2022

icipe CORE ANNUAL REPORT

PROGRAMMATIC REPORTING BASED ON *icipe's* 2021 – 2025 RESULTS BASED MANAGEMENT (RBM) FRAMEWORK

May 2023

Checkered Beetles (Family Cleridae), is so-called because of the differently coloured square shapes on the abdomen seen in some species. Most clerids are predators feeding on adults of other beetles, especially word-boring beetles and cleridae have had some success in the biological control of pests of pine trees. Some species patrol flower heads and attack other visiting insects, and there are reports of the possible importance of clerids as pollinators. The fossil record dates Cleridae to the mid-Jurassic, about 165 million years ago, so they've had plenty of time to evolve into the many different species (ca. 3500) that are distributed throughout the world.

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List of Acronyms

2iE	International Institute for Water and Environmental Engineering
AAS	African Academy of Sciences
ACIAR	Australian Centre for International Agricultural Research
AGBT	Advances in Genome Biology and Technology
AgriDI	*Accelerating inclusive green growth through agri-based Digital Innovation in West Africa*
AHUs	African Host Universities
ARPPIS	African Regional Postgraduate Programme in Insect Science
ATPS	African Technology Policy Studies Network
BAP	BioInnovate Africa Programme
BSF	Black soldier fly
BSFFF	Black soldier fly frass fertilizer
BSFL	Black solider fly larvae
BSFLF	Black soldier fly larvae-based feeds
BSU	Biosystematics Unit
CA	Cellular automata
CBC	Classical Biological Control
CBID	Capacity Building and Institutional Development
DENV	Dengue virus
DMMG	Data Management, Modelling and Geoinformation
DRIP	Dissertation Research Internship Programme
DSS	Decision Support System
EAC	East African Community
EASTECO	East African Science and Technology Commission
EIF	Enhanced Integrated Framework
EIT-Hub	Emerging Insect Technology Hub
EN	Ecological niche
EU	European Union
FAW	Fall armyworm
FLN	Free-living nematodes
FNN	Fuzzy Neural Network
GA	Glutamic acid
GBIF	Global Biodiversity Information Facility
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
GSH	Glutathione
HMPs	Host Marking Pheromones
HS-SPME	Headspace-solid phase microextraction
i4Ag	GIZ Fund for the Promotion of Innovations in Agriculture
ICT	Information and Communication Technology
INSEFF	Insects for Food, Feed and Other Uses programme
IoT	Internet of Things
IPER	*icipe* Periodic External Review
IPIs	International Partner Institutions
IPM	Integrated Pest Management
IPPM	Integrated pest and pollinator management
IRS	Indoor residual spraying
JIRA	Junior Investigator Research Award
JMTV	Jingmen tick virus
LFA	Logical Framework Approach
LLINs	Long-lasting insecticidal nets
MaDiPHS	Malawi Digital Plant Health Service
ML4EO	Machine learning for earth observation
MLI	Maize–legume intercropping

MOU	Memoranda of Understanding
MOYESH	More Opportunities for Young Entrepreneurs in Silk and Honey
MozSkills	Project to improve skills development in Mozambique
MTA	Material Transfer Agreement
NMCPs	National Malaria Control Programmes
Norad	Norwegian Agency for Development Cooperation
NTPV	Ntepes virus
PAC	Programme Advisory Committee
PASET	Partnership for skills in Applied Sciences, Engineering and Technology
PCR	Polymerase Chain Reaction
PMEL	Planning, Monitoring, Evaluation and Learning
PPNs	Plant parasitic nematodes
PPT	Push-pull technology
R&D	Research & Development
R4D	Research for Development
RBM	Results Based Management
RKN	Root-knot nematode
RMT	Residual malaria transmission
RSIF	Regional Scholarship and Innovation Fund
SDG	Sustainable Development Goals
SEI	Stockholm Environment Institute
Sida	Swedish International Development Cooperation Agency
SS	Spot spraying
SSA	sub-Sahara Africa
SSIAU	Social Science and Impact Assessment Unit
SysCom	Farming Systems Comparisons in the Tropics
TBD	Tick-borne diseases
TEA	Technoeconomic analysis
TRCT	Tsetse repellant collar technology
TWAS	The World Academy of Sciences
UU-A	Utsunomiya University-Africa
VIPPT	Vegetable Integrated Push-Pull Technology
WMSG	Wonder multistorey garden
YFV	Yellow fever virus

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We also recognise specific restricted project donors, that are supporting the ongoing implementation of various research and development projects at *icipe*.

SECTION 1: INTRODUCTION

(i) *icipe's* Results Based Management (RBM) Framework Journey

icipe's research for development (R4D) efforts have advanced greatly with support from development partners, whose contribution has been central to the execution of the vision and strategies of the Centre. During the reporting period, *icipe* received financial and technical support from its core donors: Swedish International Development Cooperation Agency (Sida); Swiss Agency for Development and Cooperation (SDC); Australian Centre for International Agricultural Research (ACIAR); Federal Democratic Republic of Ethiopia; and Government of the Republic of Kenya (Ministry of Education, State Department of University Education and Research) http://www.icipe.org/donors-and-partners/core-donors. The Centre also continues to receive support for its research and development projects from a wide range of donors and partners - http://www.icipe.org/donors-and-partners/project-donors. Together, with its development partners, *icipe* is at the forefront in developing tools and strategies that will ensure improved crop health and yield, as well as more resilient integrated agricultural-livestock systems.

icipe adopted RBM as a project planning and monitoring tool in 2011 and has had RBM framework covering the implementation periods of 2011 - 2013; and 2014 - 2020 and now 2021 – 2025: http://www.icipe.org/publications/corporate-publications/results-based-management. *icipe*'s use of RBM has been very strategic and useful in maximizing project and programme achievements by continuously learning from success as well as failure and making adaptations based on the lessons learned. At *icipe*, this is an annual activity led by the Centre's Director General (DG). To closely monitor *icipe*'s RBM, in 2018, *icipe* institutionalised its Planning, Monitoring, Evaluation and Learning (PMEL) Strategy. The Strategy emphasizes the fostering of stronger partnerships with other local and international institutions with expertise in PMEL. The Strategy is based on a self-assessment of *icipe's* current M&E system by *icipe* scientists and support staff and their shared vision of the M&E system that they would like to see in place by 2025. The evolution of the PMEL Strategy at *icipe* was based on the Centre's RBM. *icipe*'s continuing journey of RBM with the aid of the Logical Framework Approach (LFA)[1] supports the Centre's Strategic Priorities, Policies and Guidelines for research and development (R&D) of insect science. Each of *icipe's* core activity area has a specific RBM framework. All project-based activities go through a cycle of knowledge management and continuous learning. The RBM-LFA is indeed a strategic management approach that ensures *icipe*'s R&D activities are implemented in collaboration with our partners to contribute to a logical chain of results that provide knowledge-based solutions aimed at equipping the communities in Africa to sustain livelihoods within a rapidly changing global environment.

(ii) *icipe* Centre-wide Themes and Special Programmes

With keen pursuit of its 2021 – 2025 V&S as well as RBM, *icipe* has enacted its mission through its highly skilled and diverse research, capacity building and support teams that are physically located in four countries (Kenya, Ethiopia, Benin, and Uganda). The Centre operates through an organisational design that incorporates four research themes – Plant Health, Animal Health, Human Health, and Environmental Health (4-Hs) supported by various research units including social sciences, Data Management, Modelling and Geo-information, chemical and Behavioral and Chemical Ecology, Technology Transfer and others, and an array of partnerships with African and non-African universities, and research organisations, NGOs, community based organisations (CBOs), government agencies, and the private sector that encompass a majority of Africa's 54 member states. In many respects, *icipe's* work is aligned to all the SDGs, but at its core, contributes directly to SDGs 1, 2, 3, 4, 5, 7, 8, 9, 10, 12, 13, 14, 15 and 17 as evidenced by the research focus on its 4-H, its sustained and innovative commitment to postgraduate education across SSA, and its focus on research for development that provides new employment opportunities and better livelihoods for women and youth. *icipe's* mandate as Africa's principal insect and arthropod research institute continues through the following 4-H themes and special programmes:

Plant Health Theme: This Theme conducts multidisciplinary research using a One Health concept, working with a range of partners to benefit smallholder agriculture, nutrition, health and the environment in Africa. Its strategic objectives include basic and applied research on native and invasive, below- and above- ground, pre- and postharvest pests, under changing climate and habitats. The Theme harnesses the synergies in plant-insect-soil interactions through integrated pest management (IPM) options that are ecologically sustainable and economically feasible. Its focus is on biological control using predators, parasitoids, microbes and habitat management strategies.

[1]Ortengren, K. 2016. A guide to Results-Based Management (RBM), efficient project planning with the aid of the Logical Framework Approach (LFA). Swedish International Development Cooperation Agency (Sida), Stockholm, Sweden, 42p. https://www.sida.se/contentassets/9d257b83f4124113a324c61715150722/21920.pdf

Animal Health Theme: This Theme aims to develop effective solutions to improve the health, productivity and sustainable farming of livestock in Africa. Its main research niche is disease transmitting insects and arthropods, primarily tsetse flies (vectors of human and animal trypanosomosis), biting flies and ticks. Through a 'One Health' and multisectoral approach, its activities are geared towards profound understanding of the biology and population ecology of arthropod disease vectors; vector–host and vector–parasite interactions; and the epidemiology of vector-borne diseases.

Human Health Theme: This Theme contributes to the reduction, elimination and eradication of vector-borne diseases. It aims to achieve this goal by generating knowledge and developing sustainable tools and strategies that control vectors, break the cycle of transmission, and that can be integrated into other disease management efforts. Its most prominent programme has been pursuit of the malaria control through a focus on mosquito ecology, behaviour and the transmission of the malaria-causing *Plasmodium* parasites. The scientists working in the Theme have also targeted other important vector-borne diseases including dengue, Rift Valley fever, leishmaniasis, schistosomiasis (together often labelled "neglected tropical diseases" [NTDs]).

Environmental Health Theme: The focus of this 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's research thrusts include bee research; beneficial and commercial insects; bioprospecting, particularly for plant-based biopesticides and medicinal products; and habitat management to support biodiversity, pollination ecosystem services, and alternative hosts for pests and diseases. The Centre has established itself as a leader in the globally emerging insects for food, feed and other uses research agenda providing proteins in livestock feed, minerals, vitamins, antioxidants and oils. This programme aims to translate the latent benefits of insects in transforming the food system into a more sustainable and vibrant circular economy. Insects are an alternative, more affordable and nutritious source of food for people and livestock; are efficient in bioconverting waste; and are also a basis of organic fertiliser and pest control products.

Capacity Building and Institutional Development (CBID) **Programme:** Building the capacity of people and institutions to respond to arthropod-related developmental needs in Africa is a major commitment of *icipe*. This objective is achieved through world-class postgraduate and postdoctoral training; nurturing and strengthening of African research and development organisations and institutions; dissemination of technologies to national agricultural and health research and extension systems. This programme continues to deliver new knowledge and outcomes for Africa and other parts of the world. *icipe* is also managing two important **Special Programmes** that are greatly contributing to naturing talent in Africa - (i) the ***BioInnovate Africa Programme***, a regional science and innovation-driven programme that aims to convert and transfer biobased research ideas, technologies and inventions to the market; and (ii) the ***Regional Scholarship and Innovation Fund (Rsif) of the Partnerships for Skills in Applied Sciences, Engineering and Technology (PASET) [Rsif-PASET]*** that aims to contribute towards training of a critical mass of PhD and post-doctoral fellows and support for research and innovation in priority sectors of energy, ICTs, material science, climate change and food security.

(iii) *icipe* Periodic External Reviews

icipe considers the regular external and internal monitoring and evaluation of its performance an important activity to regulate both the quality of its research and development and continued relevance to ensure compliance to its mandate and mission. The *icipe* Periodic External Review (IPER), is an evaluation undertaken by the Centre every 5-years that broadly evaluates institutional mandate and programmatic activities to ensure it meets the development needs of *icipe*'s beneficiary constituency by reducing poverty, improving health, food security and their wellbeing. *icipe* will undergo its periodic external review in the first half of 2023 that will cover the period 2018 – 2022. A review of the institution's programmatic and institutional agenda is important to evaluate how *icipe* is re-positioning itself to meet the new challenges and opportunities. Most importantly, the IPER should be able to establish how well the programme agenda is in tune with the institutional mandate of co-creation of knowledge-based solutions, building capacity of individual researchers and institutions in Africa, contributing to policy development and ultimately, reducing the impact of arthropod pests and vectors and enhancing the role of beneficial insects, both of which have direct bearing on climate-resilient food production, value creation and incomes for food production, malnutrition and undernutrition, poverty, health, food security, job creations, overall ecosystem health, and well-being. The review will also serve as the benchmarking function, taking stock of what has been achieved during the reporting period and enabling a more realistic realignment of programme priorities and implementation plans for the next 5-7 years.

SECTION 2. ADVANCES IN RESEARCH AND DEVELOPMENT (R&D) OUTPUTS AND OUTCOMES

1. Overview

The way *icipe* contributes as a Centre of excellence in research and innovation in entomology for improving the well-being and resilience of people and environment to the challenges of a changing world is constantly evolving. During the year 2022, *icipe* has achieved significant progress across all its interlinking research for development (R4D) activities (discovery; proof-of-concept; piloting; scaling) for continued and effective implementation of its Vision and Strategy (2021 to 2025). *icipe*'s focus on insect science, technology and products is contributing to sustainable development through transformation of global food, nutrition and health systems in the face of a climate crisis.

Some selected highlights of R4D outputs of the Centre are described below in Section 2 on Advances in Research & Development (R&D). Major highlights include: (i) providing first evidence of the mechanisms underpinning reduced Fall armyworm (FAW) infestation in the Push-Pull companion cropping system compared to monocropped maize; (ii) providing feedback information on the impact of classical biological control to government and development partners to assist in making informed decisions on technological interventions in Kenya and at the continental level; (iii) estimating that policies that enhance the adoption of integrated pest and pollinator management (IPPM) can fast-track economic development and therefore improve the livelihoods of various actors across the avocado value chain in East Africa; (iv) demonstrating that the cricket-fortified porridge contains up to 17 times more vitamin B5,almost one and a half times more vitamin B9,and twelve times more vitamin B12, than commercially available brands; (v) developing a study protocol for a community-based house screening for malaria control; (vi) developing a much needed, non-invasive, rapid, affordable, efficient and easy method to diagnose African animal trypanosomosis. (vii) using data-driven Artificial Intelligence (AI) algorithms for modelling potential maize yield at a macro scale under maize-legume intercropping and push-pull technology for sustainable farming; (viii) estimating the impacts of a classical biological control (CBC) agent's dispersal at landscape level to provide feedback information on the impact of CBC to assist in making informed decisions on technological interventions; (viiii) determining the socioeconomic burden of trypanosomiasis for alleviating poverty in rural areas; (ix) estimating the entomologic determinants of dengue transmission for predicting dengue risk; and (xi) quantifying gut microbiota shift in layer pullets fed on black soldier fly larvae-based feeds for underpinning the potential roles of beneficial bacteria as promising prebiotics and probiotics in reshaping of the gut microbiota to maintain good gut health. A major Centre level outcome has been that the MOYESH project so far has supported 92,257 youth, accounting for 92.3% of youth recruitments out of the total target of 100,000 youth.

The Capacity Building and Institutional Development (CBID) programme of *icipe* trained a total of 65 PhD and 94 MSc scholars; 31 postdoctoral fellows; and 66 research interns representing various African nations. *icipe* also managed 278 RSIF PhD scholars from 23 countries in Africa. Women represent 40% of the total 534 scholars trained.

During this reporting period, *icipe's* contribution and recognition within the scientific community is evident, with 263 peer reviewed journal articles published. Over 50% of the peer-reviewed papers of the Centre that were published were first-authored or co-authored by postgraduate and postdoctoral fellows.

Over 600 news items related to *icipe* were published or broadcast by local and international media. This coverage added up to a cumulative potential reach of 1.64 billion people and an advertising value of US$ 16.7 million. The Centre also got approximately 8,500 mentions on social media, predominantly on Twitter (about 7,800 mentions) within the same time.

icipe epitomizes the power of world class insect science as the basis for inclusive innovations. The Centre illustrates the viability of nature based One Health approaches that have at their heart balanced and optimized benefits for people, animals and the environment. It exposes the potential of using Africa's rich biodiversity to create circular economies that have as their underlying principles of elimination of waste and pollution, circulation of products and raw materials through reuse or recycling, regeneration of natural systems by conserving or redeploying resources, and creating nature-based solutions for some of the most devastating constraints in agriculture, human and environmental health. These aspects ratify *icipe's* unique place as an African yet global institution, a thought leader and a worthwhile investment and partner.

2. Advances in Research & Development

Highlights of major advances in research for development (R4D) during the year 2022 are provided below.

