2020 *icipe* CORE ANNUAL REPORT

PROGRAMMATIC REPORTING BASED ON RESULTS BASED MANAGEMENT (RBM) WITH THE AID OF THE LOGICAL FRAMEWORK APPROACH (LFA)

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International Centre of Insect Physiology and Ecology
P.O. Box 30772-00100 Nairobi, Kenya
Phone: +254 (20) 8632000 | Fax: +254 (20) 8632001/2
Email: icipe@icipe.org | Website: www.icipe.org

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Cover photo: *Aspavia* sp. belongs to the family Pentatomidae, and they are occasional pests of grasses and rice.

List of Acronyms

ACGD	African Citrus Greening Disease
ACP	The Organisation of African, Caribbean and Pacific States
ACT	African Citrus Triozid
AIRCA	Association of International Research and Development Centres for Agriculture
ARPPIS	African Regional Postgraduate Programme in Insect Science
ASET	Applied Sciences Engineering and Technology
BMZ	German Federal Ministry of Economic Cooperation and Development
BSF	Black soldier fly
BSFLM	Black soldier fly larvae meal
CABI	Centre for Agriculture and Bioscience International
CBID	Capacity Building and Institutional Development
CCHF	Crimean-Congo haemorrhagic fever
COVID-19	Coronavirus disease 2019
DAAD	German Academic Exchange Service
DRIP	Dissertation Research Internship Programme
EASTECO	East African Science and Technology Commission
EU	The European Union
FAW	Fall armyworm (*Spodoptera frugiperda*)
FiBL	Research Institute of Organic Agriculture
GBS	Global Bioeconomy Summit
GDP	Gross Domestic Product
GFFA	Global Forum for Food and Agriculture
IITA	International Institute of Tropical Agriculture
INSEFF	Insects for Food, Feed and other uses
IP	Intellectual Property
IPM	Integrated Pest Management
IRC	Information Resources Centre
KEBS	Kenya Bureau of Standards
KLISC	Kenya Libraries and Information Services Consortium
MoU	Memorandum of Understanding
MOYESH	MOre Young Entrepreneurs in Silk and Honey Programme
OIE	World Organisation for Animal Health
PASET	Partnership for skills in Applied Sciences, Engineering and Technology
RBM	Results Based Management
R4D	Research for Development
RSIF	Africa Regional Scholarship and Innovation Fund for Applied Sciences, Engineering and Technology
SDC	Swiss Agency for Development and Cooperation
SFS	Sustainable Food Systems
Sida	Swedish International Development Cooperation Agency
SMEs	Small and Medium-sized Enterprises
SNNP	Southern Nations, Nationalities, and Peoples' Region
SSA	sub-Saharan Africa
SysCom	Long-term Farming Systems Comparison in the Tropics Programme
TBP	Tick-Borne Pathogens
TEA	Techno-Economic Analysis
TWAS	The World Academy of Sciences
VOCs	Volatile Organic Compounds
WTP	Willingness To Pay
YESH	Young Entrepreneurs in Silk and Honey

EXECUTIVE SUMMARY

icipe 2020 Results Based Management Report

This 2020 Results Based Management (RBM) Report successfully demonstrates that *icipe* continues to play a crucial and strategic role in tackling key research for development (R4D) challenges across a wide range of thematic areas in human, animal, plant and environmental health across Africa while simultaneously transferring skills and knowledge to rural communities, especially women and youth to improve their livelihoods.

icipe has entered its second 50 years of service as Africa's principal insect and related arthropod research institute (Insects for Life – A brief history of *icipe*@50 - http://www.icipe.org/publications/annual-reports). The Center has developed and launched (https://www.youtube.com/watch?v=LUBwexO5s6E) its new Vision and Strategy (V&S) document for the period of 2021 to 2025 (http://www.icipe.org/publications/corporate-publications/vision-and-strategy). The year 2020 was marked with the global emergence and spread of the coronavirus disease (COVID-19). The *icipe* family, alongside the rest of the world, continues to respond to the emerging reality of the pandemic with stringent public health guidelines. The Centre recognises the evolving nature of this threat, and its likely impact across every sphere of society. Despite the challenges, the Centre has continued with its activities albeit in an adapted manner to respond to various requirements to protect the health and safety of staff. In spite of the state of affairs during this reporting period, *icipe* has achieved significant progress across all its interlinking R4D activities (discovery; proof-of-concept; piloting; scaling) aimed at developing and disseminating technologies and strategies to control crop pests and disease vectors while contributing to various national policies. The Centre's activities have also expanded across special programmes, capacity building, socio-economics, gender, monitoring and evaluation (M&E), resource mobilisation and communication.

A major highlight was *icipe's* colourful golden jubilee celebration with the enduring theme "**Insects for Life**" which included speeches from Kenya's President Uhuru Kenyatta, Cabinet Secretaries for Agriculture and Foreign Affairs; uplifting video messages from donors and stakeholders; and the presentation of the *icipe*@50 Achievement Awards. The Centre was globally recognised with the shared US$ 1 million Curt Bergfors Foundation Food Planet Prize for the achievements of the Insects for Food, Feed and other uses (INSEFF) platform https://foodplanetprize.org/entry/prizewinner-icipe-inseff/. This is the highest accolade in the Centre's history.

Some R4D highlights from Centre's accomplishments include: (i) *Plant Health*: discovery of breeding sites for the desert locust, development of biopesticides to control *Spodoptera frugiperda*, fall armyworm (FAW), discovery of smart maize varieties with resistance to stemborer, mass release of natural enemies to control the highly destructive *Tuta absoluta* (a tomato leafminer), and FAW as part of innovative approaches for managing invasive species; (ii) *Animal Health:* discovery of tsetse odour repellency, tick and tickborne disease incidence at the human-livestock and wildlife interface, and demonstration of stable flies improving offspring fitness; (iii) *Human Health*: a major discovery illustrating that a microsporidian - a tiny parasitic fungus - called *Microsporidia MB* can block the transmission of malaria - *Plasmodium falciparum* - to the mosquito, and development of strategies for managing snail vectors of schistosomiasis (Bilharzia disease); and (iv) *Environmental Health:* assessment of the phytochemical composition of African honeybees' royal jelly, discovery of two insects for oil production, assessment of socio-economic and environmental implications of replacing conventional poultry feed with insect-based feed; and recruitment of partner youth in MOre Young Entrepreneurs in Silk and Honey (MOYESH) programme in Ethiopia.

The Centre's BioInnovate Africa Programme (BAP) and the Africa Regional Scholarship and Innovation Fund for Applied Sciences, Engineering and Technology (RSIF) have sustained commitment to capacity building, with BAP being the largest and most active regional innovation-driven sustainable bioeconomy platform in Africa, whereas RSIF fills gaps in knowledge that are critical for African growth and development by increasing the number of PhD and post-doctoral opportunities in Applied Sciences Engineering and Technology (ASET). *icipe*'s longstanding capacity building programmes trained a total of 76 PhD and 100 MSc scholars; 8 postdoctoral fellows; and 41 research interns representing 20 African nations. Women represent 45% of postgraduate scholars. *icipe* also managed 12 BioInnovate Fellows and 82 RSIF PhD scholars from 18 countries in Africa. *icipe's* contribution and recognition within the scientific community is evident, with 153 peer reviewed journal articles published during 2020.

SECTION 1: INTRODUCTION

icipe Centre-wide Themes/Programmes and brief on its Results Based Management (RBM) Framework

Established in 1970, *icipe* (www.icipe.org) is a Centre of Excellence for research, development and capacity building in insect science and its application. *icipe* is proud to present its **new Vision and Strategy (V&S) for 2021-2025** http://www.icipe.org/publications/corporate-publications/vision-and-strategy. It was developed in response to the growing demand for improved health, food security and environmental sustainability by the people of Africa setting out concrete R4D and capacity building agenda to simultaneously advance economic growth and livelihood through partnerships with diverse stakeholders. It describes how the Centre will explore opportunities for new enterprises that are based on insects and their products, and advance discoveries that enable safer and more sustainable solutions to control pests and diseases using new and emerging science disciplines that *icipe* has at hand. The Vision and Strategy is also shaped by the expansion of *icipe's* long commitment to building Africa's research capability and to taking its research findings to users for achieving its impact.

The Centre has also rolled out its **new Results Based Management (RBM) 2021 – 2025 Framework** http://www.icipe.org/publications/corporate-publications/results-based-management. The RBM 2021–2025 framework is based on the Centre's new Vision and Strategy 2021–2025 which builds on the Centre's achievements and experiences and incorporates the recommendations of the *icipe* Periodic External Review (IPER) held in 2018. It provides guidance to programmes and is intended to help establish organisation-wide standards on four main pillars: (1) Defining strategic goals which provide a focus for action; (2) Specifying expected project results which contribute to these goals and align programmes, processes and resources behind them; (3) On-going monitoring and assessment of progress and integrating lessons learned into future planning; and (4) Improving accountability and continuous feedback on progress. This *icipe* RBM 2021 - 2025 aligns with various government priorities as well as global and regional policy initiatives (such as the 2030 Sustainable Development Goals (SDGs) and the Science, Technology and Innovation Strategy for Africa (STISA–2024) and in doing so, enables the Centre to contribute to the improvement of lives on the continent and around the world.

icipe's R4D strategy is defined by the following three key elements:

(a) a focus on research domains in which insects and related arthropods have critical roles as disease vectors, pests or are the basis for beneficial uses such as for food, feed and ecosystem services and value-added products e.g. silk and honey;
(b) innovation that can be applied to develop sustainable and safe alternatives to reliance on agri-chemicals; and
(c) highly valued R4D Capacity Building and Institutional Development (CBID).

icipe has enacted this mission through its highly skilled and diverse research, capacity building and support teams that are currently located in three countries (Kenya, Ethiopia and Uganda). *icipe* continues to operate through an organisational design that incorporates four research themes – Plant Health, Animal Health, Human Health, and Environment Health - (4-H), and an array of partnerships with African and non-African universities and research organisations, NGOs and the private sector that encompass a majority of Africa's 55 member states. *icipe* is also managing two important Special Programmes – (i) the BioInnovate Africa Programme, a regional science and innovation-driven programme that aims to convert bio-based research ideas, technologies and inventions to business; 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

With the impetus of the new V&S as well as RBM, *icipe* will continue its service as Africa's principal insect and arthropod research institute through the following 4-H themes and special programmes.

Plant Health Theme: Contribute to stabilising horticultural and staple food production by reducing quantitative and qualitative pre- and post-harvest yield losses due to insect pests, mites, weeds and mycotoxin-producing fungi by developing economically viable and ecologically sound production systems with low pesticide input.

Animal Health Theme: Contribute to the improvement of livestock health and productivity through the development of integrated strategies and tools for livestock disease vectors' control and adoption by development partners, thus leading to greater availability of meat and milk, hides and draught power and thereby assisting livestock owners to get out of the poverty trap.

Human Health Theme: Contribute to the reduction of malaria and other vector-borne diseases by developing tools and strategies that control the vectors and break the cycle of transmission and integrate these with efforts to manage other diseases.

Environmental Health Theme: Conservation and sustainable utilisation of the agricultural production base and important natural ecosystems, by encouraging and utilising arthropod diversity, cataloguing and sharing biodiversity data, and discovering endemic wealth by bioprospecting for useful natural products.

Capacity Building and Institutional Development (CBID) Programme: Develop well-trained and highly motivated human capacity and strengthen institutional and policy making capacity and capability required to respond to the arthropod-related development challenges in Africa.

BioInnovate Africa Programme: BioInnovate Africa supported by the Swedish International Development Cooperation Agency (Sida) is a programme that supports scientists and innovators in the region to link biological based research ideas and technologies to business and the market. Current BioInnovate Africa partner countries are Burundi, Ethiopia, Kenya, Rwanda, Tanzania and Uganda.

The Partnership for skills in Applied Sciences, Engineering and Technology (PASET) - Regional Scholarship and Innovation Fund (RSIF) Programme: The RSIF is an Africa-led flagship initiative of PASET. The RSIF aims to address fundamental gaps in skills and knowledge needed for increasing the use of science, technology and innovation for sustained economic growth in sub-Saharan Africa (SSA). RSIF is supporting doctoral training and post-doctoral research and innovation in selected priority sectors for economic growth and development across SSA. The RSIF priority thematic areas are information, communication and technologies (ICTs) including big data and artificial intelligence; food security and agribusiness; climate change; energy including renewables; and minerals, mining and materials engineering.

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 *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.

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[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

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

icipe continues to be a thriving hub for advances in basic and applied research in tandem with steady progress in dissemination and uptake of its products and technologies. Highlights of major advances in R&D during 2020 are provided below.

2.1 PLANT HEALTH THEME

2.1.1 Discovery of breeding sites for desert locust

The desert locust is a notorious migrant pest that causes huge economic loss to food crops. The current magnitude of invasion in East Africa is unprecedented and has not been witnessed for more than 25 years. One of the recommended proactive management strategies employed by countries affected is a continuous scheme of monitoring and controlling the pest in their breeding areas. There is a need to urgently identify potential oviposition and breeding sites for the desert locust in the region to guide decision making by regional governments to initiate effective and timely control measures. Using key bio-climatic (temperature and rainfall) and edaphic (soil texture and moisture) factors, we have developed a model that effectively predicts breeding ground for desert locust among vast areas that are at high risk of providing a conducive breeding environment in Kenya, Sudan, northeastern regions of Uganda, and southeastern and northern regions of South Sudan. Preventative control operations must strengthen ground surveillance in these predicted high-risk regions and undertake timely and effective management actions at reduced financial cost.
(Publication link: https://www.nature.com/articles/s41598-020-68895-2).

2.1.2 Biopesticides for fall armyworm control

Maize is a staple crop for over 300 million people in sub-Saharan Africa (SSA) and it is cultivated on over 25 million ha. To reduce hunger and poverty in SSA, self-sufficiency in maize is essential. The pursuit to this continental self-sufficiency is constantly threatened by pre-harvest biotic constraints such as stemborers, parasitic weeds (*e.g. Striga*) and diseases that inflict 15 – 90% losses. Implementation of integrated pest management (IPM) strategies to overcome these biotic constraints has contributed to enhanced maize production. However, the recent invasion of fall armyworm (FAW) in Africa has seriously threatened maize production and food security in Africa. Though the pest has a wide range of hosts of over 80 plant species, it prefers to feed on cereal crops, especially maize and sorghum causing yield losses of up to 70%. The pest is also notorious for developing resistance to all classes of chemical pesticides. We evaluated the potency of 20 isolates of insect killing fungi from *icipe* repository of microbials and discovered highly potent isolates including isolates that already commercialized such as ICIPE 78 (Mazao Achieve ®) and ICIPE 7 (Mazao Tickoff®). Our private sector partners are currently extending labels and fast-tracking registration of these products across East Africa.
(Publication link: https://onlinelibrary.wiley.com/doi/full/10.1111/jen.12634).

2.1.3 Smart maize for stemborer control

Plants are rooted to the ground and unable to flee from attack by their enemy. However, over a 400-million-year period, they have evolved highly sophisticated ways of defending themselves from enemies such as insects. The defenses are wide ranging and can include physical barriers including compounds that lend rigidity to bark of the plant, production of antibiotic substances and interacting with natural enemies that work against insect attack. In a recent study, we have discovered that certain "smart" maize varieties can defend themselves against stemborer by summoning natural enemies of the pest. The genetic markers in the maize that are associated with the "call for help" by the maize varieties were unraveled, presenting strong possibilities for developing maize varieties that are resistant to stemborers. (Publication link: https://www.nature.com/articles/s41598-020-68075-2).

2.1.4 A system dynamics model for predicting interactions of pests and natural enemies in maize fields

Stemborers **(***Busseola fusca, Sesamia calamistis* and *Chilo partellus*), the fall armyworm (*Spodoptera frugiperda***)** (FAW) and associated parasitoids constitute an interacting system in maize fields in Kenya. A model was developed to evaluate patterns that represent the evolution of interactions by applying system thinking and system dynamics approaches with its archetypes. The results showed that when a single pest species with its associated parasitoids interact with the host plant, the species was able to establish and sustain their interactions through cyclical relationship between populations of the pest and the associated parasitoids. However, in multi-pest species systems, dominance of *S. frugiperda* and *C. partellus* over *B. fusca* and *S. calamistis* was observed, but without extinction. Nevertheless, there was a likelihood for *B. fusca* being displaced by *C. partellus*. Overall, the present models predict the co-existence of FAW with stemborer species as an additional pest of maize in Africa that need to be considered henceforth in designing IPM strategies to improve maize productivity. (Publication link: https://doi.org/10.1038/s41598-020-79553-y).

2.1.5 Mass releases of parasitoid to control *Tuta absoluta*

In a landmark move to improve tomato production in Africa, *icipe* has initiated the releases of a parasitic wasp that will naturally control the invasive and highly destructive *Tuta absoluta*, a tomato leafminer. This invasive pest was detected for the first time in Africa in 2008 and has since spread rapidly across the continent. The wasp was imported from Peru (the native home of the pest) through joint collaboration with the International Potato Center (CIP), and this is the first time it is being introduced outside of its origin. The initial field releases of the natural enemy were undertaken in Kirinyaga County, Kenya, which is the largest producer of tomatoes in the country. The wasp is expected to spread rapidly, in search of infested plant material. *icipe* and collaborators will continuously monitor its progress, in terms of establishment and suppression of *T. absoluta*, as well as overall improvement of tomato yield. Subsequent releases are planned in other major tomato growing regions of Kenya, Ethiopia and Uganda. (Press release: http://www.icipe.org/news/total-control-tuta-absoluta).

2.1.6 Mass release of indigenous natural enemies to control fall armyworm

Management of the invasive fall armyworm (FAW), scientifically known as *Spodoptera frugiperda* in Africa, requires the deployment of all tactics within the context of integrated pest management (IPM). In the last quarter of 2020 and following a comprehensive assessment of the performance of the native parasitoids, *icipe* jointly with national partners in Kenya has embarked on their mass releases. So far over 140,000 wasps each of *Telenomus remus* and *Trichogramma chilonis* that parasitize FAW eggs; and 5,000 wasps of *Cotesia icipe* that parasitize early larval stages of FAW have been released in five counties (Taita-Taveta, Machakos, Embu, Meru, and Nyeri) of Kenya with very encouraging results. The initial post release field assessments revealed that parasitism rates of FAW in the field increased by 55%, 50% and 38%, for *Trichogramma chilonis, Telenomus remus* and *Cotesia icipe*, respectively. There are further plans for mass releases of these beneficial insects in other major maize growing zones across Kenya. Also, plans are under way with the national partners to expand the releases of these natural enemies to other eastern and southern African countries. (Press release: http://www.icipe.org/news/icipe-launches-mass-release-indigenous-natural-enemies-control-fall-armyworm).

2.2 ANIMAL HEALTH THEME

2.2.1 Discovery of tsetse odour repellency

Blood-feeding insects such as tsetse flies differentially respond to the animal they feed regardless of their abundance. Such behaviour is a response to odours from the animal and can lead to identifying attractants and repellents that can be used for vector control. Previously, *icipe* scientists have developed the waterbuck repellent blend from skin odour of the animal which is repellent to some savannah-adapted tsetse flies and reduces trap catches of riverine species. Building on the earlier ground-breaking findings, we have now identified the cellular and molecular mechanisms that the fly uses to detect and code the odours. Focusing on the sensory neurons and odourant receptors in tsetse antennae, the study reveals the sensors used for the interaction between the fly and the environment – the source of the repulsive odour – and ultimately the decision to avoid it.
(Publication link: https://www.frontiersin.org/articles/10.3389/fncel.2020.00137/full).

2.2.2. Tick and tickborne disease at the human-livestock and wildlife interface

Wildlife ecosystems are known to be hotspots for a range of emerging diseases threatening human and livestock health. The role of questing ticks in the epidemiology of tick-borne diseases in Kenya's Maasai Mara National Reserve (MMNR), an ecosystem with intensified human-wildlife-livestock interactions, remains poorly understood. The diversity of questing ticks, their blood-meal hosts, and tick-borne pathogens was surveyed to understand potential effects on human and livestock health. A diversity of pathogens including the zoonotic *Rickettsia africae* and unclassified *Rickettsia* spp., were

recovered from ticks demonstrating the risk of African tick-bite fever and other spotted-fever group rickettsioses to locals and visitors. Results from this study indicated that the diverse vertebrate blood-meals of questing ticks in this ecosystem including humans, wildlife, and domestic animals may amplify transmission of tick-borne zoonoses and livestock diseases and hence warrant close attention.
(Publication link: https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0228366).

2.2.3 Oviposition decision by stable flies to improve offspring fitness

Oviposition site selection by gravid female insects is an important determinant in species distribution, abundance, and population dynamics. We assessed whether the presence of conspecific or heterospecific larvae and parasites influenced oviposition decisions by the stable fly, *Stomoxys calcitrans* (Linneaus). Using dual and multiple-choice oviposition bioassays, we found that gravid female stable fly avoided substrates with conspecific larvae, the larvae of house flies, and mite. Avoidance of conspecific and heterospecific larvae persisted in the dark, suggesting that this behavior is mediated by chemical rather than visual cues. We demonstrated that individuals of stable fly that developed in the presence of mites exhibited low egg hatchability, and poor larval and adult survival. Based on the results from this study, we recommended that the chemical cues involved in avoidance by gravid female stable fly of substrates with conspecific and heterospecific larvae should be elucidated. This could lead to the discovery of repellent chemicals that are important for managing stable flies.
(Publication link: https://www.frontiersin.org/articles/10.3389/fevo.2020.00005/full).

2.2.4 Shared volatile organic compounds between camel metabolic products elicits strong *Stomoxys calcitrans* attraction

Vectors interact with their livestock blood meal host using odours. However, it is a challenge to get a reliable odour that signifies the host. Using the camel (host)–*Stomoxys calcitrans* (vector) interaction, we collected and analyzed the volatile organic compounds (VOCs) of camels from four of its different odour sources: breath, body (skin), urine, and dung. We followed this effort with odour coding study by stable fly olfactory neurons and behavioural experiment and developed a methodology that facilitates identification of reliable behaviour modifying odours that has potential for application. The key observation of the study is that shared volatiles between metabolic products that activated more olfactory neurons signify 'host' to the stable fly 'nose' and induce significant vector attraction in the absence of camel. We established that VOCs from a range of metabolic products determine host–vector ecological interactions and may provide a more rigorous approach for discovery of unique and more potent attractants. (Publication link: https://doi.org/10.1038/s41598-020-78495-9).

2.2.5 Entomopathogenic fungi *Metarhizium anisopliae* as biopesticide for stable fly control

Entomopathogenic fungi can cause substantial mortality in harmful insects. Before killing the insect, these pathogens start by negatively affecting the biological parameters of the host. This study was aimed to assess the infection of *Stomoxys calcitrans* L. 1758 (Diptera: Muscidae) with *Metarhizium anisopliae* strains, and their impact on feeding, fecundity, fertility and other life-history traits of this fly. Among the 11 *M. anisopliae* strains screened, we identified ICIPE 30 as the most virulent strain against *S. calcitrans*. Using 11 strains of *M. anisopliae* and four high concentrations of ICIPE 30 conidia, we verified that *S. calcitrans* larvae were not susceptible to fungal infection. Although these larvae were tolerant to fungal infection, we showed that there was a significant effect on their fitness, with contaminated larvae having a small bodyweight coupled with longer developmental time as compared to uncontaminated larvae. This study provided detailed information on how fungal infection affects the biology of *S. calcitrans* and the potential of using *M. anisopliae* ICIPE 30 as a biopesticide to reduce the stable fly population.
(Publication link**:** https://doi.org/10.3389/ffunb.2021.637817).

2.2.6 New App for agroanimal health: the LiMA system

LiMA system is a platform meant to act as an agroanimal health cloud system, that links (i) the producers of the tsetse fly repellant and fungus-derived biopesticide, (ii) super agents that act like the retailers of those products, (iii) community resource persons (or Community Animal Health Workers) who provide services to the farmers, (iv) veterinary service providers, and (v) the local farmers. The Kenya Industrial Property Institute has granted to *icipe* Registration of the LiMA trademark (5th September 2019 – 5th September 2029).
Link to app: https://play.google.com/store/apps/details?id=com.mhealth.icipe.mobivet&hl=en&gl=US

2.3 HUMAN HEALTH THEME

2.3.1. New discovery of malaria transmission blocking microbe

icipe demonstrated in a highly publicized article that a previously unknown mosquito-associated symbiotic microsporidian (*Microsporidia MB*) has a strong malaria transmission-blocking capability in the mosquito. The discovered Anopheles symbiont, *Microsporidia MB*, has a strong malaria transmission-blocking phenotype in *Anopheles arabiensis*, the predominant *Anopheles gambiae* species complex member in many active transmission areas in eastern Africa. Importantly, the identified symbiont can spread in mosquito populations through both vertical (mother to offspring) and horizontal/sexual transmission. Moreover, the newly discovered symbiont is not pathogenic towards its host mosquitoes. The ability of the symbiont to block malaria transmission together with its ability to spread within mosquito populations and its avirulence makes it a very attractive candidate for the development of a symbiont-based malaria transmission blocking strategy. We investigated the characteristics and efficiencies of *Microsporidia MB* transmission between *A. arabiensis* mosquitoes. The intensity of *Microsporidia MB* infection in males was found to impact the efficiency of transmission to female *A. arabiensis* mosquitoes. In addition, female *A. arabiensis* that acquire *Microsporidia MB* horizontally are able to transmit the symbiont vertically to their offspring. *Microsporidia MB* infections were found in another primary malaria African vector (*Anopheles funestus s.s*). The finding that *Microsporidia MB* can be transmitted horizontally is relevant for the development of dissemination strategies to control malaria that are based on the targeted release of *Microsporidia MB* infected Anopheles mosquitoes.
(Publication link: https://doi.org/10.1038/s41467-020-16121-y).

2.3.2 Managing snail vectors of schistosomiasis (Bilharzia disease)

Schistosomiasis, an acute and chronic parasitic disease caused by trematode worms of the genus *Schistosoma*, affecting the poorest of the poor with infections particularly abundant among people living in rural or deprived urban or peri-urban settings. Because snails are generally highly tolerant to agrochemicals, we hypothesized that the community in a polluted environment may shift towards an increased abundance of host snails, resulting in an increased risk of infection with schistosomiasis. In complementary laboratory and field studies on Kenyan inland areas along Lake Victoria, we showed that pesticide pollution is a major driver in increasing the occurrence of host snails and thus the risk of schistosomiasis transmission. In the laboratory, snails showed higher insecticide tolerance to commonly found pesticides than associated invertebrates, in particular to the neonicotinoid, Imidacloprid and the organophosphate, Diazinon. In the field, we demonstrated at 48 sites that snails were present exclusively in habitats characterized by pesticide pollution and eutrophication. Our analysis revealed that insensitive snails dominated over their less tolerant competitors. The study shows for the first time that in the field, pesticide concentrations considered "safe" in environmental risk assessment have indirect effects on human health. Thus, there is need for rethinking in assessing the environmental risk of low pesticide concentrations and of integrating agricultural mitigation measures in the control of schistosomiasis.
(Publication link: https://www.nature.com/articles/s41598-020-60654-7).

2.3.3 Impact of larviciding with *Bacillus thuringiensis israelensis (Bti)* in Kenya and Ethiopia

A peer reviewed study on the impact of larviciding with *Bacillus thuringiensis israelensis (Bti)* in Kenya and Ethiopia showed that adding *Bti* intervention to the usage of long-lasting insecticide treated nets further reduced malaria in the low prevalence setting in Ethiopia but not in the highly endemic malaria setting in the Lake Victoria Basin in Kenya. The findings have direct relevance and learnings for *Bti* larviciding evaluation in Botswana, Eswatini and Namibia.
(Publication link: https://doi.org/10.1186/s12936-020-03464-6).

2.3.4 Willingness to pay for community-based eco-friendly malaria vector control strategies

We conducted 'Becker-DeGroot-Marschak (BDM) revealed preference auctions' with 204 participants to determine their willingness to pay (WTP) for community-based application of the biopesticide (UZIMAX) to control malaria vectors. Nearly all participants were willing to pay at the lowest bid price of the biopesticide, and the majority of them expressed great interest in pooling resources to facilitate biopesticide application. Household per capita income and building capacity of households through training significantly increased WTP. These findings imply high adoption potential of the technology

and the need to devise inclusive policy tools, especially those that enhance collective action, resource mobilization and capacity building. These inclusive policy tools will empower both men and women and stimulate investment in eco-friendly technologies for malaria prevention. Financial and labor resource mechanisms managed by the community could potentially spur adoption of the biopesticides, and in turn, generate health, environmental and economic benefits to households in malaria-prone communities.
(Publication link: https://doi.org/10.3390/su12208552).

2.3.5 Bio-ecological factors influencing the distribution of sand fly vectors of leishmaniasis
Leishmaniasis is a neglected tropical disease of public health importance in tropical areas of the world especially eastern Africa. Few options to control the disease exist targeting the vectors. The team first examined whether habitat types (animal sheds, termite mounds and house indoors) among those used for resting or breeding, harbor different composition of sand fly species and how this is related to the volatile chemistry emanating from such habitats. Findings revealed that habitat volatiles may contribute to the composition of sand flies and highlight the potential of the identified compounds for use in monitoring sand fly populations. The study demonstrated that male and female sand flies including *P. martini* and *P. duboscqi* i) similarly exhibit high rates of plant feeding, ii) commonly imbibe the sugar fructose through foraging activities, and iii) selectively feed on Acacia plants in the family Fabaceae. The volatile organic compounds could be exploited in developing attractive toxic sugar- and odor-bait technologies for sand fly control.

2.3.6 Large wildlife herbivore loss and arboviral disease emergence risk
Loss of biodiversity can affect transmission of infectious diseases in at least two ways: by altering host and vector abundance or by influencing host and vector behaviour. The *icipe* team together with collaborators from the University of Georgia (USA) and Mpala Research Centre (Kenya) investigated how wildlife biodiversity influences host-vector interactions and transmission of Rift Valley fever (RVF). Using a long-term wild herbivore exclusion experiment, the team examined the effect of simulated large herbivore wildlife loss on the abundance, survival and feeding behaviour of mosquito vectors of this disease. *Aedes mcintoshi*, the primary RVF vector, was found to be the dominant mosquito species whose abundance decreased with large herbivore loss, while blood feeding on humans increased. Despite an elevated human biting rate in the absence of large herbivores, the estimated potential for RVF transmission to humans, doubled in the presence of large herbivores. Taken together, the findings suggest that loss of wild herbivores may impact RVF disease emergence through their effects on critical traits that determine the vectorial capacity of RVF mosquitoes.
(Publication link: https://doi.org/10.1111/tbed.13918).

2.4 ENVIRONMENTAL HEALTH THEME

2.4.1 Assessing the phytochemical composition of African honeybees' royal jelly
Consumers are increasingly becoming interested in biofunctional food products, especially those from natural sources. Honeybees produce a range of natural products such as honey, bee venom, pollen, bee bread, propolis, wax, and royal jelly. Most of these are high in both nutritional compounds (*e.g.* vitamins, minerals, amino acids, proteins, carbohydrates, lipids), and bioactive molecules such as phenols and flavonoids. We evaluated the phytochemical contents, physicochemical properties, and free radical scavenging activity of royal jelly, secreted by honeybees. The study showed significant free radical scavenging potential of royal jelly suggesting the possible use of the product as a nutraceutical substance.
(Publication link: https://www.sciencedirect.com/science/article/abs/pii/S2212429220310713).

2.4.2 Reevaluation of the bee tribes and description of new species
Bees of the tribes Biastini, Neolarrini, and Townsendiellini are cleptoparasites in nests of solitary bees. Phylogenetic analyses have proved problematic because of conflicting results of studies based on either adult or larval characters. Moreover, the discovery of a new lineage associated with Biastini: the enigmatic *Schwarzia,* rendered earlier results incomplete. This study integrated phylogenomics and morphology to establish a fossil-calibrated phylogeny for the tribes Biastini, Neolarrini, and Townsendiellini. Results obtained from this study provided evidence leading to the placement of Biastini and Townsendiellini tribes within Neolarrini tribe, thereby resolving the ambiguous results of

earlier studies. The expanded tribe of Neolarrini is composed exclusively of parasites of oligolectic host bees. Field expeditions in xeric East Africa led to the discovery of three new species of *Schwarzia*. (Publication link: https://doi.org/10.1093/isd/ixaa013).

2.4.3 Characterization of the Kenyan honey bee (*Apis mellifera*) gut microbiota

Gut microbiota plays important roles in many physiological processes of the host including digestion, protection, detoxification, and development of immune responses. The honey bee (*Apis mellifera*) has emerged as a model insect for gut-microbiota host interaction studies due to its gut microbiota being highly conserved and having a simple composition. We characterised for the first time the African honey bee gut microbiota. We found that three gut microbiota core members dominate in all locations. We are currently studying a potential role in chemical detoxification and/or chemical resistance of one of this core members in the bee gut.
(Publication link: https://doi.org/10.3390/microorganisms8111721).

2.4.4 *Varroa* mite and its effects on honeybee colonies in Kenya

Absconding is one of the factors contributing to low population of *Varroa destructor* in honeybee colonies as it creates a brood-free period. We showed that *Varroa* mites are not the cause for absconding while the storage of pollen is clearly a factor supporting absconding indicating the importance of nutrition for bee colonies. Furthermore, we showed that seasonal fluctuations in numbers of *Varroa* mites occur with increased levels before and during the short rain period indicating this seasonal period as crucial time for colony controls.
(Publication link: https://doi.org/10.1007/s10493-020-00548-5).

2.4.5 Insects for Food, Feed and other uses Programme

Insect oils: Worldwide, there is growing interest in the use of insect-derived ingredients into food and feed products. Recently, we compared oils from two edible grasshopper species with oils obtained from two plant sources, olive and sesame. The two commonly consumed grasshoppers in Africa are the desert locust and the African edible bush-cricket, also known as 'nsenene'. Results showed that the insect oils were compositionally richer in omega-3 fatty acids, flavonoids, and vitamin E than the plant oils. Proximate analysis and volatile chemistry revealed that differences in aroma and taste of cookies were associated with their sources of oils. These findings indicate that the two insects are ideal candidates for mass rearing for oil production, and provide an avenue for entrepreneurs in Africa to tap into the lucrative and booming global cooking oil market, which is expected to reach about US$ 130 billion by 2024. (Publication link: https://bit.ly/2Ym8Z3V).

Establishing black soldier fly (BSF) gut microbiome: We conducted the first comprehensive analysis of bacterial and fungal communities of black soldier fly (BSF) gut across untreated substrates and highlighted the presence of conserved members, potential pathogens, and their interactions. This information will contribute to the establishment of safety measures for future processing of BSF larval meals and the development of legislation to regulate their use in animal feeds.
(Publication link: https://doi.org/10.3389/fmicb.2021.635881).

Predicting the current and future distribution of the edible long-horned grasshopper, Ruspolia differens: The edible long-horned grasshopper *Ruspolia differens* is widely distributed and consumed in sub-Saharan Africa. Efficient mass rearing of the edible grasshopper is critical to ensure their sustainable supply for food and nutritional security. Optimum temperatures for breeding the grasshopper have been determined. Currently, climate change has been predicted to shrink their suitable breeding sites from Central, East, West and southern Africa to Central and East Africa by 2050, with maximum generations per year increasing from three to four. The optimum rearing temperatures identified can guide optimization of mass rearing of *R. differens.*
(Publication link: https://doi.org/10.1016/j.jtherbio.2020.102786).

Affordable processing of edible Orthopterans provides a highly nutritive source of food ingredients: All three processed insect species (*Gryllus bimaculatus, Locusta migratoria,* and *Schistocerca gregaria*) had high protein and fat contents. Oleic and palmitic were the two most abundant fatty acids. All essential amino acids were present, with glutamic acid, alanine, and leucine being the most abundant. The minerals potassium and phosphorus were moderately high, and iron, zinc, manganese, and copper were also observed in the samples. Vitamin B12 contents were high. Our findings

demonstrate that the excellent nutritional profile of the three processed insects could serve as promising alternative ingredients for improving food and nutritional security.
(Publication link: https://doi.org/10.3390/foods10010144).

Insects for Food Standards approved: Three standards (KS 2921: Production and handling of insects for food and feed, KS 2922-1: Edible insects' products, and KS 2922-2: Products containing edible insects) on edible insects for food were approved by the Kenya Bureau of Standards (KEBS) and declared as National Standards through a Kenya Gazette Notice No. 10268 (pg. 4884) dated 4th December 2020.

Replacing conventional poultry feed with insect-based feed: Socio-economic and environmental implications: Insect farming is considered as an alternative feed source to conventional feed sources due to its low land and water requirements, its low ecological footprint, and its contribution to circular economy by converting biowaste into high-quality feed ingredients. While there is growing research on the technical feasibility and nutritional performance of insect-based feed, its potential benefits are not quantified. Using experimental and secondary data, we assessed the potential socio-economic benefits of black soldier fly larvae meal (BSFLM) to the Kenyan poultry sector. We found that replacing 5-50% of the conventional feed sources (fishmeal, maize, and soya bean meal) by BSFLM can generate a potential economic benefit of US$ 69-687 million (contribution to 0.1-1% of the total GDP) and US$ 16-159 million (0.02-0.24% of the GDP) if the entire poultry sector (contribution to the commercial poultry sector) adopts BSFLM. These benefits could translate to reducing poverty by 0.32-3.19 million (0.07-0.74 million in poultry) people, increasing employment by 25,000-252,000 (3,300-33,000 in poultry) people, and recycling of 2-18 million (0.24-2 million in poultry) tonnes of biowaste. Replacing the conventional feeds by 5-50% BSFLM in the commercial poultry sector would increase the availability of fish and maize that can feed 0.47-4.8 million people at the current per capita of fish and maize consumption in Kenya. Similarly, the foreign currency savings can increase by US$ 1-10 million by reducing feed and inorganic fertilizer importation. These findings suggest that greater investment to promote BSFLM could boost economic, environmental, and social sustainability.
(Publication link: https://www.sciencedirect.com/science/article/pii/S0959652620319181).

2.4.2 MOre Young Entrepreneurs in Silk and Honey (MOYESH) programme

Beekeeping and silk production businesses have high potential to provide a wide range of economic opportunities to unemployed youth. *icipe* has developed and currently promoting standardised innovative technologies for beekeeping and sericulture. To stimulate value chain integration and inclusiveness, functional marketplaces for honey and beeswax that support youth to process and market honey products have been established in various countries. Scaling up of proven practices with emphasis on improving market access in combination with other enabling factors such as financial access will connect youth with markets and will enhance their income and well-being. In the ongoing MOYESH programme in Ethiopia, the programme has so far recruited, trained, equipped, and enabled a total of 15,372 (59% females) unemployed young women and men in apiculture (90%) and sericulture (10%) businesses in the four target regions (Amhara, Oromia, SNNP and Tigray) of Ethiopia. The programme also created 1,162 additional indirect jobs (23% females) at 100 partnering small and mid-size enterprises (SMEs) that manufacture various project related inputs. Over 3,000 beekeeping farmers benefitted from supplying the programme with honeybee colonies. About 1,100 local extension staff of partnering institutions attended training of trainers (ToT) workshops on improved beekeeping, sericulture, and entrepreneurship skills. In collaboration with two partnering private banks, the programme has developed two digital financial products to boost access of partnering youth and SMEs to financial services.

