnership with Muliru Farmers Conservation Group, neighbouring Kakamega Forest, who were supported to domesticate various indigenous medicinal plants in their farms. Traditionally, the community harvested such plants from the forest.

Through the efforts led by *icipe* and other partners, a thriving community-based enterprise emerged. Among products that were developed and commercialised is a herbal-based, low-cost mosquito repellent known as Mozigone.

A second range of products derived from *Ocimum kilimandscharicum*, a plant of the mint family, was formulated, packaged and commercialised under the brand name Naturub. This series of balms and ointments is effective for relief from congestion, muscular aches, pains and insect bites.

Capacity Building and Institutional Development Programme

icipe continued to emphasise capacity building as an underlying factor of all the Centre's activities. Indeed, the Management proceeded on the premise that strengthening individual and institutional capacity in each African country was the surest way to realise the full impact of *icipe*'s research and development initiatives. Accordingly, efforts were geared at bolstering the capabilities of researchers, universities, non-governmental organisations and other implementing agencies, and communities. The Capacity Building programme consisted of three major areas of activity. First, was equipping African researchers for leadership roles in insect science, towards interactive technology generation and adaptation. Second, the Centre aimed to augment national capacities for technology diffusion, adoption and utilisation. Third, was the goal of facilitating dissemination and exchange of information.

Postgraduate and postdoctoral training

During this period, even against a stringent review process, a total of 25 African universities were collaborating in the ARPPIS PhD programme, and four universities were involved in MSc-level training. *icipe* provided a thesis project, research facilities and supervision.

The students were registered at any of the participating universities that provided additional research supervision, ensured that the research met international academic standards, examined the students and awarded them with degrees. Each PhD class consisted of an average of seven students. At any one time, between 20 and 40 scholars were in various stages of their research at *icipe*.

Indeed, the ARPPIS network stood as an example of South–South cooperation among research organisations and universities throughout the continent. Several ARPPIS symposia were held, leading to the formation of the ARPPIS Scholars Association registered in Kenya.

icipe conducted technical level training on sustainable and environmentally sound pest and vector management tools and strategies, and insect- and forest margin-based income generation options, among others. In particular, such training initiatives aimed to guarantee that the Centre's technologies benefitted women and children while ensuring a better future for all.

Technical training

Numerous training sessions to support uptake of technologies were conducted, for example on the push–pull technology; fruit fly identification, monitoring and control; vegetable IPM; locust control strategies; beekeeping and sericulture; and malaria IVM.

It was during this period that *icipe* institutionalised the concept of Training of Trainers (ToT) at *icipe*. International group training courses continued; for example, on tsetse management.

Cumulatively, since the beginning of the Centre, to the end of this period over 140 senior African scientists at the PhD level, and another 7000 persons, including 1000 extension agents had received training at *icipe*.

Amaranth webber, *Spoladea recurvalis*

3

Building on the vision

INTRODUCTION

On 30 September 2013, I ended my tenure at *icipe* after eight years as the Centre's Director General. During that time, we continued to build on the vision set by my predecessors and on *icipe*'s uniqueness, which is based on three factors.

First, *icipe* is an independent African-based, African-owned organisation with an African identity. Second, *icipe*'s research cuts across agriculture and health, and also incorporates the environment. The third aspect is *icipe*'s track record that is based on several key assets. The Centre has always had a dual mission of conducting fundamental scientific research while providing practical solutions that make a real change in the lives of people in Africa, primarily the rural and urban poor. Moreover, *icipe* has maintained the idea of partnerships with institutions in Africa and beyond, as one of its key strategies. Closely linked to this, is the incorporation of an interdisciplinary approach to research.

A good illustration of the convergence of these elements is the push–pull technology, which illustrates how collaboration between *icipe*, research, development and private sector partners can open up opportunities for the improvement of income and nutritional security of smallholder farmers.

Another example is the commercialisation of isolates developed through *icipe*'s long-standing research on fungi that attack crop pests, through agreements signed with Real IPM Ltd, a pan-African, Kenya-based producer of biopesticides.

Further, it is *icipe*'s growing international recognition, aptly illustrated in the designation of the Centre as a Food and Agriculture Organization of the United Nations (FAO) Reference Centre for vectors and vector-borne animal diseases in September 2012. These Centres are institutions selected by the Director General of FAO to provide specific, independent technical or scientific advice on issues related to its mandate.

During my tenure, *icipe* continued to enhance the role of a centre of excellence that provides Africa's most exceptional talent with the right opportunities and infrastructure. The *icipe* scientific team consisted of 60 scientists, half of them African nationals, working alongside peers from Asia, Europe and North America. The Centre published more than 100 peer-reviewed scientific articles per year, which demonstrates the Centre's own, and in effect Africa's, contribution to global scientific knowledge.

icipe also contributed to strengthening Africa's scientific infrastructure. For instance, the Centre established the Martin Lüscher Emerging Infectious Diseases (EID) Laboratory at its headquarters in Nairobi. This laboratory provides a specialised platform to undertake studies that will improve risk detection, early warning and response capabilities, to outbreaks of vector-borne infectious diseases in Africa. The facility is one of the few existing laboratories on the continent that have such a resource.

Moreover, *icipe* increased programmatic activities across Africa, extending to 20 countries, thus contributing to strengthening human and infrastructural scientific capacity. The Centre had a country office in Ethiopia, while the rest of the operations were administered under national research institutes in the countries of operation. *icipe* also became involved in supporting institutions in post-conflict countries. For instance, supporting the University of Somalia in Mogadishu to develop their curriculum.

Prof. Christian Borgemeister
Director General (2005–2013)

The Martin Lüscher Emerging Infectious Diseases (EID) Laboratory (bottom photo), inaugurated in November 2011, was at this point *icipe*'s biggest investment in infrastructure since the construction of the Centre's headquarters. The facility, which was funded through *icipe* core resources, with additional support from the Swiss and German governments, complemented the *icipe* R&D complex (shown in the top picture as it was at the time).

MANAGEMENT & LEADERSHIP

During this period, the Management promoted the ideal of *icipe* as an institution "working in Africa for Africa". Alongside, was the determination to enhance *icipe*'s reality as a centre of excellence that provides Africa's most exceptional talent with the right opportunities and infrastructure.

In 2010, *icipe* celebrated its 40th Anniversary, the main event being a Science Day attended by more than 400 visitors from across Africa and the globe. Further, *icipe*, in partnership with the Postal Corporation of Kenya, unveiled a range of insect-themed postage stamps. The African Academy of Sciences (AAS), an institution also established by *icipe* Founding Director, Prof. Thomas Odhiambo, was commemorating its 25th Anniversary. Therefore, *icipe* and AAS, and The World Academy of Sciences (TWAS) Regional Office for Sub-Saharan Africa (ROSSA), convened a joint conference titled: "Climate Change and Food Security: The Road for Africa". Prof. Odhiambo was one of the 11 founding members of TWAS. *icipe* hosted the 19^{th} biennial conference of the African Association of Insect Scientists (AAIS) at the Centre's Duduville Campus, Nairobi, Kenya.

In 2008, the African Regional Postgraduate Programme in Insect Science (ARPPIS) celebrated its Silver Jubilee. This milestone coincided with a strategic review of the Centre's capacity building programme. The ARPPIS alumni and *icipe* Governing Council assembled at the Centre's Duduville Campus. They reflected on the mandate, design and achievements of the Programme and its future in terms of strategic implications, opportunities and challenges.

In November 2011, *icipe* inaugurated the Martin Lüscher Emerging Infectious Diseases (EID) Laboratory at the Centre's headquarters in Kasarani, Nairobi. The GMP-compliant enhanced Biosafety level 2 and 3 facility was developed due to the increasing burden brought on by diseases such as yellow fever, dengue, Rift Valley fever, o'nyong'nyong virus, Crimean–Congo haemorrhagic fever and the chikungunya fever. Moreover, after a Rift Valley fever outbreak in Kenya, in 2006–2007, *icipe* felt challenged to join the East African, and indeed the global community, in seeking solutions for emerging infectious diseases. The Laboratory was named after the late Prof. Martin Lüscher, a long-term friend and supporter of *icipe* and one of the world's most distinguished termite research scientists.

Africa's disproportionate share of the global disease burden, amid a weak and under-resourced infrastructure for scientific research and training, was a long-running concern of the *icipe* Management. As a result, *icipe* joined two initiatives that were responding to the critical need to build capacity in health research on the continent. The Training of Health Researchers into Vocational Excellence in East Africa (THRiVE), a consortium funded by Wellcome Trust, UK, and coordinated by Makerere University, Uganda, aimed to contribute improved infrastructure, training, increased collaboration and investment in young researchers. The *icipe*-led Community of Excellence for Research in Neglected Vector-Borne Zoonotic Diseases (CERNVec), brought together scientists and institutions to study, develop, and apply knowledge and tools towards a One Health approach.

International development partners demonstrated their confidence in *icipe*'s infrastructure, expertise and leadership in research and development in several ways. First, was the designation of *icipe* as a Food and Agriculture Organization of the United Nations (FAO) Reference Centre for vectors and vector-borne animal diseases. This was due to *icipe*'s strong mission towards the development of integrated strategies and tools for control of vectors of animal diseases in Africa. Another contributing factor was previous collaboration between *icipe* and FAO in strengthening regional capacity in this area.

Second, was the appointment of *icipe* as a Regional Centre under the Stockholm Convention on Persistent Organic Pollutants (POPs). The selection was in recognition of the Centre's unwavering commitment to developing environmentally safe tools and strategies for the management of arthropods. It was also due to *icipe*'s close and effective partnerships with national, regional and international organisations, which places the Centre in a central position regarding technology transfer and capacity building. Moreover, *icipe* has continuously and actively lobbied for the reduction and elimination of pesticides and for environmentally friendly pest control in many international fora. *icipe* has especially played a leading role in articulating issues surrounding DDT, one of the pesticides regulated by the Stockholm Convention.

icipe recognised that although climate change is a global phenomenon, its impact will affect SSA the most. Therefore, the Centre joined forces with the Ministry for Foreign Affairs of Finland to launch a four-year initiative known as the Climate Change Impacts on Ecosystem Services and Food Security in Eastern Africa (CHIESA) project. The goal was to meet the urgent need for knowledge on adaptation to climate change and variability, to reduce the vulnerability of countries, and that of people at the household level. Specifically, the focus was on improving available models and predictions on the impact of climate change regarding crop diseases, insect pests and pollinators; and on sensitive and unique ecosystems and their services in Africa.

The Centre improved its resource mobilisation; and thus, stability as an organisation. Finances tripled, from US$ 9.5 million in 2005 to US$ 30 million at the end of 2013. Of this funding, 35% was unrestricted core grants provided by the governments of Denmark (until 2011), Kenya, France, Sweden, Switzerland, Germany and the UK, and Aid for Africa, USA. The remaining 65% was restricted grants from various donors.

A turning point for *icipe* was through what the Management described as a "serendipitous" encounter with Google.org, the philanthropic arm of Google Inc. This encounter led to discussions to start research in arboviral diseases, with *icipe* incorporating like-minded institutions in Kenya. A strategy was designed for a US$ 5 million, *icipe*-led consortium, bringing together four national programmes in Kenya under the Ministry of Public Health and Sanitation and the Ministry of Livestock Development; Kenya Medical Research Institute (KEMRI); and the International Livestock Research Institute (ILRI).

icipe also started plans for the construction of the African Reference Laboratory for Bee Health at the Centre's headquarters, Nairobi, with four bee health satellite stations in Burkina Faso, Cameroon, Ethiopia and Liberia. Funding for the facility, a collaborative initiative between *icipe* and the African Union Inter-African Bureau for Animal Resources (AU-IBAR), was obtained from the European Union and *icipe* core funds. The facility was envisioned to provide a coordinated process for bee health in Africa, through research and development, policy advocacy, capacity building, and strategic networking.

The Centre also initiated preliminary plans for the 'greening of *icipe*', an initiative to minimise the Centre's carbon footprint through generating renewable energy, and through innovative strategies to harvest and use water. The Swiss Agency for Development and Cooperation (SDC) committed to support this initiative.

It was also during this period that *icipe* started to contemplate evolving its research towards the emerging area of insects for food and feed. In 2012, *icipe* joined the GREEiNSECT initiative, a consortium led by University of Copenhagen, Denmark, bringing together public and private sector partners from Africa, Asia, Europe and the USA. The goal was to investigate ways of mass-rearing insects in small, medium and large-scale industries. The overall aim was to integrate insects as a new, sustainable and inclusive component in addressing food, nutritional and feed security, and as part of the transition towards greener agriculture in Kenya.

icipe re-started the incorporation of social sciences into its activities, with an embryonic group that was providing project-level support for monitoring and evaluation.

icipe also linked up with the Centre for International Migration and Development (CIM), run jointly by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, and the German Federal Employment Agency, to place experts from Europe at the Centre. As a result, an initial batch of CIM experts joined *icipe* and were vital in providing bioinformatics services; boosting research in taxonomy and biosystematics; and establishing a Geo-Information Unit, enabling the use of remote sensing and geographic information systems (GIS) to provide geospatial analysis and mapping support to *icipe*'s research themes.

Centrewide honours

Designation	Details
Food and Agriculture Organization of the United Nations (FAO) Reference Centre (for the period 2012 – 2016).	The designation of *icipe* as an FAO Reference Centre was endorsed by the Government of Kenya, through the Department of Veterinary Services.
Designation as a Stockholm Convention Regional Centre on Persistent Organic Pollutants (POPs) (for the period 2010 – 2014).	*icipe* joined 16 Stockholm and 7 Basel Regional Centres, located in Africa, Asia and the Pacific, Central and Eastern Europe, Latin America and the Caribbean, and Western Europe, selected on the basis of their expertise and capacity to provide technical assistance and capacity building to the eligible countries.

Recognition to programmes and projects

Award	Awarded to	Awarded by	Details
ApiExpo Africa Award (in 2012)	The Beekeeping Project for beekeeping technology and eco-honey production for the improvement of the livelihoods of the Tolay community, Ethiopia.	ApiTrade Africa	Recognised for outstanding contribution to modern beekeeping.
ONE Africa Award finalist (in 2012)	Muliro Farmers Conservation Group, based adjacent to Kakamega forest, which was supported by *icipe* and partners in the mission of improving the livelihoods of its members through commercial cultivation of medicinal plants while conserving the endangered forest.	ONE, a global movement campaigning to end extreme poverty and preventable disease by 2030	The award was given to organisations, groups and individuals in Africa, engaged in life-changing, innovative efforts to achieve the millennium development goals (MDGs) in their local communities, regions and countries.
Equator Prize (received in 2010)	Muliru Farmers Conservation Group	Equator Initiative of the United Nations Development Programme	This award was given to community-based initiatives that have demonstrated extraordinary achievement in reducing poverty through the conservation and sustainable use of biodiversity in the equatorial belt.
SEED Award for Entrepreneurship in Sustainable Development (received in 2010)	Muliru Farmers Conservation Group	SEED was founded at the 2002 World Summit on Sustainable Development in Johannesburg by UNEP, UNDP and IUCN as a global partnership for action on sustainable development and the green economy	Recognised for contribution to biodiversity conservation and empowering the local community to engage in alternative income-generating activities by developing products from wild indigenous medicinal plants.

Awards and honours (2005 – 2013)

Individual recognitions

Category	Staff member	Details	Awarded by
Awards	Christian Borgemeister (Director General)	Award of Distinction, received in 2011, for contributions to the development and promotion of integrated pest management in the tropics	International Association for the Plant Protection Sciences (IAPPS), Nebraska, USA
	Zeyaur Khan (Leader, Push–Pull programme)	Co-winner, TWAS Prize for Agriculture, awarded in 2011, for discovery and wide-scale implementation of the push–pull technology, a pro-poor scientific innovation for enhancing food security and environmental sustainability in Africa	The World Academy of Sciences (TWAS)
		Nan-Yao Su Award for Innovation and Creativity in Entomology, received in 2010	Entomological Society of America (ESA)
		International Integrated Pest Management (IPM) excellence award, received in 2009, in honour of outstanding contributions to IPM	Sixth International IPM Symposium, held in Portland, Oregon on 24–26 March 2009.
	Baldwyn Torto (Head, Behavioural and Chemical Ecology Unit)	ARPPIS Alumni Prize for Best Achiever in Scientific Research & Innovation, received in 2008	*icipe*
	Liz Ng'ang'a (Communication Unit)	Siemens Award for Excellence in Science Writing, received in 2006	Siemens
Special Recognitions	Christian Borgemeister	Keynote address, with a presentation titled: 'Insect science and poverty alleviation – tales from Africa'	24th International Congress of Entomology (ICE), held in Daegu, Korea, on 17 – 25 August 2012.
	Zeyaur Khan	Thomas Odhiambo Distinguished Research Fellow, accorded in 2012	*icipe*
	Baldwyn Torto	Plenary Speaker	The 2012 COLOSS Conference held in Belgrade, Serbia
		Commencement Award and Speaker, in 2012	Bowen University, Osun State, Nigeria
		Recognition award for outstanding contributions in the development of in-hive trap and attractant composition for the control of the small hive beetle, *Aethina tumida*, received in 2007	University of Florida, Gainesville, Florida, USA

Awards and honours (2005 – 2013)

Category	Staff member	Details	Awarded by
Fellowships	Christian Borgemeister	Fellow, appointed in 2012	Entomological Society of America (ESA)
		Fellow, appointed in 2011	African Academy of Sciences
		Fellow, appointed in 2006	Royal Entomological Society, UK
	Zeyaur Khan	Fellow, appointed in 2010	ESA
		Fellow, appointed in 2010	Royal Entomological Society, UK

Category	Staff member	Details	Appointed by
Appointments	Christian Borgemeister	President, International Branch (November 2011 – 2012)	ESA
		Vice President, International Branch (November 2010 – 2011)	ESA
		Editor-in-Chief (2005 – 2013)	*International Journal of Tropical Insect Science*
		Member, Advisory Board	*East African Agricultural and Forestry* journal
		Member, Editorial Board	*Bulletin of Entomological Research*
		Member	German Council for Research on Tropical and Sub-tropical Agriculture (ATSAF)
		Member	International Organisation for Biological Control (IOBC)
		Member	South African Entomological Society
		Member	African Association of Insect Scientists
		Member	German Society for General and Applied Entomology (DGaaE)
		Member	German Phytomedicine Society (DPG)
		External science reviewer/evaluator	Federal Ministry for Economic Cooperation and Development (BMZ), Germany

Awards and honours (2005 – 2013)

Category	Staff member	Details	Appointed by
	Christian Borgemeister	External science reviewer/evaluator	Federal Ministry of Education and Research (BMBF), Germany
		External science reviewer/evaluator	Volkswagen Foundation, Germany
		External science reviewer/evaluator	Swiss Institute for Technology (ETH), Zurich, Switzerland
	Sunday Ekesi	Member, appointed in 2012	The Kenya Standing Technical Committee on Imports and Exports (KSTCIE)
		Member, Editorial Board (Africa Regional Editor), appointed in 2011	*International Journal of Tropical Insect Science*
		Member, Advisory Board, appointed in 2009	*Organic Farmer* magazine
		Member, Chris Lomer Award Committee, Fungus Division, appointed in 2007	Society for Invertebrate Pathology, California, USA
		Member, Membership Committee, appointed in 2007	Society for Invertebrate Pathology, California, USA
		Member, International Fruit Fly Steering Committee (IFFSC), appointed in 2006	International Atomic Energy Agency (IAEA)
		Member-at-Large, Fungus Division (2004–2005)	Society for Invertebrate Pathology, California, USA
	Baldwyn Torto	Editorial Board, appointed in 2010	*Journal of Chemical Ecology*
		Councillor, elected in 2010	International Society of Chemical Ecology, USA
	Zeyaur Khan	Council Member, appointed in 2010	International Congress of Entomology
		Distinguished Scientist, appointed in 2010	International Branch, ESA
		Visiting Professor, appointed in 2009	Cornell University, Ithaca, New York, USA

Communication

With *icipe* research moving into large-scale field trials, the Centre's social-economic impact was ever more evident. In turn, this presented an opportunity for human interest articles concerning the effect on communities. Indeed, a story on the impacts of the *icipe* integrated tsetse management in Shimba Hills was awarded the Siemens Award for Excellence in Scientific Writing in 2016.

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Peer-reviewed journal articles were published between 2005 and October 2013.

Core donors

- Aid for Africa, USA
- Danish International Development Agency (DANIDA), Denmark
- Federal Ministry for Economic Cooperation and Development (BMZ), Germany
- Government of France
- Government of Kenya
- Japan International Research Center for Agricultural Sciences (JIRCAS)
- Swedish International Development Cooperation Agency (Sida), Sweden
- Swiss Agency for Development and Cooperation (SDC), Switzerland
- UK Aid, Government of the United Kingdom

Continuing donors (from previous phase)

- African Development Bank (AfDB)
- Biovision Foundation for Ecological Development, Switzerland
- Conservation International, USA
- Critical Ecosystem Partnership Fund of David and Lucile Packard Foundation, USA
- Directorate General for International Cooperation (DGIS), The Netherlands
- DuPont Agricultural Products, USA
- European Union
- Food and Agriculture Organization of the United Nations (FAO)
- Ford Foundation, USA
- Foundation for the National Institutes of Health, USA
- Gatsby Charitable Foundation, UK
- German Academic Exchange Service (DAAD)
- German Technical Cooperation Agency (GTZ), Germany
- German Development Service (DED)
- International Atomic Energy Agency (IAEA)
- International Foundation for Science, Sweden
- International Fund for Agricultural Development (IFAD)
- MacArthur Foundation, USA
- National Science Foundation (NSF), USA
- Organization of Petroleum Exporting Countries (OPEC) Fund for International Development
- Rockefeller Foundation, USA
- Smithsonian Institution, USA
- Swedish Agency for Research Cooperation with Developing Countries (SAREC), Sweden
- Texas A&M Research Foundation, USA
- Third World Academy of Sciences (TWAS)
- Third World Organization for Women in Science
- Toyota Environmental Activities Grant Programme FY 2006, Japan
- United Nations Children's Fund (UNICEF)
- United Nations Environment Programme-Global Environment Facility
- United States Agency for International Development, USA
- United States Department of Agriculture (USDA)
- Wellcome Trust, UK
- World Bank
- World Health Organization (WHO)

New donors

- African Wildlife Foundation
- ASAL under the Office of the President and Action Aid, Kenya
- Bill & Melinda Gates Foundation, USA
- Consortium for National Health Research (CNHR)
- CordAid
- European Union International Cooperation Programme (EU-INCO)
- Global Biodiversity Information Facility (GBIF), Denmark
- Global Fund to Fight AIDS, Tuberculosis and Malaria
- Google.org
- International Centre for Scientific Culture – World Laboratory
- International Institutes Cooperation Programme, Netherlands
- Islamic Development Bank
- Kilimo Trust, East Africa
- McKnight Foundation, USA
- Verenium Corporation, USA
- World Federation of Scientists, Switzerland

Human Health Theme

Malaria and mosquito control

By the 2000s, there was evident progress in malaria prevalence reduction, largely resulting from intensified use of insecticide-treated nets. However, *icipe* was alert to the need to continue efforts to understand mosquito behaviour and ecology. Moreover, *icipe* research in the previous phase had shown a connection between socio-economic influences, and rising malaria prevalence and geographical diversification. These elements shaped *icipe*'s basic research on mosquitoes, as well as the implementation of IVM initiatives.

Malaria vector *Anopheles gambiae* probing on the plant *Parthenium hysterophorus.*

Basic research
Over the years, the Centre had accumulated evidence in regard to the potential of compounds found in plants that are part of the nutritional ecology of *Anopheles gambiae*, to disrupt malaria transmission. During this period, the Centre generated new knowledge on several features of the plant–mosquito relationship: host–plant attractants; host–plant learning; and anti-*Plasmodium* secondary plant compounds.

In accordance, *icipe* research advanced knowledge of compounds and their blends that could be used to disrupt malaria transmission. Moreover, attractive odours that significantly affect mosquito behaviour were evaluated to assess their competitiveness against human odours, for the development of odour-baited traps for mosquitoes.

icipe researchers also explored the 'floral dimension' of malaria in Africa based on previous preliminary research conducted by the Centre that generated extensive evidence that certain plants are part of the nutritional ecology of *An. gambiae*. The studies revealed mosquito attractants in three plants, and synthetic blends were developed.

Additional studies found that malaria-infected mosquitoes develop an enhanced attraction to plant odours, as well as intensified probing of nectar sources. In turn, this alteration broadens the geographic range of mosquitoes, as they expand their search due to this craving for sugar.

icipe research also showed that some agricultural practices, such as the use of nitrogenous fertilisers in flooded rice irrigation schemes, could potentially increase suitability of mosquito breeding habitats and therefore aid in the transmission of malaria.

Integrated vector management

Malindi IVM

The government of Kenya launched the country's National Malaria Strategic Plan (2009 – 2017). The Strategy included IVM policy guidelines, and emphasised the need to strengthen advocacy, communication and social mobilisation capacities (ACSM) for malaria control. To contribute to this goal, *icipe* and KEMRI, in partnership with the Kenya Non-governmental Organisations Alliance Against Malaria (KeNAAM), and the Division of Malaria Control, Kenya, developed an IVM strategy driven by ACSM. The goal was to empower communities to make informed decisions and take the right action against malaria.

Specifically, the Strategy was integrated into the ongoing IVM initiatives (commenced in the previous phase) in Malindi, coastal Kenya, around four key strategies: preparing a comprehensive communication strategy to support essential IVM elements for the achievement of the millennium development goals (MDGs); enhancing local capacity to manage, oversee and co-ordinate application of the communication strategy; building a range of public and private partnerships in health communications; collaborating with key stakeholders to ensure operation of IVM strategies and the establishment of appropriate structures to guarantee continuity and sustainability.

At its conclusion in 2012, the project stood as a good example of the onus of IVM. First, the collaboration between interdisciplinary teams from *icipe* and KEMRI, and various Malindi stakeholders – from businesses, schools, the public sector and communities – ensured effective use of resources and capabilities. Second, the establishment of a functional IVM strategy founded on a systematic assessment of the mosquito control needs, followed by the development of required tools, and the strengthening of capabilities among researchers, led to efficient IVM implementation. Combined, these factors resulted in considerable reduction of mosquito and malaria prevalence.

The basic model of the Malindi IVM project was captured in the use of mosquito scouts, committed lay people who were trained by *icipe*–KEMRI researchers to lead community-wide implementation of appropriate IVM approaches. The mosquito scouts formed an effective network for mosquito monitoring, and training and support points, or community owned resource persons (CORPS).

Nyabondo IVM

In Nyabondo plateau, western Kenya, the *icipe*-led IVM aimed to tackle the interconnected challenge of brickmaking and malaria. For example, efforts were made to reclaim such breeding sites, to treat them with larvicides, or to pre-empt their formation in the first place through improved drainage. Door-to-door campaigns, as well as health talks in schools, were conducted to build awareness on the connection between malaria and livelihoods. The community was also supported in environmental management, and effective use of long-lasting insecticidal nets was intensified. As a result, mosquito larval densities were reduced by 71%, while those of adult mosquitoes resting indoors went down by 41%. By 2009, malaria prevalence in the region had subsided by 62%. *icipe* and partners investigated brickmaking methods that would diminish formation of breeding sites. They also recommended several livelihood options like fish farming, alongside environmental conservation measures, for example tree planting, to stop deforestation.

Simon Muriu (Kenya), an *icipe* ARPPIS scholar registered at Illinois State University, USA, conducted PhD research in the Mwea Irrigation Scheme. He made the ground-breaking finding on domestic animals as 'dead-end' hosts of mosquitoes. So critical is this finding to global malaria research that Muriu's paper achieved the 'highly-accessed' status, by the BioMed Central Statistical Office, which is based on the number of downloads for an article within the first month of publication.

'Dead-end' hosts: Livestock and mosquitoes

Studies in the Mwea Irrigation Scheme continued with a dual focus: to test environmentally-friendly microbial larvicides, and to unravel the connection between livestock and mosquitoes. It is known that mosquitoes require at least two blood meals per day, which are obtained by feeding on a human being. The interventions in the previous phase of *icipe* research had led to the introduction of a range of measures to minimise contact between the vectors and people, denying mosquitoes a source of blood meal.

During this period, *icipe* research revealed that mosquitoes were now turning to domestic animals, especially cattle, for a blood meal. But the animals were not becoming infected with the malaria parasites; a trait that made them 'dead-end' hosts. In turn, these findings pointed towards zooprophylaxis – the use of animals to protect people from disease – as a potential strategy for malaria control. However, this is an approach that requires thorough research before it is adopted.

Rift Valley fever

As anticipated, the establishment of the Martin Lüscher Emerging Infectious Diseases (EID) Laboratory at *icipe* enabled the Centre to intensify its arboviral research. Rift Valley fever was selected as the initial model because the disease is a critical constraint to health, and agricultural and economic development. Moreover, Rift Valley fever implicates all major actors in emerging diseases – from the health, veterinary, wildlife and vector control to research communities. Therefore, *icipe* and partners believed that research on Rift Valley fever would provide an opportunity for key stakeholders to strengthen skills for a multi-sectoral emerging disease challenge.

This research was conducted through an ambitious project known as the Arbovirus Incidence and Diversity (AVID). This three-year initiative brought together a consortium of experts, to develop an integrated approach to arbovirus surveillance and research.

David Tchouassi (Cameroon), then a postgraduate scholar at *icipe*, pictured collecting data in a Kenyan homestead, in a region prone to Rift Valley fever outbreaks. His research led to the development of a lure for improved trapping of mosquito vectors of the disease.

The team aimed to address important gaps in the understanding of Rift Valley fever that limit early warning and response efforts. Knowledge was also lacking on the distribution and dynamics of the virus between epidemics. The researchers employed an interdisciplinary approach encompassing various cutting-edge genomics, as well as knowledge management technologies and approaches.

Research goals included unravelling epidemiological and demographic data; and environmental factors and ecology of the Rift Valley fever virus. The intention was to enhance understanding of pathogen, vector and host dynamics, and to link this information to decision support tools to improve early warning and rapid response.

Towards improved mosquito surveillance, the researchers identified semiochemicals mediating mosquito attraction to different hosts. These findings were a groundbreaking demonstration that a lure developed from these chemicals can improve trap captures of mosquitoes by threefold. Such a technology would have an impact on disease surveillance by establishing sensitive sampling methods that maximise the detection probability of the virus, especially between epidemics.

The research also focused on developing early warning systems and appropriate response measures for Rift Valley fever. Most of the strategies that had so far been used to model outbreaks of the disease were based on flood predictions and satellite-based information using observations on amounts of rainfall, changes in temperature and signs of thriving vegetation. However, these strategies had been unreliable. For instance, in 2006, alerts on an eminent outbreak of Rift Valley fever were only issued after the rainfall and flooding had already occurred.

The *icipe* Management considered it a lucky break to link back with Rosemary Sang (Kenya), an alumna of the *icipe* ARPPIS programme, and arguably one of the foremost arbovirologists in East Africa. Based at the Kenya Medical Research Institute (KEMRI), Rosemary Sang took up a visiting scientist position within the Rift Valley fever project at *icipe*.

Through AVID, *icipe* acquired diagnostic platforms that make it possible to conduct high throughput arbovirus detection screening and sequencing. The researchers accumulated a unique collection of bio-surveillance samples from a diversity of hosts, and isolated and detected a number of viruses.

In 2012, *icipe* began a second set of studies on Rift Valley fever, this time geared towards enhancing the understanding of the ecosystem and sociological parameters that surround the disease. The research was conducted by a multidisciplinary team of virologists, ecologists, social anthropologists, epidemiologists and health geographers in northeastern Kenya.

Assessment of tsetse 'push–pull'

A key goal was to understand the socio-economic impact, as well as the attitudes, preferences and perceptions of communities, in regard to the 'push–pull strategy' initiated in the earlier period combining the *icipe* NGU traps enhanced with attractants, and the tsetse repellent collars.

A cow wearing an advanced version of the *icipe* tsetse repellent collar developed during this period.

Results showed that the *icipe* technologies provided substantial protection to cattle, enabling farmers to graze their animals for more extended periods–including in the early morning and evening hours when the flies are most active–and near the wildlife park fence, where the density of the flies is highest.

The cows were more settled when grazing or ploughing, while the disease incidence went down. As a result, farmers reported more income, since the healthier cows produced more milk, meat and traction power, and sold for higher prices.

The strategies also contributed to environmental conservation, as the farmers used trypanocides less frequently, and they no longer employed destructive methods, such as fire to smoke away the flies.

The efficacy of the repellent collars was evident from the reduced number of tsetse in traps, which were lower by about 80%, in comparison to control sites.

Upscaling tsetse repellent collars

The evaluations established that even more livestock keepers than earlier envisioned desired the tsetse technology collars. Many farmers were enticed by the idea of a mobile technology that can move along with livestock, in their search for pasture.

Therefore, starting in 2010, *icipe* enhanced efforts to expand dissemination of the tsetse repellent collars to as many farmers as possible. The process included validation of the technology, and improvement of various components, for example the dispensers. This was undertaken through large-scale trials involving hundreds of livestock keepers and thousands of cattle, in collaboration with stakeholders, for example veterinary and agricultural services.

icipe also commenced efforts towards the engagement of private sector partners in mass-production of the tsetse repellent collars. Steps for the commercialisation of the technology were also outlined, including full optimisation of the collars; and refinement of transfer, delivery and adoption systems.

Upscaling push–pull

With the push–pull technology, launched in 1995, completing its first decade in 2005, *icipe* focused on upscaling the technology, including addressing some of the challenges towards its advancement. Linkages and capacity building efforts were strengthened with key stakeholders, such as farmer organisations, extension services, non-governmental organisations and research institutions.

"I started using the push–pull technology at the lowest point of my life, having been widowed, and with three children to support. The technology lifted me. In addition to improved cereal yields, I have now ventured into dairy farming and poultry keeping." – Mrs Agnes Maureen Ambubi, Kenya.

To tackle the issue of limited availability of *Desmodium*, one of the intercrops of the push–pull technology, the Centre partnered with seed companies to commercialise production. Structures for community-based seed production, as well as vegetative propagation were also established.

Moreover, a range of innovative cost-effective dissemination channels were developed. *icipe* collaborated with several partners to test and implement a variety of pathways, such as the use of the mass media, information bulletins, video and information technology communication tools, field days, farmer teachers and farmer field schools.