2.1 Plant Health Theme

2.1.1 Providing insights and projecting the infestation of Fall armyworm (FAW) across Africa

Fall armyworm (FAW) is a major cereal pest threatening food and nutrition security in Africa and other parts of the world. Despite the various ecological studies that have been conducted to reduce FAW prevalence, the dynamics and invasion mechanisms of FAW in Africa are still poorly understood. This study applied interdisciplinary tools, analytics, and algorithms on a FAW dataset with a spatial lens to provide insights and project the intensity of FAW infestation across Africa. Results from this study showed that monthly density projections were sensitive to the type of FAW host vegetation and the seasonal variability of climatic factors. The diversity in the climate patterns and cropping systems across the African sub-regions were considered the main drivers of FAW abundance and variation. The tool developed in this study provides a framework for field monitoring of FAW in Africa that may be a basis for a future decision support system (DSS). (Publication link: https://doi.org/10.1016/j.gecco.2022.e02056)

2.1.2 Mechanisms of "Push-Pull" control of fall armyworm unraveled

Fall armyworm (*Spodoptera frugip*erda), is a serious invasive pest in Africa but "Push-Pull" companion cropping system developed by *icipe* and partners against stemborer has been reported to substantially reduce the pest's infestation. The team has elucidated the underpinning chemical ecology mechanisms of action for the control of fall armyworm (FAW). Our data provides first evidence of the mechanisms underpinning reduced FAW infestation in the Push-Pull companion cropping system compared to monocropped maize. This is achieved though volatiles from the companion crops that repel FAW while attracting its parasitoid natural enemies. (Publication link: https://doi.org/10.3389/fevo.2022.883020)

2.1.3 Effect of rabbit urine on Fall armyworm infestation

Fall armyworm (FAW) is a major cereal pest threatening food security in Africa. African smallholder farmers apply various indigenous pest management practices, including rabbit urine; however, there is no scientific evidence for its efficacy. In this study, the FAW eggs, first, second and third instar larvae and moths were exposed to rabbit urine-treated maize leaves alongside untreated maize leaves (control). More FAW larvae remained on the untreated leaves than those on the rabbit urine-treated leaves. Rabbit urine significantly reduced the survival of FAW for the first, second and third instars. The FAW female moths laid more eggs on the rabbit urine-treated plants than they did on the untreated plants. This study confirms farmers' assertions about using rabbit urine to manage FAW. For successful integration into the FAW IPM package, additional studies are needed and underway. (Publication link: https://doi.org/10.3390/agriculture12081282)

2.1.4 Intensity of adoption of integrated pest management practices in Rwanda

The push-pull technology (PPT) is considered as an alternative integrated pest management (IPM) strategy to the use of conventional pesticides for the control of fall armyworm and stemborer, among smallholder maize farmers in sub-Sahara Africa (SSA). However, the extent of PPT use in Rwanda where the technology was introduced in 2017 remains largely unexplored. This study employed a fractional logit model to assess the factors influencing the intensity of adoption of PPT among 194 smallholder maize farmers in two districts of Rwanda. The results showed that the perceived benefits of PPT, its perceived effectiveness in pest control, group membership, livestock ownership, and gender of the farmer had significant effects on the intensity of adoption of the PPT in Rwanda. These findings give compelling evidence to recommend that development initiatives should give emphasis on creating awareness on the perceived benefits of PPT adoption using group approaches that are gender disaggregated. (Publication link: https://doi.org/10.1016/j.heliyon.2022.e08735)

2.1.5 Biopesticides for managing Fall armyworm and horticultural pests (Fruit fly, Tuta, whiteflies)

Final approval for label extension and registration permits for biopesticides *Metarhizium anisopliae* ICIPE 78, Mazao Achieve® and *M. anisopliae* ICIPE 7 Mazao Detain® were obtained in Tanzania (10 July 2022 by National Biocontrol Centre) and Uganda (19 August 2022 by the Ministry of Agriculture, Animal Industry and Fisheries) for sustainable management of Fall armyworm (FAW).

2.1.6 Estimating the impacts of a classical biological control agent's dispersal at landscape level

Following the invasion of Africa by the oriental fruit fly, *Bactrocera dorsalis*, classical biological control (CBC) has been exploited as a safer alternative for its suppression by the introduction and release of the koinobiont endoparasitoid, *Fopius arisanus*. This study proposed and described an interesting and potentially powerful means to validate large-scale biocontrol agent's impacts during a CBC programme. In Kenya, the model showed that *F. arisanus* had covered a total area of 50.34 km² from the initial point of open field release; and at the continental scale, the model predicted that the parasitoid had covered a total area of 229.97 km². The model estimated that 351,855 and 3,731,330 households had directly benefited from the release of *F. arisanus* between 2013 and 2018 in Kenya and at the continental level, respectively. The study's outcome is appropriate for providing feedback information on the impact of CBC to government and development partners to assist in making informed decisions on technological interventions. (Publication link: https://doi.org/10.1016/j.biocontrol.2022.105053)

2.1.7 Developing an expert system for insect pest population dynamics prediction

Avocado (*Persea americana*) production is increasing in Kenya, with both small and large holder farming for domestic and export markets. However, one of the main challenges that limit production is infestation by insect pests, notably the oriential fruit fly *Bactocera dorsalis* and *Ceratitis* spp. fruit flies, which cause direct crop losses and are indirectly responsible for non-tariff trade barriers due to stringent export requirements. In this study, we demonstrated how Fuzzy Neural Network (FNN) models can be used as predictive tools for managing and controlling fruit fly pest populations in these plantations, and how they may be suitable to predict fruit fly or other pests in similar cropping systems. Once the input variables are known, they can be loaded into the FNN models to predict field pest populations, and based on threshold values, allow for implementation of timely and adequate control measures such as the use of biopesticides. (Publication link: https://doi.org/10.1016/j.compag.2022.107124)

2.1.8 Use of vegetable black-jack to protect two susceptible crops from root-knot nematodes

Plant parasitic nematodes (PPNs) develop through three major stages in their life cycle: hatching, infection and reproduction. Interruption of any of these stages can affect their growth and survival. We tested the hypothesis that the non-host Asteraceae plant vegetable black-jack (*Bidens pilosa*) suppress infection in two susceptible Solanaceae host plants, tomato and black nightshade. In intercrop and drip pot experiments, *B. pilosa* significantly reduced the number of galls and egg masses in root-knot nematode (RKN)-susceptible host plants by 3 to 9-fold compared to controls. Chemical analysis of the most bioactive fraction from the root exudates of *B. pilosa* identified several classes of compounds, including vitamins, a dicarboxylic acid, amino acids, aromatic acids and a flavonoid. Results from this study provided insights into how certain non-host plants can be used as companion crops to disrupt PPN infestation. (Publication link: https://doi.org/10.1021/acs.jafc.2c01748)

2.1.9 Organic maize and bean farming enhances biodiversity of free-living nematodes

Despite their important ecological roles for soil health and soil fertility, free-living nematodes (FLN) have received relatively limited research attention. This study evaluated the community structure and diversity of FLN in a field setting. The experiments were conducted using on-farm and on-station field plots that were sown to maize (*Zea mays*) and beans (*Phaseolus vulgaris*) under four cropping practices: (i) organic (compost and biopesticide use), (ii) conventional (synthetic fertilizer and pesticide applications), (iii) farmer practice (organic and synthetic amendments) and (iv) a control (non-amended plots). Farming systems influenced the abundance and diversity of free-living nematodes, with the organic farming system having higher values of maturity, enrichment and structural indices than other farming systems. This implies that the organic farming systems play a key role in improving the biodiversity and population buildup of FLN, compared with other systems. (Publication link: https://doi.org/10.1016/j.agee.2021.107846)

2.1.10 Integrated pest and pollinator management (IPPM) in avocado farming in East Africa

Using synthetic pesticides to manage pests can threaten pollination services, affecting the productivity of pollination-dependent crops such as avocado. The need to mitigate this negative externality has led to the emergence of the concept of integrated pest and pollinator management (IPPM) to achieve both pest and pollinator management, leading to complementary or synergistic benefits for yield and quality of the harvest. This study aimed to evaluate the potential economic and welfare impact of IPPM in avocado production systems in Kenya and Tanzania. The potential benefits from IPPM intervention gains are expected to reduce the number of poor people in Kenya and Tanzania by 10,464 and 1,255 people per year respectively. The findings indicated that policies that enhance the adoption of IPPM can fast-track economic development and therefore improve the livelihoods of various actors across the avocado value chain. (Publication link: https://doi.org/10.1371/journal.pone.0271241)

2.1.11 Using cereal 'push-pull technology' for sustainable production of vegetables

The push-pull technology (PPT) is an agroecological-based farming approach for buttressing food production among resource-constrained farmers in sub-Saharan Africa (SSA). In a bid to elevate PPT's nutrition-sensitivity status, cereal PPT production is intensified, based on farmer needs, by adding vegetables and legumes whilst simultaneously closing yield gaps through judicious usage of land for crop and environmental protection. Whilst 'One Health' has largely received attention regarding animal health and zoonoses, the PPT team at *icipe* in this review article opine how sustainably managed crop health, in the vegetable integrated PPT (VIPPT), contributes to the same outcomes through human and animal nutrition, food safety that bolsters developmental goals in gender equity and food security. The use of VIPPT can also contribute to fight against zoonotic diseases if companion plants that fend off disease vectors are incorporated. Such locally developed solutions, together with farmers, are urgently needed for increased behavioural change and adaptation to address regionally specific problems towards environmental sustainability and 'One Health' in African agriculture.
(Publication link: https://doi.org/10.1007/s42398-023-00260-1)

2.1.12 Data-driven Artificial Intelligence (AI) algorithms for modelling potential maize yield

Maize–legume intercropping (MLI) and push-pull technology (PPT) have been introduced to mitigate losses from pests, but the region-wide maize yield obtained remains unknown. Using climatic and edaphic variables, an artificial intelligent algorithm was used to model maize yield and map potential yield under MLI and PPT compared to maize monocrop in East Africa. The study estimated annual maize yield increases of about 1.01 and 1.96 Mg ha^{-1} under MLI and PPT, respectively. This study informs farmers and decision makers of the added value that each technology provides, creating a basis for scaling up of these practices. This study also provides yield estimates information at a macro scale that better illustrates the benefit of using sustainable farming practices to attain food and nutrition security in SSA. (Publication link: https://doi.org/10.3390/agronomy12123085)

2.1.13 Estimating the impacts of a classical biological control agent's dispersal at landscape level

Following the invasion of Africa by the oriental fruit fly, *Bactrocera dorsalis*, classical biological control (CBC) has been exploited as a safer alternative for its suppression by the introduction and release of the koinobiont endoparasitoid, *Fopius arisanus*. Although the parasitoids have been released in several African countries, the extent of their dispersal and the resulting extent in benefits to fruit growers have not yet been elucidated. This study proposes an innovative, multi-level CBC impact analysis that combines cellular automata (CA) and ecological niche models to estimate parasitoid dispersal ranges and the range of farmers who benefit from it. In Kenya, the model showed that the parasitoid had covered a total area of 50.34 km^2 from the initial point of open field release; and at the continental scale, the model predicted that the parasitoid had covered a total area of 229.97 km^2. The model estimated that 351,855 and 3,731,330 households had directly benefited from the release of *parasitoid* between 2013 and 2018 in Kenya and at the continental level, respectively. The study's outcome provides feedback information on the impact of CBC to assist in making informed decisions on technological interventions. (Publication link: https://doi.org/10.1016/j.biocontrol.2022.105053)

2.1.14 Biopesticide for *Tuta absoluta*

icipe has published the first report of the field efficacy and economic viability of Mazao Campaign®), an *icipe* biopesticide derived from strains of *Metarhizium anisopliae* (ICIPE 20), against the tomato leafminer, *Tuta absoluta*. Results indicated significantly lower fruit yield loss, improved fruit yield and marketability, and a high cost–benefit ratio. Findings from this study could be a promising milestone for the candidate entomopathogenic fungal biopesticides for managing *T. absoluta* on tomato sustainably in the field. Ongoing research at *icipe* will establish the most optimum formulations of the biopesticide, delivery and application approaches and effectiveness in diverse agroecological zones, and compatibility with commonly used pesticides in tomato production systems.
(Publication link: https://doi.org/10.3390/su142214846)

2.1.15 Field evaluation of host marking pheromones for control of fruit flies in a mango orchard

In Africa, an array of native and alien invasive fruit fly species represents a key challenge to the horticultural industry. In an effort to develop a safer management tool for these pests, we previously identified glutathione (GSH) and glutamic acid (GA), as the host marking pheromones (HMPs) of fruit fly species of *Ceratitis cosyra* and *Ceratitis rosa*, respectively. In this study, Mango (*Mangifera indica L.)* trees at two different agroecological zones in Kenya were sprayed with HMPs, and the fruits sampled periodically and assessed for fruit fly emergence. The two HMPs and spot spraying (SS) of food bait substantially decreased fruit fly emergence from the sampled mangoes. The adult emergence in pheromone-treated plants compared favorably with the positive control (SS).

However, the HMPs had little impact on reducing fruit fly, *Bactrocera dorsalis* infestation of mangoes. The decrease in fruit fly emergence observed in sampled mango fruits from HMP treated trees corroborate previous laboratory results and support the prospect of using HMPs in the management of African fruit fly species. (Publication link: https://doi.org/10.1002/ps.7331)

2.1.16 Early infestation volatile biomarkers of fruit fly *Bactrocera dorsalis* in mango

Bactrocera dorsalis infested mangoes emitted unique volatile biomarkers. The biomarkers can be used to detect early infestation of mangoes vital for food safety and early recognition of invasive insect import. We investigated the odours of mangoes infested with *B. dorsalis* and compared the volatile profiles of infested mangoes to non-infested and mechanically damaged mangoes at 24 h post-infestation. Results from this study indicated compositional and quantitative differentiation of volatile profiles among treatments for detection of infested fruit at quality checks or points of commerce. (Publication link: https://doi.org/10.1016/j.phytochem.2022.113519)

2.1.17 Assessing genetic diversity and phylogeographic structure of the Asian citrus psyllid

The Asian citrus psyllid (*Diaphorina citri Kuwayama*) is a key pest of *Citrus* sp. worldwide, as it acts as a vector for *Candidatus Liberibacter asiaticus,* the bacterial pathogen that causes citrus Huanglongbing. *Diaphorina citri* has been reported in Kenya, Tanzania, and more recently in Ethiopia and Benin. This study assessed the genetic diversity and phylogeographic structure of the pest to gain insights into the potential sources of its introduction into Africa. Results indicated that the *D. citri* populations in eastern Africa have different sources, as the Kenyan and Tanzanian populations probably originated from southeastern Asia, while the Ethiopian population most probably originated from the Americas. (Publication link: https://doi.org/10.1002/ece3.9090)

2.2 Environmental Health Theme

2.2.1 African stingless bees as an efficient alternative pollinator

The current honeybee decline necessitates the use of alternative native pollinators to ensure global food security. We compared the pollination behaviour and efficiency of the African honeybee (*Apis mellifera*) and six African endemic stingless bees (*Meliponula bocandei, Dactylurina schmidti, Meliponula lendliana, Hypotrigona gribodoi, Meliponula ferruginea* and *Meliponula togoensis*) in a greenhouse using cucumber variety, Super Marketer. The highest sugar content was recorded in fruits from flowers pollinated by the stingless bees (*M. bocandei, D. schimdti* or *M. togoensis*) with the same solid content as the gold standard method, i.e., hand cross-pollination. We found that *M. bocandei* was the most efficient cucumber pollinator of all species tested yielding the largest and heaviest fruits and the highest seed numbers. (Publication link: https://doi.org/10.1080/00218839.2021.2013421)

2.2.2 Multisource spatial data for determining the proliferation of stingless bees in Kenya

Stingless/meliponine bees are eusocial insects whose polylactic nature enables interaction with a wide variety of wild plants and crops that enhance pollination and, hence, support ecosystem services. However, their true potential regarding pollination services and honey production is yet to be fully recognized. This study sought to establish the influence of bioclimatic, topographic, and vegetation phenology on their spatial distribution and change patterns. The results from the ecological niche (EN) models showed that annual precipitation was the most influential variable for stingless bee distribution. These EN models could be utilized to inform stingless bee farming and insect pollinated crops by highlighting regions that provide highly suitable conditions for stingless bees. Results from this study could contribute to improving both bee and agricultural productivity, and forest conservation efforts through supplementary pollination services. (Publication link: https://doi.org/10.1080/15481603.2022.2049536)

2.2.3 More Young Entrepreneurs in Silk and Honey (MOYESH) programme

Due to conflict in the Tigray Region of Ethiopia, MOYESH realigned resources to the other three regional states (Amhara, Oromia, and Southern Nations, Nationalities, and Peoples' Region). The MOYESH programme so far has supported 92,257 (92.3% of target) youth, out of the total target of 100,000 youth and hence on the right trajectory to achieve its target. MOYESH programme team contributed to the formulation, review, and validation of Ethiopia's Apiculture Resource Development and Protection Directives, that are essential to regulate the indiscriminate application of pesticides. The team also contributed to the launch of a novel uncollateralized digital lending service called "Michu", a first in Ethiopia, by one of our partnering private banks, the Cooperative Bank of Oromia (CBO) in January 2022. The Mastercard Foundation and its local partners have been very keen on this development. The bank has made ETB 170 million (US$ 3.4 million) funds available for loans to 35,000 pilot

micro-enterprises in the country, including 1,000 MOYESH youth enterprises. The micro-loan services range from ETB 5,000 to ETB 50,000 per enterprise. We have selected 500 *Micro small & medium enterprises* (MSMEs) in the Oromia region (about 50 MSMEs per district) for the pilot, including input suppliers. The pilot E-commerce service has been expanded to cover eight additional programme districts.

icipe's Social Science and Impact Assessment Unit (SSIAU) estimated the potential economy-wide benefits of MOYESH programme using a modelling approach. The findings show that every dollar invested by the programme can bring about US$ 23 and US$ 10 additional income to the country if it achieves 100% and 25% of its targets, respectively. The reduction in poverty due to the MOYESH programme is about 14% of the people living below the poverty line in the MOYESH programme areas. The pollination service value of the programme amounts to US$ 284.5 million. The spill-over effects of the programme could reduce the number of people who live below the poverty line by about 1.5% in areas outside the programme districts.