3. PROGRESS REPORT ON SPECIAL PROGRAMMES

3.1 BioInnovate Africa Programme Phase II

BioInnovate Africa Programme is a regional initiative that supports scientists and innovators in the Eastern Africa region to link biological based research ideas, inventions, and technologies to business and the market. The second phase of the ongoing programme (2016-2021), implemented by *icipe*, accomplished the following:

- Continued to provide business support through Growth Africa Foundation to nine projects that are transitioning into pilot commercial enterprises. These projects have shown early commercial leads for their products and have developed, and market tested their business models. The projects involve high value nutritional foods, a seed system for sweet potato in East Africa, aroma honey toffees, biowaste water conversion, biofuels, and biofertilizers.
- BioInnovate Africa and Villgro Africa (an invention-based business support organization in Kenya) held a 4-day regional bioscience innovation bootcamp from 26 November to 1 December 2020. The aim was to enable entrepreneurial scientists develop innovative and commercially viable biological based ideas in: agroecology, food and feed, waste water treatment, biopharmaceuticals and cosmetics, bioenergy, biomaterials, diagnostics, and green chemicals (biocatalysts). The bootcamp activities involved creative ideation, design thinking, systems thinking, rapid prototyping and initial development of the product and commercial pathways. The teams (each comprising of three members) were from Burundi, Ethiopia, Kenya, Rwanda, Uganda and Tanzania.
- Commenced a collaboration with the Thayer School of Engineering at Dartmouth College, USA to conduct a specialized training on techno-economic analysis (TEA) for selected PhD students within the BioInnovate Africa network. A total of six students from Burundi (1), Ethiopia (2), Kenya (2) and Uganda (1) were competitively selected for the online course and activity.
- Completed signing contracts for five research projects addressing challenges related to COVID-19 pandemic that were selected for funding. The projects involve data science modelling on effects of the pandemic on food security in East Africa as well as diagnostics, immune boosters and investigation of herbal medicines with antiviral properties.
- Completed placement for a new cohort of 12 women scientists who were competitively selected, and started their research fellowships for 10 months, in January 2021.
- BioInnovate Africa and the East African Science and Technology Commission (EASTECO) were the official partners representing Eastern Africa at the 3rd Global Bioeconomy Summit (GBS) 2020, which took place from 16 – 20 November 2020. The summit was held virtually with the locus in Berlin, Germany. It brought together 3,000 plus bioeconomy experts and policy makers around the world.

3.2 The Africa Regional Scholarship and Innovation Fund for Applied Sciences, Engineering and Technology (RSIF) in sub-Saharan Africa

Africa Regional Scholarship and Innovation Fund for Applied Sciences, Engineering and Technology (RSIF) Programme in SSA is established to fill gaps in knowledge that are critical for African growth and development by increasing the number of PhD and post-doctoral opportunities in applied sciences, engineering and technology as well as increase the capacity of scientists and innovators to translate innovative biological science-based ideas and technologies into practical application in society and build functional innovation ecosystems. It is a flagship program of The Partnership for skills in Applied Sciences, Engineering and Technology (PASET) initiative by the African Governments and the World Bank, which *icipe* is competitively selected to manage. RSIF's major achievements during the year 2020 are listed below.

- Nine countries – Benin, Burkina Faso, Côte d'Ivoire, Ghana, Kenya, Mozambique, Rwanda, Nigeria, and Senegal – have made or are at final stages of making contributions to RSIF in addition to the Government of Korea and the World Bank.
- Agreements for financial support to *icipe* to implement RSIF were signed with two new African governments: Benin (US$ 2 million) and Nigeria (US$ 4 million).

- A proposal to the EU-ACP Innovation Fund was approved and contract has been signed. This action will extend RSIF's windows 2&3 work in West Africa with a focus on digital innovation. *icipe* will open office in Benin under the umbrella of IITA to help run this project.
- Feasibility study for establishment of a permanent fund finalized, including fundraising strategy and implementation plan.
- A call for proposals for selection of four additional African Host Universities to offer PhD programs in the PASET priority thematic areas was published, in order to create sufficient capacity for the rapidly expanding numbers of RSIF PhD students.
- A total of 82 PhD students are progressing well with their research despite Covid-19 challenges.
- Cohort I students have been matched with international partner institutions, while most of Cohort II students have reported to their host universities. An expected 116 more students will join Cohort III in 2021.
- Guidelines on Intellectual Property (IP) management that will guide research activities conducted by RSIF scholars and for research and innovation grants have been consultatively developed, approved and published. Trainings for university staff have been implemented.
- RSIF Weekly Newsletter continues to be disseminated through MailChimp (36 editions published with 6,500 subscribers).
- One of the RSIF's objectives is to correct imbalances in the number of women and disadvantaged groups in the fields of applied sciences, engineering and technology in Africa. A study conducted by *icipe* researchers has found that women take longer to complete their PhDs, and their publication outputs are less published compared to male counterparts. The paper was prepared to inform the preparation of a gender strategy for RSIF.
(Publication link: https://doi.org/10.1371/journal.pone.0241915).

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.

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

During 2020, *icipe* had a total of 319 scholars, fellows and research interns.

- *Pursuing gender equity:* 45% of African Regional Postgraduate Programme in Insect Science (ARPPIS) and Dissertation Research Internship Programme (DRIP) postgraduate scholars are women.
- *Completion:* 18 ARPPIS PhD scholars, 10 DRIP PhD scholars and 17 DRIP MSc scholars defended their theses or graduated in 2020.
- The *icipe* ARPPIS & DRIP Postgraduate, Research Internship and Postdoctoral programmes have continent-wide representation. A total of 20 African nationalities - from East, West, Central and southern Africa- were represented in the programmes during the reporting period. These include: Benin (7), Burkina Faso (4), Cameroon (8), Chad (2), Côte d'Ivoire (5)**,** DRC (2), Ethiopia (11), Ghana (14), Kenya (132), Malawi (2), Nigeria 10), Rwanda (15), Senegal (4), South Africa (1), Sudan (3), Tanzania (9), Togo (3), Uganda (13), Zambia (2), and Zimbabwe (6).

4.2 Training

icipe has continued to conduct a large number of trainings for students, researchers, national programme partners, farmers and others in knowledge intensive areas of *icipe* technologies and products, and in research and research-related skills. During 2020, *icipe* conducted more than 133 training events, and trained 59,113 individuals (56% women) from 22 African countries.

4.3 Information Resources Centre (*icipe* Library)

Previously the Information Resources Centre (IRC) had access to 16 e-resource databases, including e-journal and e-book databases, through *icipe's* partnership with Kenya Libraries and Information Services Consortium (KLISC). During 2020, the IRC acquired access to four additional databases through KLISC, greatly increasing *icipe's* access to information resources in research methods, development, social sciences, biosciences, environment and agriculture. These include: (1) **Sage Research Methods** that support research at all levels by providing material to guide users through every step of the research process, including 1000 books, reference works, journal articles, and instructional videos by academics from across the social sciences, including the largest collection of qualitative methods books available online; (2) **Taylor and Francis Journals** that provide access to more than 4 million articles in a variety of subject areas including biosciences, development studies, environment and agriculture, and social sciences; (3) **OECD iLibrary**, the online library of the Organisation for Economic Cooperation and Development, that features its books, papers and statistics and it is the gateway to OECD's analysis and data; and (4) **Project Muse e-library,** provided through Johns Hopkins University Press, which is a collaboration between libraries and publishers providing full-text access to high quality journals on humanities, arts, and social sciences published by scholarly publishers and also to book collections.

As part of the RSIF capacity building strategy, the IRC coordinated subscriptions to peer reviewed e-journals and e-books for the 11 African Hosted Universities. The IRC carried out plagiarism checks on more than 1,000 RSIF PhD Scholarship applications using the Turnitin software. The IRC populated the *icipe* digital Repository with theses from completing PhD and Master's scholars. (http://34.250.91.188:8080/xmlui/).

5. PUBLICATIONS

Peer reviewed publications: In 2020, *icipe* has published 153 peer reviewed journal articles. The complete list of publications is provided in **Annex 1**.

Non-peer reviewed publications: In 2020 *icipe* published 93 publications that are non-peer reviewed but are of significant scientific value. This include books; book chapters; conference papers; policy briefings; case studies/thematic summaries; toolkits and procedures; training manuals, and brochures as well as posters, and an additional 113 educational videos.

6. COMMUNICATIONS AND MEDIA

6.1 Media coverage

During 2020, more than 1,100 news items related to *icipe* were published in local and international media outlets, adding up to a potential reach of 4.16 billion people. The potential advertising value of this coverage was an estimated US$ 38.6 million. *icipe* was mentioned in more than 797 publications globally and top publications were Advance Africa (22 articles) followed by AllAfrica.com (18 articles) and Daily Nation (also 18 articles). A few examples of the top international media that covered *icipe* research include BBC World News, Yahoo! News UK, Mediacongo.net, DailyHunt English, The People (London, UK) (Print Edition), and Reuters. Between April and June 2020, *icipe* was mentioned in 72 countries.

6.2 *icipe* website

Approximately 110,000 visitors and 390,000-page views were registered on the *icipe* website during 2020. The top countries (ranked in order of visitor numbers) were: Kenya; United States of America; Ethiopia; United Kingdom; India; Uganda; Tanzania; Germany; South Africa; Nigeria; Belgium; Netherlands; France; Ghana; Switzerland; China; Canada; Cameroon; Japan and Rwanda.

6.3 *icipe*@50

Celebrations to mark *icipe*'s 50th anniversary was a popular news item during the last quarter of 2020. Indeed, '50th anniversary' was one of the institution's top five trending themes, alongside 'science and research', 'youth', 'entrepreneurial opportunities' and 'application'. President of Kenya, Uhuru Kenyatta's congratulatory podcast garnered 4,900 views on Twitter, and the livestream of the event held at Duduville Campus on 20 November 2020 had 3,700 views on *icipe*'s YouTube channel. There was an outpouring of congratulatory messages on all social media channels during and after the function.

6.4 Press Releases

Other popular articles have revolved around integrated pest management, for instance the release of a parasitoid to control *Tuta absoluta*. The release of the wasp that is the natural enemy of the highly destructive tomato pest has been shared in various publications and languages around the world, and has raised hopes of reducing the use of inorganic pesticides, lowering production costs, and enhancing safe tomato production. Recently, *icipe* also launched the mass releases of indigenous natural enemies of fall armyworm in Kenya. This also gained traction in the media, especially in Africa, where growers of maize, a staple food, have suffered yield losses of 8 – 20 million tonnes due to the pest.

6.5 Social media

On social media, *icipe* was most mentioned on Twitter (6,459 out of a total 8,510 social media mentions), with the top five themes being 'microbe', 'disease', 'transmission of malaria', 'mosquitoes' and 'mosquito populations'. Indeed, *icipe*'s discovery of a microbe that blocks malaria transmission in mosquitoes was a major news item globally and it was the most welcome positivity amid the COVID-19 pandemic. This led to a sharp increase in the Centre's potential reach to 1.2 billion people in the second quarter of 2020.

Another topic of continuing interest is the locust invasion in East Africa, particularly *icipe*'s research on the use of insects for food and feed, and involvement in the Kenyan government's locust control advisory committee/task force.

7. COVID-19 CHALLENGE

In 2020, the COVID-19 pandemic has brought unprecedented economic, health and other related challenges across the globe. At the same time, science has distinguished itself in continuously providing knowledge that will hopefully see us triumph this difficulty. In April 2020, *icipe* contributed and signed a letter with other likeminded organizations to G7, G20 and other world leaders urging them to design COVID-19 response measures that reduce the risks of global and regional food security crises. As captured in the *icipe* communique of March 2020, we restate that our response to the COVID-19 situation remains purposeful; envisioned to safeguard our staff and their families, as well as our visitors, while minimising disruptions on commitments to our stakeholders, including our development partners, donors, collaborators and beneficiaries. The Centre is joining the African and global community in contemplating the sustainable development path beyond COVID-19. It is expected that there is an increased risk of food and nutrition insecurity due to disruptions in food and input supply systems, rise in food prices, a shift of funding priorities away from food security-related research, and loss of jobs. *icipe*'s holistic 4Hs themes approach presents an important model for investments in a "One Health" strategy, to strengthen resilience across diverse sectors in Africa, and elsewhere in the tropics.

SECTION 3: RESULTS BASED MANAGEMENT (RBM) FRAMEWORK: PROGRAMMATIC PROGRESS REPORT FOR 2020

(i) Plant Health Theme: Results Based Management (RBM) Rolling Framework Report

Outputs	Outcomes	Performance indicators	2020 Progress in Achieving Outcomes	2020 Lessons Learned
Broad objective 1: Make available IPM options for staple crops by 2025.				
Specific objective: Long-term farming systems comparisons in Kenya and participatory on-farm research of locally adapted technologies for organic agriculture.				
1.Long-term farming systems are well managed based on best management practices feasible for the farmers; good quality agronomic, ecological and economic data are generated; main research findings are disseminated for the academic community, decision makers and sector-relevant stakeholders at national and global level.	Science based know-how on the comparative performance of organic and conventional agricultural production systems in different agro-ecological regions is made available and taken up by stakeholders.	Management practices are implemented according to plan. Yield, and pest and disease incidences are acceptable for well performing farmers. Verified data on parameters as defined in the country-specific documents are stored in databases. Soil, plant and input samples. 8 publications.	Various planned activities and studies were implemented and managed successfully. Data and samples were collected and analyzed successfully despite the prevailing challenges, especially with COVID 19.	Having a consistent and well-trained workforce in the field is essential, especially during implementation of key activities when there are restrictions of movement to the field sites. Virtual engagements during meetings and workshops saves a lot of time and resources.
2.Innovations addressing bottlenecks of sustainable agricultural production systems are developed through participatory on-farm research in concert with long-term farming systems and are taken up by local stakeholders; concepts for the future of the project sites are agreed and embedded in the strategies of partner institutions, which are strengthened through empowerment and capacity building within functional networks.	Sustainable agricultural production systems in project areas are fostered through participatory development of innovations addressing bottlenecks, and by improved capacities of partner institutions.	Technical leaflets, manuals and contributions to relevant events. Local stakeholders promote the innovations. Concepts and partners statements/strategies. Capacity building targeting farmers, research, extension officers and students. Activities initiated by the networks.	1 PhD student successfully completed his studies and graduated. 1 PhD student and 1 MSc student submitted their thesis for examination. Only 1 training of farmers took place early February before COVID 19 restrictions were introduced. The planned stakeholder workshop and field days did not take place due to COVID 19 prevention directives.	All our project farmers continued with the project trials without dropping out. Farmers are looking for innovative ways and technologies of farming that can perfect organic farming systems. Introduction of companion cropping in organic farming system to manage pests was very well adopted by farmers.
Specific objective: A knowledge hub on organic agriculture (OA) established.				
3. Validated technical and methodological knowledge for the promotion of organic agriculture, including	1 compendium/repository of analyzed, validated good organic farming practices is	1 compendium in each of the 4 countries. 100 flyers/factsheets in English and 2 local languages.	Developed 4 new manuals on maize stemborer and *Tuta absoluta* describing IPM tactics and climate-smart technology.	*icipe* technologies align with the concept of organic Agriculture. An intern recruited to inventory and database *icipe* technologies.

processing, is prepared for the context of the participating countries and stakeholder groups, and made available through suitable knowledge products**.**	created (database) for each of the participating countries. 187 technically and methodologically state-of-the-art knowledge products have been created in suitable formats (flyers/factsheets, videos, radio and TV ads, mobile apps, training modules, etc.) in English and selected local languages of the 4 participating countries. The East African specific section of the central internet platform for disseminating validated knowledge products has been tested by 3 member organizations in the region, with positive results in terms of its functionality.	40 videos in 4 local languages (by Access Agriculture). 40 radio or TV ads in 3 Languages (English and 2 local languages) 3 mobile apps in 1 language (English) 3 positive tests by participating country partners in East Africa.		IPM tactics integrated on TTU microsite.
Validated technical and methodological knowledge, strategies and good practices in the field of organic agriculture adapted to the contexts of the countries participating in the Eastern Africa regional knowledge hub, have been disseminated.	80% of the individuals registered as multipliers in the regional knowledge hub specifically contribute to the transfer of knowledge on organic production, processing and marketing practices. The number of trainers trained in organic production, processing and marketing practices and methods has increased by an average of 10% in the 4 countries participating in the East African regional hub. value chain actors in the 4 participating countries are reached by means of video presentations and radio broadcasts carried out by	80% registered multipliers. 10% trainers trained. Video presentations with actors (50% women). Radio broadcast with actors (50% women). Number of demonstration plots established, 120,000 beneficiaries reached (50,000 women; 15,000 youth).	Established collaboration with new partners for the promotion of organic agriculture including PELUM (Uganda, Kenya, Swaziland), Sustainable Agriculture Tanzania, Farming Wonder.	None.

	the regional knowledge hub. An average of 50% of the actors reached are women. 12 demonstration plots established. Numbers of farmers reached by OA knowledge disaggregated by women and youth.			
Specific objective: Contribute to improve livelihoods and resilience of smallholder farmers in Eastern Africa maize production systems through enhanced preparedness, integrated and eco-friendly management of the invasive fall armyworm (FAW) *Spodoptera frugiperda* for food and nutritional security by 2022.				
1.Regional preparedness, early warning, information on available management options and capacity for timely response to FAW infestation in Eastern Africa enhanced.	Governments in Eastern Africa and smallholders are prepared to tackle FAW infestation with available and sustainable management options.	At least 100 extension officers per target country have access to monitoring surveillance tools by 2022. At least 100,000 maize growers (of which 30% are women) in Kenya, 75,000 in Tanzania, 75,000 in Ethiopia, 20,000 in Rwanda and 20,000 in Uganda have access to monitoring surveillance tools by 2022. By 2020, 1 additional effective FAW IPM option registered and available for commercialization. At least 3 best-bet cultural practices identified and promoted by 2019.	Enhanced understanding on FAW hotspots and possible migrations in the continent established (Niassy et al 2021). CLIMEX based modelling of FAW distribution in the current and future climate change scenario undertaken (Tamilsena et al 2021). Capacity of >15,000 growers and >1,000 extension officers in the target countries enhanced to detect and diagnose FAW and its management. Efficacy assessment of commercial FAW pheromones undertaken in Kenya and Ethiopia. On-farm validation of climate resilient push-pull technology in 30 farms in 12 Kenyan regions completed. Field demonstration plots of effective biopesticides in Kenya (10 plots) and Tanzania (5 plots) completed. Permits for registration/label extension of two strains of *icipe* biopesticides obtained in Kenya, Tanzania and Uganda. Mass production and release of >150,000 egg (*Telenomus remus* and *Trichogramma chilonis*) and larval parasitoids (*Cotesia icipe)* completed in Kenya.	Significant improvements in our understanding of the FAW biology, ecology and future dynamics achieved. Technologies such as push-pull, biopesticides and natural enemies are available for roll out to farmers for FAW management More extensive engagement with policy makers, private sector partners and other stakeholders is needed for rapid scale up of effective technologies.
2. An effective and sustainable IPM strategy to counter FAW in Eastern Africa developed for dissemination.	Effective and sustainable IPM strategies suited for different agro-ecologies made available to effectively manage FAW and mitigate losses in Eastern Africa. Development of sustainable IPM strategies taking into account the interactions between FAW and a community of lepidopteran maize stemborers with their associated parasitoids.	At least 3 effective and sustainable IPM strategies to counter FAW developed for different agro-ecologies and countries by 2022. Development of a dynamic simulation model of the interactions between FAW and a community of lepidopteran maize stemborers with their associated parasitoids by 2021. At least 3 publications highlighting FAW bioecology completed by 2021.	The intensity of infestation of FAW and its parasitoids across Africa predicted with an accuracy of 88% at pixels of 1 km. First models to predict habitat suitability for key FAW parasitoids considered for classical biological control established (Tepa-Yotto et al 2021). Interactions and dynamics between stemborers, FAW and associated parasitoids modelled by applying system dynamics approaches (Sokame et al 2021). Interaction of FAW, stemborers and their associated parasitoids assessed in diverse agroecologies in Kenya and Uganda (Hailu et al 2021). New parasitoids belonging to *Ascogaster* sp. parasitizing FAW identified.	New knowledge on FAW biology, ecology and refinement of best bet FAW IPM technologies continues to be developed, which needs to be effectively integrated, evaluated in large-scale trials and promoted. Partnerships with other R4D partners in areas such as host plant resistance needs to be strengthened.

		At least 1 effective natural enemy released in 3 target countries by 2020. At least 100,000 parasitoids released per country by 2022. At least 2 biocontrol technologies developed by 2020. At least 25,000 growers in 3 target countries directly benefitting from biocontrol technologies by 2022. 25,000 maize growers using push-pull for FAW control by 2022. At least 1 FAW resistant cultivar (or hybrid) availed and disseminated in partnering countries.	Detailed assessment of the parasitism levels of parasitoids in the laboratory completed. Initial release of 150,000 egg and larval parasitoids undertaken in Murang'a, Nyeri, Meru and Embu Counties, Kenya. Post-release field assessment revealed that parasitism rates of FAW in the field increased by 55, 50 and 38%, for *T. chilonis*, *Telenomus remus* and *C. icipe*, respectively. In partnership with IITA, potential for successful establishment of other exotic parasitoids considered for classical biological control (*Chelonus insularis*, *Cotesia marginiventris*, *Eiphosoma laphygmae*, *Telenomus remus* and *Trichogramma pretiosum*). Bioprospecting for EPF conducted in Kakamega and Bungoma counties and potent *B. bassiana* isolates identified. Field bioprospecting for baculoviruses infecting FAW ongoing in Kenya with Wageningen University. Prospects of combined use of ICIPE 7, 78 and 41 being assessed to enhance larval mortality. Optimum temperatures for production of the fungal isolates were modelled and identified to be between 25-30˚C for all the isolates. *Beauveria bassiana* ICIPE 621 and *M. anisopliae* ICIPE 7 were found very effective against adult FAW by causing 100% mortality of the moths with the lowest LT_{50} values. Both isolates were also found compatible with commercial lures (Akutse et al 2020). Non-target study of *M. anisopliae* ICIPE 78, ICIPE 7 and ICIPE 41 on *Telenomus remus* and *Trichogramma chilonis* undertaken and found compatible. Socioeconomic studies and field trials of Mazao Detain and Mazao Achieve to assess their efficacy under different cropping systems (push-pull, monocropping, farmer field practices) are currently ongoing in Uganda. Multilocational field efficacy trials to fast-track registration of both biopesticides are completed in Kenya, Tanzania and Uganda Climate-smart push-pull assessed in comparison to adjacent monocrop maize in 30 selected farmer fields from each of the 12 study sites within Western Kenya. Climate-smart push-pull resulted in 66-88% reduction in larval incidence. Field evaluation of third generation push-pull in comparison to climate-smart push-pull and farmer's practice undertaken in 5 locations in Western Kenya. Farmers preferred the third generation push-pull technology for important traits possessed by the companion plants used in this technology. We continue to evaluate for more attractive trap plants than *Brachiaria* sp. and Napier grass.	

			Maize volatiles combined with *Desmodium* sp. was less attractive and deterred oviposition to FAW moths more than volatiles from maize alone. Farmer training on push-pull and FAW management in 8 counties in Western Kenya resulted in training of 2,477 male and 3,481 female farmers. Cultivar 'SC Duma 43' was found to be slightly resistant to FAW infestation but its difference in plant damage was not statistically significant in the field (Chiriboga Morales et al 2021). FAW natural enemies were found to be attracted to maize plants with volatiles of FAW feeding/oviposition.	
3. Implementation of IPM strategy to counter FAW infestation in Eastern Africa jointly with maize crop growers, private sector, NARS, NGOs and growers enhanced.	Maize growers, private sector, NARS, NGOs and government regulatory authorities in Eastern Africa are widely aware of FAW and its constraints and sustainable FAW-IPM technologies.	At least 100,000 maize growers in Kenya, 75,000 in Tanzania, 75,000 in Ethiopia, 20,000 in Rwanda and 20,000 in Uganda reached with sustainable FAW-IPM technologies by 2021. At least 40% of the maize production area affected by FAW (341,262 ha) in the target project areas covered by at least 1 effective FAW IPM options by 2022. At least 3 technologies demonstrations in each country in each year. At least 1 TV program/Youtube video, 1 radio program and 1 news article per year developed and translated. At least 5,000 booklets/posters/brochures on FAW developed, printed and distributed each year. At least 1 FAW microsite developed and maintained.	Validation trials for commercial FAW pheromones have been initiated in 4 Sub-Counties in Kenya and 5 Districts in Ethiopia. Large-scale participatory field trials involving farming communities in Uganda and Kenya conducted. Seed production for push-pull companion crops continues to be pushed with addition of new private sector partners (Beula Seeds, Tropical Seeds EA, Alexis Seeds). Informal seed production through community seed bulking has benefited >200 farmers with root splits and *Desmodium* sp. cuttings 300 ToT events conducted on push-pull companion crop management and production of planting materials. We continue to expand our partnership with NGOs, private sector and CBO/FBOs for scaling FAW IPM technologies. In 2020, new partners engaged include Safi Organics**,** Kenyatta Agricultural Training Center in Kenya; NACCRI in Uganda; Send-a-Cow, Bako Agriculture Training Center in Ethiopia; African Inland Church of Tanzania, Tanzania Human Charity (TAHUCHA), Sustainable Agriculture Tanzania (SAT), Beula Seed Company, and Tropical Seeds EA in Tanzania. Country-level WhatsApp groups have been created resulting in wide interaction among stakeholders and enhanced implementation of FAW IPM technologies. 1 policy brief highlighting key policy support areas in promotion of FAW IPM technologies developed. In Kenya, 5 field days facilitated by peer farmers, resulted in >1,900 small-scale farmers obtaining FAW IPM technology skills. In partnership with Biovision Africa Trust (BvAT), 4 radio programs were aired on Radio Maisha to create awareness on the damage caused by FAW, monitoring and management using the push-pull system. A total of >3 million people were reached with these programs.	Extensive awareness on the FAW IPM technologies have been created in the target countries. Restriction in field activities due to COVID 19 has hampered direct engagement with the stakeholders. Hence, there is a need to strengthen online training options, social media interactions to continue creation of awareness. Efforts need to be further strengthened for establishment of partnerships with the private sector, NARES, NGOs and CBOs for ensuring adequate availability of tools for FAW IPM technologies.

			FAW IPM technologies demonstrated in national and regional Nane-Nane Agricultural Shows in Tanzania involving >10,000 famers. 3,000 copies of the FAW IPM manual were distributed to farmers and extension personnel in Kenya, Uganda, Tanzania, Rwanda and Ethiopia. An additional 1,000 copies of the push-pull FAW management comic book were distributed in Kenya and Tanzania. 10 farmer field day events were hosted at the learning sites in Kenya and Tanzania through which >1,000 farmers were trained on the various FAW management options and 120 new farmers benefited from *Desmodium* sp. cuttings and *Brachiaria* sp. root splits for establishing their new push-pull plots. 5 farmer field schools and 11 technology learning sites were established to facilitate farmer learning; (4 in Kenya, 3 in Uganda, 2 in Tanzania, 2 in Ethiopia).	
4. Research capacity in Eastern Africa to develop and implement a sustainable IPM strategy for FAW enhanced.	Stakeholders and researchers in the maize value chain are capable of developing and implementing an sustainable IPM strategy for FAW.	At least 750 stakeholders trained through ToT events by 2022. At least 3,000 lead maize growers in each project country participate in technology dissemination activities. At least 1 Postdoc, and 3 PhD and 5 MSc students trained on FAW research by 2022. at least 1 open day for policy makers and NARS partners in each year.	In Ethiopia, 28 researchers, 16 technical/field assistants, 12 crop protection experts and heads, 12 extension workers and heads, 10 development agents and 5 model farmers were trained in a ToT training on pest monitoring, surveillance, diagnosis and early management of FAW. 60 farmers and other stakeholders were trained through demonstration sites. Through TARI Ukiriguru in Tanzania, awareness meetings were held at provincial and district levels to lobby for government support. Another ToT event conducted in January 2020 in Ethiopia effectively trained 15 lead farmers and 15 government extension officers on FAW IPM technologies. In partnership with Food for the Hungry Rwanda, RAB and MINAGRI, 2 ToT events involving 52 trainees were held in 2020. 3 Postdocs and 6 PhD/MSc students from seven countries are being trained on various aspects of FAW biology and sustainable management. ToT event conducted in January 2020 in Ethiopia, effectively training 15 lead farmers and 15 government extension officers on FAW IPM technologies. 1 ToT webinar involving 80 stakeholders and lead farmers from the 5 project countries (as well as Ghana, Zimbabwe, Malawi, Zambia, DRC, Burundi, Cameroon, UK) was conducted to develop the capacity of trainers and to harmonize the extension package on FAW monitoring and management.	Extensive awareness on FAW IPM technologies have been created in the target countries. Restriction in field activities due to COVID 19 has hampered direct engagement with the stakeholders. Hence, there is a need to strengthen online training options, social media interactions to continue creation of awareness. Capacity to research on FAW has been significantly enhanced with training of students and researchers at Postdoc, PhD and MSc level.

5. Livelihood, environmental and gender impacts of FAW along the maize value chain in Eastern Africa determined and utilized for decision-making.	Policy makers, researchers and growers are aware of precise impacts and benefits of FAW IPM interventions in Eastern Africa to facilitate informed decisions.	At least 150 high-level stakeholders reached per country with FAW evidence data by 2022. At least 50% of the maize growers to be included in the survey in the target areas aware of the socio-economic benefits of sustainable FAW IPM options.	We utilized data from cereal growers in Kenya and Uganda to assess their knowledge and management practices of common pests and willingness to pay (WTP) for biopesticides. The contingent valuation method was used to assess the WTP and associated factors among 600 and 700 farmers in Kenya and Uganda, respectively. >50% of the maize growers were willing to pay a premium price for biopesticides. The WTP price was estimated at US$18.27/acre among maize growers (Nyangau et al 2020). We assessed the moderating effect of women's empowerment on the relationship between adoption of agricultural technology such as push-pull and women's dietary diversity score in Kenya. Results show that the adoption of push-pull technology positively impacts women's dietary diversity regardless of empowerment status. We estimated FAW-induced maize production losses in Ethiopia by combining unique community survey data collected in 2020 in seven agro-ecologies with a nationally representative farm household survey. The data cover 150 villages and 1,100 (10%) maize growing smallholder farmers. The total maize production loss between 2017/18 and 2019/20 is estimated at 0.68 million tonnes of maize (0.23 million tonnes/year), equivalent to US$ 200 million. This amount could have fed 4.32 million more people (1.44 million people/year) at the current per capita maize consumption level.	With better understanding of the impacts of FAW on maize production, benefits of the IPM intervention and willingness of farmers to adopt FAW IPM technologies, there is need to create greater awareness among policy makers to support scaling of FAW IPM technologies.
Specific objective: Developing, commercializing and upscaling of biopesticides for integrated FAW management to improve the livelihoods of smallholder farmers.				
1. Stakeholders involved in the biopesticide sector including policy makers and regulatory authorities sensitized on policy and regulatory needs and socio-economic aspects related to use of biopesticides for FAW management.	Biopesticide stakeholders, regulatory authorities and policy makers sensitized on the availability of fungal-based biopesticides to tackle FAW in East Africa. Maize growers, private sector, NARS, government regulatory authorities and policy makers in Eastern Africa are widely aware of FAW and its sustainable management using biopesticides. Demand and willingness-to-pay for biopesticides for FAW management established.	1 sensitization workshop for regulatory authorities and policy makers. Policy review on regulatory procedures for biopesticides completed and documented. 1 report on demand for and cost-effectiveness of biopesticides for FAW management. Combination formulations developed and screened in the laboratory. Field efficacy of combination products established in multi-country/locational trials. Potential for 'lure and infect' strategy for FAW in combination with commercial lures initiated.	1 project inception and sensitization workshop for regulatory authorities and policy markers organized. A consultant has been contracted to conduct a review of policy and regulatory procedures, and subsequently guide the registration of biopesticides against fall armyworm in Kenya, Tanzania, Ethiopia and Uganda. A policy brief was developed. A strategic insight policy review on regulatory procedures for biopesticide development, registration and use was drafted. Policies on biopesticides in Ghana and South Africa were reviewed and compared to the harmonized biopesticides registration guidelines of the East African Community (EAC). A press release was distributed on the key findings of fall armyworm biopesticides. An insight interview on fall armyworm biopesticide development, commercialization and upscaling was published in SciDev.	With high collaboration and awareness creation among regulatory authorities and policy makers, registration of biopesticides becomes a participatory action involving developers (R&D institutions), the private sector and regulatory authorities/policy makers. Public-private partnerships (PPPs) are a key to effectively strengthen the biopesticide value chain.

	Harmonization of biopesticides registration guidelines developed and adopted.	Registration initiated for commercial biopesticides with proven record in target countries.	Willingness to pay (WTP) and cost-effectiveness of biopesticides for fall armyworm management in Kenya and Uganda was published. A MoU was developed between *icipe* and RealIPM to facilitate the multilocational field efficacy registration trails, and fast-track the registration of the key biopesticides, Mazao Detain and Mazao Achieve in the target countries (Kenya, Uganda, Tanzania and Ethiopia).	
2. Label-extension procedures initiated for proven commercially available biopesticides and novel combination formulation product developed and validated in the field.	Biopesticide registration fast-tracked. and made available to control FAW and mitigate losses and reduce synthetic pesticides use. Development of new formulations taking into account the interactions between biopesticides and FAW parasitoids,	Field-efficacy trials with Mazao Tickoff and Mazao Achieve 78, and label extension procedures initiated and accomplished with private sector partners and regulatory authorities Non-target effects of Tickoff and Achieve on FAW natural enemies assessed. Commercial biopesticides with proven efficacy introduced in target countries.	6 field efficacy permits were obtained in Kenya (2), Tanzania (2) and Uganda (2) to fast-tract registration of *M. anisopliae* ICIPE 7 and ICIPE 78 as Mazao Detain and Mazao Achieve, respectively, for fall armyworm control. Field efficacy validation of Mazao Detain and Mazao Achieve in Kenya (Embu, Bukura and Mbita) was conducted for two consecutive seasons. Multilocational field efficacy trials to fast-track registration of both biopesticides are currently ongoing in Kenya, Tanzania and Uganda, and are close to completion. In Kenya, multilocational registration trials for *M. anisopliae* ICIPE 78 (Mazao Achieve) have been completed and the report submitted to the PCPB awaiting approval for label extension. First season of the registration trial for *M. anisopliae* ICIPE 7 (Mazao Detain) in Kenya is completed, while the second season trial is underway. In Uganda, two seasons of registration trials for both Mazao Detain and Mazao Achieve are completed, and the last season trial is underway, awaiting yield data for report compilation and submission to MoAAIF and CICB for final registration. In Tanzania, the second season of registration trials for both Mazao Detain and Mazao Achieve is currently ongoing and will be completed in 2 months for report compilation and submission to NBCC and NPPAC. In Ethiopia, discussions are underway with the regulatory authorities to introduce and fast-track registration of the above biopesticides. Socioeconomic field trials of Mazao Detain and Mazao Achieve to assess their efficacy under different cropping systems (push-pull, monocropping and farmer field practices), and impacts of using these biopesticides on small-scale farmers are currently ongoing in Uganda and planned in Kenya.	It is very important to involve regulatory authorities and policy makers from the conception of the project to facilitate the fast-track registration or label extension of biopesticides. Regional guidelines for biopesticide registration enable the biocontrol products introduction, registration, commercialization and upscaling.
3. Additional novel biopesticide products developed and	Portfolio of biopesticides against FAW increased and	At least 5 novel entomopathogens for FAW management identified and curated.	*Beauveria bassiana* ICIPE 676 was found to cause moderate mortality of 30% to second instar larvae of fall armyworm.	Bioprospecting is key to increase the portfolio of biopesticides, especially in the

commercialized through public-private partnerships for FAW management.	new pathogen isolates identified and characterized. New biopesticide products developed, registered and commercialized in partnership with the private sector to manage FAW.	Protocols for pathogenicity and mass production of potent entomopathogens developed, optimized and communicated to the private sector and community organizations. Novel formulations of entomopathogens tested and shelf-life and non-target studies initiated. Eco- and mammalian toxicity for novel formulations generated. Field efficacy of novel formulations of potent isolates established. Registration of at least 2 novel biopesticide products initiated.	*Metarhizium anisopliae* ICIPE 78, ICIPE 40 and ICIPE 20 caused egg mortalities of 87.0, 83.0 and 79.5%, respectively. 22 fungal isolates were screened against adult fall armyworm, and *B. bassiana* ICIPE 621 and *M. anisopliae* ICIPE 7 outperformed all the other isolates causing 100% mortality in adult moths with the lowest LT_{50} values. *Beauveria bassiana* ICIPE 621 and *M. anisopliae* ICIPE 7 were found to be compatible with the fall armyworm pheromone Falltrack with >97% conidial germination in the laboratory. Fall armyworm infected with *B. bassiana* ICIPE 621 and *M. anisopliae* ICIPE 7 were able to transmit infection to untreated moths. 1 peer-reviewed paper published in Journal of Invertebrate Pathology on the efficacy of *B. bassiana* ICIPE 621 and *M. anisopliae* ICIPE 7, and their compatibility with Falltrack. Improved biopesticide application strategies against fall armyworm developed using ICIPE 7 and ICIPE 621 dry conidia in combination with the pheromone through an autodissemination approach. Kenya Biologics has indicated high interest to register and commercialize *M. anisopliae* ICIPE 41 against fall armyworm, and a material transfer agreement is under development. Field efficacy trials with *M. anisopliae* ICIPE 41 are ongoing to validate the laboratory results. Combination of biopesticides (*M. anisopliae* ICIPE 7, ICIPE 78 and ICIPE 41) as 'three in one' was initiated and promising results were obtained. Non-target study of *M. anisopliae* ICIPE 78, ICIPE 7 and ICIPE 41 on key parasitoids of fall armyworm was conducted and no significant effects were found on the performance of these parasitoids. Different oil formulations of *M. anisopliae* ICIPE 41 were tested on second instar larvae of fall armyworm in the laboratory, and corn oil was found to be the best. A bioprospecting study in Kakamega and Bungoma counties yielded 2 *B. bassiana*, 1 *Penicillum rubens* and 1 *Fusarium oxysporum* isolate. In the laboratory, the 2 *B. bassiana* isolates caused >85% second instar larval mortality.	case of invasive pests such as the fall armyworm. Private sector partners are key to upscale newly developed biopesticides.
4. Capacity of partners strengthened for promoting and scaling the use of biopesticides as important components of FAW IPM.	Stakeholders and researchers in the maize value chain are capable of developing, implementing, adopting and promoting biopesticides as a	Training and dissemination materials on biopesticide production and use, and other FAW IPM developed and distributed to reach at least 30,000	6 MSc students have been recruited in Kenya and Uganda. 10,485 households were involved in field demonstrations and training activities on the potential of biopesticides (ICIPE 78 and ICIPE 7) for the management of fall armyworm in the target countries (Kenya, Uganda, Tanzania).	Strengthening capacity through various training activities at different levels is very important for knowledge sharing and involvement of all stakeholders.

	sustainable IPM component for FAW management. Biopesticide use enhanced to reduce synthetic pesticides use for FAW control.	maize growers and extension officers in each target country. Local entrepreneurs trained on biopesticides production through business incubation. At least 6 participatory field demonstration sites established and awareness on efficacy of biopesticides created among at least 6,000 lead farmers. Public-private partnerships established for biopesticide production in target countries and commercialization initiated. Biopesticide use enhanced to contribute to reduction of synthetic pesticide use for FAW control.	In Tanzania, 310 lead farmers were trained through training-of-trainer (ToT) programmes. In Kenya, 200 lead farmers were trained through ToT programs. 5 demonstration farms on vegetable- and maize-intercropping with beans were established in Tanzania to train farmers and organize field days. 15 demonstration farms were established in Kenya. In Uganda, through ToT, 40 lead farmers were trained. An in-depth socioeconomic study on farmers' knowledge and management practices of cereal, legume and vegetable insect pests and farmers' willingness to pay for biopesticides was conducted among 600 and 700 farmers in Kenya and Uganda, respectively. A Licensing Agreement between *icipe* and the private partner Russell Bio Solutions for *M. anisopliae* ICIPE 20 registration and commercialization has been initiated. *icipe* has helped in procuring basic equipment for establishment of a pilot biopesticide mass-production unit at Isinya, Kenya and consequently trained entrepreneurs and farmer groups on biopesticide development and commercialization.	
Specific objective: Enhanced food security, resilience and livelihoods of smallholder maize and tomato farmers through scaling of climate-smart integrated pest management (CSPM) practices and technologies to counter the effects of climate change on pest management by 2022.				
1. Improved knowledge and capacity of farmers, farmer organizations and extension services to implement and policy makers to advocate CSPM technologies to manage pests.	● Provide training to farmers, farmer organizations and extension services to implement and upscale CSPM. ● Engage NARES institutions and policy makers working on climate change and agriculture for scaling and advocating CSPM. ● Provide support to the private sector to create awareness and deliver CSPM technologies to end-users.	● Capacity of at least 2,100 model female and male farmers built to train other farmers by 2022. ● At least 100 farmer-based organizations participate in capacity development for ToT by 2022. ● At least 500 female and male agricultural extension agents participate in training on CSPM technologies and their use to train farmers by 2022. ● Capacity of at least 20 private sector and civil societies built through training by 2022. ● 200 experts from NARES and institutions working on climate change trained on CSPM technologies and mass-rearing of parasitoids to support extension officers by 2022. 100 policy makers engaged.	● Sub-contract agreement was developed between icipe and all 5 projects partners in Ugandan and Ethiopia. ● Parasitoids were mass-reared at icipe. ● Development of guide documents on how to rear pests (stemborers and T. absoluta) and their parasitoids completed. ● 458 farmers were trained in Uganda and 362 farmers were trained in Ethiopia.	●None.