To bolster the capacity of women farmers to use push–pull, *icipe* conducted studies to understand the processes and the socio-economic factors that affect their ability to adopt technologies. The results enabled the Centre and partners to design strategies that facilitated more women to use the push–pull technology, and to integrate other initiatives; for instance, organic farming, into their agricultural systems.

Further, push–pull proved to be an appropriate agricultural alternative for farmers living with disabilities, who often struggle with the heavy physical toil demanded by agriculture. This is because once a push–pull plot is established, little labour is required.

By the end of 2012, 60,000 smallholder farmers in East Africa had adopted the push–pull technology in western Kenya, eastern Uganda and northern Tanzania.

Starting climate-smart push–pull

icipe noted that due to climate change, some cereal-growing regions of Africa were becoming increasingly dry and hot. In response, in 2011, the Centre commenced efforts to develop a climate-smart version of push–pull.

One of the first trial sites in the development of a climate-smart push–pull at the *icipe* Thomas Odhiambo Campus.

The Centre used a conservation agriculture approach to identify crops that are grown in dry areas, mainly sorghum and millet, and the companion crops that could be integrated into a more drought-resilient push–pull.

The studies aimed to select crops against the basic principles employed in the original design of the technology: suitable chemistry in terms of ability to attract and repel stemborers; *Striga* suppression; proficiency in improving soil fertility, moisture retention and organic matter; and added value, for example in provision of high quality fodder.

Napier stunt disease

Napier, also known as elephant grass, is a tall fast-growing indigenous and highly important plant in eastern Africa. Over 80% of smallholder dairy producers in the region rely on it as a source of cattle fodder. The grass is also a key crop in the *icipe*'s push–pull technology. At the time, the Napier grass was being threatened by a stunt disease, which, as the name suggests, inhibits its growth. Once infected by the disease, shoots of Napier turn a pale yellow-green colour and become completely dwarfed. In some cases the grass dies altogether. Indeed, many smallholder farmers were losing entire Napier crops to the stunt disease. Most varieties of Napier grown in the region appear to be susceptible to the disease. There was also a risk that the disease could spread to Gramineae food crops; for instance, sugarcane, rice, millet and sorghum.

icipe conducted an evaluation of Napier grass for resistance to stunt disease and palatability to cattle through a participatory approach involving farmers.

icipe identified the cause of the disease, which had remained elusive for a long time, to be a phytoplasma and discovered a leafhopper known as *Recilia banda* Kramer to be one of its vectors in Kenya.

The Centre also created a molecular based diagnostic tool for screening Napier grass for the phytoplasma. The assay, which is known as the loop-mediated isothermal amplification (LAMP) of DNA, replaces the nested polymerase chain reaction (nPCR), which is laborious, costly and technically demanding. LAMP has also proven to be 20-fold more sensitive than the nPCR, and allows the detection of phytoplasma in settings with limited infrastructure.

Using this protocol, the Centre identified the phytoplasama in plants several months before the appearance of any symptoms of the Napier stunt disease. The tool also facilitated the discovery of genotypes of Napier grass that are resistant to the phytoplasma of the stunt disease, which were recommended to farmers. This knowledge will also be useful in future breeding strategies of Napier grass.

Biological control of stemborers

As discussed in the previous chapters, the introduction from Asia and the release of a parasitic wasp known as *Cotesia flavipes* led to the effective management of the spotted stemborer in eastern and southern Africa. However, indigenous African stemborers continued to be a significant problem, one of the most important being *Busseola fusca*.

This species is a serious pest in the cooler regions of eastern and southern Africa. In West Africa, the pest is common in the dry savannahs 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. This difference is explained by the existence of different geographic races of the pest, that vary in their climatic requirements, and also differences in natural enemy species occurring in specific regions. *icipe* conducted comparison studies of the performance of natural enemies of *B. fusca* found in eastern and southern Africa. As a result, *icipe* identified a wasp known as *Cotesia sesamiae* to be effective in controlling *B. fusca* in lowland regions. Thus, *icipe* and partners introduced the wasp into West Africa in 2006.

Managing the larger grain borer

icipe also enhanced efforts to manage the larger grain borer, *Prostephanus truncatus*, an invasive beetle that is native to Central America that arrived in Africa in the early 1980s. Since then, the pest has spread over most of Africa, causing 30–90% losses in stored grain. In Kenya alone, the larger grain borer inflicts damage amounting to an estimated US$ 116 million annually. The attack of grains by the larger grain borer provides a point of entry for mould, thus resulting in the production of aflatoxins. At the time, there was growing concern, as the beetle continued to spread throughout Africa invading the cooler, high potential maize-surplus regions.

icipe started the search for biological control agents of the larger grain borer in Central America in the 1980s and 1990s that revealed a beetle, *Teretrius nigrescens*, to be a predator. *icipe* made the releases of this predator beetle in several regions of Africa between 1991 and 1996. However, its effectiveness appears to depend on climatic conditions, the greatest success being in hot-humid areas, while less in hot-dry climates and cool temperatures. Based on these results, during this period *icipe* continued to introduce new races of *T. nigrescens* adapted to different climates. The Centre developed new molecular tools to allow their differentiation after releases in the field.

Postharvest research

icipe spearheaded studies on mitigating postharvest losses of cereals and other crops, and investigated better storage strategies that did not require the use of chemical pesticides. The Centre helped to compile systematic evidence that will assist decision makers in optimising post-production policies and strategies.

icipe tested super-absorbent polymers for their potential in drying maize in an enclosed environment with temperature control in an oven.

Further, *icipe* and partners, in collaboration with Purdue University, USA, trialled the PICS triple bagging approach (hermetic sealing using plastic bags) against maize weevils and larger grain borer.

Stemborer research

icipe and the Institut de Recherche pour le Développement (IRD) continued research to evaluate the diversity, abundance and distribution of stemborers and their natural enemies, particularly parasitoids, in wild habitats around cultivated grasses.

Cotesia typhae

The studies led to the discovery of a considerable number of previously unreported species of stemborers. The research also described the parasitoids associated with these stemborers. A new wasp species, *Cotesia typhae*, was discovered in Kenya, with the potential of being used as a biological control agent against the *Sesamia nonagrioides* stemborers in France.

The findings predicted that due to the destruction and fragmentation of wild habitats as a result of increasing demands for more agricultural land, some current and future stemborer pests of grasses will originate from wild host plants. Indeed this shift is already occurring.

The results also showed that sheds used to store cereal crop residues provide a refuge not only to maize stemborers but also to their associated parasitoids between cropping seasons.

Fruit fly IPM

icipe continued to advance its fruit fly IPM packages around two goals: the development and implementation of an IPM strategy that minimises the use of insecticides and their residues, and the exploration of opportunities to improve the marketing of fruits from Africa.

The Centre's focus was on completing knowledge on the invasive *Bactrocera* fruit fly, which, as reported in the previous chapter, was first reported in Africa in 2003.

Mrs Francisca Mueni Katona from eastern Kenya is one of the *icipe* mango model farmers, selected on the basis of their outstanding performance using the Centre's fruit fly IPM, and willingness to contribute to the training of other farmers accordingly.

The activities included: continuous monitoring, which showed the predominance of the invasive species and displacement of indigenous fruit flies; population dynamics studies; identification of the pest's host plants; and testing of various IPM strategies for its management.

The researchers also sought natural enemies of the pest in its putative aboriginal home, Sri Lanka, and other parts of the world. This long and arduous search resulted in the importation of two effective natural enemies (both wasps): *Fopius arisanus* and *Diachasmimorpha longicaudata* from the United States Department of Agriculture-Agricultural Research Service (USDA-ARS) laboratory in Hawaii, USA, in 2008. Pilot releases were conducted in Kenya, Tanzania and Benin, and later in Mozambique.

The release of the parasitoids to control the invasive *Bactrocera* species was undertaken alongside the dissemination of other *icipe* IPM strategies. The package included locally available protein baits, soft pesticides and fungal-based biopesticides, baiting techniques; male annihilation (removal of a large number of males using a male attractant and a killing agent); orchard sanitation using a tent-like structure called ‘augmentorium’; and conservation of indigenous natural enemies.

The dissemination of the fruit fly IPM packages was supported by strengthening of the capacity of national agricultural research organisations, and quarantine personnel; massive awareness building; establishment of learning sites; and distribution of IPM starter kits and hands-on training of mango growers. By 2013, over 50,000 farmers, the majority of them low-income families and women, were benefiting from the *icipe* IPM packages.

Africa is considered to have some of the finest avocado varieties in the world, with Kenya and South Africa among leading global exporters of the fruit. A proper postharvest protocol is essential for improved marketing opportunities of the crop.

The overall outcomes included improved household income, and nutritional and environmental health. Specifically, the interventions led to suppression of fruit flies by 80 – 90%, and mango seed weevil by 92–100% in the field. Mango yields increased by 30% in the benchmark sites.

Even with the success of the *icipe* fruit fly IPM packages, to fully meet the quarantine security required for fruits and vegetables before export, additional measures were necessary. As such, *icipe* conducted studies leading to the development of appropriate protocols for phytosanitary treatment to eliminate *Bactrocera* larvae in citrus fruits and avocado.

Vegetable IPM

Thrips packages

In Africa, thrips – tiny, slender insects that have acquired their name from their fringed wings – cause extensive damage to a wide array of high value crops, either directly by feeding on them, or indirectly by transmitting tospoviruses. The management of thrips and tospoviruses is constrained by factors such as the ability of thrips to resist synthetic insecticides, the invasive nature of some species, difficulties in targeting thrips that attack crops from cryptic locations, and the lack of adequate capacity to identify and effectively monitor thrips.

icipe produced and made available occurrence maps of over 60 species of thrips and some of their natural enemies. Significantly, the Centre reported the presence of several thrip species for the first time in East Africa, namely *Frankliniella williamsi*, *F. borinquen*, *Ceratothripoides claratris* and *Gynaikothrips uzeli*. Two tospoviruses: the *Iris yellow spot virus*, and *Tomato yellow ring virus*, were observed to be infecting onions and tomatoes, respectively, in the region.

In partnership with Martin Luther University, Germany, the Centre developed a user-friendly software that greatly enhanced the capacity of quarantine agencies, agricultural extension officers and research organisations to identify and monitor thrips and their natural enemies in the region.

icipe also emphasised need-based applications of entomopathogenic fungi. In this regard, the Centre reached an agreement with Real IPM Ltd, a Kenya based commercial biopesticide producer, for the commercialisation of ICIPE 69, a thrips-effective isolate developed by the Centre from *Metarhizium anisopliae*. As a result, the biopesticide was registered in several countries in Africa, under the brand name of Campaign®.

Studies showed that LUREM-TR, a thrips attractant developed by the Plant Research International, Netherlands, and Plant & Food Research, New Zealand, can enhance thrips attraction and trapping. *icipe* completed a proof-of-concept for the development of a ‘lure-and-kill’ strategy combining Campaign® with LUREM-TR.

The *icipe* thrips IPM package also consisted of intercropping, use of host plant resistance and biological control approaches. For instance, the researchers observed that intercropping French beans with baby corn or sunflower significantly reduces thrips infestations, increasing the marketable yield by over 50%.

Pest risk assessment of the invasive western flower thrips, *Frankliniella occidentalis* in Africa was conducted through innovative phenology modelling. Initial predictions, refined against biological and ecological factors, indicated future, wider distribution of these thrips in Africa due to climate change.

Capacity of collaborating organisations in the monitoring and integrated management of thrips and tospoviruses was enhanced in national agricultural research institutes, and quarantine agencies from Kenya, Tanzania, Uganda, Somalia and South Sudan.

Scaling-out DBM management

Based on the success (reported in the previous chapter), in the use of parasitoids to manage DBM in Kenya, Tanzania, Uganda, Ethiopia and Cameroon, *icipe* and partners embarked on scaling-out activities to Malawi, Mozambique, Rwanda and Zambia. The focus was on mass release of the imported parasitic wasp, *Diadegma semiclausum*. In addition, efforts were made to understand and boost populations of naturally present enemy species. This goal was achieved through extensive awareness-building among key stakeholders, to reduce use of broad-spectrum insecticides that not only affect crucifer pests, but also beneficial parasitoids. Extension agents and farmers were also trained in the use of integrated pest management approaches, in general.

Aphids IPM

Aphids, small sap-sucking insects that are also known as 'plant lice', are among the most destructive insect pests in temperate climates, causing considerable losses in the yield and quality of crops through direct damage and transmission of viral diseases.

In 2012, *icipe* joined a three-year multi-institutional programme aimed at developing, testing and adapting sustainable and environmentally-friendly options for the management of aphids on okra, kale and cabbage, while reducing the synthetic pesticide load on these crops

The research involved developing appropriate user-friendly tools for identifying and monitoring aphids and their associated natural enemies, their species composition and their abundance while understanding windows of opportunity for interventions.

Aphids seen through a microscope feeding on a cabbage. These sap-sucking insects cause huge losses in the yield and quality of crops through direct damage and transmission of viral diseases.

The process included the development of geo-referenced maps of the distribution of aphids and their viruses, as well as guides for their diagnosis. The studies also determined and modelled the role of biotic and abiotic factors affecting the dynamics of aphids on the three crops.

Leafminers

Liriomyza leafmining flies are invasive pests of great importance in the production of horticultural crops and potatoes. Preliminary studies by *icipe* established weaknesses in good agricultural practices (GAP) required in international export markets. The research also showed that many commonly used insecticides were inefficient against the pests, and also detrimental to natural enemies. Therefore, *icipe* imported two effective parasitoids from Peru into Kenya. Trials showed neem and pyrethrum botanicals to be effective in controlling leafminers, and harmless to natural enemies. Hundreds of farmers and staff from agricultural ministries in East Africa were trained in GAP and IPM techniques.

Liriomyza huidobrensis

Pod borers

Maruca vitrata is a voracious pod borer that intensely attacks and ruins cowpea and other legumes. *icipe* partnered in a project led by AVRDC, the World Vegetable Centre, whose goal was to reduce losses on vegetable legumes in Southeast Asia (SEA) and sub-Saharan Africa (SSA). *icipe's* role was to improve existing technologies that are based on sex pheromones, entomopathogens and botanicals, while also exploring for specific natural enemies in the aboriginal home.

Red spider mites

The Centre also continued research on the red spider mite, *Tetranychus evansi*, an invasive pest of tomatoes. The studies showed that an isolate of *M. anisopliae*, ICIPE 78, in combination with a predatory mite imported from Brazil, is effective in the management of the pest. Moreover, eco-friendly nets for protecting tomatoes were also tested with commendable success in collaboration with CIRAD.

Cash crops IPM

Cashew IPM

icipe aimed to contribute to sustainable IPM technologies for pests affecting cashew, a key cash crop in Africa. The research focused on understanding the bioecology of the key insect pest complex and their natural enemies in diverse habitats and landscapes. The Centre explored strategies that minimise or eliminate the use of excessive sulphur dust, the most commonly used fungicide for powdery mildew management. Assessments were also conducted on the effects of sulphur alternatives on beneficial insects like pollinators, and the natural enemies of the bugs. These activities provided a better understanding of the dynamics of cashew pests and their interactions with natural enemies. They also led to the identification of the weaver ant, entomopathogenic fungi, and fungal antagonists, as components of IPM to minimise the use of synthetic pesticides. New knowledge was generated on chemical and sex attractants of coreid and mirid bugs, pests of cashew. Potentially, such attractants could be used to monitor and lure pests on cashew and other crops that are known to infest coconut, cocoa and macadamia.

Coffee research

The coffee berry borer, *Hypothenemus hampei* is the most important biotic constraint of commercial coffee production worldwide. Despite many years of research, the pest's biology and ecology, and especially the chemical ecology of the insect, are not clearly understood. *icipe* conducted basic research in these areas, to unveil key cues used by *H. hampei* during its host location and colonisation phases. This knowledge was aimed at providing leads on the major attractants or repellents of *H. hampei*, opening up new and innovative possibilities to effectively control the pest. A second series of studies was on the effect that climate change will have on the coffee berry borer.

In addition, climate change is forecasted to have huge implications for coffee production throughout the tropics. Therefore, *icipe* conducted a second set of studies on thermal tolerance, and modelled the pest's distribution in East Africa under current conditions and future climate change scenarios. In collaboration with colleagues from CIRAD and CIAT, the researchers also mapped compounded coffee pests and diseases suitability under climate change scenarios and agroecosystem types in Central America and East Africa.

For several African economies, coffee is one of the most important cash crops, with its importance expected to rise with growing international demand. Addressing the interlinked challenges of climate change and pest damage could have a significant benefit, especially for women who play an essential role in the coffee value chain.

Environmental Health Theme

Commercial insects

icipe Commercial Insects Programme entered its second decade with activities focusing on three main thrusts: development of technologies for beekeeping and silk farming; conservation of forests and fragile ecosystems; and improvement of the socio-economic conditions of the communities that live adjacent to such areas.

The Centre continued to produce new knowledge on rearing various species of bees, as well as information to enhance management practices in the production of honey and hive products. Further, research focused on ways to broaden beekeeping as an occupation; for instance, by promoting pollination services and other livelihood options to strengthen farming systems. With sericulture still a relatively new venture (especially in Africa), *icipe* continued to advance the basics of wild and mulberry silk farming in different agroecological regions across Africa.

icipe team member pictured during an exhibition, with a display of high quality honey packaged by the Centre, having been sourced from communities participating in the commercial insects R&D activities.

Wild silk production is a unique eco-friendly agro-practice with the potential for environmental amelioration, employment and income generation. During this period, *icipe* recorded 58 wild silkmoth species in East Africa, which opened the avenue for their rearing.

In the Near East and North Africa (NENA) region, the Centre's activities were implemented in the protected forests and semi-arid zones to reduce poverty through improved food security and income levels within projects funded by IFAD through participatory agroforestry management.

To intensify capacity building, a research and training facility was established at *icipe* with egg grainage, rearing and post silk processing units, serving as a training centre in Africa.

The Centre aimed to support communities to develop various apiculture and sericulture products, based on the quality regulations of the European Union, Organisation for Economic Co-operation and Development (OECD) and other trade agencies. For example, *icipe* supported a process towards the organic certification of honey produced through *icipe*-led efforts by a community in Mwingi county, eastern Kenya, based on the European Union ISO 65 (EU-ISO65), obtained in 2009.

This certification enabled the beekeepers to attract international trade partners interested in issues of fair trade. Also, the strategies instituted as part of the certification process improved the management of the natural resources and land practices in Mwingi, with benefits beyond beekeeping.

Between 2007 and 2012, *icipe* implemented commercial insects activities in Africa and the NENA region: Algeria, Botswana, Burundi, Congo, Ghana, Ethiopia, Egypt, Libya, Madagascar, Morocco, Yemen, Rwanda, Sudan, South Sudan, Tanzania, Tunisia, Uganda and Zambia.

Bee health

As discussed in previous sections of this chapter, during this period, *icipe* made a decision to set up a dedicated bee health amenity. This resolve was based on a number of factors. First, it was grounded on *icipe*'s extensive experience researching bees, to improve livelihoods while conserving biodiversity. Through these activities, *icipe* recognised the rising threats to bees in Africa, resulting from factors such as climate change and habitat loss due to deforestation caused by population pressure, among others. Second, and against this background, *icipe* noted gaps in knowledge, and the absence of systematic procedures to monitor, analyse and safeguard bees. Moreover, the Centre observed a lack of proper approaches to incorporate bees into development strategies in Africa, as well as an inadequate understanding of their economic impact, especially regarding pollination services.

The third aspect was the growing global anxiety surrounding bee health against the background of the colony collapse disorder (CCD). This is a phenomenon that has since 2006 become a serious problem and a major threat to commercial beekeeping and pollination operations in Europe and USA. The most likely contributors to CCD include *Varroa* mites, diseases (particularly through viruses vectored by *Varroa*), pesticide exposure, stresses associated with modern beekeeping practices, and poor nutrition.

Invasive bee pests in Africa

In 2008, *icipe* launched activities to develop monitoring and control programmes for invasive pests of bees. Through extensive nation-wide surveys of hive beetles in Kenya, the researchers discovered two related beetles, *Oplostomus haroldi* and *O. fuligineus*, to be the key pests of African honey bee colonies. The Centre's studies on the biology and chemical ecology of the beetles led to the generation of DNA barcodes to aid morphological taxonomy and identification of origin of the beetles, in the event of these pests becoming threats to honey bee colonies of a different race outside Africa.

Further, the researchers explained the chemistry of the interaction between the two beetles and honey bee, developed a trapping system, and tested its performance in capturing the Africa-endemic small hive beetle, *Aethina tumida*, before expanding the tool to other species. Alternate hosts of the beetles were also identified, to understand factors that could contribute to the spread and distribution of the pests. These findings provided the basis for developing policy guidelines for the movement of honey bee colonies within and outside Kenya, to reduce the introduction of pollinator pests into new geographic and agricultural areas.

Two related scarabs, *Oplostomus haroldi* and *O. fuligineus*, are known to be the key pests of African honey bee colonies.

Contribution to tackling CCD

One of the *icipe*'s major contributions was through an international collaboration aimed at understanding the biology, ecology and management of African bees, within the context of CCD. The goal was to verify whether the maladies affecting European bees are present in African bees. In addition, the researchers sought to understand the mechanisms that allow African bees to tolerate these problems and the management techniques employed by beekeepers to minimise their impact. *icipe* studies showed that African bees in Africa are less vulnerable to brood diseases, parasites such as those transmitted by *Varroa* mites, and pests like the small hive beetle. In addition, in the United States, Africanised bees, many of which are hybridised crosses with European species, tolerate these maladies better, and do not often succumb to them.

Staff in the Behavioural and Chemical Ecology Unit conducted the *icipe* Bee Health studies reported in this section. Some members of the Unit are featured here: Onesmus Kaye Wanyama (left), Senior Research Assistant responsible for instrumentation; and Bridget Bobadoye (right), a postgraduate scholar who researched host–pest interactions.

icipe's evaluation of the health of honey bee populations led to the discovery of *Varroa* mites for the first time in honey bee colonies in Kenya, Uganda and Tanzania. This finding facilitated a new initiative between *icipe* and Penn State University, USA, to undertake outreach programmes to beekeepers in East Africa, towards sustainable honey bee management practices that are not dependent on pesticides and miticides.

The Centre also conducted research towards understanding the factors and mechanisms that mediate the interactions of *Varroa* mites and diseases with honey bees. The main aim was to explore the factors that contribute to the resistance of bees to these pests and pathogens.

The studies led to the description of the occurrence of *Varroa* mites in honey bee colonies, and the determination of their pathogen loads. The researchers also documented the hygienic behaviour in honey bee colonies. For the first time in Kenya, bacterial pathogens were detected, in this case the genus *Nosema*, and viruses such as *Black queen cell virus*. This knowledge, as well as skills to improve beekeeping practices, was transferred to beekeepers.

Bioprospecting

icipe continued its activities towards protecting East Africa's rich biodiversity resources while improving the livelihoods of the people living adjacent to them. The Centre's strategy was to combine modern science, traditional knowledge and practices, and partnerships with local communities, development partners and the private sector.

Members of the Muliru Farmers Conservation Group (MFCG), which contributes to the conservation of Kakamega Forest through the domestication of indigenous medicinal and insecticidal plants, pictured with samples from their Naturub range of products. MFCG, which is supported by *icipe* and partners, has received several international awards.

A key focus remained bioprospecting for commercial products from plants that local communities have traditionally used for insecticidal, medicinal or aromatic purposes. Such insights would then be used towards on-farm cultivation, supported with scientific back-up and the necessary skills for the production and marketing of products derived from the plants. As a result, *icipe* contributed to the emergence of thriving community-based, income-generating enterprises. The result was the creation of income and employment opportunities while relieving economic pressure on biodiversity resources.

By 2012, over 1789 households in Kenya, Tanzania and Uganda were involved in such nature-based enterprises. Several commercially available products had been developed. Of these, the most notable are Naturub®, a range of medicinal products developed from *Ocimum kilimandscharicum*, and Mondia tonic produced from *Mondia whytei*.

Between 2005 and 2008, *icipe* implemented sustainable nature-based businesses for communities living adjacent to the Eastern Arc Mountains and Coastal Forests of Kenya and Tanzania hotspot, one of the 25 global biodiversity hotspots. Among the projects that *icipe* introduced were the improved production of beehive products and the cultivation and processing of *Ocimum kilimandscharicum*. *icipe* developed two products for the community-based enterprise adjacent to the East Usambara Mountain forests in Tanzania.

icipe's activities also included the search for plant-derived pesticides for disease vectors, such as mosquitoes, and postharvest and storage pests, from ethnobotanically selected plants in East Africa. The Centre identified a range of mosquito larvicidal extracts and compounds, for further investigation.

Climate change

icipe's studies were founded on the knowledge that although climate change is a global phenomenon, its impact will be felt most in Africa. Moreover, available models and predictions on the impact of climate change had insufficiently addressed issues regarding crop diseases, insect pests and pollinators. Further, there was a general lack of information on the effects of climate change on sensitive and unique ecosystems and their services in Africa.

Mount Kilimanjaro's Kibo Peak, as seen from Moshi, Tanzania. Sub-Saharan Africa consists of a mosaic of landscapes that include valuable ecosystems that are likely to be more sensitive to the impacts of climate change and climate variability.

CHIESA

In 2011, *icipe* and the Ministry for Foreign Affairs of Finland launched the Climate Change Impacts on Ecosystem Services and Food Security in Eastern Africa (CHIESA) project, a four-year initiative aimed at capacity building and development of adaptation strategies towards climate change impacts.

The team implemented the activities in the Taita Hills in Kenya; the Didessa River Basin in Jimma Highlands, Ethiopia; and along the southeastern slope of Mount Kilimanjaro in Tanzania. Four key crops (maize, crucifers, avocado and coffee) were selected for on-farm studies.

Through a multidisciplinary team of scientists from several universities and research institutes in East Africa and Europe, the aim was to develop models and predictions on the impact of temperature variations on crop diseases, insect pests and pollinators. Also, the researchers intended to address the general lack of information on the impacts of climate change on sensitive and unique ecosystems and their services in Africa.

The beneficiaries of the CHIESA project were first and foremost, the farming communities whose livelihoods depend on the ecosystem services in the selected areas. The plan was to engage them in the planning, design and implementation of the identified adaptation options through wide dissemination of the project results and public awareness campaigns, in partnership with extension officers in agriculture, livestock, environment, forestry and hydrology sectors in the formulation of the adaptation tools and training farmers to use them.

Capacity Building and Institutional Development Programme

The Centre's Management believed that Africa's most precious resource was the intellectual capacity of the continent's people. Therefore, the focus was on equipping collaborating communities with the necessary know-how to improve their livelihoods, as a way of unlocking the continent's full potential for development.

During this period, *icipe* initially employed a two-pronged approach: research training and institutional building; and knowledge sharing and exchange. In October 2012, an independent review of the *icipe* capacity building activities recommended three result areas: capacity building and professional development of African scientists and professionals; institutional development by nurturing and strengthening African higher education institutions; and promoting innovation in insect science in collaboration with regional and national agricultural research and advisory services and the private sector.

The primary platform for the first target area was the African Regional Postgraduate Programme in Insect Science (ARPPIS). Then a network of 34 universities, ARPPIS progressed its mandate of doctoral and MSc training, with about 120 postgraduate and postdoctoral fellows ongoing at *icipe*. But, it also became clear that the programme needed to be broadened, in terms of its geographical and institutional reach, in Africa and beyond. Specifically, it was important to extend ARPPIS into West and Central Africa (including Francophone countries) and southern African countries.

The Dissertation Research Internship Programme (DRIP) served as a complementary programme to ARPPIS, offering PhD and MSc degree training to students registered in universities anywhere in the world. The programme is funded by development partners or one of *icipe*'s projects, with the Centre providing research projects and facilities, as well as supervision.

Further, the African Association of Insect Scientists (AAIS), provided a basis for cooperation and networking. The ARPPIS Scholars Association (ASA), hosted by *icipe*, presented a continental platform for the exchange of information and experiences with peers working in Africa.

Professional development schemes at *icipe* for postdoctoral fellows, research associates, and visiting scientists continued. The International Group Training Courses, and training initiatives for technologists, practitioners and community members maintained their central position, within the Centre's activities. While successful, the 2012 review recommended improvements of the group training courses, to shift from a purely technological and scientific approach. Curricula needed to become more holistic, in alignment with the ideals of research for development.

Moreover, it was necessary to develop training courses on topical issues and concerns, like climate change, biodiversity conservation, ecosystem services, and management of invasive species. Also, it was important to create capacity building strategies that would empower communities to innovate within their environments.

4

Recommitment to excellence

INTRODUCTION

I am honoured to be the first woman and the second African to lead *icipe*. I believe that this unique institution epitomises my vision of contributing to building world-class research capacity in developing countries, particulary in Africa, where such competence is most needed.

Having grown up in a remote village in Ethiopia, I know only too well the problems that rural communities face. I am aware that many people, especially women, continue to undertake backbreaking, endless chores daily while also contending with a multitude of socio-economic challenges. Therefore, my dream has always been to play a role in lessening the heavy burden borne by rural communities.

Being at the helm of *icipe* continues to be an important opportunity, as it enables me to contribute to the development and dissemination of technologies and strategies that have a real impact on livelihoods in Africa.

As outlined in the various sections of this chapter, during my tenure, we have maintained a vigilant approach taking into account the past, the present and the future. In other words, it has been our goal to secure *icipe*'s rich and unique legacy, making adjustments to rectify past challenges, seizing new opportunities as they arise, while fortifying the Centre's growing importance in a fast-changing local and global environment.

We have made major adjustments aimed at developing appropriate governance systems to improve day-to-day operations, underpinned by a culture of transparency, equity and accountability. We have been able to sustain core funding and to increase restricted finances. Indeed, the Centre has attracted 41 new organisations that have provided funding for various research programmes during this period. There has also been a rise in the number of African governments supporting *icipe*. The government of Ethiopia is now a core donor, while the governments of Burkina Faso, Côte d'Ivoire, Ghana, Rwanda and Senegal are making contributions to the Regional Scholarship and Innovation Fund (RSIF) of the Partnership for Skills in Applied Sciences, Engineering and Technology (PASET), managed by *icipe* since 2018. This is in addition to the government of Kenya, our host country, which has been *icipe*'s long-standing supporter, and is contributing to RSIF.

As we have progressed, we have identified the need to reassess our research strategy against emerging developmental issues and changing donor trends. In accordance, the Insects for Food and Feed Programme stands out as a major and exciting new area of focus at *icipe*. We have also enhanced our portfolio to include studies on insect microbiomes and plant-parasitic nematodes, while also incorporating tools such as data management, geographic information systems and remote sensing. Meanwhile, *icipe* has enhanced the translation of the Centre's knowledge and discoveries into innovative, impactful technologies and strategies through the creation of a Technology Transfer Unit and a much stronger Social Science and Impact Assessment Unit. Further, *icipe* continues to make constant efforts to align its research, not only to national aspirations but also to regional and international development agendas – for example, the United Nations Sustainable Development Goals (SDGs) 2030, the African Union Agenda 2063, the Science, Technology and Innovation Strategy for Africa (STISA-2024), the Comprehensive Africa Agriculture Development Programme (CAADP) and the African Bioscience Initiative.

Indeed, *icipe*'s institutional strengths, as well as the Centre's role in the advancement of biosciences-based innovations, are well recognised. As a result, the Centre has been mandated to host and manage two landmark initiatives: RSIF (mentioned previously in this section) and BioInnovate Africa Programme, one of the most significant regional innovation-driven science initiatives on the continent.

icipe has also made concerted efforts to respond to the growing urgency to create productive employment for young people in Africa. Most significantly, in 2016, the Centre commenced a partnership with the Mastercard Foundation through a five-year project known as the Young Entrepreneurs in Silk and Honey (YESH), which spawned jobs for 12,500 young men and women in Ethiopia. Capitalising on this success, in 2019, *icipe*, the Mastercard Foundation and the Ethiopia Jobs Creation Commission (JCC), launched the MOre Young Entrepreneurs in Silk and Honey (MOYESH) project. The initiative aims to see 100,000 young men and women in Ethiopia secure dignified and fulfilling work along honey and silk value chains over the next five years.

icipe prides itself as an African organisation, and currently, the Centre has activities in 41 African countries. We have also boosted our country offices and operations in Uganda, and in Ethiopia an office that had just five staff members in 2013 and has over 100 in 2020.

An institution is only as good as its team. As such, upon commencement of my leadership of *icipe* in November 2013, we embarked on a process of strategic recruitment to fill in prevailing gaps and strengthen existing teams.

icipe provides modern research facilities and well-equipped laboratories. During the past five years, I have built on some of the visions of my predecessors. These goals include the establishment of a dedicated research infrastructure for bee health and the 'greening of *icipe*', an initiative that is aimed at minimising the Centre's carbon footprint by generating renewable energy, and through innovative strategies to harvest and use water. Also, we have upgraded and renovated the Centre's main research and development complex and field stations, while also modernising some of our laboratories and insectaries.

Numerous elements have enabled *icipe* to flourish, in particular, the Centre's partnerships. Indeed, we have expanded our network of national, regional and international partners, enabling us to synergise resources and expertise, to translate broader global visions into locally acceptable, affordable, and effective technologies. Indeed, together we have demonstrated that science can improve food and nutritional security, health and environment, in Africa and other tropical regions.

"Looking forward, we are aware that in Africa and beyond challenges persist, for example, due to migratory pests and new insect-vectored diseases, exacerbated by climate change, loss of biodiversity and unhealthy ecosystems. This scenario places an unassailable, most urgent call-to-action: to intensify research; allocate sufficient resources; advocate for policies; and to recruit, retain and reward the best and brightest in agriculture, ecology and insect science; because our well-being depends on it."

Dr Segenet Kelemu
Director General & CEO
(November 2013 – present)

MANAGEMENT & LEADERSHIP

One of *icipe*'s major achievements has been significant improvement of financial, human resources management and control systems. These advancements have been overseen by the Director of Finance and Administration (appointed during this period), working closely with the Director General and the Centre's Governing Council (GC).

Effective administrative systems have contributed to the delivery of quality science, the functioning of the Centre, and the maintenance of funding levels. This scenario has influenced the efficient use of resources, particularly the balance between indirect costs and resources directed to *icipe*'s core business of research for development.