The project team contributed to the design and formulation of a national mega flagship programme with apiculture being one of the four key commodities. Over 300 staff of key partnering institutions were trained as trainers in various technical skills to prepare them for training and technical supervision of project partner youth. Exporters of honey and silk products started contractual purchase of table honey and silk yarn from youth enterprises.

Successful organic certification was accomplished for production and processing of honey and beeswax in two project sites, Gungua and Sakala under the Enhanced Integrated Framework (EIF) Tier II Project supported by the World Trade Organization. Expansion of this is foreseen in MOYESH programme sites.

2.2.4 Documenting insect biodiversity in Africa

A few years ago**, t**he Biosystematics Unit (BSU) initiated the development of a comprehensive database of insects sampled throughout Kenya and processed for accession into *icipe's* collection. Similarly, we have continued to liaise with taxonomic experts at institutions throughout the world in an effort to document the existence of formerly unknown species. This project is important in light of the effects of climate change on formerly stable habitats. Both of these related endeavors have reached significant milestones this year. Our database now includes over 60,000 records with complete geographical and temporal data for each unique specimen, and with images. Also, the number of new species described by the BSU and partners is currently >200.

2.2.5 Performance of kale and Swiss chard grown with black soldier fly frass fertilizer

The wonder multistorey garden (WMSG) is an innovative vertical farming system tailored for urban settings that can be constrained by the irrigation regime, and by types and levels of fertilizer application. This study evaluated the effects of applying NPK fertilizer and black soldier fly frass fertilizer (BSFFF) under different irrigation regimes on the growth, yield, and pest infestation of kale (*Brassica oleracea*) and Swiss chard (*Beta vulgaris*). Irrigation regime significantly affected the leaf production of both vegetables. Fertilizer application significantly affected pest population, with the lowest pest infestation being recorded from kale and Swiss chard grown in soil amended with BSFFF. The application of 100% BSFFF or NPK, together with daily irrigation, significantly increased the fresh shoot weight and leaf dry matter of kale and Swiss chard, as compared with the control. This study advocates for the scaling of WMSG and BSFFF for sustainable food systems in urban settings. (Publication link: https://doi.org/10.3390/agronomy12092211)

2.2.6 Issues related to rearing and international trade of edible insects in Africa

Insect rearing and farming for food and feed are new ventures that could meet the continued rise in demand for protein while reducing high rates of unemployment in Africa and elsewhere. However, for this sector to thrive, its value chain must be regulated to ensure its sustainability and safety for consumers and the environment. While a few African countries including Kenya, Uganda and Rwanda have developed standards for the use of insects for food and feed, in other countries efforts need to continue and appropriate policies must be put in place to govern this sector. In this study, we analyzed the safety, regulatory and environmental issues related to the farming and international trade of edible insects in Africa and presented case studies and recommendations for the sustainable use of insects for human food and animal feed. (Publication link: https://doi.org/10.20506/rst.41.1.3309)

2.2.7 Newly discovered African crickets fortify African porridge

icipe researchers have used insect nutrients to transform African porridge from a basic, often low-nutrient meal, into a super-food that meets and exceeds micronutrient requirements for people. The result of the *icipe* study is a flavour-full, fortified porridge flour that has twice as much protein, three to four times more crude fat and double

the amount of iron and zinc. Depending on the processing technique, the cricket-fortified porridge contains up to 17 times more vitamin B5, almost one and a half times more vitamin B9, and twelve times more vitamin B12,than commercially available brands. The product also has three essential omega-3 fatty acids. (Publication link: https://doi.org/10.3390/foods11071047)

2.2.8 Edible insect farming as an emerging and profitable enterprise in East Africa

Insect farming is a novel and rapidly growing enterprise for protein and income in East Africa. More than 80% of feed processors and farmers are willing to integrate insects in their livestock and fish feeds. Over 65% of those consuming insects as food would prefer processed flour to whole insect products. Some of the major lessons learnt include: (i) the growing interest of youth and women entrepreneurs entering the commercial edible insect agribusiness; (ii) lack of enabling environment for youth to access financing, input and output markets for their products, and information services through digital solutions, marketplaces, and business-to-business linkages; (iii) Biosafety of insect-based products remains a major concern; (iv) Training and technical backstopping of insect farming activities significantly reduce dropout; and (v) financing insect farming innovation at the very early stages is relevant for effective take-off of businesses. (Publication link: https://doi.org/10.1016/j.cois.2021.09.007)

2.2.9 Superiority of insect-based animal feeds

As part of *icipe*'s ongoing efforts to harness the potential of insects in the transformation of the current food system into a more sustainable and vibrant circular economy, a recent study has demonstrated that the incorporation of black soldier fly larvae in poultry feeds increases the wealth of beneficial bacteria in the gut of poultry, thus promoting the overall health and growth of the birds. Results from this study are significant against the ongoing inquiry, in Africa and globally, to re-evaluate and reduce the use of antibiotics in poultry farming. While the use of antibiotics to enhance growth or manage diseases in poultry has largely been useful, there are concerns about the rising resistance to antibiotics by harmful bacteria in poultry. (Publication link: https://doi.org/10.1038/s41598-022-20736-0)

2.2.10 Pesticide contamination and their botanical sources in pollen loads collected by honeybees

Honeybees are generalists, and therefore, a wide range of flowering plants can easily be identified from their collected pollen loads. In this study, the levels of pesticide contamination on corbicular pollen were investigated using two approaches: (i) unsorted colony level collected; and (ii) sorted pollen samples (according to botanical origin). This study was carried out in Murang'a county, Kenya, across three landscape types. From the results, 11 pesticides (nine insecticides and two fungicides) were detected. These pesticides were further traced to 11 plant families, from which Poaceae, Rubiceae, and Astereceae were contaminated with more than 70% of the 11 detected pesticides. Acetamiprid concentration was found to be extremely higher than the recommended European Union (EU) limit. Additionally, chlorpyriphos concentration was found to be higher than the EU set limit. Additionally, pollen from Rubiaceae and Poaceae plant families were the most collected during the period of this study. It was further noted that pesticides and plant families identified varied across sampling time, but not across landscapes.(Publication link: https://doi.org/10.1016/j.agee.2022.108264)

2.2.11 Gut microbiota shift in layer pullets fed on black soldier fly larvae-based feeds

The utilization of Insect-Based diets to improve the gastrointestinal function and gut health in poultry is increasingly gaining global attention. Here, the team evaluated the potential roles of commercial black soldier fly (*Hermetia illucens*) larvae-based feeds (BSFLF) in reshaping the abundance, composition and diversity of the gut microbiota of layer chickens. Intra-species beta diversity assessment revealed that the diet types significantly influenced the abundance of the microbiota, but differences between most abundant taxa were similar. There was an increase in abundance of potentially beneficial bacteria (Lactobacillus, Bacteroides and Enterococcus) with increased inclusion levels of BSFLF in layer pullets' diets. Across the different gut segments, *Lactobacillus* dominated all the eight regions, and the ceca was the most diverse segment. Findings from this study contributed to unravel complex gut microbial shift in laying hen fed BSFLF and therefore underpins the potential roles of beneficial bacteria as promising prebiotics and probiotics in reshaping of the gut microbiota to maintain good gut health. (Publication link: https://doi.org/10.1038/s41598-022-20736-0)

2.2.12 Gendered awareness of pig and poultry farmers on the potential of Black Soldier Fly farming

The black soldier fly (BSF) is gaining traction worldwide as an alternative protein source. In Kenya, BSF production and its use as a feed component is an emerging business, but farmer awareness of the potential use of BSF in animal feed has received limited attention. This study examined the factors influencing farmer awareness of insect farming and its usefulness as ingredient in livestock feed from a gender perspective. The study was

implemented in Kiambu County, Kenya. About 44% of the farmers were aware of the use of BSF in the animal feed industry, of which 46.7% were female, and 41.6% were male. From the results, years of education, the number of chickens owned, and membership in agricultural groups significantly influenced male and female farmers' awareness. In addition, age and the number of pigs owned significantly influenced female farmers' awareness. Results from this study indicated that these factors are important to consider when strategies are developed to create awareness of BSF farming. (Publication link: https://doi.org/10.3390/su15043613)

2.3 Human Health Theme

2.3.1 Determinants of residual malaria transmission

Long-lasting insecticidal nets (LLINs) and indoor residual spraying (IRS) have resulted in a major decrease in malaria transmission. However, it has become apparent that malaria can be effectively transmitted despite high coverage of LLINs/IRS. Outdoor biting behavior by *Anopheles* vectors is one of the contributors to residual malaria transmission (RMT). The present study was designed to gain insights into malaria persistence in dryland ecosystems, where malaria is thought to be seasonal and prone to epidemics. The findings revealed: (i) *An. longipalpis* C as the dominant outdoor vector species in the *An. funestus* group exhibiting a high *Plasmodium falciparum* sporozoite rate with presence of mutations that confer metabolic resistance to pyrethroid/DDT; and (ii) the discovery of at least 6 cryptic species most of which were infected with *P. falciparum*. Results from this study are useful in updating risk map of key vectors in Kenya and providing evidence-based decision in selection and implementation of appropriate interventions against malaria in the study areas. (Publication link: https://doi.org/10.1038/s41598-022-11333-2)

2.3.2 Repellent-treated fabric strips as a substitute for full screening from malaria mosquito bites

Providing protection from malaria vector bites, both indoors and outdoors, is crucial to curbing malaria parasite transmission. Screening of house entry points, especially with incorporated insecticides, confers significant protection but remains a costly and labour-intensive application. Use of spatial repellents has shown promise in creating areas of protection in peri-domestic areas. The findings suggest that transfluthrin-treated fabric strips can provide a substitute for complete eave screens. They are a simple, easy-to-handle tool for protecting people from malaria mosquito bites indoors and potentially around the house in climatic areas where evening and night-time temperatures are relatively high. (Publication link: https://doi.org/10.1186/s13071-022-05384-7)

2.3.3 Grass-like plants release general volatile cues attractive for gravid malaria mosquitoes

Understanding the ecology and behaviour of disease vectors, including the olfactory cues used to orient and select hosts and egg-laying sites, are essential for the development of novel, insecticide-free control tools. Selected graminoid plants have been shown to release volatile chemicals attracting malaria vectors. However, whether the attraction is selective to individual plants or more general across genera and families is still unclear. The present study confirms that gravid *Anopheles gambiae* sensu stricto use chemical cues released from graminoid plants to orientate. These cues are released from a variety of graminoid plant species in both the Cyperaceae and Poaceae family. Given the general nature of these cues, it appears unlikely that they are exclusively used for the location of suitable oviposition sites. The utilization of these chemical cues for attract-and-kill trapping strategies must be explored under natural conditions to investigate their efficiency when in competition with complex interacting natural cues. (Publication link: https://doi.org/10.1186/s13071-021-04939-4)

2.3.4 Microsporidia: a promising vector control tool for residual malaria transmission

Residual malaria transmission (RMT) is likely to be the most significant hurdle to achieving the goal of malaria eradication and therefore research and development efforts are needed towards developing new tools and strategies that can control RMT. One of the most promising strategies involves biological agents that are part of the mosquito microbiome and influence the ability of Anopheles to transmit Plasmodium. These differ from biological agents previously used for vector control in that their primary effect is on vectoral capacity rather than the longevity and fitness of Anopheles (which may or may not be affected). An example of this type of biological agent is Microsporidia MB, which was identified in field collected *Anopheles arabiensis* and caused complete inhibition of *Plasmodium falciparum* transmission without effecting the longevity and fitness of the host. Microsporidia MB belongs to a unique group of rapidly adapting and evolving intracellular parasites and symbionts called microsporidia. This review article discussed the advances in general biology of microsporidians and the inherent characteristics that make some of them particularly suitable for malaria control. It also outlined the

research priorities for developing a transmission blocking strategy for the currently leading microsporidian candidate Microsporidia MB for malaria control. (Publication link: https://doi.org/10.3389/fitd.2022.957109)

2.3.5 A study protocol for a community-based house screening for malaria control

House screening, a non-insecticidal method, has a long history in malaria control, but it is still not widely adopted in SSA. This study aimed to provide the much-needed high-quality entomological and epidemiological evidence-based impact of house screening on malaria transmission from three well-designed randomized controlled trials from three eco-epidemiological settings in southern Africa (Zambia, Mozambique and Zimbabwe). The study used a household randomized trial in low transmission settings by assessing the efficacy, impact, and feasibility of house screening in areas where long-lasting insecticidal nets (LLINs) are conventionally used for malaria control. This study will provide high-quality data for evidence-based policy adoption of house screening a mosquito abatement tool. (Publication link: https://doi.org/10.1186/s13063-021-05768-7)

2.3.6 Mosquitoes larvicidal activity under laboratory and field-simulated conditions

The use of synthetic chemical insecticides for mosquito control has been associated with resistance development and detrimental human, and ecological effects. For a safer alternative, the emulsified *Ocimum kilimandscharicum* oil formulation was evaluated for its larvicidal activity. Under field conditions, the formulation inflicted 98% mortality after 24 h, compared to only 54% by *Bacillus thuringiensis*. Even under sublethal doses, the formulation induced malformation of the mosquito larva highlighting its potential use as a botanical larvicide. The oil formulation is currently marketed as UZIMAX®, with high potential for scale up. (Publication link: https://doi.org/10.3390/insects13020203)

2.3.7 Yellow fever transmission risk in major cities of Kenya

Yellow fever virus (YFV) continues to present a major threat to humanity in Africa despite availability of safe and efficacious vaccine. Increasing frequency of outbreaks in the Eastern African region presents a particular concern. Although previous outbreaks in the region were sylvatic in nature, there is increasing concern that urban outbreaks driven by *Aedes aegypti* (as seen during the Luanda, Angola outbreak) may take root and lead to catastrophic outbreaks in major cities which are densely populated. This project sought to establish the vector competence of *Aedes aegypti* the urban vector, in major cities of Kenya and determine risk for such an event occurring. Our findings revealed *Aedes aegypti* populations in the three cities of Nairobi, Mombasa, and Kisumu to be inefficient in YFV transmission. *Aedes simpson*, (stegomyia species) was found to occupy similar niche as *Aedes aegypti* and it may be an efficient vector and a culprit to watch in efforts to monitor, prevent and control YFV in the country. (Publication link: https://doi.org/10.1371/journal.pntd.0010171)

2.3.8 Six decades of malaria vector control in southern Africa

Countries in the southern Africa region have set targets for malaria elimination between 2020 and 2030. Malaria vector control is among the key strategies being implemented to achieve this goal. This study critically reviewed published entomological research over the past six decades in three frontline malaria elimination countries namely, Botswana Eswatini and Namibia, and three second-line malaria elimination countries including Mozambique, Zambia, and Zimbabwe. The review reveals a dearth of information about malaria vectors and their control, most noticeable among the frontline elimination countries: Namibia, Eswatini and Botswana. It is of paramount importance that malaria vector research capacity and routine entomological monitoring and evaluation are strengthened to enhance decision-making, considering changing vector bionomics and insecticide resistance, among other determinants of malaria vector control. (Publication link: https://doi.org/10.1186/s12936-022-04292-6)

2.3.9 Entomologic determinants of dengue transmission

Aedes aegypti is the primary vector of dengue, an arboviral disease caused by dengue virus (DENV) that exists as four distinct serotypes (DENV 1-4). In experimental infection assays, the team found that a population of *Ae. aegypti* at the coast (highly endemic for dengue) comprises more of the domestic form and is highly susceptible to both DENV 2 and 3 serotypes; however, with potential for differential transmission of the former (DENV2) owing to a shorter extrinsic incubation period to attain dissemination and transmission. By analysing wild *Ae. aegypti*, the team found differential survival abilities between populations in the coast (Rabai) and Kerio Valley at the Kenyan Rift Valley, at low risk of dengue. Both vector abundance and human blood-feeding rates were consistently lower in Kerio Valley indicating that DENV transmission risk is related to the degree of urbanisation. These bionomic traits could be integrated with suitable ecological influences into a modeling framework to predict dengue risk.