2. Climate-smart pest management technologies integrated, adapted and scaled in Ethiopia and Uganda.	● Strengthen/establish learning sites for scaling CSPM technologies and practices. ● Awareness creation and sensitization campaigns organized among stakeholders on CSPM technologies by partners and *icipe* using multiple communication messages and media tailored to a range of stakeholders including religious/public gathering events, existing mobile phone SMS platforms with a free service farmer hotline, policy briefs, field schools, demonstrations, field days/workshops, TV and radio programs, publications and other extension materials. ● Awareness creation among youth on pests and CSPM technologies. ● Mass-rearing and release of parasitoids for maize stemborers, stemborers and *Tuta absoluta* (~24,000 wasps per week). ● Select viable solutions with public and private sector stakeholders to promote partnerships for scaling CSPM. ● Strengthen farmers' linkages with CSPM technology providers to facilitate uptake. ● Monitor and evaluate the uptake of information and CSPM technologies by	● At least 105,000 farmers (~40% women) reached with either of CSPM technologies in both countries by 2022. ● Synthetic insecticides use reduced by 30% by 2022. ● At least 500 CSPM learning sites established in the target areas by 2022. ● 840,000 beneficiaries (farmers, NGOs, private sectors, farmer-based organizations and policy makers) aware of CSPM technologies. ● Farmers have access to CSPM technologies and practices through multiple communication strategies including SMS, radio, schools, project meetings, social gatherings, etc. by 2022. ● ~24,000 wasps produced per week throughout the project duration. ● 1,500 extension materials distributed by 2022. ● 100 secondary and high schools reached by 2022. ● 41,500 students and school communities made aware of impact of pests and CSPM technologies. ● 1,000 parasitoids per hectare mass produced in local laboratories of NARS in Ethiopia and Uganda. ● 65,100 ha of land under maize and tomato systems benefit from the release of parasitoids for key pest species by 2022. ● At least 100 private-public sector organizations/ institutions/societies involved in assessing the feasibility of parasitoid mass-rearing with the perspective of long-term industrial production and commercialization.	● Mechanism to engage with multiple stakeholders on CSPM technologies established in both countries. ● A multiple purpose platform was developed, and we are currently integrating applications for massive communication. ● Parasitoid import permits were obtained from the regulatory bodies in the target countries. ● Parasitoid export permits were obtained from the regulatory body (KEPHIS) in Kenya.	●None.

	getting feedback through the mobile phone application.	• Level of linkages between farmers and private-public sector improved. 200 mobile phones are made available to role model farmers (champions).		
3. Existing insect pest monitoring networks improved and strengthened to support risk prevention and rapid response.	• Strengthen existing community-based pest monitoring system networks through the use of semio-chemical traps, training of scouts in selected villages and the use of mobile phone applications. • Strengthen access to downscaled climate projections and remote sensing data for the NARES and policy makers.	• At least 1 best existing pest monitoring system improved by 2020. • At least 20 scouts involved in carrying out pest surveillance by 2022. • At least 180 voluntary farmers participate in pest scouting by 2022. • 20 scouts trained on collecting pest data using mobile applications by 2022. • 180 voluntary farmers trained and participate in pest scouting by 2022. • By 2022, at least 20 community-based systems for pest monitoring established. At least 10 NARES have improved access to climate projection and remote sensing database by 2022.	• We have finalized the development of the training materials, enhancing our training capacity and experience.	•None.
4. Impact of and barriers to scaling of CSPM technologies and practices determined.	• Identification of barriers and opportunities to scale CSPM technologies through a value chain analysis. • Generate and document evidence on the benefits of CSPM technologies, practices and services to foster a learning environment and further strengthen the scaling processes in other countries.	• A working paper on barriers and opportunities to upscale CSPM technologies produced and shared with partners by 2020. • Data on socio-economic analysis of CSPM technologies and impacts of key pests available by mid-2022. At least 2 papers documenting benefits of CSPM technologies produced by mid-2022.	• M&E data collection and management tool developed. • Online training on the use of the developed data collection and management tool conducted.	•None.
Specific objective: Joint action to develop biocontrol methods against the invasive FAW in Africa.				
• Productive research links between the Swedish University of Agricultural Sciences (SLU) and *icipe* for FAW management established.	Active research collaboration between SLU and *icipe* formed, developing innovative and sustainable FAW control methods.	Number of joint research proposals and scientific publications. Number of collaborative research undertakings. Knowledge and experience sharing visits and workshops.	Fund transfer agreement being finalized to commence the collaborative research.	Another grant proposal being developed for possible funding by Swedish Research Council.

• Preference and performance FAW and FAW parasitoids on different host plant species determined.	Influence of different host plant species on FAW development and parasitism rates determined by 2023.	Number of peer-reviewed publications on host suitability.	The activities have been rescheduled to commence in 2021 due to delay in fund transfer. FAW parasitoids have been collected and maintained for subsequent studies.	Two new FAW parasitoids have been identified and maintained.
• Competition with other Lepidoptera stemborer pest species determined.	Inter species competition between FAW and stemborer species determined by 2023.	Number of peer-reviewed publications.	The activities have been rescheduled to commence in 2021 due to delay in fund transfer. Preliminary screenhouse and insectary operations started.	Relevant literature review conducted. Activities to commence in 2021 when the fund transfer is effected.
Specific objective: Reinforcing and expanding the community-based FAW monitoring, forecasting for early warning and timely management to protect food security and improve livelihoods of vulnerable communities.				
1. Information generated by CBFAMFEW modeled and used for technology upscaling.	Build capacity of communities for increased awareness, preparedness and decision-making.	Number of people trained in FAW IPM. Number and percentage of hectares protected against FAW. Number and percentage of people practicing appropriate FAW management practices. Percent of maize postharvest loss reduced. Percentage of people trained who retain skills and knowledge after 2 months. Percentage of attendees at joint planning meetings who are from the local community,	Information generated under CBFAMFEW I analyzed and published in 2 peer-reviewed publications.	CBFAMFEW data provide an insight into FAW bioecology and guide policy on actions needed to overcome FAW.
2. Environmentally friendly FAW IPM tools scaled up in partnership with national partners supported by FAW monitoring and prediction initiatives.	Reduced pests and pesticides.	Number of months of household food self-sufficiency on maize as a result of improved agricultural production programming. Number of people directly benefiting from improving agricultural production and/or food security activities. Number of hectares of maize under improved agricultural methods.	FAW IPM technologies (push-pull, maize-legume intercropping, biopesticides, biological control, biorationals, monitoring systems) packaged in form of manuals, videos and disseminated in target countries.	FAW IPM tools are highly appreciated by farmers. However, their availability and accessibility is a challenge. More awareness and engagement efforts with the public and private sector are needed to either roll out the technologies within the extension system or to ensure their availability and affordability.
3. Capacity to scale management options and implementation of sustainable FAW IPM enhanced.	Improving agricultural production and food security.	Number of people participating in project training. Percentage of households with access to sufficient maize seed to plant.	In addition to Ethiopia, Uganda and Rwanda, CBFAMFEW I scaled up to new countries (Zambia and Malawi under CBFAMFEW II).	Despite the COVID-19 pandemic, the use of virtual platforms such as Zoom and Microsoft Teams has been handy to conduct ToTs. >100 extension officers have been trained on FAW biology, ecology and IPM in Zambia and Malawi.
4. Coordination, M&E and Impact assessment.	Build capacity of communities for increased awareness,	Number of people participating in project training/	Working closely with *icipe*'s SSIA team, a M&E strategy has been implemented in Kenya, Uganda and Rwanda.	None.

	preparedness and decision-making. Global advocacy and engagement. Public-private partnerships.	Percentage of people trained who retain skills and knowledge after 2 months/ Percentage of attendees at joint planning meetings who are from the local community/ Number of people trained in FAW preparedness, risk reduction and management/ Percentage of people trained on FAMEWS. Number of students (MSc and PhD) trained. Number of jointly organized events held. Number of private sector businesses directly engaged in FAW response as a result of the program. Total number of individuals indirectly benefiting from FAW IPM program activities. Number of government disaster contingency plans that incorporate private sector aspects as a result of the program.		
Specific objective: Sustainable management of FAW through the FAO Program for Action in Africa, North Africa and the Middle East.				
1. VIPS - a Norwegian open source technology platform for prognosis, monitoring and decision support in agriculture - integrated with FAMEWS to provide FAW forecasting, and ecological model for FAW for Malawi climatic zone developed.	Two-way communication with farmers as an incentive for farmer use. Increased precision of FAMEWS. FAMEWS targets and benefits the farmers directly. FAW ecological model for Southern Africa that can serve as a template to be adapted for other ecozones.	Increased end-user interaction with FAMEWS. Information provided by FAMEWS is found of immediate value for farmers. More efficient scouting and information flow.	Assignment finalized; VIPS engine is part of FAMEWS and further development of the app as expected can make use of the VIPS expert system if desired.	Substantial changes in the FAO FAW task force changed some priorities.
Specific objective: Baseline information on the impact of fall armyworm (FAW) invasion on maize stemborers' communities and their associated parasitoids.				
1. Impact of fall armyworm invasion on maize stemborers' communities and their associated parasitoids in	Study on the influence of temperature on the interactions for resource utilization between FAW and a community of lepidopteran	Peer-reviewed publications.	The intraspecific interaction of fall armyworm larvae resource utilization and their interspecific interactions with maize stemborer communities (including *B. fusca, S. calamistis* and *C. partellus*) was characterized, as well as the effect of temperature on these interactions under laboratory conditions.	Temperature increase caused by climate change is likely to confer an advantage to *C. partellus* over fall armyworm and other maize stemborers.

maize field in a context of climate change.	maize stemborers under laboratory conditions. Study on the larval dispersal capacity of FAW as compared to maize stemborer's larvae. Study on the impact of FAW on larval parasitoids associated with lepidopteran maize stemborers in Kenya. Study on the effect of larval density and duration on the competition outcomes between lepidopteran maize stemborers community and the fall armyworm under laboratory conditions. Study on the Influence of the recent introduction of the fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae), on maize stemborers and their associated parasitoids composition in maize fields in Kenya. Develop a system dynamics model for pests and natural enemies interactions.		Larval dispersal by means of ballooning off and crawling between fall armyworm and stemborers was compared. *Cotesia flavipes* and *C. sesamiae* are not able to parasitize *S. frugiperda* but are attracted to plants infested by fall armyworm.	The invasive characteristic of fall armyworm can be explained, in part, by its higher larval dispersal capacity compared to stemborers. Fall armyworm can impact existing stemborer-parasitoid interactions associated with maize; it might therefore have a negative impact on current stemborer biological control.
Specific objective: Baseline information on host selection and development of parasitoids used in biological control programs.				
1. Baseline information on host selection mechanisms by *Cotesia* spp. parasitoids (Braconidae) of Lepidoptera stemborers.	Determination of the candidate genes involved in host acceptance by *Cotesia sesamiae*.	Peer-reviewed publication(s).	Genetic studies have been initiated that involve use of two *Cotesia sesamiae* populations of Kenya (differing in *B. fusca* acceptance). Cross-mating of the two *C. sesamiae* populations in the laboratory provided evidence for the heritability of host acceptance in the resulting progenies.	The cross-mating experiments are too time- and resource-consuming, as well as too complicated to do. In this context, populations directly collected from the field will be used for genome sequencing.
Specific objective: Use of *Cotesia typhae* in the biocontrol of the Mediterranean corn borer in France.				
1. To conduct research and development for assessing	To analyze the reproductive success of *C. typhae* and	Good parasitoid production for a biological control program of	Reproductive success of *C. typhae* and the molecular mechanisms of virulence analysed.	Time consuming processes to get permits from both France and Kenya.

the feasibility of a future use in France of *Cotesia typhae* as a new biocontrol agent against the maize stemborer *Sesamia nonagrioides* (Lepidoptera: Noctuidae), an important pest of maize in France.	analyze the molecular mechanisms of virulence. This implies a better understanding of the inter-genome interactions that exist between parasitoid wasps and their lepidopteran hosts in general. For that the activities consist: (i) to characterize the bracoviruses of parasitoid wasps (virus types which serve them to efficiently parasitize and develop into the lepidopteran hosts) by genome sequencing of the Cotesia genus available at icipe: *Cotesia typhae*, *Cotesia sesamiae*, *Cotesia icipe* and *Cotesia flavipes*; and (ii) to characterize their pattern of virulence by high throughput illumina sequencing of the related caterpillar hosts, respectively: *Sesamia nonagrioides*, *Busseola fusca/Sesamia calamistis*, *Spodoptera frugiperda* and *Chilo partellus*. To evaluate the potential environmental risk of introducing *C. typhae* in France: risk to non-target insects, risk of establishment and dispersal capacity. To evaluate the parasitism potential of *C. typhae* against the Mediterranean corn borer on corn plantations in insect-proof greenhouses. To evaluate the feasibility of parasitoid mass rearing with	*Sesamia nonagrioides*, an important maize pest in France.	The potential environmental risk of introducing *C. typhae* in France initiated. The parasitism potential of *C. typhae* against the Mediterranean corn borer on corn plantations in insect-proof greenhouses evaluated.	

	the perspective of industrial production and commercialization.			
Broad objective 2: Make available IPM options for horticultural crops.				
Specific objective: Scale out integrated pre- and postharvest pest management approaches for thrips and tospoviruses infesting vegetables and grain legume crops in East Africa in collaboration with international and national partners by 2023.				
1. Dissemination and scaling of thrips IPM strategies based on intercropping, use of biopesticides and semio-chemicals in Eastern Africa.	● IPM strategies for thrips and tospoviruses widely disseminated and adopted by grain legume and vegetable growers.	At least 1,000 French bean, tomato, onion and grain legume farmers and stakeholders reached with thrips and tospovirus IPM strategies by 2021. At least 3 field demonstration of thrips IPM strategies based on intercropping, use of biopesticides and semio-chemicals undertaken in Kenya by 2021. At least 2 popular articles on thrips and tospovirus IPM published by 2021. At least 2 publications on thrips and tospovirus IPM by 2022.	Large-scale field efficacy and demonstration trials for fungal endophyte-based protection of French beans against thrips and other pest infestations undertaken in Kenya. Field assessment of bean flower thrips pheromone components and blends were undertaken in cowpea and French bean farms in Kenya. Performance of the bean flower thrips pheromone in the field seems to be influenced by other factors resulting in a variable response. Compatibility of bean flower thrips pheromones with fungal biopesticides assessed in the laboratory and found to be moderately compatible (Mfuti et al 2021). Detailed assessment of the mating behaviour of bean flower thrips and influence of pheromones on the mating behaviour has been assessed. Evidence for impact of age of sexes on mate choice has been revealed (Adeyemi et al 2021, Awouche et al 2021). Training of 2 Postdocs on bean flower thrips pheromone research and biopesticides completed.	There is a need to strengthen partnership with the private sector for commercialization of endophytes and optimization of bean flower thrips pheromones. Factors influencing variability of bean flower thrips pheromones need to be unraveled.
Specific objective: To explore the potentially synergistic relationship between MAT and SIT when applied simultaneously to improve the efficacy of *Bactrocera dorsalis* fruit fly management.				
1. To assess alternative semio-chemicals for treating sterilized *B. dorsalis* before release to minimize attraction to methyl eugenol.	Pre-release alternative semio-chemicals elucidated for sexual enhancement of sterilized *B. dorsalis* to complement SIT.	Potential alternative semio-chemicals for sexual enhancement of sterilized *B. dorsalis* screened by 2021. Potential alternative semio-chemicals for sexual enhancement of sterilized *B. dorsalis* field validated by 2022.	The native plant *Mondia whitei* is currently being evaluated for its potential to be added in fruit fly diet for sterile *Bactrocera dorsalis* prior to release for SIT. Preliminary results are encouraging, with fed males showing little response to methyl eugenol after feeding for 1 week.	Growers' indigenous knowledge can be adopted in advancing scientific knowledge.
Specific objective: Diversity of endosymbionts and entomopathogens of Dipteran pests and their impacts on dipteran mass-rearing for SIT applications				
1. Assess the diversity of endosymbionts and entomopathogens in mass-reared colonies of fruit flies, *Ceratitis* sp, *Bactrocera* sp. and the tsetse fly *Glossina* sp.	Screen mass-reared colonies of fruit flies (*Ceratitis quilicii*, *Bactrocera latifrons*, B. *dorsalis*) and *Glossina fuscipes fuscipes* for endosymbionts. Screen for entomopathogenic fungi isolates that are less virulent to tsetse fly for	Diversity of endosymbionts in mass-reared colonies of *B. latifrons*, *B. dorsalis* and *Glossina* sp. documented by 2023. Alternative fungi isolates that are less virulent to tsetse fly for compatibility with SIT programs identified by 2023.	Out of 16 *Metarhizium anisopliae* isolates screened on *Glossina palidipes*, 5 have been identified to be compatible with sterile insect technique (SIT). Further work is on-going.	None.

	compatibility with SIT programs for this pest.			
Specific objective: Upscaling and institutionalizing fruit fly IPM technology among smallholder fruit growers in East Africa				
1. Establish the baseline damage caused by different fruit fly species on mangoes and intensify dissemination of fruit fly IPM approaches in the new project action sites in Kenya, Ethiopia and Tanzania.	Regular and systematic fruit sampling of mango in the new target locations to ascertain the damage, abundance and fruit fly composition. Catalogue and establish the host range of major fruit-infesting fruit flies in the locations and establish seasonality of major mango-infesting fruit flies in the target locations. Catalogue and assess the level of parasitism by native natural enemies attacking major fruit fly species in various locations in Zanzibar. Identify suitable and easily accessible sites in consultation with NARS, growers and farming communities in the new project benchmark sites and establish IPM learning sites. Participatory demonstration activities carried out that encompass various IPM management options and assess the impact jointly with NARS and growers. Boost colonies of the two parasitoid species (*Fopius arisanus* and *Diachasmimorpha longicaudata*) at *icipe* for introduction and mass releases in the project benchmark sites.	Quantification of damage and composition of fruit flies. Knowledge on host range of the main fruit flies. Knowledge on seasonality of major fruit flies in target locations. Availability of inventory of native enemies of fruit flies attacking key fruits and their parasitism levels in the project benchmark sites of Zanzibar. Number of IPM technology sites established. Number of model farms with display panels. Number of demonstration sessions on the available fruit fly IPM technologies to growers with NARS. Number of impact assessments undertaken by NARS. Condition of *icipe* cultures of the two parasitoid species. Number of mass releases carried out. Availability of parasitism levels of the two parasitoid species.	• The damage levels recorded were 58.5% in Ethiopia, 65.2% in Kenya and 85.8% in Zanzibar (Tanzania). • Trap catches are still very high though the numbers are in a downward trend over time as IPM interventions are implemented. • 9 host plants were found to be highly susceptible to attack by fruit fly species. • A host range survey of *B. dorsalis* in Zanzibar recorded an additional 3 host plants such as soursop, rubbervine fruit, and Madras thorn. • 4 native parasitoids have been identified in Kenya, Ethiopia and Tanzania with extremely low parasitism rates (>0.5%). • In Zanzibar, despite the incubation of a large number of fruits and vegetables from the field, no native parasitoid species have been recorded by *icipe*. • 21 learning sites, (3 in Zanzibar, 10 in Kenya, 8 in Ethiopia) have been established for IPM activities. • 10 demonstration activities were conducted (3 in Kenya, 2 in Zanzibar, 5 in Ethiopia). • Baseline survey on existing fruit fly IPM technologies with 207 households interviewed in Zanzibar was completed. • 20,000 wasps of both parasitoids were shipped to Ethiopia for mass rearing in the laboratory. • 3 mass parasitoids field releases carried out in Ethiopia at Arba Minch (5,962 wasps released). Two mass releases of parasitoids have been conducted in Kibwezi and Makueni sub-counties in Makueni County, Kenya (6,500 wasps of each species).	• Based on field trials, the best IPM strategy for Ethiopia is the use of lures and the release of parasitoids since biopesticides have not been registered. • In Kenya, the IPM package is complete and also includes baits. • For Zanzibar, since we still have permit issues, the best IPM strategy is based on lures, baits and biopesticides. Trap catches of *B. dorsalis* in Zanzibar are still very high. Intensive application of IPM interventions is required. Furthermore, the growers may need to seek assistance from their local government to access the available management options or subsidies.

2. Develop capacity on IPM and good agricultural practices (GAP) for NARS and growers to support upscaling of fruit fly IPM technologies in the project target countries.	ToT workshop on fruit fly biocontrol and IPM technologies conducted for extension officers and community extension service providers in the project benchmark sites. Awareness campaigns and sensitization on availability of fruit fly IPM in project benchmark sites in Kenya, Ethiopia and Tanzania conducted for farmers, farmer groups and the community at large. ToT workshop on parasitoid rearing carried out at *icipe* for NARS partners on natural enemy production, releases and assessment of impact.	Number of NARS and community extension service providers (CESPs) trained. Number of training materials handed out. Number of awareness campaigns. Number of growers reached. Number of NARs trained on parasitoid rearing.	• 131 extension officers and model farmers have received detailed training on fruit fly IPM technologies, parasitoid rearing and good agricultural practices along the value chain. • 750 English training materials were distributed to growers in Makueni subcounty. • 1,800 training materials (1,200 English and 600 Kiswahili Flyers on fruit fly IPM) were distributed through the BvAT Farmer Communication Outreach Resource Centers to growers in Kenya. • 9 awareness campaigns have been organized to train farmers (15) and extension officers (30). • 739 growers (566 males, 173 females) with 65,343 trees have been sensitised and trained on fruit fly IPM interventions. • Starter-kits were distributed to farmers in the target countries.	• BvAT has a strong farmer communication team on the ground that can assist to facilitate dissemination activities. Despite movement restrictions, we teamed with BvAT for dissemination activities.
3. To create linkages and partnerships for enhanced transfer and upscaling of fruit fly IPM technologies and strengthening of the mango value chain in Kenya, Ethiopia and Tanzania.	Approval by county governments to open outlets to supply fruit fly IPM technologies at the grassroot level for growers' accessibility. Database of mango growers in the project countries created. Linkages between suppliers and growers/growers' association created to increase demand/supply of the fruit fly IPM technologies at the grassroot level and enhance scaling up and uptake of the technologies. Innovative market information exchange apps (interactive platforms) for fruit fly IPM technologies developed that link the growers (vegetables and fruits) and the suppliers.	• Numbers of stakeholder meetings taken place. • Number of approvals by county governments. • Number of databases of mango growers reached from previous project phases and the proposed phase. • Accessibility of database. • Awareness of private sector. • Number of private sector partners supplying the technologies to the growers. • Number of interactive platforms. • Number of committees formed. Number of meetings with NARS on resource mobilization for IPM technologies sustainability.	• 1 interactive communication platform is running and 2 live radio interactive programs have been aired on the radio station Mwatu FM targeting farmers in Eastern Kenya. • 488 growers have been databased and 17 advisory messages sent to them. • Two radio programs have been aired that reached 200,000 growers. • 3 private companies producing and selling fruit fly IPM technologies (Kenya Biologics, Real IPM and Farmtrack Consulting) have been linked to NARS and other stakeholders.	• Grower list for the interactive platform is being updated regularly for wider dissemination despite movement restrictions.

	Contract and engage NARS partners and growers in resource mobilization at local and regional levels to enable them undertake field testing and continued sharing of the fruit fly IPM technologies in the communities.			
Specific objective: Integrating pest and pollinators management (IPPM) to enhance productivity of avocado and cucurbits among smallholder growers in East Africa				
1. Avocado-cucurbit-production systems in diverse agro-ecologies characterized for the role of pollinators and insect pests, and associated extrinsic and intrinsic factors.	Avocado-cucurbit production systems in diverse agro-ecologies assessed.	Landscape dynamics for cucurbit-avocado production systems in 3 diverse agro-ecology characterized. Species composition and genetic diversity of insect pests and pollinators and their abundance on target crops in 3 production systems assessed. Pollination deficit in the target crops assessed in at least 3 landscapes. Symbionts in key pests and pollinators of cucurbits and avocado characterized.	2 avocado systems (Kilimanjaro, Tanzania; Muranga, Kenya) and one cucurbit system (Machakos, Kenya) characterized according to vegetation productivity dynamics, land use/land cover (LULC) and farming systems. Cropping systems characterized for Machakos. For avocado, innovative mapping methods have been tested. Pest and pollinator occurrence/densities were linked to avocado systems (Muranga). Best agricultural practices documented during the baseline and knowledge, attitude and practices (KAP) surveys. Analysis of genetic diversity of honey bees ongoing; their abundance has been established on avocado and is ongoing for cucurbits. Data on floral patterns is collected, with analysis ongoing. Symbionts of honey bees characterized. 5 MSc ongoing on landscape characteristics/symbionts.	We confirmed the presence of core gut microbiota in honey bees. Phenological variables were extracted from free satellite data using a new procedure, and used to improve LULC, farming and cropping systems maps, including agro-forestry systems. In Muranga, Bactrocera dorsalis population density was lower in high vegetation classes (NDVI), while that of *Thaumatotibia leucotreta* did not vary. Small-scale farms showed higher frequencies of bees, while large-scale farms showed higher frequencies of Diptera/Lepidoptera. Pollination deficit was 27% in small-scale farms. With pollination services (PS), pollination deficit in farms in high and medium NDVI was removed completely, while in low NDVI reduced to 4%.
2. Potential for integrating pollination and IPM services assessed at landscape level.	Knowledge of integrating pollination and IPM of the target pests enhanced.	Pest management practices and floral biology in the target crops characterized by 2019. At least 4 existing (biopesticide, protein food bait, male attractants, sanitation) and 1 new IPM option for sustainable management of insect pests of cucurbits and avocado adapted for IPPM and implemented. The nature and magnitude of interactions between the pollinators and IPM practices documented. Impact of integrating pollination and IPM on key cucurbit and avocado pests and pollinators' health established.	Pest management practices have been assessed for avocado and cucurbits, data on avocado floral cycles collected with analysis ongoing; data on cucurbit floral cycles ongoing. Optimum hive density for avocado ongoing. Existing IPM packages for avocado/cucurbit pests assessed for integration with pollination services (PS). Biopesticides screened against adults/pupae of 2 fruit fly species. Biopesticides screened with/without traps in the field. Effect of biopesticides assessed on honey and stingless bees in the laboratory. On-farm validation of existing and new IPM options that enhance pollinator diversity is ongoing in 92 farmer fields. 1 MSc/1 PhD ongoing on symbionts/field IPPM.	Among 15 fungal isolates, ICIPE 69 caused highest *Zeugodacus cucurbitae* adult (94%) and pupal mortality (74%); was found to be compatible with a commercial lure; had an effect on oviposition; and can be horizontally transmitted among male and female flies. Based on development of new models for conidial germination and mycelial growth, we identified isolates ICIPE 7, ICIPE 20, ICIPE 62 and ICIPE 69 as thermotolerant, and we are investigating ICIPE 69 on pollinators in screenhouses. A bioassay showed that isolates ICIPE 7, ICIPE 20 and ICIPE 69 moderately affected survival of honey bees (15-40% mortality) but not of stingless bees.

3. Management interventions for target crops based on improved pollination services and IPM practices adapted, validated and implemented.	Increased production of quality avocado and cucurbit as a result of enhanced pollination and application of IPM of the target pest. Income of avocado and cucurbit farmers enhanced.	Pollination services intensified through their conservation (managed and wild). Sustainable pollination and best-bet IPM options for cucurbits and avocado promoted. Impact of enhanced pollination services and IPM on avocado-cucurbit system productivity established.	Large on-farm trials implemented and results are being analyzed, leading to strategies for enhancing PS across landscapes. IPM, PS and IPPM being promoted through farmer-of-farmer trainings and demonstration gardens. O3 indicators: ongoing. Impact of enhanced PS and IPM on productivity established for avocado, ongoing for cucurbits.	Large-scale trials (79 farms) were conducted in all sites to test the combined benefits of IPM and PS in avocado and cucurbits. In Muranga, diversity of pollinators increased drastically with increasing vegetation. Pest densities were higher in low than in high NDVI. Pest populations were reduced by IPM across all landscapes. Avocado fruit set (but not yield) increased in both PS and IPM. *Apis mellifera* was the most abundant pollinator but did not significantly increase in the PS treatment. Other pollinators were more abundant and diverse in medium and high NDVI.
4. Impacts of integrating pollination and IPM services on farmers' livelihoods determined.	Benefit and impact of integrating pollination services and IPM of the target pest on farmers' livelihoods documented.	Knowledge, attitude and practices (KAP) towards IPPM documented. Impacts of IPPM interventions on livelihoods of cucurbits and avocado producers documented. Ex-ante adoption of IPM pollination services documented.	KAP related to IPM and PS assessed for cucurbits. Economic efficacy of IPM/PS integration will be finalized after the endline study in 2021. Constraints and opportunities of adopting IPM/PS studied through a willingness-to-pay (WTP) study in all sites. 1 MSc on socio-economics completed.	Based on a baseline study comprising 436 (Tanzania) and 410 (Kenya) avocado-growing households, ex-ante analysis demonstrated that total economic surplus of IPPM in Kenya averages US$ 352.1 million/year. In Tanzania, total economic surplus averaged US$ 19.7 million/year. IPPM is expected to lift 55,509 and 14,231 people/year out of poverty in Kenya and Tanzania, respectively.
5. Strengthen capacity, transfer technology and create policy awareness on IPM-pollination integration.	Knowledge and skills of avocado and cucurbit farmers, growers, extension officers, policy makers and other stakeholders related to IPM-pollination integration enhanced. A cohort of trained young scientists created.	At least 3 ToTs and 4 farmer field days on integration of IPM and pollination services targeting 6,100 beneficiaries held. At least 2 public-private partnership agreements formed to enhance availability of IPPM products for end-users. At least 3 awareness events targeting growers and policy makers held. At least 3 PhD and 2 MSc students trained on bee symbionts, integration of IPM with pollination services and GIS/earth observation tools.	132 NARS personnel (TPRI: 26; KALRO/Kenyan research organizations: 40; local governments: 66) and 2,411 growers (Kilimanjaro: 964; Muranga: 1,411; Machakos: 36) trained. 5 public-private partnerships (PPPs) continue: RealIPM (Kenya), Kenya Biologics (Kenya) for protein baits, biopesticides, traps; JustBees (Tanzania) for stingless bees; Africado (Tanzania), Kakuzi (Kenya) for joint research/access to outgrower groups. Awareness events for growers/policy makers will be held in 2021. 2 MSc students completed, 8 MSc and 4 PhD students will finalize during 2021.	2,411 growers (1,370 M/1,041 F), 66 extensionists (35 M/31 F) and 66 NARS personnel (33 M/33 F) were trained as experts. Training materials were produced and used for training-of-trainers. 14 students (10 MSc/4 PhD; 6 M/8 F) have or are conducting research in the project. The COVID pandemic halted training of farmers in Machakos and Kilimanjaro, but training happened in Muranga. In lieu of an annual workshop, virtual one-on-one meetings were held. Partner changes: TARI finished activities due to lack of cucurbit sites in Tanzania. No-cost extension: will be implemented to finalize activities that were postponed due to pandemic.
Specific objective: Combating arthropod pest for better health, food and resilience to climate change (CAP-Africa)				

1. The influence of climate change on pollinators in Kenya and Tanzania documented.	Past and present pollinators population level and pollination deficit in Kenya and Tanzania determined.	Historical data collected on key pollinators, pests and natural enemies of avocado, cucurbits, and tomatoes at the action sites by 2022. Catalogue of pollinator diversities of one of the target crops developed by 2022.	The Western honeybee *Apis mellifera* was the most dominant pollinator. Other pollinators recorded on avocado were in the orders Diptera, Coleoptera, Lepidoptera. Field assessment of pollinator diversity was undertaken at two sites in Kenya (Embu and Taita Hills). Identification of 2,000 specimens is currently ongoing and will be reported in the following reporting period.	None.
2. Strategies to mitigate the threat by invasive species in Africa developed and the most critical pathways of entry determined.	Risk maps and pest risk analysis (PRA) as early warning tools to safeguard against invasion by alien invasive pests documented.	Number of growers trained on the IPM of key invasive pests of the target crops by 2021. Ecological models simulated to produce maps for potential threatening invasive species by 2022. PRA for at least 3 invasive pests threatening Africa documented by 2022.	307 tomato growers (44%females) were trained on *T. absoluta* management 654 avocado growers (38% females) were trained on management of fruit flies. Maps for potential invasion by and establishment of the Asian citrus greening disease were developed (Ajene et al 2020). The Asian citrus psyllid *Diaphorina citri* was detected for the first time in Ethiopia (Ajene et al 2020). 1 Msc student has been recruited to conduct pest risk analysis of *Drosophila suzukii*.	None.
Specific objective: Assessment of innovative pest biocontrol technologies for sustainable intensification of fruit production systems				
1. Existing farmers' knowledge, perception and practices that may enhance or constraint the adoption of innovative fruit fly management strategies understood.	Farmers' knowledge, perception, and practices that may enhance or constraint the adoption of innovative fruit fly management strategies documented and shared with stakeholders.	1 baseline survey in at least 2 sites in Kenya and Senegal by end of 2019. At least 1 working paper by mid-2020.	Paper generated from the baseline survey data and it was presented at the 2020 Tropentag conference (9-11 September 2020). It is entitled 'Adoption and dis-adoption of sustainable agriculture: a case of farmers' innovations and integrated fruit fly management in Kenya'. The above paper submitted for peer-review and consideration for publication in the journal, Agriculture.	The study revealed that despite the rigorous dissemination and promotion of fruit fly IPM, use of chemical pesticides remains the main method for management of pesticides. Dis-adoption of the technology was also evident, and associated with limited access to the technology, costs and technical knowledge.
2. Demonstrate the agronomical and socio-economical effectiveness of innovative fruit fly management strategies on a pilot territory.	Socio-economic impacts of the innovative fruit fly management strategy established and shared with partners.	Field pilot experiment (RCT format) in at least 2 sites in Kenya and Senegal by end of 2021. At least 1 peer-reviewed manuscript by end of 2021.	Field pilot experiment was designed and initiated during the onset of the 2020/2021 mango season.	Initial observations showed significant differences between IPM users and the control groups. Results from the entire season will be reported in 2021.
Specific objective: Combating the invasive tomato leafminer *T. absoluta* through the Implementation of an eco-friendly IPM approach on tomato in East Africa.				
1. Classical biocontrol of *T. absoluta* in the target country using the parasitoid *Dolichogenidea gelechiidivoris* undertaken.	The performance of the co-evolved parasitoid tested in the laboratriy. Parasitoid released in the field and its impact on the target pest assessed.	The laboratory performance of the parasitoid against *T. absoluta* determined by 2020. Field release of the parasitoid undertaken, and parasitism level assessed by 2021.	Laboratory studies on performance of *D. gelechiidivoris* against the African population of *T. absoluta* yielded outstanding results (over 70% parasitism). Details of this study were published (Aigbedion-Atalor et al 2020).	Close collaboration with NARS and the regulatory body in fast-tracking the importing and release of natural enemies.