Specifically, the Centre has succeeded in streamlining and improving transparency, efficiency, financial management; creating checks and balances in procurement; and handling evaluations and review of risks through an internal audit unit.

icipe has developed new policies that have been approved by the *icipe* GC, while other policies have been updated. The *icipe* Management monitors cost control measures to ensure that the Centre breaks even every year while building up financial reserves to minimise risk. Currency revaluation reserve has been established as a line item in the financial statements, to reduce the Centre's risk in view of currency fluctuations.

Computerised business systems have been enhanced through introduction of a standardised pre-populated budget template, a job application system, a travel requisition system, and a staff requisition system. As well, the Centre has started implementing an integrated Enterprise Resource Planning (ERP) system. Furthermore, the Centre has developed a protected portal on the web for document repository to promote effective communication, proper management and timely distribution of, and access to, important records and governance documents.

There have been various changes in staffing across levels to improve capacity and to better align skills with functions. Amongst other changes, the Centre's Management has developed and actualised a staff promotion system for scientists and initiated and implemented a job classification procedure for technical and support staff. These efforts have had a positive impact on the Centre, and how it manages its people.

The above improvements of the management, financial and other accountability, transparency and human resources systems at *icipe* are embedded in the Centre by a commitment to a programme of continuous improvement in all components of administration. Such systems result in increasing interoperability and justify the effort expended that results in the effective use of public resources.

In 2018, the Centre's Governing Council commissioned the *icipe* Periodic External Review (IPER) for 2013 – 2017. The Review Team was composed of three international experts: John Lynam (USA), a globally renowned agricultural expert; Bruce Pengelly (Australia), an agricultural consultant; and Serap Aksoy (USA), Professor of Epidemiology, Yale School of Medicine, USA. The team concluded that *icipe* is a well-managed and highly productive research centre. The detailed findings of the review have been useful towards the strategic positioning of *icipe* in the medium-term future.

icipe has developed its *Vision and Strategy 2021–2025*. The document builds on the Centre's achievements and experiences and incorporates recommendations of the IPER (discussed above). The strategy aligns *icipe*'s effort to global and regional policy initiatives like the 2030 Sustainable Development Goals and the Science, Technology and Innovation Strategy for Africa (STISA-2024).

Awards and honours (November 2013 – present)

Centrewide Honours

Award title	Awarded by
Stockholm Convention Regional Centre (after first designation for the period 2011 – 2015, *icipe* has since received two formal endorsements for 2016 – 2019; and 2020 – 2023)	Conference of the Parties to the Stockholm Convention
Food and Agriculture Organisation of the United Nations (FAO) Reference Centre for vectors and vector-borne animal diseases (initially appointed for the period 2012 – 2016; then endorsed for 2016 – 2020; with the period for 2020 – 2024 underway as of May 2020)	Director General of FAO, after a thorough evaluation of the degree of progress and compliance, as well as quality contributions that *icipe* has made to assist FAO in its mission of providing authoritative advice to its Members, and in particular the developing countries
Certificate of Excellence to *icipe* Ethiopia office (received in 2018)	Ministry of Agriculture and Livestock Resources, Ethiopia
Certificate of Appreciation (received in 2018)	Borlaug-Ruan International Internship Programme of the World Food Prize Foundation
Certificate of Registration (received in 2017)	National Commission for Science, Technology and Innovation (NACOSTI), jointly endorsed by the Cabinet Secretary, Ministry of Education, Science and Technology, and the Director General, NACOSTI
OIE Collaborating Centre for Bee Health in Africa (designated in 2017)	OIE – World Organisation for Animal Health (the intergovernmental organisation responsible for improving animal health worldwide)
Certificate of Recognition (received in 2015)	33rd General Conference of the International Scientific Council for Trypanosomiasis Research and Control (ISCTRC) and 14th Pan African Tsetse and Trypanosomiasis Eradication Campaign (PATTEC) coordinators meeting

Recognition to programmes and projects

Award	Awarded to	Awarded by	Details
Special mention (received in 2019)	Young Entrepreneurs in Silk and Honey (YESH) project (implemented from 2016 – 2020), funded by Mastercard Foundation	International Innovation Award for Sustainable Food and Agriculture. The Award is funded by FAO and the Federal government of Switzerland	The YESH project was recognised in the category of innovations that empower youth in agriculture and food systems
Selection as example and success story (in 2019)	*icipe* Nematology Laboratory	The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH communication team	The laboratory was chosen as a success story for the GIZ Centre for International Migration (CIM) cooperation with AR4D partners. The laboratory is headed by Solveig Haukeland (Norway), a CIM Expert at *icipe*

Award	Awarded to	Awarded by	Details
NETFUND Green Innovations Award (received in 2014)	Muliru Farmers Conservation Group, a community group based adjacent to Kakamega forest, which is supported by *icipe* and partners	Government of Kenya, with support from the Swedish International Development Cooperation Agency (Sida)	Recognised for their mission of improving its members livelihoods while conserving the forest

Individual Recognitions

Category	Staff member	Award	Awarded by
Awards	Segenet Kelemu (Director General)	Ellis Island Medal of Honor, awarded in 2020	Ellis Island Honors Society, New York, USA
		Danforth Award for Plant Science, awarded in 2019 (becoming the first African recipient) for distinguished career in advancing international agricultural research to deliver impact for African farmers	Donald Danforth Plant Science Center, St. Louis, Missouri, USA
		Woman of the Decade in Natural and Sustainable Ecosystems, awarded in 2018, for outstanding leadership in the Natural and Sustainable Ecosystems category	Women Economic Forum (WEF)
		L'Oréal-UNESCO Award for Women in Science Laureate for Africa and the Arab States, awarded in 2014	L'Oréal-UNESCO for Women in Science
	Sunday Ekesi (Director of Research and Partnerships)	Grand Challenges Annual Meeting Call-to-Action Award, awarded in 2020	Bill & Melinda Gates Foundation, USA
	Fathiya Khamis (Scientist)	Abdool Karim Award in biological sciences, awarded in 2019, for research on native and invasive pests of fruits and vegetables, and for promotion of sustainable management of agriculture in Africa	TWAS, The World Academy of Sciences
	Baldwyn Torto (Head, Behavioural and Chemical Ecology Unit)	Agropolis Louis Malassis International Prize for Food and Agriculture, under the Outstanding Career in Agricultural Development category, awarded in 2019	Agropolis Foundation, Montpellier, France
		2018 Research Article of the Year and Lectureship Award of the *Journal of Agricultural and Food Chemistry* (AGRO Division), for a peer-reviewed article (published in the journal in October 2017) titled: 'Identification of the ubiquitous antioxidant tripeptide glutathione as a fruit fly semiochemical'	American Chemical Society

Awards and honours (November 2013 – present)

Category	Staff member	Award	Awarded by
Awards	Paul-Andre Calatayud (Visiting Scientist/ IRD)	Prix Réaumur, received in 2015, for a co-authored book titled: *Interactions insectes-plantes* (Insect– Plant Interactions)	French Entomological Society
	Zeyaur Khan (Leader, Push–pull Integrated Pest Management Programme)	Louis Malassis Prize for Outstanding Career in Agricultural Development, awarded in 2015	Agropolis Foundation, France
Special recognitions	Segenet Kelemu	Featured by UN Women among "seven women scientists you need to know and celebrate" in the context of the International Day of Women and Girls in STEM, in 2020	UN Women
		Honorary Doctorate, awarded in 2019	Bahir Dar University, Ethiopia
		Featured as one of four Ethiopian outstanding women in the March–April 2019 issue	*Selamta*, the inflight magazine of Ethiopian Airlines
		One of five "heroes in the field" selected by leading philanthropist, Bill Gates, for using their talents to fight poverty, hunger and disease, while providing opportunities for the next generation	Bill Gates
		Featured as one of the exceptional leaders from around the world, breaking ground and shattering the glass ceiling	*The CEO Magazine*, Australia
		Featured in 2017, among 30 renowned thinkers and scientists in an international VPRO documentary series exploring the human destiny and the world of tomorrow	*The Mind of the Universe* (open source science TV)
		Honorary Doctorate, awarded in 2016	Tel Aviv University (TAU), Israel
		Listed as one of the top 10 influential African women in Agriculture in 2015	*Journal of Gender, Agriculture and Food Security* (AgriGender Journal)
		Included in a commemorative calender in 2014, celebrating the 25th anniversary of OWSD	Organisation for Women in Science for the Developing World (OWSD – under the auspices of TWAS)
		Featured in a globally broadcast episode in 2014	*CNN African Voices*

Awards and honours (November 2013 – present)

Category	Staff member	Award	Awarded by
Special recognitions	Segenet Kelemu	Celebrated on Ada Lovelace Day, on 15 October 2013	The event celebrates achievements of women in science, technology, engineering and mathematics, and creates new role models for girls and women in these fields.
		Featured in an article titled: "Dr Kelemu's rise: From climbing trees in rural Ethiopia to excelling in science', in May 2014	*The EastAfrican*
		Featured in May 2014 as one of the top 100 most influential African women	*Forbes Africa*
	Baldwyn Torto	Honoured for commitment and outstanding mentorship to Justice Kwaku Addo, who graduated with a PhD in chemistry, in 2018	University of Cape Coast, School of Graduate Studies, Ghana
		Recognised as one of the top 50 scientists in Africa, and featured in the *African Researchers* booklet, published in celebration of Africa Science Day, in 2017	Department of Science and Technology, South Africa
		Appointed Extraordinary Professor, appointed in 2017	Department of Zoology and Entomology, University of Pretoria, South Africa
		Plenary Speaker, XXV International Congress of Entomology, held on 25 – 30 September 2016 in Orlando, Florida, USA	Entomological Society of America
		Plenary Speaker	European Union and United Nations Environment Programme Symposium on Global Declining Bee Populations, held in 2013 at University of Liege, Brussels
	Clifford Mutero (Scientist, Integrated Vector Management for Malaria Programme)	Recognised as one of the top 50 scientists, and featured in the *African Researchers* booklet, published in celebration of Africa Science Day (2017)	Department of Science and Technology, South Africa
	Robert R. Jackson (Visiting Scientist/ University of Canterbury, New Zealand)	Honoured in a Festschrift (a collection of writings celebrating the accomplishments of a scholar), in 2016	*New Zealand Journal of Zoology*

Awards and honours (November 2013 – present)

Category	Staff member	Award	Awarded by
Special recognitions	Charles Midega (Scientist)	Distinguished Africanist Scholar, awarded in 2014	Cornell University, Ithaca, USA
Fellowships	Segenet Kelemu	International Fellow, appointed in 2020	Royal Swedish Academy of Agriculture and Forestry
		Alumni Fellow from the College of Agriculture, appointed in 2019	Kansas State University, USA
		Fellow, appointed in 2016	TWAS
		Fellow, appointed in 2014	Ethiopian Academy of Sciences
		Fellow, appointed in 2014	African Academy of Sciences (AAS)
	Sunday Ekesi	Fellow, appointed in 2018	Royal Entomological Society, UK
		Fellow, appointed in 2015	AAS
		Honorary Fellow, appointed in 2015	Royal Entomological Society, UK
	Baldwyn Torto	Fellow, appointed in 2016	Entomological Society of America (ESA)
		Fellow, appointed in 2013	AAS
	Zeyaur Khan	Honorary Fellow, appointed in 2015	Royal Entomological Society, UK
		Fellow, appointed in 2013	TWAS
	Workneh Ayalew (Project Coordinator, YESH/MOYESH)	Fellow, appointed in 2018	Ethiopian Academy of Sciences
Appointments	Segenet Kelemu	Member, Policy Advisory Council, appointed in 2020	Australian Centre for International Agricultural Research (ACIAR)
		Ambassador	Food and Land Use Coalition
		Member, Advisory Board, appointed in 2018	Bill & Melinda Gates Foundation – Africa Plant Health Initiative (APHI)

Awards and honours (November 2013 – present)

Category	Staff member	Award	Awarded by
Appointments	Segenet Kelemu	Member, Program Advisory Board, Ceres 2030: Sustainable Solutions to End Hunger project, appointed in 2018	Cornell University, USA, International Food Policy Research Institute (IFPRI) and International Institute for Sustainable Development (IISD)
		Member, International Evaluation Panel of BMI prize, appointed in 2017	Boris Mints Institute (BMI) for Strategic Policy Solutions to Global Challenges, Tel Aviv University, Israel
		Member, International Academic Committee, appointed in 2017	BMI
		Member, International Jury panel of the 2016 series of the Rolex Awards marking its 40th anniversary	Rolex Awards for Enterprise
		Member, appointed in 2016	National Science and Technology Council of Rwanda, the governing body of the Country's National Commission for Science and Technology (NCST)
		Member, Governing Council, appointed in 2016	United Nations University (UNU), Japan, at the invitation of United Nations Secretary General
		Jury Member, in 2015	L'Oréal-UNESCO for Women in Science Sub-Saharan Africa programme
		International Jury Member, Louis Malassis and Olam Prizes, in 2015	Agropolis Foundation, France
		Member, International Advisory Board, appointed in 2013	Manna Food Security Center, Tel Aviv University, Israel
		Member, Scientific Advisory Committee, appointed in 2013	Canadian International Food Security Research Fund
		Member, Independent Science and Partnership Council (2014 – 2016)	CGIAR (A global research partnership for a food secure future; formerly: Consultative Group on International Agricultural Research)
	Sunday Ekesi	Member, Global Action on Fall Armyworm Technical Committee (2020 – 2023)	FAO
		Member, Scientific and Strategic Committee (2020 – 2023)	French National Research Institute for Sustainable Development (IRD)

Awards and honours (November 2013 – present)

Category	Staff member	Award	Awarded by
Appointments	Sunday Ekesi	Member, National & International Liaison Group, Fall Armyworm Preparedness and Control (2020 – 2022)	Centre for Environmental Stress and Adaptation Research (CESAR), Australia
		Member, Scientific Advisory Committee (2019 – 2021)	International Congress of Entomology (ICE2020), Helsinki, Finland
		Member, Fall armyworm R4D Consortium, appointed in 2018	CGIAR-led consortium to tackle fall armyworm
		Member, Technical Advisory Committee (2018 – 2021)	Virginia Tech IPM Innovation Lab, USAID
		Member, Programme Advisory Committee (2017 – 2022)	BioInnovate Africa Programme
		Membership Advisory Committee (MAC) in the field of Agricultural and Nutritional Sciences, appointed in 2017	AAS
		Selection and Membership Committee, appointed in 2016	AAS
		Member, Regional Programme for Fruit Fly Monitoring and Control in West Africa (2016 – 2020)	EU, CORAF/WECARD
		Member, Biovision Africa Trust (BvAT), Farmer Communication Programme, appointed in 2015	Biovision Foundation for Ecological Development
		Member, Editorial Board, appointed in 2014	*Journal of Insects as Food and Feed*
		Member, Editorial Board (2009–2013)	Tephritid Workers of Europe, Africa and the Middle East (TEAM)
	Baldwyn Torto	President, Board of Trustees, appointed in 2020	JRS Biodiversity Foundation, Seattle, Washington, USA
		Member, Editorial Board, appointed in 2020	*Current Opinion in Insect Science*
		Associate Editor, appointed in 2019	*Proceedings of the Royal Society B: Biological Sciences*, UK
		Member, Editorial Advisory Board, appointed in 2017	*Journal of Agricultural and Food Chemistry*, American Chemical Society
		Associate Editor, appointed in 2016	*Pest Management Science*, Society of Chemical Industry, UK

Awards and honours (November 2013 – present)

Category	Staff member	Award	Awarded by
Appointments	Baldwyn Torto	Reviewer panelist, Kwame Nkrumah Awards for Scientific Excellence: Rules of Procedure, appointed in 2016	African Union Commission
		Associate Editor, appointed in 2015	*International Journal of Tropical Insect Science*, African Association of Insect Scientists (AAIS)
		Member, Commission on Science Education, appointed in 2015	AAS
	Menale Kassie (Head, Social Science and Impact Assessment Unit)	Member, Research Committee for the Environment for Development (EfD) initiative, appointed in 2017	University of Gothenburg, Sweden
	Robert Skilton (Head, Capacity Building and Institutional Development Programme)	Selection panel member, appointed in 2018	L'Oreal UNESCO for Women in Science Fellowships – Africa
	Merid Getahun (Scientist)	Head, Max Planck Partner Group, appointed in December 2017	Max Planck Institutes, Germany
	Zeyaur Khan (Programme Leader, Push–Pull IPM Technology)	Adjunct Professor of Entomology, appointed in 2015	Cornell University, Ithaca, USA
	Subramanian Sevgan (Scientist)	Editorial Board Member, appointed in 2015	*SpringerPlus*

Communications

Never before has *icipe* achieved such high, regular and positive media coverage. The Director General's numerous awards and high profile event participation; the Centre's research breakthroughs; and regional and global importance, have kept the world press glued on *icipe*. Professional media monitoring shows that between 2013 – 2020, more than 3550 articles on the Centre were published or broadcast in local, regional and international media. Most of this coverage is available online, with many of the items reproduced, on average, by five additional outlets (beyond the initial publisher or broadcaster). As such, *icipe* news items have appeared in over 17,750 outlets. The cumulative potential reach of *icipe*'s coverage is approximately 300 million people, and the value of this publicity (advertising potential) is US$ 31 million.

879

Peer-reviewed journal articles were published between November 2013 and February 2020.

549

Books and other publications.

Donors (November 2013 – 2020)

Core donors

Aid for Africa, USA (until January 2017)

Federal Ministry for Economic Cooperation and Development (BMZ), Germany (until 31 December 2016)

Government of the Federal Democratic Republic of Ethiopia

Ministry of Higher Education, Science and Technology, Kenya

Swedish International Development Cooperation Agency (Sida), Sweden

Swiss Agency for Development and Cooperation (SDC), Switzerland

UK Aid, Government of the United Kingdom

Project donors continuing from previous period

Bill & Melinda Gates Foundation, Grand Challenges in Global Health

Biovision Foundation for Ecological Development, Switzerland

Canadian Government through International Development Research Centre (IDRC) and Grand Challenges Canada (GCC)

Consortium for National Health Research (CNHR), Kenya

Danish International Development Agency (DANIDA)

European Union

Food and Agriculture Organization of the United Nations (FAO)

Foundation for the National Institutes of Health (FNIH), USA

German Academic Exchange Service (DAAD)

German Agency for International Cooperation (GIZ)

Government of Finland

International Atomic Energy Agency (IAEA)

International Development Research Centre (IDRC)

International Fund for Agricultural Development (IFAD)

McKnight Foundation, USA

National Institutes of Health (NIH), USA

National Science Foundation (NSF), USA

Research Institute of Organic Agriculture (FiBL), Switzerland

Rockefeller Foundation, USA

Swiss National Science Foundation (SNSF)

TWAS, The World Academy of Sciences through Organization for Women in Science for the Developing World (OWSD)

United Nations Environment Programme (UNEP)/ Global Environment Facility (GEF)

United States Agency for International Development (USAID)

United States Department of Agriculture-Agricultural Research Service (USDA-ARS)

Wageningen University and Research Centre, The Netherlands

Wellcome Trust, UK

World Federation of Scientists, Switzerland

World Health Organization-Regional Office for Africa (WHO-AFRO)

New donors November 2013 – 2020

Austraining International, Australia

Australian Centre for International Agricultural Research (ACIAR) jointly with International Development Research Centre (IDRC) through Cultivate Africa's Future Fund (CultiAF)

Bayer AG, Germany

Bertha Foundation, UK

Bill & Melinda Gates Foundation Global Grand Challenges partnership

BioInnovate Africa Programme Phase II, supported by Sida, Sweden

British Council – Newton Fund Institutional Links 2016 Call

Cambridge-Africa ALBORADA Research Fund 2019

Ethiopian Catholic Church Social Development Commission

Food & Business Global Challenges Programme/ Netherlands Organization for Scientific Research (NWO-WOTRO)

Future Leaders – African Independent Research (FLAIR) Fellowships 2019

Global Challenges Research Fund (GCRF) – Global Agricultural and Food Systems Research, led by Biotechnology and Biological Sciences Research Council (BBSRC)

Innovate UK (formerly Technology Strategy Board)

L'Oréal Corporate Foundation, France

Mastercard Foundation, Canada

Max-Planck Gesellschaft through Max-Planck Institute for Chemical Ecology, Germany

Mozilla Foundation, USA

National Geographic Society, USA

National Research Fund – Multidisciplinary Research Grant, Government of Kenya

Norwegian Agency for Development Cooperation (Norad)

Partnership for Enhanced Engagement in Research Programme (PEER) supported by US National Academy of Sciences (NAS)/United States Agency for International Development (USAID)

R. Geigy Foundation, Switzerland

Scottish Funding Council, through the University of Glasgow, Scotland, UK

Sir Henry Wellcome Postdoctoral Fellowship, through University of Glasgow, Scotland, UK

Stichting Katholieke Universiteit, Netherlands (programme for appropriate technology in health)

Swedish Research Council

Swiss Family through Biovision Foundation for Ecological Development

SWITCH Africa Green, funded by the European Union and implemented by United Nations Environment Programme (UNEP) in collaboration with United Nations Development Programme (UNDP) and United Nations Office for Project Services (UNOPS)

Virginia Tech Management Entity of the Feed the Future Collaborative Research on Integrated Pest Management Innovation Lab (IPM IL), USA

Volkswagen Foundation, Germany

Funding sources for PASET-RSIF include:

Government of Burkina Faso

Government of Côte d'Ivoire

Government of Ghana

Government of Kenya

Government of Rwanda

Government of Senegal

Government of South Korea

World Bank

Schwarzia sp. (Hymenoptera: Apidae) to be named *icipensis* (in litt.) is a cleptoparasitic bee that invades the nests of pollen-collecting bees, deposits its egg(s), and the larvae that hatch from the eggs feed on the pollen of the unsuspecting host. It is a previously undescribed species named after *icipe* to commemorate its 50th Anniversary.

RESEARCH HIGHLIGHTS

Human Health Theme

The *icipe* Human Health Theme contributes towards the reduction, elimination and eradication of vector-borne diseases. The Centre aims to achieve this goal by generating knowledge and developing sustainable tools and strategies that control vectors, break the cycle of transmission, and which can be integrated into other disease management efforts.

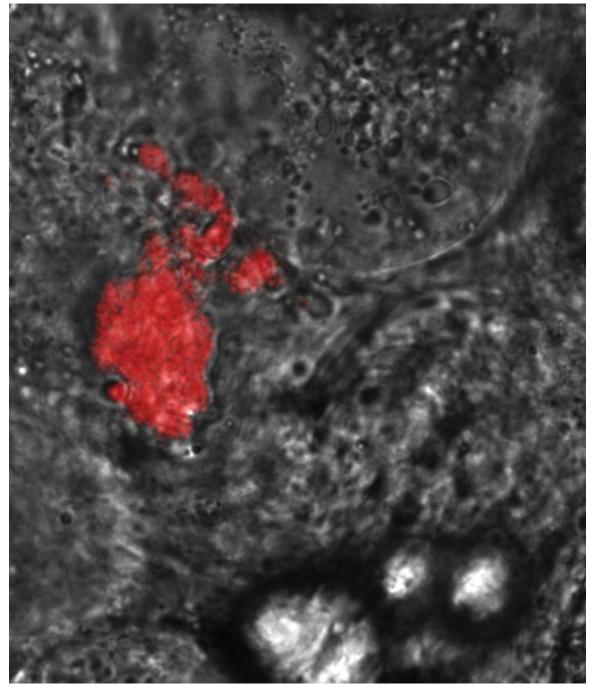
Malaria and mosquito control

By 2015, significant gains in malaria prevalence reduction were evident. However, *icipe* recognised that the sustainability of these accomplishments was being undermined by various factors. These obstacles include: increasing resistance by mosquitoes to insecticides; adjustments in feeding behaviour of the vectors; and growing ability of the insects to bite people outdoors; as well as a shift in their biting times. In fact, while past efforts had lowered malaria cases by an estimated 40%, from around 2016 there has been a noticeable plateau. This scenario shows the need for continued surveillance and vigilant tracking of changes in vector populations; vector–parasite, vector–host, host–parasite interactions; and malaria transmission patterns. These goals are shaping *icipe*'s basic research, and integrated vector management activities.

Basic research

In 2014, *icipe* commenced studies to explore the potential of endosymbionts that make insects more resistant to pathogens, as a basis for tools or strategies to prevent transmission of vector-borne diseases. In collaboration with colleagues from the University of Glasgow, UK, the *icipe* researchers have identified a microbe in malaria-transmitting mosquitoes that is capable of blocking transmission of the disease from the insects to people. The study was conducted on mosquitoes in their natural environments, mainly on the shores of Lake Victoria in Kenya. The researchers established that mosquitoes carrying the microbe, which they have named *Microsporidia MB*, do not harbour malaria parasites either in nature, or after experimental infection in the laboratory. The research also showed that the microbe is transmitted vertically; by being passed from female mosquitoes to their offspring at high rates, and the microbe does not kill or cause obvious harm to the mosquito host. Although the new *Microsporidia MB* symbiont is naturally found at relatively low levels in malaria mosquitoes in Kenya, the researchers believe that there may be ways to increase the proportion of moquitoes that carry it, to block their capacity to transmit malaria.

Further studies will be needed to determine precisely how *Microsporidia MB* could be used to control malaria. So, the next phase of *icipe* research will investigate the dynamics of the microbes in large mosquito populations in screen house 'semi-field' facilities.



Fluorescence microscopy image demonstrating how *Microsporidia MB* is able to enter the ovaries of the malaria mosquito.

The Centre also advanced knowledge on genetic make-up of mosquito groups, specifically *Anopheles funestus* mosquitoes that have recently been implicated in persistent malaria transmission. The researchers found locally adapted populations within *An. funestus* that can impact the distribution of genes of interest, such as insecticide resistance genes and gene drive initiatives. The studies revealed a wider array of species in the group than previously reported in Kenya. The findings also showed changed behaviour in biting, resting outdoors, feeding on diverse livestock, as well as people. Further, the researchers uncovered a potential new malaria vector in Kenya within the *An. funestus* group.

Further studies by *icipe* established that human odours have significant potential for development into robust, non-invasive diagnostic markers and predictors of symptomatic and asymptomatic malaria infections.

Researchers collecting mosquitoes in what they dubbed as 'magical mud', sites containing cedrol, where mosquitoes were more than twice as likely to lay eggs than in water fresh from Lake Victoria.

The use of an environmental DNA (eDNA) analysis technique in monitoring the malaria-transmitting *An. gambiae* larvae in experimental aquatic habitats was evaluated. This study showed that eDNA detection at species level rather than species complex level is achievable. Such a strategy could potentially save costs and time in monitoring these vectors.

In a world first, *icipe* found a naturally-occurring chemical that attracts pregnant malaria-transmitting mosquitoes. The chemical, known as cedrol, was found in mosquito breeding sites near Lake Victoria, Kenya. It could be used in traps that would 'attract-and-kill' the female mosquito, preventing reproduction before egg-laying.

The Centre reported that a highly aggressive invasive weed known as *Parthenium hysterophorus*, and within the region as famine weed, could increase malaria incidents in East Africa. This is because *Parthenium* has the ability to sustain the malaria-transmitting mosquito, *An. gambiae,* by feeding on it for sugars and extending its life even in the absence of a blood meal.

Integrated vector management

An IVM initiative commenced in 2008 in Tolay, Ghibe Valley, Ethiopia, was completed in 2019. This project built on previous successful efforts by *icipe* to manage animal trypanosomosis. The IVM activities were incorporated into the overall development programme in the area, addressing interlinked issues of poverty, environmental degradation and crop pest damage, while strengthening institutional linkages with partnering organisations, community groups and other stakeholders. The actions included sensitising people to the danger presented by malaria-transmitting mosquitoes, the relationship between mosquitoes and malaria, as well as guidance on environmental management and correct use of bednets.

Ethiopian women farmers and their daughters receiving tree seedlings to plant on their farms, a strategy that contributes to the protection of East Africa's rich biodiversity resources.

The prolonged use of synthetic pesticides to control disease vectors had become an environmental and health hazard to the communities in the region. Therefore, *icipe* introduced the use of eco-friendly botanicals in mosquito control strategies, with a triple purpose: to tackle the problems of resistance to the existing pesticides; conserve the environment; and provide the communities with a new source of income generation. Through collaborative efforts with the community, mosquito breeding sites were dried out and blocked water channels were cleared. Where this was impossible, stagnant bodies of water were treated with the mosquito larvicide Bti (*Bacillus thuringiensis israelensis*).

Mosquito scouts were involved in ensuring the long-term success of the project. The *icipe* project in Ethiopia benefitted 12,000 people. Within the 17 cells of the intervention, the activities reduced the density of malaria populations by 50%, and made significant progress in diminishing and maintaining the malaria challenge to very low levels. The quest for alternatives to insecticides led to the discovery of plants with larvicidal, insecticidal and repellent potential. Two plants that showed effectiveness were introduced for on-farm cultivation by the communities, towards the commercial development of biopesticides.

At policy level, *icipe* contributed to the establishment in 2017 of an IVM interagency coordinating committee (IVM-ICC) under the Kenya Ministry of Health, to champion intersectoral implementation of IVM in Ethiopia.

AFRO-II

icipe's success in IVM implementation over the years has provided impetus for the development of a major IVM regional project, commonly referred to as AFRO-II project, developed with support and funding from the Global Environment Facility (GEF), the United Nations Environment Programme (UNEP) and the World Health Organization Regional Office for Africa (WHO-AFRO). The purpose of the AFRO-II project is to support African countries aiming for malaria elimination to expedite implementation of IVM approaches. A salient feature of the project is the evaluation and demonstration of the effectiveness of diversified, environmentally-safe innovative vector control methods, including the use of alternative chemicals to DDT for malaria control. Specific interventions under evaluation include house screening to stop mosquito entry, and winter-larviciding of mosquito larval habitats to eliminate the development of larvae in the countries where the favoured breeding habitats exist. *icipe* was selected to be the key technical partner for this multi-country project running from 2017–2022.

Solar-powered mosquito trapping system

Through a collaboration with Wageningen University, Netherlands, a solar-powered mosquito trapping system (SMoT), baited with a synthetic odour blend that mimics human odour, was developed. The technology was tested through a project known as SolarMal between 2012 and 2015 in Rusinga Island, western Kenya. It led to a 70% decline in the population of *Anopheles* mosquitoes. Households using SMoTs recorded malaria infection rates that are 30% lower than those not using the technology. The innovation also contributed to a reduction in the negative impacts of kerosene use, such as upper respiratory tract infections, and kerosene-related accidents. Children were also able to study at home during the evenings due to availability of lighting from the SMoTs. The technology also elicited a saving culture, with approximately 100 women groups involved in saving towards sustaining the maintenance of SMoTs.

Predatory arthropods research

Since 1994, *icipe* and the University of Canterbury, New Zealand, have been researching on predatory arthropods, often referred to as 'the spider-malaria project'. These studies pertain to examples of unusually intricate predatory specialisation, with particular attention to cognitive behaviour. The goal is to link basic research on predators to application in human health. In this context, research on mosquito-specialist predators is a dominant theme, with a large portion of the studies focused on *Evarcha culicivora*, a spider that feeds indirectly on blood.

The spider expresses an active preference for blood-carrying mosquitoes, and specifically targets malaria vectors. In 2015, the researchers published an invited paper in the *Journal of Arachnology*, consisting of a comprehensive review of their research on *E. culicivora* over the years.

Uzimax, a plant-derived mosquito larvicidal product developed by *icipe* was registered by the Pesticides Control Products Board of Kenya. The product is now undergoing large-scale field trials to confirm its effect on non-target organisms and residual activity, determine community acceptance, and initiate commercialisation.

Neglected tropical diseases

Neglected tropical diseases or NTDs are a diverse group of parasitic and bacterial infectious ailments that prevail in tropical and subtropical conditions in 149 countries, affecting more than one billion people, and costing developing economies billions of dollars every year. NTDs mainly affect populations living in poverty and cause immense human suffering and long-term disability, and are the cause of death of over 500,000 people per year. *icipe* commenced research on NTDs at its founding, and in recent years, the Centre has intensified efforts towards developing One Health approaches to prevent such ailments.

Rift Valley fever
Building on studies from the previous phase, *icipe* has developed a cost-effective sampling framework for better understanding of the risk pathways and vulnerabilities related to Rift Valley fever, including vectors, pathogens and livelihoods, in the context of climate change and agroenvironmental transformations.

The Centre's studies have also focused on generating further knowledge on the impact of the current mode of communication and infrastructure development, and on access and barriers to human and animal health care among pastoral communities in northeastern Kenya.

The ecology of vectors of Rift Valley fever has been explored, for monitoring and control purposes, and to detect emerging risks. The findings show that the Rift Valley fever vectors use specific plants as resting sites. These spaces provide a unique microclimatic to extend mosquito survival, thereby contributing to their ability to transmit pathogens, including the Rift Valley fever virus. Such sites could be targeted, to break transmission during intense transmission.

In addition, *icipe* has generated knowledge of the microbial communities associated with disease vectors that can be explored for symbiotic control of vector-borne diseases. The studies report distinct bacterial communities harboured by primary Rift Valley fever vectors in Kenya: *Aedes mcintoshi* and *Aedes ochraceus*, highlighting their potential differences in competence in the viral disease.

Yellow fever is an acute viral haemorrhagic disease transmitted by infected mosquitoes of the *Stegomyia* subgenus. The first-ever outbreak of yellow fever in Kenya occurred between 1992 and 1995. This outbreak was controlled through a mass vaccination exercise in 1993, which was repeated in 2003. *icipe* research has aimed to: determine existence and locality of yellow fever transmission foci in Northern Kenya at border points with endemic countries; assess vector species presence and their vector potential; and assess the potential for urban *Aedes* mosquitoes to sustain yellow fever outbreak in major urban centres in Kenya.

Dengue fever is a mosquito-borne viral disease that has spread in many regions in recent years. The dengue virus (DENV), the cause of dengue fever, is transmitted by female mosquitoes mainly of the species *Aedes aegypti*. *icipe*'s recent accomplishments include: identification of suitable odours and tools for attracting and sampling dengue vectors; screening of an odour bait for forest-dwelling *Aedes* mosquito species; and establishment of the chemical profile differences in people and primates.