(Publication link: https://doi.org/10.1155/2023/8402682 and https://doi.org/10.3389/fitd.2023.1113531)

2.3.10 Predictive surveillance of emerging arboviral threats

Viruses vectored by arthropods (arboviruses) contribute to human diseases of unknown etiologies. Surveillance of vectors is a critical component of arboviral disease control providing an early detection and warning of presence of existing or new viruses to reduce the potential for human disease. These vector groups are not actively surveyed for arboviruses in East Africa, although they are increasingly associated with viruses-causing human diseases or infections. This was instituted in dryland ecosystems (Baringo and Kajiado counties) in the Kenyan Rift Valley, that harbour wildlife conservancies with frequent human-livestock-wildlife interaction posing a risk for zoonotic pathogen transmission. Findings from this work have revealed circulation of newly emerging human arboviral pathogens such as Jingmen tick virus (JMTV) and phleboviruses in ticks. This research indicates high exposure risk to arboviruses of public health significance and highlights the importance of predictive arbovirus surveys in understanding arboviruses ecology which is crucial for epidemic preparedness and disease control.
(Publication link: https://doi.org/10.3390/v14051041 and https://doi.org/10.1016/j.ttbdis.2022.102087)

2.3.11 Entomologic risk factors of emerging sandfly-borne viruses

Phleboviruses transmitted by sandflies are among emerging public health threats. The team recently discovered and described a novel *Phlebovirus* named Ntepes virus (NTPV) and found to infect humans from a wide geographic area in Kenya. However, the entomologic risk factors of this virus such as the potential vectors and the transmission cycles remain poorly defined. In experimental infection assays fed orally to an infectious dose of the NTPV, the sandfly *Phlebotomus duboscqi* prevalent where NTPV was isolated, was found not to be a competent vector of the virus. However, analysis of wild engorged sand fly specimens from the NTPV focus, revealed almost exclusive feeding on humans by diverse sandfly species, and the visceral leishmaniasis vector *Phlebotomus martini*. The high human-feeding rate by diverse sandfly species increases the likelihood of human exposure to pathogens associated with these sandflies. (Publication link: https://doi.org/10.1155/2022/4231978)

2.3.12 Tungiasis in East Africa

Tungiasis is a neglected tropical disease caused by skin-penetrating female *Tunga penetrans* fleas. Although tungiasis causes severe health problems, its ecology is poorly understood, and morphological descriptions of the larvae are unavailable. To identify *T. penetrans* immature stages and sites where they develop, diagnostic polymerase chain reaction (PCR)-based tools are required. However, flea larvae feed on soil organic matter which is rich in PCR inhibitors. Over the past 12 months, the team has developed and published novel molecular techniques to distinguish *T. penetrans* juvenile stages from other flea species.
(Publication link: https://doi.org/10.3390/insects14010005)

2.3.13 Exploring the community perception and infestation dynamics of bedbugs

Bedbugs have experienced an extraordinary upsurge in the recent past across the world. This cross-sectional study aimed to explore the community perception of the pest outbreaks, the population dynamics, and dispersal patterns under different habitat systems. A survey was conducted within communities in nine counties in Kenya. Results from this study indicated that majority of the respondents had ample knowledge on bedbugs and were concerned about the physico-psychologic and socio-economic health effects. Spatial distribution analysis showed regions in Kenya with optimal to suitable for bedbug occurrence in the whole country, and similar results were found at continental level across Africa. Furthermore, infestation dynamics results showed a rapid mobility of bedbugs from one house to another. In terms of management strategies, the models showed that the combination of chemical with other control methods was considerably much more effective compared to the use of chemical approach only, appointing integrated pest management strategy as a better intervention approach in controlling the pest. (Publication link: https://doi.org/10.1038/s41598-022-24339-7)

2.4 Animal Health Theme

2.4.1 Easy method to diagnose African animal trypanosomosis

African animal trypanosomosis causes direct and indirect losses of approximately USD 4.75 billion per year in Africa. icipe scientists have identified biomarkers in the urine of cows, which indicate with certainty the presence of trypanosomes infection, even at low levels that would not be detectable through microscopy. This is a much needed, non-invasive, rapid, affordable, efficient and easy method to diagnose African animal trypanosomosis. (Publication link: https://doi.org/10.3389/fmicb.2022.922760)

2.4.2 A comparative investigation of volatile organic compounds of cattle rumen metabolites
In the rapidly increasing field of metabolomic research, fast and accurate trapping of volatile odour compounds from biological samples is critical. A comparative evaluation of HS-SPME and PoraPak-Q adsorbent odour trapping methods followed by GC-MS analysis were used to determine volatile compounds in cattle rumen. In the context of metabolomics analysis from biological samples, the two different methods vary in determination of chemo-diversities, qualitatively and abundance of shared odour, and time required to trap oduors, which are critical in such studies. This is an important consideration in optimizing the best methods of odour collection to study livestock and their ecological interaction. (Publication link: https://doi.org/10.1080/22297928.2022.2100276)

2.4.3 Evaluating the efficacy of Mazao Tickoff® to control natural tick infestations on cattle
Ticks and tick-borne diseases cause substantial economic losses to the livestock industry in SSA. Mazao Tickoff® is a novel bioacaricide developed for tick control and is based on icipe isolate of entomopathogenic fungus *Metarhizium anisopliae* sensu lato (s.l.) isolate ICIPE 7. To date, no randomized controlled study has been undertaken to demonstrate the efficacy of this bioacaricide in reducing natural tick infestation on cattle. This study was designed to evaluate the anti-tick efficacy of Mazao Tickoff ® on cattle in coastal Kenya compared to a standard chemical tick control protocol. The protocol describes the first rigorous evaluation of the efficacy of Mazao Tickoff® and its potential as a viable alternative non-chemical acaricide tool for tick control in Kenya and elsewhere. (Publication link: https://doi.org/10.1371/journal.pone.0272865)

2.4.4 Detection of antibodies to tick-borne disease in dromedary camels and go-grazing sheep
A disease with clinical and post-mortem presentation similar to those seen in heartwater, a tick-borne disease of domestic and wild ruminants caused by the intracellular bacterium *Ehrlichia ruminantium*, was first reported in dromedary camels in Kenya in 2016. Investigations carried out at the time to determine the cause were inconclusive. Results from this study indicated that: (i) Kenyan camels are frequently exposed to *E. ruminantium* from an early age; (ii) *E. ruminantium* was unlikely to have been the sole cause of the outbreak of heartwater-like disease; and (iii) *Ca. E. regneryi* does not appreciably cross-react with *E. ruminantium* in the PC-ELISA. (Publication link: https://doi.org/10.3390/microorganisms10050916)

2.4.5 Prevalence of hemopathogens in livestock and their associated blood-feeding biting keds
Livestock are key sources of livelihood among pastoral communities. Livestock productivity is chiefly constrained by pests and diseases. Due to inadequate disease surveillance in northern Kenya, little is known about pathogens circulating within livestock and the role of livestock-associated biting keds (genus *Hippobosca*) in disease transmission. We aimed to identify the prevalence of selected hemopathogens in livestock and their associated blood-feeding keds and found that livestock and their associated ectoparasitic biting keds carry several infectious hemopathogens, including the zoonotic *B. abortus*. Dog keds harboured the most pathogens, suggesting dogs, which closely interact with livestock and humans, as key reservoirs of diseases in Laisamis, Marsabit County in Kenya. These findings can guide policy makers in disease control. (Publication link: https://doi.org/10.12688/openresafrica.13404.1)

2.4.6 Socioeconomic burden of trypanosomiasis
Trypanosomiasis is one of the neglected tropical livestock diseases detrimental to rural development and in achieving sustainable development goals. This study was aimed to quantify the impact of trypanosomiasis on crop and livestock production and on poverty alleviation, using three rounds of panel datasets in Ethiopia. Trypanosomiasis increased the value of livestock death and production costs. Crop production tends to decrease when farmers report trypanosomiasis and death of oxen simultaneously. The estimated trypanosomiasis-induced economic losses are about US$ 94 million per annum. Had the government prevented this economic loss and invested it in social protection programmes, it could have lifted about 9,000 people in the study districts and about 200,000 people living in rural areas from absolute poverty. These findings indicate that trypanosomiasis remains a major production constraint in Ethiopia. Controlling trypanosomiasis appears to be pro-poor, calling for more policy attention. (Publication link: https://doi.org/10.1111/1477-9552.12531)

2.4.7 Tsetse repellant collar technology improves farm performance and household welfare
We measured the impact of collaring tsetse using tsetse repellant collar technology (TRCT) on livestock performance and welfare of livestock keepers in Kenya. Using ex-post non-experimental data and 632 cattle-keeping households in Kwale County, TRCT increased cattle market value and decreased the prevalence of poverty. In addition, the technology reduced the household food insecurity coping strategy index and hunger scale

among adopting farmers by 36% and 24%, respectively. The evidence from this study can contribute to advancing the scaling of TRCT. (Publication link: https://doi.org/10.1007/s12571-022-01342-4)

2.4.8 Molecular characterization of pathogenic African trypanosomes in biting flies and camels

African animal trypanosomosis (nagana) is becoming prevalent beyond its traditionally defined geographical boundaries in African tsetse belts. This study characterized the potential mechanical vectors, their host feeding patterns, and trypanosome infection in them and domestic animals outside the tsetse belt in the northern Kenya. Three trypanosome species were recovered in biting flies as well as in camels (*Camelus dromedarius*). The diversity of parasites in the biting flies was similar to that detected in the tsetse fly *Glossina pallidipes* collected from the tsetse infested Shimba Hills, in coastal Kenya, suggesting a wide geographic distribution of the trypanosomes in Kenya. The biting flies fed on camels, cattle, goats, and sheep. This study also identified diverse clinical outcomes based on packed cell volume (anemia), heamorrhagia associated with infection with disparate *Trypanosoma* species. Thus, infection of flies and camels by diverse *Trypanosoma* species could contribute to the complex epidemiology of observed trypanosomosis in camels. (Publication link: https://doi.org/10.1007/s42690-022-00896-2)

2.4.9 Epidemiology of tick-borne pathogens of cattle and tick control practices

Tick-borne diseases (TBD) are a major constraint to livestock health and productivity in SSA. Nonetheless, there are relatively few robust epidemiologic studies documenting TBD and their management in different endemic settings in Kenya. Therefore, a cross-sectional study using multi-stage cluster sampling was undertaken to characterize the epidemiology of TBD and management factors among zebu cattle reared under an extensive system in coastal Kenya. Blood samples from 1486 cattle from 160 herds in 14 villages were screened for the presence of tick-borne bacterial and protozoan pathogens. Respondents identified East Coast fever as the most important disease and Butalex® (buparvaquone) was the most commonly administered drug in response to perceived TBD in cattle. Results from this study provided updated molecular-based information on the epidemiological status of tick-borne pathogens of cattle and herd management practices in coastal Kenya. This information can be used in designing cost-effective control strategies for combating these TBD in the region. (Publication link: https://doi.org/10.1016/j.prevetmed.2022.105777)

2.5 Special Programmes

2.5.1 BioInnovate Africa Programme (BA)

BioInnovate Africa Programme entered its 3rd Phase in April 2022. With funding support from Sida, Sweden, the programme aims to strengthen the capacity of scientists in eastern African universities, research institutes, and private sector to translate biologically based research outputs into practical solutions that address the region's development priorities. Scientists from eight countries (Burundi, Ethiopia, Democratic Republic of the Congo (DR Congo), Kenya, Rwanda, South Sudan, Tanzania, and Uganda) will receive support through competitive grants for regional research and innovation collaboration projects administered by BioInnovate Africa Programme. Some highlights of the Phase III programme are as follows:

- *icipe* Director General (DG) appointed a new Programme Advisory Committee (PAC) for the period April 2022 to December 2026. The eight-member PAC is Chaired by Dr Yifru Tafesse, Deputy Director General of the Ethiopian Agricultural Transformation Agency (ATA).
- BioInnovate Africa Programme and the Thayer School of Engineering, Dartmouth College, USA, collaborated to build capacity for technoeconomic analysis (TEA) of innovation projects in Eastern Africa through a six-month tailormade online course. Five students from BioInnovate Africa participating universities in eastern Africa commenced the course in January 2022 and completed successfully by the end of June 2022.
- BioInnovate Africa Programme in partnership with the East African Science and Technology Commission (EASTECO) and the Stockholm Environment Institute (SEI)-Africa Centre, launched the first State of Bioeconomy in Eastern Africa Report on 23 June 2022, in Arusha, Tanzania. The event was preceded by a regional bioeconomy roundtable policy dialogue on the implementation of the East Africa Regional Bioeconomy Strategy. The report provides the latest scientific evidence of the status of bioeconomy in the region, including technical overview of the availability of bioresources and the competitive edge for developing a sustainable bioeconomy.
- The East African Community (EAC) Council of Ministers approved a new ten-year regional bioeconomy strategy for East Africa in April 2022, the first of its kind in Africa and the second in the world after the

European Union (EU). The regional bioeconomy strategy widens opportunities for the countries in East Africa to deepen their cooperation in developing a sustainable and resilient bioeconomy. The development of the strategy was through a national and regional consultative process spearheaded by EASTECO and the councils and commissions of science and technology and supported by BioInnovate Africa Programme. Plans are underway to formally launch the strategy.

2.5.2 Regional Scholarship and Innovation Fund

Africa Regional Scholarship and Innovation Fund (RSIF) of the Partnerships for Skills in Applied Sciences, Engineering and Technology (PASET) project in SSA seeks to identify and nurture African talent in science, engineering and technology through post graduate research and innovation training grants as well as institutional capacity building. Major progress made by Rsif during the reporting period includes:

- Ten PhD graduates returned to their home countries/institutions to start science careers and train next generation science leaders. Five of these graduates/alumni have been provided with small grants (Junior Investigator Research Award - JIRA) to initiate research programmes.
- An Rsif Alumni Network was formed and has developed a draft version of the constitution of the network.
- The second call for award of Research Grants to RSIF post-doctoral graduates (JIRA) was published in December 2022. The Rsif JIRA supports Rsif post-doctoral scientists to establish their research careers.
- Journal publications from the Rsif students have now reached 116.
- Rsif International partner institutions (IPIs) increased from 21 to 23.
- There are 278 Rsif scholars (24 nationalities; 37% women) across five themes: Food security and agribusiness (30%); energy including renewables (20%); climate change (17%); ICT including data science and artificial intelligence (17%); and minerals, mining and material science (16%) that were registered in 15 African Host Universities (AHUs):
    - Cohort 1 (2018 - 15 scholars): 10 scholars have graduated, 5 are at AHUs finalizing thesis.
    - Cohort 2 (2020 - 64 scholars): 32 scholars at international research placement, 30 at AHUs/field, 2 discontinued. Of the 56 scholars matched so far, 20 are matched to IPIs in Korea, 15 in Europe, 15 in Africa, and 6 in the USA.
    - Cohort 3 (2021 - 93 scholars): 73 at AHUs, 12 collecting data in the field, 1 at IPI and 7 to report in March 2023. 28% (26 of 93) matched with IPIs so far.
    - Cohort 4 (2022 - 106 scholars): 91 scholars at AHUs pursuing studies, 15 to report in March 2023. 6 scholars matched with IPIs.

- 54 Rsif research and innovation grants awarded in 8 countries (Total value: US$ 5.7 million).
    - Twenty-seven in the 1st and 2nd round of funding (26 under implementation and one that concluded).
    - Ten AGriDI projects (9 under implementation) with a total value of € 2.73 million.
    - Twelve Rsif/MozSkills grants to Mozambican researchers and innovators (6 under implementation and 6 under contracting).
    - Five JIRA grants to Rsif post-doctoral fellows (contracting in progress).

- Selected results of research and innovation projects: 546 faculty and scholars in AHUs trained on entrepreneurship and innovation; 17 publications from research work of faculty and students; 3 prototypes developed [Internet of Things (IoT) devices, solar heat pump drier for fruit and vegetables, biopesticides for yam fungi] and two patents secured (in oil and gas by the University of Port Harcourt).
- Co-organized PASET governance meetings (1-2 February 2023) on *A Regional Approach to Strengthening Science, Technology and Innovation Capacity for Responding to Current and Emerging Challenges* with the Ministry of Education, Rwanda and World Bank.
- US$ 54.7 million raised from 12 funders (Benin, Burkina Faso, Côte d'Ivoire, Ghana, Kenya, Mozambique, Nigeria, Rwanda and Senegal, Government of Korea, the ACP Innovation Fund of the European Union and the World Bank).
- Proposals under review by OCP Africa and the Carnegie Corporation of New York.
- Rsif Weekly Newsletter continues to be disseminated through Mail Chimp (64 editions published until the end of August 2022 with 13,586 subscribers; and a further 69 editions published until February 2023 with 13,878 subscribers).

3. Publications

A total of 263 peer reviewed journal articles were published during the period under review; and an additional 12 were accepted for publication, and 14 were submitted for peer review. The complete list of publications is provided in **Annex 1**.

Postgraduate and postdoctoral fellows continue to make a major contribution to the publication output of *icipe*: Over 50% of the peer-reviewed papers published by *icipe* during the reporting period were first-authored or co-authored by postgraduate or postdoctoral fellows.

4. Capacity Building and Institutional Development (CBID) Programme

Building the capacity of individual researchers, institutions and communities in Africa is integral to *icipe*'s research and sustainable development activities. *icipe* continues to make a substantial contribution to building the capacity of individuals and institutions through the development of MSc, PhD and postdoctoral fellows and research interns, and continued to conduct training and capacity building for numerous stakeholders.

4.1 Post-graduate (MSc and PhD), Postdoctoral and Research Internship training

During the reporting period *icipe* had:

- 159 postgraduate students (65 PhD fellows (34 ARPPIS PhD, 31 DRIP PhD) & 94 DRIP MSc fellows);
- 66 Research interns; and
- 31 Postdoctoral fellows.