			D. gelechiidivoris was released in Kirinyaga, Kenya, being the first time the parasitoid is released outside its native range of South America. 1 Ph.D student has been recruited to work on various aspects of the project including following up on field establishment of the parasitoid.	
2. Socio-economic impact of vegetable pest management technologies assessed.	Farmers' perceptions of the impact and management of *T. absoluta* assessed. The economic burden of *T. absoluta* in tomato production in the target project sites determined. Ex-ante demand for IPM technologies for management of *T. absoluta* among tomato growers estimated.	Stakeholders and partners made aware of the economic burden of *T. absoluta* by 2020. Farmers' perceptions of management of *T. absoluta* documented by 2021. Potential demand of the innovative *T. absoluta* management approaches determined and shared with stakeholders by 2021.	Socioeconomic baseline data collected, and descriptive and empirical data analysis is in progress.	None.
Specific objective: Promote sustainable management of *T. absoluta*, an invasive pest of solanaceous vegetables, for food and nutritional security in East Africa.				
1. Efficacy of potent entomopathogenic (EPF) and endophytic fungal isolate(s) for *T. absoluta* suppression validated.	Screening and validation of EPF- and endophyte-based pesticides. Development of an attract and kill product based on pheromone lures and EPF-based biopesticides. Assess the role of fungal endophytes in inducing systemic resistance against *T. absoluta* in tomato.	The most promising EPFs validated on large scale by 2020. Parameters for an attract and kill product based on EPFs with lure strategies standardized by end of 2019. Induction of system resistance by endophytic fungi explored by end of 2020.	• Endophytic and insecticidal properties of 15 fungal isolates in two *T. absoluta* host plants (*Solanum lycopersicum* and *S. scabrum*) published (Agbessenou et al 2020). • 3 potent EPF isolates have been identified as good biocontrol candidates in combination with pheromones for mass trapping to suppress the pest population in solanaceous production system (Akutse et al 2020).	Behavioural response assays of *T. absoluta* to endophyte-colonized tomato and nightshade plants will add value to management strategies that are being rolled out.
2. Solanaceous crop IPM targeting *T. absoluta* validated and demonstrated.	*T. absoluta* IPM strategy encompassing mass trapping, garden sanitation, agronet technology, endophytes and EPF validated under controlled field trials. Based on efficacy, availability and acceptability by growers of the various IPM options, an IPM package encompassing at least 2	IPM package for *T. absoluta* validated in at least 1 benchmark sites in each of the project countries by end 2020. Best-bet IPM options for *T. absoluta* suppression implemented by mid 2020. At least 2 potent management options of the *T. absoluta* IPM package widely disseminated and demonstrated to growers in the 3 project countries by end 2020.	Survey for *T. absoluta* occurrence in tomato production fields was conducted in the Eastern region (districts of Mbale and Kapchorwa) and Central region (Masaka district) of Uganda. • 65 tomato fields were surveyed to determine the distribution, abundance, dynamics, host plants, damage levels and natural enemies of *T. absoluta*. • Highest *T. absoluta* damage was observed in Masaka while lowest damage was observed in Mbale. • In Tanzania, activity on diversity and abundance of *T. absoluta* associated entomopathogenic fungi under different tomato agro-	• Main pest on tomato in all the 3 project countries is *T. absoluta*. • EPF strains have been isolated in Tanzania and Uganda, and these can be developed further as biopesticides.

	potent management options demonstrated with growers in the 3 target countries. Utilization of chemo-ecological characteristics of local wild tomato for *T. absoluta* suppression.	Blends for *T. absoluta* repellency from wild tomato identified and characterized by end 2021 and evaluated for *T. absoluta* suppression in a push-pull arrangement by 2021.	ecological zones of Tanzania was initiated through a soil survey in Morogoro and Arusha region. Further work on characterization is on-going.	
3. Socio-economic impact of vegetable pest management technologies assessed.	Knowledge, attitudes and practices (KAP) of at least 2,000 farmers in regard to tomato production and IPM technologies assessed. Tomato production systems in the target sites documented and shared with stakeholders/tomato supply chain actors. Stakeholders and partners made aware of the economic burden of *T. absoluta*. Potential demand of the innovative *T. absoluta* management approaches determined and shared with stakeholders. Tomato market value chain actors informed about the economic feasibility of commercializing fungal-based biopesticides.	Baseline survey datasets. At least 1 report on farmers' KAP on tomato production and pest management in Kenya and Uganda by end of 2019. At least 1 report before end of 2019. At least 1 report before end of 2020. At least 1 peer-reviewed paper by mid-2020. At least 1 report before end of 2020. At least 1 report before end of 2021.	• A study revealed that growers had adequate knowledge regarding the pest, with >60% of the respondents correctly identifying *T. absoluta* symptoms and associated it with 36% loss of the tomato crop. • The use of synthetic chemicals was reported as the main method for the management of *T. absoluta (*100% of the respondents), with >69% of them using a cocktail of different insecticides to make them more effective. • Insecticides comprise the largest share of the variable input costs, with 70% of the insecticide cost targeting *T. absoluta.* • Using economic impact quotient (EIQ) and gross margin analysis, we showed that, on average, tomato growers in Kenya and Uganda earned a gross income of $3,282 and $895 per year, respectively. • A high proportion of farmers were willing to adopt the IPM strategy for management of *T. absoluta.*	Overuse of pesticides is very rampant on tomato agro-ecologies.
4. Capacity of NARS for management of *T. absoluta* strengthened.	ToT workshop for capacity building of NARS, NGOs and private sector partners on *T. absoluta* IPM in the target countries. Farmer field schools for hands-on training on IPM technologies. Public awareness to facilitate large-scale adoption of technologies. Provide advanced level training to national partners.	At least 30 NARS from each project country trained on the developed IPM package by end of 2020. At least 1 FFS conducted in each project country by mid 2021. At least 2 awareness campaigns undertaken in each project country for large scale adoption of the developed IPM technologies for *T. absoluta* management by the end of the project. At least 2 PhD and 1 MSc students trained on IPM technologies for *T.*	• 7 trainer of trainers (ToT) workshops and 2 farmer field days have been conducted. For the ToT, 124 individuals were trained (88 males, 36 females) while for the farmers field days, 88 farmers were trained (49 males, 39 females). • 220 *T. absoluta* male lures, 120 *T. absoluta* water traps, 100 delta traps, 100 sticky pads and 440 educational materials were distributed amongst the trained farmers. • 3 PhD students and 6 MSc students were recruited to work on different aspects of the project.	With the COVID-19 pandemic, virtual training offers a platform for training of trainers, although with limitations in hands on field demonstrations of IPM.

		absoluta suppression by end of the project.		
Specific objective: Alien invasive fruit flies in Southern Africa: implementation of a sustainable IPM program to combat their menaces.				
1. Sustainability of mango production for food and nutrition security through the adaptation, dissemination and upscaling of proven fruit fly IPM technologies enhanced.	Enhanced mango yields. Use of synthetic chemical insecticide significantly reduced.	Mango yield increased by at least 25% by 2022. Reduction in chemical insecticide use by 50% by 2022. 40 demonstration and learning sites for scaling up proven IPM technologies established in Zambia, Zimbabwe, Malawi and Mozambique by 2021. At least 1 working paper on landscape level land use and land cover characterization to guide the implementation of the IPM technologies by 2021. Maps and a working paper elucidating suitable areas for parasitoid establishment to guide their release by 2021.	40 demonstration learning sites were established in the four project-implementing countries in Southern Africa. Training on implementation of the fruit fly IPM package currently ongoing. Ground-based data on land use/land cover (LULC) classes were collected in Malawi and Zambia, and are currently being used as reference points to classify satellite imagery and produce LULC characterization maps using machine learning classification algorithms. GIS work in Mozambique and Zimbabwe slowed down by COVID-19 pandemic restrictions.	Flexibility is needed in adjusting the project activities in response to accommodate unforeseen emergency such as the COVID-19 pandemic.
2. The role of biocontrol agents (*F. arisanus* and *D. longicaudata*) in suppression of the alien invasive *B. dorsalis* enhanced.	Institutional and personnel capacity on application of biological enhancement. Native and invasive fruit flies significantly suppressed. National laboratories for parasitoid rearing upgraded.	Mass-rearing of introduced parasitoids by 2021. Upgrading national laboratories for parasitoid rearing by 2021. Obtain and renew import permits for the introduction and releases of parasitoids in the target countries throughout the project period. Introduction and large-scale augmentative releases of *F. arisanus* and *D. longicaudata* by 2022. Assessment of establishment, colonization and dispersal of released parasitoids, and assessment of their effectiveness on *B. dorsalis* populations by 2022.	Colonies of parasitoids were boosted at *icipe*, and the rearing unit has now a capacity to produce 25,000 wasps/month. Laboratories in Zimbabwe and Mozambique have initiated the rearing of the two parasitoids and *icipe* is providing technical backstopping. The two fruit fly parasitoids were released in Zimbabwe for the first time and the event was officiated by top government officials and attended by local and traditional leaders.	Selection of the right partners in project implementation is vital should icipe be unable to physically coordinate activities on the ground (such as during the COVID-19 pandemic).
3. Socio-economic and gender impact of the IPM interventions in the mango	Differential impact of socio-economic status and gender on fruit fly IPM interventions	At least 1 ex-ante study undertaken by 2021.	An abbreviated women's empowerment in agriculture index (A-WEAI) survey was conducted in Malawi to measure women empowerment. In Zimbabwe, key informant interviews and focus group discussions	None.

production and value chain assessed.	in the mango production and value chain elucidated and documented.	At least 100 researchers, policymakers, farmers, extension officers and donors are aware and recognize the economic, social, environmental and human health impacts of interventions by 2022. The socio-economic and gender impact of the IPM interventions in the mango production and value chain assessed by 2022. Barriers and success factors for promoting and upscaling IPM technologies among women and youth in the mango value chain understood by 2021. Cost-benefit analysis of the existing management practices and the proposed IPM technologies conducted by 2022.	(FGDs) were done. Data have been collected and are currently being analyzed. More socioeconomic work will be conducted in 2021 in Zambia using the project-level WEAI (pro-WEAI). Training is ongoing, with a total of 54 agricultural extension officers and model farmers (46.3% male, 53.7% female) trained in Zimbabwe and Zambia to date.	
4. Human and institutional capacity for research and development for sustainable mango production in the target countries and beyond enhanced.	Capacity of the beneficiaries in the target countries for sustainable mango production improved. National and regional networks for implementation of area-wide fruit fly management Initiated and fostered. Agricultural innovation platforms (AIPs) to enhance stakeholder interaction and capacity for effective information sharing and market linkages strengthened.	At least 12 ToT workshops carried out by 2022. At least 10 AIPs established by 2022. 10,000 school students (disaggregated by gender) receive education on and become aware of IPM fruit fly management by 2022. 20,000 extension training materials produced by 2022. 1 million resource-poor farmers and policy makers aware of fruit fly IPM by 2022. 3 postgraduate students graduated by 2022.	A total of 2 ToTs were conducted in Zimbabwe and Zambia, and more are expected to be conducted in Mozambique and Malawi as restrictions on movement and gatherings due to the COVID-19 pandemic are eased. 1 PhD student is currently enrolled in the project in Malawi.	None.
Specific objective: Investigate the diversity and potential of plant-vectored viruses as a biopesticide against insect and insect-transmitted plant viruses in common bean.				
1. Identify the diversity of insect-infecting viruses and the plants that host them.	Usable genomic knowledge of a 'common virome, between plants and vectors.	Virus sequences and whole-genome information of circulating dicistroviruses in aphids and common bean.	Meta-transcriptomic detection of dicistroviruses from aphids and their host plants generated a large dataset. We detected the presence of Big Sioux River virus in a significant collection of samples and viruses similar to the Hubei Virus-55 Spider virus in aphids collected from maize.	A variety of technologies can be used to generate this data. The preference was for HTS data generated by Illumina sequencing to maintain consistency. However, due to the disruptions experienced in generating this

				data in a timely manner, other platforms such as Oxford Nanopore will be used.
2. Investigate how dicistroviruses affect aphid performance, feeding behaviour and plant virus vectoring ability.	Established dicistrovirus-carrying aphid populations from 'clean' aphids that can be used in bioassays.	Generate and launch a full-length cDNA clone of at least 1 dicistrovirus (ALPV) into aphids or in a host plant.	Due to difficulties of access to insectary facilities because of the Covid-19 and the delay in starting the project, experiments planned at Cambridge University have not yet started. At *icipe*, procurement of insect containment consumables and setting up of the experiments has commenced in 2020.	The difficulty in accessing facilities for an extended period of time was not anticipated. In future, colonies of aphids will be kept at i*cipe* so that there is no complete stop to activities.
Specific objective: An integrated approach to mango production to improve smallholders' food security and incomes in Ethiopia.				
1. To develop, implement and scale a holistic approach to mango production, based on IPM, that will increase production and productivity, reduce crop losses, and promote eco-friendly pest management.	An integrated mango production approach widely practiced, mango production and productivity improved. Fruit losses abated and growers' income increased, food and nutritional security enhanced. Ecologically friendly participatory IPM technologies, information, and biocontrol agents for managing key pests of mango advanced. Capacity of local institutions and partner skills and knowledge transformed.	Number of IPM tools scaled. Number of smallholder growers trained. Number of nursery and orchard management tools, postharvest handling tools. A classical biocontrol program against the white mango scale implemented.	Planned activities and baseline studies are being implemented successfully; host farmers selected, partners identified, sites selected to implement the project activities.	None.
Specific objective: Development of ant-based repellent semio-chemicals as new IPM tools for fruit fly management.				
1. Identification of an ant-based repellent volatile.	• Insect rearing program. • Identification of the gland synthetizing the repellent. • Identification of the bioactive compound.	• Number of colonies. • Number of bioassays. • Number of biological models tested. • Number of bioactive compounds tested.	• 2 publications. • Thesis.	• Some candidate repellent compounds have been identified from the alkene and carboxylic acid family. • The chemical compositions of 4 glands have been identified.
2. Assessment of ant-based semio-chemicals on parasitoids.	• Assessment of negative impact of repellent semio-chemicals on parasitoids. • Combination of repellent semio-chemicals with parasitoids in an IPM program.	• Number of bioassays. Number of biological models tested.	Design of the protocol.	• There was an issue to reach a satisfying parasitism rate in the bioassays for *Fopius arisanus*. • Assays are ongoing for the parasitoid *Diachomismorpha longinoda*.
3. Assessment of the presence of ant on mango pollinators.	• Identification of flower visitors and efficient pollinators.	• Field survey. • Number of DNA barcodes.	• No known pollinators were identified in August but some were discovered in March 2021. • A new mission will be organized in September 2021.	• The blooming stage of the mango flower seems to play a key role in the attraction of pollinators.

	● Impact of predators on pollinators and pollination.			• Stingless bees have been identified and will be DNA-barcoded.
Specific objective: Development of a new control strategy based on the combination of sterile flies and entomovectoring of biopesticides to control *B. dorsalis*.				
1. Identification of the behavioural determinants and chemical cues in mating success.	● Optimization of the mating success and lekking of males.	Number of bioassays.	A first article is finished and readied for submission based on mesocosm results.	• There is no negative effect on rearing, sterility or infestation. • The dynamics of pheromone production has been analysed on methyl eugenol diet. The methyl eugenol diet increased mating and lekking behavior.
2. Optimization of the new strategy in a mesocosm.	● Development of the biocontrol technology for pilot implementation.	Number of bioassays.	There was a delay due to the COVID-19 pandemic as no sterile flies could be received.	After 2 weeks, 80% of the fly population died.
Specific objective: Development of new control strategy based on the combination of netting technology and biocontrol to control tomato pests.				
1. Optimization of the netting technology and biocontrol.	New tomato production system for smallholder farmers.	Number of field trials.	Nairobi, Kenya locked down due to the COVID-19 pandemic, and only the first replication was done.	• The kairomone seems to be an attractant for the whitefly parasitoids as the parasitism rate increased in plots with the kairomone.
2. Vulgarization of the netting technology and biocontrol.	● Leaflet and video clips distributed.	● Number of leaflets. Number of video clips.	1 video clip has been produced. 1 leaflet has been produced.	A second shooting needs to be conducted as not all pests were present in the field.
Specific objective: Establishing the status of the alien invasive *Drosophila suzukii* in Kenya and develop measure for its containment and management.				
1. Delimiting survey for *D. suzukii* in major berry-producing areas undertaken.	The status and extent of spread of the pest determined.	The status of the pest in Kenya established by 2021. The extent of spread of the pest documented by 2021.	Delimiting survey to establish the extent of spread of *D. suzukii* was undertaken in major berry-producing areas. So far, the pest is limited to Naivasha, Kenya. A paper detailing the findings has been published (Kwadha et al 2020).	It is important to stockpile the trapping material in the face of a pandemic such as COVID-19.
2. IPM measure to contain the pest implemented.	The pest confined to the detection area.	The spread of the pest to other areas curtailed by 2022.	Trapping using various lures implemented at the detection site.	None.
Broad objective 3: Make available IPM options for industrial crops.				
Specific objective: Generate sustainable wealth creation for improved livelihood and poverty alleviation in rural areas, through a green circular economy and sustainable coffee production (SCP) promotion in Africa.				
1. Implementing and achieving a triple certification scheme: fairtrade (FT), organic (ECO) and geographic indication (GI).	● Mount Rwenzori coffee production chain is capacitated and empowered. An organized structure is created, which is suitably trained and equipped, and meant to remain operational after the termination of the project.	● Training publication (factsheets, guidebooks). ● A practical handbook on the triple certification scheme. ● GI book of requirements. ● Project database created. 21,000 contracts with farmers for GI, FT and ECO certification.	● Geographic indication activity delayed due to non-access to sites/partners cooperatives (planned training seminars postponed; coffee quality map not finalized). ● Fairtrade and organic certification process on-going.	• No field access from Nairobi for 10 months in 2020. It has been a challenge to organize remotely the implementation of the activities.
2. Creating and implementing a dynamic, interactive	A platform providing a powerful organizational tool	● GI, FT and ECO certification criteria compendium.	● Platform 90% achieved. ● Field validation initiated, not finalized	• The activity requires serious follow-up for adoption and implementation by

knowledge platform, supporting project development.	for information exchange, learning, management (monitoring), visibility and advocacy of the triple certification process.	Various site maps created (topography, administration, climate, agrosystems, production quality, quality traceability) for project management and commercial interface (relation with buyers).		cooperatives; this could not be ensured during 2020, hence an important delay.
3. Expertise transferred to and acquired by partners in the domains of IT, quality management and certification program implementation.	Farmers' coffee income is improved by a minimum of 35% from certification; a price premium is obtained through the general improvement of Mount Rwenzori coffee performance.	● Quality management procedure. ● Recruited staff position. Social and legal prospective study developed.	Only partial training done, slowing the adoption process of IT tools.	None.
4. An IPM strategy for Mt Rwenzori coffee production implemented; a climate change impact assessment and adaptation strategy developed; a GIS system-based, descriptive and dynamic representation of certified Mount Rwenzori coffee production; publicity and visibility of the project.	The 'green' performance of Mount Rwenzori coffee value chains and SCP practices are implemented are enhanced; waste production is reduced and inorganic chemical are banned.	● Compendium on coffee pest and disease control measures in compliance with ECO certification. ● IPM and climate change adaptation strategy guidebook. ● Pamphlets, factsheets. ● SWITCH regional conference compendium. ● Policy recommendations. Platform implementation.	● Important delay to capture relevant data sets. ● Partial data sets obtained for pest and disease, and weather information.	● The activity requires follow-up for adoption and implementation by cooperatives; serious effort needed in 2021 to evaluate the impact of the loss of data on the expected outputs, and to see if the impact can be mitigated.
Specific objective: Support the sustainable development strategy of Uganda's green economy by improving the performance of coffee agroforestry production systems to mitigate climate change impact on the national agriculture and forestry sectors.				
1. Improved coffee agroforestry systems are designed both for high and low altitude along 5 transects.	Promoted agroforestry models improve farmers capacity to face climate change challenge.	Number of farmers adopting improved agroforestry systems. Acreage and regions where improved agroforestry systems are implemented. Amount of carbon sequestrated.	No 2020 outputs yet.	None.
2. Options delivered to diversify farms and farm products with fruit trees to decrease economic dependence on one cash crop and ensure environmental sustainability.	Increased fruit production and increased income of coffee farmers	Fruit production statistics Number of farmers adopting/increasing fruit production	No 2020 outputs yet.	None.
3. A web-based, IT platform implemented to ensure information sharing, facilitate	New management and information exchange tool is created.	Number of coffee producers with access to web-based knowledge platform.	No 2020 outputs yet.	None.

project management (M&E, database management) and enhance project visibility to external stakeholders.		Number of mobile device applications created. Number of applications installed. Number of consultations of the platform. Compendium generated about coffee and fruit production.		
4. At least 50,000 producers are involved in at least one certification scheme.	FT and ECO become widely used standards for coffee production in Ethiopia. GI becomes more popular among producers.	Number of producers involved. Number of contracts signed. Number of cooperatives certified.	No 2020 outputs yet.	None.
5. Support the creation and development of micro-enterprises that produce briquettes with full financial autonomy.	In the context of national reduction of greenhouse gas emissions, renewable energy production is promoted, providing job opportunities for vulnerable groups.	At least 10 micro-enterprises created, recycling coffee waste (husk) into briquettes for fuel. Enterprises managed by previously unemployed youth and women.	No 2020 outputs yet.	None.
6. Beekeeping as an income diversification option in agroforestry systems studied and promoted.	Options for integration of beekeeping with agroforestry systems studied. Organic coffee honey certified for specialty markets.	At least 2 coffee-based beekeeper cooperatives established.	No 2020 outputs yet.	None.
Broad objective 4: Develop push-pull systems.				
Specific objective: Improve ecological and economic performance of push-pull technology through comprehensive management of striga, stemborers and FAW infestation in collaboration with international and national partners by 2025.				
1. Push-pull technology implemented by over 350,000 farm households, and indirectly benefitting over 2 million people in sub-Saharan Africa.	Food sufficiency and household incomes of 350,000 push-pull farmers increased by at least 50% by 2025 through higher and sustained crop, fodder and milk yields.	● Acreage of farmland under push-pull. ● Household income levels attributable to push-pull. ● Number of households having food sufficiency. ● Number of farmers having improved dairy animals. ● Number of push-pull farmers utilising fodder from push-pull in their dairy production. ● Number of dissemination channels optimized and employed. ● Cereal and fodder yields and milk production levels among target farmers. ● Number of partnerships formed.	● Cumulatively push-pull is implemented by 258,574 (114,218 female, 144,356 male) farmers on >105,000 ha, among whom 170,891 farmers (81,955 females and 88,936 males) have adopted the climate-smart push-pull technology, gaining between 3.5-6.2 t/ha, and providing food sufficiency to >1,550,000 people. ● About 120,000 farmers have improved dairy animals utilizing fodder for push-pull with milk yields >460 litres/cow/pear. ● Secondary reach through partners, social media and mass media created awareness of 5.6 million people in 18 sub-Saharan African countries. ● >33 partnerships maintained for adaptation, validation and scaling up of climate-smart push-pull in 18 sub-Saharan countries. ● Large scale dissemination of climate-smart push-pull reached 46,299 new farmers (24,726 males and 21,573 females) directly and through partnerships in 2020.	●To improve further resilience of the push-pull system under current and predicted impacts of climate change, a third generation version of the push-pull technology has been developed. The adapted version retains the basic principles of the technology: suitable chemistry to control stemborers, *Striga* sp. weed and fall armyworm; with proficiency in improving soil fertility, moisture retention and organic matter; and added value, for example in provision of high-quality fodder. The selected farmer-preferred and drought-tolerant companion plants are *Desmodium incanum* (legume), an excellent seed yielder and *Brachiaria* cv *Xaraes* (grass), which is

		Number of stakeholders trained.		resistant to red spider mites and produces higher biomass.
2. Stemborer management approach developed by exploiting early herbivory traits and plant signalling.	● Novel scientific knowledge on early herbivory and plant signalling generated and applied in crop protection by scientists, extension agents and policy makers by 2023. ● Staple grain yield increased by 30% for >20,000 farmers in sub-Saharan Africa by 2025 through early herbivory alert.	● Number of 'smart' maize varieties with early herbivory traits identified. ● Number of farmers adopting the use of 'smart' maize varieties. ● Increase in grain yields. ● Number of food-sufficient households as a result of use of 'smart' maize varieties. ● Number of peer-reviewed publications on early herbivory and plant signalling. ● Number of stakeholders trained on stemborer and FAW control by exploiting inherent plant defence traits.	● Studies to establish the potential role such plants can play in improving stemborer control efficiency of push-pull were continued. ● Genetic variability in induced responses to stemborer egg-laying in maize was investigated, and a genome wide association study (GWAS) conducted on 146 maize genotypes comprising of landraces, inbred lines and commercial hybrids. ● Attraction of the parasitic wasp *Cotesia sesamiae* to odours of plants exposed to *C. partellus* eggs and pest parasitism levels were again measured on the selected lines. Plants were phenotyped in bioassays measuring *C. sesamiae* attraction to volatiles collected from plants exposed to *C. partellus* eggs. Genotyping-by-sequencing was used to generate maize germplasm SNP data for GWAS. ● A paper was published on GWAS of a stemborer egg induced 'call-for-help' defence trait in maize (Tamiru et al 2020).	● Smart defence traits identified in cereal lines can be exploited to enhance effectiveness of the technology in managing stemborer pests as tritrophic interactions allow plants to recruit natural enemies for protection against herbivory. ● The egg-induced parasitoid attraction trait was more common in landraces than in improved inbred lines and hybrids. There was also an association with a transmembrane protein kinase that may function as a receptor for the egg elicitor and other genes implicated in early plant defence signalling. Maize genomic regions associated with indirect defence provide a valuable resource for future studies of tritrophic interactions in maize. The markers identified may facilitate selection of indirect defence by maize breeders.
3. FAW management approach developed by understanding the mechanisms by which push-pull controls the pest and by incorporating suitable companion plants in the push-pull system by 2025.	● Scientific knowledge generated on tritrophic interactions and innate plant defences, push-pull control mechanisms and suitable companion plants by 2023. ● Scientific knowledge included in integrated management of FAW in Africa by scientists, extension agents and policy makers by 2025.	● Number of scientific outputs generated. ● Percentage change in FAW infestation in push-pull cereal fields. ● Number of farmers adopting the use of push-pull integrated FAW management approaches. ● Number of peer-reviewed publications on integrated management of FAW using push-pull technology. ● Number of stakeholders trained on FAW control by using the push-pull strategy.	• The functionality of push-pull variants for the management of the fall armyworm were evaluated. Field observation together with both biophysical and socio-economic data were used to evaluate fall armyworm distribution and intensity of infestation. • Information on the effect of push-pull variants on fall armyworm infestation was disseminated. Although the project was not able to conduct mass field days because of COVID-19 restrictions, on-farm training was delivered to. 2,477 male and 3,481 female farmers. • Large scale dissemination of integrated management of fall armyworm using push-pull technology reached 46,299 new farmers (24,726 males and 21,573 females) directly and through partnerships in 2020. • The chemistry of push-pull companion plants and the underlying control mechanisms as well as farmers' experience with push-pull vis-à-vis fall armyworm were further investigated. There was no significant difference in fall armyworm infestation between climate-smart and conventional push-pull. However, severity of infestation was lowest in climate-smart push-pull compared with maize intercropped with leguminous crops and mono-cropped maize. Infestation of maize by fall armyworm in push-pull fields was significantly lower, compared with maize intercropped with	● Reductions of 82.7% in average number of fall armyworm larvae/plant and 86.7% in plant damage per plot were observed in climate-adapted push-pull compared to maize monocrop plots. ●Preliminary studies show that SOS chemicals (e.g. nonatrine, (E)-ß-ocimene, α-terpinolene, β-caryophyllene and humulene) produced by *Desmodium* sp. repel ovipositing females of fall armyworm. ●Infestation symptoms in climate-smart and conventional push-pull technology systems were 36% and 38%, respectively, compared with maize mono-crop, where 95% infestation was recorded. ●Similarly, maize grain yields were significantly higher (2.7 times) in the climate-adapted push-pull plots. These results demonstrate that the technology is effective in controlling fall armyworm with concomitant maize grain yield increases, and represent the first documentation of a

			bean, soybean and groundnut. The severity of infestation was highest on mono-cropped maize compared with all the treatments. These results provide tangible proof that push-pull technology can significantly reduce fall armyworm infestations in maize.	technology that can be immediately deployed for management of the pest. Agro-ecological approaches offer culturally appropriate low-cost pest control strategies that can be readily integrated into existing efforts to improve smallholder incomes and resilience through sustainable intensification. Such approaches should therefore be promoted as a core component of IPM programmes for fall armyworm in combination with crop breeding for pest resistance, classical biological control and selective use of safe pesticides.
4. An integrated management approach developed and implemented for striga control in maize in sub-Saharan Africa.	● Food sufficiency and livelihoods of at least 350,000 smallholder farmers improved through efficient control of striga resulting in increases in maize yields by at least 50% by 2025.	● Number of farmers practising integrated striga control methods. ● Acreage under integrated striga control methods. ● Grain yield increases attributable to integrated striga control. ● Number of stakeholders trained on integrated striga control. ● Number of publications. ● Number of partnerships formed. ● Number of partners' joint field days conducted.	● Trials were conducted in farmers' fields across five locations in Western Kenya for two cropping seasons, while a semi-structured questionnaire was used to assess farmers' opinions. ● In on-station trials, both climate-smart and third generation push-pull plots recorded significantly lower means for stemborer damage and *Striga* sp. count, and higher means for grain yield than in control plots. Both push-pull plots did not significantly differ in *Striga* sp. count but the climate-smart push-pull exhibited higher stemborer damage than third generation push-pull. ● Generally, in on-farm trials, both push-pull plots recorded significantly lower means for *Striga* sp. count, fall armyworm and stemborer damage; and higher grain yield than in plots that followed farmers' own practices.	● Climate-smart and third generation push-pull reduced *Striga* sp. infestation (by 93.8% and 84.3%, respectively), stemborer damage (by 71.2% and 70%, respectively), fall armyworm larvae (89.7% and 85.5%, respectively) and fall armyworm damage (71% and 60%, respectively); and increased maize yield (by 95.2% and 88.2%, respectively) as compared with farmers' own practices. ●Farmers preferred the third generation push-pull technology for resistance to spider mites, biomass yield and drought tolerance, while D. *incanum*, was rated 'very good' for seed production and drought tolerance. ●The third generation push-pull technology, therefore, presents a better option to upscale the technology and meet different needs of farmers, especially in arid and semi-arid conditions.
Specific objective: Intensify push-pull technology to improve food security, nutrition and incomes.				
1. The push-pull system intensified by integrating high-value vegetable crops through farmer participatory research.	● A new push-pull system developed for vegetables. ● At least 3,000 farmers in Western Kenya reached by 2025 with new knowledge on integration of vegetables in push-pull. ● Vegetable production and consumption in 3,000	Number of farm households reached with the concept of cereal-vegetable push-pull systems to control pests Number of farmers' preferred vegetables to be integrated within push-pull system. Number of household surveys conducted to find farmers' preference on high value vegetables	● The successful cereal push-pull system was intensified by integrating high-value vegetable crops through farmer participatory research. A new push-pull was developed and tested against pests and diseases in integrated vegetable-maize push-pull. The new system was piloted both at *icipe* Thomas Odhiambo Campus and on 120 farms in 5 counties in western Kenya, to be scaled up to >3,000 farmers.	● Two-season results suggest that vegetable crops can be easily integrated with maize in push-pull without negative competition, within a low-input crop protection strategy for both maize and vegetables. The integration of vegetables into push-pull system could also be an important driver for wider adoption of push-pull, improved farm incomes and resource conservation.

	households adopting the technology increased by at least 20% by 2025. ● At least 3,000 famers (including women and youth) increase farm incomes by 30% from vegetable sales by 2025.	to be integrated within push-pull system. Number of market surveys conducted in various target areas to identify farmers' preferred vegetables. Number of farmers' preferred vegetables identified. Number of farmer participatory surveys conducted to identify major pests of farmers' preferred vegetables and their management options.		
2. Push-pull-vegetable integration options designed and tested; impact of cereal push-pull system on vegetable pests and their natural enemies established; and the chemical ecology of vegetable pest-plant-natural enemy interactions elucidated.	● At least 2 agronomic designs for push-pull/vegetable intercropping tested by 2022. ● Proven and validated push-pull vegetable agronomic designs adopted by 3,000 farmers by 2025. ● At least 1 study conducted on impact of integrated system on vegetable pests and natural enemies. ● At least 2 active semio-chemicals, produced by companion plants, evaluated on the behaviour of vegetable pests and their natural enemies by 2022. ● At least 2 publications by end of 2024 on impact of the integrated system on vegetable pests and natural enemies, including mechanisms of pest control. ● At least 1 economic study undertaken on the newly designed system by 2024.	● Number of on-station and on-farm trials. ● Number of farmers and learning sites adopting new push-pull vegetable agronomic designs. ● Percentage reduction of pest and disease infestation in push-pull vegetables cropping systems ● Number of studies on impact of the integrated system on vegetable pests and their natural enemies. ● Number of active semio-chemicals from companion plants evaluated on the behaviour of vegetable pests and natural enemies. ● Number of publications on impact of the integrated system on vegetable pests and natural enemies, including mechanisms of pest control. ● Number of economic studies undertaken on the newly designed integrated push-pull system.	● Farmer-preferred vegetables grown in Western Kenya were identified through household and market surveys. Major pests of farmer preferred vegetables were identified and their current management options studied. ● Push-pull-vegetable integration options were designed and tested through 120 on-farm and on-station trials. ● 1 economic study is being conducted on the cost-benefit ratio and return to labour and to land of the newly designed push-pull system. ● The impact of cereal push-pull system on vegetable pests and their natural enemies is being studied; and the chemical ecology of vegetable pest-plant-natural enemy interactions elucidated within the context of integrated push-pull system.	● Preliminary results suggest that *Desmodium* sp. have potential to reduce pest and disease infestation, e.g. diamond back moth on kales, leaf miners on tomatoes, and blight disease on tomatoes and kales. The experiments are being refined and repeated. The next cycle of experiments will narrow down to *Desmodium* sp. that are most effective.
Specific objective: Combat arthropod pests to achieve better health, food and resilience to climate change (CAP-Africa).				
1. A third-generation climate-resilient push-pull technology developed and scaled up	● Climate-smart push-pull extended to 1 additional	● Number of farmers reached and trained on push-pull technology.	● A new, third generation version of the push-pull technology has been developed. The adapted version retains the basic principles of the technology: suitable chemistry to attract and repel	● Trials were conducted in farmers' fields across five locations in western Kenya for two cropping seasons. On-station results

under different agro-climatic conditions and farmers' practices in a participatory approach with stakeholders.	agro-ecology and 1 additional farming system by 2024. ● Climate-smart push-pull adopted by about 100,000 farmers by 2025. ● At least 2 policy guidelines developed on push-pull technology transfer by 2024. ● 2 impact studies conducted covering Eastern Africa by 2025.	● Number and quality of policy guidelines developed on technology transfer recommendations for different farming systems and contexts. ● Number and quality of studies on facilitators and barriers to adoption of different technology variants. ● Number and quality of impact studies conducted.	stemborers, fall armyworm control, and attraction of natural predators of the pests; *Striga* sp. suppression; proficiency in improving soil fertility, moisture retention and organic matter; and added value in provision of high-quality fodder. ● A manuscript was prepared and submitted for publication on field evaluation of a new third generation push-pull technology (Cheruiyot et al 2021).	show the third generation push-pull plots have significantly lower stemborer damage and *Striga* sp. count and higher grain yield than in control plots. On-farm, the third generation push-pull technology reduced *Striga* sp. infestation by 84.3%, stemborer damage by 70%, fall armyworm larvae by 85.5%, and fall armyworm damage by 60%, and increased maize yield by 88.2% as compared with farmers' own practices. ● The selected farmer-preferred, and drought-tolerant, companion plants are *Desmodium incanum*, an excellent seed yielder and Brachiaria variety *Xaraes*, which is resistant to red spider mites and produces higher biomass. This extends push-pull applicability to an additional drier agroecology and farming system.
Specific objective: Promote biocontrol of FAW in smallholder cropping systems by enhancing crop diversity and ecosystem services.				
1. FAW resistance of farmer-preferred maize, millet and sorghum varieties assessed, including assessment of response to egg laying (early herbivore alert).	● At least 4 farmer-preferred cereal varieties assessed by 2022.	● Number of farmer-preferred cereal varieties assessed.	● An oviposition bioassay was carried out under greenhouse conditions at ITOC, Mbita on *Desmodium* sp. intercrop and *Brachiaria* sp. border plants' attraction/repellency of *S. frugiperda* female moths in the push-pull system. 6 different treatments were tested: (i) green leaf *Desmodium* sp. (GL); (ii) silver leaf *Desmodium* sp. (SL); (iii) *Brachiaria* Mulato II; (iv) maize hybrid Duma as a control treatment; (v) Duma+GL; (vi) Duma+SL.	● The number of fall armyworm eggs laid indicate repellency effects of green leaf *Desmodium* sp., silver leaf *Desmodium* sp. and *Brachiaria* Mulato II plants against fall armyworm female moths.
2. Potential trap plants evaluated to develop a new push-pull system that resists FAW attack.	A novel FAW-resilient push-pull system, which will include control of stemborers and striga weed, developed and adopted by 30,000 farmers by 2023. ● FAW-resistant companion crops, which repel the pest and attract pest's natural enemies (egg and larval parasitoids), evaluated and incorporated in a resilient push-pull system by 2024.	● Number of farmers introduced to a novel resilient push-pull system combining efficacy against stemborers, striga weed and FAW. ● Number and quality of companion crops evaluated for FAW resistance, egg and larval parasitoids recruitment and early herbivory alert.	● Field surveys and on-farm field assessments were conducted and the impact of Push-pull technology on suppression of FAW validated. Better adapted and effective companion plants (*Brachiaria* var. Xaraes, *Brachiaria* var. Piata, *Desmodium incanum* and *Desmodium ramosissimum*) were identified and incorporated for more effective FAW management. ● Moreover, *Brachiaria brizantha* cv Mulato II and *B. brizantha* cv Xaraes were identified and used in the Third-Generation Push-pull. ● *Desmodium incanum* and Brachiara cv. *xaraes* were also intercropped with sorghum and the system was also tested againt FAW infestation. ● Further, on-station trials included treatments, replicated four times, of Greenleaf desmodium, common bean, green grams, groundnuts, crotalaria, cowpea and maize monocrop as a control.	● Both the climate-smart and third generation push-pull technology reduced fall armyworm larvae (89.7% and 85.5%, respectively) and fall armyworm damage (71% and 60%, respectively) and increased maize yield (by 95.2% and 88.2%, respectively) as compared with farmers' own practices. ●The results show that climate-adapted push-pull technology (5.8%) and 3rd generation push-pull technology (5.4%) reduce fall armyworm infestation compared to sorghum monocrop. The yields from the two treatments; climate adapted technology (2.4 t/ha) and 3th generation push-pull (2.3 t/ha) were higher than that from the control (1 t/ha).