The current studies on NTDs at *icipe* aptly illustrate the transition and connection of the Centre's research activities throughout its history. For example, the Centre is building on significant studies undertaken in the 1980s and 1990s that contributed knowledge on vector diversity, parasite biology and disease epidemiology of yellow fever and leishmaniasis. First, *icipe* continues to explore the connection – revealed by the Centre's researchers during that period – between sand flies and *Leishmania* parasites. Second, in its early years, the Centre had characterised sand fly species using various techniques, including chemical approaches and morphological descriptions. These approaches are now being complemented with molecular tools, to improve accuracy of identification of the vectors at a much higher throughput. Third, studies are ongoing to explore a hypothesis that sand flies, alongside other blood feeding insects play important roles in the maintenance of viruses (including those causing Rift Valley fever and various arboviral diseases) between epidemics. This research is also investigating how sand fly association with plants impacts on their survival, with the view of developing innovative surveillance and control tools against them.

Leishmaniasis is one of the most debilitating NTDs, with about one million new cases reported globally annually. The eastern Africa region is a key, active transmission area of leishmaniasis. The current *icipe* studies aim to limit infections in endemic areas in Kenya. *icipe*'s current research is aimed at determining the magnitude and dynamics of visceral leishmaniasis and cutaneous leishmaniasis, through population-based screening, understanding the ecology of sand fly vectors (including their feeding patterns), and determining their infection burden. The knowledge on epidemiological factors will enable the design of tools and development of strategies to limit contact between sand flies and people. Further, the researchers hope to explore sand fly microbiomes as a leishmaniasis transmission blocking strategy. A possibility is the use of *M. anisopliae* that has been found to kill adult sand flies. The researchers are investigating suitable devices for its deployment.

Tungiasis (commonly known as jiggers) is a neglected tropical skin disease caused by the female sand flea, affecting millions of people in SSA. The insect burrows into the skin, causing intense pain, itching and debilitation. The Centre's researchers and partners have analysed tungiasis risk factors, and tested a locally-made, herbal remedy consisting of neem and coconut oil for treatment of tungiasis. Building on the Centre's research, collaborative efforts to develop sustainable flooring solutions for communities to interrupt the sand flea life cycle and prevent tungiasis are ongoing. *icipe* is also now a partner in a national task force on ectoparasitic diseases.

Schistosomiasis is an acute and chronic parasitic disease caused by trematode worms of the genus *Schistosoma*. Despite the significant role of snails in disease transmission, malacological studies are rare. The Centre has tested and confirmed the hypothesis that pesticide pollution may favour the development and spread of host snails. Activities have included comprehensive statistic data analysis of extensive and complex ecological data, and field sampling and dose response tests to assess the acute sensitivity of *Schistosoma*-host snails and associated tropical macroinvertebrate species to representative insecticides relevant in freshwater bodies of western Kenya.
The findings show that pesticides used in agriculture may well be an outright driver of schistosomiasis.

Research within the Animal Health Theme is aligned to *icipe*'s vision to extend sustainable land management, increase food supply and reduce hunger, and improve agricultural research, technology dissemination and adoption. The activities focus on developing tools and strategies to control livestock diseases transmitted by two important vectors on the continent: tsetse flies and ticks. Recently, *icipe* has commenced research to address camel health and productivity.

Tsetse collar technology

Upscaling and commercialisation

icipe has made significant progress in upscaling the tsetse repellent collar technology in Kenya and Ethiopia. Simultaneously, the Centre and private–public partners have advanced commercial availability of the technology, while also facilitating its integration into broad-based agricultural development practices. One of the highlights during this period was the registration of the blend by the Pest Control Products Board of Kenya, which is the main component in the *icipe* tsetse repellent collars. As reported in previous chapters of this report, the blend was developed from the odour-profile of chemicals identified by *icipe* in waterbuck, an animal known to be unpreferred by tsetse. The registration is important as it supports more effective commercialisation of tsetse repellent collars. In accordance, the Centre is progressing plans to licence private sector manufacturers.

The Centre continues to improve the tsetse repellent collar technology to make it more effective and affordable. Optimised dispensers are being produced in partnership with small-scale artisanal facilities.

The Centre has bolstered marketing and distribution of the tsetse repellent collars through production agreements with private sector partners, use of community owned resource persons (CORPs), training of the Kenya Tsetse and Trypanosomiasis Eradication Council staff and other government officials, and a cloud-based agrovet system known as LiMA developed and implemented through a partnership with mHealth Kenya Ltd.

Milk value chain, Somaliland

Between June 2013 and December 2017, *icipe* was involved in a collaborative project aimed at developing a sustainable peri-urban milk value chain in Somaliland. Specifically, the Centre contributed to the goal of improved milk production, and quality and market linkages. *icipe* developed an inventory of the nutritive value of native grasses and feed resources. The studies showed that inclusion of crushed pods of *Prosopis juliflora* (an invasive shrub) in a livestock diet of sorghum stalks and indigenous grass increased milk production by 52.6%. The *icipe* push–pull technology was also introduced for production of fodder, but with a broader view of long-term benefits of the technology for communities. Non-chemical control of ticks as an alternative to acaricides using the ICIPE 7 biopesticide was successfully tested. These activities were supported by extensive capacity building of local authorities and dairy sector stakeholders.

Basic research on tsetse

Decoding the tsetse fly genome

icipe was a key partner in the genome sequencing of the *Glossina morsitans morsitans* tsetse species, completed in 2014. This milestone was achieved through a 10-year project led by the International Glossina Genome Initiative (IGGI), which brought together more than 150 researchers from nearly 100 institutions across the world. *icipe* was instrumental in the description of the sensory genes, which, in this and other tsetse species, are responsible for guiding the interactions between the flies and their environment.

Chemical sensing in tsetse

In 2014, *icipe* published findings identifying the genes responsible for chemical sensing in tsetse. The researchers reported the surprising discovery that although tsetse fly species differ in their responses to animal odours, they all use the same set of genes to find hosts (people or animals) on which to feed. Because tsetse use chemical sensing to survive (to find food, places to produce their larvae, and find mates, as well as to escape from enemies), these results indicate a possible way to manipulate their behaviour, and to design appropriate control strategies.

Among global recognitions of this research include its publication in the prestigious *Science* journal (prominently featured on the cover page of the 25 April 2014 issue), and in several satellite papers in the *PLoS* family of journals.

Zebra scent: New leads for tsetse control

icipe research found that zebras, specifically odours found in their skin, may provide leads to boost the management of trypanosomosis further. Previous research has shown that tsetse flies avoid, and hardly bite zebras, even though zebras are commonly present in areas infested by the flies. Until now, the reason for this evasion has been unclear, with speculations that the zebras' striped skin is a contributing factor. However, the zebra stripes are only visible to tsetse flies at about 5–10 metres. Beyond this distance, zebras appear uniformly grey to the flies. The *icipe* study established that zebras produce certain scents that repel tsetse flies. The researchers also found a blend of three of these odours that could enhance the effectiveness of existing tsetse management tools, including the *icipe* tsetse repellent collar technology and NGU traps. The blend is being optimised against *G. morsitans morsitans* and *G. m. centralis* tsetse species in Zambia, as of 2019.

All in the brain: Tsetse odour repellency

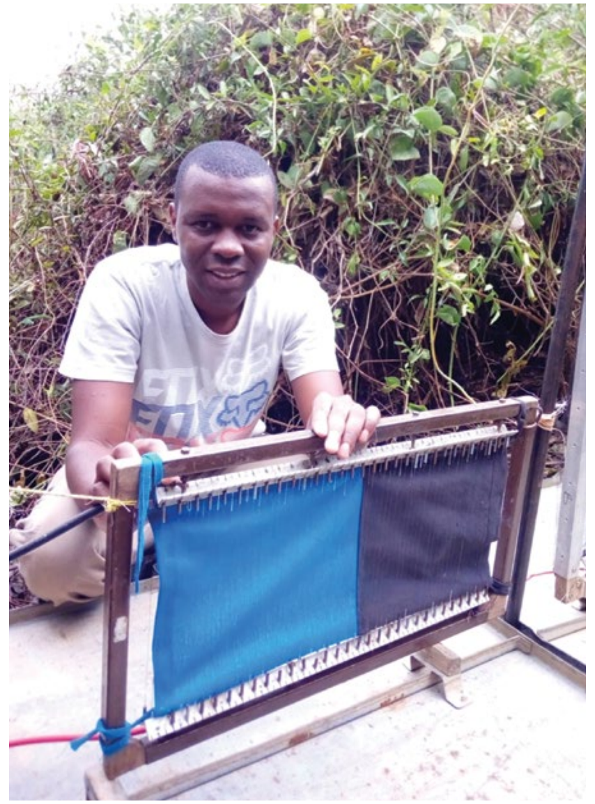
Building on *icipe's* groundbreaking findings of tsetse repellent compounds in waterbuck, the Centre has now identified the cellular and molecular mechanisms that the fly uses to detect and code the odours. Focusing on the sensory neurons and odourant receptors in tsetse antennae, the study reveals the sensors used for the interaction between the fly and the environment – the source of the repulsive odour – and ultimately the decision to avoid it.

Moreover, in separate studies, the Centre has identified the putative proteins that bind the specific odour components, paving the way for evaluation of novel ligand (attractive or repellent) design.

Tsetse midgut

Tsetse flies harbour endosymbionts that perform different functions. Primary symbionts (for example *Wolbachia* bacteria) support the survival of tsetse by providing nutritional supplements. Secondary symbionts, such as *Sodalis* bacteria, are not obligatory. *icipe*'s research shows that these modulate susceptibility of tsetse flies to infection with trypanosomes. Identifying the molecules responsible for modulating vectorial capacity could lead to novel options for blocking transmission, the passage of trypanosomes from tsetse flies to humans and livestock.

Sticky panels:
Trapping HAT tsetse
icipe-led research identified a possible novel technology for sampling *Glossina fuscipes fuscipes*, the tsetse species that transmit human African trypanosomiosis. The researchers found that small sticky panels made of blue cloth and insecticide-treated black netting material attract and kill more tsetse than the commonly used biconical traps. They also determined how colour differently influences the choice by female and male tsetse on where to land on the panels.



Joshua Njelembo conducted the studies that led to this research as an *icipe* ARPPIS student, registered at the University of Zambia. Now a Principal Tsetse Biologist at the Tsetse and Trypanosomiasis Control Unit (TTCU), Zambia, Joshua is the contact person for a new collaboration with *icipe* to expand research and scale up the Centre's technologies in the country.

Knowledge on trypanosomes
In their life cycle in tsetse, trypanosomes, the parasites that cause trypanosomosis, must undergo several transformations, which can result in high mortalities for the parasites. As reported in previous chapters of this publication *icipe*'s early studies focused on understanding the factors that promote trypanosomes in the tsetse midgut – when bloodstream form parasites originating from the vertebrate host enter into the insect's midgut, by transforming into a form (known as procyclic), which is better suited for survival in the harsh environment created by the vector (tsetse fly) hosts. This research led to the identification of a trypsin-lectin molecule, as a key factor in the survival of the parasites in this stage. More recently, the Centre's research has focused on the trypanosomes stage when the parasites transform into a metacyclic form that enables movement to the tsetse salivary glands. The parasites are expelled through the tsetse's saliva whenever the insect seeks a blood meal.

The movement of trypanosomes is generated by the beat of a flagellum, a whip-like appendage attached to their surface. This motility is key for survival, and has characteristic adaptations that are species-specific. In 2015, *icipe* completed a study to compare and characterise the movement and behaviour of four trypanosome species that infect livestock, namely: *Trypanosoma vivax*, *T. brucei*, *T. evansi*, and *T. congolense*. Although the mechanism that propels the flagella is the same in all trypanosome species, *icipe*'s research, in collaboration with the University of Würzburg, Germany, established that different species have distinct swimming patterns, speeds, and flagella wave frequencies. This adaptation may also explain why adaptation of some species of the parasite can invade and populate specific tissues in the mammalian host. The findings also suggest that the ability to clear antibodies mounted by tsetse is similar in all trypanosomes, irrespective of the significant variations in swimming speeds. Modulating this motility could guide development of novel disease control tools.

The Centre's studies in the field have also shown the presence of multiple trypanosome species, in some cases more than one species in tsetse flies. This is also the case in biting flies, such as the stable fly *Stomoxys calcitrans*, that act as mechanical vectors of trypanosomes, especially in the absence of tsetse flies.

Camel diseases: Biting flies management

In 2015, based on the experience and knowledge gained through the development of technologies for the control of tsetse flies, *icipe* initiated new research for the control of camel disease vectors in arid and semi-arid lands of SSA. Specifically, the focus was on camel trypanosomosis, or surra, a parasitic disease caused by trypanosomes transmitted by biting flies. There has been limited understanding of the actual vectors involved in surra transmission, as well as lack of vector control technologies. In addition, there has been poor diagnosis of the disease, as well as increasing resistance to many of the drugs used to treat it. As a result, in many cases, the only option for farmers is to allow animals that become infected with surra to die. *icipe*'s goal is to pioneer research, and to develop affordable, environmentally-friendly control technologies.

The Centre has made significant progress, starting with research findings that show that camel trypanosomosis is the most significant disease affecting these animals, probably caused by a complex of trypanosomes species including *Trypanosoma evansi*, *T. brucei*, *T. vivax* and *T. congolense*.

The studies also identified four major species of biting flies and potential vectors of surra associated with camels: *Hippobosca camelina*, *Pangonia ruppellii*, *Tabanus* spp. and *Stomoxys calcitrans*.

The biting flies repellent identified by *icipe* is being disseminated through the already existing 'camel collar' that pastoralists use to keep track of their animals.

The findings have led to the development of an integrated surra vectors management, composed of a repellent being disseminated through a 'camel-collar', and an attractant, being employed in an odour-baited trap. Both the attractant and repellent are dispensed from a nano polymer beads dispenser that maintains stability of the compounds and slow release.

This integrated technology has demonstrated promising results in the control of the biting flies. This trend is supported by improved camel health, as indicated by rising packed cell volume in animals that were noted to be anaemic at the start of the studies. Surra transmission has also been contained. A simple visual test for identifying infected camels using a non-invasive urine test was developed.

icipe researchers showed stable flies feed on various plants as sugar sources. Supplementing blood with plant feeding significantly increases larval emergence as compared to when the flies feed on blood alone. Therefore, specific plants may be exploited for the control of stable flies and the diseases they transmit.

Further studies by the Centre have identified chemical odours in specific animal dung that guide pregnant female stable flies (*S. calcitrans)* to lay their eggs on the most suitable droppings. This optimum selection facilitates survival of the eggs and the emergence of stronger offspring, thus ensuring thriving generations of the flies. These findings could lead to the development of odour-baited traps for these highly destructive, extremely adaptive, yet little studied insects.

Ticks control: An integrated approach

icipe has continued research on ticks, this time employing an integrated approach that encompasses other hosts beyond livestock, for example wildlife; other disease vectors, including mosquito, tick, and tsetse fly species; diverse pathogens (arboviruses, trypanosomes, tick-borne pathogens) that they harbour; and extending to diverse ecosystems.

Early surveillance research in northern Kenya revealed multiple tick–pathogen associations, including the following viruses: Dugbe, Kupe, Dhori and Ngari. These findings underlined the significant infection risk in livestock, in addition to other parasitic and bacterial infections, some transmitted by ticks. These studies also showed evidence of circulation of Crimean-Congo haemorrhagic fever, a zoonotic tick-borne pathogen with high case fatality rates.

Significant parts of these studies were conducted in the world-renowned Shimba Hills and Maasai Mara National reserves. High rates of *Theileria parva* (the causative agent of East Coast fever) were found in *Rhipicephalus appendiculatus* ticks in the Maasai Mara, whereas in Shimba Hills, the more benign *Theileria velifera* was more common. Active circulation of *Rickettsia africae*, the causative agent of African tick-bite fever, was identified in both reserves.

In other studies, *icipe* researchers identified, for the first time in ticks from diseased camels, a tick-borne bacterium known as *Ehrlichia ruminantium* that causes heartwater disease in sheep. This bacterium was also found in high rates in ticks sampled from tortoises of Baringo County, Rift Valley, Kenya, suggesting a possible role of these animals in disease epidemiology. Similarly, ticks sampled from monitor lizards in Homa Bay County, along Lake Victoria, Kenya, had high rates of *Ehrlichia canis*, the causative agent of a flu-like illness known as ehrlichiosis in canines.

Most recently, a study on tick samples from livestock markets in western Kenya, identified Crimean-Congo haemorrhagic fever in rhipicephaline ticks.

In July 2019, *icipe* started integrated tsetse and tick control activities in Benishangul Gumuz region, Ethiopia. By 2020, progress had been made in data compilation on household level livestock inventory, and design of intervention protocol and baseline epidemiologic surveillance. In addition, cattle blood samples had been obtained for analysis. Capacity building efforts on integrated vector control strategies were also being undertaken among animal health assistants, veterinarians, and agricultural extension workers.

Ticks are known to be resistant to available chemical acaricides. Since inception, *icipe* has made it a goal to search for alternatives. This long-running quest is now bearing encouraging results. Recent trials have established that an isolate from *M. anisopliae* is effective against ticks.

Ticks feed on almost all animals, including monitor lizards, as shown in this picture. Therefore, *icipe* is progressively broadening its research on these vectors, beyond livestock.

Plant Health Theme

The Plant Health Theme undertakes innovative basic and applied research, with the underlying principle of developing control options for crop pests that reduce the use of pesticides and their subsequent impacts on the environment, as well as the inevitable pesticide resistance that comes from their extended use. The Theme's research is based on discovery and strategic use of biopesticides, semiochemicals, and other naturally-occurring compounds that can be employed to disrupt the life cycles of pests and their control through identification and release of parasitoids.

icipe Management visiting a push–pull farm in Ethiopia.

Push–pull technology

In 2011, *icipe* started to develop a climate-smart version of the push–pull technology, in relation to the dry and hot conditions associated with climate change. During this period, the Centre conducted intense investigations that revealed greenleaf desmodium (*Desmodium intortum*) and *Brachiaria* cv Mulato, as the ideal intercrop and border crop, respectively.

icipe found these drought-tolerant varieties to have similar characteristics as those used in the conventional push–pull. They can repel and trap stemborers, suppress *Striga*, improve soil health, provide high-quality fodder and accrue benefits for farmers; for example, by facilitating crop–livestock integration, thus expanding income streams.

An economic assessment study has shown that the climate-smart push–pull technology increases yields by between 2.5 and 3.8 tonnes per hectare.

The transformative impact of push–pull is evident in improved yield, as seen in this thriving plot.

icipe trained 970,700 (524,832 female, 442,268 male) farmers directly and through partners in Africa, and more than 92 million farmers were indirectly reached through secondary channels, for example through mass media.

A cumulative number of 241,040 farmers had adopted push–pull, 133,465 (55%) of them were female farmers, directly benefiting approximately 1,500,000 people (using a household size of six people).

By end of 2019 push–pull had been introduced in 17 African countries: Benin, Burkina Faso, Burundi, Cameroon, Democratic Republic of Congo, Ethiopia, Ghana, Kenya, Malawi, Mozambique, Rwanda, Senegal, Tanzania, Togo, Uganda, Zambia and Zimbabwe.

Fall armyworm

The fall armyworm is a destructive moth that causes devastating damage to almost 100 plant species, including sorghum, rice, wheat and sugarcane, as well as a variety of horticultural crops. As a result, the pest threatens food and nutritional security, trade, household incomes and overall national economies. Until 2016, the fall armyworm was restricted to its native region of origin, the Western Hemisphere (from the United States of America to Argentina). However, in January 2016, the pest was reported in Nigeria, and it has since spread at an alarming rate across Africa. By 2020, 47 African countries had confirmed the presence of the pest.

Estimates in 2018 from 12 African countries suggested an annual loss of 4.1 to 17.7 million tonnes of maize valued between US$ 1.1 – 4.7 billion annually due to fall armyworm invasion. Fall armyworm is likely to affect over 300 million people in Africa, who, directly or indirectly, depend on the crop for food and wellbeing.

Efforts to control the fall armyworm through conventional methods (such as the use of insecticides) are complicated by the fact that the adult stage of the pest is most active at night, and farmers detect the infestation only after damage to the crop. The pest also has a diverse range of alternative host plants that enables its populations to persist and spread.

Moreover, fall armyworm has developed resistance to some insecticides. At the same time, the performance of such chemicals is also hindered by limited knowledge and purchasing power of farmers, resulting in the use of low quality, and often harmful products.

Mr and Mrs Chingoli, farmers from Malawi, were among the first to report, in 2016, that the push–pull technology could be tackling the fall armyworm.

In 2017, *icipe* studies established that the climate-adapted version of push–pull is effective in controlling the fall armyworm, providing a suitable, accessible, environmentally-friendly and cost-effective strategy for management of the pest. These findings represented the first documented report of a readily available technology that could be immediately deployed in Africa to manage the fall armyworm efficiently.

The ability to manage such a devastating pest demonstrates push–pull's utility as a platform technology in addressing the multitude of challenges that affect cereal–livestock farming systems in Africa. *icipe* intends to continue disseminating the technology as widely as possible across Africa while advancing studies to understand the scientific basis of its effectiveness against the fall armyworm.

icipe assessed 21 fungal isolates from three different genera (*Metarhizium*, *Beauveria* and *Isaria*) against the egg stage of fall armyworm. Results showed good performance of isolates of *M. anisopliae*, ICIPE 78, ICIPE 40 and ICIPE 20. ICIPE 78, which has been commercialised as Mazao Achieve® against spider mites by Real IPM Ltd, could be used as a potential biopesticide to suppress fall armyworm in Africa.

The Centre and partners also undertook surveys for indigenous natural enemies attacking fall armyworm in Ethiopia, Kenya and Tanzania. They found that one native egg parasitoid (*Chelonus curvimaculatus*) and four native larval parasitoids (*Charops ater*, *Coccigydium luteum*, *Palexorita zonata* and *Cotesia icipe*) to have formed new associations with fall armyworm in Africa. Among these parasitoids, *Cotesia icipe* was widely distributed.

Maize lethal necrosis research

The outbreak and spread of maize lethal necrosis disease (MLND) from 2011 threatened food security in the eastern Africa region. In Africa, MLN is caused by a co-infection by *Maize chlorotic mottle virus* (MCMV) and *Sugarcane mosaic virus* (SCMV). Corn thrips, *Frankliniella williamsi*, and corn leaf aphid, *Rophalosiphum maidis*, were known to vector MCMV and SCMV, respectively. However, information on the identity and distribution of potential vectors of MCMV and SCMV in eastern Africa, their host plants, and management strategies was lacking.

icipe identified six insect vectors of MCMV (*Carpophilus* sp., *Frankliniella williamsi*, *F. schultzei* [pale form], *Thrips tabaci*, *T. pusillus*, and a curculionid weevil), and one vector species of SCMV (*Rhopalosiphum maidis*). *icipe* also made the first report on lethal necrosis infection on finger millet.

Photo taken by *icipe* researchers in a field in Rift Valley, Kenya, where the first report of lethal necrosis disease on finger millet was made.

Smart maize

icipe research revealed the superiority of the innate defence mechanism of maize landraces, the so-called 'smart maize', to stemborers in comparison to some commercial hybrid maize varieties. Stemborers damage the maize crop in their larval stage, triggering a defence reaction from the maize. The *icipe* study found that 'smart maize' can defend itself from the egg stage of stemborers before they hatch into larvae, pre-empting damage on the crop.

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Further, *icipe* researchers identified genetic markers linked to this stemborer resistance trait in the smart maize germplasm. These findings will facilitate use and delivery of the natural stemborer resistance to farmer-preferred maize cultivars with other agronomically desirable traits. In a related study, researchers identified the structures of chemical compounds (elicitors) that activate the defence response on smart plants from the stemborer egg material associated with attachment to the leaves. These discoveries open up opportunities to search for sorghum germplasm that demonstrates this favourable trait.

Amanuel Tamiru (Ethiopia), a scientist at *icipe*, collecting volatiles from maize seedlings as part of the smart maize research.

Fruit fly IPM

This period has been characterised by intensified efforts to upscale the *icipe* fruit fly IPM tools, technologies and strategies. An exciting development has been the Centre's scientific breakthroughs in basic science on fruit flies as a foundation for the control of these pests. Such knowledge has enabled the Centre to advance and boost its packages.

Scientific advances

icipe researchers reported the resolution of the identity of the *Bactrocera* invasive fruit fly. The pest, which was first recorded in Kenya in 2003 before its spread across the continent, was initially inaccurately described as a new pest to science and accorded the name *Bactrocera invadens* in 2005. This imprecise identification created challenges for African fruit growers, due to phytosanitary restrictions imposed by lucrative horticultural import markets based on the pest's seemingly novel status. However, using integrative taxonomy (including morphometric techniques and molecular barcoding), the study established the pest to be synonymous to the oriental fruit fly, *B. dorsalis*, already present in many countries worldwide. The settlement of the pest's identity will enable researchers to adapt control tools developed for the *B. dorsalis* species complex from regions where the pest has been in existence for a longer period.

icipe generated knowledge on the host-marking pheromones that enable certain fruit fly species to deposit a chemical (pheromone) to indicate fruits where they have already laid eggs, thereby preventing repeated egg-laying on the same fruit. Knowledge on this specific chemical, commonly known as a 'host-marking pheromone', is useful in the control of species that exhibit such a phenomenon. For instance, if a product containing such host-marking pheromone(s) is sprayed onto fruits, it could deter and prevent some fruit flies from laying eggs on them.

In a global first, *icipe* designed novel primers to identify endosymbionts in African fruit flies. Of particular interest was the discovery of *Spiroplasma* species that are new to science in both native and exotic species. The Centre has also increased knowledge in the under-researched area of the gut microbiome of fruit flies. Available information suggests a wide range of insect–microbe interactions in nature.

Five new fruit fly species (*Ceratitis quilicii*, *C. pallidula*, *C. taitaensis*, *C. sawahilensis*, *C. flavipennata*), in the genus *Ceratitis* were identified and genetic barcode libraries constructed to ease the identification process. Employment of integrative taxonomy and subtle differences in molecular and morphological characters led to the recognition that the two *Ceratitis rosa* species entities (lowland and highlands) were separate, sibling species designated as *Ceratitis rosa* sensu stricto and the newly described *C. quilicii*.

The Centre also identified potential natural gut microbes and hosts transcriptional profiles that could be used to define and differentiate the two fruit fly sibling species *Ceratitis quilicii* and *Ceratitis rosa* sensu stricto. *icipe* is testing control strategies based on these two sets of findings in farmers' fields.

Postharvest
The Centre has developed protocols for postharvest disinfestation of *Bactrocera dorsalis* in mango. This will facilitate access to lucrative export markets in Europe, USA and Japan. These protocols are being translated into technologies and commercial set-ups that will benefit mango growers in the region. These activities are in progress, in partnership with private sector partners in Kenya and Uganda.

Fathiya Khamis (second right), a former *icipe* ARPPIS student and now a Scientist at the Centre pictured with team members: (left to right) Judy Gitonga, Evalyne Ndotono and Levi Ombura. Fathiya won the 2019 TWAS - Abdool Karim Award in biological sciences, for her research on native and invasive pests that devour fruits and vegetables, and for her promotion of sustainable management of agriculture in Africa.

Bait facility
A Fruit Fly Protein Bait Facility to enable local, commercial production of Fruit Fly Mania™, a product developed based on *icipe* research, was established through a partnership with Kenya Biologics Ltd. Fruit Fly Mania™ has a lower retail price in comparison to other commercially available products. The Facility, the only one in the continent outside the Republic of South Africa, has a production capacity that is enough to meet the demand of over 229,000 households whose livelihoods depend on mango production in Kenya. An additional 400,000 mango growers will benefit from Fruit Fly Mania™, once the product is registered across East Africa.

Upscaling and impact
Studies in Kenya in 2015 showed that the *icipe* fruit fly IPM package can reduce the pests' infestation in mango by more than 80%. Follow-up assessments between 2016 and 2018 showed that the use of fruit fly IPM technologies increases net income by 9 – 137% and decreases insecticide use by 74%. The estimated economic value of the fruit fly IPM is US$ 19 million per year in Kenya with a benefit–cost ratio of 27:1 and with a potential to reduce the number of rural poor people by 72,642.

Between 2015 and 2019, the *icipe* fruit fly IPM packages were expanded to Ethiopia, in Arba Minch region, where fruit fly infestation has been reduced from about 70% to 10–13%.

Based on this success, *icipe* is upscaling the fruit fly IPM packages in Kenya and Ethiopia, and commenced implementation in Malawi, Mozambique, Tanzania, Uganda, Zambia and Zimbabwe.

These efforts are supported by intensive training; for example, through the establishment of more learning centres, training of more extension officers, and awareness creation on IPM strategies. By 2020, a total number of 8,175,957 mango growers had benefited from *icipe* fruit fly IPM technologies. This figure includes direct beneficiaries; those who received hands-on training on the use of the fruit flies IPM technology and received IPM starter packs (49,739), those who benefited through parasitoid releases (627,200), as well as the 6,499,018 growers who indirectly benefited through interaction with the trained growers, extension officers and community service providers. In addition, approximately one million growers have been reached through mass media campaigns on the *icipe* fruit fly IPM technologies.

Citrus IPM

The Centre commenced studies in addressing two of the most serious pests of citrus: the African citrus triozid, *Trioza erytreae*, and the false codling moth.

In addition to other damage, *T. erytreae* transmits a devastating bacterium known as *Candidatus* Liberibacter africanus (CLaf), which is responsible for the African citrus greening disease. In addition, false codling moth is a quarantine pest.

Helen Heya (right), a laboratory technologist at the Kenya Plant Health Inspectorate Service (KEPHIS), one of the Centre's collaborators, and Peterson Nderitu, an *icipe* research assistant, sampling citrus pests using an aspirator.

Moreover, the Asian citrus psyllid *Diaphorina citri*, which transmits the devastating huanglongbing or Asian citrus greening disease, was detected in Africa in 2015. If uncontrolled, the pest could devastate citrus production in Africa as has been the case in Florida, USA.

The Centre's accomplishments include the development of the first-ever DNA barcode reference library of *T. erytreae*, presenting a basis for rapid and accurate identification of the pest to aid phytosanitary measures.

In close collaboration with relevant regulatory authorities, *icipe* has made progress in the management of *D. citri*, including design of methods, tools and technologies (traps, attractants, sampling design and methods) to monitor and detect the pest early to guide intervention and minimise spread.

A pan-African task force spearheaded by *icipe* has been formed to develop an action plan for the containment and prevention of the further spread of these pests and diseases.

Vegetable IPM

Scaling out thrips and tospoviruses management

Activities continued towards scaling out the thrips and tospoviruses IPM strategies in East Africa, through effective public–private partnerships that resulted in the commercialisation of biopesticides, field demonstration of technologies and building capacity among quarantine agencies and agricultural extension officers. Improved application strategies were developed for biopesticides, such as the 'lure-and-infect', autodissemination and spot-spray application techniques that minimise the cost of biopesticide application while retaining the efficacy.

Bean flower thrips
(Megalurothrips sjostedti)

icipe and partners discovered chemical odours that could be exploited to develop technologies for trapping bean flower thrips (*Megalurothrips sjostedti*), in Africa. The research identified chemical odours, scientifically referred to as aggregation pheromones, released by male bean flower thrips that attract male as well as female thrips. The pheromones cause bean flower thrips to assemble in a focal point on the plant, and can, therefore, be used to lure them.

This study provided the first information regarding the aggregation pheromone among the thrips belonging to the *Megalurothrips* group in Africa. The chemical odours can be integrated with other thrips management options, such as insect pathogenic fungal biopesticides. For instance, the pheromones could be useful in the effective timing of sprays of biopesticides to achieve maximum control. The pheromones could also be used to draw thrips away from the crop to a focal point where the pests are infected with biopesticides.

Integrated pest and pollinators management

In 2018, *icipe* launched a three-year project on integrated pest and pollinators management (IPPM), aimed at enhancing productivity of avocado and cucurbits in East Africa. The IPPM project was built on the premise that environmental services (such as pollination and integrated pest management) are key drivers, and two components that can interact in a variety of ways, resulting in healthier agricultural landscapes and improved food security. Cucurbits (cucumber, butternut and pumpkin), and avocado are economically important crops in East Africa, which are also highly dependent on pollination services and are severely affected by several insect pests.

African indigenous vegetables

In Africa, indigenous vegetables are becoming increasingly important in efforts to improve people's nutritional security. Spurred on by this imperative, *icipe* is conducting research on African indigenous vegetables and the need to address challenges that have kept yield and quality of these crops way below their potential and demand.

Amaranth (*Amaranthus* spp.) is a traditional, fast-growing, leafy vegetable that is becoming increasingly popular in many parts of Africa. The leaves are rich in protein, vitamins, and minerals.

African nightshade (*Solanum scabrum*)

icipe is developing eco-friendly management strategies against pests of African nightshade, amaranth and leafy cowpea. Research activities have included increasing understanding of the agro-ecology of major arthropod and nematode pests, as well as their natural enemies. Exploratory studies have also been conducted to develop IPM technologies involving parasitoids, biopesticides, attractants, resistant varieties, cultural practices and soft pesticides. In addition, the researchers have assessed the socio-economic attributes of African indigenous vegetables production and IPM techniques, while also strengthening the capacities of farmers and agricultural officers.

One of the outcomes has been the discovery that a species of the African nightshade, a widely consumed indigenous vegetable in Africa, has evolved a unique ability to defend itself against one of its major pests, the tomato red spider mite. *icipe*'s findings show a distinctive resistance strategy in the plant, which is based on opposing roles, with the chemicals acting as attractants in the leaves and the trichomes defending the plant against certain behaviours of the attacking pests. In effect the pest is lured to its 'dead end'. The Centre will advance this research with the aim of developing integrated pest management strategies to control tomato red spider mites on African nightshade.

Managing *Tuta absoluta*

In 2015, Africa was taken by surprise by the invasion of the tomato leafminer, *Tuta absoluta*, its presence and devastation immediately noticeable on solanaceous vegetables, especially tomato, in the continent. As tomato production is one of the most important income-generating activities for small- and medium-scale tomato growers, the presence of this pest was a source of great concern. *icipe* sprung into action, developing basic knowledge on this invader: its bioecology, host range and distribution, as well as association with indigenous natural enemies. *icipe* has developed promising fungal-based biopesticide and endophytes to tackle the various stages of the pest.

icipe has established the invasion pathway of the pest using microsatellite markers. The Centre also generated prediction maps of the spatial–temporal spread of *T. absoluta* in Africa.