In addition, *icipe* managed scholarships awarded to 278 RSIF students (cohort 1,2,3 and 4), drawn from 23 African countries. Of these 103 (37%) are female. A total of 62 scholars (cohort 2 and 3) have been matched with International Partner Institutions (IPIs) for their sandwich programmes. Of these, 25 are female.

Pursuing gender equity: 42% of ARPPIS and DRIP postgraduate scholars are women. Women's representation is highest in the DRIP MSc programme (45%). Representation by women in the *icipe* postdoctoral programme stand at 13%. About 37% of PhD scholars in the RSIF programme are women.

Completion: 4 ARPPIS PhD scholars, 5 DRIP PhD scholars, 23 DRIP MSc scholars defended their thesis or graduated during the reporting period. Two additional Cohort 1 RSIF scholars graduated in September 2022 These two join another 5 cohort 1 RSIF scholars who graduated earlier and have since returned to their home countries as faculty, while one is pursuing a post doc position at Sokoine University of Agriculture, in Tanzania.

The *icipe* ARPPIS & DRIP Postgraduate, Research Internship and Postdoctoral programmes have continent-wide representation: African nationalities - from east, west, central and southern Africa- were represented in the programmes during the reporting period: Benin (2), Cameroon (5), Comoros (1), DRC (4), Ethiopia (13), Ghana (2), Kenya (164), Liberia (1), Malawi (2), Nigeria (6), Rwanda (3), South Africa (1), South Sudan (2), Sudan (4), Tanzania (5), Togo (5), Uganda (13), Zambia (5), Zimbabwe (3).

Continental representation in the RSIF: 24 African nationalities are represented from Benin (21), Burkina Faso (16), Burundi (3), Cameroon (7), Chad (4), Côte d'Ivoire (11), DRC (5), Ethiopia (11), Ghana (23), Kenya (26), Mali (2), Malawi (4), Mozambique (32), Niger (2), Nigeria (43), Rwanda (22), Republic of Congo (1), Senegal (17), South Sudan (2), Sudan (2), Tanzania (11), Togo (1), Uganda (8), Zimbabwe (5).

New ARPPIS and DRIP PhD/MSc scholars

- *ARPPIS PhD scholars:* Eleven new ARPPIS PhD scholars joined *icipe* in the reporting period (nationalities: Ethiopia (1), Kenya (5), Cameroon (2), Comoros (1), Democratic Republic of Congo (1), South Sudan (1) (1female, 10male)
- *DRIP PhD scholars:* Nine new DRIP PhD scholars joined *icipe* in the reporting period (nationalities: Ethiopia (1), Kenya (4), Costa Rica (1); United States of America (1), Netherlands (1), Nigeria (1) (6 female, 3male)

- *DRIP MSc scholars:* 37 new DRIP MSc scholars joined *icipe* in the reporting period (nationalities: Kenya (28), Ethiopia (1), Malawi (1), Rwanda (2), Uganda (1), Colombia (1), Zambia (2), South Sudan (1) (17 female and 20 male)

4.2 Training

During the period under review *icipe* has conducted large number of trainings for students, researchers, national program partners, farmers and others in knowledge intensive areas of *icipe* technologies and products, and in research and research-related skills. *icipe* conducted more than 160 training events, and trained over 21,500 individuals (50% women) from 32 African countries (Angola, Benin, Burundi, Burkina Faso, Cameroon, Cape Verde, Chad, Comoros, Congo, Côte d'Ivoire, Djibouti, DR Congo, Ethiopia, Ghana, Kenya, Liberia, Malawi, Mali, Mozambique, Niger, Nigeria, Rwanda, Senegal, South Sudan, Sudan, Somalia, South Africa, Tanzania, Togo, Uganda, Zambia, Zimbabwe) and 3 other countries (Netherlands, UK and USA). Trainings were held in 8 countries in Africa (Ethiopia, Kenya, Uganda, Zambia, South Africa, Cape Verde, Côte d'Ivoire and Rwanda).

5. Partnerships

icipe signed over twenty project partnership agreements, six Memoranda of Understanding (MOU) and seven Material Transfer Agreements (MTA). During the same year, *icipe* re-engaged with the Global Biodiversity Information Facility (GBIF) for access to biodiversity data through the Data Management, Modelling and Geoinformation (DMMG) Unit. Additionally, MOUs between 18 RSIF - IPIs and four African Host Universities (AHUs) were signed. Some of the new AHUs are International Institute for Water and Environmental Engineering (2iE), Burkina Faso; University of Abomey-Calavi, Cotonou, Benin; Haramaya University, Ethiopia; and Makerere University, Uganda. A total of 12 tripartite agreements for RSIF African Host Universities (AHUs) in Senegal, Côte d'Ivoire, Tanzania and Nigeria were signed with International Partners Institutes (IPIs) in South Korea, Morocco, United Kingdom and France.

6. Communications and Media

6.1 Media Coverage

During this reporting period, over 600 news items related to *icipe* were published or broadcast by local and international media. This coverage added up to a cumulative potential reach of 1.64 billion people and an advertising value of US$ 16.7 million. The Centre also got approximately 8,500 mentions on social media, predominantly on Twitter (approx.. 7,800 mentions), Facebook (approx.. 300 mentions), and the other mentions (approx.. 400) on blogs within the same period. The top themes on social media were 'Food Security', 'First Woman', 'Insect Science' and 'Organic honey'. The media houses/publishers with the highest number of news items mentioning *icipe* were: Multidisciplinary Digital Publishing Institute (32), Science Africa (24) Daily Nation (13), Nature (10), Opera News (10), All Africa (7), Standard Digital News (7), Springer (6) and Farmers Review Africa (5) and Targeted News Service (5).

6.2 Press Releases

A total of twelve press releases have been generated and distributed to *icipe*'s mailing list and social media, in the year 2022.

6.3 *icipe* Website

Over sixty thousand users visited the *icipe* website, resulting in over 219,000 page views with an average of 1.62 sessions per user. Kenya, United States of America, Ethiopia, China, United Kingdom, Uganda, Germany, India, Nigeria, and Tanzania were the top ranked countries in terms of visitor numbers.

6.4 *icipe* Videos

Forty three videos (**Annex 3 - B**) were produced from various *icipe* research for development activities.

8.5 *icipe* e-bulletin

Two *icipe* e-bulletins were produced in 2022. The bulletins featured the Director General's Thought Leadership column on: Towards inclusive innovation - *icipe* offers evidence for a holistic, balanced and effective approach as well as how the Centre has emerged as a data science hub in Africa. The bulletins were distributed to over 4,700 readers.

7. Significant developments

7.1 FAO Science and Innovation Forum 2022

The FAO Science and Innovation Forum 2022 was held on 17-21 October 2022. The *icipe* Director General was invited to join the steering committee. The Forum focussed on highlighting the centrality of science, technology and innovation for agrifood systems transformation. Two virtual *icipe* side events on nature-based solutions for biodiversity, food security and health and edible insects were featured as a prelude to the meeting on 13th and 14th October 2022, respectively.

7.2 Emerging Insect Technology Hub

AgriFutures, Australia; the Australian Centre for International Agricultural Research (ACIAR); and *icipe*, have created the Emerging Insect Technology Hub (EIT-Hub). The platform will enable collaboration and knowledge-sharing among research and industry partners, scientists and investors in Africa and Australia. The EIT-Hub will capitalise on the goal of promoting insect farming as an emerging industry in Australia, by AgriFutures Australia. It will also build on the investments by various development partners in the insects for food and feed sector in Africa, through *icipe*. It will also benefit from the Centre's globally reputed leadership in advancing knowledge, and a thriving insect-based sector in Africa and beyond.

7.3 Regional bioeconomy strategy

In April 2022, the East African Community (EAC) council of ministers approved a 10-year regional bioeconomy strategy for the region; the first of its kind in Africa and the second in the world after the European Union. The strategy was developed through a national and regional consultative process spearheaded by the East African Science and Technology Commission (EASTECO), in partnership with the region's councils and commissions of science and technology; African Technology Policy Studies Network (ATPS); Stockholm Environment Institute (SEI) – Africa Centre; Scinnovent Centre Limited; and Bioinnovations Company Limited; with support from *icipe's* BioInnovate Africa Programme.

7.4 Regional Scholarship and Innovation Fund Conference

The 2022 Pan African hybrid Regional Scholarship and Innovation Fund (RSIF) conference was held on 28-29 June 2022 at University Mohammed VI Polytechnic, Ben Guerir, Morocco, themed "*African-led Science, Technology and Innovation for Contributing to the SDGs and Stimulating Global Development*". More than 50 speakers covered digital innovation, responding to global challenges; building Africa's STI capacity to support industrialisation; nurturing collaboration between universities and industry; and green growth for Sustainable Development *(See communique and session recordings.)* Development partner roundtables were also held on *Investing in building STI capacities and higher education in Africa. RSIF's value proposition and progress to date. Possibilities for collaboration.* The objective of the conference was to showcase achievements of RSIF and discuss RSIF sustainability.

7.5 Engagement with Wellcome Trust

On 24th November 2022, *icipe* scientists led by the Director General met with a team from Wellcome Trust led by an Interim Advisor and Head of Major International Programmes to discuss areas of mutual interest. The discussion focused on four areas namely: (i) Climate change and diseases; vector population and changes in vector-borne diseases; (ii) Vector biology and disease diagnostics; early detection/surveillance; (iii) Data management, digital technology in relation to health management; and (iv) Emerging infectious zoonoses at the wildlife, livestock and human interface. There was an agreement on common areas and the two teams agreed to look for opportunities to continue the discussion.

7.6 Vector Atlas partner meeting

The Vector Atlas is a University of Oxford, *icipe* and Malaria Atlas Project initiative, funded by the Bill and Melinda Gates Foundation and working in collaboration with several partners. The project seeks to build a data-hub that links 'core' African vector occurrence, bionomics and insecticide resistance data to provide a 'one stop shop' of relatable and cross-referenced data access. Data from combined sources will inform novel spatial models and maps that promote and evolve our understanding of the variables that drive malaria transmission. From 5 – 9 December 2022, the project convened a partner meeting of over 50 vector experts from across Africa representing National Malaria Control Programmes (NMCPs), vector researchers as well as our Vector Atlas partners, to the first Vector Atlas stakeholder meeting at *icipes's* Mbita campus on Lake Victoria. Through a series of presentations and discussions held throughout the meeting, the current 'in country' challenges in malaria vector control were highlighted and led to discussions on how and where spatial data, maps and models could help in finding solutions.

New collaborations have been formed that will drive the Vector Atlas forward and ensure we produce spatial products that are relevant and impactful across national to continent-wide scales. Capacity building is a key component of the Vector Atlas and this meeting highlighted a clear need within NMCPs and their close partners for more training and help in applying and using spatial models and analyses to address current on-the-ground issues.

8. The Way Forward

8.1 *icipe* Periodic External Review (IPER) 2018 – 2022

Since 1983, the Sponsoring Group of *icipe* (SGI) together with the Governing Council (GC), have commissioned the *icipe* Periodic External Review (IPER). These reviews are undertaken every 5 or 6 years. The last IPER was held in 2018 (for the period 2013-2017) and in 2022 *icipe* initiated preparations for an external review of its science for development portfolio. This will be undertaken during the first half of 2023 and will cover the duration 2018 – 2022. This is an important Centre level task, which will help shape the Centre's future research strategies and directions for at least the next five years.

8.2 *icipe*-IKEA Foundation partnership to tackle developmental challenges for 'One Health'

In October 2022, *icipe* became a direct grantee of the IKEA Foundation after a process of mutually engaging discussions and exchange of ideas to tackle developmental challenges in an integrated manner. The project will be implemented to scale a combination of black soldier fly farming innovations and vegetable push-pull cropping systems in rural Kenya, Rwanda and Uganda. Over the next five years, the project will contribute to policy and behavioural change towards regenerative, circular, climate-resilient, and inclusive agri-food systems.

8.3 Implementing 'One Health' Strategy through Capacity Building and Integrated Sciences

In response to IPER recommendations made in 2018 and as part of *icipe*'s Vision and Strategy 2021-2025, the Centre is developing a 'One Health' strategic framework to reach out, network, and align its objectives with the diverse partners to move from concept to implementation and from policy to practice and will ensure the entrenchment of 'One Health' in addressing global developmental challenges. The implementation of 'One Health' strategy of *icipe* will be coordinated through the office of the Head of the Capacity Building and Integrated Sciences (CBIS). The Head of CBIS ensures that new cross-thematic initiatives are generated and that opportunities are taken for integration of programmes across themes and units to deliver 'One Health' interventions.

SECTION 3: RESULTS BASED MANAGEMENT (RBM) FRAMEWORK: PROGRAMMATIC *SUMMARY* PROGRESS REPORT FOR 2022

(i) Plant Health Theme: RBM Rolling Framework Key Achievements
(ii) Animal Health Theme: RBM Rolling Framework Key Achievements
(iii) Human Health Theme: RBM Rolling Framework Key Achievements
(iv) Environmental Health Theme: RBM Rolling Framework Key Achievements
(vi) Capacity Building & Institutional Development Programme: RBM Rolling Framework Key Achievements
(vii) BioInnovate Africa Programme: RBM Rolling Framework Key Achievements
(viii) PASET - RSIF: RBM Rolling Framework Key Achievements

RESULTS BASED MANAGEMENT (RBM) FRAMEWORK: PROGRAMMATIC *SUMMARY* PROGRESS REPORT

icipe **mission**: "*Help alleviate poverty, ensure food security and improve the overall health status of peoples of the tropics by developing and extending management tools and strategies for harmful and useful arthropods, while preserving the natural resource base through research and capacity building*".

icipe **vision:** "*Pioneering global science in entomology to improve the wellbeing and resilience of people and the environment to the challenges of a changing world, through innovative and applied research, alongside deep exploratory study, impact assessment, evaluation and sustainable capacity building".*

icipe **mandate**: ..as stated in its Charter "…*the primary mandate of* icipe *shall be research in integrated control methodologies for crop and livestock insect pests and other related arthropods, and insect vectors of tropical diseases and the strengthening of scientific and technological capacities of the developing countries in insect science and its application through training and collaborative work".*

Overall objective for Plant Health:
Improved plant health benefiting smallholder agriculture, nutrition, health and the environment through world class knowledge, solutions, partnerships and capacity.

2022 Highlights of key achievements and outputs

Flagship 'staple crop IPM': Full registration permits of ICIPE 7 and ICIPE 78 against the fall armyworm (*Spodoptera frugiperda*) in Tanzania and Uganda: Based on previous laboratory and field studies, *Metarhizium anisopliae* ICIPE 7 and ICIPE 78, which are currently registered by RealIPM (Thika, Nairobi), a subsidiary of Biobest (Westerlo, Belgium) as TickOff and Achieve, respectively, for use against ticks and mites, respectively, were found to be very potent biopesticides against the fall armyworm *S. frugiperda*. In 2022, *icipe* facilitated full registration of these biopesticides in Uganda and Tanzania for use against *S. spodoptera* as Detain and Achieve, respectively. In Kenya, the final report on the field efficacy of Detain has been submitted to Pest Control Products Board (PCPB, Nairobi, Kenya) and is awaiting

final approval for the registration permit. In addition, *M. anisopliae* ICIPE 41 formulated in corn oil significantly supressed *S. frugiperda* in the laboratory and the field, with no negative effects on its parasitoids (*Cotesia icipe*, *Telenomus remus* and *Trichogramma chilonis*). A combination of Achieve, Detain and *M. anisopliae* ICIPE 41, together with parasitoids, provides better management of *S. frugiperda*.

Flagship 'horticulture IPM': Mechanism of endophyte-induced compounds on host location and herbivory of the tomato leafminer *Phthorimaea absoluta: Trichoderma asperellum* M2RT4 can successfully colonize tomato plants as an endophyte through seed inoculation. We found from a previous study that *P. absoluta* females significantly avoided inoculated tomato plants and investigated the mechanism. Chemical analysis revealed the emission of methyl salicylate in inoculated plants, and both methyl salicylate and (Z)-jasmone in inoculated *P. absoluta*-infested tomato plants. *T. asperellum* M2RT4 modulates tomato plant chemistry through the production of (Z)-jasmone, thus activating both salicylic and jasmonic acid defense pathways and consequently affecting the host location and herbivory of *T. absoluta*. Methyl salicylate affects host location of *T. absoluta* females, while (Z)-jasmone affects herbivory of the pest. Methyl salicylate could therefore be considered as a good semiochemical-based candidate for sustainable *P. absoluta* management using a push-pull approach.

Semiochemicals to enhance biological control of *P. absoluta* with parasitoids: *Dolichogenidea gelechiidivoris* is an efficient parasitoid of *P. absoluta*, a major pest of tomato. Semiochemicals such as herbivore-induced plant volatiles and host chemicals serve as communication signals for host location. However, the attractive compounds used by *D. gelechiidivoris* to locate *P. absoluta* are not known. Through behavioural assays and chemical analyses, we investigate the chemical basis of the tritrophic interactions, and found that *D. gelechiidivoris* was attracted to *P. absoluta*-infested plants and preferred volatiles of *P. absoluta*-infested plants over those of healthy plants. Additionally, volatiles of plants infested with a higher number larvae (20) were more attractive to the parasitoid than those infested with a lower number of larvae (5 and 10). Also, the parasitoid was attracted to host pheromones and volatiles from larval frass. On the other hand, the parasitoid was not attracted to larvae at any of the densities tested. These findings pave the way for potential use of these attractants as kairomone-based lures to enhance biocontrol of *P. absoluta* with D. *gelechiidivoris*.