				● Fall armyworm infestation in the different legumes ranged from 19.7% in green leaf *Desmodium* sp. intercrop to 62.5% in the maize monocrop. Maize intercropped with green leaf *Desmodium* sp. had the least infestation, which was significantly different than the other treatments. ● Yield data collected from the plots with different legume intercrops with maize showed green leaf *Desmodium* sp. registered the highest yield (4.7 t/ha), while maize mono registered the least yield (0.7 t/ha). Maize intercropped with *Crotalaria* sp. was the second best (2.7 t/ha) and maize+beans (2.0 t/ha) was the 3rd highest.
3. FAW sampled in field locations to determine which natural enemies attack it in Kenya and conduct experiments to assess tritrophic interactions with crops.	● FAW natural enemies identified in sample field locations by 2022. Tritrophic interactions between FAW natural enemies and host crops assessed by 2023.	● Number of FAW natural enemies identified. ● Number of experiments conducted to assess interactions between FAW natural enemies and host crops.	● Laboratory bioassays were conducted to understand the interaction of maize genotypes with fall armyworm and its natural enemies.	● The fall armyworm natural enemy *Cotesia icipe* was attracted to maize volatiles induced by larvae feeding. The main induced maize volatiles include aromatic indole, and mono- and sesquiterpenes.
4. Chemical and electrophysiological analysis of secondary metabolites conducted from biologically active plant samples.	Biologically active compounds mediating FAW-host plant-natural enemy interactions determined by 2024.	● Number of plant samples analyzed.	● To understand the scientific mechanisms of fall armyworm management using the push-pull system, volatiles were collected from companion plants (*Desmodium* sp. and *Brachiaria* sp.) for bioassays and electrophysiological recordings with S. *frugiperda* and parasitoid wasps. ● Volatiles were also collected from plant species, *Brachiaria* var. *Xaraes*, *Brachiaria* var. *Piata*, *Desmodium incanum* and *Desmodium ramosissimum* gathered from diverse agroecosystems in Western Kenya to better understand the interaction of companion plants in push-pull systems. ● Laboratory bioassays were also conducted to understand the interaction of maize genotypes with fall armyworm and its natural enemies.	● In wind tunnel bioassays, maize volatiles mixed with *Desmodium* sp. volatiles were less attractive to moths than maize alone. Coupled GC-electroantennogram (GC-EAG) recordings showed robust fall armyworm responses to eight classes of volatile compounds, namely alcohols, aldehydes, benzenoids, esters, homoterpenes, ketones, monoterpenes and sesquiterpenes.
5. New management methods, crop varieties and companion plants for FAW control evaluated by farmers.	A novel resilient push-pull system validated by farmers in terms of control of stemborers, striga weed and FAW by 2024.	● Number of farmers validating a novel resilient push-pull system for the control of stemborers, striga weed and FAW.	● The climate-smart push-pull option was validated for the combined control of stemborers, *Striga* sp. and fall armyworm on 858 farmers' fields in different agro-climatic conditions in 9 counties in Western Kenya and Northern Tanzania for fall armyworm management.	● In-farm trials, both climate-smart and 3rd generation push-pull plots recorded significantly lower means for *Striga* sp. count, fall armyworm and stemborer damage; and higher grain yield than in plots that followed farmers' own practices. There was no statistically significant difference between the two push-pull plots except for

				stemborer damage, for which the third generation push-pull recorded higher damage than the climate-smart push-pull. Climate-smart and third generation push-pull reduced *Striga* sp. infestation (by 93.8% and 84.3%, respectively), stemborer damage (by 71.2% and 70%, respectively), fall armyworm larvae (89.7% and 85.5%, respectively) and fall armyworm damage (71% and 60%, respectively), and increased maize yield (by 95.2% and 88.2%, respectively) as compared with farmers' own practices.
Specific objective: Scale up biocontrol innovations in Africa.				
1. Current knowledge of Push-pull biocontrol practices analyzed and synthesized, including innovations and traditional practices,	Study conducted to identify how biocontrol interventions have been successfully adopted, and understand the bottlenecks to further adoption by 2022.	● Number of biocontrol innovations and traditional practices analyzed. ● Rate of successful adoptions of biocontrol innovations and traditional practices.	● The current knowledge of push-pull biocontrol practices, as well as traditional innovations and practices, were analysed through a systematic mapping of published literature (91 studies from 83 articles) on biological control interventions. Key facts, barriers to adoption and research gaps were established through literature screening. Most studies were agroecological studies exploring the effectiveness of biological control interventions on pest incidence, natural enemies' incidence, pest damage and yield. Social science studies examined farmers' perception of pests and pest control practices. 5 studies combined agroecological studies with farmer surveys and/or economic analysis.	● The dataset originating from the systematic map could be used to inform more specific research syntheses and evaluation methods, such as meta-analysis of the effectiveness of various biocontrol interventions on different outcome measures.
2. Farmer-farmer networking evaluated and developed using advances in push-pull biocontrol as a test case.	Study conducted to evaluate how farmer-farmer networking can be facilitated using a prototype mobile phone-based information sharing system by 2023.	● Number of farmer-farmer networking models evaluated and selected with participation of farmers.	● A mobile phone app is being developed in cooperation with a private developer to transmit push-pull biocontrol technology information via mobile phone GSM networks in Africa.	● The mobile app is under development.
Specific Objective: Elucidation of the science and effectiveness of local innovations for managing fall armyworm (LIMFA).				
1. To determine the effectiveness of selected local materials for the control of FAW under laboratory conditions.	Laboratory observation to determine effectiveness of local innovations to control FAW.	● Effective plant extracts, detergent and soil assessed on preference, feeding and survival rates assessed.	● This study found detergent to be the most effective, causing 100% mortality in <24 hours. ● Larvae fed with ash-treated leaves were unable to feed. ● Despite the FAW larvae feeding on neem treated leaves, none were able to pupate.	● The laboratory observation confirmed the role of local innovations to provide control of FAW. ● The study provided an insight regarding the roles of local innovations in the management of FAW
2. To evaluate effectiveness of different locally available	Participatory evaluation of local innovations to control FAW was conducted on-farm in two districts	● Effective plant extracts, detergent and soil assessed on maize infestation by FAW.	Field evaluation of the neem, lantana leaf extracts, detergent, wood ash and insecticide were evaluated under farmers condition in two districts in Uganda.	● Farmers appreciated the participatory evaluation of the local innovations applied by some farmers in the area.

innovations to control FAW under field condition.		● Effect of the treatments on maize yield was determined.	Neem extract and insecticide applied plots were comparable and no significant difference was observed. ● The highest number of egg batches and number of larvae was from neem treated plots. The laboratory observations also showed similar result, however none of the larvae were able to pupate, implying a significant reduction of emerging adults for the subsequent season.	●Joint evaluation conducted together with the farmers during the field day was instrumental to discuss about future intervention. ●Farmers mentioned to continue evaluating the plant extracts guided by scouting.
Specific Objective: Enhance cropping system resilience under climate change towards sustainable maize production in East Africa.				
1. Levels and stability of pest control and yield under climate change in push-pull cropping systems evaluated.	Analyze how push-pull cropping systems contributes to maize production levels and stability across land-use and climate gradients by 2021.	● Number of analyses on pests control stability using long term data (10 years) on pest control and yield across different landscapes.	● 2005-2016 long-term dataset has been retrieved and reorganized for analysis on pest control and yield across different landscapes. ● A draft manuscript is being finalized.	●Some data were missing from the baseline.
2. Predator community composition, food-web structure and functional redundancy in push-pull and monocrop systems evaluated.	Study pest control levels and food-web structure, and explore whether push-pull increases foodweb redundancy and resilience in different land-use and climate contexts by 2022.	● Number of predator diversity and community composition, parasitism rates and biocontrol effectiveness identified in different cropping systems and landscape structure ● Number of quantitative foodwebs built using a novel approach of estimated densities of predators and predator-prey body size ratios.	Three seasons' field surveys have been completed on pests and predator diversity. Morphological identification of arthropods collected from push-pull and non-push-pull farms done for the first season sampling and data analysis on densities of arthropods is ongoing to inform on food webs. Effect of landscape structure surrounding maize farms on pests diversity has been completed and a manuscript is under preparation. Work on molecular identification of arthropod community in push-pull and non-push-pull cropping system is ongoing.	Landscape structure surrounding maize farms plays a key role as stemborer and fall armyworm reservoirs.
3. Ecological and economic effectiveness of push-pull systems under future conditions modelled.	Model for maize yield formation, predicting where in the region push-pull will contribute to closing yield gaps now and in the longer term by 2023.	● Bayesian state-space model combining yearly time-series data developed for sites with and without push-pull to train a model predicting the effectiveness of push-pull under varying conditions.	Pest and yield data have already been cleaned up and organized for the model. Weather data for the 2005-2016 period for the fields of interest are missing and this is being pursued from meteorological departments.	Tedious process of getting weather data for the field sites and other parts of Kenya for the model.
Specific objective: Develop a push-pull system exclusively for vegetables.				
1. Characterize different vegetable cropping systems in different agro-ecologies and identify key pest constraints.	Vegetable cropping systems in diverse agro-ecologies assessed and key pest constraint identified.	Vegetable cropping systems dynamics in 3 diverse agro-ecology characterized by 2021. Species composition and genetic diversity of key insect pests and their abundance on vegetable crops in different vegetable cropping systems in 3 diverse agro-ecologies assessed by 2021. ● Natural enemies of key vegetable pests in different vegetable cropping	Funding for this activity has not yet materialized and hence no activities were carried out. Three concept ideas have been submitted to donors for funding to pursue this idea.	Funding is a challenge.

		systems in 3 different agro-ecologies assessed by 2021.		
2. Potential companion crops evaluated to develop a vegetable push-pull cropping system.	Companion push and pull plants for use in vegetable push-pull cropping system against key pests evaluated.	● Number and quality of companion crops evaluated for push and pull functionality in vegetable push-pull cropping system.	● In collaboration with existing projects, a companion plants garden is being established for identifying prospective companion plants for vegetable push-pull cropping systems.	● Funds limitation can be a challenge but collaboration with existing projects can kickstart some activities at a lower level.
3. Chemical and electrophysiological analysis of secondary metabolites conducted from identified potential companion plants against key vegetable pests.	Biologically active semio-chemicals from companion plants for attracting and repelling key vegetable pests elucidated by 2023.	● No of biologically active semio-chemicals from companion plants against key vegetable pests identified for use in vegetable push-pull system.	Preliminary laboratory biossays of false codling moth and *Desmodium* sp. plants have been carried out.	False codling moth is repelled by *Desmodium* sp. volatiles.
4. Multitrophic interactions of identified companion plants-vegetables crops-key pests and natural enemies evaluated.	Nature of multitrophic interactions among key vegetable pests-vegetable crops-companion plants and natural enemies evaluated.	● Number of multitrophic interactions established with different companion plants identified for use in vegetable push-pull system.	These activities have not yet been done.	None.
5. Push-pull for vegetables designed and tested on-farm; impact of vegetable push-pull on vegetable pests, yield and natural enemies elucidated.	At least 2 agronomic designs for vegetable push-pull cropping system tested by 2025. At least 1 study conducted on impact of vegetable push-pull system on vegetable pests, natural enemies and yield.	Number of vegetable push-pull cropping system for key vegetable pests. ● Number of studies on impact of vegetable push-pull cropping system on key pests, natural enemies and yield.	These activities have not yet been done.	None.
Broad objective 5: Make available IPM options for invasive and migrant pests				
Specific objective: Established a decision-oriented tool to predicting insect damage on crops under climate change by 2021.				
1. Experimentally measure yield losses due to insects, and empirically develop crop damage and loss functions.	Mechanisms that govern maize yield losses due to insects established.	At least 1 high impact paper published.	● Experiments ongoing in screenhouse trials and started in phytotron. Preliminary results demonstrate a big impact of maize damage as a function of temperature.	● Arrival of the phytotron was delayed. In addition, the phytotron required finetuning and refurbishment of a new air-conditioned room.
Specific objective: In and out of Africa: Pre-emptively combating the threat of invasive crop pests.				
1. Surveillance for key pests implemented.	● Available parameters on host crops, environment, pests and control options collated. ● Parameter gaps quantified through research and/or specific surveys. ● Regular pest surveillance in key areas conducted with national partners.	Surveillance for at least 3 pests implemented, based on quantified parameters and using existing and novel surveillance tools.	● Discussions are ongoing with donors to fund this work.	● None.

	● Novel and innovative surveillance tools developed. In-country phytosanitary and surveillance capacity strengthened.			
2. Forecasts for key pests developed using modelling.	● Space- and time-explicit predictive models developed using epidemiological parameters. ● Models validated in-country. Capacity built of national partners in pest forecasting.	Space- and time-explicit predictive models for at least 3 pests developed.	● Discussions are ongoing with donors to fund this work.	●None.
3. Real-time early warning and proactive IPM management implemented for key pests.	● Accurate and timely early-warning systems piloted. ● In-country capacity for early warning systems strengthened. ● Proactive IPM management tools for outbreaks and new invasions developed, collated and implemented. ● Novel tools and partnerships investigated and implemented for delivering real-time and cost-effective early-warning and IPM systems.	Real-time early warning and proactive IPM management systems implemented for at least 3 pests.	● Discussions are ongoing with donors to fund this work.	●None.
Specific objective: Digital IPM: customizing VIPS to combat invasive crop pests.				
1. An adapted version of the VIPS app for Kenya and Uganda of a selected numbers of invasive pests developed, with ecological models for target pests available through open source.	Strengthened pest surveillance. Strengthened pest outbreak forecasts. Targeted and real-time advisory services to farmers and government agencies. More efficient pest management.	Rapid responses based on early warnings. Near real-time information on pest presence in an area. Targeted spraying. Reduced use of pesticide.	Due to the COVID-19 pandemic, discussions with donors to engage in optimizing VIPS for Kenya and Uganda is on hold.	None.
Specific objective: A proactive and sustainable management strategy for the desert locust *Schistocerca gregaria* in Africa.				
1. Increased understanding of locust biology and ecology, and modelling in new	● Areas of locust breeding predicted with high precision at local, regional and global	● Pesticide resistance among locust populations known.	● No results yet. Funding is still being sourced.	●None.

invasion zones for better targeting of control strategies.	scale through high-throughput data mining and biogeographical data modelling. ● Remote-sensing based approaches integrated and used for real-time and accurate surveillance of locust breeding sites and swarming bands. Pesticide resistance screened among locust populations in Kenya and other Eastern African countries.	● New invasion zones of locusts predicted. ● Number of models.		
2. Developing biopesticides and biorationals for sustainable locust management.	● Portfolio of biopesticides and biorationals identified to expand supply chains for commercial products. ● New isolates and botanicals screened for commercialization. ● Efficacy of existing and new biopesticides/biorationals assessed against locusts and non-target organisms in the field. Mass production, novel formulations, shelf-life and improved application strategies assessed.	● Number of isolates tested. Number of isolates commercialized.	● No results yet. Funding is still being sourced.	●None.
3. Development of advanced molecular and gene-drive-based approaches for novel, innovative locust management tools.	● Differentially expressed gene profiles of the two locust phases generated through induction of gregarizing pheromones and trans-generational screening from eggs to first instars. ● Differentially expressed genes identified that play a key role in phase transition.	● Gene profiles of locust phases characterized. At least 1 gene-drive based approach for locust management explored.	No results yet. Funding is still being sourced.	None.

	Gene-drive approaches for locust management developed and tested.			
4. Harness semio-chemicals for monitoring, locust phase change and control.	● Egg hatching stimulant responsible for mass hatching under high moisture content characterized. ● Female sex pheromone identified for solitary locusts. ● Gregarious male pheromone (phenylacetonitrile (PAL)) tested for aggregation disruption and lure and kill in combination with biopesticides and biorationals. Behavioural modulation roles of locust semio-chemicals and their optimal ratios validated through advanced insect tracking technologies in the field.	● PAL assessed for use with biopesticides and biorationals. ● Behavioural modulation of at least 3 pheromones (hatching stimulant, female sex pheromone, gregarious male pheromone) known.	No results yet. Funding is still being sourced.	None.
5. Socio-economic and environmental impact of the locust invasion assessed to inform policy.	● Stakeholder perception assessed on locust threat and effectiveness of control strategies. ● Economic, human health and environmental costs caused by locust swarm control quantified. Cost-benefits of biopesticides versus chemicals compared to inform policy.	● Study quantifying the economic, human and environmental costs. Cost-benefit analysis of biopesticides versus chemical control.	● No results yet. Funding is still being sourced.	●None.
Broad objective 6: Make available IPM options for soil pests and enhance soil health				
Specific objective: Microbial uptakes for sustainable management of major banana pests and diseases.				
1. Endophytes and biocontrol agents (EBCAs) identified and selected for bio-management of banana nematodes and the banana weevil.	Sustainable intensification of *Musa* spp. and enset crops. Improved resilience of *Musa* spp. and enset crops towards key pests and diseases.	At least 20 EBCAs screened against banana nematodes and the banana weevil. At least 6 EBCAs selected and active against banana nematodes and the banana weevil.	Completed in vitro antagonism assessment of three bacterial (1HR-B1, 1HR-B3, 1DR-B4) and two fungal (T34, TRC900) isolates against *Radopholus similis*. Enhancement of banana tissue culture plantlets with the highest dose (1.0×10^8 spores/ml) of fungal endophyte resulted into 51 and 73% eduction in *R. similis* infection for ICIPE 697 and ICIPE 700, respectively.	For >5 months, movement of staff to and from work stations was hampered and only limited to essential staff due to the COVID-19 restrictions. In addition, a key staff had travelled to Uganda in March 2019 for field activities, however, for 6 months he could not

		Antagonistic effect of EBCAs combinations tested against banana nematodes and the banana weevil.		travel back to Nairobi, Kenya due to the ban on cross-border travel. Delays in supply of banana tissue culture plantlets for use in bioassay experiments due to reduced staffing in accordance with COVID-19 guidelines.
2. Improve/sustain yields through introduction of the selected EBCAs in field assays.	Contribute to reduced economic losses caused by pests and diseases. Contribute to reduced use of pesticides, minimising risks for human health with low environmental impact.	EBCAs for field trials selected and active against banana nematodes and the banana weevil.	PhD thesis in good progress, one manuscript submitted. Field trials ongoing.	None.
Specific objective: Diagnostic tool for the identification and quantification of the potato cyst nematode (PCN).				
1. A user-friendly tool developed for on-farm detection of PCN.	Contribute to better agronomic practices by detecting key pests early. Contribute to reduced pesticide use. Improved potato yields.	Soil samples collected in at least 2 agro-ecological sites in Kenya to assess presence/absence of PCN. Identification of species. PCN diagnostic tool tested under laboratory and field conditions.	Soil sampling completed and analysis ongoing. Good progress on testing the diagnostic tool.	The project is extended until end of July 2021 through a no-cost extension. Travel budget underspent due to COVID-19 restrictions. Budget change request submitted.
Specific objective: Smart crop approaches for promoting potato and sweet potato GAP in Eastern Africa (Kenya, Malawi).				
1. Local production of quality seed initiated.	Seed availability increased. Quality potato production.	Evaluate existing seed production systems in at least 2 main potato growing regions in Kenya. Initiate measures and actions to increase seed production.	In discussions with FAO sub- Regional Office for Eastern Africa (SFE) for the way forward and funding opportunities.	None.
2. Farmer awareness and uptake of GAP enhanced and adopted.	Farmer awareness enhanced. GAP widely adopted.	Field surveys and on-farm demonstrations of GAP to tackle key pests and diseases. Intelligent crop rotation involving trap crops.	In discussions with FAO sub- Regional Office for Eastern Africa (SFE) for the way forward and funding opportunities.	None.
3. Potato yields improved.	Potato yields reached 15t/ha among smallholder farmers.	On-farm field trials with management practices demonstrated.	In discussions with FAO sub- Regional Office for Eastern Africa (SFE) for the way forward and funding opportunities.	None.
4. Potato value chain evaluated, and action initiated to address main bottlenecks.	Understanding the value chain.	Survey questionnaire.	In discussions with FAO sub- Regional Office for Eastern Africa (SFE) for the way forward and funding opportunities.	None.
Specific objective: Soil health initiative with the International Institute of Tropical Agriculture (IITA).				
1. The interactions between legume-cereal cropping systems with soil biota determined.	● Determine the effects of legume-cereal cropping systems on soil biota.	● Interactions from soil biota that increase P availability elucidated. Interactions from soil biota that increase Rhizobacteria functions elucidated.	● No funding received yet but it is anticipated for 2021.	●None.

	● Determine the effects of soil biota on legume-cereal cropping systems. Explore how soil biota may be manipulated to enhance legume-cereal cropping systems.			
2. Explore conservation and augmentation of soil biota for enhanced vegetable and banana cropping systems.	● Identification of novel microorganisms suitable as bio-fertilizers, bio-stimulants and bio-preservatives. ● Germplasm evaluation for local key traits. ● Compatibility of microbial agents with crops and cultivars. Explore chemical signalling to identify attractants/repellents for exploitation.	At least 2 biocontrol organisms identified for exploitation.	● No funding received yet but it is anticipated for 2021.	●None.

(ii) Animal Health Theme: Results Based Management (RBM) Rolling Framework Report

Outputs	Outcomes	Performance indicators	2020 Progress in Achieving Outcomes	2020 Lessons Learned
Broad Objective 1: To develop a sustainable integrated biorational strategy for controlling vectors of animal trypanosomiasis by 2025				
1. Effective integrated biorational technologies and strategy for controlling vectors of Animal trypanosomiasis (AT) developed and implemented to reduce AT and increase animal production and productivity	• Four technologies for controlling tsetse and biting flies developed by 2025 • At least 100,000 small holder farmers (30% women and youth) impacted by icipe technologies by 2025 • 30-50% reduction in the prevalence of AT in intervened sites by 2025 • 20-30% increase in animal production and productivity in intervened sites by 2025	• Number of technologies and strategies developed • Numbers of smallholder farmers impacted • % reduction in the prevalence of AT in intervened sites • % increment in animal production and productivity	• One strategy developed for deploying limited number of traps developed and currently being evaluated in Kwale County, Kenya. • 1838 households intervened in efficacy trials in Kenya and Ethiopia • Routine implementation of monitoring for disease reduction and changes in livestock production implemented in 2021	Impact of trypanosomiasis is made worse by the ubiquitous occurrence of ticks and tick-borne pathogens. Future intervention strategies will likely be easier to upscale if integrated with tick control. Integrating mobile platforms with community participation can enable systematic documentation of livestock response to interventions. Starting in 2020, we are able to for the first time collect empirical data for herd structures, immigrations and emigrations, and production.
Specific objective: To develop and evaluate effective, low-cost baits and repellent blends for vectors of camel trypanosomiasis (surra) by 2025				
2. Baits and repellents developed for protecting camels against vectors of Surra	• One olfactory bait developed and evaluated for vectors of Surra by 2022 • One repellent blend developed and tested for biting flies by 2023	• Number of repellents available for vectors of Surra • Number of attractants available for vectors of Surra	• We have developed five repellent blends, which are also antifeedant to repel biting flies from camel. • We have identified 10 attractants for biting flies.	• One of the repellent blends incorporated into the existing camel wooden bell and implemented together with attractant. The technology demonstrated a positive effect in reducing infection and improving camel health. • We aim to collaborate and mobilize more resources to test the integrated vectors management at a scale.
Specific Objective: to improve traps and targets for tsetse and biting flies by enhancing the visual attractivity of these by 2025				
3. Improved traps/targets for tsetse and biting flies developed and evaluated	• One trap/target developed for tsetse flies by 2022 • One trap/target developed for biting flies by 2023	• Number of traps and targets developed and evaluated for tsetse and biting flies	• One prototype target screen developed in 2021 with high efficacy for tsetse, Stomoxys and houseflies and therefore potential for one-health interventions for tsetse and biting fly borne diseases	Using photoreceptor models can accelerate the improvement of 2D visual based tools for controlling biting flies. Collaborations and equipping the theme with the technology has increased output for the same.
Specific Objective: To upscale the integrated use of novel tsetse and biting fly traps, attractants and repellents in partnership with the private sector by 2025				

1. The integrated use of traps/target screens, olfactory baits and repellents optimized in push-pull strategies to reduce the transmission of AT	• Three complementary technologies developed for the control of tsetse and biting flies by 2024 • One effective integration of traps/target screens with baits and repellents for tsetse and biting flies by 2024	• Number of complementary technologies identified with potential for integration for a push-pull strategy • Push-pull strategy optimized and evaluated	• In 2021 we integrated repellent traps and targets for a trial intervention in Kwale County • The Tickoff biopesticide was identified and demonstrated as potential technology to integrated in the concurrent tsetse and tick control	While several technologies developed by *icipe* have proven efficacy, many of these are not field ready. There will be need to work with the private sector to re-package these technologies appropriately for upscaling.
2. Technology for large scale production and distribution of vector control tools passed over to the private sector	• One agreement signed with private partners for R4D of baits, repellents and traps/targets screens by 2024 • One private partner producing and distributing vector control technologies by 2024	• Number of agreements signed with private partners • Number of private partners actively producing and distributing technologies	• Agreements established with Innova Biologicals Ltd and RealIPM for the production and distribution of tsetse repellents and ICIPE 7 biopesticide. • Innova Biologicals Ltd is currently actively distributing the tsetse repellent in Kenya. Real IPM mass produces the biopesticide for trials across Kenya pending registration	
3. Enhanced advocacy for use of integrated biorational vector control technologies for tsetse and biting flies	• One advocacy event every year between 2021-2025 • Five meetings with multilateral bodies in the agricultural sector with potential for influencing vector control policies by 2025	• Number of advocacy events • Number of meetings with multilateral agricultural bodies • Meetings with local governments and national agricultural research and extension systems • Number of policy documents for vector control with biorational technologies	• Six advocacy events have been implemented in Kwale and Kilifi Counties of Kenya • Four meetings were held with the county governments in 2021	This activity has been slowed by the ongoing COVID-19 pandemic. In this context we have learnt and integrated alternatives to one-on-one group meetings
Specific Objective: To update tsetse and trypanosomiasis risk maps for Kenya and East Africa				
1. Algorithms for predictive mapping of tsetse infestation and spatial risk for trypanosomiasis developed	• One effective algorithm for predicting the spatial occurrence of tsetse developed by 2023	• Number of practical algorithms developed and evaluated	• Partnership Established with University of Twente to enhance capacity for earth modelling (Drs Skidmore, Vrieling and Groen) • PhD Student (Ms. Stella Gachoki) recruited to implement study • One algorithm developed that uses satellite-based mapping to model the distribution of newly emerged tsetse and predict breeding sites • One manuscript: Gachoki et al 2021 Satellite-based modelling of potential tsetse breeding and foraging	Even though tsetse are widely distributed, breeding sites are difficult to identify. Using satellite derived data, and field date, we can with reasonable accuracy predict breeding and foraging sites. Targeting breeding sites could improve the cost-effectiveness of tsetse control and fast-track control and possibly elimination.

			sites using teneral and non-teneral fly occurrence data (submitted to Parasites and Vectors). • PhD student received grant for extending the research activities in Kwale	
2. Maps developed for tsetse and animal trypanosomiasis in Kenya	• One map for the occurrence of Glossina pallidipes in Kwale County	Number of maps for tsetse distribution in different counties in Kenya	One improved map for tsetse foraging and breeding sites around the Shimba Hills National Reserve One manuscript is under review	There is earlier indication that many tsetse breeding and potential reinvasion occurs in wildlife restricted environments. This suggests that control in the future must involve very close collaboration and involvement of government and private agencies that focus on the management of such resources.
Specific Objective: To optimize a strategy for reducing the transmission of trypanosomiasis with enhanced trapping of trypanosome-infected tsetse flies by 2025				
1. Impact of infections with trypanosomes of host animal semiochemicals profile investigated	• Changes in host chemical due to trypanosome infection of hosts identified by 2022 • Specific semiochemicals induced by trypanosomal infection identified by 2023	• Chemical profiles for livestock infected with trypanosomes • Number of Novel semiochemicals identified	• Six trypanosome induced biomarkers from cow urine and breath identified and characterized. The biomarkers are conserved between two important trypanosomes (*T.congolense* and *T.vivax*)	• Trypanosomes manipulate its host (livestock) metabolites, which can be used as biomarkers.
2. Behavioural responses of tsetse and biting flies infected with trypanosomes to trypanosome induced host-specific semiochemicals documented	• Behavioural responses of tsetse and biting flies to trypanosome induced semiochemicals determined by 2022 • Semiochemicals that influence the behaviour of tsetse and biting flies identified by 2023	• Dataset for the responses of tsetse and biting flies to trypanosome-induced semiochemicals • Number of attractive trypanosome induced semiochemicals identified	• Three novel blends using trypanosome induced biomarkers formulated. • The attractiveness of the blends tested under field conditions	• The three novel blends were tested under field conditions and more attractive to tsetse flies as compared to the widely used and recommended tsetse lure.
3. Toolkit for detecting trypanosome induced semiochemical markers for trypanosome infections developed (diagnostic kit)	• Biomarkers for trypanosomiasis infections in livestock identified by 2023 • Prototype toolkit for trypanosomiasis diagnosis developed by 2024 • Partnerships established for optimizing novel diagnostic kits for trypanosomiasis by 2024	• Numbers of biomarkers identified • Availability of prototype toolkit for diagnosis • Number of private partner agreements for the development of diagnostic kits	• One urine based non-invasive animal trypanosomiasis diagnostic method developed.	• The diagnostic demonstrated high sensitivity, selectivity, and works for three trypanosomes and in various livestock, such as cattle, camel, and goat. • We are looking for a private partnership, and resource to make it commercially available.
4. Bait for infected tsetse and biting flies developed	• One high efficacy bait for tsetse and biting flies infected with trypanosomes by 2023	• Number of baits for infected tsetse and biting flies	• We have shown urine of trypanosome infected cow urine attracts 5x more infected flies as compared to control. With the attempt to mimic the trypanosome infected cow urine we formulated three blends and one of the blends attracted 2x more infected tsetse flies as compared to control.	• It is possible to selectively attract infected tsetse flies, which are responsible for the spread of the pathogens that will result in transmission blocking. Still we need to mimic the infected cow

			• An attractant that is more attractive to gravid stomoxys identified. • We have formulated attractant that is more attractive to host searching *Stomoxys calcitrans*	urine better to attract more infected tsetse flies. Targeting infected tsetse flies, and gravid biting flies will have maximum positive impact in blocking pathogen transmission and suppressing biting flies population to minimize livestock diseases burden.
5. Dispensers for deploying semiochemicals for control of tsetse and biting flies developed	• One dispenser for tsetse and biting fly baits developed by 2024	• Numbers of dispensers developed and evaluated	• We have compared various dispensers, dry and liquid formulation but we identified the nanopolymer beads as the best.	• Using nanopolymer beads we were able to keep the integrity of the odor, stability and able to create strong strand that has strong behavioral impact. It is also more economical as compared to liquid formulation without compromising its efficacy.
Specific Objective: Explore the potential use of the tsetse endosymbiont bacteria species, Sodalis glossinidius in controlling African trypanosomiasis				
1. Prevalence and density of Sodalis glossinidius in wild tsetse populations in Kenya determined	• Prevalence of Sodalis glossinidius in Glossina pallidipes populations from Lambwe Valley, Homabay County of Kenya established by 2021 • Density of Sodalis glossinidius populations from Shimba Hills, Kwale County, Kenya determined by 2022	• Number of datasets for the prevalence of Sodalis glossinidius in wild Glossina pallidipes • Density estimates of Sodalis glossinidius in wild Glossina pallidipes	• Dataset available for *Sodalis glossinidius* in wild *Glossina pallidipes* trapped in Kinango Sub-County, Kwale County. • Approximate infection rate of 1% determined.	Multiple populations of tsetse flies, and inclusion of other species needed for a better understanding of the impact of symbiosis.
2. Effect of Sodalis glossinidius on the establishment and development of trypanosomes in tsetse determined	• Sodalis glossinidius isolated and cryopreserved by 2022 • Secretomes of Sodalis glosinidius (Sodalis soup) isolated, and the effect of trypanosomes establishment and development evaluated by 2023	• Number of Sodalis glossinidius isolates cryopreserved • Effect of Sodalis soup on trypanosome establishment and development in tsetse flies documented	• Data does not show a correlation between *Sodalis* infection and trypanosome establishment. This is based on one dataset, more studies underway.	It is necessary to undertake these studies on multiple populations of tsetse flies, because location may influence the relationship between endosymbiont and trypanosome establishment.
3. Research collaborations established to enhance studies with Sodalis glossinidius	• One collaboration for research with tsetse endosymbionts established by 2021 • One training for research with Sodalis glossinidius in icipe completed by 2023	• Number of research collaborations established • Number of research associates/students trained	Collaboration established with Liverpool School of Tropical Medicine, and Kenya Wildlife Service (KWS).	Training will be undertaken when the COVID-19 situation stabilizes.

Broad Objective 2: Novel tools and strategies for biorational tick management developed, evaluated and implemented by 2025				
1. Effective biorational technologies and strategies for controlling ticks on animals and in ranges developed, evaluated and scaled	• Two biorational products/technologies for tick control developed, evaluated and upscaled	• Number of biorational tick control products developed and evaluated	• One randomized controlled Efficacy trial initiated for tick bioacaricide in Kilifi County in collaboration with the local government • Research initiated in the to identify synthetic equivalent of the tick botanical attractant, *Carpunia aurea*	Diversity of ticks and tick-borne diseases in Kilifi, Kwale and Lambwe counties established. Tick-borne diseases included novel pathogen with potential for zoonoses.
Specific Objective: Novel bioacaricide for topical application developed, evaluated, registered and upscaled to at least 50,000 small holder farmers by 2025				
1. Bioacaricde based on Metarhizium anisopliae evaluated and registered in different eco-epidemiological settings	• Bioacaricide evaluated in two sites in Kenya and Ethiopia by 2022 • Bioacaricide registered in at least one county	• Number of places where bioacaricide is evaluated • Number of countries where bioacaricide is registered	• Tick biopesticide evaluation ongoing in several sites in Kwale and Kilifi counties, Kenya • No objection approval obtained from the directorate of veterinary service to enable trial pending registration.	The registration of veterinary products is slow and resource intensive. Changes in national protocols for the same made it difficult to complete this in time. In response, a no objection permit was obtained that has enabled the intervention study to proceed.
2. Novel tick product (bioacaricide) market survey completed in Tanzania and Uganda	• Two market surveys completed by 2023	• Number of market surveys completed	• Tools for these were developed but the surveys are not yet implemented	
3. Strategy and tools for area-wide tick control with bioacaricides developed and implemented	• One strategy/tool for area-wide application of bioacaricides developed by 2025	• Number of strategies for area-wide application of bioacaricides	• Action already initiated to identify tick attractants that will be used for this	
Broad Objective 3: To sensitize and enhance the capacity of smallholder farmers and national agricultural research and extension systems (NARES) to implement area-wide tsetse flies, biting flies and tick control with biorational technologies by 2025				
1. Train National Agriculture Research and Extension (NARES) officials	• At least three stakeholder trainings held	• Number of trainings held	• Four trainings on the use of tick biopesticides and tsetse repellents in Kenya and Ethiopia	
2. Train smallholder farmers on use of biorational technologies	• At least three awareness creation workshops held for smallholders	• Number of awareness workshops implemented	• Six awareness workshops held in Kenya and Ethiopia	
Broad Objective 4: To increase the training and capacity building for the biology, ecology and management of livestock and zoonotic diseases vectors by 2025				
1. Train postgraduate students from different countries in sub-Saharan Africa	• At least ten postgraduate students trained by 2025	• Number of postgraduate students trained	• Five postgraduate students (2 female) engaged • Three PhD students (Souleymane Diallo, Steve Baleba Soh, Tatenda Chiuya) graduated; five MSc in progress.	
2. Train interns	• At least 20 interns trained by 2025	• Number of internships provided	• Five interns trained	

(iii) Human Health Theme: Results Based Management (RBM) Rolling Framework Report

Outputs	Outcomes	Performance Indicator	2020 Progress in Achieving Outcomes	2020 Lessons Learned
Objective 1: Contribute towards malaria elimination through the development of effective vector control strategies and public health initiatives by 2025				
Specific objective 1.1 To support countries to implement integrated vector management (IVM) approaches for malaria control and elimination; through demonstration of the effectiveness of diversified, environmentally safe innovative vector control methods, capacity building and policy advocacy by 2022				
• Evaluation of the effectiveness of house screening, bio-larviciding and environmental management as additional complementary interventions for IVM in the context of malaria control and elimination. • Improvement of mosquito vector surveillance tools • Cost-effectiveness analyses of IVM approaches involving house screening and/or larviciding relative to exclusive use of insecticide-based methods (long-lasting insecticide-treated nets and indoor residual spraying). • Socio-demographic and socio-economic surveys of households in study districts.	• Research evidence on effectiveness and feasibility of IVM for malaria control and elimination in eastern and southern Africa available. • Reduced burden of malaria in eastern and southern Africa through implementation of IVM strategies and policy efforts. • Reduced health expenditure and lost days of work, school and other activities for individuals and households	• Number of articles on malaria IVM theme published in peer reviewed journals. • At least 3 policy briefs for guidance on implementation of IVM in project countries. • Levels of malaria prevalence and mosquito relative density in study areas with and without IVM interventions. • Change in socio-economic status of households in areas involved in IVM	• The validity of using IVM for mosquito and malaria control was demonstrated from two icipe studies. • In the first study, findings in Nyabondo, western Kenya, where there is intense all-year round malaria transmission, showed that combined use of long-lasting insecticide treated nets and screening of house eaves with mosquito-proof wire mesh reduced malaria cases by between 63% and 100% compared to when long-lasting insecticide treated nets (LLINs) were used on their own. • The second study shows that in Tolay, Ethiopia where malaria prevalence is generally low, the disease was reduced by a further 50% when usage of (LLINs) was supplemented with the application of *Bacillus thuringiensis israelensis*. Publications: Mutero CM, Okoyo C, Girma M, Mwangangi J et al. (2020). Evaluating the impact of larviciding with Bti and community education and mobilization as supplementary integrated vector management interventions for malaria control in Kenya and Ethiopia. Malar J. 19:301. Diiro GM, Kassie M, Muriithi B, Gathogo N et al. (2020). Are Individuals willing to pay for community-based eco-friendly malaria vector control strategies? A case of mosquito larviciding using plant-based biopesticides in Kenya. Sustainability 12: 8552; doi:10.3390/su12208552 Ng'ang'a PN, Okoyo C, Mbogo C, Mutero CM (2020). Evaluating effectiveness of screening house eaves as an intervention for integrated vector management for malaria control in a rural area of	• *icipe*'s publication of outputs with research evidence on effectiveness of house screening and bio-larviciding was timely and will likely inform decision-making by the national programmes regarding the two practical interventions for malaria vector control in Kenya and Ethiopia. • A business continuity plan for IVM work in the context of COVID-19 was important in ensuring that implementation of malaria research activities continued with minimum interruptions.