A natural enemy, *Doligochenidea gelichiidivoris*, of *T. absoluta*, has been introduced from Peru (the native home of the pest) and, after preliminary laboratory studies, is now being released in the field.

Two isolates of the entomopathogenic fungus, *Metarhizium anisopliae* have been found to be pathogenic to *T. absoluta*.

Rice, maize and chickpea IPM

icipe has been part of a five-year (2015–2020) project funded by USAID through the Feed the Future Integrated Pest Management Innovation Lab at Virginia Tech, USA that aims to benefit smallholder farmers of Ethiopia, Kenya and Tanzania to implement proven, robust and locally adapted IPM options.

As a result, the push–pull technology was upscaled in the three countries, improved rice varieties and IPM practices were promoted to control rice stemborers and rice blast disease, as well as chickpea wilt, rootrot, blight, and pod borer.

Over 50,000 farmers were reached through a total of 30 workshops, 55 training sessions, 23 farmers field days and three exhibitions organised in the three countries. Alongside, the capacity of community, researchers and institutions was also strengthened.

A socio-economic impact study indicated that the adoption of push–pull technology increases crop yield by 61.9% and maize income by 38.6%. The study also showed the importance of collaboration between governments, NGOs, research institutions and communities to address the IPM challenges in the region and to improve the implementation of existing pest management policies.

icipe and collaborators in this initiative received a certificate of appreciation from the Ministry of Agriculture, Ethiopia, for outstanding achievement, specifically in the implementation of the push–pull technology in the country.

Coffee IPM

In collaboration with the French Agricultural Research Centre for International Development (CIRAD), the Centre has embarked on research to develop IPM tools and strategies to manage coffee pests and diseases in East Africa. These studies have led to the development of risk maps to predict the distribution of coffee pests in the context of climate change. Temperature-based development models are useful to assess the risk of pest occurrence on coffee in Africa, and at a world scale for the coffee berry borer, *Hypothenemus hampei*.

The chemical ecology of the antestia bug, *Antestiopsis thunbergii* has led to the development of a trapping system, currently tested in coffee plantations with promising results. Also, icipe is implementing IPM best practices in Uganda geared towards a triple certification scheme (organic, fair trade and geographical indication).

Biopesticides development and commercialisation

As mentioned in various sections of this publication, since the 1980s, *icipe* has conducted extensive, systematic bioprospecting for arthropod pathogens. This research has been accompanied by trials to establish the efficiency of various isolates on a variety of crop pests and disease vectors. These efforts led to the establishment of an Arthropod Pathogen Germplasm Repository at the Centre in 1992. As of 2020, this bank houses an estimated 450 isolates, largely from entomopathogenic fungi.

Moreover, *icipe* has developed a range of biopesticides, primarily from strains obtained from *Metarhizium anisopliae* fungus. Alongside, the Centre has developed innovative application strategies for such products combined with insect attractants, such as: lure-and-infect; autodissemination; using insects infected with the fungus to spread it to others; and spot-spraying, which is the application of biopesticides to a focal point alone where insects are attracted.

In 2005, *icipe* started earnest commericalisation of various isolates in partnership with the private sector, notably the Kenya-based Real IPM (now a member of the Biobest Group NV, Belgium). They include ICIPE 69, ICIPE 78 and ICIPE 62, for the management of a variety of pests that attack crops, and ICIPE 7 for the management of livestock ticks.

By 2019, the biopesticide products commercialised through the *icipe*–Real IPM public–private partnership had been used by 53,198 farmers, and applied in a total area of 132,994 hectares. The biopesticides have been registered in nine African countries (Ethiopia, Ghana, Kenya, Mozambique, South Africa, Tanzania, Uganda, Zambia, Zimbabwe), and in Canada. Registration is ongoing in several other countries.

Moreover, in view of recent pest invasions in Africa, including the fall armyworm that arrived in the continent in 2016, and the locust outbreak in eastern Africa, which started in January 2020, the Centre has identified potent entomopathogenic fungal products as alternatives to the harmful synthetic insecticides being employed. These products are being registered in East African countries.

Nematodes research

Since establishment, *icipe* has intermittently conducted research on soil-dwelling nematodes. Although the majority of nematode species are beneficial and contribute to nutrient cycling and suppression of insect pests, a number of them are detrimental to plant health. While a complex community of plant-parasitic nematode species affect crop production in Africa, the most significant group are root-knot nematodes (*Meloidogyne* spp.). These nematodes infect roots and cause direct yield losses by preventing adequate water and nutrient uptake by the plant, or indirect losses by facilitating fungal and bacterial infections through wounds and damage that they cause. Root-knot nematodes are particularly destructive and infect most, if not all, cultivated crops.

Recent research on plant-parasitic nematodes at *icipe* began in earnest in 2013 within the Behavioural and Chemical Ecology Unit (BCEU). In 2014, through the GIZ-funded CIM integrated expert programme, a nematologist joined *icipe* tasked with developing nematology expertise at the Centre in partnership with the International Institute of Tropical Agriculture (IITA). In tandem, BCEU and the nematology-dedicated groups from *icipe* and IITA have made significant accomplishments in generating new knowledge on nematodes, capacity building and awareness creation towards the management of these pests in Africa.

Chemical ecology of plant-parasitic nematodes

Studies conducted in BCEU include investigations on the chemical cues in high-value vegetables (such as tomato, spinach and pepper) that lead to infection by root-knot nematodes.

Lucy Kananu (Kenya), who conducted studies on plant-parasitic nematodes, as part of postdoctoral research, based in the *icipe* BCEU.

The chemical signals involved in the interaction between the root-knot nematode species, *M. incognita* (a highly damaging species), and a common sweet pepper cultivar grown in East Africa have been identified. Although previous studies have shown that roots of host plants may attract or repel nematodes, this is the first time that the mediating chemicals have been determined. These findings provide the potential for breeding peppers that are resistant to root-knot nematodes.

The Unit also collaborates closely with IITA on various initiatives, including joint participation in a project led by North Carolina State University, USA, to develop a biodegradable matrix from banana fibre (banana paper) that acts as a carrier for effective application of micro-dosages of nematicides, for the management of potato cyst nematodes (PCN). This research seeks to expound the underpinning principle of the banana paper from a chemical ecology perspective. Findings so far indicate that the banana paper absorbs and adsorbs PCN hatching factors; significantly reduces PCN hatch by 37% with the abamectin-treated paper and 35% with untreated paper; and slows down PCN development.

Further research has revealed that it may be possible to PCN by inducing ‘suicidal hatching’ of the pests using naturally occurring chemicals in crop roots. Blends of the compounds obtained from crude material of such plants may be used to treat potato fields as organic soil amendments. This approach would be environmentally attractive and better than using nematicides, which can be hazardous, and due to their dependence on single compounds, are prone to pest resistance.

Managing potato cyst nematode

The *icipe* Nematology Group has taken a leadership role in the management of PCN, an invasive quarantine pest that was first reported in Kenya in 2014. With the support of the Food and Agriculture Organization of the United Nations (FAO), and in partnership with national partners, the team has trained technicians to determine the prevalence, general severity, and species diversity of PCN across Kenya. The Centre has generated knowledge on PCN biology under Kenyan conditions; identified potential biological control agents and trap crops; evaluated potato cultivars that are resistant to PCN; and created awareness among farmers and plant health workers in the country. These efforts are being extended regionally.

Further studies by the team indicate that certain crops act as dead-end PCN traps: while the nematodes are attracted to, and infect the roots of such plants, they are unable to survive on them. This discovery presents promising leads for PCN management, and studies are currently ongoing on the possibility of using African nightshade as a dead-end trap crop strategy for PCN in eastern Africa.

In addition, *icipe* is a partner in an initiative funded by Innovate UK, led by Crop Health and Protection (CHAP); and PES Technologies, UK, to develop a diagnostic tool to identify and quantify PCN.

Confocal image of female potato cyst nematode, *Globodera pallida*, and eggs after staining.

Bananas and nematodes

As a partner in an EU-supported project known as **M**icrobial **U**ptakes for **S**ustainable Management of Major Banan**A** Pests and Diseases (MUSA), the researchers are conducting studies and testing strategies on endophytes and biocontrol agents against key banana pests. Specifically, *icipe* is undertaking research on free-living nematodes, insect (pest) parasitic nematodes, parasitic nematodes of slug pests, as well as microbiological management of plant-parasitic nematodes.

Towards a hub of nematology

icipe and IITA have established a dedicated Nematology Laboratory and, arguably, the largest active nematology group in the region, and conceptualised an informal platform dubbed NemAfrica, leading to *icipe* becoming a recognised hub of nematology research.

This laboratory has become a training platform where students from regional universities can efficiently and effectively conduct thesis practical work, or undertake internships that initiate them into advanced studies, or careers in nematology or broader agricultural areas.

Networks have been enhanced, for example through a formal partnership between *icipe* and IITA, and Gent University, Belgium, which enables multi-faceted collaborative capacity building for scholars from Africa and beyond, with training being conducted in Kenya and Belgium.

Links have been forged with farmers, institutes, universities and private sector partners in East Africa, further boosting training opportunities, awareness, capacity building and professional technical support on nematodes.

A review of nematode pests and their impact on food security in SSA, the first of its kind in terms of scope, jointly published by *icipe*, IITA and partners was recognised as the most outstanding publication of 2018 by the IITA Board of Trustees.

In 2019, the GIZ communication team selected the *icipe* Nematology Laboratory as an example and success story of CIM cooperation with agriculture for research development partners.

Environmental Health Theme

The focus of the Environmental Health Theme is to broaden knowledge on arthropods and their diversity and role in ecosystems, contribute to conservation and sustainable use of biodiversity, and develop strategies for climate change mitigation and adaptation. The Theme pursues specific lines of research, including: bee research; bioprospecting, particularly for plants for biopesticides and medicinal products; and habitat management, which supports biodiversity, pollination ecosystem services, and alternative hosts for pests and diseases.

Bee research

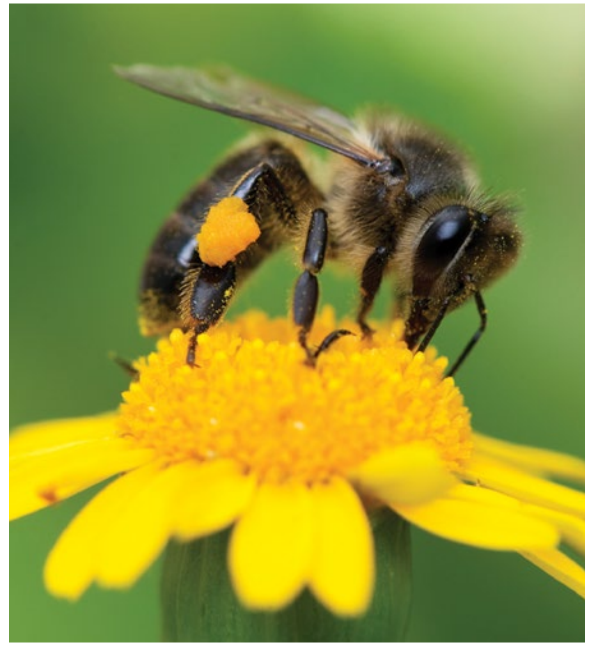
icipe has refined its activities in this area through a Bee Research Strategy based on four major pillars: bee health; pollination; nutrition of bees; and microbiome research. *icipe* aims to complete gaps in knowledge and to rectify the absence of systematic procedures and capacity to monitor, analyse and safeguard bees. The Centre is addressing these aspects through the African Reference Laboratory for Bee Health, headquartered at *icipe* Duduville Campus, Nairobi, Kenya, and satellite stations in Ethiopia, Burkina Faso, Cameroon and Liberia.

In 2017, *icipe* was designated as an OIE Collaborating Centre for Bee Health in Africa by OIE – World Organisation for Animal Health (the intergovernmental organisation responsible for improving animal health worldwide). This designation is significant as it formally recognises *icipe*'s role as a hub of bee health expertise in Africa and globally.

icipe Director General, Segenet Kelemu, presents a gift to Jean Philippe-Dop, Deputy Director General, OIE, during his visit to the African Reference Laboratory for Bee Health.

The Centre continues to contribute knowledge on colony collapse disorder (CCD), while also mapping bee health risk factors, and exploring mitigating strategies in Africa and globally. This research builds on past *icipe* studies, which showed that honey bees in Africa are less vulnerable to brood diseases, parasites such as *Varroa* mites, and pests like the small hive beetle. *icipe* research also found that Africanised honey bees in the USA, many of which are hybridised crosses with European species, tolerate maladies associated with CCD better.

Recent *icipe* studies have revealed a higher rate of grooming (hygienic behaviour) in African bees compared to European bees. Further, the Centre's findings indicate that African bees can detect *Varroa*-infested brood cells, open them and remove the mites without harming the developing bee pupae.



icipe researchers are characterising the gut microbiota of the African honey bee and stingless bees, the 'friendly bacteria' that aid insect nutrition and defence against pathogens. Findings indicate that the bee microbiome in Africa is conserved compared to bees in the northern hemisphere. However, the former differs in the abundance of certain members. These changes might highlight differences in ecological niches and thus different roles of the gut microbiota in bee physiology. The hope is that this increased understanding of how gut microbiota influences the health of bees will lay a foundation for microbe-based strategies for bee health management.

Importantly, *icipe* is focusing on the often overlooked, but vital role of bees in boosting agricultural productivity through pollination of crop and wild plants, and the provision of essential ecosystem services. In this regard, *icipe* has conducted studies on pollinator–nectar–microbe interactions, the pollination efficiency of various stingless bee species on horticultural crops, and on the effect of supplementation of farms with pollinators to close the pollination deficit.

Through its bioprospecting activities, *icipe* has developed a new plant-based biofumigant and repellent for bee pests and diseases known as Apicure®. The product has been tested in small-scale field trials in various regions in Kenya, Ethiopia, Madagascar, Liberia and Burkina Faso, where it is effective in killing *Varroa* mites and in repelling small hive beetles in bee colonies. *icipe* has made two patent applications in Kenya, and internationally.

Commercial and beneficial insects

icipe, with the support of the International Fund for Agricultural Development (IFAD), has been implementing beekeeping activities as part of efforts towards Alternative Livelihoods for Food and Income Security, in four Indian Ocean Island Nations (Mauritius, Seychelles, Comoros and Madagascar) and Zanzibar (United Republic of Tanzania). The efforts include technology transfer in beekeeping, capacity building, development of honey marketplaces and bee health research. The first phase of this initiative was concluded in September 2017. *icipe* launched a new phase in 2019.

icipe launched a pilot beekeeping project supported by Biovision Foundation for Ecological Development in Wag Himra Zone, Ethiopia. It recruited and supported a total of 300 youth to establish 30 youth beekeeper enterprises, and operations have started as planned. The goal is to draw lessons from the pilot phase to inform a planned beekeeping commercialisation cluster financed by the Government of Ethiopia in Tekeze valley, Amhara Region.

Loredana Sorg (second left), Biovision Foundation for Ecological Development, Switzerland, pictured during a visit to the new beekeeping pilot project site, with Mulu Getaneh (left), a local trader who prepares refined beeswax plates for use as foundation sheets by *icipe* researchers. Also in the picture is Workneh Ayalew (second right), *icipe* Ethiopia Office, and Muluken Zeryihun (right), Deputy Manager, Amhara Regional State Livestock Resources Development Promotion Agency, a partner in the project.

From YESH to MoYESH

As a true expression of one of *icipe*'s main strengths – constant alertness to the changing dynamics due to emerging issues in Africa – in 2016, the Centre, in partnership with Mastercard Foundation launched the Young Entrepreneurs in Silk and Honey (YESH) project, a five-year initiative aimed at benefitting unemployed and out-of-school youth in Ethiopia. By 2019, the YESH project had generated jobs for 12,500 young men and women in the country through honey and silk enterprises.

MoYESH Youth beekeepers: (l–r) Eskeziaw Mogne, Tsehaynesh Neber, Birhan Alehegn and Dires Cheru from East and West Gojjam, Ethiopia.

Youth silkworm growers: (l–r) Aynalem Choke, Mitiku Denbel and Samrawit Chernet in Cahno Mille, Gamo Zone, Ethiopia.

The scheme also established functional marketplaces for honey and beeswax. It served as a platform for *icipe* to lead the development of a National Sericulture Development Strategy, at the request of the Ministry of Agriculture of the Federal Democratic Republic of Ethiopia.

Building on this progress, in 2019, *icipe* and the Mastercard Foundation, in partnership with the Ethiopia Jobs Creation Commission launched the MOre Young Entrepreneurs in Silk and Honey (MoYESH) programme, a five-year initiative aimed towards enabling 100,000 young men and women in Ethiopia secure dignified and fulfilling direct employment along honey and silk value chains.

Domestication of stingless bees

icipe has over the last decade implemented activities that have led to the domestication of more than 15 African stingless bee species of economic importance. The Centre has established pilot rearing demonstration sites in Burkina Faso, Cameroon, Kenya, Democratic Republic of Congo, Ethiopia and Tanzania. *icipe* has also conducted studies to understand: improved hive technology and simple colony division; major pests and pathogens; habitat deterioration (including natural forest loss); and reforestation and afforestation with exotic tree species negatively impacting the species richness and diversity of stingless bees in SSA.

Stingless bee honey

Future research will focus on investigating the physico-chemical and biofunctional properties, *in vitro* production of queens and mass colony production, and food resources used by stingless bees from different ecological zones in Africa, to better understand how these bees rely on plant resources. Additionally, the Centre is revising the stingless bee diversity of Africa and their pollination efficiency on greenhouse horticulture fruit crops.

In collaboration with communities, *icipe* is conducting rearing trials of wild silk (*Gonometa* sp.) in Mwingi County, eastern Kenya. Over the past 20 years, *icipe*'s beneficial and commercial insects projects have had a significant impact in this dry area, prone to sporadic rainfall.

Advancing sericulture in Africa

The Centre is researching the development of various sericulture products, based on the quality regulations of the European Union, Organisation for Economic Co-operation and Development (OECD) and other trade agencies. As silk farming is still a novel area in Africa, *icipe*'s activities have focused on establishing the basics of wild, mulberry and eri silk farming in different agroecological regions.

So far, *icipe* has completed studies to understand the biology of the eri silkmoths, *Samia cynthia ricini* and *Philosamia cynthia ricini*, and their subspecies. Future research will focus on the African wild silkmoths, *Gonometa postica*, *Argema* sp., *Anaphe* sp. and *Epiphora* sp., from different ecological zones in Kenya, to understand their genetic variation.

icipe aims to identify and develop strains and hybrids with productive merit. Silkworm biotechnology research and diversification of silkworm products using silk 3Fs: Fabric, Food and Feed is ongoing. Indeed, this will be the future silk way to prosperity.

Climate change

As reported in the previous chapter, in 2011, *icipe* and the Ministry for Foreign Affairs of Finland commenced the Climate Change Impacts on Ecosystem Services and Food Security in Eastern Africa (CHIESA) project, a five-year initiative aimed at researching potential innovative strategies to enhance climate change adaptation capacity in Africa. The project was concluded in 2015, with a range of key outcomes as listed in the sections that follow.

Production of microclimatic information specific to the study areas, that is Taita Hills in Kenya; the Didessa River Basin in Jimma Highlands, Ethiopia; and along the southeastern slope of Mount Kilimanjaro in Tanzania.

Development of life-tables of pests and natural enemies of four key crops (maize, crucifers, avocado and coffee). Additional factors likely to influence the pest dynamics, such as farming practices and soil factors, were also investigated and correlated with environmental data.

Recommendations to minimise the predicted risks, include:

Use of suitable natural enemies for the control of stemborers in higher altitude areas. Guided by knowledge on their efficacy and tolerance to temperature, natural enemies were released to control *Bactrocera dorsalis* fruit flies. To sustain pollination efficiency of the honey bee, *Apis mellifera*, conservation of flowering plants and maintaining of beehives in avocado orchards was proposed. Since the efficiency of *Cotesia vestalis*, a wasp that controls the diamondback moth naturally in the lower altitudes is expected to improve in higher altitudes, the wasp can be used in biological control in the latter regions.

Training on controlling vegetable pests, in view of climate change.

Wild crucifers need to be conserved as a way of naturally controlling the pest. Some strategies to reduce coffee pest and disease impact in present and future climatic conditions, and prevention of deforestation include: promotion of tree planting in coffee farms to provide shade; dissemination of existing good coffee agronomic practices; use of risk analysis tools, such as distribution maps and prediction models; and biological control of pests and diseases.

The findings of the CHIESA project were validated and disseminated through the Adaptation for Ecosystem Resilience in Africa (AFERIA), a two-year project implemented from 2016 – 2018 by *icipe* and the Ministry for Foreign Affairs of Finland, and various partners. AFERIA was implemented in the highland ecosystems of Jimma, Ethiopia; and Taita Hills and Murang'a county, in coastal and central Kenya respectively, benefiting 15,000 farmers.

The strategies disseminated include: controlling maize pests; planting economic and indigenous trees; awareness-raising campaigns; training of trainers on the importance of beekeeping in climate change mitigation; modern beekeeping technologies and standard maintenance for quality honey production; and use of improved coffee varieties.

Biosystematics

Continuing its ever-expanding insect biodiversity programme, the Biosystematics Unit has provided source material to over 30 collaborators working in institutions across five continents. The 13 wasp and three fly species pictured here represent a small percentage of the more than 150 new species from *icipe*'s collection that have been described to date, addressing the substantial gaps in our knowledge of East African insects. As representatives of the different functional groups present in ecologically healthy habitats, each of these predators, parasitoids, frugivores, detritivores, etc. are important contributors to the stabilisation of the habitat in which they are found.

These new species and the other insect specimens we collect are being databased, an exercise that will provide access to important data on species distributions in space and time, which are essential baseline data for evaluating the effects of human disturbance and climate change on insect communities. In naming the new species, the researchers have immortalised various sites, ethnic groups and individuals in Africa and from across the world. Some of the wasp species are of immediate importance to humans through their suppression of pests of cultivated crops. For example, collaborative research between *icipe* and the Institut de Recherche pour le Développement (IRD) in France has led to the identification of a new *Cotesia* species that one can use as a biological control agent in suppressing populations of the moth *Sesamia nonagrioides*, an important maize pest in France.


Anachrysis, female


Muhaka icipe, paratype


Alhajarmyia Stuckenberg


Aphelopus severancei, male


Hermannomyia ukasi


Megastigmus sp. nov. 1, female

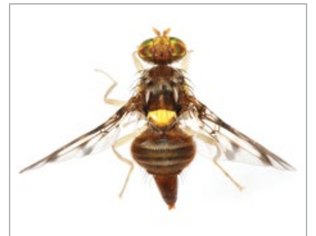

Anteon copelandi, female


Anteon alteri, female


Anteon shimbanum, female


Dinapsis, female


Hedychridium


Ceratitis, female


Embolemus burundensis


Cyphacolus copelandi, female


Megastigmus sp. nov. 6, male


Paramblynotus ruvubuensis

Insects for Food and Feed Programme

As discussed in the previous chapter of this report, in 2012, *icipe* began to consider insects for food and feed as new strategic research. In 2014, the Centre conducted background research, prepared proposals, and established linkages with national and international stakeholders, including donors, research institutions, and public and private sector institutions. *icipe* compiled an inventory entitled 'African edible insects for food and feed: Inventory, diversity, commonalities and contribution to food security', which the *Journal of Insects as Food and Feed* published in the first volume. The Centre also established the Insects for Food, Feed and Other Uses Programme (INSEFF), as the platform for its activities in this area.

Accomplishments

Generated knowledge on the diversity, host plants and abundance of various edible saturniid caterpillars among them *Gonimbrasia zambesina*, *G. belina*, *Bunea alcinoe*, *Nudaurelia krucki* and *Cirina forda*.

Discovered, a new edible cricket species, *Scapsipedus icipe* Hugel & Tanga nov. sp., and documented its true scientific information.

Documented the natural regulatory factors of these insects (parasitoids, predators and pathogens) that influence their abundance in nature, and commenced investigations on strategies to mitigate them.

Completed nutritional profiles of 28 insect species for food and feed. Results show 92% of these insects to have higher crude protein than fishmeal. Findings also indicate that the saturniid caterpillars and edible crickets have higher levels of calcium and magnesium as compared to the longhorned grasshopper, *Ruspolia differens*. Dietary iron and copper contents were higher in the edible insects, as well as key vitamins such as β-carotene, β-cryptoxanthin, lutein, zeaxanthin and riboflavin (Vitamin B2).

Showed that consumption of the meat of the desert locust could be good for people's hearts. *icipe* studies showed that the desert locust (*Schistocerca gregaria*), contains a rich composition of compounds known as sterols, which in turn have cholesterol-lowering properties, thereby reducing the risk of heart disease.

Found orthopteran species (edible and non-edible) to be the richest in essential fatty acids, antioxidants (flavonoids) and vitamin E, making them ideal candidates for mass rearing for oil production.

Improved traditional traps of the edible longhorned grasshopper *Ruspolia differens* to increase catches, filter out harmful or non-target insects, and enable safer and energy-saving options.

Developed rearing protocols for 16 insect species, the most productive colonies being black soldier fly (*Hermetia illucens*); crickets (*Scapsipedus icipe* and *Gryllus bimaculatus*); grasshoppers (*Schistocerca gregaria* and *Ruspolia differens*); silkworm (*Bombyx mori*) and American cockroach (*Periplaneta americana*).

Developed simple methods for extracting insect oils that could be used as food ingredients and in skincare products. The strategies are ideal for low-income households to generate additional income.

Adapted semiochemical lures to trap the palm weevil, *Rhynchophorus phoenicis* as a crop protection strategy, and to also collect the weevils for mass production of edible larvae in Uganda and Kenya.

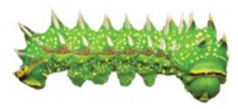
Developed, and launched quality standards for compounding animal feed with dry insect products in Kenya and Uganda, which has enabled small-, medium- and large-scale feed producers to integrate insects into feed production.

Trained a total of 1294 young entrepreneurs, policymakers and scientists on insect rearing for integration into animal feed.


Desert locust, *Schistocerca gregaria*


Long-horned grasshopper, *Ruspolia differens*


African house cricket, *Scapsipedus icipe*


Speckled emperor moth, *Gynanisa maja*


Cabbage tree emperor moth, *Bunaea alcinoe*


Zambezi emperor moth, *Gonimbrasia zambesina*

Socio-economic findings

The production capacity of insect colonies (cricket and black soldier flies) by smallholder producers varies from 200,000–600,000 adults per week. Over 80% of fish and poultry farmers, 65% of pig farmers, and 75% of feed traders and processors, interviewed through an *icipe* survey are willing to use insects as feed.

Egg production of poultry reared on feed that included insect-based protein compared favourably with that of birds reared on feed containing the traditionally used fishmeal. A higher cost–benefit ratio and better return on investment was recorded when poultry was reared on the highest inclusion of black soldier fly meal, compared to the conventional diet. Replacement of 20% fishmeal in conventional poultry feed with black soldier flies resulted in higher (53%) egg production and improved quality compared to conventional feed.

icipe studies have shown that insect rearing is a sustainable practice that can be undertaken with minimal inputs and is, therefore, ideal for women farmers who are often constrained by limited access to agricultural resources.

Performance studies focusing on catfish fingerlings revealed 37% higher growth rate and 23% higher weight gain through black soldier flies-based feed, compared to conventional feed. Nile tilapia fed with black soldier flies-based feed were 23% heavier than those fed with conventional feed.

Performance studies focusing on pigs revealed 25%, 50%, 75% and 100% fishmeal replacement by black soldier fly provided similar growth rate, weight gain and nutrient profile compared to 100% fishmeal.

At an average productivity rate of two metric tonnes of dry insects per year per entrepreneur, the insects for food and feed sector can potentially create 22,500 new jobs in Kenya alone.

Insects as a protein source are estimated to reduce protein cost in feed production by 25% – 37.5%. By substituting 50% of the animal protein additive in feeds with insect-based proteins, Kenya alone will require 45,000 metric tonnes of dry insects per year. A kilogramme of dried black soldier fly sells for US$ 0.9. Therefore, 100% replacement of animal protein in feed in Kenya, at the current market demand of 45,000 tonnes with black soldier fly will amount to a value of US$ 40.5 million.

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Social Science and Impact Assessment Unit

The Social Science and Impact Assessment (SSIA) Unit has been strengthened and now has a mandate and internal demand that often exceeds its capacity. The Unit has placed a particular focus on understanding the drivers of technology adoption and impact assessment published in high-quality peer-reviewed journals. The SSIA Unit also has the responsibility for implementing *icipe*'s recently developed Centre-wide Monitoring & Evaluation (M&E) and gender strategies.

Women empowerment and agricultural productivity

The researchers explored the impact of women empowerment on agricultural productivity using the Women Empowerment in Agriculture Index as a tool to measure empowerment. The findings show that women's empowerment in agriculture has increased maize yield in western Kenya. These findings demonstrate the importance of improving women's empowerment in Kenya's agricultural sector to reduce food insecurity and poverty. The effect of empowerment is significant on maize plots managed by women but insignificant on maize plots managed by men, or by both spouses.

Infographic showing interactions between the *icipe* 4H Themes.

Integrating *icipe* 4H interventions

Results show that, on average, the implementation of just one *icipe* 4H intervention increases a household's net annual income by 49%, relative to a baseline scenario. However, when all *icipe*'s (Plant health, Human health, Animal health, and Environmental health) components are applied, household net annual income can go up by an additional 126%, compared to a single 4H intervention. Farm households can generate additional income of US$ 368 per year due to the integration of *icipe*'s 4H components. In contrast, just a single *icipe* intervention can raise the price of farmland by as much as 100%.

Push–pull technology

The push–pull technology has the potential to lead to an additional total income (economic surplus) of US$ 72–73 million in western Kenya, under the current technology adoption level (14.4%). Further findings suggest that the technology is gender-neutral, as there are no differences in its adoption between men and women. Also, push–pull technology adoption reduces labour requirements during ploughing, weeding and threshing but significantly increases harvesting labour. In comparison to men, women save more labour hours during weeding and threshing periods but less during ploughing. Adoption of push–pull technology increases child education investment and shifts household expenditures towards goods associated with female consumption preferences. Moreover, the push–pull technology enhances women and household dietary diversity scores.

Fruit fly IPM

Adoption of the *icipe* mango fruit fly IPM packages contributes to economic benefits and human and environmental health due to reduced use of insecticides. Besides, although individual components of IPM have an impact on economic, human and environmental health, the most significant effect is achieved when the components are used in combination. The packages: increase mango income by 9–137%; and lower insecticide use, and their adverse health and environment effects by 68–89%, and 35–40%, respectively.

Tsetse repellent collar technology

Findings show a 75% reduction in the proportion of animals falling ill with trypanosomiasis; 75% reduction in animal mortality rate according to farmers' perception; 42% improvement in cow calving interval; 45% and 33% increase in milk yield and lactation period, respectively; 68% increase in the market price of oxen, and 29% increase in draught animal power.

*More information on socio-economic impact of *icipe*'s technologies is available within respective Themes chapters.

Insects for feed

Replacing conventional protein sources by 5–15% of black soldier fly larvae feed in the entire poultry sector of Kenya can increase the national gross domestic product (GDP) by US$ 69–206 million per year. A 5–15% adoption of black soldier fly larvae across the commercial poultry sector can increase foreign currency savings by US$ 1–3 million through reduced importation of conventional protein sources and chemical fertilisers. The same replacing rate in the commercial poultry sector can create employment for 3300–10,000 people per year. This figure should increase if the entire poultry sector uses black soldier flies. Insects for feed production provides good business opportunities for women and youth as investment costs to start insect production are relatively low, and one needs a small piece of land.

Technology Transfer Unit

icipe's recently launched Technology Transfer Unit (TTU) has the mission of identifying methods, approaches, processes and technologies, and communicating them to a broad community of scientists, donors, the private sector and end-users, to stimulate uptake. The TTU strategy encompasses five work streams, namely: database and knowledge management; packaging and innovation; communication, capacity building, delivery and impact assessment; strategic partnerships; and backstopping and legal framework development.

TTU work streams

Accomplishments

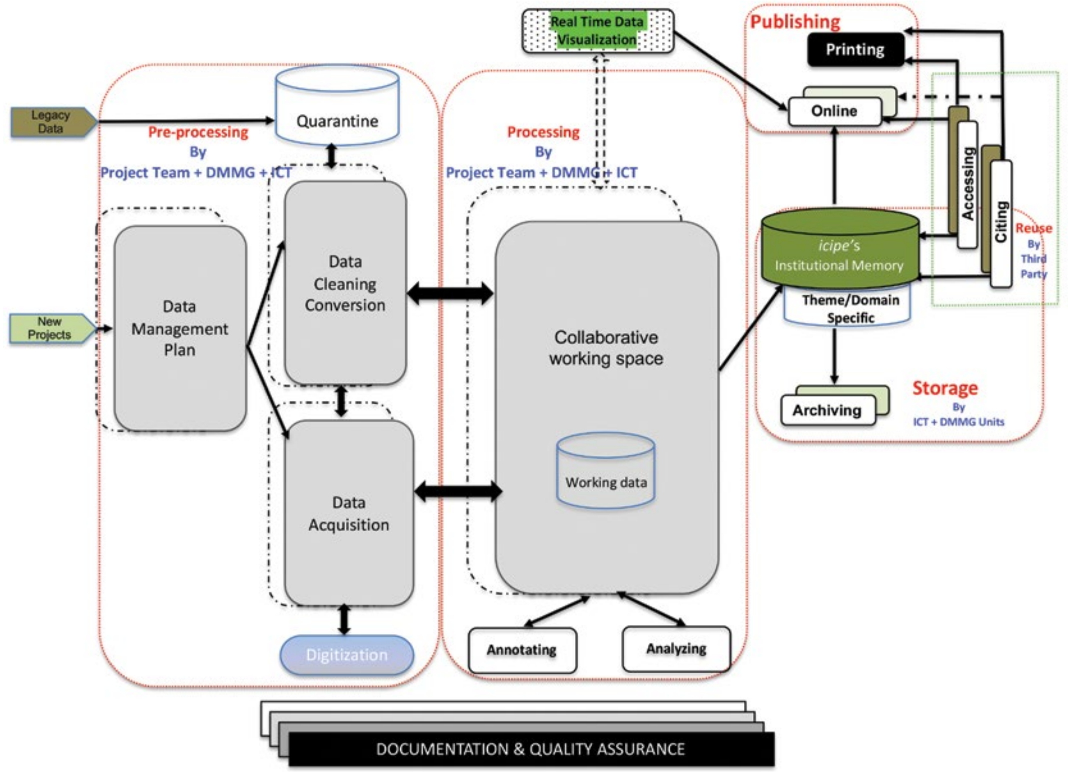
The Unit has prepared an inventory of *icipe* research results, technologies, tools and products, including their profiles (background information that captures status and value); and ranking and grading (categorisation in terms of readiness or development cycle). This process is useful to facilitate packaging and coordinated and effective dissemination.