Prediction of virulence of biopesticides against *P. absoluta*. We previously demonstrated that *M. anisopliae* ICIPE 18 and ICIPE 20 are effective against adult *P. absoluta* and could be developed as biopesticides. Both isolates can successfully be mass-produced on rice using a simple, fast and cost-effective mass production technique. However, adequate strain selection and accurate spatial prediction are fundamental to optimize their efficacy and formulations before field deployment. We assessed the thermotolerance, conidial yield and virulence (between 15 and 35°C) of ICIPE 18 and ICIPE 20. Spatial prediction revealed suitable locations for ICIPE 18 and ICIPE 20 deployment against *P. absoluta* in Kenya, Tanzania and Uganda. In general, environmental conditions appeared to be conducive to the pathogen virulence across the three countries. These strains are currently being commercialized together with Russell IPM (Deeside, UK), but our study indicates that field validation trials under different agroecological zones may are required.

Flagship 'push-pull technology': Elucidation of mechanism for control of *S. frugiperda* in maize push-pull fields: Maize push-pull fields control *S. frugiperda*, but the mechanisms were not known. We tested two hypotheses relating to the volatiles released by push-pull companion crops (*Desmodium intortum*, *Desmodium uncinatum*, *Brachiaria* Mulato II): (1) the volatiles deter female *S. frugiperda* from ovipositing

on maize (push); (2) the volatiles recruit *S. frugiperda* parasitoids (pull). In wind tunnel bioassays, maize volatiles mixed with *Desmodium* sp. volatiles were less attractive to *S. frugiperda* than maize alone. In oviposition bioassays, *S. frugiperda* laid significantly fewer eggs on maize when *Desmodium* sp. volatiles were present. Conversely, in an olfactometer bioassay, parasitoids were attracted to the scent of both *Desmodium* sp. and *Brachiaria* sp. Coupled GC-electroantennogram recordings showed robust responses to certain aromatic and terpenoid volatile compounds. Our study provides evidence of the chemical ecology mechanisms underpinning reduced *S. frugiperda* infestation in the push-pull systems: volatiles from companion crops repel S. *frugiperda* while attracting its parasitoid natural enemies.

Push-pull soil legacies. The effect of push-pull soil legacies on plant phytochemistry and pest resistance is largely unknown. We conducted research on how conditioning soil with push-pull affected maize metabolism and resistance to *S. frugiperda*. We analysed volatile and non-volatile maize metabolites, and their impact on larval feeding and parasitoid attraction in push-pull conditioned soil. Push-pull soil increased volatile and non-volatile defense metabolites in maize. The altered maize metabolism negatively affected larval feeding and attracted *S. frugiperda* egg-larval parasitoids. The link between soil legacies and associated plant metabolism represents an additional mechanism through which the push-pull cropping system controls the invasive *S. frugiperda*.

Stemborer and *Striga* sp. suppression and yield efficiency in long-term trials. Long-term data sets were collected on stemborer and Striga sp. pressure, and maize yields from a large number of farms (495) with push-pull and non-push-pull fields across eight regions of Western Kenya for 17 years (2005-2016). At each farm, the same farmer managed one push-pull and one non-push-pull field planted with maize. In collaboration with Cornell University (Ithaca, USA), we analyzed farm datasets. We found that not only did pest control effect of the push-pull system remained robust over time, its control of stemborers and *Striga* sp. improved with time since establishment, while its impact on yield did not change. While this study did not directly address the mechanisms, it seems likely that pests in the push-pull system are not successfully adapting to overcome its pest management effects. Similar studies are undertaken on *S. frugiperda*, which invaded Africa in 2016. In collaboration with Lund University (Lund, Sweden) and Cornell University, we are assessing the ability of push-pull technology to contribute to yield stability against climatic extremes that are becoming more common.

Exploring wild tomato volatiles for development of vegetable push-pull systems. Based on field observations, we found that a wild tomato plant, *Solanum lycopersicum* var. *cerasiforme*, grown in the Mount Kenya region, is less attacked by *P. absoluta*. We hypothesized that the wild tomato plant may be actively avoided by gravid *P. absoluta* females because of the emission of repellent allelochemicals. Therefore, we compared infestation levels (mines) by the pest in field monocrops and intercrops of the two tomato genotypes. We found significant reductions in infestation levels in the monocrop of the wild tomato, and intercrops of wild and cultivated tomato plants, compared to the monocrop. *Phthorimaea absoluta* infestations were lower when the wild tomato was used as border crop than when it was used as interline crop. We identified the most discriminating compounds using two methods. (Z)-3-hexenol, camphor, citronellal and limonene were found to be the most discriminating compounds and were detected only in the wild tomato. A blend of these compounds showed dose-dependent repellence to *P. absoluta* females in a wind tunnel. This study provides groundwork for exploiting the allelochemicals of wild tomato in the development of novel IPM approaches against *P. absoluta*.

Flagship 'invasive and migratory pests'. Modelling crop yield loss to insect pests under a warming climate: Insect-mediated crop losses due to climate change are not known. Research on insect-mediated crop losses are disconnected from models predicting changes in crop yield due to a changing climate. For the first time, we empirically measured yield losses to insects; establish crop damage and loss functions; and coupled crop and pest models. Using phytotrons, incubators and greenhouse studies, temperature and CO_2-dependent pest feeding, and survival data were collected, and crop damage and yield loss functions were established; and incorporated in an overarching model where the two models (crop damage and yield loss models) were coupled, in which the crop model drives the damage model and vice versa. Using the model, we found that increasing levels of CO_2 induced higher damage than increasing levels of T; which, is transited into yield losses with the same trend.

Flagship 'soil health'. 'Wrap and plant' banana fiber paper against potato cyst nematodes (*Globodera* spp.)**:.** The use of banana fibre paper for nematode management, termed 'wrap & plant', presents a novel and effective mechanism. *icipe* and the International Institute of Tropical Agriculture (IITA, Ibadan, Nigeria) have been working on the technology as a novel technique to protect potatoes against the invasive potato cyst nematode (*Globodera* spp.). Our work has shown that banana fibre paper acts as a physical barrier to invading nematodes adsorbs by absorbing hatching factors (root exudates) and delaying hatching, thus protecting the potato seed. With the addition of micro-dosages of a nematicide to the paper, it is highly effective, yet environmentally safe. The unique combination of lignin and cellulose in banana fibre enables adsorption of ultra-low densities of nematicides, which is released slowly over time as the matrix decomposes. Ongoing work has also shown that the paper is an effective delivery mechanism for biologically based pesticides, such as microbial antagonists (e.g. *Trichoderma* sp.). In recent field trials with sweet potato, we compared vines wrapped with banana paper to unwrapped (farmer practice) vines. We found that the banana paper appears to protect the plants and resulting tubers from both nematode and sweet potato weevil attack. Wrap & plan technology provides a promising new option to revolutionize the protection of planting material against nematodes and other cryptic soil-borne threats in an environmentally effective manner.

Overall objective for Animal Health:
To improve livestock health and productivity through the development of integrated strategies and tools for livestock vectors' control, thus leading to greater availability of meat and milk, hides and draught power, and thus enhancing food security.

2022 Highlights of key achievements and outputs

Implemented a randomized controlled study to assess the efficacy of utilizing a biorational ticks control agent (based on fugus *Metarhizium anisopliae* ICIPE 7) for ticks infesting livestock in Kilifi County, Kenya.

Provided evidence of tick biodiversity in Kenya to the Directorate of Veterinary Services (DVSs) to support decision-making.
Identified tick species and tick-borne diseases in several endemic areas, including northern Kenya (camels, cattle), coastal Kenya (cattle, small ruminants), and Ethiopia (cattle).

Conducted training events on management of vector-borne diseases in Kenya and Ethiopia.

Demonstrated the utility of a urine-based test for trypanosomiasis in cattle and camels.

Developed a trapping device more selective for biting flies biased on the monoconical trap design.

Nanopolymer beads as carrier matrixes for attractants and repellents for biting flies were optimized.

Completed a fine-scale map of tsetse flies in Kwale, Kenya, determined environmental drivers for more infectious tsetse flies, and developed a new algorithm for identifying potential tsetse breeding sites for optimized vector control.

Established a new research area using microbiome and proteomics analyses to determine the role of tick endosymbionts in tick-borne pathogen transmission in livestock.

Established a novel protocol for collecting and screening microbiomes and tick-borne pathogens from tick saliva and haemolymph as well as salivary glands and midgut of individual ticks to disentangle infection status from likely vector competence.

Overall objective for Human Health:
To contribute to the reduction of vector-borne diseases by developing tools and strategies that control the vectors and break the cycle of transmission, and which can be integrated with other disease management efforts.

2022 Highlights of key achievements and outputs

Demonstrated the operational feasibility of integrated vector management adding larviciding or house screening into routine malaria control programs using long-lasting insecticidal nets and indoor residual spraying in 6 southern African countries.

Implemented a randomized controlled study to assess the impact of a community led One Health intervention, utilizing a biorational vector control agent (based on fugus *Metarhizium*) to target biting arthropods on cattle to prevent human and animal diseases.

Developed novel intervention tools for the control of the neglected parasitic skin disease, tungiasis (sand flea disease); including improved hygiene education packages, low-cost flooring solutions and insecticidal interventions such as insect growth regulators for the control of off-host sand flea stages.

Completed pioneering studies on the impact of tungiasis on the cognitive development of children and on their quality of life.

Designed a novel training concept, the 'healthy home demonstration' for integrated One Health education in and around the homestead.

Improved our understanding of the links between environment and health through the study of freshwater pollution and its indirect impact on the risk of schistosomiasis transmission.

Developed a rapid and cost-effective MALDI-TOF based bioassay for the detection of *Microsporidia MB,* a *Plasmodium*-inhibiting natural symbiont, *in Anopheles* mosquitoes.

Enhanced the capacity for research (transmission, ecology, genetics, genomics, and modelling) of symbiont-based malaria transmission blocking strategies.

Developed the capacity for implementation (Engagement with regulators, stakeholder, and community) of symbiont-based malaria transmission blocking strategies.

Supported the MoH Neglected Tropical Diseases unit to establish two treatment Centres in Kajiado County, Kenya, a new focus for transmission of leishmaniasis, and identified potential vectors and pathogens in the outbreak.

Overall objective for Environmental Health:
To develop and advance world class knowledge, capacity, and solutions to understand the importance of, and threats to arthropod biodiversity in the changing world, and to help maintain, and utilize the ecosystem services mediates for sustainable development of Africa and beyond

2022 Highlights of key achievements and outputs

Bee Research
In partnership with the University of Pretoria, South Africa and Core project chairs of the colony loss monitoring group of COLOSS, a survey on managed honey bee colony losses and causes across nine Sub-Saharan African countries has been initiated.

New research with Ethiopian honey bees revealed that grooming behaviour, which is influenced by landscapes and season, play a major role in tolerance to Varroa mites.

The Bee research group has taken significant efforts to characterise various types of honey produced across Kenya. Results indicate high levels of antioxidants and antibacterial metabolites in some of the African honey. Using peak honey profiling by H1 NMR spectroscopy, we demonstrated that of honeys from undomesticated bee species was different from domesticated bee species (Noiset et al., 2022; Mokaya et al., 2022).

We have demonstrated that some stingless bee species such as *M. bocandei* and *M. ferruginea* are efficient pollinators than *Apis mellifera* on cucurbits (Cucumber, Watermelon, sweet melon). These stingless bees can increase yield and fruit quality (dimension, weight) up to 20% against 5% from the honey bee (Kiatoko et al., 2022).

We studied the influence of bioclimatic, topographic, and vegetation phenology on the spatial distribution and change patterns of 12 Stingless bee species in Kenya. The results from the ecological niche models showed that annual precipitation was the most influential variable to stingless bee distribution. Vegetation phenology (21.36%) and topography (14.36%) had moderate effect on stingless bee species' distribution.

Apiculture and Sericulture:
During 2022, additional 51,709 (57% females) needy and interested youths secured direct jobs in apiculture and sericulture value chains in Ethiopia. This increased the total MOYESH programme direct outreach to 117,196. In addition, 247,292 (55% females) indirect jobs (in input supply and service delivery) were created. This increased the total achievements in indirect jobs to 548,512. The total incremental honey supplied to the market by youth enterprises reached 1,465.7 tons, and 222 tons of silk products generating total cash revenue of US$8.5 million. MOYESH programme contributed to the design of the national mega livestock development programme that prioritized milk, chicken meat, eggs, and honey for household level nutritional security, import substitution and rural agri-business transformation.

Through various capacity building efforts, Hands-on-training improved and best bee keeping practices were disseminated to national stakeholders in Kenya, Zanzibar, Seychelles, Mauritius, Comoros and Madagascar through funding from European Union, IFAD and Biovision.

Biosystematics
Since 2018, 206 new species of the Kenyan insect fauna have been described in peer reviewed journals. A further 21 new species are now in manuscript. To date, 48 collaborators in various museums and universities described these new species. So far, over 65,000 specimens collected during ICIPE's Insect Survey and Inventory Project have each been labelled with a unique database number (identifier). A database of Syrphidae (hoverflies) in the ICIPE insect collection was published in 2020 on the Global Biodiversity Information Facility (GBIF), which has been cited 19 times. The first author of this database was Josephat Bukhebi, a technical assistant in the BSU.

In 2022, the biosystematics unit has upgraded the macro-photography instrumentation with a Macropod. This has resulted in high resolution and detailed imaging of insects, facilitating increased awareness on insect biodiversity and identification of new species.

Applied Bioprospecting:
We discovered that the repellent activity of our novel oil formulation combining insect oil and essential oils from plants compared favorably with that of the synthetic insect repellent, N,N,-Diethyl-toluamide (DEET). icipe and partners developed and tested effective mosquito repellent products (lotion and soap) using essential oils extracted from the catnip (Nepeta cataria) plant. We have also compiled ethnobotanical knowledge, diversity, and geographical distribution of plant species of interest in malaria control in Burundi.

Insects for food, feed and other uses:

The edible long-horned grasshopper mass production has been optimized with innovative feedstocks based on different combinations of plant and animal protein substrates optimized (Margaret et al., 2022; Leonard et al., 2022). Further post-harvest processing methods for long-horned grasshoppers have been optimized with positive impacts on nutritional quality (Ochieng et al., 2022). Four novel porridge products blended with edible cricket (*Scapsipedus icipe*) developed and its nutritional quality assessed (Maiyo et al., 2022).

Pioneering research on the shift in the gut microbiota of chicken feed on black soldier fly larvae-based feeds revealed increases in healthy gut microbial community when fed on insects. This highlights the potential to strengthen immune responses of insect fed chicken and reduce dependence on antibiotics (Ndotono et al., 2022a, b).

Significant achievements on optimizing the inclusion of insects in aquaculture and poultry feeds have been made (Mutisya et al., 2022; Were et al., 2022). Further consumer perception on poultry products obtained from insect-based feed inclusion has been assessed (Khaemba et al., 2022). Ex ante assessment of socio-economic impacts of insect-based feed inclusion in poultry sector of Uganda has been completed.

Significant efforts towards creation of enabling environments of edible insect sector in Rwanda and Ethiopia have been achieved. Further partnership with African Standards Organization, a constituent organization of African union towards harmonization of policies across the continent has been strengthened.

Liquid BSF frass fertilizers have been developed. Nutritional assessment showed that liquid BSF frass fertilizers had higher concentrations of macronutrients (1.1 – 11 folds), secondary nutrients and micronutrients required for optimal crop growth compared to other commercial liquid fertilizers.

We have demonstrated the high potential of chitin-fortified BSF frass fertilizers to suppress soil-borne pests such as potato cyst nematodes, root knot nematodes, and onion root flies by 50 – 96%, 96 – 100%, 45 - 65%, respectively. Furthermore, chitin-fortified BSF frass fertilizers achieved nematode mortality (89 – 95%) that was comparable to the value obtained using commercial nematicide (96%). Soil amendment with chitin-fortified BSF frass fertilizer increased the yields of potatoes and onions by 50 – 96% and 13– 50%, respectively, compared to commercial fertilizer.

Data management and modelling unit

A novel suitability model was developed for monthly monitoring of transhumance patterns in Africa, related to pasture, water availability and conflict areas over resources A new data science methodology was developed for assessing high resolution time-series satellite data in cloudy regions such as Kenya. Using time-series data from this method, land use classifications to help landscape pollination studies in cloudy areas (mountain transects) could be consistently improved by >5%, based on overall classification accuracy scores (https://dmmg.icipe.org/dataportal/dataset/land-cover-land-use-for-muranga-ke-and-kilimanjaro-tz)

Overall Objective of Capacity Building:
To nurture young, talented researchers to meet the demand for doctoral-level researchers and middle level practitioners for regional leadership roles and internationally competitive research careers required to respond to arthropod-related research and development challenges in Africa.

2022 Highlights of key achievements and outputs

During 2022, there were 73 PhD fellows and 170 MSc fellows at various stages of their postgraduate training programme at *icipe*.