			Western Kenya. Malar J. 19:341. doi.org/10.1186/s12936-020-03413-3. Kgoroebutswe TK, Makate N, Fillinger U, Mpho M, Segoea G, Sangoro PO, Mutero CM et al. .. Nkya TE (2020). Vector control for malaria elimination in Botswana: progress, gaps and opportunities. Malar J. 19:301 https://doi.org/10.1186/s12936-020-03375-6	
• Regular participatory in-country trainings in IVM for malaria control and elimination. • Periodic regional trainings in IVM held at icipe in collaboration with multilateral partners including WHO-AFRO and UNEP. • Development of extra curriculum programme on IVM for participation of local schools in malaria control (Ethiopia). • Development of IVM information, education and communication (IEC), and behavioural change communication (BCC) materials. • IVM Policy advocacy and dialogue workshops	• Regional and national capacity for implementation of malaria IVM strengthened. • icipe's role as a regional hub for IVM training in Africa significantly enhanced from 2020 onwards as a result of increased regional collaboration also involving key partners including WHO-AFRO, UNEP, GEF, Stockholm Convention, and Biovision. • Enhanced community participation in IVM for malaria control. • Policy guidelines on IVM for control and elimination of malaria in eastern and southern Africa available	• icipe's ongoing role as a co-executing partner and lead research organization for evaluation of new innovative IVM interventions in the context of AFRO-II project Global Environment Facility (GEF)/UNEP- through the main Executing Agency is WHO-AFRO • Number of MSc and PhD students trained in IVM approaches, including in development of vector surveillance tools. At least 200 national program staff of eastern and southern Africa countries trained in IVM for malaria control by 2025. • Number of IVM workshops held for policy makers and other key stakeholders. • Number of community members (male and female) trained in IVM for malaria control and elimination in at least seven African countries. • Number of regional IVM training courses for malaria control held at icipe.	Databases were established for Botswana, Eswatini, Namibia, Mozambique, Zambia and Zimbabwe, collating data on: socio demographics; knowledge, attitudes and practices; baseline malaria clinical cases and prevalence; and entomological assessments. In Eswatini, *icipe*'s championing of biological larviciding for malaria vector control was commended by the United Nations Environment Programme (UNEP) as a model for "eco-friendly alternatives to toxic solutions".	*icipe*-led human health research collaboration is gaining greater recognition among country partners in southern African aiming for malaria elimination, and also international partners led by WHO and UNEP.

		• Number of countries (ministries of health) which have adopted IVM policy for malaria control since 2020.		
Specific Objective 1.2 Development of non-insecticidal monitoring and control tools based on the odour-orientation behaviour of vectors by 2025				
• Studying the influence of invasive plants and metabolites on the breeding ecology and infection success of disease vectors to identify potent larvicides and malaria transmission blockers	• Larvicidal assays to plants and synthesized metabolites implemented • Oviposition assays to plants and metabolites implemented and attractants identified • Knowledge on pathogen transmission modulating activity of plants and/or key metabolites for potential drug development	• Publications • Theses/students trained • Proposals submitted • Chemicals tested as larvicides and oviposition attractants • Plants/chemicals tested as transmission blockers for Plasmodium or arbovirus pathogens	• Protocol for isolation of parthenin, a sesquiterpene lactone, from a malaria vector preferred plant, *Parthenium hysterophorus* established and well as synthesis of derivatives • Evidence of enhanced larvicidal activities of derivatives of parthenin against the malaria vector *Anopheles gambiae* • 2 interns trained Publication: Milugo TK, Tchouassi DP, Kavishe RA, Dinglasan RR,Torto, B. (2021), Derivatization increases mosquito larvicidal activity of the sesquiterpene lactone parthenin isolated from the invasive weed *Parthenium hysterophorus*. Pest Manag Sci, 77: 659-665. https://doi.org/10.1002/ps.6131.	• Findings advance the use of structural modification approach in the development of lead chemical molecules for potential exploitation in larval source management for disease vector control.
Specific Objective 1.3. to determine entomologic risk of arbovirus transmission and /or outbreaks in selected regions of East Africa by 2024				
• Distribution and Bionomics of adult target mosquito vectors in relation to climatic variables determined.	Risk of transmission and opportunities for control identified	• Community engagement. • Publications • Donor and other reports • Thesis Interns/students trained	• Evidence of variation in bionomics (composition, abundance, human blood feeding index, survival rates) among key yellow fever and dengue vectors (*Aedes aegypti*, *Ae. simpsoni*, *Ae. africanus*) in selected sites of Kenya, potentially indicative of differential risk levels between the areas. • 2 interns trained	
• Vector genetics of selected species elucidated	Variation of disease risk established	• Publications • Donor and other reports • Thesis Interns/students trained	• Protocol for molecular differentiation of species complexes (e.g. *Ae. simpsoni* s.l.) adopted for population characterization and vectorial capacity estimates.	
• Mosquito larval ecology characterized.	Productive sites mapped for inform targeted control	• Publications • Donor and other reports • Thesis • Interns/students trained	Evidence of variation in breeding ecology of dengue and Yellow fever vectors	
• Virus infection rates determined	• Geographic risk of disease transmission Incrimination of arbovirus vectors	• Publications • Donor and other reports • Thesis Interns/students trained	Diverse viruses with potential to cause disease in human and animal populations have been detected in different vector host systems with signatures of potentially novel viruses that require further analysis (e.g. whole genome sequencing) for confirmation	

• vector competence of selected species for specific viruses determined	• Insights into disease risk and potential areas of adaptation The researchers identify the competent and refractory vector populations for arbovirus transmission	• Publications • Donor and other reports • Thesis Interns/students trained	• 1 manuscript submitted • 1 PhD student graduated (Edith Chepkorir; Oct 2020; University of Pretoria) • 2 interns trained	
Specific objective 1.4. To determine the distribution and exposure risk of arboviruses to human and association domestic and peridomestic vertebrate				
• Seroprevalence of selected arboviruses in humans and other hosts selected areas determined	Evidence of disease occurrence in population to inform policy	• Publications • Donor and other reports. • Stakeholder information sharing meetings • Thesis • Interns/students trained Proposals	• Human samples from Marigat and Nguruman health facilities collected and biobanked for analysis at MLEID laboratory • 2 interns trained • Primate samples (from Coast and KV) similarly biobanked at MLEID laboratory and being analyzed	
• Biobank of samples and associated metadata established	Well characterised sample repository for retrospective and prospective studies	• Data sheet • Back up files		
Specific objective 1.5. In depth virus surveillance, characterization and discovery done by 2023				
Novel viruses characterised	Highlight of epidemiology and potential public health importance of novel viruses	• Publications • Donor reports • Thesis • Interns/students trained • Sequences submitted to public databases Proposals submitted	• 2 graduate students are being trained (here and in Germany) on in-depth virus characterization and discovery.	
Specific objective 1.6: To develop trapping tools for conduction vector surveillance to improve surveillance of YF and dengue.				
• Trapping tools based on primate and human-derived attractants for improved surveillance of YF and dengue in sylvatic and domestic settings developed	• The team identifies suitable odours and tools for attracting and sampling YF and DEN vector populations. • Effective lures optimized and field tested in sylvatic and domestic settings in Kenya Odor-baits used by scientists for mosquito surveillance in research programs	• Publications • Donor and other reports • Stakeholder information sharing meetings • Students trained/Thesis • Posters/conference presentations Presence/use of attractants by researchers and national control programmes	• Enhanced performance of human and primate-derived odorants as lures for dengue and Yf vectors based on field trials	
• Semiochemical basis of larval breeding choice elucidated	• Volatile profiles of different breeding sites characterised for development of lures for gravid cohorts	• Publications • Donor and other reports • Students trained/Thesis	• Semiochemical basis for oviposition site preference and identification of scent compounds contributing to this selection. • Volatile profiles of breeding sites of dengue/Yellow fever vectors established as well as from cultured microbes.	

	• Microbiota from breeding water and emerged adults characterised Suitable odours for sampling gravid Aedes mosquitoes analysed for field testing	• Posters/conference presentations		
Objective. 3. Understanding freshwater pollution and the links to the distribution of Schistosoma host snails in Western Kenya				
Specific objective 3.1. Does the abundance of host snails for human pathogenic trematodes increase with pesticide pollution, and is this increase associated with a decrease of antagonistic macroinvertebrate species? Does the portion of infected host snails and the number of Schistosoma cercariae produced by infected snails change with pesticide pollution? Can the pesticide pollution in tropical freshwater bodies after runoff be predicted from the community composition of sensitive and insensitive macroinvertebrate taxa?				
• Risk factor analyses implemented. • Pollution associated with abundance of snails, antagonistic invertebrates, and cercaria infection.	• Pesticides bioindicator index developed for the effect of pesticide pollution on macroinvertebrates to tropical freshwater habitats by 2020	• Filed sites identified • Two field campaigns successfully completed, • Dataset compiled for analysis. • Publications. • Donor and other reports. • Thesis chapter.	• Pesticide bioindicator index developed and published. • PhD thesis chapter completed. • Extension of funding approved for another 3 years. Publications: • Calibration of the SPEARpesticides Bioindicator for Cost-effective Pesticide Monitoring in East African Streams. Environmental Science Europe DOI: 10.21203/rs.3.rs-252210/v1 published as Preprint at Research Square • Occurrence and risk assessment of organic micropollutants in freshwater systems within the Lake Victoria South Basin, Kenya. Science of the Total Environment, Volume 714, 20 April 2020, 136748 • Multi-compartment chemical characterization and risk assessment of chemicals of emerging concern in freshwater systems of western Kenya. Environ Sci Eur 32, 115 (2020). https://doi.org/10.1186/s12302-020-00392-9	
Specific objective 3.2 What is the acute pesticide sensitivity of host snails compared to relevant antagonistic species?				
• Pesticide sensitivity established in comparison to antagonistic species.	• Tools available to predict impact of pesticide pollution on snail distribution by 2020	• Toxicity tests designed and successfully implemented. • Publications. • Donor and other reports. • Thesis chapter	• Toxicity tests completed and snail sensitivity established. • Pesticide pollution identified as important risk factor for schistosomiasis transmission. • PhD thesis chapter competed. Publication: • Pesticide pollution in freshwater paves the way for schistosomiasis transmission. Sci Rep 10, 3650 (2020).	
Specific objective 3.3 Does the composition of pathogenic and non-pathogenic trematode species differ in host snails from polluted and non-polluted sites?				

• Composition of pathogenic and non-pathogenic trematode species from host snails identified.	• Risk of schistosomiasis based on habitat pollution assessed for predicting disease risk by 2020.	• Laboratory techniques established, • Successful analyses of data • Publications. • Donor and other reports. • Stakeholder information sharing meetings. • Thesis chapter.	• Ethical approvals sought. • Laboratory techniques established. • Sample analysis ongoing.	
Specific objective 3.4. Experiments to investigate how pulse exposure to pesticides affects the competitive balance and the predator-prey relationship of the most common host snails and their natural antagonists; how does pulse exposure to pesticides affects the production of cercariae in the host snails, and how pesticide exposure affects the survival of cercariae in the absence and presence of predators.				
• Experimental assessment of impact of pollution on predator-prey relationships, snail vector competence and parasite survival.	• Risk of schistosomiasis based on habitat pollution assessed for predicting disease risk by 2020.	• Macrocosm experiments established and completed, • Database established, • Publications. • Donor and other reports. • Stakeholder information sharing meetings. • Thesis chapter.	• Macrocosm experiments completed. • PhD chapter completed. • Data included in publications listed under 3.1 and 3.2.	
Objective. 4. Investigating the disease ecology of tungiasis (sand flea disease) for the development of treatment and prevention strategies				
Specific objective 4.1. Analyzing school- and household-based risk factors associated with disease outcome				
• Risk factors associated with disease identified.	• Improved awareness of the association between certain environmental, socio-economic and behavioural risk factors and disease by all project stakeholders (scientists, Ministry of Health, communities)	• Ethical approval for study. • Field surveys completed. • Dataset compiled for analysis. • Statistical analysis. • Publications. • Donor and other reports. • Proposals for prevention trials developed.	• Data collection completed, data analyzed and published. • Based on findings, new study designed targeting larger sample size, multiple locations and in-depth evalautaion of some of the risk factors (see 4.4) Publication: • Prevalence, intensity and risk factors of tungiasis in Kilifi County, Kenya II. Results from a school-based observational study. PLoS Negl Trop Dis (2019): 13(5): e0007326.	
Specific objective 4.2. Testing of herbal remedy used by communities based on neem oil for tungiasis treatment in a clinical trial (phase II)				
• The impact of neem oil treatment on tungiasis infestation and inflammation established.	• Novel treatment recommendations that can be incorporated in the Kenya National Guideline for Tungiasis Control	• Ethical approval for study from KEMRI granted. • Approval for the study granted by the Expert Committee for Clinical Trials of the Pharmacy and Poisons Board. • Independent Trial monitor contracted.	• Data collection completed, and manuscript of phase IIA trial published. Publication: • Efficacy of a mixture of neem seed oil (*Azadirachta indica*) and coconut oil (*Cocos nucifera*) for topical treatment of tungiasis. A randomized controlled, proof-of-principle study. PLoS Negl Trop Dis 13(11): e0007822.	

		• Trial documentation, forms, SOPs, monitoring plan, etc compiled as per national guidelines. • Project staff training completed. • Field survey completed. • Dataset compiled for analysis. • Statistical analysis. • Report to Expert Committee for Clinical Trials. • Donor report. • Publication. • Proposals for phase III study	• Funding for larger phase III trial currently sought.	
Specific objective 4.3. Developing tungiasis prevention tools by 2025				
• Impact of novel prevention tools known.	• Recommendations for prevention made to Ministry of Health for incorporation in the Kenya National Guideline for Tungiasis Control by end 2025.	• Proposals developed. • Funding secured. • Ethical approvals from KEMRI granted. • Project staff training completed. • Field tests completed. • Datasets compiled for analysis. • Statistical analyses. • Donor reports. • Publications.	• Proposal to MRC call 'Health in Context' approved for funding to investigate the impact of improved household flooring on transmission of tungiasis, soil transmitted helminths and bacterial infections in children. • Pilot funding for testing neem solution for control of sandflea larvae on dirt floors approved (OxBer Funding). • KEMRI SERU approval granted for both projects. • Project staff training ongoing. • Engineering partners at JKUAT engaged. • Protocols developed and staff and students recruited.	
Specific objective 4.4: Identify the factors driving intense transmission & responsible for a high tungiasis disease burden				
• Environmental behavioural socio-economic risk factors identified. • Intra-domiciliary and extra-domiciliary transmission sites identified. • Seasonal changes in transmission dynamics analysed and described.	• Factors driving intense transmission & responsible for a high tungiasis disease burden identified. • County and National MoH and NTD Unit engaged, and recommendations provided by 2022.	• Ethical approval from KEMRI-SERU granted. • Study locations selected. • Stakeholders identified and engaged. • Cross-sectional studies in schools and household (HH) in three endemic areas implemented. • Examination of soil/floor sample, systematically collected during the cross-sectioned and the longitudinal studies, analysed.	• Cross-sectional studies in three field sites completed. • Datasets compiled and data cleaning ongoing for comprehensive analysis. • Soild samples screened for Tunga larvae and sample catalogue compiled. • Molecular tool for flea larvae identification developed and sample analysis ongoing.	

		• Molecular tools for identification of off-host stages developed and applied. • Longitudinal studies (school, HH, floor, soil during dry and wet seasons implemented. • 2 manuscripts • PhD student training • Donor reports and presentations		
Specific objective 4.5 Understand pathogenesis & identify determinants of severe morbidity in tungiasis by 2023				
• Impact of tungiasis on life quality documented • Impact of tungiasis on academic achievement documented. • Novel rapid assessment of tungiasis-associated inflammation established. • Scores for acute and chronic pathology validated. • Impact of T. penetrans on host mobility documented. • Pathogenic bacteria in inflamed lesions identified and pig as model for tungiasis associated morbidity in humans validated.	• Impact of tungiasis on cognitive child development estimated. • Care giver behaviour risk factors established. • Guidelines for thermography for pathology survey compiled. • County and National MoH and NTD Unit engaged and recommendations provided by 2023.	• Development and application of tools to assess tungiasis-associated life quality impairment in children. • Development and application of tungiasis-associated impairment of school performance • High resolution infrared thermography for quantifying inflammation surveys implemented. • Semi-quantitative assessment of clinical pathology completed, • Impaired mobility [using pedometers and GPS-trackers assessed. • Small scale metagenomics analyses comparing bacterial infection of tungiasis lesions between human and pigs implemented.	• All field surveys, including cognitive tests and development assessments completed. • Data cleaning ongoing in preparation for analysis.	High resolution infrared thermography is difficult to manage under field conditions and likely can not replace pathology surveys.
Specific objective 4.6 Determine the ecology of off-host stages of T. penetrans by 2024				
• Optimal transmission conditions identified. • Seasonality in development of off-host stages described. • Environmental conditions for off-host stages identified	• Better understanding of the heterogeneous distribution of tungiasis in different climate and ecological zones. • Contribution to prediction of disease outbreaks by end 2024.	• Soil/floor sample surveys implemented. • Identification of off-host stages completed. • Repeated cross-sectional studies (school/HH/floor) during	• Soil sampling completed from routine household risk factor survey. • Flea larvae extracted from soil samples and molecular analysis ongoing.	

		dry and wet seasons completed. • Field experiments to assess environmental conditions needed for off-host development done.		
Objective 5: Understanding leishmaniasis transmission dynamics in Kenya and development of control strategies by 2025				
Specific objective 5.1: Risk mapping and bioecological studies of leishmaniasis disease vectors				
• Elucidate the plant feeding ecology and habitat preference of sand flies	• Extent of plant feeding among different sand fly species determined • Specific plants fed upon by sand flies identified • Plant derived attractive volatile organic compounds identified • Sand fly composition and diversity in selected habitat types determined Semiochemical basis for habitat selection in sand flies assessed	• Conference presentations • Peer-reviewed publications • No. of graduate students/thesis produced • Data on preferred sand fly host plants • Plant-derived attractants identified Funding	Key Findings: • Variation in sand fly abundance and diversity between habitats likely mediated by volatile organic compounds (VOCs) • Selective feeding of sand flies including the leishmaniasis vectors Phlebotomus martini and *P. duboscqi* on plants in the family Fabaceae • Development of plant-derived attractant blend for potential use as a lure for surveillance and control of Afrotropical sand flies • 1 additional manuscript submitted Publications: • Hassaballa IB, Sole CL, Cheseto X, Torto B, Tchouassi DP (2021) Afrotropical sand fly-host plant relationships in a leishmaniasis endemic area, Kenya. PLoS Negl Trop Dis 15(2): e0009041. https://doi.org/10.1371/journal.pntd.0009041. • Hassaballa IB, Torto B, Sole CL, Tchouassi DP (2021) Exploring the influence of different habitats and their volatile chemistry in modulating sand fly population structure in a leishmaniasis endemic foci, Kenya. PLoS Negl Trop Dis 15(2): e0009062. https://doi.org/10.1371/journal.pntd.0009062	
• Investigate pheromone and host-derived communication in sand flies	• Pheromones produced by the CL vector Phlebotomus duboscqi identified • Behavioural response in lab and field to candidate compound(s) assessed Sand fly response to enantiomers of 1-octen-3-ol determined	• Protocol for chemical analysis established • Conference presentations • Peer-reviewed publications • No. of graduate students/thesis produced • Funding	Volatile profile of sand fly extracts of both sexes of *P. duboscqi* and behavioural activity on respective sexes established	
• Determination of densities, species diversity and host feeding preference of sand flies	• New vectors of leishmania species identified in Marsabit and Gilgil Vector	• Publication • Project reports • Conference presentations.	• Sand fly habitats and active transmission area in Isiolo County described. • Species identification of infectious leismania parasites identified.	• Monitoring of parasites in vectors is a viable xenomonitoring tool for surveillance in

	species of leishmaniasis from various habitats in disease endemics regions documented Sandfly densities recorded • Source of bloodmeals established		Publications: • Owino, B.O., Mwangi, J.M., Kiplagat, S., Mwangi, H.N., Ingonga, J.M., Chebet, A., Ngumbi, P.M., Villinger, J., Masiga, D.K. and Matoke-Muhia, D., 2021. Molecular detection of Leishmania donovani, Leishmania major, and Trypanosoma species in Sergentomyia squamipleuris sand flies from a visceral leishmaniasis focus in Merti sub-County, eastern Kenya. Parasites & Vectors, 14(1), pp.1-11. • Owino, B.O., Matoke-Muhia, D., Alraey, Y., Mwangi, J.M., Ingonga, J.M., Ngumbi, P.M., Casas-Sanchez, A., Acosta-Serrano, A. and Masiga, D.K., 2019. Association of Phlebotomus guggisbergi with L. major and L. tropica in a complex transmission setting for cutaneous leishmaniasis in Gilgil, Nakuru county, Kenya. PLoS Neglected Tropical Diseases, 13(10), p.e0007712.	endemic areas and those where the vector is present, but with low transmission rates.
• Leishmaniasis parasite identification	• Vectors screened of leishmaniasis parasite species	• Publication • Project reports Conference presentations.	• Parasites identified using molecular tools.	
Specific objective 5.2: To develop an odour-baited sandfly attraction trapping device - the "SanTrap" for the control of leishmaniasis				
• Development of odour baited sandfly attraction trapping device - the "SanTrap" for the control of leishmaniasis	• Novel approach in the control of sandfly bites developed . • Efficacy and efficiency of the attract-and-kill tool on sandflies established. • Vector species of leishmaniasis from various habitats in disease endemics regions documented.	• Publications. • Reports • SanTrap tool Patent	Evaluation of responses of Phlebotomus dubosci to visual cues undertaken. A prototype trap design developed to facilitate testing. • Sand fly habitats and active transmission area in Isiolo County described. • Species identification of infectious leismania parasites identified. Publication • Owino, B.O., Mwangi, J.M., Kiplagat, S., Mwangi, H.N., Ingonga, J.M., Chebet, A., Ngumbi, P.M., Villinger, J., Masiga, D.K. and Matoke-Muhia, D., 2021. Molecular detection of Leishmania donovani, Leishmania major, and Trypanosoma species in Sergentomyia squamipleuris sand flies from a visceral leishmaniasis focus in Merti sub-County, eastern Kenya. Parasites & Vectors, 14(1), pp.1-11.	
Specific objective 5.3: Epidemiological factors associated with cutaneous leishmaniasis transmission in Gilgil, Nakuru County, Kenya.				

• Vector species for Cutaneous leishmaniasis and parasite transmission in Gilgil, Nakuru County identification	• Identification and mapping of cutaneous leishmaniasis vectors Ecological factors mapping Cutaneous Leishmania reservoir identification	• Publications. • 1 MSc Stakeholder information sharing meetings.	• Sand fly habitats and active transmission area in Gilgil County described. • Species identification of infectious leismania parasites identified. Publications: Owino, B.O., Matoke-Muhia, D., Alraey, Y., Mwangi, J.M., Ingonga, J.M., Ngumbi, P.M., Casas-Sanchez, A., Acosta-Serrano, A. and Masiga, D.K., 2019. Association of Phlebotomus guggisbergi with L. major and L. tropica in a complex transmission setting for cutaneous leishmaniasis in Gilgil, Nakuru county, Kenya. PLoS Neglected Tropical Diseases, 13(10), p.e0007712.	Monitoring of parasites in vectors is a viable xenomonitoring tool for surveillance in endemic areas and those where the vector is present, but with low transmission rates.
• Correlation of exposure to sand fly bites and the CL outcome and the risk factors associated with disease exposure in Gilgil	• Identification of exposure to sand fly bites and the associated risk factors	Publications.	Vector sampling Patient samples analyses Laboratory analysis	
Specific objective 5.4: Identifying sand-fly endosymbionts and their potential effect on Leishmania transmission				
• Diversity of Wolbachia, Rickettsia, Spiroplasma, Arsenophonus, Ochrabactrum Serratia, Cardinium, and microsporidia symbionts in Kenyan sand-fly species done	• Identification and mapping of endosymbionts	• Publication Stakeholder information sharing meetings	• Field collection • Sample identification. Laboratory analysis	
• Experimental correlation of symbiont infection with infectivity to Leishmania	• Establishment of sand-fly colonies Identification of transmission blocking potential of key endosymbionts	Publication	• Experimental data • Established sand-fly colonies • Clearing of symbionts in subset of colonized sand-flies Experimental infection of Leishmania parasites in sand-flies with and without symbionts	

(iv) Environmental Health Theme: Results Based Management (RBM) Rolling Framework Report

Outputs	Outcomes	Performance Indicator	2020 Progress in Achieving Outcomes	2020 Lessons Learned
Objective 1: Survey, inventory, and description of new species of East African insects published and data made internet-accessible by 2025				
1.1 At least 50 international experts agree to study and publish results of examination of insects collected in Burundi and Kenya, by 2025.	Taxonomists agree to study East African specimens.	Number of taxonomists agreeing to participate.	• Number of collaborating taxonomists has now increased from 46 to 49	• Covid 19 led to the long-term closure of most museums and universities, limiting or postponing collaboration with their taxonomists.
1.2 At least 25 manuscripts produced by 2025 exclusively devoted to, or incorporating significant numbers of, East African insect taxa.	Taxonomists study and publish on East African insect taxa.	Number of manuscripts published on generic revisions, species descriptions, and regional checklists.	• Co-authored seven papers published in 2020. Rasowo BA, et al. 2020. Journal of Applied Entomology 145(1-2): 104-116. Bossert, S., et al. 2020. Insect Systematics and Diversity 4(6): 1; 1-29. Mekonnen, B et al. 2020. Entomologia Generalis 40(4): 437-441. Bukhebi J. er al. 2020. https://www.gbif.org/dataset/029ca2ac-d525-4dd0-bfc5-288102358341 Quicke, DLJ, et al. 2020. Entomological Society of Washington 122(4): 890-895. Leonard, Alfonce et al. 2020, Journal of Economic Entomology 113(5): 2150-2162. van Noort, Simon & RS Copeland.2020. Journal of Natural History, 54:9-12, 703-722,	
1.3. At least 100,000 insect specimens databased by 2025, and targeted groups (pollinators and parasitoids) matched, where possible, to unique-specimen barcodes and made available on the internet on the Global Biodiversity Information Facility (GBIF – (http://www.gbif.org)	Taxonomists and biogeographers access data base.	Number of visits to GBIF, including number of downloads of database information.	• 36,000 records of individual specimens collected by ICIPE have now been databased.	•
1.4. At least 10 taxonomists or biogeographers cite (via GBIF) icipe collection database in papers or reports by 2025.	Taxonomists and biogeographers access data base and use data in independent reports or papers.	Number of reports or published papers.	• Dermaptera in the icipe collection – 8 citations in 2020 • Sand flies of Eastern Africa – 11 citations in 2020 • Tsetse flies of East Africa update -8 citations in 2020	•

1.5 At least 350 new species discovered in East Africa and described in peer-reviewed journals by 2025.	Knowledge of East African insect diversity is increased and National Museums of Kenya type collection increased appreciably.	Published papers with collector and georeferenced location refer to ICIPE-provided type specimens.	As of end of 2020, 179 new species have been described and published in peer-reviewed journals. In addition, 23 more are at manuscript level.	• Covid-19 led to the long-term closure of most museums and universities, limiting or postponing collaboration with their taxonomists. •
Objective 2: Information on important pollinating Diptera (true flies) collected and made available on the internet by 2025				
2.1. *icipe's* collection of fly pollinators databased and made available to the international community on GBIF by 2025.	Data on Diptera important in plant pollination services made available to conservation biologists, taxonomists and interested parties.	Number of visits to GBIF, including number of downloads of data.	• Published online in 2020	
2.2 Three field visits per year through end of 2025 made to Kenyan forests and savannahs to increase the collection of Kenyan wild-bee pollinators	Information on wild-bee pollinators is increased, underscoring importance of non-Apis bees in providing pollination services.	Database of wild-bee pollinators increases during period indicated	Over 5,200 individual records of bees were databased by end of 2020	•
Objective 3: Taxonomic information on African insects including major African pests and vectors used by scientists, students and public by 2025.				
3.1 One training session per year on insect identification for ARPPIS students and other interested staff conducted through 2025.	• Students and staff know and apply modern taxonomic techniques, including preparation morphological identification, and DNA techniques to identify insects.	Number of students and staff members trained	• None	Cancelled in 2020 due to Covid-19.
3.2 At least four donor-funded projects with relevant taxonomic perspective request and receive taxonomic and/or photographic support from the Biosystematics Support Unit by 2025.	Scientists incorporate taxonomic information into planning and carrying out of projects	Number of projects funded that incorporate taxonomic data.	Five donor-funded projects received identification and/or photographic services during 2020	
Objective 4: At least 4 new eco-friendly nature-based products for pest and vector control adopted for improvement of livelihoods of rural and wider community members in East Africa by the year 2025.				
4.1.1 At least 2 new potential products for mosquito control identified from plants	• Two plant-derived insecticidal products adopted for use in mosquito control by a	• Number of products produced and used.	Products • One mosquito repellent product formulated by fusion of insect oil and essential oil for prolonged protection time. The product is still in further screening	• Policies that address the economic and legal barriers to product commercialization, as well as financial incentives, should be prioritized

based on efficacy, safety, and ease of application. 4.1.2 At least two plant-derived products for mosquito control formulated and packaged. 4.1.3. Community-based cultivation of selected insecticidal plants initiated. 4.1.4. Community-based production and use of plant-derived products for mosquito control initiated in at least one project site. 4.1.5. At least 1 PhD and 1 MSc students trained. 4.1.6. At least three papers prepared and submitted to international journals. 4.1.7. A plant processing facility for the community established	local community by 2025. • Three papers or patents on potential mosquito control products published by 2025. • One prerational processing facility	• Number of community members using the mosquito control products. • Number of reports and publications. • Number of students trained. Number of processing facility established	• Community-based cultivation of 5 insecticidal plants ongoing in Ethiopia, Kenya, Burundi, and Tanzania. Capacity building • 1 Ph.D. students graduated. • Over 16,395 participating community members benefit through acquisition of additional knowledge and skills in biodiversity conservation and enterprise management. Reports submitted. • Impact sheet on Up-scaling sustainable commercial production of medicinal plants by a community-based conservation groups at Kakamega forest in Kenya • 2 case studies on imapct sheet on Up-scaling sustainable commercial production of medicinal plants by a community-based conservation groups at Kakamega forest in Kenya Manuscripts: • Diiro et al. (2020). Sustainability 2020, 12, 8552 • Ywaya et al. (2020) Journal of Essential Oil-Bearing Plants, DOI: 10.1080/0972060X.2020.1780954 • Mutero et al. (2020). Scientific Reports (in press). • Apicure®, an essential oil-based biopesticide was evaluated for its role of olfaction in small hive beetle (SHB), Aethina tumida whose response showed that it has potential for the management of honeybee pests and diseases.	• Bringing markets closer to the farms is likely to increase participation among Medicinal Plant producers • COVID-19 pandemic has shown the world how adopting preventive measures is essential to secure global health from the introduction and spread of devastating pests. • COVID-19 stagnated research due to availability of research funds and restricted movement
Objective 5: Evaluation of the contribution of the gut microbiota to honeybees and stingless bee physiologies, nutrition, and resistance against natural pathogens and agro-chemicals.				
5.1. Characterization of the gut microbiota of managed honeybees in Africa. 5.2. Characterization of the gut microbiota of feral honeybees in Africa. 5.3. Determine gut microbiota adaptability and flexibility to colonize	• Understand the composition of the gut microbiota in Apis mellifera subspecies. • Understand human impact on the honeybee gut microbiota at the strain-level and functional diversity.	• List of bacterial species inhabiting the honeybee gut in Kenya. • Establishment of a gut microbiota laboratory. • Scientific publications • Establishment of international collaborations. Number of graduated students.	• We comprehensively characterised for the first time the East-African managed honeybee gut microbiota. Tola, Y. H., Waweru, J. W., Hurst, G. D. D., Slippers, B., & Paredes, J. C. (2020). Characterization of the Kenyan honeybee (*Apis mellifera*) gut microbiota: A first look at tropical and Sub-Saharan African bee associated microbiomes. Microorganisms, 8, 1721. https://doi.org/doi:10.3390/microorganisms8111721 • Feral colonies gut microbiota studies are currently planned for July-August (since SPIRIT grant starting date was moved from July 2020 to January 2021).	Discriminating between managed and unmanaged bees in Kenya is not trivial. Whereas completely feral can be found in natural parks, semi-managed (log hives) might be also considered “wild” since they have no real human interventions (only capturing the swarm and harvesting the honey). Since we plan to condcut metagenomics instead of 16S library analysis, we are confident that we will be able to uncover any differences between “wild”, “semi-managed", and “managed bees.

different Apis mellifera subspecies.	Establishment of a bacterial strain library for future research.		• We have currently established a bacteria library of core gut microbiota strains and environmental strains found in the bee gut. Additionally, we plan to isolate more core members in the next 6 months. • We are currently analysing the data form the Indian Ocean Islands Nations and plan to submit a manuscript in the next 2-3 months. • Yosef Hamba Tola will submit his thesis this month and graduate in the next 2-3 months. • Mary Chege will submit her article and also graduate in the current academic year.	
5.4. Characterization of the gut microbiota of at least 8 species of stingless bees. 5.5. Determine gut microbiota adaptability and flexibility to colonize different Apis mellifera subspecies.	• Understand the composition of the gut microbiota of at least 8 stingless bee species. • Establishment of a bacterial strain library for future research. Understand and characterized potential obligated symbionts for stingless bees.	• List of bacterial species inhabiting the gut of at least 8 stingless bee species. • Establishment of a gut microbiota laboratory. • Scientific publications • Establishment of international collaborations. • Number of graduated students.	• Samples were collected and data were analysed. We are currently writing a manuscript that should be submitted soon. • We plan to isolate, and culture come of the gut microbiota members in the coming months. • Yosef Hamba Tola will submit his thesis and graduate in the next 2-3 months.	Without using a CO_2 incubator for anaerobic bacterial cultures, isolation and culturing of some of the core members have revealed to be more complicated than expected. We are contemplating using GazPack technologies.
5.6. Determine the effects of chemicals (pesticides, fertilizers, etc.) on bee gut microbiota tested	• Determine the toxicity levels of commonly used herbicides. • Determine if there are potential developments of gut microbiota resistance against these herbicides. • Establish the effect of these chemicals on the gut microbiota abundance and diversity. • Determine the metabolic pathways involved in chemical detoxification. • Understand how all these aspects listed above translate into	• Scientific publications • Number of graduated students	• We have determined the lethal doses for glyphosate and paraquat for the African *Apis mellifera* bee. • A manuscript should be submitted soon about the LC50 of paraquat and glyphosate. • Zamira Wesonga Mukwanbu will submit her article and graduate in the current academic year. • We are currently analysing the effects of paraquat and glysphosate on the bee gut microbiota and on oxidative gut epithelium stress. Data have already been collected; we are currently analysing the results. • Finally, by multiple gut microbiota passages, we might have isolated herbicide resistant strains. In the next two months we will have a clear idea if a/some bacterial strains are conferring such protection.	• We experienced a big delay with reagents and consumables ordering and shipment both due to COVIDand delays in procurement procedures. This has considerably delayed Zamira's work and has implications with stringent student contract extension policy • We need a qPCR machine at BH, we cannot rely anymore on the IED since qPCR are getting heavily used by other users and delays considerably our analyses.

	detrimental effects on bee physiology.			
Objective 6: Increasing honey and silk production by 20% in selected African farming communities by 2022.				
6.1 Potential and healthy silk and bee races identified for enterprise development in Africa by 2022. 6.2 Healthy silk and bee races are distributed to 1,000 trainers for the farmer groups. 6.3 At least 5 PhD and 10 MSc students trained. 6.4 At least 50 peer reviewed papers and five books/proceedings published in international journals.	• 60% of the farmers use improved bee and silk races. • Development of strains and identification of hybrids with productive merit. • Establish germplasm for silkworm races in Africa.	• Number of farmers using improved races. • Disease resistant races selected. • Production hybrids breeds for silkworm selected • No. of thesis produced. • No. of manuscripts published.	• Two (M.Sc) students registered in Kenya on sericulture, working on rearing of silkworm conditions in Rift valley and degumming silk using enzymes. The students are registered at Eldoret and Nairobi Universities, respectively. • 1 PhD (Landscape characteristics and honeybee integrity: A case study of Mwingi, Eastern Kenya). • 1 MSc (Varroa-specific hygienic behaviour and population abundance of Varroa destructor in colonies of *Apis mellifera scutellata* in Karura Forest, Kenya). • S.K. Cheruiyot et al (2020). Experimental and Applied Acarology, 82 (2).	• Local capacities for breeding of silk and bee races need to be enhanced for sustainability.
6.5 Training material developed and training sessions held for 2,000 trainers.	Knowledge of sericulture and apiculture is applied by at least 750 farmer groups (each 50 to 100).	• Number of farmers trained. • Number of certificates (exam). Number of farmers applying their new knowledge.	• 20 Farmers from Cheremi sericuluture farm trained in at Ruai farm and *icipe* in the month of February and April • 9 training modules along the honey value chain developed. • 250 farmers trained on improved beekeeping technologies •	• Unforeseen Covid-19 affected training arrangements • Digital content delivery needs to be explored/enhanced to overcome unforeseen challenges (pandemics)
6.6 Business model developed using value chain approach.	Business model and business responsibility adopted by at least 400 farmer groups.	• Number of enterprises registered. Private sectors working with farmer groups	• Two (2) private enterprises namely Silk Origin Ltd in Nakuru county and Dermott sericulture in Bungoma county registered and collaborates with *icipe* on sericulture production chain.	• Private sector registering in sericulture is increasing
6.7 16 to 20 marketplaces (honey and silk harvesting, processing and selling units) established.	20% increase in honey and silk quantity by 2022.	• DC registry. Production records.	• Over 200 kg of Cocoons produced in Kenya by *icipe* in collaboration with Cheremi farm in Ruai, Nairobi • Post-harvest equipment for 5 honey marketplaces procured. • 2 marketplaces (Zanzibar) operationalised. • Establishment of 3 honey marketplaces on-going (Madagascar, Comoros, Seychelles)	• Unforeseen pandemics affects production • Communities need professional support, especially from Government departments, to run marketplaces as businesses.
6.8 Modern beehives supplied to farmers and rearing houses (silk moth) established.	500 beehives supplied to farmers by 2021.	Project records.	• Two (2) silkworm rearing houses established in Silk Origin, Elementaita, Nakuru and Cheremi farm at Ruai, Nairobi, respectively. Egg producing grainage established at Silk origin Elementaita Nakuru and 150 beehives supplied	