Through the Push–Pull sub-Saharan Africa project, funded by Biovision Foundation for Ecological Development, Switzerland, TTU has contributed to expanding the technology across Africa. Working in partnership with the *icipe* Uganda Office, push–pull has been expanded to Burkina Faso, Burundi, Ghana, Malawi, Senegal, Rwanda, Zambia and Zimbabwe. The Unit is also responding to requests from Côte d'Ivoire, Democratic Republic of Congo, Eritrea, Mali, Mozambique and Niger.

In response to the fall armyworm invasion in Africa, USAID, in collaboration with FAO, launched a project to help monitor the abundance of the pest and scout the level of infestation in different cropping systems. The *icipe* Uganda Office and TTU were instrumental in the implementation of the project, and the Community Based Fall Armyworm Monitoring, Forecasting and Early Warning System (CBFAMFEWS). Community Focal Persons were identified in selected countries and trained on the biology and damage potential of fall armyworm, monitoring using pheromone traps, as well as scouting on maize crops. They also received mobile phones with Apps for data collection and sharing.

Cross-linkages have been strengthened between *icipe*, development partners, collaborators, end-users, the private sector and policymakers. As a result, better processes are now in place for information exchange, technology development and dissemination, capacity building, and innovative project development and business incubation.

In 2019, *icipe* made concerted efforts to boost the Centre's capacity for the development of the next generation of decision-making tools, models, software and mobile phone applications for crop, pest and disease management. The goal is to encompass the development and application of advanced data analytics and approaches (such as data and model fusion), to strengthen *icipe's* 4H themes.



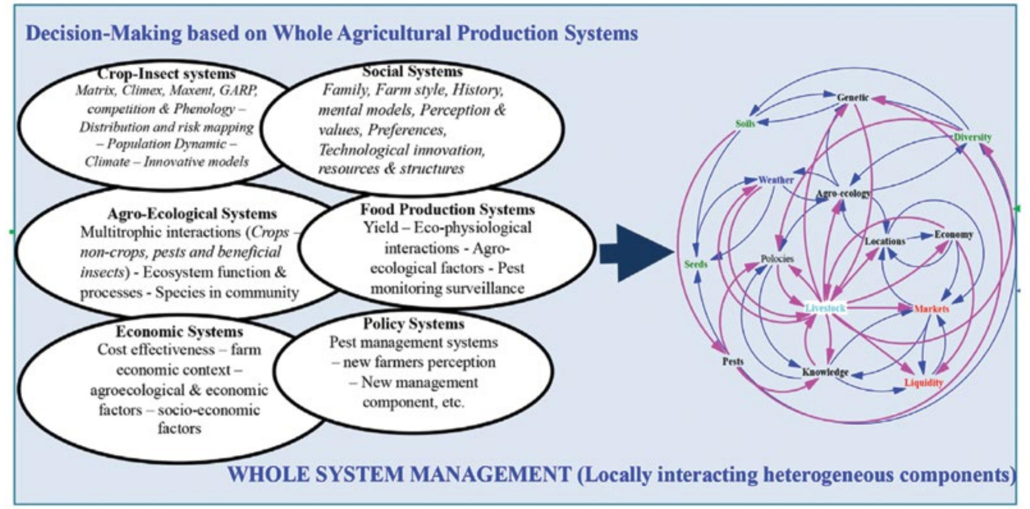
Data management workflow model

The Data Management, Modelling and Geo-Information (DMMG) Unit has a workflow for a collaborative framework, envisioning cooperation between project teams, the DMMG and the Information Communication Technology (ICT) units. The workflow comprises five phases starting with pre-processing, focusing on the design of a data management plan, followed by the development of templates and digital tools for data acquisition, cleaning and conversion.

In the processing phase, data are processed, annotated and analysed in a collaborative workspace by the project team, DMMG and ICT units. Within this phase, analytics are applied to the data to capture, map, and visualise *icipe*'s work using graphs and numbers. In the third and fourth phases, the data are then published and stored, ready for reuse by third parties in the final phase.

Modelling

Activities apply advanced mathematical, physical and statistical methods to data on pests and diseases in animals, ecosystems, plants, and humans. Emphasis is placed on research activities aimed at developing, applying and exploring new computational techniques for decision support in the context of agricultural systems, integrated pest management (IPM) implementation practices and interventions, and climate change and variability impact assessments. Forward-thinking, system design, system thinking and system dynamics techniques, including nonlinearities with feedback loops within landscape lens are used to make informed decisions.



Putting the system thinking perspective in practice for pest management

Geo-information and remote sensing

Recent contributions include the impact of climate on honey bee pest distributional patterns using long-term climate data and time-series remote sensing vegetation variables to understand the role of landscape structure and fragmentation on honey bee colony integrity. Satellite-based remote sensing data and geo-information tools have also been applied to predict the habitat suitability of key horticultural pests. Species-suitable habitats have been mapped to guide the upscaling of *icipe*'s technologies, such as Push–Pull in sub-Saharan Africa.

Locust management

In 2020, East Africa experienced the worst desert locust outbreak in decades. To contribute to the management of this crisis, the DMMG Unit obtained from the literature and open access databases, 2500 records of desert locust nymphs. The team applied machine learning techniques, and combined environmental variables in predicting the potential breeding areas of desert locust in East Africa. This study demonstrated that large areas of Kenya, northwestern and northeastern Uganda, middle and central regions of South Sudan have the highest potential in providing conducive breeding for the pests. Such specific knowledge of these insect-breeding sites will enable optimisation of action and reduced financial cost in the implementation of preventive measures to control locust outbreaks.

Invasive Species Activities

The term invasive species refers to arthropod pests, diseases and weeds introduced accidentally or deliberately outside their natural habitats or countries of origin. Worldwide, the threat of such species continues at an alarming rate, bolstered by globalisation, increasing movement of people and goods, land-use changes, climate change, and physical and chemical disturbance to species distribution. Indeed, globally, invasive species are now considered the second-most important threat to nature, due to their severe and cross-cutting impact on ecosystems, human and animal health, infrastructure, and economic and cultural resources. In sub-Saharan Africa (SSA), one of the most susceptible regions, the list of invasive species is long and diverse; their destruction often horrendous. Over the past several years, *icipe* has increased its efforts in the management of invasive species, with some examples listed below.

In the horticultural sector, new invasive species within the last five years alone include the oriental fruit fly, *Bactrocera dorsalis*, a native of Asia, which is now present in more than 30 African countries. Aside from ruining fruit and vegetable yield, at times up to 100%, *B. dorsalis*, like other fruit fly species, is also a quarantine pest. Its presence in Africa restricts the export of produce from the continent to European and emerging markets in North America.

The fall armyworm is a caterpillar that is endemic to the Americas that has been devastating maize and other crops in at least 20 African countries since January 2016, placing at risk the food security, and indeed the livelihoods of around 300 million people.

Other invasive fruit fly species on the continent include *Bactrocera zonata*, *B. cucurbitae* and *B. latifrons*. Further, *icipe* and partners have recently detected the Asian citrus psyllid, *Diaphorina citri*, a sap-sucking insect that can transmit the lethal citrus disease huanglongbing, also known as 'citrus greening'.

Potato cyst nematodes (PCN), microscopic, soil-dwelling roundworms that are destructive to potatoes worldwide were first reported in eastern Africa in 2014. *icipe* and partners, through the support of the Food and Agriculture Organization of the United Nations (FAO), have established that the pest has invaded several potato-growing areas in Kenya.

Invasive weeds include *Parthenium hysterophorus*, known as famine weed in parts of East Africa and its relationship to increase malaria incidents in East Africa. A native of North and South America, *Parthenium* is considered one of the world's most serious invasive plants. In East Africa, *Parthenium* is spread over cultivated and pastoral lands. A significant element is the weed's ability to sustain the malaria-transmitting mosquito, *Anopheles gambiae*, by extending its life, as a preferred sugar source, even in the absence of a blood meal.

Tuta absoluta, a devastating leafminer originating from Peru, has swept across Africa, leading to the declaration of a state of emergency in some of the continent's main tomato-producing areas. *icipe* and partners are making progress in addressing this challenge.

In February 2018, *icipe*, CABI and IITA organised a major forum aimed towards developing a strategy for tackling invasive species in SSA. Some of the key recommendations of the forum include:

- Development of high-level scientific and policy dialogue between relevant authorities and stakeholders regarding invasive species, and broad awareness of their economic impact.
- Strengthening of phytosanitary capacity and systems in Africa.
- Reinforcement of interdisciplinary research in the design and implementation of scientific and programmatic interventions for invasive species.
- Support for the continent and nationwide surveillance of invasive species.
- Integration of invasive species threats into national disaster response units.
- Creation of coordinated and collaborative resource mobilisation for invasive species activities.
- Emphasis on novel intervention solutions that provide a sustainable way of controlling invasive pests.
- Support for crowd-sourcing and citizen science in the management of invasive species.

The degree of invasive pests introductions, globally but especially in Africa, suggests lack of adequate contingency planning, preparedness and management measures. A three-stage approach is recognised internationally: prevention, early detection and control, and restoration.

Prevention involves pest risk analysis by relevant regulatory authorities to predict possible arrival, potential pathways, and the chances of a particular pest or pathogen becoming established in a new location. This information should allow regulators to determine the risk mitigation steps and the necessary phytosanitary measures to ensure that the risk is kept at acceptable levels. Ultimately, attention should be given to accurate and timely detection of invasive species as a solid basis to respond to invasive species, reducing prophylactic treatments in case of already-established species and ensuring economic and environmental benefits.

The steps outlined above should create a systematic, coordinated, consolidated, proactive and rapid response, based on a clear contingency plan, supported by enforceable policies, reference points, and an inventory of management options. Unfortunately, in many cases in SSA, the response to invasive pests has been reactive and ad hoc rather than proactive.

Capacity Building and Institutional Development Programme

Over the past five years, *icipe* has aimed to transform its capacity-building development efforts from functional training to high quality mentoring. The Centre believes this approach lays a stronger career foundation and supports research capacity in Africa more effectively. *icipe*'s training now provides not only technical skills in specific research areas but also a more extensive range of academic and professional capabilities, as well as research leadership. The Centre also ensures the presence of qualified and motivated supervisors and mentors, and institutes strategies for progressive interactions among them and the students, while also maintaining a supportive academic environment across the Centre.

Moreover, *icipe* has made a concerted effort to enhance gender equity and geographical diversity. As a result, the *icipe* African Regional Postgraduate Programme in Insect Science (ARPPIS) and the Dissertation Research Internship Programme (DRIP) stand as showcases of nurturing scientific capacity and leadership. Also, each year *icipe* holds training courses, workshops and other training events for research students and scientists, research and development collaborators, farmers and extension workers, and other stakeholders. Training covers a range of research and development activities, spanning the continuum from basic strategic research to technology development and validation, to community-based adoption of new technologies.

723

postgraduates (346 ARPPIS and DRIP PhD scholars; and 377 DRIP MSc students) from 34 African countries have completed their studies at *icipe* since 1983.

41%

of all ARPPIS and DRIP PhD scholars; and DRIP MSc scholars trained at *icipe* since 1983 were women.

36

Postdoctoral fellows have conducted research at *icipe* over the past five years (2014–2019).

24

African countries are currently represented in *icipe* postgraduate and postdoctoral training programmes: Benin, Burkina Faso, Burundi, Cameroon, Congo (Democratic Republic of the), Côte d'Ivoire, Eritrea, Ethiopia, Gambia, Ghana, Kenya, Malawi, Mozambique, Nigeria, Rwanda, Senegal, South Africa, Sudan, Tanzania, Togo, Tunisia, Uganda, Zambia, Zimbabwe.

15

Non-African countries are currently represented in *icipe* postgraduate and postdoctoral training programmes: Belgium, Cambodia, China, Colombia, France, Germany, Indonesia, Italy, Mexico, Netherlands, New Zealand, Oman, Philippines, United Kingdom, United States of America.

icipe is also coordinating the Eastern Africa Network for Bioinformatics Training (EANBiT), a network of three universities and four research institutes in Kenya, Tanzania and Uganda, established to develop a critical mass of practitioners in these regions who can develop and use bioinformatics approaches to biosciences.

38%

of all journal articles published by *icipe* between November 2013 – December 2019 were lead-authored by postgraduate scholars; and 8% by postdoctoral fellows.

488

workshops and other training events were held between November 2013 and December 2019 in 48 African countries, involving 66,857 participants (55% women).

74%

of ARPPIS PhD alumni are 'active' in Africa, according to a web-based tracer study conducted in 2017. Almost all are working in research, development or higher education in universities, national and international research institutes, other national systems, government, and private sector organisations.

Outstanding scholars*

2019		2018	
Olabimpe Yewande Olaide (PhD, Nigeria)	Olaide O.Y., Tchouassi D.P., Yusuf A.A., Pirk C.W.W., Masiga D.K., Saini R.K., Torto B. (2019) Zebra skin odor repels the savannah tsetse fly, *Glossina pallidipes* (Diptera: Glossinidae). *PLOS Neglected Tropical Diseases* 13 (6), e0007460. https:// doi.org/10.1371/journal.pntd.0007460 IF 4.487	**Teresiah Nyambura Njihia (PhD, Kenya)**	Njihia T.N., Torto B., Murungi L.K., Irungu J., Mwenda D.M. and Babin R. (2018) Ripe coffee berry volatiles repel second instar nymphs of *Antestia* bugs (Heteroptera: Pentatomidae: *Antestiopsis thunbergii*). *Chemoecology* 28, 91–100. https://doi.org/10.1007/s00049-018-0259-3 IF 2.488
Bernard Steve Soh Baleba (PhD, Cameroon)	Baleba B.S.S., Torto B., Masiga D., Weldon C.W. and Getahun M.N. (2019) Egg-laying decisions based on olfactory cues enhance offspring fitness in *Stomoxys calcitrans* L. (Diptera: Muscidae). *Scientific Reports* 9, article number: 3850 https://doi.org/3810.1038/s41598-41019-40479-41599 IF 4.122	**Beatrice Tchuidjang Nganso (PhD, Cameroon)**	Nganso B.T., Fombong A.T., Yusuf A.A., Pirk C.W.W., Stuhl C. and Torto B. (2018) Low fertility, fecundity and numbers of mated female offspring explain the lower reproductive success of the parasitic mite *Varroa destructor* in African honeybees. *Parasitology* 145: 1633–1639. https://doi.org/1610.1017/S0031182018000616 IF 2.511
Hilaire Kpongbe (PhD, Benin)	Kpongbe H., Van Den Berg J., Khamis F., Tamò M. and Torto B. (2019) Isopentyl butanoate: Aggregation pheromone of the brown spiny bug, *Clavigralla tomentosicollis* (Hemiptera: Coreidae), and kairomone for the egg parasitoid *Gryon* sp. (Hymenoptera: Scelionidae). *Journal of Chemical Ecology*, 45, 570–578. https://doi.org/510.1007/s10886-10019-01081-10885 IF 3.151	**Nelson Litunya Mwando (PhD, Kenya)**	Mwando N.L., Tamiru A., Nyasani J.O., Obonyo M.A.O., Caulfield J.C., Bruce T.J.A. and Subramanian S. (2018) Maize Chlorotic Mottle virus induces changes in host plant volatiles that attract vector thrips species. *Journal of Chemical Ecology* 44, 681–689. https://doi.org/10.1007/s10886-018-0973-x IF 2.419

*As per *icipe* Governing Council Student Awards.

Outstanding scholars*

2017

Annette Obukosia Busula (PhD, Kenya)

Busula A.O., Bousema T., Mweresa C.K., Masiga D., Logan J.G., Sauerwein R.W., Verhulst N.O., Takken W. and de Boer J.G. (2017) Gametocytemia and attractiveness of *Plasmodium falciparum*-infected Kenyan children to *Anopheles gambiae* mosquitoes. The *Journal of Infectious Diseases* 216, 291–295. doi: 210.1093/infdis/jix1214.

Ruth Muthoni Kihika (PhD, Kenya)

Kihika R.M., Murungi L.K., Ng'ang'a M.M., Coyne, D.L., Teal, P.E.A., Hassanali A. and Torto B. (2017) Parasitic nematode *Meloidogyne incognita* interactions with different *Capsicum annum* cultivars reveal the chemical constituents modulating root herbivory. *Scientific Reports* 7, 2903, doi: 10.1038/s41598-017-02379-8.

David Mfuti (PhD, Democratic Republic of Congo)

Mfuti D.K., Niassy S., Subramanian S., du Plessis H., Ekesi S. and Maniania N.K. (2017) Lure and infect strategy for application of entomopathogenic fungus for the control of bean flower thrips in cowpea. *Biological Control* 107, 70–76.

2016

Rosaline Wanjiru Macharia (PhD, Kenya)

Macharia R., Mireji P., Murungi E., Murilla G., Christoffels A., Aksoy S. and Masiga D.K. (2016) Genome-wide comparative analysis of chemosensory gene families in five tsetse fly species. *PLOS Neglected Tropical Diseases* 10, e0004421.doi:0004410.0001371/journal.pntd.0004421.

Matilda Wangeci Gikonyo (MSc, Kenya)

Gikonyo M. W., Niassy S., Moritz G.B., Khamis F. M., Magiri E. and Subramanian S. (2016) Resolving the taxonomic status of *Frankliniella schultzei* (Thysanoptera: Thripidae) colour forms in Kenya – A morphological-, biological-, molecular -and ecological-based approach. *International Journal of Tropical Insect Science* 37, 57–70. https://doi.org/10.1017/S1742758416000126.

Mercy Mumbi Murigu (MSc, Kenya)

Murigu M., Nana P., Waruiru R.M., Nga'ng'a C.J., Ekesi S. and Maniania N.K. (2016) Laboratory and field evaluation of entomopathogenic fungi for the control of amitraz-resistant and susceptible strains of *Rhipicephalus decoloratus*. *Veterinary Parasitology* 225, 12–18.

2015

Xavier Cheseto (PhD, Kenya)

Cheseto X., Kuate S.P., Tchouassi D.P., Ndung'u M., Teal P.E.A. and Torto B. (2015) Potential of the desert locust *Schistocerca gregaria* (Orthoptera: Acrididae) as an unconventional source of dietary and therapeutic sterols. *PLOS ONE* 10, e0127171. doi:10.1371/journal.pone.0127171.

2014

Edith Chepkorir (PhD, Kenya)

Chepkorir E., Lutomiah J., Mutisya J., Mulwa F., Limbaso K., Orindi B., Ng'ang'a Z. and Sang R. (2014) Vector competence of A*edes aegypti* populations from Kilifi and Nairobi for dengue 2 virus and the influence of temperature. *Parasites & Vectors* 7, 435. doi:10.1186/1756-3305-7-435.

Purity Ngina Kipanga (MSc, Kenya)

Kipanga P.N., Omondi D., Mireji P.O, Sawa P., Masiga D.K. and Villinger J. (2014) High-resolution melting analysis reveals low *Plasmodium* parasitaemia infections among microscopically negative febrile patients in western Kenya. *Malaria Journal* 13, 429. doi:10.1186/1475-2875-13-429.

**As per icipe* Governing Council Student Awards.

External awards, grants and fellowships (November 2013 – present)

Category	Scholar	Details	Awarded by
Awards and prizes	Joel Bargul (Postdoctoral Fellow, Kenya)	Best presenter award, on research findings on the presence of epizoonotic and zoonotic pathogens in camels in northern Kenya	Deltas Africa Scientific conference, held on 15 – 17 July 2019, at Dakar, Senegal
	Geoffrey Muricho (Postdoctoral Fellow, Kenya)	Best poster award for a poster titled: 'Women's empowerment in agriculture and determinants of empowerment indicators in rural Kenya'	Agricultural Economics Society's 91st annual conference, held on 24 – 26 April 2017, at the Royal Dublin Society, Ireland
	Damaris Matoke (Postdoctoral Fellow, Kenya)	Best biotechnology presenter, for a presentation on environmental determinants of sand fly and leishmaniasis distribution	6th KEMRI Annual Scientific and Health (KASH) conference, held on 9 – 10 February 2016, at Kenya Medical Research Institute, Nairobi, Kenya
	Benard Kulohoma (Postdoctoral Fellow, Kenya)	Young Researcher Award, which came with a six months fellowship to gain professional experience in a Merck R&D hub	UNESCO – Merck Africa Research Summit 'MARS 2015' held on 19 – 20 October, 2015, in Geneva, Switzerland
	Ruth Kihika (ARPPIS PhD scholar, Kenya)	Young Talent Sub-Saharan Africa Awards, of the L'Oréal-UNESCO for Women in Science programme, received in 2019	L'Oréal-UNESCO
		First prize (a book prize of Euros 150), in the student oral presentation	15th Horticultural Association of Kenya workshop on Sustainable Horticultural Production in the Tropics, held on 30 November – 5 December 2015, at Kenya Agricultural and Livestock Research Organization (KALRO), Thika, Kenya
	Bethelihem Mekonnen (ARPPIS PhD scholar, Ethiopia)	Best presentation by a female student for her presentation titled: 'Trait-mediated avoidance behavior of fruit flies to semiochemicals of *Oecophylla longinoda* L. (Hymenoptera: Formicidae)'	African Association of Insect Scientists 23rd Conference held on 18 – 22 November, 2019, in Abidjan, Côte d'Ivoire
	James Kisaakye (ARPPIS PhD scholar, Uganda)	Best student poster presentations for 'Effect of dual fungal endophytes, *Beauveria bassiana* and *Fusarium oxysporum* on *Radopholus similis* infection of East African Highland bananas'	Organisers of the 22nd Nematological Society of Southern Africa (NSSA) symposium held on 6 – 16 May 2019, in North-West University, South Africa
	Beatrice Nganso (former PhD scholar, Cameroon)	Early Career Researcher Award, received in 2019	*Parasitology* journal
	Joshua Njelembo (former PhD scholar, Zambia)	Excellence Award: Promising Young Scientist	Organisers of the 70th anniversary of the International Scientific Council for Trypanosomiasis Research and Control (ISCTRC) held in Abuja, Nigeria, in September 2019

External awards, grants and fellowships (November 2013 – present)

Category	Scholar	Details	Awarded by
Awards and prizes	Martha Muthina Luka (EANBiT MSc scholar, Kenya)	Runner-up for an oral presentation titled: ‘Molecular epidemiology of human rhinovirus from one-year surveillance among school going children in rural coastal Kenya’, at the ISCB-Africa ASBCB Conference on Bioinformatics, held on 11 – 15 November 2019, in Kumasi, Ghana	International Society for Computational Biology - African Society for Bioinformatics and Computational Biology
	Brian Bwanya Edward (EANBiT MSc scholar, Kenya)	Best poster presentation titled: ‘Comparison of mitochondrial genetics of zoophilic and domestic *Aedes aegypti* strains in East Africa to strictly anthropophilic strains in other continents’ at the ISCB- Africa ASBCB Conference on Bioinformatics, held on 11 – 15 November 2019, in Kumasi, Ghana	International Society for Computational Biology - African Society for Bioinformatics and Computational Biology
	Naomi Riithi (DRIP MSc scholar, Kenya)	Best oral presenter prize during the East Africa Research in Progress (EARIP) conference, held on 26 – 28 September 2019, at Kilimanjaro Christian Medical Centre, Moshi, Tanzania, for her presentation on the prospects of fabric panels for applying *Metarhizium anisopliae* against vectors of sleeping sickness	Royal Society of Tropical Medicine and Hygiene (RSTMH)
	Teresiah Njihia (ARPPIS PhD scholar, Kenya)	Mawazo PhD Scholars Programme, accepted in 2018	Mawazo Institute, Nairobi, Kenya
	Xavier Cheseto (ARPPIS PhD scholar, Kenya)	Research Article of the Year award (AGRO Division), for article titled: ‘Identification of the ubiquitous antioxidant Tripeptide Glutathione as a Fruit Fly Semiochemical’, received in 2018	*Journal of Agricultural and Food Chemistry*
	Justice Kwaku Addo (DRIP PhD scholar, Ghana)	Outstanding Research award, received in June 2018	University of Cape Coast, South Africa
	Hillary Kirwa Kipchirchir (DRIP MSc scholar, Kenya)	Best Oral Presentation, titled: ‘Root knot nematode herbivory of tomato *Solanum lycopersicum*, is influenced by root exudate chemistry’	Horticultural Association of Kenya, 18th HAK Workshop, held on 26–30 November 2018, at Taita-Taveta, Kenya.
		Awarded a grant to conduct MSc research on Species identification and discrimination in illegal bush meat trade, in 2017	National Research Foundation (NRF), Kenya
	Sheila Agha (ARPPIS PhD scholar, Cameroon)	Best oral presentation award	5th Medical and Veterinary Virus Research conference (MVVR), held on 7 – 8 December 2017, in Nairobi, Kenya

External awards, grants and fellowships (November 2013 – present)

Category	Scholar	Details	Awarded by
Awards and prizes	Akbar Ganatra (DRIP PhD scholar, Kenya)	Best poster award for a poster on the effect of pollutants on the distribution and infectivity of schistosomiasis intermediate host snails in western Kenya	11th Annual Neglected Tropical Diseases Conference hosted by Ministry of Health and KEMRI, Nairobi, Kenya, held on 6 – 7 December 2017.
	Nelly Ndungu (ARPPIS PhD scholar, Kenya)	Genome Award: Best Presentation for Resolving taxonomic ambiguity and cryptic speciation of *Hypotrigona* species through morphometrics and DNA barcoding	7th International Barcode of Life Conference, held on 20 – 24 November 2017, at Kruger National Park, South Africa.
		Pensoft Award for Best Presentation on Identification of stingless bees (Hymenoptera: Apidae) in Kenya using morphometrics and DNA barcoding	7th International Barcode of Life Conference, held on 20 – 24 November 2017, at Kruger National Park, South Africa.
	Grace Nyambura Mwangi (intern, Nematology Laboratory, Kenya)	VLIR-UOS scholarship for the International Master of Science in Agro- and Environmental Nematology at the University of Ghent, Belgium, awarded in 2017	Vlaamse Interuniversitaire Raad (Flemish Interuniversities Council) (VLIR) – Universitaire Ontwikkelings samenwerking (University Development Co-operation) (UOS).
	Kelvin Gitau (intern, Nematology Laboratory, Kenya)	VLIR-UOS scholarship for the International Master of Science in Agro- and Environmental Nematology at the University of Ghent, Belgium, awarded in 2017	VLIR –UOS
	Teresiah Njihia (ARPPIS PhD scholar, Kenya)	Best oral presentation, on Volatile compounds from coffee berries elicit responses in the coffee stink bug	Workshop on Sustainable Horticultural Production in the Tropics, held from 28 November – 2 December 2016, in Chuka University, Kenya.
	Vincent Nyasembe (ARPPIS PhD scholar, Kenya)	Received a travel award to attend an ISCE conference held from 4 – 8 July 2016, in Igauazo, Brazil	International Society of Chemical Ecology meeting.
	Richard Kyalo (DRIP PhD scholar, Kenya)	Presentation of paper on mapping maize lethal necrosis severity in Kenya using multi-spectral satellite imagery selected as the most innovative out of more than 1500 oral paper presentations	European Space Agency (ESA) Living Planet Symposium held on 9 – 13 May 2016, at Prague, Czech Republic.
	Annette Busula (DRIP PhD scholar, Kenya)	Best student presentation on Microorganism-mediated behaviour of malaria mosquitoes	British Society of Parasitology Spring meeting, held from 1 –13 April 2016, at Imperial College London, England.
	Ryan Awori (DRIP MSc scholar, Kenya)	Winner, Nairobi Falling Walls 2016 ‘innovation pitching’ competition on MSc research on antimicrobial agents from soil bacteria. Ryan was invited to present at the Falling Walls grand final in Berlin in November 2016	Falling Walls Foundation, Berlin, Germany.
	Rosaline Macharia (ARPPIS PhD scholar, Kenya)	Best Oral Presentation — Young Investigators Forum, received in 2015	6th Kenya Medical Research Institute (KEMRI) Annual Scientific and Health (KASH) conference.
	Micky Mwamuye (DRIP MSc scholar, Kenya)	Emerging Research Talent Award	UNESCO–Merck Africa Research Summit ‘MARS 2015’, held on 19 – 20 October 2015, in Geneva, Switzerland.

External awards, grants and fellowships (November 2013 – present)

Category	Scholar	Details	Awarded by
Awards and prizes	Matilda Gikonyo (DRIP MSc scholar, Kenya)	PhD scholarship, at the Max Planck Institute for Chemical Ecology, Jena, Germany, awarded in 2015.	Max Planck Institute for Chemical Ecology, Jena, Germany
	Peter Njenga (DRIP MSc Scholar)	Scholarship to undertake PhD studies at the University of Freiburg, Germany, at the Institute of Toxicology and Pharmacology, received in 2015.	DAAD
Special recognitions	Benard Kulohoma (Postdoctoral Fellow, Kenya)	Recognised as an exceptional researcher and trainer, and selected as the '2015 H3Africa-Harvard Fellow'.	H3ABioNet, a Pan African Bioinformatics Network for the Human Heredity and Health in Africa (H3Africa) consortium; supported by the H3ABioNet Harvard node.
	Gladys Mosomtai (ARPPIS PhD scholar)	Addressed a high-level meeting on French–Kenyan partnerships in developing skills, knowledge and innovation, in the presence of President Emmanuel Macron of France at the University of Nairobi, on 14 March 2019.	
	Yosef Hamba Tola (ARPPIS PhD scholar)	Global Mendeley Advisor recognition certificate and badge, awarded in 2019. Mendeley is a desktop and web programme for managing and sharing research papers, discovering research data and collaborating online.	Elsevier, Amsterdam, The Netherlands
Research fellowships and grants	Michael Okal (Postdoctoral Fellow, Kenya)	THRiVE-2 Career Development Award to support research on Investigating livestock as reservoirs of emerging zoonoses in the human–wildlife–livestock interface of Kubo South, Kwale County, Kenya, awarded in 2017.	Developing Excellence in Leadership, Training and Science (DELTAS) Africa Initiative grant to THRiVE-2. DELTAS Africa is funded by the Wellcome Trust and the Department for International Development (DFID), UK.
	Edwin Ochieng Ogola (ARPPIS PhD scholar, Kenya)	Grant to carry out a study on yellow fever in Kenya, received in 2019.	National Institute for Health Research (NIHR), UK
	Trizah Koyi Milugo (DRIP PhD scholar, Kenya)	Award to conduct a study titled 'Using a participatory approach to identify novel approaches to control malaria', received in 2019.	Training Health Researchers into Vocational Excellence in East Africa (THRiVE) Research Enrichment for Community and Public Engagement (RECPE) Award.
		DELTAS Africa Community and Public Engagement (CPE) Seed Fund Award to carry out a study titled 'Science-based conversation, knowledge and skill transfer to students in selected secondary schools in western Kenya', received in 2019.	African Academy of Sciences (AAS) with the support of Wellcome Trust and DFID.
	Naomi Riithi (DRIP, MSc scholar, Kenya)	Grant to carry out a study on evaluating attractive fabric panels impregnated with *Metarhizium anisopliae* against vectors of sleeping sickness, received in 2019.	National Institute for Health Research (NIHR)/Royal Society of Tropical Medicine and Hygiene (RSTMH's) 2019 small grants programme.
	Faith Obange (DRIP MSc scholar)	Grant to conduct research on Host cell surface receptors for *Deformed wing virus* (DWV) that mediate host-pathogen interactions in honeybee, awarded in 2017.	National Research Fund, Kenya

Category	Scholar	Details	Awarded by
	Oscar Mbare (Postdoctoral Fellow)	Wellcome Trust Training Fellowship in Public Health and Tropical Medicine to research on understanding the risks and benefits of newly developed irrigation schemes in western Kenya in the context of malaria elimination, awarded in 2017	Wellcome Trust, UK
Research fellowships and grants	Gladys Mosomtai (ARPPIS PhD scholar)	L'Oréal-UNESCO for Women in Science Africa doctoral fellowship award in December 2019	L'Oréal-UNESCO
	Xavier Cheseto (DRIP PhD Scholar)	Rothamsted International Fellowship, to conduct research on the enantioselective synthesis of plant-based semiochemical kairomones of tropical insect disease vectors, awarded in 2016	Rothamsted Research, UK
	Edith Chepkorir (ARPPIS PhD scholar)	L'Oréal–UNESCO for Women in Science Sub-Saharan Africa Award, received in 2015	L'Oréal–UNESCO
	George Obiero (ARPPIS PhD Scholar)	Georg Forster Research Fellowship, tenable for two years at the Max Plank Institute for Chemical Ecology, Jena, awarded in 2015	Alexander von Humboldt Foundation, Germany
	Barack Omondi (DRIP MSc Scholar)	Wellcome Trust Master's Fellowship in Public Health and Tropical Medicine, awarded in 2017	Wellcome Trust, UK
Appointments	Lucy Kananu Murungi (Postdoctoral Fellow)	Affiliate Member (2016 – 2020)	AAS
	Pamela Ochungo (ARPPIS PhD scholar)	Appointed Right Livelihood Junior Scientist and participated in the workshop 'Greening the Future: Sustainable Agriculture and Forestry in African and Asian Drylands' held on 14 – 19 September, 2019 in Bonn, Germany	Right Livelihood Foundation
	Gladys Mosomtai (ARPPIS PhD scholar)	Ambassador, Next Einstein Forum, an African Institute for Mathematical Science (AIMS) initiative, appointed in 2019	NEF
	Joel Odero (DRIP PhD Scholar)	Student Ambassador, appointed in 2019, one of only 24 student ambassadors worldwide and seven in Africa	Royal Society of Tropical Medicine and Hygiene (RSTMH), UK

BioInnovate Africa Programme

In 2016, the Swedish International Development Cooperation Agency (Sida) and *icipe* reached an agreement for the Centre to host and manage the Bioresources Innovations Network for Eastern Africa Development (BioInnovate Africa) Programme, Phase II (2016– 2021). One of Africa's largest regional science and innovation-driven initiatives, BioInnovate Africa was established in 2010 with support from Sida, its first phase running up to 2015. The Programme provides grants to enable scientists, researchers, innovators and entrepreneurs in eastern Africa (Burundi, Ethiopia, Kenya, Rwanda, Tanzania and Uganda), work together to turn innovative ideas and technologies based on biological sciences into viable businesses.

icipe has become a true home for BioInnovate Africa, based on synergies between the Centre and the Programme in the vision of working with researchers, policymakers and private sector actors towards inclusive growth and sustainable development across the continent. Sida supports award grants, currently to 20 regional initiatives involving scientists, business executives and policymakers in over 80 organisations in the six eastern African countries.