In 2022, women represented 45% of all postgraduate fellows at *icipe*.

In 2022, twenty two (22) African nationalities, from all sub-regions of SSA were represented by postgraduate students at *icipe* (Benin, Cameroon, Comoros, DR Congo, Ethiopia, Gambia, Ghana, Kenya, Liberia, Malawi, Mali, Nigeria, Rwanda, Senegal, South Africa, South Sudan, Sudan, Tanzania, Togo, Uganda, Zambia, Zimbabwe).

In 2022, 10 PhD and 28 MSc students completed postgraduate training with *icipe*. Of these, 10 PhD students 5 (50%) are currently engaged in research, development or higher education in Africa; 4 (40%) are engaged in research outside Africa and 1 (10%) is currently seeking employment. Of the 28 MSc students, 8 (28%) are pursuing a career in R&D or higher education in Africa, 7 (25%) are undertaking a PhD and 1 (4%) is seeking PhD opportunities. No data is available for the remaining 12 (43%) MSc students who completed their studies with *icipe*.

In 2022, of the 263 peer-reviewed papers published by *icipe*, 90 (34%) were authored by postgraduate students, 74 (28%) as lead authors.

29 postdoctoral fellows were engaged in research at *icipe* in 2022.

43 peer-reviewed articles were published by postdoctoral fellows (20 as lead author), representing 16% of all *icipe* peer-reviewed publications in 2022.

In 2022, *icipe* postdoctoral fellows participated in 57 grant applications; 15 were awarded and signed; 3 approved - awaiting contract; 11 under review with various funders; and 28 were unsuccessful (i.e., at least 32% success rate). In the third quarter of the year, two postdoctoral fellows were promoted to research scientist.

58 research interns were trained in 2022 (37 [64%] women). The interns were engaged for periods of between 3-6 months.

173 training courses were held in 2022 for 14,343 researchers, mid-level practitioners and extension workers from 31 Africa countries (Benin, Burkina Faso, Burundi, Cameroon, Cape Verde, Comoros, Congo, Djibouti, D R Congo, Eswatini, Ethiopia, Ivory Coast, Ghana,

Kenya, Liberia, Malawi, Mali, Mozambique, Niger, Nigeria, Rwanda, Senegal, Somalia, South Africa, South Sudan, Sudan, Tanzania, Togo, Uganda, Zambia and Zimbabwe) and 3 non-African countries (Netherlands, UK, USA).

Overall Objective of Bioinnovate Africa Programme:
Universities, research institutes and firms in eastern Africa actively translate innovative biological based ideas and inventions into business prospects

2022 Highlights of key achievements and outputs

Overview of Achievements:
20 innovation projects and five (5) COVID-19 projects (supported in Phase II) were successfully closed.

Sida and *icipe* signed a new cooperation agreement to implement BioInnovate Africa Programme Phase III (1 April 2022 – 31 Dec 2026)

A new BioInnovate Africa Programme Advisory Committee (PAC) was appointed.

10 new regional innovation collaboration projects were competitively selected for funding.

The East Africa Bioeconomy Strategy was published and launched by the East African Community.

Outputs:

Of the 20 innovation projects that closed in Phase II, seven (7) successfully launched products in the market; seven (7) successfully tested and validated their products in the market, three (3) produced minimum viable products while two (2) stopped at prototype stage. One (1) did not go beyond proof of concept.

Of the five (5) COVID-19 projects closed in Phase II, four (4) produced prototypes of biobased solutions in response to the pandemic. One (1) project developed a standard COVID-19 data tracking/ aggregation system for selected countries.

Eight (8) scientific papers (including articles) were published in various regional and international journals.

The BioInnovate Africa PAC held their 14th, 15th, and 16th meetings. At their 16th meeting, PAC competitively selected 10 new regional innovation projects to be supported in Phase III.

The East African Community (EAC) launched and published the East African Regional Bioeconomy Strategy through a press release on 15 December 2022.

One (1) Bioeconomy policy dialogue was held with the EAC in Arusha, Tanzania to discuss implementation plans of the regional bioeconomy strategy.

An East Africa Bioeconomy Status Report 2022 jointly prepared with the East African Commission for Science and Technology (EASTECO) and the Stockholm Environment Institute (SEI) was launched at the EAC in Arusha, Tanzania.

BioInnovate Africa became an associate member of the Roundtable on Sustainable Biomaterials (RSB) to expand its network with industry players in the circular and biobased economy.

BioInnovate Africa co-authored a commentary for Nature on Bioeconomy: gamechanger for climate action (see Nature 610, 630 (2022)

BioInnovate Africa in collaboration with Chalmers University of Technology, Sweden delivered a capacity-strengthening program to support Grid Innovation and Incubation Hub (GIIH) of the University of Rwanda.

A second cohort of students conducting a remote course on Techno-economic analysis (TEA) completed it in June 2022. A third cohort of students was selected jointly with the Thayer School of Engineering, Dartmouth College who are facilitators of the course.

A BioInnovate Africa documentary on innovation in the development context of Eastern Africa was officially released on 15 September 2022.

Overall Objective of PASET RSIF

To strengthen the institutional capacity for quality and sustainable doctoral training, research and innovation in transformative technologies in Sub-Saharan Africa (SSA) by 2025

2022 Highlights of key achievements and outputs

RSIF growth: The number of African governments' supporting Rsif increased from eight to nine, as Nigeria made its contribution of USD 4 million to Rsif. The nine countries now include Benin, Burkina Faso, Côte d'Ivoire, Ghana, Kenya, Mozambique, Nigeria, Rwanda and Senegal. Additionally, Rwanda pledged a second contribution of USD 2 million – becoming the first PASET country to do so. By the end of 2022, total portfolio of Rsif was USD 54.7 million, which includes contributions from the 12 African governments, Government of Korea, the ACP Innovation Fund of the European Union and the World Bank.

Number of scholarships and grants successfully administered: In 2022, 105 Cohort 4 scholarships were awarded of which 34% were women, 48% faculty and 23 nationalities. This brings the total Rsif scholarships awarded to 291.

54 grants worth USD 6.37M (28 research projects and 26 innovation projects) were awarded. Some of technical support for grants implementation were provided as follows:

- 12 new grants for Mozambique were presented at a seminar organized by the Mozambican Minister of Science, Technology and Higher Education in Maputo in October 2022.
- In West Africa, 9 AGriDI innovation grants were initiated and grantees were trained on financial management and results-based project management.

Rsif African host universities' (AHUs) capacity for improved quality of doctoral programs and research in ASET: 15 Rsif AHUs hosted Rsif PhD students and benefited from institutional strengthening, including the four new AHUs that received Rsif students in 2022: Haramaya University, Ethiopia; Makerere University, Uganda; University of Abomey-Calavi, Benin and Institut International d'Ingénierie de l'Eau et de l'Environnement (2iE), Burkina Faso.

Seven Rsif scholars graduated, and an Rsif alumni association was founded in June 2022 by the first group of Rsif scholars to graduate from PhD program. Five of the seven graduates were selected to receive the Junior Investigator Research Awards in 2022.

Enrolled students progressing well (37% women): Cohort 1 finalizing thesis and graduating (7 of 15 by end 2022, including one woman); cohort 2 starting international research placements (56 matched of which 23 female (41%)); Cohort 3 at AHUs collecting data in the field; and Cohort 4 reporting to AHUs, in first year of study. More than 80% of Rsif scholars are satisfied with the quality of the learning environment and delivery of the target doctoral program at AHUs.

Rsif PhD students' publications in peer reviewed journals reached 100**.** The publications can eb accessed from the Rsif digital repository: https://www.rsif-paset.org/resources/.

The Pan-African Rsif 2022 conference was held in a hybrid format in Morocco on the theme: *African-led Science, Technology and Innovation for Contributing to the SDGs and Stimulating Global Development.* More than 50 speakers on various topics including digital innovation, Africa's STI capacity, universities and industry collaboration, and green growth for sustainable development. *(See communique and session recordings.)* A total of 102 participants attended in person at University Mohammed 6 Polytechnique (UM6P) in Morocco and 1,082 attended virtually.

Partnerships were formed with advanced international institutions and private sector partners including Nestlé, South Africa; IBM Research Africa and the Samsung Dream Scholarship Foundation. As of end 2022, MoUs had been signed with 23 International Partner Institutions (IPIs) for collaboration on Rsif. The IPIs provide a a sandwich opportunity for Rsif PhD scholars. Over 120 Rsif scholars were matched to undertake their sandwich program in these partner institutions. 12 of the 23 IPIs fully signed tripartite agreements with one or more AHUs for placement of scholars.

SECTION 4: LIST OF JOURNAL ARTICLES (PEER REVIEWED); BOOKS; PROCEEDINGS AND NON-REFEREED PUBLICATIONS (JANUARY – DECEMBER 2022)

Annex 1 – List of Publications (Journal Articles – Peer Reviewed)

2022 (263)

1. *Abiya*, A. A., *Kupesa*, D. M., *Beesigamukama*, D., *Kassie*, M., Mureithi, D., Thairu, D., Wesonga, J., *Tanga*, C. M., & *Niassy*, S. (2022). Agronomic performance of kale (*brassica oleracea*) and swiss chard (*Beta vulgaris*) grown on soil amended with black soldier fly frass fertilizer under Wonder Multistorey Gardening System. *Agronomy*, *12*(9), 2211. https://doi.org/10.3390/agronomy12092211
2. *Abrha*, H., & Hagos, H. (2022). Characterization of changing trends of baseline and future predicted precipitation and temperature of Tigray, Ethiopia. *Journal of Agrometeorology*, *24*(3), 235–240. https://doi.org/10.54386/jam.v24i3.1709
3. *Abro*, Z., Kassie, M., Tiku, H. A., *Taye*, B., Ayele, Z. A., & *Ayalew*, W. (2022). The impact of beekeeping on household income: Evidence from north-western Ethiopia. *Heliyon*, e09492. https://doi.org/10.1016/j.heliyon.2022.e09492
4. *Abro*, Z., Macharia, I., *Mulungu*, K., *Subramanian*, S., *Tanga*, C. M., & *Kassie*, M. (2022). The potential economic benefits of insect-based feed in Uganda. *Frontiers in Insect Science,* 2:968042. https://doi.org/10.3389/FINSC.2022.968042
5. *Addo*, J. K., Owusu-Ansah, E., Dayie, N. T. K. D., *Cheseto*, X., & *Torto*, B. (2022). Synthesis of 1,2,3-triazole-thymol derivatives as potential antimicrobial agents. *Heliyon*, *8*(10), e10836. https://doi.org/10.1016/j.heliyon.2022.e10836
6. Adesanya, A. W., Gomez, M. I., Morrell, K., *Midega*, C., *Khan*, Z., Kessler, A., & Poveda, K. (2022). Plant growth and defense traits in sorghum bicolor's response to *Chilo partellus* in the tropics. *Journal of Pest Science*, *95*, 1357–1369. https://doi.org/10.1007/S10340-021-01472-2
7. Afolayan, D. O., *Komadja*, G. C., & Onwualu, A. P. (2022). Physico-chemical studies and mineralogical characterisation of clays for ceramic raw materials. *Arabian Journal of Geosciences*, *15*(17), 1–15. https://doi.org/10.1007/s12517-022-10716-z
8. *Agbessenou*, A., *Akutse*, K. S., Yusuf, A. A., & *Khamis*, F. M. (2022). The endophyte *Trichoderma asperellum* M2RT4 induces the systemic release of methyl salicylate and (Z)-jasmone in tomato plant affecting host location and herbivory of *Tuta absoluta*. *Frontiers in Plant Science*, 13:860309 https://doi.org/10.3389/fpls.2022.860309
9. *Agboka*, K. M., *Tonnang*, H. E. Z., *Abdel-Rahman*, E. M., *Kimathi*, E., Mutanga, O., Odindi, J., *Niassy*, S., *Mohamed*, S. A., & *Ekesi*, S. (2022). A systematic methodological approach to estimate the impacts of a classical biological control agent's dispersal at landscape: Application to fruit fly *Bactrocera dorsalis* and its endoparasitoid *Fopius arisanus*. *Biological Control*, *175*, 105053. https://doi.org/10.1016/j.biocontrol.2022.105053
10. *Agboka*, K. M., *Tonnang*, H. E. Z., *Abdel-Rahman*, E. M., Odindi, J., Mutanga, O., & *Mohamed*, S. A. (2022). A fuzzy-based model to predict the spatio-temporal performance of the *Dolichogenidea gelechiidivoris* natural enemy against *Tuta absoluta* under climate vhange. *Biology*, *11*(9), 1280. https://doi.org/10.3390/biology11091280
11. *Agboka*, K. M., *Tonnang*, H. E. Z., *Abdel-Rahman*, E. M., Odindi, J., Mutanga, O., & *Niassy*, S. (2022). Data-Driven Artificial Intelligence (AI) Algorithms for Modelling Potential Maize Yield under Maize–Legume Farming Systems in East Africa. *Agronomy*, *12*(12), 3085. https://doi.org/10.3390/agronomy12123085
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Annex 2 – List of Books/Book chapters/proceedings

2022 (16)

1. Ayarza, M., *Rao*, I., Vilela, L., Lascano, C., & Vera-Infanzón, R. (2022). Soil carbon accumulation in crop-livestock systems in acid soil savannas of South America: A review. *Advances in Agronomy*, 173, 163–226. https://doi.org/https://doi.org/10.1016/bs.agron.2022.02.003
2. *Beesigamukama*, D., Gómez-Brandón, M., & *Tanga*, C. M. (2022). Potential of entomocomposting toward soil pathogen suppression. In: Fate of Biological Contaminants During Recycling of Organic Wastes (1st Ed). Elsevier (Amsterdam, Netherlands). 47-70. https://www.elsevier.com/books/fate-of-biological-contaminants-during-recycling-of-organic-wastes/huang/978-0-323-95998-8
3. *Copeland*, R. S., Mekonnen, B., & Delvare, G. (2022). Parasitisation of Weaver Ants by a Species of *Smicromorpha* Girault (Hymenoptera: Chalcididae: Smicromorphinae) and Unequivocal Evidence of Its Presence in the Afrotropical Region. *Proceedings of the Entomological Society of Washington*, *124*(1), 13–17. https://doi.org/10.4289/0013-8797.124.1.13
4. Dary, S. K., Issahaku, H., & *Abu*, B. M. (2022). Trade credit financing and firm growth: a panel study of listed firms in Africa. In *The Palgrave Handbook of Africa's Economic Sectors* (pp. 551–576). Springer International Publishing. https://doi.org/10.1007/978-3-030-75556-0_21
5. *Egonyu*, J.P., Wanjala, M.N., Olubowa, R.R., Orinda, M., Nyongesah, J.M., *Tanga*, C.M., *Cheseto*, X., *Kassie,* M., & *Subramanian,* S. (2022). Beetle grubs as a source of food and feed in western Kenya: cultural practices and nutritional status. Oral presentation at the Insects to Feed the World 2022; June 12 – 16, 2022; Journal of Insects as Food and Feed 8 Supplement 1, S112. https://doi.org/10.3920/JIFF2022.S1
6. Elson, L., Feldmeier, H., & *Fillinger*, U. (2022). Tungiasis. In *Promoting global community skin health through education* (pp. 18-23). *Community Skin Health,* 8(2) https://tinyurl.com/2zc9jb23
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8. *Maginga*, T., Nsenga, J., Bakunzibake, P., & Masabo, E. (2022). Smallholder farmer-centric integration of IoT and chatbot for early Maize diseases detection and management in pre-visual symptoms phase. *IEEE, 2022 IEEE Global Humanitarian Technology Conference (GHTC),* 369–372. https://doi.org/10.1109/ghtc55712.2022.9911047

9. Margenot, A. J. & *Rao*, I. M. (2022). Nutrient deficiencies. In: Y. Dang, N. Menzies and R. Dalal (eds.). Soil constraints to crop production. Cambridge Scholars Publishing, UK, pp. 196-217. https://www.cambridgescholars.com/product/978-1-5275-8706-9
10. Muhanguzi, D., Ndekezi, C., Nkamwesiga, J., *Kalayou*, S., Ochwo, S., Vuyani, M., & Kimuda, M.P. (2022). Anti-Tick vaccines: Current advances and future prospects. *Methods in Molecular Biology*, *2411*, 253–267. https://doi.org/10.1007/978-1-0716-1888-2_15
11. *Palm*, S. F., Waita, S., Nyangonda, T., & Chebak, A. (2022). Performance study of a grid connected solar PV system in Zagtouli, Burkina Faso. *2022 IEEE PES/IAS PowerAfrica*, 1–5. https://doi.org/10.1109/PowerAfrica53997.2022.9905290
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14. Steck, G. J., *Ndlela*, S., Somma, L. A., Diaz, J., Moore, M. R., & Awad, J. (2022). Description of the Immature Stages of *Dacus bivittatus* (Diptera: Tephritidae), the Greater Pumpkin Fruit Fly. *Proceedings of the Entomological Society of Washington*, *124*(3), 661–682. https://doi.org/10.4289/0013-8797.124.3.661
15. *Tchouassi*, D. P., *Wanjiku*, C., & *Torto*, B. (2022). Chapter 33: Host-derived attractants for surveillance and control of mosquitoes. In *Sensory ecology of disease vectors* (pp. 851–877). Wageningen Academic Publishers. https://doi.org/10.3920/978-90-8686-932-9_33
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Annex 3 – List of Non-refereed Publications