6.9. Internal control system (ICS) training for 3,000 trainers conducted.	Percentage of communities producing honey and silk to European Union (EU) standards increases from 20 to 30% by 2021.	Honey and silk quality assessed and certified.	• ICS beekeeping manual (inclusive of organic beekeeping standards) developed and adopted by beekeepers in Madagascar and Zanzibar. • 52 beekeepers trained on ICS for organic honey production.	• Digital content delivery needs to be explored/enhanced to overcome unforeseen challenges (pandemics)
Objective 7: Integrative Pollinator-Plant Interaction Assessment of Ecosystem Service Diversity in Sub-Saharan Africa (JRS Biodiversity Foundation Project) by the year 2021				
7.1 Web-based platform (database) for Plant-Pollinator Interactions.	Deepened understanding of plant-pollinator interactions for conservation of pollination services.	Web-based platform (APPI) in usage.	• Database under construction, mobile data collection tool finished (https://play.google.com/store/apps/details?id=org.icipe.collect&hl=en)	• Initial partner stepped out of project after 9 months, search for new partner delayed development of platform
7.2 Data collected and deployed in database for two ecosystems in Kenya.	Deepened understanding of plant-pollinator interactions for conservation of pollination services.	Number of data records deployed in database (10,000 interaction records).	• Data collected (18,000 records)	• Due to delayed platform development, data were not deployed
7,3 Assess risks for common pollinator species using species distribution modelling.	Assessment of risks for distribution due to climate change, land use change etc. to inform conservation measures.	Species distribution models.	• Assessment done, manuscript submitted (Dicks et al Nat Ecol Evol, revision submitted) • Species distribution of 108 pollinator species • To be improved by selecting species with occurrence data <100 • Study of beta-diversity along sampling sites and across seasons indicated that temperature seasonality and beta diversity of foraging plants as major factors (Dzekashu et al., in prep.)	• Species with many occurrence data are needed • Risk factors are known to experts, still their confidence on effects is low due to the lack of research results
7.4 Establish plant-pollinator networks for different land use types.	Deepened understanding of plant-pollinator interactions for conservation of pollination services.	Plant-pollinator networks.	Data available for 100 plots (50 each in Taita Hills and Murang'a) sampled at 4 different seasons for 185 bee species and 150 plant species resulting in 18,000 interaction records.	• Handling of large data sets • Computational power is needed
7.5 Assess genetic diversity of pollinators using DNA barcoding.	Deepened understanding of plant-pollinator interactions for conservation of pollination services.	300 molecular barcodes of bees provided.	• 185 morphospecies identified, DNA extracted, partially amplified (20%) • Sequencing done with Oxford Nanopore Technology	DNA extraction of small and tiny individuals needs to be adjusted
7.6 Capacity building of stakeholders in database usage.	Increased uptake of database usage by other stakeholders.	• Data records on interactions deployed. Database usage records (registered users).	• Workshop held in January 2020 at *icipe* (35 participants)	• ongoing participation of participants in testing products like mobile data collection tool and database is difficult to achieve

7.7 Capacity building for biodiversity bioinformatics for icipe staff.	Independent database development and management at icipe.	Number of staff to be trained in biodiversity databases.	• This activity has been postponed due to the prevailing COVID situation	• Delayed by measures to prevent Covid-19, • Training to be done virtual using zoom, TeamViewer etc.
Objective 8: Evaluate the pollination efficiency of different stingless bee species in enhancing fruit quality and contribute in discriminating the African stingless bee species using molecular tools by 2021.				
8.1 Assess of pollination efficiency of 10 stingless bee species and African honeybees in two greenhouse crops in Kenya	• Pollination efficiency of seven stingless bee species and African honeybees assessed for strawberry and blue berry crops in greenhouse in Kenya. • Plant-pollinator-microbe interaction assessed on 1 horticulture crop. • One Msc student trained One PhD student trained	• Data on fruits quality and quantity records per tested crop species. • Pollinator-Nectar-dwelling micro-organisms data available for 1 tested crop. • At least one papers per crop prepared and submitted to journals. • One MSc student thesis on Blue berry pollination by stingless bees. One PhD student thesis on strawberry pollination by stingless bees.	• Pollination efficiency study on blue berry: - Greenhouse experiment achieved in collaboration with Kakuzi PLC. - Lab analysis of antioxidant and flavonoids content in fruit achieved. -Statistical analysis of data and manuscript writing on going in collaboration with research partners in Belgium. • Pollination efficiency study on strawberry: - Experimentation faced delay due to sourcing of seedlings and Covid-19. -Seedlings were purchased and planted at end of the year. Management of plants for setting experimentation is ongoing. • Pollinator-Nectar-dwelling micro-organisms: -Sample collection achieved on yellow bell pepper crops. -Collection of field data on nectar volume achieved. -Lab analysis of nectar sugar concentration and composition from field samples achieved. -Lab culture of nectar microbes from field samples achieved. -Bacterial and Fungi samples collected from cultures and sent to USA for identification. • Training one Msc student: - Mr. James Kamau from plant science department at Kenyatta University trained on managed pollination of blue berry crops. - Msc thesis writing ongoing. • Training one PhD student: -Miss Regina Waiganjo from plant science department at Kenyatta University is being trained on managed pollination of strawberry crops.	• Collaboration between icipe and external scientist improved our knowledge on methodologies and technologies related to collection of specific pollination parameters.
8.2 Assess stingless bee species distribution using modelling technics.	Assessment of environmental and climatic factors explaining species distribution to inform species conservation measures	• Species distribution models provided for project countries. • Establish training Centre in Kenya for stingless bees farming technology dissemination.	• Modelling stingless bee species distribution: - Species distribution models provided for project countries through MSc thesis of Mr. Eliott DEPRINS presented in 2020 in collaboration with Prof. Nicolas Vereecken of ULB, Belgium -Additional study on species distribution for Kenya being conducted by David Makori, a PhD student in collaboration with Dr. Elfathi (*icipe*).	

		At least one paper prepared and submitted to journals.	-Manuscript in progress for case study in Kenya with David Makori, but with delays from the student.	
8.3 Assess genetic diversity of African stingless bees using DNA barcoding and morphometric analysis	• Species discrimination based on wing morphometric. • Species discrimination based on genetic differentiation. Species phylogeny	• Wing geometric morphometric of African stingless bee species provided. • Molecular barcodes of African stingless bee species provided. • Booklet on African stingless bees provided. At least four papers prepared and submitted to journals.	• Species discrimination based on wing geomorphometric: -Data on wing geometry and morphometrics from species of large and mid-sized stingless bee species availed for 749 samples collected and analysed from 11 countries distributed in Indian ocean islands, East, Central and West Africa. - manuscript on the above data written by Nelly under reviewwith partners. - Data on wing geometric morphometrics of small body size stingless bee species availed for 2100 samples collected from 11 countries distributed in Indian ocean islands, East, Central and West Africa. Statistical analysis on-going and manuscript development pending taxonomy confirmation by Prof. Alain Pauly. • Species discrimination based on genetic differentiation: - DNA sequences generated for 706 stingless bee samples collected from 11 countries distributed in Indian ocean islands, East, Central and West Africa. Delay due to Covid-19 (Travel restrictions). -Identification of cryptic and potential novel species awaiting confirmation by the expert partner Prof. Pauley. -Finalization of statistical analysis and manuscript with Nelly as first author awaiting species taxonomy confirmation by the expert partner Prof. Alain Pauly.	• Collaboration between *icipe* and external scientist improved our staff's knowledge on analytical tools and quality assessments.
8.4 Capacity building of stakeholders in meliponiculture	Training of at least one ToT from Botswana	List of trained people	• This activity has not been achieved due to long delay in communication by the focal point in Botswana. • We also faced delay due to Covid-19 (Travel restrictions).	• It would be better to work with private sectors or researchers from educational Institutions considering the delays.
8.5 Capacity building of university students on conducting pollination efficiency evaluation studies.	Training of at least two University student (Master and PhD level).	List of students on attachment	• Jame Kamau, ongoing Msc thesis on pollination of Blue berry by stingless bees. • Regina Waiganjo, Ongoing PhD on pollination of strawberry by stingless bees.	The contribution of pollinators to food security is a scarcely understood subject among university students. We will address this issue by extending our collaboration to more Universities and also by involving BSc students to conduct their school project in pollination related topics.
Objective 9: Generate 100,000 dignified and fulfilling employment opportunities for unemployed young women and men in honey and silk value chains and complementary income generating activities by 2024 (MOYESH program)				
9.1 Establish partnerships and identify and develop resources for scaling up beekeeping and silk farming	Increased honey, hive products and silk production by youth enterprises	Amount of honey, hive products, silkworm cocoons and silk yarn produced by the youth enterprises	After successful commencement of project activities across the four regions, engagement of key public and private institutions and selection of project sites, over 16 thousand interested and needy unemployed young women (59%) and young men were recruited.	The strong desire to commence with implementation compromises essential preparations that need to be made for effective and coherent kick off. This can be made more

enterprises to increase employment and learning opportunities for youths (PARTNERSHIP AND RESOURCES MOBILIZATION)			At least 88 SME that employ 181 female and 636 male workers were engaged to manufacture starter kit items and supply to the project. From one region alone, 9,295 kg of honey was produced during this commencement year; the other 3 regions harvest several months later. From two test runs, 60 kg cocoons were produced in one region.	complicated by such unexpected global risks like the COVID-19 pandemic and the official restrictions imposed to prevent its spread.
9.2 Link young men and women with financial service providers through digital financial services and business-to-business (B2B) linkages (FINANCIAL INCLUSION)	• Increased utilization of affordable financial services for the young men and women targeted by the program • Youth enterprises secure working capital through linkage with private actors (producers, processors, aggregators and exporters) • Increased utilization of digital and youth friendly financial products and services by young men and women • Youth mobilized saving and create funds for investment in beekeeping and silk farming or related businesses	• Number of youths that received credit services from financial service providers (MFIs and Banks) • Number of youth enterprises that accessed working capital through B2B agreements with private actors • Number of youths that used youth friendly financial products and services (saving, credit appraisal, mobile and agent banking services) • Amount of loans and savings mobilized through VSLA	• Youth beneficiaries were guided to mobilize about US$400 thousand of savings in their group bank savings accounts as working capital and to prepare for loan applications from partnering private banks and MFIs. Arrangements initiated to pilot two digital financial services with two private banks. Agreement signed to utilize a functional B2B e-commerce platform to sell products of youth enterprises.	Delivery of suitable micro-finance services is perceived by local banks as too risky, making collaboration with MFIs even more important.
9.3 Develop market linkages and youth-owned profitable beekeeping, sericulture and complementary enterprises (MARKET LINKAGES AND ENTERPRISES ESTABLISHMENT)	• Youth enterprises established and generated income in silk and honey value chains • Increased honey and hive products value addition and processing for better market value and quality • Increased silk value addition and processing for better market value	• Number of youth enterprises that started generating income from silk, honey and related value chains • Volume of honey and hive products processed in the marketplaces • Volume of silk yarn and fabrics produced at the silk processing centers in kg • Amount of income received by youth from	Recruited beneficiary youth organized into 1,419 business enterprises and started to run their core and complementary businesses. During this commencement year only about 9 tons of honey and 60 kg of cocoon was produced from trial runs.	Market development is a slow process, especially when it involves small and medium enterprises with small and developing production capacity. Role of private sector actors is critical in establishing and developing market linkages.

	• Increased income from complementary side businesses Increased honey and hive products quality and residue analysis for export certification	complementary side businesses Amount of honey and hive products tested for export		
9.4 Develop skills and capacity of youth and partners to undertake and manage successful and sustainable beekeeping and silk enterprises as well as complementary activities (SKILLS CAPACITY DEVELOPMENT)	• Increased capacity of partners to support youth enterprises as well as complementary IGAs • Increased capacity of youth to establish and manage successful and sustainable beekeeping and silk enterprises as well as complementary IGAs Improved youth business, entrepreneurship and soft skills to run successful enterprises	• Percent of stakeholders reported improved capacity in providing technical support and training to youth to establish successful and sustainable enterprises. • Percent of youth reported improved technical skills and knowledge in beekeeping and silk farming activities Percent of youth reported improved entrepreneurship, business and soft skills (soft skills score)	For institutional capacity building, the project identified and trained 1,031 (35% female) local extension staff (450 in apiculture technical skills, 124 in sericulture technical skill development and 457 in Entrepreneurship Skills development). These trainees have trained more than 16,000 partner youths and provided technical support for the youths and other farmers. At least 88 SMEs provided with technical capacity and given supply contracts to manufacture local starter kit items for the project.	For a massive scaling up project like MOYESH, building the technical and supervisory capacities of staff in key partnering institutions is essential for enhanced institutional ownership of the project as well as smooth implementation of project activities.
9.5 Develop and implement gender sensitive monitoring, evaluation and learning (MEL) system to guide decision making and facilitate learning (MEL)	• MOYESH MEL framework developed and made operational • Baseline data collected and baseline values and target established • Web based (digital) monitoring system established and made operational • Periodic monitoring conducted and evidence of progress or lack thereof documented and shared • Evidence of success, failure and lessons documented and shared	• MOYESH MEL framework in place • Baseline survey report and completed M&E Matrix • Functional web based (MIS) monitoring system in place • Number of monitoring reports produced and shared • Number of case studies, success stories, technical studies and best practices produced and shared Mid-term and final evaluations conducted, and reports made available	The project MEL framework and M&E martix fully developed. Gender mainstreaming integrated into the MEL framework. Baseline survey completed and reported on. Web based data management system developed and tested. Progress reporting and visualization tool developed. First year progress monitoring survey conducted.	New and developing ICT technologies can become handy tools to develop a robust MEL framework that responds to needs for prompt progress updates to inform adaptive project management.

	Midterm and end term evaluations conducted			
9.6 Establish effective project coordination, partnerships and communication strategies for successful management and implementation of the program (COORDINATION AND IMPLEMENTATION SUPPORT)	• Program launching conducted at regional and federal levels • Program planning and progress review meetings conducted at national and regional levels • National and regional steering committee meetings conducted • Program communication plan developed and implemented • Program achievements and best practices documented and disseminated • MOYESH Program website designed and launched • Digital information exchange/sharing platform developed • MOYESH training manuals published and translated to regional languages • Program partners (Private and NGOs) identified and engaged • MOYESH Program technical and financial reports and monthly briefs prepared and submitted to the MCF MOYESH Program Quarterly and monthly briefs prepared and submitted to the MCF and	• Number of program launching workshops • Number of annual program review and planning meetings conducted • Number of regional and national steering committee meetings conducted • Program communication plan in place and under implementation • Number of communication outputs prepared and disseminated (leaflets, banners, etc.) • MOYESH Program website developed and functional • MOYESH digital information exchange platform developed and used to share information with youth and stakeholders • Number of training manuals published and translated to regional languages • Number of NGOs and private sectors that signed MoUs to support implementation of MOYESH Program • Number of Technical and Financial Reports produced and shared with the Foundation Number of quarterly and monthly reports produced and shared with the MCF and Program Management Committee	All 70 newly recruited staff brought on board. Four regional project offices established. Regional project steering committees initiated. Communication strategy prepared. Several additional institutional partnership arrangements initiated. Smooth and dynamic relationships developed and maintained.	The strong desire to commence with implementation compromises essential preparations that need to be made for effective and coherent kick off. This can be made more complicated by such unexpected global risks like the COVID-19 pandemic and the official restrictions imposed to prevent its spread.

	Program Management Committee			
Objective 10: Investigate the ecology and evolution of sub-Saharan African stingless bees by 2025				
10.1. Analyse the physico-chemical and bifunctional properties of African stingless honey, determine host plants and model ecological niches of stingless bees in Africa, Asia and South America	• Physico-chemical composition of various African stingless bees known and published. Biofunctional properties of various African stingless bees known and published	One PhD staff trained 2 publications	• One joint manuscript submitted for publication by Hosea (*icipe*, lab technician)	• Activities delayed due to delays in recruitment of PhD student from partners
Objective 11: Participatory beekeeping for ecological protection of Mangrove forests in Zanzibar (ZanBee) done by 2022				
11.1 To develop a mutual link between beekeeping and environment for improved honey production, through promotion of multipurpose and all-season nectar and pollen supply plants through community nurseries and training	Increase to 25% of beekeepers engaged in other environmental activities Increase in planting of multipurpose trees in area to 100 pieces (per beekeeping group) by project end 1-2 different products derived from beneficial trees	Number of beekeepers who are engaged in environmental activities availability of forage plants over the whole year Number of products derived from beneficial trees produced	• Visit of communities selected by local partner in November 2020 • Initial trainings on beekeeping to be held by local ToTs trained in IFAD ALFIS I & II project	• Delayed by measures to prevent Covid-19
11.2 To promote beekeeping and enhancement of honey production through practical beekeeping training, development of capacity for monitoring of honeybee health and product quality	Increase of honey production by 500 kg per year (by 2022 compared to 2021) Increase of high quality of honey produced by 80% of farmers 50% of participating farmers keep records of the health of their bees	kg of honey produced quality of honey produced availability of information on bee health (provided by beekeepers)	• Delayed due to COVID, activities to be accomplished in 2021 and 2022	• Delayed by measures to prevent Covid-19
11.3 To increase incomes through improved market access facilitated through hive product diversification and value addition	At least 20% of farmers increase price of their products during project period by 20% At least 20% of participating farmers	level of honey & wax price number of farmers diversifying their hive products number of marketing partners • kg of honey sold	• Delayed due to COVID, activities to be accomplished in 2021 and 2022	• Delayed by measures to prevent Covid-19

	engage in hive product diversification Linkages with at least 5 marketing partners established 500 kg of honey sold			
Broad objective 12: Development of insects for food, feed and other uses by 2025				
Specific objective: Insect feed for poultry, pigs and fish production in Sub-Saharan Africa.				
Cost-effectiveness and potential livelihood effects of insect-based feed technologies assessed through a gender lens along the value chain.	• The economic benefits of insect farming and insect-based feed for poultry, fish and pig production systems along the value chain determined by 2019. • The long-term potential impact of insect-based feed technologies on food and nutritional security predicted by 2019. Economic viability of insect-based feed supply chain models to guide scaling up pathways by 2020.	• 2 scientific papers on efficient insect mass-rearing techniques as affected by different agro-ecological zones. • 1 training guide on insect mass-rearing for feed with reference to production scales and gender developed. • 3 scientific publications on cost-effective organic fertilizer production through insect mass-rearing. • Stories of change focusing on experience and success from youth, men and women and other actors involved in the use of insect as feed documented. • At least 300 insect mass-rearing enterprises owned by women, men and youth established. • At least 10 feed producers integrating insect in their feed. • 2 MSc and 1 PhD student trained.	• Three (3) MSc students registered in Kenya to conduct socioeconomic survey in the project. • Akrica et al. (2020) Farmers' Perception of Commercial Insect-Based Feed for Sustainable Livestock Production. Submitted to Sustainability Journal. • Abro et al. (2020) Socio-economic and environmental implications of replacing conventional poultry feed with insect-based feed in Kenya. Journal of Cleaner Production. 265: 121871. • Macharia et al. (2020) Gendered analysis of the demand for poultry feed in Kenya, Agrekon, DOI: 10.1080/03031853.2020.1742747. • Kamau et al. (2020) Gendered perceptions on land ownership and it's influence on women's intra-household decision making power among smallholder livestock farmers (under review) • Mutuku et al. (2020) Effect of women's empowerment on dietary diversity among women pig and poultry farmers (under review) • Mutuku et al. (2020) Determinants of profitability of black soldier fly enterprise in Kenya. Submitted to JIFF. • Bulinda et al. (2020) Factors affecting farmers awareness on black soldier fly farming in Kenya (under review)	• There are clear indicators that black soldier fly farming is profitable. However, issues related to labour as well as organic waste input needs to be carefully addressed to increase the gross margins.
Finetune and deploy rearing techniques under small- and medium-scale on-farm conditions to improve capacity planning to meet	• Traceability and capacity planning for reliable and timely meeting of	• Report produced on existing supply chain models for key commodities in Kenya; and on the role of youth, women	• 1 PhD student completed his studies on the development of insect-based compost for sustainable soil health management using by-products from insect mass rearing for feed.	• Black soldier fly farming requires less space, less water and less capital investment input from smallholder farmers.

customer demand for insect-based protein and fertilizer.	customers' demands improved by 2021. • Quality organic fertilizer alongside high-yielding insect production developed by 2020. Insect rearing under various on-farm conditions present, and its performance assessed based on different models (gender and age of farmer, scale of production, agro-ecology) by 2021.	and men in feed supply chains. • Publication on the gender differential economic benefits of insect farming and insect-based feed for poultry, fish and pig production systems along the value chain in Kenya. • Publication on the long-term potential impact of insect-based feed technologies on food and nutrition security in Kenya. • Report on economic viability of insect-based feed supply chain models in Kenya. • At least 2 MSc students trained.	• 1 MSc student worked on Influence of Insect-Based Organic Fertilizer Soil Amendments on the Growth and Yield of *Phaseolus vulgaris*, *Solanum lycopersicum* and *Brassica oleracea* var. acephala in Kenya (completed) • Sumbule et al. (2020) Strengthening the Growth and Economic Performance of Layer Chicks and Growers through Sustainable Utilization of Black Soldier Fly Larvae Meal in Feeds. Submitted to Sustainability Journal. • Beesigamukama et al. (2020) In situ nitrogen mineralization and nutrient release by soil amended with black soldier fly frass fertilizer. Submitted to Scientific reports (under review) • Beesigamukama et al. (2020) Black soldier fly turns agro-industrial food waste into organic fertilizer: Cost- and eco-effectiveness from a circular economy perspective. Submitted to JIFF (under review) • Beesigamukama et al. (2020). Nitrogen fertilizer equivalence of black soldier fly frass fertilizer and synchrony of nitrogen mineralization for maize production. Agronomy, 10, 1395; doi:10.3390/agronomy10091395. • Beesigamukama et al. (2020). Biochar and gypsum amendment of agro-industrial waste for enhanced black soldier fly larval biomass and quality frass fertilizer. PloS one, 15(8), p.e0238154. • Beesigamukama et al. (2020) Exploring black soldier fly frass as novel fertilizer for improved growth, yield, and nitrogen use efficiency of maize under field conditions. Front. Plant Sci. 11:574592. doi: 10.3389/fpls.2020.574592. • Chia et al. (2020). Nutritional composition of black soldier fly larvae feeding on agro-industrial by-products. Entomologia Experimentalis et Applicata. doi: 10.1111/EEA.12940. • Chia et al. (2020) Smallholder farmers' knowledge and willingness to pay for insect-based feeds in Kenya. PLOS One 15, e0230552. • Sumbule et al. (2020) Layer feed enriched with insect meal (*Hermetia illucens*) enhances egg production, quality, and profitability: Evidence from Africa (under review) • Mutisya et al. (2020) Can black soldier fly larvae-*Desmodium intortum* based diets enhance the performance of Cobb500® broiler chickens and smallholder farmers' profit in Kenya? Poultry Science 100(8) DOI: 10.1016/j.psj.2020.11.021.	• Farmers who have tested commercial insect-based feeds on-farm have confirmed the advantages in terms of growth, carcass quality and economic returns over the conventional fishmeal-based feeds • The development of the residues from black soldier fly rearing into frass fertilizer brings enormous benefits to the insect farmers. • Frass fertilizer has been proven both in screenhouse and in open field to improve soil fertility, crop yield, and nutrient quality of the crops.

Develop and test gender-inclusive insect feed supply models and build capacity along the value chain.	• Awareness creation. Develop, test and compare different supply chain models linking insect production with feed manufacturing.	• Training manual developed. • At least 3,000 fliers produced and distributed. • At least 300 posters produced and distributed. • At least 6 training reports produced. • A curriculum on insect use in animal feed developed. • At least 3,000 youth, men and women trained. • At least 10 entrepreneurs with successfully financed business models. • Report on existing supply chains in other commodities and their applicability to insect-based feed produced. • At least 5 radio and TV programs.	• Mutuku et al. (2020) Telling the full story: Using mixed methods to better understand women's empowerment and its correlates in central Kenya. Submitted to journal of Mixed Methods Research (under review) • Step by step manual for smallholder farmers haves been developed. • Over 1250 youths and women were trained in 2020 and supplied with fliers • Two radio and 3 TV programs on black soldier fly production were carried out. • Report on existing supply chain of black soldier fly-based feed has been documented. • Over 38 government extension officers trained on black soldier fly production in Kiambu. • More than 53 small and medium-sized enterprises (SMEs) established in Kiambu.	• Black soldier fly farming can be a very good gender empowerment tool and adoption by women has been very encouraging.
Characterized the BSF gut microbiota and its potential effect on BSF nutrition and safety	• Understand the composition of the gut microbiota of BSF in 4 different substrates. • Determine if the BSF has a core gut microbiota. • Determine potential microbial pathogens that can represent a safety risk for the use of BSF and food and feed.	• List of bacterial species inhabiting the BSF gut in 4 common substrates used in Kenya. • Scientific publications	• We comprehensively characterised for the first time BSF gut microbiota in Africa in 4 different diets. Tanga, C. M., Waweru, J. W., Tola, Y. H., Onyoni, A. A., Khamis, F. M., Ekesi, S., & Paredes, J. C. (2021). Organic waste substrates induce important shifts in gut microbiota of black soldier fly (*Hermetia illucens* L .): Coexistence of conserved, variable, and potential pathogenic microbes. Frontiers in Microbiology, 12(February), 1–11. https://doi.org/10.3389/fmicb.2021.635881 • Khamis et al. (2020) Insights in the global genetics and gut microbiome of black soldier fly, *Hermetia illucens*: Implications for animal feed safety control. Front. Microbiol. 11:1538. doi: 10.3389/fmicb.2020.01538.	• The contaminant of black soldier fly larvae reared in various waste streams have been tested and proper biosafety measures developed to ensure safe protein products for animal feed industry.
Specific objective: Testing business models for scaling insect-based protein feed for use in poultry farming and aquaculture in Kenya				
Markets and marketing channels for insect-based protein feed using different business models developed.	• Identify and adapt potential business models for insect-based protein for feed in poultry and fish production.	• Cost-effective and suitable commercial models identified and adapted for use of insects as feed.	• Five cost-effective and suitable business models identified and tested in the project benchmark site. • Afrika et al. (2020) Farmers' preferences toward black soldier fly insect-based commercial chicken feed (under review)	• The market demand for insect protein is very high but more effort is required to develop more enterprises to guarantee the volume needed by the processors to overcome the protein gap experienced in the region and beyond.

	• Map the potential insect-based protein feed supply chains. • Establish and monitor the linkages between insect-based protein feed value chain actors. • Work with the private sector partners to support various components, including training, financing and awareness creation. Develop insect-based protein feed production and marketing information exchange platform to link actors along the value chain.	• Supply chains model for commercial production of insects documented. • Out-grower models utilizing insect for feed by farmers and private sectors established. • Private sector feed millers subcontract entrepreneurs and contribute to the training and awareness campaigns of BSF production. • Pre-financing for different needs in the production system documented. • SMEs develop outgrower models for sourcing insects from farmers/cooperatives and established market linkages with feed processors.	• All SMEs develop have engaged in out grower models development and source their insects from other farmers, thus creating ready market with feed processors. • The potential insect-based protein feed supply chains have been mapped. • Five (5) feed millers have been engaged to formulate and commercialize insect-based feeds for smallholder farmers in Kiambu.	
Transfer and promote insect-based protein feed technologies among the various actors along the value chain.	• Establish BSF rearing facilities for demonstration and training on best practices related to production, processing and packaging. • Provide starter kits for production of insect-based protein. • Develop and disseminate, production protocols, training and outreach materials to sensitize and create awareness on insect-based protein feed. ToT workshops on all aspects of the project outputs.	• Simple and cheap mass production technology with high potential for scale at the farm and SME levels established. • The most effective technologies for different commercial models documented. • The constraints/challenges of BSF production and options/challenges documented. • At least 200 entrepreneurs and start-ups have access to proven low-cost technologies. • At least 200 farmers adopt the technology of mass production of BSF for feed on-farm.	• Over 375 farmers trained in 2020 and supplied with starter population of black soldier fly. • Constraints associated with black soldier fly farming such as mites, parasitoids and other pathogens have been identified and potential solutions ascribed.	• Uptake of insect farming is rapidly growing in Kenya with minimal constraints to hinder the industry from achieving its full potential.

Evidence-based data to support scaling and adoption of insect-based protein feed enterprises generated.	• Establish baseline and end-line data. • Optimize modular insect production systems for scaling, based on stakeholder feedback, and monitor for product quality and safety. • Assess the household level socio-economic benefits of insect-based protein feed farming and formulation among millers and farmers in the poultry and aquaculture industry. Assess the potential for employment generation and country level economic benefits of insect-based protein feed for poultry farming in Kenya.	• Develop a business case for production of insect for feeds via the different models and make recommendations on the most viable business models. • Develop and distribute an easy-to-use manual for setting up of successful insect farms with details on costing. • At least 2,500 metric ton of insect-based protein produced and utilized for on-farm trails. • At least 3 optimal facilities for effectively scaling out on-farm production of BSF established. • Nutritional and safety qualities of BSF reared on various substrates under different production models compared to laboratory-reared BSF. • 200 farmers recruited to participate in on-farm assessment and performance of insect-based protein feed on poultry and fish in target locations. • Nutrient quality established of formulated feeds produced by private feed millers to meet the nutritional demand of poultry and fish for optimal on-farm productivity. • Establish the socio-economic benefits of insect-based protein farming and feed formulation in poultry and	• Four M.Sc. students registered (2 conducting socioeconomic survey and 2 on insect-based feed trails on fish) • Mawai et al. (2020) Consumer preferences and willingness to pay for meat derived from chicken fed on insect-based feeds. (Under review) • Nabwile et al. (2020) Determinants of consumer perceptions of eggs from hen fed diet with black soldier fly (Hermatia ilucens) larvae meal (under review). • Afrika et al. (2020) An economic analysis of on-farm trial of commercial insect-based Feed for broiler chicken production (data analysis ongoing) • Nabwile et al. (2020) Cost-benefit analysis of on-farm trial of commercial insect-based Feed for egg production (data analysis ongoing) • Step by step manual easy to use by smallholder farmers haves been developed and distributed. • A total of 75 farmers were recruited and participated in on-farm assessment and performance of insect-based protein feed on poultry in Kiambu. • Feed millers were supplied with dried black soldier fly larvae to formulate commercials feeds for on-farm feeding trails with poultry farmers. • The nutrient composition and safety of commercial insect-based feed was established before the commencement of the on-farm trails. • More than 5 demonstration facilities for effectively scaling out on-farm production of BSF have been established and the top production facility employing over 64 youths (80% women) • J. de Haan (2020) Using black soldier fly as fishmeal replacement and its effect on the production and growth of Nile tilapia. Msc thesis completed, Wageningen University and Research • Vera Sollie (2020) The effect of black soldier fly extracts on the health of Nile tilapia (*Oreochromis niloticus*) fry in recirculating aquaculture systems. Msc thesis completed, Wageningen University and Research • Bulinda et al. (2020) Gross margins of different black soldier fly farming in different business models (under review) • Bulinda et al. (2020) Insect farming enterprise budget – small scale farm case studies established (under review)	• Several studies have clearly demonstrated that black soldier fly larvae protein is an excellent alternative to the expensive and scarce fishmeal or soya bean used in animal feeds. • More than 75% of farmers and feed millers are willing to adopt insect-based feeds.

		aquaculture production by 2020. • Establish the viability of insect-based protein enterprises for job creation among youths and women by 2020.		
Specific objective: Systematic review of the state of research, product development and utilization of the long-horned grasshopper Ruspolia differens in Africa.				
Expert review and documentation of past and current research and development initiatives related to R. differens.	Scientific and technical report on the state of research on R. differens in Africa completed.	• A review scientific publication on the state-of-art of R. differens research and product development in Africa.	• Tanga et al. (2020) *Ruspolia differens Serville* (Orthoptera: Tettigoniidae) as nutrient-rich source of food in Sub-Saharan Africa: A review (under review). The LHGH has been well-documented to be rich in crude protein, fat, fibre, energy contents, omega-3/6 fatty acids, well-balanced levels of essential amino acids, minerals (Ca, Fe and Zn) and vitamins [D3, B12, E and A].	Involving different experts working on research for development of the longhorned grasshopper industry across Kenya, Uganda and Tanzania was critical in producing the comprehensive review
Organize a stakeholder validation workshop in Kampala, Uganda.	Evaluate expert reviews from stakeholders of R. differens value chains.	• 1 workshop organized in Uganda with stakeholders drawn from 5 different countries.	• An expert review meeting of 35 participants drawn from 6 countries (Uganda, Kenya, Tanzania, Finland, Belgium and Burundi) was held in Uganda for 5 days	• The expert review meeting provided a roadmap to research activities related to LHGH grasshopper in the region and beyond. • It also allowed for the first-time collaborative network development amongst key actors like farmers, researchers, policy makers, NGOs, traders etc
Specific objective: Promotion of insect meal Commercial Production in Rwanda.				
Orientation and stakeholder workshop.	• Stakeholder meeting with the Government of Rwanda (GoR), feed companies and BSF companies. • Recruitment of MSc students and technical staff. Learning trip to icipe of 5 Rwandan BSF company members.	• 1 stakeholder meeting organized by end 2020. • 1 MSc student and 1 technical staff recruited by end 2020. • 1 exchange visit to icipe organized by mid 2021.	• An inception meets with held with 28 participants. • 1 Msc student has been recruited. • 1 Technical staff (consultant) has been recruited in Rwanda.	• No exchange visit has been organized due to the covid-19 travel restrictions imposed in both countries.
Work with selected BSF companies to develop substrate rearing and formulation.	• 3-4 BSF Rwandan companies to finalise their plans.	• At least 3 companies selected, with finalized workplan and rearing	• Four (4) private companies have been selected, trained and side visits to the various production sites have been conducted.	• Three (3) out of the 4 private companies were successful through the selective process to scale BSF production in Rwanda.

	• Orientation visit to selected Rwandan BSF companies. • Optimization of the rearing parameters and techniques standardized for the development of mother colonies with BSF companies. • Nutritional and bioactive compound profiling on various substrates.	parameters for mother colonies by early 2021. • Establish the nutritional profile of BSF reared on various substrates by mid 2021.	• Insect samples have been processed in Rwanda for nutritional analyses to guide the development of insect-based feeds.	
Work with the GoR.	• Meetings with RAB, FDA and other key GoR bodies. • Identify relevant areas for these agencies, warranting support.	• Work with GoR to get permit by end 2020.	• A permit to export BSF samples from Kenya to Rwanda has been established.	• Despite the permit, the transportation of BSF eggs to Rwanda remains a huge challenge due to imposed export charges.
Provide support to relevant public sector agencies on insect feed related policy and regulations instruments.	• Develop draft insect feed regulations and standards with GoR. • Develop a risk report on heavy metals, pesticide residue, mycotoxins and other toxin risks, and microbiological safety.	• A draft standard on the use insects in animal feed by mid 2021. • Information of risk and safety assessment by mid 2021.	• Two virtual meetings with RAB, FDA, GoR, RBS and other agencies have been organized and the roadmap for standard development established. • Samples for heavy metals, pesticide residues, mycotoxins and microbial loads have been sent to the laboratory in Rwanda for analyses.	• The roadmap for the development of insect-based feed standards in Rwanda have been established.
Specific objective: Harnessing desert locust for animal feed through multi-sectoral stakeholder engagement and community partnerships				
Develop and implement technologies for mass-trapping and harvesting of locusts for livestock feed.	• Develop techniques for mass-harvesting locusts during swarms. • Establish the nutritional profiles of different life stages of locusts harvested from the wild. • Develop safe feed using locust for poultry, pigs and fish. • Estimate microbial and chemical safety of locust-based feed additives.	• Mass harvesting tools for locust wild population developed. • Comprehensive nutrient profile of wild locust established • Increase production of feed for livestock and fish developed. • Determine the contaminants in processed desert locust meals.	• A draft review on locust as food and feed was documented, which indicates that levels of protein, fat, energy, omega-3/6 fatty acids, useful sterols, lysine, methionine, Ca, Fe, Zn and vitamins (vitamin D3, B12, E and β-carotene [precursor of vitamin A]) were comparable or superior to those of conventional animal and plant sources. However, pesticide residues, microbial contaminants and allergy (though less reported) were some of the key challenges shown to be associated with use of locusts for food and feed.	• Efficient technologies for mass collection of desert locust swarms to a level that minimises their damaging impact is critical for guiding policy actions to embrace the use of desert locusts as food and feed and as an alternative and environmentally friendly control strategy to manage this invasive pest.