Projects being supported by BioInnovate Africa Programme, as of 2020, include:

Fruit and vegetables drying technology; digital solutions for virus-free sweet potato vines; postharvest disinfestation of horticultural crops; and *Striga* weed resistant maize and finger millet.

Nutritionally enhanced sorghum and millet products; small-scale biorefineries for products from sorghum stems; bakery products from orange-fleshed sweet potato; and nutrient-rich high-quality aroma honey toffee.

Fungal biopesticides; nitrogen bio-fortified, commercial-grade organic fertiliser; bio-alkanol gel fuel alternative for rural households; and substrate blocks for growing mushrooms.

Novel enzymes for eco-friendly processing of hides and skins; industrial wastewater treatment methods; and use of earthworms to decompose coffee waste.

Insect-based proteins for food and feed; and insect feed for fish and poultry.

Catnip products for malaria prevention; and novel repellents and attractants for control of tsetse flies.

Other activities

Contributing to refined pathways to market innovative products, training and mentoring, by streamlining expectations from researchers and business leaders in project implementation.

Supporting commercialisation capacities of participating firms, by assisting collaborating partners to harmonise roles and responsibilities as co-developers, which is vital for sustainability of the products, once introduced into the markets.

Enhancing gender participation in the African bioeconomy through a fellowship scheme for women scientists,undertaken in selected BioInnovate Africa-funded projects outside their home countries for four to six months, to advance their skills, innovation capacity and overall career progression. As of 2019, fellowships had been awarded to a total of 24 women scientists.

Participating in the development of a bioeconomy strategy for eastern Africa, through an initiative led by the East African Science and Technology Commission (EASTECO), Rwanda, and the following collaborators: African Technology Policy Studies Network (ATPS), Kenya; Stockholm Environment Institute SEI – Africa Centre, Kenya; The Scinnovent Centre Limited, Kenya; and Bioinnovations Company Limited, Uganda.

Regional Scholarship and Innovation Fund (RSIF)

The Regional Scholarship and Innovation Fund (www.rsif-paset.org), is the flagship programme of the Partnership for Skills in Applied Sciences, Engineering and Technology (PASET), an initiative by African governments that aims to address fundamental gaps in skills and knowledge necessary for long-term, sustained economic growth in sub-Saharan Africa (SSA). Representatives of Brazil, China, India, Korea, Singapore and Malaysia have participated in various activities of PASET.

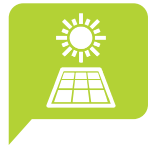
Specifically, the goal of RSIF is to strengthen doctoral training, as well as research and innovation in applied sciences, engineering and technology (ASET), in Africa. RSIF is led by the governments of Burkina Faso, Côte d'Ivoire, Ghana, Ethiopia, Kenya, Rwanda and Senegal. So far, more than 20 African countries have indicated interest to join the initiative.

PASET has identified five priority areas for RSIF:

ICTs, including big data and artificial intelligence

Food security and agribusiness

Minerals, mining and materials engineering



Energy, including renewables

Climate change

In 2018, *icipe* was competitively selected as the Regional Coordination Unit (RCU) of RSIF. *icipe* has a mandate that includes overall coordination planning, and monitoring and evaluation of RSIF activities. The Centre also manages RSIF funds, strengthens the capacity of universities and partnering institutions to train PhDs, and facilitates research and innovation in the PASET priority sectors.

The World Bank has provided US$ 15 million, and the Government of South Korea has contributed US$ 9 million. RSIF has received US$ 2 million from the governments of Kenya and Rwanda (each), and US$ 1 million from the government of Côte d'Ivoire. Agreements for contribution from Ghana, Burkina Faso and Senegal are being executed.

RSIF is:

Aligned to national, continental and global development aspirations, like Agenda 2063 of the African Union and the United Nations Agenda 2030 and its 17 Sustainable Development Goals (SDGs).

Supporting the use of transformative technologies to tackle the continent's most pressing challenges.

Supporting all levels of capacity building from doctoral and postdoctoral, to research and innovation and institutional strengthening, with excellence at the core, in collaboration with selected African host universities and other regional and international partners.

Providing a model for inter-Africa study, pan-African collaboration and knowledge exchange.

Building a critical mass of skilled science and engineering leaders, innovators and entrepreneurs, including a cadre of women PhD holders in ASET fields in SSA.

Establishing a permanent Fund expected to grow to more than US$ 15 million by 2024 through contributions from African governments, donors, the private sector and philanthropists. Proceeds will be channelled into the General Fund, supporting PhD training, research and innovation projects, and institutional capacity building.

Fully Africa-led and managed by an African institution, *icipe*, an organisation reputed for robust processes and systems, good governance, world-class research and development, research commercialisation, and experience in capacity building in Africa.

Representatives of RSIF AHUs pictured with *icipe* and PASET representatives during an occasion of signing Partnership Agreements.

Achievements

Institution of a highly skilled team to implement various aspects of *icipe's* RSIF mandate.

Expansion of the RSIF network, with a total of 11 African Host Universities (AHUs), competitively and rigorously selected universities that offer a PhD programme in any one of the PASET priority thematic areas.

Awarded PhD scholarships to 67 young African scientists, who are now enrolled in the AHUs. The RSIF scholars have the opportunity to conduct part of their research in international institutions, leading to a network system that ensures collaborative and innovative research, and world-class mentorship.

Designed a research and innovation grants system and issued three calls for proposals: i) RSIF research awards for university-led teams who are engaged in PhD training in AHUs; ii) RSIF cooperability grants to encourage public–private partnerships and support commercialisation of innovative research outputs; and iii) RSIF Institutional Capacity Building Programme Grants to support the AHUs to develop institutional frameworks for strengthened innovation ecosystems.

Supported the organisation of, and participated in the fifth PASET Forum, themed, Destination Digital Africa: Preparing our Youth for the Future, held in Kigali, Rwanda, 20–22 May 2019.

Coordinated study visits for 11 RSIF AHUs to Japan and Morocco; facilitated training in soft skills for RSIF scholars in research communication, digital storytelling, research ethics, information literacy, reference management and open access e-resources.

Reinforcing participation of women in STEM, for example, by co-organising the Global Forum on Women in Scientific Research (GoFoWiSeR), held in Dakar, Senegal, on 18 and 19 July 2019. RSIF is developing a gender strategy to institutionalise these practices in all the programme activities.

2019 and 2018 FINANCIAL STATEMENTS

Statement of Financial Position

DESCRIPTION	**2019**	**2018**
	"USD 000"	**USD "000"**
Non-Current Assets	9,830	9,536
Current Assets	42,656	44,519
Total Assets	52,486	54,055
Current Liabilities	28,560	31,426
Long-term Liabilities	527	387
Total Liabilities	29,087	31,813
Total Assets less Total Liabilities	**23,399**	**22,242**
Financed By:		
Capital Fund and Reserves	**23,399**	**22,242**

Statement of Comprehensive Income & Activities

DESCRIPTION	**2019**	**2018**
	"USD 000"	**USD "000"**
Income		
Unrestricted Grants	4,320	4,544
Restricted Grants	24,959	17,960
Other	2,441	2,571
Total Income	**31,720**	**25,075**
Appropriation		
Research	26,501	20,628
Institutional	4,704	4,169
Transfer to Reserves	515	278
Total Appropriations	**31,720**	**25,075**

Note: The detailed Financial statements are available at www.icipe.org

Meganomia rossi (Melttidae)

5

icipe beyond 50

Over the past 50 years, the validity of the founding mission of *icipe*, that of a centre of excellence devoted to insect science as a basis for enhanced agricultural production, better health, and better livelihoods, has been proven beyond a shadow of a doubt. As illustrated in this publication, world-class knowledge produced by *icipe* has led to the development of highly impactful tools and strategies for the management of pests of crops and disease vectors, and for the sustainable exploitation of beneficial insects. We are conscious of the fact that our remarkable history mandates us towards an even more determined future. So, as *icipe* moves towards the next phase, it is with the solemn declaration of 'Insects for Life'. This slogan is a dual expression of the interlinkage between the 4H Themes – Human Health, Animal Health, Plant Health and Environment Health – and the unwavering commitment to our longstanding vision and mission. In accordance, as we continue to advance ongoing activities, we will also be guided by the *icipe Vision and Strategy 2021 – 2025*. This document identifies and proposes responses to a diverse set of emerging challenges and opportunities, as presented in the following sections.

Continued threat of invasive species

Current trends show that invasive species — arthropod pests, diseases and weeds — will continue to be a major challenge in Africa. The locust outbreak in eastern Africa since the beginning of 2020; the fall armyworm invasion that started in 2016; the arrival of the tomato leafminer, *Tuta absoluta*, in 2015 and the potato cyst nematode in 2014; as well as new fruit fly species entrants over the past 10 years, are just a few examples of alien invasive pests having a dramatic impact on agriculture and livelihoods across the continent.

This scenario stipulates the urgent need for systematic, coordinated, consolidated, proactive and sufficiently financed national, regional and international strategies to mitigate invasive pests. *icipe* will build on its ongoing activities, in line with the Centre's institutional strengths and through collaborative efforts with partners, to reduce the risks of invasive species.

Global decline in insects and biodiversity

Current data suggests an overall pattern of decline in the diversity and abundance of insects, with more than 40% of species diminishing, and a third endangered. Indeed, the rate of insect and arthropods extinction is eight times faster than that of mammals, birds and reptiles. The main drivers of this trend include: agriculture, particularly the heavy use of pesticides; habitat destruction, fragmentation and quality loss; as well as urbanisation. Moreover, climate change will have a profound impact on insects.

icipe will endeavour to contribute to global efforts to overcome insect decline by supporting the adoption of innovative methods of pest control that do not depend on harmful products. Other possible research areas include the impacts of climate change on insect populations and diversity. Such insights should be supported by studies on insect physiology and phenology, as well as ecological networks that can maintain and improve the resilience of insect populations. *icipe* recognises that this level of knowledge will only be possible through global partnerships.

Neglect of critical areas of insect sciences

In recent years, concern has been raised about the global slump in certain fields of science, like entomology, taxonomy and agronomy. This scenario is well-illustrated in an article in *Time* magazine in 2018 (https://time.com/5144257/fewer-scientists-studying-insects-entomology/). And yet, *icipe* and other similar organisations stand as testaments of the importance of insect science. Moreover, the Centre's interdisciplinary approach to research makes a case for diverse competencies. For example, using taxonomic knowledge in combination with chemical ecology and molecular sciences, *icipe* researchers have been able to accurately identify and understand the behaviour of a range of crop pests and disease vector species, facilitating the development of relevant surveillance and control systems. *icipe* will continue to do its part in enhancing capacity in these neglected disciplines. However, the goal of reviving such underrated fields and skills will require the dedicated efforts of research and academic institutions, policymakers and development partners.

Microbiome research

Since 2014, *icipe* has intensified research on beneficial microbes that sustain the health and fitness of their host insects and pathogens, providing new opportunities to reduce disease transmission and control crop pests. In particular, endosymbiotic microbes (found inside the cells or bodies of insects), have a significant impact on the interactions between their host insects and pathogens. *icipe* will build on its breakthroughs in endosymbionts of mosquitoes, fruit flies and bees, to microbiome research across the Centre's Themes.

Soil health

icipe will expand its research agenda to study and promote soil health. Poor soil fertility remains a key constraint to successful crop production in SSA. Below-ground pests, such as plant-parasitic nematodes, are ill-researched; yet, become important pests, especially under poor agricultural practices. On the other hand, plant rhizospheres and soils harbour an undiscovered treasure of microbes, including endophytes that have the potential to be harnessed for the development of novel biopesticides.

One Health

The increasing impacts of climate change being felt through higher incidences of zoonoses and transboundary animal diseases point to the need for coordinated, holistic responses across science disciplines. In response, *icipe* will continue efforts towards the adoption of the One Health concept across the Centre's 4H Themes.

6

Annexes

ANNEX A: PARTNERS

Partners (1970–1994)

African Academy of Sciences; African Biosciences Network (ABN); Agricultural Development Corporation (ADC), Kenya; Agricultural Research Institute (ARI), Tanzania; Applied Physics Laboratory, Johns Hopkins University; ApproTECH; Association of African Universities; Biological Control Facility of Texas A&M University; Biological Control Laboratory, Chinese Academy of Sciences, China; CARE International; Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia; Commonwealth Agricultural Bureaux International (CABI); Commonwealth Regional Health Community Secretariat (CRHS); Consultative Group on International Agricultural Research (CGIAR); Department of Applied Chemistry and Microbiology of University of Helsinki, Finland; Department of Livestock Development, Kenya; Department of Plant and Forest Protection of Swedish University of Agricultural Sciences, Uppsala, Sweden; Division of Biotechnology, University of Arizona, Tucson, USA; Division of Communicable Diseases Control and Research of the Ministry of Health, Kenya; Division of Communicable Diseases and Research, Kitui, Kenya; Dschang University Centre, Cameroon; Desert Locust Control Organisation for Eastern Africa (DLCO-EA), Ethiopia; East African Agricultural and Forestry Research Organisation; East African Veterinary Organisation; Government of Ethiopia; Government of Ivory Coast; Government of Kenya; Government of Mozambique; Government of Rwanda; Government of Somalia; Government of Sudan; Government of Uganda; Government of Zambia; Groupe d'Etude et de Recherche en Microscopie Electronique (GERME), Côte d'Ivoire; Imperial College, United Kingdom; Instituto Guido Donagani, Italy; International Committee of the Red Cross (ICRC); International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), India; International Commission on the Application of Science to Agriculture, Forestry and Aquaculture (CASAFA), France; International Centre for Research in Agroforestry (ICRAF); International Federation of Institutions for Advanced Studies; International Food Policy Research Institute; International Livestock Center for Africa (ILCA), Ethiopia; International Laboratory for Research on Animal Diseases (ILRAD); International Organization for Chemical Sciences in Development (IOCD); International Rice Research Institute (IRRI); International Maize and Wheat Improvement Center (CIMMYT), Mexico; International Institute of Tropical Agriculture (IITA); Jomo Kenyatta University of Agriculture and Technology, Kenya; Kagera Basin Authority (KBA); Kenya Agricultural Research Institute (KARI); Kenya Medical Research Institute (KEMRI); Kenya Meteorological Department (KMD); Kenya Trypanosomiasis Research Institute (KETRI); Kenya Wildlife Service (KWS); Kenya Rangeland Ecological Monitoring Unit (KREMU); Kenyatta University College, Kenya; Kuvin Centre for the Study of Infectious and Tropical Diseases, Israel; Kyoto University, Japan; Liverpool School of Tropical Medicine; Lutheran World Federation (LWF); Makerere University, Uganda; Ministry of Agriculture, Ethiopia; Ministry of Agriculture and Livestock Development, Kenya; Ministry of Agriculture, Animal Industry and Fisheries, Uganda; Ministry of Agriculture and Water Development, Zambia; Ministry of Health, Kenya; Ministry of Tourism and Wildlife, Kenya; national agricultural research systems (NARS), Kenya, Somalia, Rwanda and Zambia; National Council for Scientific Research (CNRS); National Museums of Kenya, Nairobi; National Veterinary Laboratories, Kabete, Kenya; Network of Deans, Directors and Coordinators of Graduate Studies in Eastern and Southern African Universities (NDGS); Overseas Development Natural Resources Institute (ODNRI); Oxford University, UK: Pan-African Development Information System (PADIS); Pheromone Group of Department of Biological Sciences, Lund University, Sweden; Philippine Council for Agriculture, Aquatic and Resources Research and Development; Philippine Rice Research Institute; Plant Health Management Division of International Institute of Tropical Agriculture (IITA), Cotonou, Benin; Purdue University, USA; Rangeland Insect Laboratory, Bozeman, USA; Regional Centre for Services in Surveying, Mapping and Remote Sensing (RCSSMRS), Kenya; Regional Phytosanitary Training Centre, Cameroon; Rivers State University of Science and Technology (RSUST), Nigeria; Royal Society, London; Scientific, Technical and Research Commission of Organisation of African Unity (OAU/STRC); Tanga Trypanosomiasis Research Institute (TTRI), Tanzania; Tanzania Agricultural Research Organisation (TARO), Tanzania; Texas A&M University; Texas Agricultural Experimental Station, Lubbock, USA; Third World Academy of Sciences (TWAS); Tropical Pesticides Research Institute, Tanzania; United Nations Centre for Human Settlements (HABITAT); Universidade Federale de Minas Gerais, Brazil; University of Abidjan, Côte d'Ivoire; University of Addis Ababa, Ethiopia; University of Bern, Switzerland; University of Bonn, Germany; University of Copenhagen, Denmark; University of Dar es Salaam, Tanzania; University of East Anglia, UK; University of Gezira, Sudan; University of Ghana, Legon; University of Helsinki, Finland; University of Ibadan, Nigeria; University of Illinois, Urbana-Champaign, USA; University of Khartoum, Sudan; University of London, UK; University of Lund, Sweden; University of Malawi; University of Nairobi, Kenya; University of Neuchatel, Switzerland; University of Oldenberg, Germany; University of Sierra Leone; University of Zambia; University of Zimbabwe; Uppsala University, Sweden; Veterinary Research Department of Kenya Agricultural Research Institute; Walter Reed Army Institute of Research, USA; Wageningen Agricultural University (WAU), Netherlands; West African Rice Development Association (WARDA); Zimbabwean Veterinary Services.

Partners (1995–2005)

Addis Ababa University, Ethiopia; African Butterfly Research Institute, Kenya; Agricultural Research Corporation (ARC), Sudan; Agricultural Research Institute (ARI), Tanzania; Agricultural Research Institute (ARI) Uganda; Agricultural Training and Extension Service (Agritex), Harare, Zimbabwe; Ahmadu Bello University, Nigeria; Alemaya University of Agriculture, Ethiopia; Arab Organisation for Agricultural Development (AOAD), Khartoum, Sudan; Asian Vegetable Research and Development Centre (AVRDC); Association of African Universities (AAU); Benishangul Gumuz Bureau of Agriculture, Ethiopia; Ethiopian Institute of Agricultural Research; Biological Research Institute (BBA), Darmstadt, Germany; Bishop Museum, Papua New Guinea; Bvumbwe Agricultural Research Station (BARS), Malawi; B.t. Research and Development Centre (BtRDC), Hubei, China; Carnegie Museum of Natural History, Pennsylvania, USA; Central Silk Board (CSB), India; Centre de cooperation internationale en recherche agronomique pour le developpement – Departement des productions fruiteres et horticoles, Reunion; Centre of Sericulture and Biological Pest Management Research (CSBR), India; Centre for Bioelectrostatics, UK; Centres for Disease Control (CDC), USA; Centre International de recherche et de developpement sur l'elevage en zone subhumide (CIRDES); Centre National de Recherche Agronomique (CNRA), Côte d'Ivoire; Centre for Biology and Management of Populations (CBGP), France; Centre for Advanced Study of African Society (CASAS), Republic of South Africa; Consultative Group on International Agricultural Research, System-Wide IPM Initiative; Chinese Academy of Agricultural Sciences (CAAS), China; Coffee Research Foundation (CRF), Kenya; Chinese Agricultural University; Centre for Pest Information Technology and Transfer (C-PITT), Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia; Coordinating Office for the Control of Trypanosomiasis in Uganda (COCTU), Uganda; Czech Academy of Sciences, Czechoslovakia; Department of Resource

Surveys and Remote Sensing (DRSRS), Kenya; Desert Locust Control Organisation for Eastern Africa (DLCO-EA), Ethiopia; Directorate of Veterinary Services, Burkina Faso; Department of Research & Specialist Services, Zimbabwe; Direction de la Protection des Vegetaux, Senegal; Dschang University, Cameroon; Dudutech Limited, Kenya; East African Herbarium, Kenya; East African Wildlife Society, Kenya; Eastern and Southern Africa Centre for the Improvement of Cassava, Banana and Plantain (ESARC), International Institute of Tropical Agriculture (IITA), Uganda; Ecole Nationale Superieure Agronomique (ENSAM), France; Ecological Society of America, USA; Eduardo Mondlane University, Mozambique; Egerton University, Kenya; El Colegio de la Frontera Sur (ECOSUR), Mexico; Empresa Brasiliera de Pesquisa Agropecuaria (Brazilian Agricultural Research Corporation) (EMBRAPA), Brazil; ENEA (Italian Agency for New Technology, Energy and Environment), Italy; Enugu State University, Nigeria; Entomological Information Services, USA; Escola Superior de Agricultura 'Luiz de Queiroz' (ESALQ), University of Sao Paulo, Brazil; ETH (Swiss Federal Institute of Technology), Switzerland; Ethiopian Agricultural Research Organisation (EARO), Ethiopia; Ethiopian Health and Nutrition Research Institute, Ethiopia; Ethiopian Social Rehabilitation and Development Fund (ESRDF); Ethiopian Science and Technology Commission (ESTC); Export Processing Zones (EPZ) Authority, Kenya; Faculte des Sciences Agronomiques, Belgium; Farmers' Groups in Shimba Hills and Kinango (Kwale), Vitengeni (Kilifi); Fresh Produce Exporters Association of Kenya (FPEAK); Federal Biological Research Centre for Agriculture and Forestry (FBRCAF), Germany; Finlay Flowers, Kenya; Food for the Hungry International, Mozambique; Foundation CERESLOCUSTOX, Senegal; GAC Products Limited, Finland; Genebank of Kenya; German Mosquito Control Association, Germany; German Centre for Documentation and Information in Agriculture (ZADI), Germany; Global IPM Facility, FAO; Government of Kenya; Harvard University, USA; Hebrew University of Jerusalem, Israel; Horticultural Crops Development Authority (HCDA), Kenya; Horticultural Research and Training Institute (HORTI), Tanzania; Homegrown, Kakuzi Limited, Kenya; Hortitech (K) Ltd; Howard University, USA; Honey Care International, Kenya; Horticultural Research Centre, Zimbabwe; Ifakara Health Research and Development Centre, Tanzania; Indian Agricultural Research Institute (IARI), India; Indian Council of Agricultural Research (ICAR), India; Insect Biological Control Laboratory, France; Institut de l'Environnement et de Recherches Agricoles (INERA), Burkina Faso; Institut de Pasteur, Madagascar; Institut fur Phytomedizin-University of Hohenheim, Germany; Institut National de la Recherche Agronomique, France; lnstitut de Recherche pour le Developpement, France; Institute for Stored Product Protection, Germany; Institute Pasteur, Senegal; lnstitute of Rural Economy, Mali; Instituto de Investigacao Agronomica-Departmento de Botanica e Melhoramento de Plantas, Programa de Investigacao dos Cereais, Luanda, Angola; Instituto de Investigaciones en Ingenieria Genatica y Biologia Molecular, Argentina; Integrated Approach to Crop Research (IACR)-Rothamsted, UK; International Service for the Acquisition of Agri Biotechnology Application (ISAAA); International Bee Research Association (IBRA), UK; International Centre for Research in Agroforestry (ICRAF); International Centre for Scientific Culture (ICSC), World Laboratory; International Institute of Entomology (IIE), UK; International Water Management Institute (IWMI); Interafrican Phytosanitary Council (OAU/IAPSC); International Livestock Research lnstitute (ILRI), Ethiopia; International Steering Committee for Trypanosomiasis Research and Control (OAU-ISCTRC), Ethiopia; International Trypanotolerance Centre (ITC), Gambia; Institute for Systematic Zoology, Museum of Natural History of Humboldt, University of Berlin, Germany; lnter-Governmental SubGroup on Tropical Fruits (IGG-TF), Commodity and Trade Division; IDRC Acacia Initiative, Kenya; Intermediate Technology Development Group (ITDG), Kenya; Instituto Nacional de lnvestigacao Veterinaria (INTVE), Mozambique; International Red Locust Control Organisation for Central and Southern Africa (IRLCO-CSA), Zambia; Japan International Research Centre for Agricultural Sciences; Jestan Herbal Health Clinic Inc., Kenya; John Innes Centre (JIC), UK; Joint Food and Agriculture Organisation of the United Nations/International Atomic Energy Agency (FAO/IAEA) Laboratories, Austria; Jomo Kenyatta University of Agriculture and Technology, (JKUAT), Kenya; Kajiado District Development Committee, Kenya; Kazakh Scientific Research Institute for Plant

Protection, Kazakhstan; Kenya Agricultural Research Institute (KARI); Kenya Industrial Research and Development Institute (KIRDI); Kenya Polytechnic University; Kenya Rural Enterprise Programme (K-REP), Kenya; Kenya Trypanosomiasis Research Institute (KETRI); Kenya Wildlife Service (KWS); Kimron Veterinary Institute (KVI), Israel; Laboratorie d'Entomologie, Reunion; Liverpool School of Tropical Medicine, UK; Lund University, Sweden; Malagasy Research Centre (FOFIFA), Madagascar; Malaria Research and Training Centre, Mali; Medical Research Training Centre, Mali; Ministry of Agriculture, Livestock Development and Marketing (MOALDM), Kenya; Ministry of Agriculture-Kwale/Kilifi Districts, Kenya; Ministry of Agriculture and Forestry, Sudan; Ministries of Agriculture and Livestock in Benin, Cameroon, Chad, Djibouti, Ethiopia, Ghana, Tanzania, Uganda, and Zambia; Ministry of Agriculture and Livestock, Algeria; Ministry of Agriculture and Livestock, Burkina Faso; Ministry of Agriculture and Livestock, Côte d'Ivoire; Ministry of Agriculture and Livestock, Eritrea; Ministry of Agriculture and Livestock, Libya; Ministry of Agriculture, Livestock and Fisheries, Madagascar; Ministry of Agriculture and Livestock, Malawi-Chitidze Research Station; Ministry of Agriculture and Rural Development, Mozambique; Ministry of Agriculture and Cooperatives-Malkerns Research Station, Swaziland; Ministry of Health, Eritrea; Ministry of Health, Uganda; Ministry of Health, Kenya-Division of Vector-Borne Diseases (DVBD); Ministry of Natural Resources, Kenya - Forest Department; Moi University, Kenya; Mpala Research Centre, Kenya; Municipal Council of Kisumu, Kenya; Municipal Council of Malindi, Kenya; Museum Koenig, Bonn, Germany; Natal Museum, Republic of South Africa; national agricultural research systems; Kenya Agricultural Research Institute (KARI), Kenya; National Museums of Kenya (NMK); National Institute for Medical Research, Tanzania; Natural Resources Institute (NRI), UK; National Agricultural Research Laboratories (NARL), Kenya; National Bee Keeping Division of Ministry of Agriculture of Kenya; National Project Directorate for Biological Control (PDBC), Bangalore, India; National Council for Science and Technology, Kenya; National Irrigation Board, Kenya; NGO Council of Kenya; National University of Lesotho, Lesotho; Natural History Museum (NHM), UK; Natural History Museum of Los Angeles County, USA; Netherlands Institute of Cooperative Entrepreneurship, Netherlands; Nnamdi Azikiwe University, Nigeria; Novosibirsk State University, Russia; Ogun State University, Nigeria; Ol Jogi Ranch, Kenya; Onderstepoort Veterinary Institute (OVI), Republic of South Africa; Organisation of African Unity (OAU), Ethiopia-Inter-African Bureau for Animal Resources (OAU-IBAR), Ethiopia; Oy GAC Ab, Finland; Pavia University, Italy; Peasant Associations of Damot Weyde Woreda, North Omo Zone, Ethiopia; Peasant Associations of Cheha, Enemar and Goro Woredas, Gurage Zone, Ethiopia; Permaculture and Parasitology Institute (PPI), Ethiopia; Plant Protection Research Centre, Ethiopia; Plant Protection Research Institute (PPRI)-Agricultural Research Council, Republic of South Africa; Plant Protection Research Institute, Harare, Zimbabwe; Regional Tsetse and Trypanosomiasis Control Programme (RTTCP), Zimbabwe; Research Cooperation Technologies Inc., USA; Rice Research Station, Sierra Leone; Rivers State University of S&T, Nigeria; Royal Botanic Gardens, Edinburgh, UK; Royal Museum for Central Africa, Tervuren, Belgium; Rusinga island farmers, Kenya; San Diego Supercomputer Center, USA; Sasakawa Global 2000, Mozambique; Selian Agricultural Research Institute, Tanzania; Sericulture Research Institute (SRI), China; SAROC Ltd, Kenya; Shalimar Flowers, Kenya; Shanshi Seritech, China; Station de Bassivi Martin, Reunion; Senegalese Institute for Agricultural Research (ISRA), Senegal; South Africa Museum, Republic of South Africa; Society for Hospital and Resources Exchange (SHARE), Kenya; Sokoine University of Agriculture, Tanzania; State University of New York, USA; Swedish University of Agricultural Sciences, Sweden; Taita Hills Biodiversity Project, Kenya; Tamil Nadu Agricultural University (TNAU), India; Tel Aviv University, Israel; Texas A&M University, USA; Tropical Soil Biology and Fertility Programme, Kenya; Tropical Fruit Network (TFNet), Kuala Lumpur, Malaysia; Tropical Pesticides Research Institute (TPRI), Tanzania; Tulane University, USA; United States Department of Agriculture/Agricultural Research Service (USDA/ARS), Montpellier, France; Universidade de Lavras, Brazil; Universidade Regional do Cariri, Brazil; Universidae Federal Rural de Pernambuco, Brazil; Universite de Dschang, Cameroon; University of Aberdeen, Scotland, UK;

University of Agriculture, Nigeria; University of Aleppo, Syria; University of Asmara, Eritrea; University of Bayreuth, Germany; University of Bern, Switzerland; University of Bonn, Germany; University of Buenos Aires, Argentina; University of California, Berkeley, USA; University of Cape Coast, Ghana; University of Cape Town, Republic of South Africa; University of Constance, Germany; University of Copenhagen, Denmark; University of Costa Rica; University of Crete, Greece; University Experimental Station, Kauai, Hawaii, USA; University of Florida, USA; University of Fort Hare, Republic of South Africa; University of Gezira (UOG), Sudan; University of Greenwich, UK; University of Haifa, Israel; University of Hannover, Germany; University of Ibadan, Nigeria; University of Illinois, USA; University of Jena, Germany; University of Khartoum, Sudan; University of Kiel, Germany; University of Molise, Italy; University of Nairobi, Kenya; University of KwaZulu-Natal, Republic of South Africa; University of Newcastle-upon-Tyne, UK; University of Nijmegen, Netherlands; University of Papua New Guinea; University of Parma, Italy; University of Pavia, Italy; University of Pennsylvania, USA; University of Pretoria, Republic of South Africa; University of Queensland, Australia; University of Reggio di Calabria, Italy; University of Rome, Italy; University of Swaziland; University of Vermont, USA; University of Victoria, Canada; University of Washington, USA; University of Zimbabwe; University of Wageningen, Netherlands; Uppsala University, Sweden; US National Center for Ecological Synthesis and Analysis, USA; UTA/CABI-Lutte Biologique Contre les Locustes et les Sauteriaux (LUBILOSA), Benin; Virginia Polytechnic Institute and State University (Virginia Tech), USA; Volcani Centre, Israel; Winrock International; Wild Silk Research Station, China; Wild Silk Research Station, India; World Vision, Mozambique; Xerces Society, USA; Yale University, USA; Yoder Farm, Kenya.