2022 (75)

A. Conference paper presentations (12)

1. *Andrew Abiya* (Kenya, DRIP MSc) gave an oral presentation titled: "Productivity of Kale *Brassica oleracea* L. and Spinach *Spinacia oleracea* L. under BSFF Fertilizers in the Wonder Multi-Storey Garden Technology" at the UU-A Student Summit 2022 held on 8-10 March 2022
2. *Ayaovi Agbessenou* (Togo, DRIP PhD) gave an oral presentation titled: "*Trichoderma asperellum* M2RT4 endophytically-vaccinated tomato plant induces the systemic release of methyl salicylate and (*Z*)-jasmone affecting host location and herbivory of *Tuta absoluta"* at the International Congress on Invertebrate Pathology and Microbial Control and the 54th Annual Meeting of the Society for Invertebrate Pathology held in Nelson Mandela Bay, South Africa (Virtual meeting) on the 1 - 4 August 2022
3. *Bashiru Adams* (Ghana, ARPPIS PhD) gave an oral presentation during the 36th annual joint meeting of the International Society of Chemical Ecology (ISCE) and the Asia-Pacific Association of Chemical Ecologists (APACE) at the EQ Kuala Lumpur Hotel, Malaysia from 8th – 12th August 2022
4. *Emmanuel Anedo* (Nigeria, ARPPIS PhD) oral presentation on Chitin-fortified black soldier fly frass fertilizer suppresses potato cyst nematodes and improves potato yield under greenhouse conditions at the 19th International Triennial Symposium of the International Society for Tropical Root Crops (ISTRC) at the Safari Park, Hotel, Nairobi, Kenya. 21-25 December 2022.
5. *Fairo Dzekashu* (Cameroon, ARPPIS PhD) gave an oral presentation titled: "Impact of global change on plant-bee interaction networks on two mountain slopes in Kenya" at the International Union for the Study of Social Insects (IUSSI) conference, San Diego, USA, July 3-7, 2022 (Virtual),
6. *Fairo Dzekashu* (Cameroon, ARPPIS PhD) gave an oral presentation titled: "Seasonality in bee diversity under climate change in East African mountains" at the Sustainable living, working and doing research (creating change) workshop, University of Wurzburg, Germany, July 1-7, 2022.
7. *Kochelani Saili* (Zambia, ARPPIS PhD) oral presentation on (1) *Anopheles rufipes* implicated in both indoor and outdoor malaria transmission alongside *Anopheles funestus* and *Anopheles arabiensis* in rural south-east Zambia and (2) House screening reduces exposure of indoor biting and resting malaria vectors-evidence from rural

south-east Zambia at the 1st National symposium for Entomological Society of Zambia, hosted by the University of Zambia, School of Veterinary Science. 22nd December 2022.

8. *Lawrence Ouma* (Kenya, DRIP MSc) oral presentation on "Incidence, severity and management of soil-dwelling insect pests of key horticultural crops in Kenya" at the 22nd workshop of the Horticultural Association of Kenya (HAK) at Jomo Kenyatta University of Agriculture and Technology (JKUAT), Nairobi Kenya (28 November – 2 December 2022).
9. *Mutyambai D.M.*, *Khan Z.R.* and *Subramanian S.* (2021) Soil conditioning by novel maize cropping system induces plant volatiles attractive to parasitic wasps. 2nd International Congress of Biological Control-Symposium: Semiochemistry applied to biological control: using the language of natural enemies, Virtual Conference held on 26–30th April 2021.
10. *Rehema Gwokyalya* (Uganda, ARPPIS PhD) oral presentation on Friend or foe: Symbiotic bacteria in *Bactrocera dorsalis*-parasitoid associations. Presented at 11th Symposium on Fruit flies of Economic Importance, 13 – 18 November 2022, Sydney, Australia.
11. *Sahadatou Mama Sambo* (Benin, ARPPIS PhD) gave an oral presentation on the topic "Interactions between the entomopathogenic fungus *Metarhizium anisopliae* ICIPE 20 and the endoparasitoid *Dolichogenidea gelechiidivoris*, and implications for combined biocontrol of *Tuta absoluta*" at the International Congress on Invertebrate Pathology and Microbial Control and the 54th Annual Meeting of the Society for Invertebrate Pathology held in Nelson Mandela Bay, South Africa (Virtual meeting) on the 1 - 4 August 2022.
12. *Sahadatou Mama Sambo* (Benin, ARPPIS PhD) gave an oral presentation on the topic "Promising native parasitoids of *Tuta absoluta* in Kenya and their interaction with the introduced *Dolichogenidea gelechiidivoris"* at the 24th meeting of African Association of Insect Science, Addis Ababa, Ethiopia, 21-25 March 2022.

B. Videos (43)

1. *icipe* discovers trypanosome biomarkers: https://youtu.be/0SxwnRLZwyc
2. Sida boosts *icipe*'s Centre of Excellence in insect science, with new, high-tech scientific equipment: https://youtu.be/APb_fT1xN_o
3. **የነብሳት ውለታ** (**ክፍል**-1): https://youtu.be/zAUBJIc9KF0
4. **የነብሳት ውለታ** (**ክፍል**-2): https://youtu.be/3ZJhQfrzs5g
5. AFRO II Project Documentary, *icipe* -J ul 8, 2022: https://youtu.be/GSFpi1hVNcA
6. Bioinformatics in Africa and *icipe's* leading role -Jul 6, 2022: https://youtu.be/C5cYCgR4pgU
7. Successful use of parasitoids in the management of fall armyworm in Embu County, Eastern Kenya Jul 5, 2022: https://youtu.be/5NrEnxI37KQ
8. Mechanisms through which the *icipe* push-pull technology conquers the fall armyworm Jun 23, 2022: https://youtu.be/O5N-h7eTFR4
9. *icipe* Annual Report 2021-May 10, 2022: https://youtu.be/mRcOLhGGStA
10. African Fruit Fly Programme – 20 years - Apr 8, 2022: https://youtu.be/9Xmo4SPRrBA
11. Rwanda National Standards launch Mar 17, 2022: https://youtu.be/naX9Nm7yLgU
12. Banana waste, potato's gain Mar 1, 2022: https://youtu.be/ZEti_nJ80fs
13. Introduction to biopesticides-Feb 8, 2022: https://youtu.be/eMTEWyRQ6DU
14. Episode 2: Waste sourcing Feb 8, 2022: https://youtu.be/ZlatLtQ8_Sw
15. Episode 4: Feeding and rearing black soldier fly larvae-Feb 8, 2022: https://youtu.be/M8vcd0fBMoU
16. Episode 5: Harvesting and processing larvae-Feb 8, 2022: https://youtu.be/hF7BmAJTJ8U
17. Episode 6: Making frass fertilizer - Feb 9, 2022: https://youtu.be/e5vDOd1B56I
18. Day 3 June 2022 mission Kenya: recap by *ICIPE* and Aria Samimi: https://youtu.be/Ct7J2DHtRZw
19. Developing a PCN Assessment Tool in Kenya nematology department: https://t.co/L3GT0x0hT5
20. AFRO II Malaria Project: Winter-larviciding and House Screening Evaluation in Southern Africa - Feb 25, 2022: https://youtu.be/LnznoiL_1xM
21. About the IESIC 2022: Prof. Zeyaur Khan (*icipe*) Nairobi, Kenya, Apr 9, 2022: https://youtu.be/IILg59hw1ug

Push-Pull

22. https://youtu.be/1M35qsGOFQY
23. https://youtu.be/qbAdkdrO054
24. https://youtu.be/1oc7mGVwZRI
25. https://youtu.be/pgerz0RDT0s

26. https://youtu.be/C8nKp4V3LNk

Rsif Videos

27. RSIF-UM6P Hybrid Pan-African Conference 2022 -Aug 16, 2022: https://youtu.be/BDPniaxoSWo
28. Dr Moses Osiru welcome message to RSIF UM6P Conference 28-29 June, 2022: https://youtu.be/CCWe4HjZsEk
29. A message from Prof. Aminata Sall Diallo, PASET Executive Director. Jun 23, 2022: https://youtu.be/W2OCiP1n4kc
30. RSIF Morocco Policymakers Sep 1, 2022: https://youtu.be/JiO_M7WAaic

Bioinnovate Africa Programme

31. Information Webinar for the *icipe*/BioInnovate Africa Call for Concept Notes, 16 June 2022: https://youtu.be/9UtBYzsACNk
32. BioInnovate Africa Profile: https://youtu.be/IzPQkARmduI
33. *icipe's* vision of science and innovation in Africa: https://youtu.be/HBL3hz2mxjY
34. Development of eastern Africa bioeconomy for a sustainable and resilient future: https://youtu.be/XFr9ry8dLXQ
35. Good governance and science for Africa's development: https://youtu.be/uWSDaLLE-Ik
36. Sida's support to regional collaboration in science and innovation in Eastern Africa: https://youtu.be/g7MKMnq0zWA
37. *icipe's* vision of science and innovation in Africa Mar 18, 2022: https://youtu.be/HBL3hz2mxjY
38. *icipe's* perspective on financial management systems for scientific research and innovation: https://youtu.be/pJp5UVBioFI
39. Session 1: Realising the Vision of an African Bioeconomy: https://youtu.be/WX9hbhR2E2o
40. Speed networking with BioInnovate Africa pilot commercial enterprises - Bioeconomy Conference: https://youtu.be/YZkYLxgwTKk
41. Leapfrogging Africa's development: https://youtu.be/vHqTkF6rDfs
42. Information Webinar for the *icipe*/BioInnovate Africa Call for Concept Notes, 16 June 2022: https://youtu.be/9UtBYzsACNk
43. Innovation in the development context of eastern Africa: BioInnovate Africa full documentary: https://youtu.be/XReBNVWW46E

Keynote address (1)

1. ***Dr. Tadele Tefera*** 21st - 25th March 2022, Addis Ababa University, Addis Ababa, Ethiopia. Adoption and barriers to scaling up of fruit fly IPM technologies in Africa. AAIS Meeting and Scientific Conference "Migratory Pests and Invasive Species: Early Warning System, Monitoring, Control and their Impact on Food Security, Environment and Livelihoods during COVID-19 pandemic.

Briefings (2)

1. *Dr Saliou Niassy* 2 June 2022, Kampala, Uganda About *icipe* – Overview of *icipe* programs and achievements Workshop to introduce *icipe* Uganda Country office and present the *icipe* Uganda program Framework and action planning 2023-2027
2. *Dr Saliou Niassy* 4-5 July 2022, Nairobi, Kenya. Biology and Ecology of African Armyworm, Spodoptera exempta for sustainable Management. FAO Subregional Task Force Meeting for the Reactivation of the Early Warning and Management System for African Armyworm in Eastern Africa.

Posters (17)

1. Elucidating Camel-Tick Chemical Communication in the Fight against Camel Tick-borne Diseases *JohnMark O. Makwatta1*,2 , Paul N. Ndegwa2, Florence A. Oyieke2, Daniel K. Masiga1, Merid N. Getahun1 1International Centre of Insect Physiology and Ecology (*icipe*), Kenya 2Department of Biology, Faculty of Science and Technology, University of Nairobi (UoN), Kenya jmakwatta@*icipe*.org
2. Gut Microbial shift in Broiler and layer Chicken Fed Black Soldier Fly Larvae-Based Meal as a Dietary Protein Source *Evalyne W. Ndotono* 1,2, Fathiya M. Khamis 1, Joel L. Bargul 1,2 and Chrysantus M. Tanga 1 1International Centre of Insect Physiology and Ecology (*icipe*), Nairobi, Kenya; 2Department of Biochemistry, Jomo Kenyatta University of Agriculture and Technology (JKUAT) * endotono@*icipe*.org

3. Non-host plant odours influence the tritrophic interaction between tomato, its foliar herbivore Tuta absoluta and the mirid predator, Nesidiocoris tenuis *Bashiru Adams1*,2 , Abdullahi A. Yusuf2 , Baldwyn Torto1,2 , Fathiya Khamis1 1International Centre of Insect Physiology and Ecology; P.O. Box 30772-00100 Nairobi, Kenya 2Department of Zoology and Entomology, University of Pretoria, Pretoria, South Africa badams@*icipe*.org
4. Outdoor malaria vector species profile in dryland ecosystem of Kenya Fiona Kinya1,2*,, Clifford Mutero*1, Edwin Ogola1, Gilbert Rotich1, Eunice A. Owino2, Charles Wondji 3, Baldwyn Torto1 and David P. Tchouassi1 1International Centre of Insect Physiology and Ecology, Nairobi, Kenya 2University of Nairobi, Nairobi, Kenya 3Department of Vector Biology, Liverpool School of Tropical Medicine, Liverpool, UK Corresponding author: fkinya@*icipe*.org
5. Artificial Intelligence (AI) algorithms for modelling attainable maize yield under maize-legume farming systems in East Africa *Komi Mensah Agboka1*,2* , Henri E. Z. Tonnang1 , Elfatih M. Abdel-Rahman1, John Odindi2 , Onisimo Mutanga2 , Saliou Niassy1 1International Centre of Insect Physiology and Ecology (*icipe*), Nairobi, Kenya; 2 University of KwaZulu-Natal, School of Agricultural, Earth, and Environmental Sciences, Pietermaritzburg 3209, South Africa *kagboka@*icipe*.org, dilaneagboka@gmail.com
6. Investigating symbiont-based immunity in anopheles mosquitoes against plasmodium falciparum infection Jacqueline Wahura Waweru1,2, Lilian Mbaisi3, Thomas Onchuru1, Edward Edmond Makhulu1,2, Rehemah Gwokyalya1, Joseph Gichuhi1, Anne W. Wairimu, Lizette Koekemoer2, Daniel Masiga1, Jeremy Herren1 1International Centre of Insect Physiology and Ecology 2University of the Witwatersrand, Johannesburg 3Rhodes University *Correspondence to: jwahura@*icipe*.org and jherren@*icipe*.org
7. Metatranscriptomics-aided Identification of Lignocellulolytic Bacteria and CAZymes from the Gut Microbiome of Black Soldier Fly Larvae Eric G. Kariuki1,2*, Caleb Kibet1, Juan C. Paredes2, Gerald Mboowa2, Daniel Masiga2, Timothy D.H. Bugg3, Chrysantus Tanga2* ctanga@*icipe*.org
8. Hot Water Treatment for Postharvest Disinfestation of Bactrocera dorsalis (Diptera: Tephritidae) and Its Effect on cv. Tommy Atkins Mango. *Mwando*, N. LShepard Ndlela, Rainer Meyhöfer, Sevgan Subramanian1 and Samira A. Mohamed
9. Unto the good lands: Microsporidia MB tissue tropism and distribution *Edward Makhulu1*, Thomas Onchuru, Anne Wairimu1, Joseph Muthoni1, Joseph Gichuhi1, Fidel Gabriel Otieno1 , Lizette Koekemoer, Jeremy Herren.
10. Combating the tomato pest Tuta absoluta using an assembly of native and exotic parasitoids Sahadatou *Mama Sambo1*,2, Shepard Ndlela1, Hannalene du Plessis2, Esther Owino1, Abdelmutalab G. A. Azrag1 , Samira A. Mohamed 1International Centre of Insect Physiology and Ecology (*icipe*), Nairobi P.O. Box 30772-00100, Kenya; 2Unit for Environmental Sciences and Management, North-West University, Potchefstroom, South Africa. smama@*icipe*.org
11. Molecular identification of tick-borne pathogens in camel blood and tick tissues *Rua Khogali* 1 , Armanda Bastos 2 , Caleb Kibet 1 , Dennis Getange 1 , James Kabii1 , David Wainaina 1 , Daniel Masiga 1 ,Jandouwe Villinger International Centre of Insect Physiology and Ecology (*icipe*), 2Department of Zoology and Entomology, University of Pretoria rkhogali@*icipe*.org
12. Investigating the role of insect-specific flaviviruses (ISFVs) in arbovirus transmission blocking in mosquitoes *Joseph Muthoni*, Dickens Ondifu, Jandouwe Villinger International Center of Insect Physiology and Ecology (*icipe*), Nairobi, Kenya
13. *Noel Gahamanyi* [1,2,*], Leonard E. G. Mboera [2], Mecky I. Matee [3], Dieudonné Mutangana [4], Raghavendra G. Amachawadi [5], Cheol-Ho Pan [1], Erick V. G. Komba [2] Email: gahanoel1984@gmail.com Molecular epidemiology and antimicrobial susceptibility profiles of thermophilic *Campylobacter* species from humans and animal feces in South Korea and Tanzania
14. *Nana okyir Baidoo* (PhD Candidate, University of Ghana) nanaob3gh@gmail.com Economic Profitability and Livelihood Diversification Among Cocoa Farmers in Ghana
15. *Jeanne Pauline Munganyinka* African University of Science and Technology, Abuja,
16. Nigeria Worcester Polytechnique Institute, Ma, USA * jmunganyinka@aust.edu.ng Geometallurgical studies of selected gold ores with the application of environmentally friendly lixiviants
17. *E. Effah, O. Thiare* and a. wyglinsky eeffah@umat.edu.gh, alexw@wpi.edu and ousmane.thiare@ugb.edu.sn robust and affordable smart agri-iot technology

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