Partners (2006 – 2013)

African Agricultural Technology Foundation (AATF); African Development Bank, Côte d'Ivoire; Africa 2000, Uganda; Agri-Service Ethiopia; Biodiversity International; Bio-Net International, USA; BirdLife International; Bushenyi Silk Association, Uganda; CABI-Africa, Kenya; Centro Internacional de Agricultura Tropical (CIAT); Central Coordination Unit for IFAD Projects, Sudan; Centre de Recherche Agronomique de Loudima, Congo; Consultative Group on International Agricultural Research (CGIAR) Systemwide Initiative on Malaria and Agriculture; Cranfield University, UK; Delegue Provincial de l'Agriculture et du Development Rural de l'Adamaoua, Cameroon; District Veterinary Officer-Kapenguria, Kenya; Drought Management Officer-Kapenguria, Kenya; Duke University, USA; East African Wildlife Society, Tanzania; Ecole Nationale Superieure Agronomique, France; Ethiopian Agricultural Research Centre, Ethiopia; Faculty of Agronomy at Eduardo Mondlane University, Mozambique; Fairchild Tropical Botanic Garden, USA; Federal Ministry for Economic Cooperation and Development, Germany; Forum for Agricultural Research in Africa (FARA); Global Biodiversity Information Facility, Denmark; GTZ Sectoral Project Agriculture and Trade, Germany; Gulu University, Uganda; Heifer International, Kenya; Hoima District Local Government, Uganda; HORTI-Tengeru, Tanzania; Horticultural Crops Research and Development Institute, Sri Lanka; Illinois State University, USA; International Centre for Maize and Wheat Improvement (CIMMYT); International Fund for Agricultural Development (IFAD), Italy; International Institute of Tropical Agriculture (IITA), Benin; International Livestock Research Institute (ILRI), Kenya; International Potato Center (CIP), Peru; International Water Management Institute (IWMI), Sri Lanka; INERA, Burkina Faso; IFAD Loan Project Coordinators in Yemen, Egypt and Uganda; Institut de Recherche pour le Développement (IRD), France; Institut de Recherche Agricole pour le Developpement, Cameroon; Jomo Kenyatta University of Agriculture and Technology (JKUAT), Kenya; Kenya Agricultural Research Institute; Kenya Camel Association; Kenya Forest Service; Kenya Gatsby Trust; Kenya Medical Research Institute (KEMRI); Kenya Organic Agriculture Network; Kenya Plant Health Inspectorate Service; Kenya Seed Company; Kenya Veterinary Department-Veterinary Investigation Laboratories, Kenya; Kenya Wildlife Service (KWS); Kenyatta University, Kenya; Kilimanjaro Christian Medical College (KCMC), Tanzania; Liverpool School of Tropical Medicine, UK; London School of Hygiene and Tropical Medicine (LSHTM), UK; Lund University, Sweden; Makerere University, Uganda; Mbeere County Council, Kenya; Max Planck Institute of Infection Biology, Germany; Ministry of Agriculture, Egypt; Ministries of Agriculture in Kenya, Uganda and Tanzania; Ministry of Agriculture, Yemen; Ministry of Agriculture, Zanzibar; Ministry of Agriculture and Animal Resources, Rwanda; Ministry of Agriculture and Forestry, Government of Southern Sudan; Ministry of Environment and Mineral Resources, Kenya; Ministry of Foreign Affairs, Kenya; Ministry of Health, Kenya; Ministry of Public Health and Sanitation (MOPH&S), Kenya; Ministry of Livestock and Fisheries-Kapenguria, Kenya; Ministry of Livestock Development (MOLD), Kenya; Ministry of Livestock Development, District Livestock Production Officer-Mwingi, Kenya; Museum national d'Histoire naturelle, France; National Agricultural Research Organisation (NARO), Uganda; National Agriculture and Livestock Extension Programme (NALEP), Kenya; National Biological Control Programme, Tanzania; National Environmental Management Authority, Kenya; National Irrigation Board, Kenya; National Institutes of Health, USA; National Museums of Kenya; Nature Kenya; National Institute for Medical Research (NIMR), Tanzania; National University of Rwanda; North West University, Republic of South Africa; Nthagaiya mango growers, Kenya; Ohio State University, USA; Paperazzi Limited, Kenya; Plant Protection Research Institute, Zimbabwe; Plant Protection Directorate, Sudan; Projet de Lutte Preventive Antiacridienne, Ministere de l'Agriculture and Malagasy Research Centre, Madagascar; Rothamsted Research, UK; Simon Fraser University, Canada; South African National Bioinformatics Institute, Republic of South Africa; Swiss Agency for Development; Swiss Federal Institute of Technology; Swiss Mosquito Control Agency; Staatliche Naturhistorische Sammlungen, Germany; Sugar Research Institute, Republic of South Africa; Tanzania Forest Conservation Group; Terra Verde, Switzerland; Transvaal Museum, Republic of South Africa; Tropical Soil Biology and Fertility Institute of CIAT (TSBF-CIAT); Third World Organization for Women in Science, Italy; Uganda Virus Research Institute (UVRI), Uganda; United Nations Environment Programme (UNEP); Universidade de Sao Paulo, Brazil; Universidade Federal Rural de Pernambuco, Brazil; Universidade Regional do Cariri, Brazil; Universidade de Lavras, Brazil; Universita degli Studi del Molise, Italy; Universita Mediterranea di Reggio Calabria, Italy; University of Alabama, USA; University of Buea, Cameroon; University of California, Santa Barbara, USA; University of Cambridge, UK; University of California at Davis, USA; University of California at Irvine, USA; University of Cape Coast, Ghana; University of Dschang, Cameroon; University of Edinburgh, UK; University of Exeter, UK; University of Hannover, Germany; University of Helsinki, Finland; University of Hohenheim, Germany; University of KwaZulu-Natal, Republic of South Africa; University of Nairobi, Kenya; University of Oxford, UK; University of Pretoria, Republic of South Africa; University of Virginia, USA; University of Würzburg, Germany; University of York, UK; USDA/ARS Centre for Medical, Agricultural and Veterinary Entomology, USA; Valent BioSciences Corporation, USA; Viking Limited, Kenya; Virginia Tech University (Virginia Polytechnic Institute and State University), USA; Wageningen University and Research Centre, Netherlands; Wagga Wagga Agricultural Institute, Australia; Wellcome Trust Sanger Institute, UK; Wild Living, Kenya; World Agroforestry Centre (ICRAF), Kenya; World Federation of Scientists, Switzerland; World Health Organization (WHO); World Vegetable Center (WorldVeg), Taiwan; World Wide Fund for Nature-Eastern Africa Region Programme Office.

Partners (2014–present)

A to Z Textiles Limited, Tanzania; Africa Oil Ethiopia, B.V.; African Academy of Sciences (AAS); African Conservation Tillage Network, Malawi and Zambia; African Inland Church, Tanzania (AICT); African Union Inter-African Bureau for Animal Resources (AU-IBAR); African Women in Agricultural Research and Development (AWARD); Afrika Green Revolution (AGREE), Kenya; AgBiTech, Texas, USA; Agrarian Systems Ltd. Uganda; Agri Seed Company Limited, Kenya; Agricultural Chemicals Board, Uganda; Agricultural Research Corporation (ARC), Sudan; Agricultural Research and Extension Trust (ARET), Malawi; Agricultural Sector Development Support Programme (ASDSP), Kenya; Agricultural, Technical and Extension Services (AGRITEX), Zimbabwe; Agricultural Transformation Agency (ATA), Ethiopia; Agroecology Lab, Université Libre de Bruxelles (ULB), Belgium; Agroscope, Switzerland; Alexander von Humboldt Foundation (AvH), Germany; Alexis Business Limited, Rwanda; Ambo University, Ethiopia; Andermatt Ltd, Grossdietwil, Switzerland and South Africa; Anglican Development Services (ADS), Kenya; Arid Regions Institute, Tunisia; Arvalis - Institut du Végétal, France; Austin Investment Ltd, Kenya; Avocado Growers Association, South Africa; Bamboo for Integrated Development (BIDG), Ghana; BCRL – Pest Control India Ltd; Biobest Group NV, Belgium; Biotechnology Research Institute, Kenya Agricultural and Livestock Research Organisation (KALRO); Bioversity International; Biovision Foundation for Ecological Development, Switzerland; Busitema University, Uganda; Centre de coopération internationale en recherche agronomique pour le développement (CIRAD), France; Centre de Biologie pour la Gestion des Populations, France; Centre for African Bio-Entrepreneurship (CABE), Kenya; Centre for Agriculture and Bioscience International (CABI), Kenya; Centre for Development Research (ZEF), University of Bonn, Germany; Centre for Earth Observation and Citizen Science of IIASA- International Institute for Applied Systems Analysis, Austria; Centre National de la Recherche Scientifique, France; CEVA, France; Charité-Universitätsmedizin, Germany; Chora Botter Woreda (District) Agriculture and Rural Development Office, Ethiopia; Chora Botter Woreda (District) Cooperative Agency, Ethiopia; Citrus Biocontrol Research Laboratories (BCRL), India; Citrus Research International, Republic of South Africa; Coffee Research Institute (CRI), Kenya; College of Agricultural Sciences, Pennsylvania State University (Penn State), USA; Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia; Conservation Farming Unit (CFU), Zambia; County governments of Marsabit and Isiolo, Kenya; Crop Health and Protection (CHAP), UK; Dabaso Tujengane Self Help Group – Watamu Marine Association, Kenya; Dedan Kimathi University of Technology, Kenya; Department of Agricultural Research Services (DARS), Malawi; Department of Research and Specialist Services, Zimbabwe; Director of Veterinary Services, Kabete Veterinary Research Laboratories, Kenya; Division of Disease Surveillance and Response, Ministry of Public Health and Sanitation, Kenya; Division of Plant Industry, Florida Department of Agriculture and Consumer Services, USA; Dudutech Ltd, Kenya; Duke University, USA; Durham University, UK; Dynamic Microfinance Institution S.C. Ethiopia; East Africa Nutraceuticals Ltd (EAN), Kenya; East African Seed Co. Ltd, Kenya; East Usambara Farmers Group, Tanzania; Eastern Archdiocesan Development Network (EADEN), Uganda; Ecodudu Limited, Kenya; Eden Springs Farm, Kenya; Eduardo Mondlane University, Mozambique; Egerton University, Kenya; Elephant Vert, Morocco; Embu University, Kenya; Emmanuel International (EI), Tanzania; Estación Experimental de la Asociación de Agricultores de Cañete (EEAAC), Peru; Ethiopian Institute of Agricultural Research (EIAR); ETH Zurich, Switzerland; Evangelical Lutheran Church, Tanzania (ELCT); Faculty of Agricultural Sciences, University of Kinshasa (DR Congo); Faculty of Biology and Biotechnology, Ruhr-University, Bochum, Germany; Farm Radio International (FRI), Uganda and Kenya; Farmers Development Trust (FDT), Uganda; Farmtrack Consulting Ltd, Kenya; Federal Ministry of Health, Ethiopia; Federal Ministry for Economic Cooperation and Development (BMZ), Germany; Food and Agriculture Organization of the United Nations (FAO); FAO Reference Centre; Food and Nutrition Solutions Ltd (FONUS),

Uganda; Food for the Hungry (FH), Rwanda; Food Security Center, University of Hohenheim, Germany; Forum for Agricultural Research in Africa (FARA); Free University of Berlin, Germany; Gaea Foods Ltd, Kenya; German Aerospace Center (DLR); German Centre for Integrative Biodiversity Research (iDiv), Germany; Ghent University, Belgium; Global Agricultural Development Organization, USA; Global Agro Concept Limited, Rwanda; Gollis University, Somaliland; Green Enzyme Technologies Ltd (GETL), Kenya; Groupe Éléphant Vert, Switzerland; Guavay Company Limited, Tanzania; Haramaya University, Ethiopia; Hawassa University, Ethiopia; Harvard T.H. Chan School of Public Health, Harvard University, USA; Heifer Project International – Kenya (HPI-K); Heifer Project International – Tanzania (HPI-T); Helmholtz Centre for Environmental Research (UFZ), Germany; Higher Agronomic Institute of Chott-Meriem, Tunisia; Holeta Bee Research Centre, Ethiopia; Horticultural Research and Training Institute (HORTI-Tengeru), Tanzania; HottiServe East Africa Limited, Kenya; Humboldt State University, USA; Humboldt-Universität zu Berlin, Germany; Humidtropics CGIAR Research Programme (CRP) led by IITA; Ifakara Health Institute, Tanzania; Institut de Recherche pour le Développement (IRD), France; Institut de l'Environment et Recherches Agricoles (INERA), Burkina Faso; Institute of Agronomic Sciences of Burundi (ISABU); Institut national de la recherche agronomique (INRA), France; Institut sénégalais de recherches agricoles (ISRA), Senegal; Institute for Biological Control, Julius Kuehn-Institut (JKI), Germany; Institute for Sustainable Development (ISD), Ethiopia; Institute of Organic Chemistry and Biochemistry, Academy of Sciences of Czech Republic; Institute of Primate Research, National Museums of Kenya; International Center for Agricultural Research in the Dry Areas (ICARDA), Syria; International Center for Tropical Agriculture (CIAT), Colombia; International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), India; International Food Policy Research Institute (IFPRI), USA; International Foundation for Science (IFS), Sweden; International Institute of Tropical Agriculture (IITA); International Livestock Research Institute (ILRI), Kenya; International Maize and Wheat Improvement Center (CIMMYT), Mexico; International Potato Center (CIP), Peru; International Water Management Institute (IWMI), Sri Lanka; iTEC, Tanzania; Iziko South Africa Museum, South Africa; Jaramogi Oginga Odinga University of Science and Technology (JOOUST), Kenya; Jimma University, Ethiopia; Johns Hopkins University, USA; Jomo Kenyatta University of Agriculture and Technology (JKUAT), Kenya; Julius Kühn Institute, Federal Research Institute for Cultivated Plants (JKI), Germany; Kajiado, Kirinyaga, Kitui, Makueni, Meru, Taita-Taveta and Tharaka Nithi counties Ministries of Agriculture, Kenya; Kakuzi PLC, Kenya; Kamaki Cooperative Society Ltd, Kenya; Kamili Nature Brands Limited, Kenya; Kassel University, Germany; Kasisi Agricultural Training Centre (KATC), Zambia; Keele University, UK; Kenya Agricultural and Livestock Research Organization (KALRO), Kenya; Kenya Agricultural and Livestock Research Organization, Horticulture Research Institute (KALRO-HRI); Kenya Agricultural and Livestock Research Organization (KALRO) (National Sericulture Research Centre); Kenya Biologics Ltd; Kenya Bureau of Standards (KEBS); Kenya Industrial Research and Development Institute (KIRDI), Kenya; Kenya Institute of Organic Farming (KIOF); Kenya Livestock Producers Association (KLPA); Kenya Marine and Fisheries Research Institute (KMFRI); Kenya Medical Research Institute (KEMRI); KEMRI - Wellcome Trust Research Programme, Kenya; Kenya Organic Agriculture Network (KOAN); Kenya Plant Health Inspectorate Service (KEPHIS); Kenya Tsetse and Trypanosomiasis Eradication Council (KENTTEC), Kenya; Kenya Wildlife Service; Kenyatta University, Kenya; Kibwezi Agro Limited, Kenya; Koppert, Kenya; KTH Royal Institute of Technology, Sweden; Kushereketa Rural Development Organization (KURDO), Zimbabwe; Kwame Nkrumah University, Zambia; Lake Zone Agricultural Research and Development Institute (LZARDI), Tanzania; Lasting Solutions Ltd, Kenya and Uganda; Leibniz Universität Hannover (LUH), Germany; Lilongwe University of Agriculture & Natural Resources (LUANAR), Malawi; Liverpool School of Tropical Medicine, UK; London School of Hygiene & Tropical Medicine, UK; Luleå University of Technology, Sweden; Makerere University, Uganda; Marsabit County Livestock Office, Kenya; Martin Luther University of Halle-Wittenberg, Germany; Masaka Basenene Association, Uganda; Maseno University, Kenya; Max Planck Institute for

Chemical Ecology, Germany; Metals and Engineering Corporation (METEC), Ethiopia; mHealth Kenya Limited, Kenya; Mikocheni Agricultural Research Institute, Tanzania; Milba Brands Associates Limited, Kenya; Millennium Institute, USA; MIMEA International Kenya Limited, Kenya; Ministries of Agriculture of Botswana, Namibia, Liberia, Zambia and Zimbabwe; Ministry of Agriculture (MoA), Nyabondo, Kenya; Ministry of Agriculture and Animal Resources (MINAGRI), Rwanda; Ministry of Agriculture and Forestry, Government of South Sudan; Ministry of Agriculture and Natural Resources, Ethiopia; Ministry of Agriculture, Plant Health Clinics, Arba Minch, Ethiopia; Ministry of Agriculture, Food Security and Cooperatives, Tanzania; Ministry of Agriculture, Animal Industry and Fisheries (MAAIF), Uganda; Ministry of Agriculture, Fisheries, Environment and Urban Planning, Comoros; Ministry of Agriculture, Livestock and Fisheries (Directorate of Livestock Production), Madagascar; Ministry of Agriculture, Livestock and Fisheries, Kenya; Ministry of Agriculture, Livestock & Fisheries and Department of Veterinary Services in Kwale County, Kenya; Ministry of Agriculture, Natural Resources, Livestock and Fisheries, Zanzibar; Ministry of Agro-industry and Food Security (Entomology Division), Mauritius; Ministry of Animal Resources and Fisheries, Burkina Faso; Ministry of Health & Municipal Council of Malindi, Kenya; Ministries of Health in Kenya and Ethiopia; Ministry of Livestock, Somaliland; Ministry of Livestock, Fisheries and Animal Industries, Cameroon; Ministry of Livestock and Fisheries, Ethiopia; Ministry of Public Health and Sanitation, Nyabondo, Kenya; Ministry of Trade, Industry and Cooperatives, Uganda; Madorera Research Institute, Zimbabwe; Mogabiri Farm Extension Centre (MFEC), Tanzania; Moi University, Kenya; Mosquito Control in Nyabondo (MOCON) community group, Nyabondo, Kenya; Mount Kenya University, Kenya; Muliru Farmers Conservation Group (MFCG), Kenya; Muhimbili University of Health and Allied Sciences (MUHAS), Tanzania; Mukushi Seed Company, Zimbabwe; Murang'a Coffee Cooperative Union, Kenya; National Agriculture and Food Research Organization, Japan; National Agricultural and Extension Services, Ethiopia; National Agricultural Research Organisation (NARO), Uganda; National Agricultural Research Laboratories (NARL), Uganda; national agricultural research systems (NARS); National Beekeeping Station, Kenya; National Biocontrol Programme, Tanzania; National Crops Resources Research Institute (NaCCRI), Uganda; National Fisheries Resources Research Institute (NaFIRRI), Uganda; National Horticultural Research Institute (NIHORT), Nigeria; National Livestock Resources Research Institute (NaLIRRI), Uganda; National Malaria Control Programmes (NMCPs) of Botswana, Kingdom of eSwatini, Mozambique, Namibia, Zambia and Zimbabwe; National Museums of Kenya; National Museum, Bloemfontein, South Africa; National Potato Council, Kenya; National Semi Arid Resources Research Institute (NASARRI), Uganda; Nelson Mandela African Institution of Science and Technology (NM-AIST), Tanzania; New Zealand Institute for Plant & Food Research Ltd; North-West University, Republic of South Africa; Norwegian Institute for Bioeconomy Research (NIBIO); Norwegian University of Life Sciences, Norway; Nutri Africa Ltd, Kenya; Nutreal Ltd, Uganda; Nyendo Grasshopper Association, Uganda; Ohio State University, USA; OKOA Society, NGO, Tanzania; One Acre Fund, Kenya and Uganda; Operation Wealth Creation (OWC), Uganda; Organic Consumers Alliance (OCA), Kenya; Pan Africa University, Kenya; Pangani Basin Water Board, Tanzania; Partnership for Economic Policy (PEP); Pennsylvania State University, USA; Pesticide Control Products Board (PCBP), Kenya; P.E.S. Technologies (PES), UK; Plant Health Regulatory Directorate (PHRD), Ethiopia; Plant Health Service, HORTI-Tengeru, Tanzania; Plant Research International, Wageningen University and Research Centre (Resource Ecology group), Netherlands; Poverty Alleviation Department, Office of the President, Uganda; Punguza Mbu na Malaria Malindi (PUMMA) community group, Malindi, Kenya; Pwani University (PU), Kenya; Radboud University, Netherlands; Real IPM Company Limited, Kenya; Reed College, USA; Remote Sensing Solutions, Germany; Rothamsted Research, UK; Research Institute of Organic Agriculture (FiBL), Switzerland; Royal Museum for Central Africa, Tervuren, Belgium; Ruhr-Universität Bochum, Germany; Russell IPM, UK; Rusinga Island community, Kenya; Rwanda Agricultural and Animal Resources Board (RAB); RWTH Aachen University, Germany; Sanergy Limited, Kenya; Schmalhausen Institute of Zoology, Ukraine; SCORE Against Poverty,

Zimbabwe; Secure Harvest Limited, UK; Seed Co, Zimbabwe; Seed Control and Certification Institute of Zambia; SENAI Farm Supplies Limited, Uganda; Send a Cow, Kenya and Rwanda; Send-a-Cow farmers' groups; Service Chrétien d'Appui à l'Animation Rurale (SECAAR), Togo and Benin; Seychelles Agricultural Agency; Share an Opportunity (SAO), Uganda; Sigma Feeds Ltd, Kenya; Smithsonian Institution, USA; Smithsonian National Museum of Natural History, USA; Sokoine University of Agriculture, Tanzania; Solidaridad East and Central Africa, Kenya; Stellenbosch University, Department of Conservation Ecology and Entomology, Republic of South Africa; Strand Life Sciences, India; Sulma Foods Limited, Uganda; Sumitomo Chemicals, Japan; Sustainable Land Management (SLM), Somaliland; Sustainable Use of Plant Diversity (SUPD), Uganda; Swedish University of Agricultural Sciences (SLU), Sweden; Swiss Tropical and Public Health Institute, Switzerland; Syngenta, Kenya; Taita Environmental Research and Resource Arc (TERRA), Kenya; Tanzania Agricultural Research Institute (TARI-Ukiriguru); Tanzania Commission for Science and Technology (COSTECH); Tanzania Farmers Conservation Group (TFCG); Tanzania Humane Charity (THC); Tanzania Industrial Research and Development Organization (TIRDO); Tanzania Wildlife Research Institute (TAWIRI); Tanzania National Parks; Tea Research Foundation of Central Africa (TRFCA), Malawi; Technical University of Vienna, Austria; Technical University of Munich, Germany; TechnoServe, Kenya; Tel Aviv University, Israel; TWAS, The World Academy of Sciences; Tigray Agricultural Research Institute (TARI), Ethiopia; TONNET Agro-engineering Company Limited, Uganda; Total LandCare, Malawi and Zambia; Treasure Industries Limited (TIL), Kenya; Tropical Entomology Research Center, Italy; Tropical Pesticides Research Institute, Tanzania; Tropical Soil Biology and Fertility (TSBF) Institute of CIAT; Tropical University of Dschang, Cameroon; Tuscia University, Italy; Tursam Investment Limited (TIL), Uganda; Ugachick Poultry Breeders Uganda Limited, Uganda; Uganda National Bureau of Standards (UNBS); Uganda Registration Service Bureau (URSB); Ultimate Products (Aust) Pty Ltd, Australia; Umeå University, Sweden; Unga Feeds Ltd, Kenya; United States Department of Agriculture-Agricultural Research Service (USDA-ARS), USA; United States International University (USIU), Kenya; Universidad Nacional Agraria La Molina (UNALM), Peru; Université Cheikh Anta Diop de Dakar, Senegal; University of Amsterdam, Netherlands; University of Bonn, Germany; University of California, Davis, USA; University of Cambridge, UK; University of Canterbury, New Zealand; University of Cape Coast, Ghana; University of Constance, Germany; University of Copenhagen, Denmark; University of Dar es Salaam, Tanzania; University of Eldoret, Kenya; University of Geneva, Switzerland; University of Gezira, Sudan; University of Ghana; University of Greenwich (Natural Resources Institute), UK; University of Helsinki, Finland; University of Hohenheim, Germany; University of Ibadan, Nigeria; University of Illinois, USA; University of Kansas, USA; University of KwaZulu-Natal, Republic of South Africa; University of Liverpool, UK; University of Maryland, USA; University of Michigan, USA; University of Nairobi, Kenya; University of Pavia, Italy; University of Pretoria, Republic of South Africa; University of Rwanda; University of Sousse, Tunisia; University of Tuscia, Italy; University of Twente, Netherlands; University of the Western Cape, Republic of South Africa; University of Umea, Sweden; University of the Witwatersrand, Republic of South Africa; University of Würzburg, Germany; University of Yaoundé I, Cameroon; University of York, UK; University of Zambia, Zambia; University of Zürich, Switzerland; Upande Ltd, Kenya; Vanderbilt University, USA; Village Care International, Uganda; Villgro, Kenya; Virginia Polytechnic Institute and State University, USA; Wellcome Sanger Institute, UK; WeRATE; W.E Tilley Fish Processors, Kenya; World Agroforestry Centre (ICRAF), Kenya; World Health Organization-Regional Office for Africa (WHO-AFRO); World Vegetable Centre (WorldVeg), Taiwan and Tanzania; World Vision Kenya; Yale School of Public Health, USA; Yale University, USA; Yeungnam University, South Korea; Zambia Agriculture Research Institute (ZARI).

ANNEX B: LIST OF ACRONYMS AND ABBREVIATIONS

AAIS	African Association of Insect Scientists
AAS	African Academy of Sciences
ABOS	Belgian Administration for Development Cooperation
ACIAR	Australian Centre for International Agricultural Research
ACSM	advocacy, communication and social mobilisation capacities
ACT	artemisinin-based combination therapy
ADC	Austrian Development Cooperation
AfDB	African Development Bank
AFERIA	Adaptation for Ecosystem Resilience in Africa
AFESD	Arab Fund for Economic and Social Development
AHUs	African Host Universities
AIMS	African Institute for Mathematical Science
AOAD	Arab Organisation for Agricultural Development
APHI	Africa Plant Health Initiative
AR4D	Agricultural Research for Development
ARPPIS	African Regional Postgraduate Programme in Insect Science
ARQU	Animal Rearing and Quarantine Unit
ASA	ARPPIS Scholars Association
ASET	applied sciences, engineering and technology
ATPS	African Technology Policy Studies Network (Kenya)
ATSAF	German Council for Research on Tropical and Subtropical Agriculture
AU-IBAR	African Union Inter-African Bureau for Animal Resources
AVID	Arbovirus Incidence and Diversity project
AVRDC	The World Vegetable Centre
BADEA	Arab Bank for Economic Development in Africa
BBSRC	Biotechnology and Biological Sciences Research Council
BCEU	Behavioural and Chemical Ecology Unit
BMBF	Federal Ministry of Education and Research (Germany)
BMI	Boris Mints Institute
BMZ	Federal Ministry for Economic Cooperation and Development (Germany)
Bti	*Bacillus thuringiensis israelensis*
BvAT	Biovision Africa Trust
CAADP	Comprehensive Africa Agriculture Development Programme
CABI	Centre for Agriculture and Bioscience International
CBFAMFEWS	Community Based Fall Armyworm Monitoring, Forecasting and Early Warning System
CCD	colony collapse disorder
CERNVec	Community of Excellence for Research in Neglected Vector-Borne Zoonotic Diseases
CGIAR	Consortium of International Agricultural Research Centers (formerly Consultative Group on International Agricultural Research)
CHIESA	Climate Change Impacts on Ecosystem Services and Food Security in Eastern Africa
CIAT	International Center for Tropical Agriculture
CIDA	Canadian International Development Agency
CIM	Centre for International Migration and Development
CIMMYT	International Maize and Wheat Improvement Center
CIRAD	French Agricultural Research Centre for International Development
CLaf	*Candidatus* Liberibacter africanus
CNHR	Consortium for National Health Research
CORAF/WECARD	West and Central African Council for Agricultural Research and Development
CORPs	community owned resource persons
CPE	Community and Public Engagement
CTA	Technical Centre for Agricultural and Rural Cooperation (Wageningen, Netherlands)
CultiAF	Cultivate Africa's Future Fund
DAAD	German Academic Exchange Service
DANIDA	Danish International Development Agency
DBM	diamondback moth
DDA	Directorate for Development Cooperation and Humanitarian Aid
DED	German Development Service
DELTAS	Developing Excellence in Leadership, Training and Science
DFID	Department for International Development (UK)
DGaaE	German Society for General and Applied Entomology
DGIS	Directorate General for International Cooperation (Netherlands)
DMMG	Data Management, Modelling and Geo-Information
DPG	German Phytomedicine Society
DPO	International Education and Research Programme
DRIP	Dissertation Research Internship Programme
DWV	Deformed wing virus
EANBiT	Eastern Africa Network for Bioinformatics Training
EASTECO	East African Science and Technology Commission (Rwanda)
EEC	European Economic Community
ERP	Enterprise Resource Planning
ESA	Entomological Society of America
EU	European Union
EU-INCO	European Union International Cooperation Programme
FAO	Food and Agriculture Organization of the United Nations
FiBL	Research Institute of Organic Agriculture (Frick, Switzerland)
FINNIDA	Finnish International Development Agency
FNIH	Foundation for the National Institutes of Health (USA)
FPEAK	Fresh Produce Exporters Association of Kenya
GAP	good agricultural practices
GBIF	Global Biodiversity Information Facility
GC	Governing Council
GCC	Grand Challenges Canada
GCRF	Global Challenges Research Fund (UK)
GEF	Global Environment Facility
GIS	geographic information system
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
GMP	good manufacturing practice
GoFoWiSeR	Global Forum on Women in Scientific Research
GTZ	German Agency for Technical Cooperation
H3Africa	Human Heredity and Health in Africa initiative
HAK	Horticultural Association of Kenya
IAASTD	International Assessment of Agricultural Knowledge, Science and Technology for Development
IAEA	International Atomic Energy Agency (Austria)
IAP	InterAcademy Partnership
IAPPS	International Association for the Plant Protection Sciences
IBRD	International Bank for Reconstruction and Development
ICRC	International Committee of the Red Cross
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics (India)
ICSC	International Centre for Scientific Culture-World Laboratory
ICSU	International Council for Scientific Unions
IDRC	International Development Research Centre (Canada)
IFAD	International Fund for Agricultural Development (Rome)
IFFSC	International Fruit Fly Steering Committee
IFPRI	International Food Policy Research Institute (USA)
IFS	International Foundation for Science

IGD	Istituto Tecnico Industriale Guido Donegani
IGGI	International Glossina Genome Initiative
IISD	International Institute for Sustainable Development (Canada)
IITA	International Institute of Tropical Agriculture
ILO	International Labour Organization (Switzerland)
ILRI	International Livestock Research Institute (Kenya)
INERA	Institut de l'Environnement et Recherches Agricoles (Burkina Faso)
INSEFF	Insects for Food, Feed and Other Uses programme
IOBC	International Organisation for Biological Control
IPER	*icipe* Periodic External Review
IPES-Food	International Panel of Experts on Sustainable Food Systems
IPM	integrated pest management
IPPM	integrated pest and pollinators management
IRD	Institut de Recherche pour le Développement (France)
IRRI	International Rice Research Institute (Philippines)
ISCE	International Society of Chemical Ecology
ISCTRC	International Scientific Council for Trypanosomiasis Research and Control
IUCN	International Union for Conservation of Nature
IVM	integrated vector management
IVM-ICC	IVM interagency coordinating committee
JCC	Jobs Creation Commission (Ethiopia)
JIRCAS	Japan International Research Center for Agricultural Sciences
JSPS	Japanese Society for the Promotion of Science
KALRO	Kenya Agricultural and Livestock Research Organisation
KARI	Kenya Agricultural Research Institute
KEMRI	Kenya Medical Research Institute
KeNAAM	Kenya NGOs Alliance Against Malaria
KEPHIS	Kenya Plant Health Inspectorate Service
KSTCIE	Kenya Standing Technical Committee on Imports and Exports
KWS	Kenya Wildlife Service
LIT	lethal insect technique
M&E	Monitoring & Evaluation
MCMV	*Maize chlorotic mottle virus*
MDGs	millennium development goals
MFCG	Muliru Farmers' Conservation Group
MLND	Maize Lethal Necrosis Disease
MOYESH	MOre Young Entrepreneurs in Silk and Honey
MRLs	maximum residue levels
MUSA	Microbial Uptakes for Sustainable Management of Major Banana Pests and Diseases project
NACOSTI	National Commission for Science, Technology and Innovation
NAS	US National Academy of Sciences
NCST	National Commission for Science and Technology
NENA	Near East and North Africa region
NGOs	non-governmental organisation
NIH	National Institutes of Health (USA)
NIHR	National Institute for Health Research
Norad	Norwegian Agency for Development Cooperation
NWO-WOTRO	Food & Business Global Challenges Programme/Netherlands Organization for Scientific Research
NRF	National Research Foundation (Kenya)
NRI	Natural Resources Institute (UK)
NSF	National Science Foundation (USA)
NSSA	Nematological Society of Southern Africa
NTDs	neglected tropical diseases
OAU	Organisation of African Unity
ODA	Overseas Development Administration (UK)
OECD	Organisation for Economic Co-operation and Development
OIE	World Organisation for Animal Health
OPEC	Organization of the Petroleum Exporting Countries
OWSD	Organisation for Women in Science for the Developing World
PAN	phenylacetonitrile
PASET	Partnership for Skills in Applied Sciences, Engineering and Technology
PATTEC	Pan African Tsetse and Trypanosomiasis Eradication Campaign
PCN	potato cyst nematode
PEER	Partnerships for Enhanced Engagement in Research programme
PESTNET	Pest Management Research and Development Network
PICS	Purdue Improved Crop Storage bags
POPs	persistent organic pollutants
PUMMA	Punguza Mbu Malindi
R&D	research and development
RCU	Regional Coordination Unit of RSIF
RSIF	Regional Scholarship and Innovation Fund
RSTMH	Royal Society of Tropical Medicine and Hygiene
SAFGRAD	Semi-Arid Food Grain Research and Development
SARDNet Africa	Sericulture, Apiculture Research and Development Network in Africa
SAREC	Swedish Agency for Research Cooperation with Developing Countries
SCMV	*Sugarcane mosaic virus*
SDC	Swiss Agency for Development and Cooperation
SDGs	Sustainable Development Goals
SEED	Supporting Entrepreneurs for Environment and Development.
SEI	Stockholm Environment Institute
SGI	Sponsoring Group of *icipe*
Sida	Swedish International Development Cooperation Agency
SMoTs	solar-powered mosquito trapping systems
SNSF	Swiss National Science Foundation
SSIA	Social Science and Impact Assessment Unit
SSIRU	Social Science Interface Research Unit
SSRC	Social Science Research Council (USA)
STEM	science, technology, engineering and mathematics
STISA	Science, Technology and Innovation Strategy for Africa
TEAM	Tephritid Workers of Europe, Africa and the Middle East
THRiVE	Training of Health Researchers into Vocational Excellence in East Africa
TIGR	The Institute for Genomic Research
ToT	Training of Trainers
TRAI	tick resistance antigenic indicators
TTCU	Tsetse and Trypanosomiasis Control Unit (Zambia)
TTU	Technology Transfer Unit
TWAS/ROSSA	The World Academy of Sciences Regional Office for Sub-Saharan Africa
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNHCR	United Nations High Commissioner for Refugees
UNICEF	United Nations Children's Fund
UNOPS	United Nations Office for Project Services
UNU	United Nations University (Japan)
USAID	United States Agency for International Development
USDA-ARS	United States Department of Agriculture-Agricultural Research Service
VLIR-UOS	Vlaamse Interuniversitaire Raad (Flemish Interuniversities Council) (VLIR) – Universitaire Ontwikkelings samenwerking (University Development Co-operation) (UOS)
WARDA	West Africa Rice Development Association
WHO	World Health Organization
WHO-AFRO	World Health Organization Regional Office for Africa
WRI	World Resources Institute (USA)
YESH	Young Entrepreneurs in Silk and Honey

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Jewel bee, *Amegilla vivida*