	Establish protocols for extraction and processing of chitin from locust. Create awareness among stakeholders in the feed value-chain on the potential use of locust meal in livestock feed formulation. Establish market linkages for locust-based feed products.	• Easy-to-use protocol for isolating chitin from locust established. • Train and equip feed millers with adequate knowledge to include insect meal in feeds. • Establish markets for locust-based feed products.		
Specific objective: Insect-based agribusiness for sustainable grasshopper and cricket production and processing for food in Kenya and Uganda.				
Market potential and market performance of insect-based food products assessed.	Informed investment in insect-based food product commercialization increased by 2020.	• At least 2 private sector players invest in insect-producing agro-businesses in Kenya and Uganda. • Market potential for grasshopper and cricket products in Kenya and Uganda established. • Market performance (penetration and cost-benefit performance) for grasshopper and cricket products in Kenya and Uganda established.	• Market demand and supply surveys were conducted in Kenya and Uganda. In Kenya, results show that access to training by NGOs and research institutions increased quantities of crickets by 45 and 57%, respectively. Over 32.8% cricket consuming households were identified, implying that cricket supply will increase by 7.5% if non-consuming households adopt entomophagy. • In Uganda, the cost benefit analysis shows a production cost ranging from UGX 36,417 – 38,433 per kilo with the highest contributors to costs being rearing troughs, feed and egg trays. • Sengendo et al (2021), International Journal of Tropical Insect Science, DOI 10.1007/s42690-021-00505-8 determined that trapping edible grasshoppers is a highly profitable venture, using both the traditional technique used in Uganda and the improved technique developed by *icipe*. However, the improved trapping technique was more profitable than the the traditional technique. Moreover, high costs of electricity and harmful non-target insects, especially the Nairobi fly (*Paederus* sp.) which causes dermatitis were other difficulties associated with the traditional trapping technique. • InsectiPro Farm (Kenya), Agrarian Systems Ltd and Nutreal Limited (Uganda) have taken up cricket and grasshopper production as a business enterprise. Kusia et al (2021), International Journal of Tropical Insect Science doi: 10.1007/s42690-021-00469-9, established that in Kenya, termites (88%), grasshoppers (28%), saturniids (8.3%), crickets (6.8%), compost grubs (3%) and lake flies (1.5%) were the most frequently consumed insects, but the level of consumption varied considerably across regions. Insect consumption was shown to be influenced by age, occupation, and gender but not by region or	• The rearing process of the LHGH has been largely successful and scaling up in screenhouses is ongoing.

			educational level. Children (92.3%) and women (98.6%) were prominently involved in wild harvesting and sale of edible insects. The most common edible insects observed in local markets included termites in western and saturniids in coastal Kenya. Over 73% of the respondents were willing to rear saturniid caterpillar primarily for income.	
Mass-rearing protocols for crickets and grasshoppers adapted, piloted and upscaled.	Safe protocols for cricket and grasshopper rearing established and widely adopted at various scales.	• At least 2 SMEs mass-rear crickets and grasshoppers in Kenya and Uganda by 2020. • Rearing facilities for grasshoppers and crickets established and active insect rearing activities initiated. • At least 2 SMEs use the protocol and tools for safe crickets and grasshoppers mass-rearing. • Protocols for healthy insect rearing documented. • Postharvest protocols for cricket and grasshoppers rearing and trading in SMEs documented. • Insect-based products commercialized are maintained under safe conditions. • Well packaged insect-based food products on the market. • Regional large-scale retailers commercializing insect-based feed.	• Sengendo et al (2021), Journal of Economic Entomology, doi: 10.1093/jee/toab025; developed a cost-effective, safe, and environmentally friendly trapping technology for harvesting wild long horned grasshopper (LHGH), *Ruspolia differens*. This is based on light emitting diode lamps and collection drums fitted with funnels to retain the catch and meshes to filter non-target insects. • Labu et al (2020) Microbial contaminants in wild harvested and traded edible long-horned grasshopper *Ruspolia differens* in Uganda was submitted to the Journal of Insects as Food and Feed, DOI 10.3920/JIFF2020.0069 (in press). Results identified points at different segments of the value chain with high risk of contamination with human pathogens. • Leonard et al (2021), Journal of Thermal Biology, 95: 102786, determined that optimal temperatures for rearing longhorned grasshoppers were 27-30 ◦C. Using Insect Life Cycle Modeling software, the future potential distribution of LHGH was shown to shrink in the West, Southern and at the Horn of Africa when compared to the current distribution. The model further predicted three generations per year for *R. differens* in sub-Saharan Africa under current scenarios with potential to increase to 4 generations under future climate scenarios. • Leonard et al, Journal of Economic Entomology, 113:2150-2162, identified host-plants of longhorned grasshoppers through molecular analysis of gut content of wild collected populations. Diet formulations with inclusion of suitable host plant materials significantly boosted adult survival and enhanced egg laying under laboratory conditions. • Egonyu et al (in press), Journal of Insects as Food and Feed, DOI 10.3920/JIFF2021.0018, developed techniques for trapping [using semiochemicals lures] and rearing the palm weevil *Rhynchphorus phoenicis* in Kenya and Uganda. The baited traps placed on wild raffia palms caught 4-fold more weevils than those placed adjacent to oil palms irrespective of their distance apart. Over 95% of the pupae developed into adult beetles.	• The improved technique for trapping longhorned grasshoppers is ready for scaling in Uganda and other African countries where the insect is commercially harvested. • Factors such as genetic make up of palm weevil populations, geographical location, environmental conditions (especially temperatures and relative humidity) and type of diet used may influence productivity of palm weevil colonies.

			• Forkwa et al. (2020) Affordable processing of edible orthopterans provides a highly nutritive source of food ingredients was submitted to the Foods Journal. https://doi.org/10.3390/foods10010144. *Gryllus bimaculatus*, *Locusta migratoria*, and *Schistocerca gregaria* after blanching and oven-drying showed high protein (65.3, 54.2, and 61.4%, respectively) and fat. These insects were shown to be rich in essential amino acids, minerals, and vitamins. • Onyango et al. (2020) draft of a manuscript on the impacts of processing methods on the nutritional and phytochemical composition of *Ruspolia differens* is ongoing. • Key aspects on pesticide residues, microbial contaminants and allergy were documented.	
Ready-to-eat whole insects and insect flours for use as ingredients in food preparation developed and characterized, and insect-enriched porridge flours and cookies processed.	Adoption and use of insect-based food standards in Kenya and Uganda, and increased consumer confidence in insect-based products.	• At least 2 food-based SMEs produce and commercialize insect-based food. • At least 2 safely packaged insect products available on the market. • Effect of various rearing and processing conditions on nutritional characteristics of crickets and grasshoppers documented. • Insect-based products for women of reproductive age and 5-year-old children or below developed and commercialized. • Insect-based novel food available on supermarket shelves.	• Two MSc, 2 PhD and 2 Bioinnovate fellows recruited. • Maiyo et al. (2020) Processing methods enhance the bioavailability of zinc, iron, and calcium in finger–millet–amaranth meal porridge fortified with cricket Powder (draft for submission to food chemistry). • Murugu et al. (2020) Crickets as a good source of protein, minerals, and vitamins for improved human nutrition in Sub-Saharan Africa (draft manuscript to be submitted to Frontiers in Nutrition) • Niyibigira et al. (2020) Report on the development and sensory evaluation of cookies enriched with flavored grasshoppers (*Ruspolia differens*) powder. • Niyibigira et al. (2020) Report is completed on the development of ready-to -eat food products fortified with grasshopper flour and chitosan. • Namayanja et al. (2020) Report is completed on the evaluation of the nutritional profile of bakery product enriched with insect flour and consumer acceptability in Kenya and Uganda. • Onyango et al. (2020) Experiments were initiated to evaluate the nutritional value, microbial quality, shelf-life, and consumer acceptability of cookies enriched with Ruspolia differens flour from different processing methods. • Cricket enriched products, i.e., cookies, krickies (extruded snacks), and porridge flour have been introduced into the supermarkets in Kampala. Over 63% of the population were willing to taste the new products while 82% were willing to pay. The 18% who dislike the product recommended	• Activities on market penetrability slowed down due to immobility caused by the COVID-19 crisis.

			reduction in price and further improvement of the aroma and taste of the products. • Mugo et al. (2020) Microbial safety of edible long-horned grasshoppers, *Ruspolia differens* and food hygiene practices among its vendors in Uganda was submitted to the International Journal of Tropical Insect Science (under review) For storability, cricket powder or flours with 14%, 8% and 5% moisture content package and stored in high barrier polybag or normal polybag are being evaluated for shelf-life stability.	
Favourable enabling environment for insect-based food through policy, advocacy and awareness creation established.	High consumer acceptability for insect-based products in Kenya and Uganda.	• Policy briefs, advocacy and awareness creation materials produced. • Insect-based food standards developed and approved in both countries. • At least 3 workshops conducted. • At least 1 policy brief on food standard development produced. • Insect-based food advocacy materials developed. • At least 2 radio programs held. • At least 1 policy briefs developed on insect-based food. • At least 2 promotion materials disseminated on novel insect-based foods. • At least 2 exhibitions of insect-based food products.	• Three new gazetted standards to regulate the production, handling, and processing of insects for food were published in Kenya and Uganda, which is critical because insect harvesters, farmers and processing industries can now get accreditation and their products can be issued with a Kenya or Uganda Bureau of Standards certificates to enable them to market their products locally or internationally. • Activities on the development of policy briefs on insect-based food standards and preparation for radio programs were initiated.	• Activities on exhibitions of insect-based food products will be conducted when the travel and gathering restrictions are lifted as the COVID-19 situation improves in Uganda and Kenya.

(v) Social Science and Impact Assessment Unit: Results Based Management (RBM) Rolling Framework Report

Outputs	Outcomes	Performance Indicator	2020 Progress Observed in Achieving Outcomes	2020 Lessons Learned
I. Integrated pest management strategy to counter the threat of invasive fall armyworm to food security in eastern Africa (FAW-IPM)				
Objective 1: Livelihood, environmental, and gender impacts of FAW along the maize value chain in East Africa determined and utilized for decision making				
1. Understand Knowledge, Attitudes, and Practices (KAP) and the enabling policy related to FAW	• Stakeholders are aware of current knowledge and management practices of FAW and available policies	• One paper documenting information about current knowledge and management practices of FAW by stakeholders and enabling policies	• Knowledge and management practice of FAW in Ethiopia identified. This is a part of the working paper on economics, food Security, and health effects of fall armyworm.	88% are aware of FAW, and 97% identify FAW from pics. Various combination management practices were identified, including synthetic chemicals, though their effectiveness to control FAW is less.
2. Quantify the economic impacts of FAW damage for the different social groups	• Stakeholder aware economic burden of FAW and make an informed decision on control and management of FAW	• A paper documenting evidence on the economic burden of FAW	• A draft manuscript produced on the economics, food security, and health effects of fall armyworm in Ethiopia.	FAW creates a significant socioeconomic burden on Ethiopia and its farmers by reducing maize yield by 36% per year. The lost maize production could have met the per capita maize consumption of 4 million people.
3. Establish the economic, environmental, nutrition, and human health impacts of pesticides use and the various biological control (BC) methods	• Policymakers and development partners use better evidence in decision making to diffuse biological control of FAW	• One paper on economic, environmental and nutrition impacts of BC	• The health and environmental impacts of insecticides used to control FAW are documented as indicated above.	The environmental effects of insecticide use to control FAW were found high. The human health impact is relatively low. The long-term consequence of insecticide use is likely high. Managing FAW has high direct costs to the government. For instance, we find the government spent US$ 4 million on insecticide use.
4. Assess the impact of Push-Pull technology on household livelihoods in Rwanda	• Enhanced evidence of PPT on households	• Manuscript on the adoption and willingness to pay of PPT among smallholder maize farmers in Rwanda	A manuscript drafted on push-pull technology (PPT) as a climate-smart integrated pest management strategy in southern Ethiopia A manuscript published on adoption and willingness to pay for push-pull technology among smallholder maize farmers in Rwanda. International Journal of Agricultural Extension and Rural Development. ISSN 3254-5428 Vol. 8 (1), pp. 001-005.	Using a household survey data, the study finds that PPT reduces maize production losses due to fall armyworm and stemborers in the range of 15% and 23%, respectively. PPT also increases maize yield by 10%. This calls to promote PPT as an additional control strategy to mitigate FAW burden. Our Rwanda study shows that household heads with spouses who belong to farmer groups or receive extension support for crop production were likely to adopt PPT. Regarding willingness to pay for PPT, the study finds that resource-constrained farmers, those needing credit for crop production, and living relatively far away from input stockists, were less likely to pay for PPT. In contrast, farmers with livestock and receiving extension support for crop production were more likely to pay for PPT. These

				results imply that farmers' decisions to adopt and pay for PPT depend on their socioeconomic circumstances and technology performance.
II. Insfeed: Strengthening "out-grower" models for commercial production of high-quality and sustainable Insect-based animal feed protein engaging smallholder farmers and other value chain actors in Kenya (SiPfeed)				
Objective 1: To support the development of markets and marketing channels for insect-based protein feed using different business models				
Different out-grower based supply chain models linking insect production with feed manufacturing sector evaluated	Enhanced information of partners and stakeholders about the existing supply chain models for key commodities in Kenya	One report on mapping and feasibility of supply chain models	• Business-model-canvas developed for Cooperative led, cyclic, substrate led, medium scale and contract led	The canvases describe theoretical business models. Only Cyclic are into wider use but don't have any additional value chain (VC) knots.
Objective 3: To generate evidence-based data to support scaling and adoption of insect-based protein feed enterprises				
Impact of insect farming and insect-based protein for feed on the livelihoods of farmers determined	Policymakers, development agents are more informed about the potential benefits of insect farming and formulation of insect-based feed	• Working paper on optimal and economical feed ratios for poultry and fish production produced • A case study on impact of insect farming and insect-feed for poultry and fish production systems on productivity, income and, dietary diversity produced	• A draft manuscript on "Farmers' perception of commercial insect-based feeds in Kenya" was submitted to Sustainability Journal. • A second draft manuscript, "Farmers' willingness to pay for insect-based commercial chicken feeds in Kenya: A choice experiment analysis" is in advanced stage of publication • Two on-farm trials on profitability of different insect-based feed ratios implemented in Kiambu County	Over 90% of the farmers are ready and willing to use Insect-Based Feed (IBF). We find feed performance, social acceptability of use of insects in feed formulation, versatility of the feed and marketability of livestock products reared on IBF as the key qualities that would inform farmers' decision-making to purchase. Awareness of IBF attributes, group membership, off-farm income, wealth status and education significantly influenced farmers' perceptions of IBF. Interventions such as experimental demonstrations that increase farmers' technical knowledge on the productivity of livestock fed on IBF are crucial in reducing farmers' uncertainties towards acceptability of IBF. Public partnerships with resource-endowed farmers and societal groups are recommended to improve knowledge sharing on IBF.
III. INSFEED2: Insect feed for poultry, fish and pig production in Sub-Saharan Africa- Phase 2 (Cultivate Africa's Future Phase 2 (CultiAF 2)				
Objective 1: Assess the cost-effectiveness and potential livelihood effects of insect-based feed technologies through gender lens along the value chain				
1. Existing supply chain models for key commodities in Kenya and the role of the youth, women	Enhanced information about the existing supply chain models	One report the existing supply chain models for key livestock feed in Kenya produced.	• Analysis of business models for existing insect farmers in Kiambu, Murang'a, Nairobi, Machakos and Kajiado counties	Supply chain for insect feed components still rudimentary and dominated by cyclic production to make a full value chain analysis
2. Economic benefits of insect farming and insect-based feed for poultry, fish and pig production systems	Policy makers and partners use improved evidence and knowledge on impacts of economic benefits of insect farming and insect-based feed	One paper on the gender differential economic benefits of insect farming and insect-based feed for poultry, fish and pig production systems along the value chain in Kenya produced	• Gender disaggregated statistics from BSF producers and correlations of enterprise structures and production quantities available	Value chain for insect feed rudimentary and dominated by cyclic production which implies only limited number of value chain knot actors.

along the value chain determined				
3. Long-term potential impact of insect-based feed technologies on food and nutrition security estimated	Enhanced knowledge policy makers and partners on long-term potential long-term impact of insect-based feed technologies on food and nutrition security	One paper on the long-term potential impact of insect-based feed technologies on food and nutrition security in Kenya produced	Socioeconomic and environmental implications of replacing conventional poultry feed with insect-based feed in Kenya (https://doi.org/10.1016/j.jclepro.2020.121871)	We demondatred the high impact of insect-based feed on macroeconomy, food security, employment, and waste recycling. We find that replacing 5 to 50% of the conventional feed sources (fishmeal, maize, and soya bean meal) by BSFLM can generate a potential economic benefit of USD 69 to 687 million (0.1 to 1% of the total GDP) and USD 16 to 159 million (0.02 to 0.24% of the GDP) if the entire poultry sector (the commercial poultry sector) adopts BSFLM. These could translate to reducing poverty by 0.32 to 3.19 million (0.07 to 0.74 million) people, increasing employment by 25,000 to 252,000 (3,300 to 33,000) people, and recycling of 2 to 18 million (0.24 to 2 million) tonnes of biowaste. Further, our findings show that replacing the conventional feeds by 5 to 50% BSFLM in the commercial poultry sector would increase the availability of fish and maize that can feed 0.47 to 4.8 million people at the current per capita of fish and maize consumption in Kenya. Similarly, the foreign currency savings can increase by USD 1 to 10 million by reducing feed and inorganic fertilzer importation. These findings suggest that greater investment to promote BSFLM could boost economic, environmental and social sustainability.
4. Economic viability of insect-based feed supply chain models to guide scaling up pathways evaluated and determined	Policy makers and partners devise scaling up strategies based on improved evidence and knowledge of economic viability of insect-based feed supply chain models in Kenya	One report on economic viability of insect-based feed supply chain models in Kenya produced	• A draft publication on "Determinants of consumers' perception of eggs derived from layer chickens fed commercial insect-based feeds" is in advanced stage for submission to a peer-reviewed journal	This study was conducted with 200 consumers in Kiambu County. The study employed exploratory factor analysis as a method to establish underlying constructs on consumers perception on eggs derived from black soldier fly-based feed. With the binary logit determinants of consumers' perception were occupation on- and -off farm employment, unemployment, awareness of insects as feed, low income, and access to credit. Being aware of the use of insects as feed, purchasing eggs from open markets and having access to credit increased the perception of eggs derived from black soldier fly-based feed. The findings of this study provide insight into the market perception of eggs derived from black soldier fly-based feed in Kiambu County. Dissemination of information to consumers on the use of insects and their benefits may promote the perception on

				acceptance of this kind of eggs and consequently increase the use of insects as a protein source.
IV. Leap-Agri Sustainable intensification of fruit production systems through innovative pest biocontrol technologies (Pest-free fruit)				
1. Existing farmers' knowledge, perception, and practices that may enhance or constraint the adoption of innovative fruit fly management strategies understood	Farmers' knowledge, perception, and practices that may enhance or constraint the adoption of innovative fruit fly management strategies documented and shared with stakeholders	• One baseline survey in at least two sites in Kenya and Senegal by end of 2019 • At least one working paper by mid-2020	Paper generated from the baseline survey data presented at the 2020 Tropentag conference, Virtual Event, 9-11 September 2020. Wangithi C.M, Muriithi B.W. & Belmin R. 2020. Adoption and dis-adoption of sustainable agriculture: A case of farmers' innovations and integrated fruit fly management in Kenya. -The above paper submitted for peer review and is in consideration for publication with the journal, Agriculture	The study revealed that despite the rigorous dissemination and promotion of fruit fly IPM, use of chemical pesticides remains the main method for management of pesticides. Disadoption of the technology was also evident, and associated with limited access to the technology, costs and technical knowledge.
2. Demonstrate the agronomical and socio-economical effectiveness of innovative fruit fly management strategies on a pilot territory	Socioeconomic impacts of the innovative fruit fly management strategy established and shared with partners	• Field pilot experiment (RCT format) in at least two sites in Kenya and Senegal by end of 2021 • At least one peer review manuscript by end of 2021	Field pilot experiment was designed and initiated during the onset of the 2020/2021 mango season.	-Initial observations reported significant differences between IPM users and the control groups. Results from the entire season will be reported in 2021
V. Combating Arthropod Pests for Better Health, Food and Resilience to Climate Change (CAP-Africa)				
Objective 1: Test innovative approaches for stimulating increased adoption and impact of push-pull technology (PPT)				
1. The role of social learning on adoption of PPT determined and documented	Policymakers and development agents have improved understanding and knowledge of social learning as a strategy for stimulating technology adoption	• Working paper on the effect of social learning on the adoption of PPT by gender groups (men and women)	A paper on incentives, social learning, and diffusion of new agricultural technology (PPT): Experimental evidence from North-Western Ethiopia.	Using randomized control trials, the paper shows that promoting PPT using social networks increase the probability of dissemntaing PPT knowledge
2. Impacts of PPT adoption on maize and milk productivity, household food security, and income determined	Enhanced knowledge policymakers and partners on milk productivity, household food security, and income determined	• Working paper on the impacts of PPT adoption on maize and milk productivity, household food security, and income	Draft manuscript prepared on push-pull technology as a climate-smart integrated pest management strategy in southern Ethiopia	Using a household survey data, the study finds that PPT reduces maize production losses due to fall armyworm and stemborers in the range of 15% and 23%, respectively. PPT also increases maize yield by 10%. This calls to promote PPT as an additional control strategy to mitigate FAW burden.
3. Production risk impact of PPT adoption determined and documented	Enhanced knowledge of policy makers and partners on the production risk implications of PPT adoption	Peer-reviewed paper on PPT adoption and agricultural productivity risk	This is not done as we could not be able to collect second-round data in Kenya due to Covid-19.	
4. Effect of PPT on Women's labor supply	Policy makers and development partners have improved evidence	Working paper on labor allocation impact of PPT	A working paper drafted: How does agricultural technology adoption affect intrahousehold resource	The results showed that PPT adoption increases household labor allocation for harvesting of maize, the

and dietary diversity of women & children determined	and enhanced knowledge on the gender differentiated impacts of PPT adoption	Working paper on PPT and women's empowerment	allocations? The case of push-pull technology in Western Kenya	staple crop, but reduces the labor required for other tasks, including ploughing, weeding, and threshing. Overall, the technology is labor saving, with men experiencing a slightly greater workload reduction than women. In terms of expenditure impacts, results revealed that PPT uptake increases household expenditures on children's education and consumption of goods commonly associated with female preferences, such as furniture and kitchen utensils. Taken together, study findings suggest that promoting wider uptake of PPT can trigger gains in social and economic wellbeing for both men and women farmers.
5. Assess women's empowerment impact on individual and household nutrition	Policymakers, researchers and development partners use research results to enhance capacity and improve gender intervention in agriculture	Working paper on women's empowerment on nutrition		We found that women's empowerment has a positive and significant effect on the women's dietary diversity score regardless of technology adoption status. We further showed that women's empowerment enhances the positive effects of technology adoption on women's dietary diversity. Although technology adoption has a positive impact on women's dietary diversity regardless of empowerment status, its effect is stronger for households with empowered vs. disempowered women. Study results suggest that individual and household welfare could be enhanced to a greater degree through interventions that promote women's empowerment and technology adoption simultaneously rather than separately.
Objective 2: Establish the economic burden of malaria and livelihood impacts of IVM interventions for malaria prevention and control among rural households				
1. Assess the gender differential impact of malaria on labor productivity, and income determined	Policy makers and development partners have enhanced knowledge on the gender differentiated impacts of malaria burden in rural households	One paper on impact of malaria on labor supply and income	Working paper drafted on Health-seeking behavior of rural households, malaria, and productivity in Northwestern Ethiopia	Using a household survey data, the paper showed that good health seeking behavior of farmers reduce malaria incidence, but malaria incidence does not affect productivity (hence income because labor loss is compensated by hired labor and community labor exchange).
2. Impacts of IVM intervention strategies on household health and Economic welfare determined	Policy makers and development partners have enhanced knowledge on livelihood impacts of implementing IVM strategies	One papers on IVM intervention impact on household health and economic welfare	This is a work in porgress	
Objective 3: Developed and operationalize Performance, Monitoring, and evaluation framework (PME) for the project to facilitate learning, monitoring and dissemination of lessons learned				
1. M&E specialist trains researchers from host countries and project staff in implementing	Enhanced knowledge and appreciation of the common result framework by researchers and project staff	• 20 stakeholders trained in M&E aspects and tools	This is not acheived due to COVID-19	

common result framework;				
vii. Promote sustainable management of Tuta absoluta, an invasive pest of Solanaceous vegetables for food and nutritional security in East Africa				
Objective 1: Knowledge on socioeconomic impact of the Tuta absoluta tomato growers' livelihood prior to the intervention enhanced				
1. Growers' knowledge, attitudes and practices (KAP) related to tomato production and IPM technologies assessed	•At least 2000 farmers and other tomato value chain actors are aware of the knowledge, attitudes and practices (KAP) of farmers as regards tomato production and IPM technologies assessed	• Baseline survey datasets • At least one (1) report on "Farmers' Knowledge, attitudes and practices on tomato production and pest management in Kenya and Uganda" by end of Dec 2019	-One report and a draft manuscript from the baseline data developed and shared with the project team. Title: "Knowledge, attitude, and practices of tomato leaf miner (*Tuta absoluta*) and potential demand for Integrated Pest Management among smallholder farmers in Kenya and Uganda"	The study revealed adequate knowledge regarding the pest and associated it with about 36% loss of tomato crop. The use of synthetic chemicals was reported as the main method for the management of *T. absoluta* (100% of the respondents), with over 69% of them using a cocktail of different insecticides. Insecticides comprise the largest share of the variable input costs (70%).
2. Tomato farming systems in the study areas and availability, access and utilization of different pest management practices including IPM products for combating the invasive tomato leaf miner, T. absoluta documented	Tomato production systems in the target sites documented and shared with stakeholders/tomato supply chain actors	• At least one (1) report produced before end of 2019	-One report produced from baseline survey and shared with stakeholders	-Tomato production is mainly done by smallholder farmers on less than 1 acre plots; the producer relies on local market; high post-harvest losses mainly at farm level and attributed to pests and diseases
3. Economic impact (economic burden) of tomato leaf miner, T. absoluta on tomato production evaluated	Stakeholders and partners made aware of the economic burden of tomato leaf miner, T. absoluta	• At least one (1) report produced before end of 2020 • At least 1 peer-reviewed paper by mid-2020	-One report produced from baseline survey data and shared with stakeholders -Empirical analysis of the baseline survey data completed and a draft paper produced. Title: "Economic burden of tomato leaf miner *Tuta absoluta* in tomato production in Kenya and Uganda".	The results showed that on average, tomato growers in Kenya and Uganda earned a gross income of USD 3,282 and 895 per year, respectively. The potential tomato production in both countries was seen to be affected largely by *T. absoluta* infestation. The opportunity cost lost was valued at USD 8 and 646 in Kenya and Uganda, respectively using NPV through the most pessimistic scenario, while BCR had USD 1 and 5 in Kenya and Uganda, respectively.
4. Potential adoption, implementation feasibility and future sustenance of T. absoluta management approaches determined.	Potential demand of the innovative T.absoluta management approaches determined and shared with stakeholders	• At least one (1) report produced before end of 2020 • At least 1 peer-reviewed paper by mid-2020	-One draft manuscript (same as 1) produced from the baseline survey	A significant proportion of the farmers were willing to adopt the IPM strategy for the management of *T. absoluta*. The probability of adoption increases by the farmer being a male, shorter distances to input market, training, and good knowledge, attitude, and practices on management of the pest.

5. Economic feasibility of commercialising the fungal based biopesticide by the private sector assessed.	Tomato market value chain actors informed about the economic feasibility of commercialising fungal based biopesticide	• At least one (1) report produced before end of 2021	Baseline survey conducted in September 2020, involving 114 agro-dealers in Mwea East and Mwea West sub-counties of Kirinyaga County, Kenya. Data analysis completed, and a draft manuscript produced. Title: Agro-dealer's knowledge, perception, and willingness to stock a fungal based biopesticide (ICIPE 20) for management of *Tuta absoluta* in Kenya	Results showed that traders stocked a wide range of chemicals for *T. absoluta* management. About 82% of the Agrodealers (were willing to pay for ICIPE 20 at the same price as Collagen (most popular pesticide) and most importantly, they were WTP a much higher price (Ksh 749.66/ per litre) for the biopesticide.
viii. Combating the invasive tomato leafminer, Tuta absoluta through the implementation of eco-friendly IPM approach on tomato in East Africa (Tuta IPM)				
Objective 1: To assess socioeconomic impact of vegetable pest management technologies (Note"implemented together with Project VII)				
1. Assess farmers' perceptions of the impacts of and management of tomato leaf miner and other Solanaceous vegetable pests	t least 1000 farmers and other tomato value chain actors are aware of farmers' perceptions of the impacts of and management of tomato leaf miner	• Baseline survey dataset • One (1) survey report on "Farmers' knowledge, attitudes and practices on tomato production and pest management in Kenya, Uganda and Tanzania"	-One report and a draft manuscript from the baseline data developed and shared with the project team. Title: "Knowledge, attitude, and practices of tomato leaf miner (*Tuta absoluta*) and potential demand for Integrated Pest Management among smallholder farmers in Kenya and Uganda"	The study revealed adequate knowledge regarding the pest and changes associated with it causing about 36% loss of tomato crop. The use of synthetic chemicals was reported as the main method for the management of *T. absoluta* (100% of the respondents), with over 69% of them using a cocktail of different insecticides. Insecticides comprise the largest share of the variable input costs (70%).
2. Investigate the economic burden of T. absoluta in tomato production in the target project sites	Stakeholders and partners made aware of the economic burden of tomato leaf miner, T. absoluta	• At least one (1) working paper on "Economic burden of tomato leaf miner, *T. absoluta* on tomato production in Kenya, Uganda and Tanzania"	-One report produced from baseline survey data and shared with stakeholders -Empirical analysis of the baseline survey data completed and a draft paper produced. Title: "Economic burden of tomato leaf miner *Tuta absoluta* in tomato production in Kenya and Uganda"	The results showed that on average, tomato growers in Kenya and Uganda earned a gross income of USD 3,282 and 895 per year, respectively. The potential tomato production in both countries was seen to be affected largely by *T. absoluta* infestation. The opportunity cost lost was valued at USD 8 and 646 in Kenya and Uganda, respectively using NPV through the most pessimistic scenario, while BCR had USD 1 and 5 in Kenya and Uganda, respectively.
3. Estimate ex-ante demand for IPM technologies for management of T. absoluta among tomato growers	Potential demand of the innovative T.absoluta management approaches determined and shared with stakeholders	• At least one (1) working paper on "Potential adoption, and constraints and opportunities of adopting IPM and in the study areas in Kenya, Uganda and Tanzania"	-One draft manuscript (same as 1) produced from the baseline survey	A significant proportion of the farmers were willing to adopt the IPM strategy for the management of *T. absoluta*. The probability of adoption increases by the farmer being a male, shorter distances to input market, training, and good knowledge, attitude, and practices on management of the pest.
vii. Improving food and nutritional security through integrated control of tsetse and tick-borne livestock diseases (ICTLD)				

Objective 1: Impact of integrated tsetse and tick control using novel eco-friendly technologies on the livelihood of smallholder farmers evaluated				
1. Livestock producers' perceptions on the impacts and management practices of trypanosomiasis and tick-borne diseases, and constraints and opportunities to scale up improved livestock health management technologies in the target areas assessed	• Farmers perceptions and constraints to adoption of integrated tsetse and ticks management practices documented and shared with project partners and other livestock value chain actors	•Dataset •A report by end of 2019	- Household and FDG survey tool developed -Extensive literature review on perceptions and constraints to adoption of integrated tsetse and ticks management practices conducted and documented	-The current pandemic delayed the field survey, implemented in 2021
2. Ex-ante demand of the integrated tsetse and tick control and management technologies in the target areas determined	Traders and development partners in the livestock value chains made aware of the potential demand of the integrated tsetse and ticks management practices	• At least one (1) working paper by mid-2021	- Household and FDG survey tool developed -Extensive literature review on perceptions and constraints to adoption of integrated tsetse and ticks management practices conducted and documented	As above
3. Cost-effectiveness of the integrated tsetse and tick control and management technologies estimated	Traders and development partners in the livestock value chains made aware of the potential demand of the integrated tsetse and ticks management practices	At least one (1) working paper by mid-2021	- Household and FDG survey tool developed -Extensive literature review on perceptions and constraints to adoption of integrated tsetse and ticks management practices conducted and documented	As above
4. Economic and nutrition effects of integrated tsetse and tick control and management technologies with emphasis on women and their children determined	At least 3,000 community members in tsetse and ticks prone areas are made aware of the economic and nutrition effects of integrated tsetse and tick control and management practices and results shared with	At least one (1) working paper by the end of 2021	- Household and FDG survey tool developed -Extensive literature review on perceptions and constraints to adoption of integrated tsetse and ticks management practices conducted and documented	As above
viii. Three diseases, One Health; A one health, participatory approach to combating a complex of zoonotic diseases in northern				
1. Community awareness and practical knowledge on disease risk,	• Stakeholders are aware of the community knowledge, beliefs and behaviors towards RVF, leishmaniasis and brucellosis	• Survey tool and dataset • One report on community	Evaluating knowledge, beliefs, and management of arboviral diseases in Kenya: A multivariate probit approach	We found that 51, 54, and 22 percent of the respondents were aware of Rift Valley fever, Chikungunya fever, and Dengue fever, respectively. Less than a quarter of the respondents had knowledge on management of the

prevention and control assessed and documented		knowledge Awareness and practical knowledge on disease risk, prevention and control		diseases. However, more than 45 percent of the respondents had positive beliefs regarding the three diseases. Our results revealed that gender, religion, access to information, and asset ownership significantly impacted respondents' knowledge of arboviral diseases (ADs). On the other hand, respondents' beliefs and management of the diseases were influenced by access to information, income, education and social capital. These results imply that strategies aimed at combating ADs should focus on public health education campaigns to mitigate behavioral barriers in rural communities.
2. Impact of interventions on knowledge about the diseases assessed and documented	• Policy makers and partners have improved evidence and knowledge of the impact of project interventions on community knowledge about the diseases	One working paper on interventions and their impact on the diseases	This is a work in progress	
ix. Evaluating The Feasibility And Impact On Malaria Transmission Of Community-Based House Screening As An Additional Vector Control Intervention In Zambia				
Objective 1: To assess social / economic incremental costs and benefits of Integrated Vector Management interventions (addition of house screening to providing Long Lasting Insecticidal Nets)				
1. The effects of house screening on in-door mosquito prevalence, and the effect of the number of malaria cases averted and economic on households including labour productivity, incomes and educational attainment determined	Policy makers and partners/stakeholders have evidence and enhanced knowledge on the health and economic effects of IVM in households	One working paper on health and economic effects of IVM strategies	This is a work in progress	NA
2. The incremental cost-effectiveness of adding house screening to LLINs from the societal and provider perspective measured and documented	Stakeholders are aware of the cost-effectiveness of adding house screening to LLN	One working paper on incremental cost-effectiveness of adding house screening to LLINs from the societal and provider perspective	This is a work in progress	NA

3. The effect of price paid for screens on health promoting behavior and the future willingness to pay examined and determined	Policy makers and partners are aware of the community's WTP for house screening	One working paper on effect of price paid for screens on health promoting behavior and the future willingness to pay	This is a work in progress	NA
x. Alien invasive fruit flies in Southern Africa: Implementation of a sustainable IPM programme to combat their menaces				
Objective 1: Assess the socioeconomic and gender impact of the IPM interventions in the mango production and value chain;				
1. Understand barriers and success factors for promoting, scaling up IPM technologies and increase women's and youth participation in the mango value chain.	Stakeholders are aware of the barriers and opportunities for promoting fruit fly IPM technologies especially among women and youth mango farmers	-Data sets (qualitative and quantitative) -One PHD thesis -At least 1 report and manuscript with a gender focus	-Baseline surveys: – household level surveys in Zambia and Malawi, and community level survey in Zimbabwe conducted. In Malawi, data collected at both individual and household level to facilitate computation of the Abbreviated Women Empowerment in Agriculture Index (A-WEAI). Similar approach was followed in Zimbabwe where gender disaggregated FDGs were conducted A PhD student recruited in Malawi to address all the objectives of the project based on Malawi data	-Fruit flies are a pest of economic importance across the three countries; limited knowledge of IPM and other non-pesticide control strategies. As expected, the definition and understanding of women empowerment is different across the project countries, and this might affect the adoption of the proposed technologies differently
2. Forecast the potential demand for the developed IPM technologies in the target	Market players and development partners have evidence on the expected demand for the fruit fly IPM technologies	At least 1 report and manuscript	As above	As above
3. Assess the impact of IPM interventions on income, nutrition, human health and environment outcomes using gender disaggregated data	Stakeholders have evidence on the impact of using fruit fly IPM products as opposed to conventional methods	- At least 1 report and manuscript	As above	As above
4. Conduct cost-benefit analysis of the existing management practices and the proposed IPM technologies	Farmers, policymakers, and development partners are aware of the costs and benefits of the existing fruit fly management practices and proposed IPM technologies	At least 1 report and manuscript	As above	As above

5. Assessing and promoting successful modalities to connect smallholders with value chains	Farmers, policymakers, and development partners are aware of successful market linkages for smallholder farmers	Market survey dataset -At least (1) report -At least (1) manuscript	As above	
6. Analysis of women's empowerment in at least one target country	Policymakers and development partners are aware of Women's Empowerment in Agriculture Index (pro- WEAI) among mango growers in one of the target project countries	At least 1 report and manuscript-	As above	As above
xi. Partnership for skills in Applied Sciences, Engineering and Technology (PASET) Regional Scholarship and Innovation Fund (RSIF)				
Specific Objective 1: To develop the capacity for growth and management of a scholarship, research and innovation fund				
1. Conduct a mixed-methods gender study to understand why women have low representation in STEM fields in sub-Saharan Africa.	• Enhanced knowledge of the main socio-cultural, economic, and institutional factors that explain low representation of women in STEM fields.	• Gender consultant hired. •Mixed-methods datasets collected. •A report and journal manuscript prepared.	Paper published: Making it to the PhD: Gender and student performance in sub-Saharan Africa. PLoS ONE 15(12): e0241915. https://doi.org/10.1371/journal.	We found that, compared to their male counterparts, sampled women had about one less paper accepted for publication during their doctoral studies and took about half a year longer to finish their PhD training. Results indicate that the correlation coefficients of publication productivity and time to PhD completion were very similar for women and men, but some gender-based differences were observed. For publication output, we found that good supervision had a stronger impact for men than women; and getting married during the PhD reduced women's publication productivity but increased that of men. Becoming a parent during the PhD training was a key reason that women took longer time to complete the PhD, according to our results. Nevertheless, women's underrepresentation in STEM impedes progress in solving Africa's complex development problems. As in other regions, women's participation in STEM drops progressively moving up the education and career ladder, with women currently constituting 30% of Africa's STEM researchers. Two options for priority interventions emerged from this study: (1) family-friendly policies and facilities that are supportive of women's roles as wives and mothers, and (2) fostering broader linkages and networks for women in STEM, including ensuring mentoring and supervisory support that is tailored to their specific needs and circumstances.

2. Develop a gender strategy to enhance women's participation in STEM PhD programs and research at African Universities.	• RSIF and host institutions informed of practical strategies to enhance women's participation in RSIF Ph.D., programs.	Gender strategy document.	A gender strategy documented and shared with partners	
3. Provide continuous monitoring and evaluation oversight functions and capacity building for the project	An enhanced understanding of the project approach and how it will be evaluated for impact	Project progress tracked and documented	• Held a two-day online monitoring and evaluation course for PhD students and African Host Universities (AHUs)-RSIF coordinators • Project progress was tracked and reported on against the Results Framework in four quarterly progress reports	• Delays caused by the Covid-19 pandemic are likely to further delay PhD students' progress and completion of their PhD projects
4. Develop and roll out the program theory of change and evaluation framework	An enhanced understanding of the project approach and how it will be evaluated for impact	Evaluation Framework published	• Implemented the first semi-annual stakeholder satisfaction survey • M&E frameworks designed for 14 research and innovations grants awarded to African Host Universities (AHUs) and their partners • Evaluation framework used to rollout the project Mid-Term Review (MTR)	
xii. BioInnovate Africa programme				
Objective 1: Project monitoring and evaluation system implemented				
1. Provide continuous monitoring and evaluation oversight functions and capacity building for the project	An enhanced understanding of the project approach and how it will be evaluated for impact	Project progress tracked and documented	• Project progress tracked and reported on	
2. Develop and rollout the program theory of change and evaluation framework	An enhanced understanding of the project approach and how it will be evaluated for impact	Evaluation Framework published	• An external project evaluation was initiated. The external evaluation also aimed at informing the next phase of the project	
Objective 2: To determine the impact of and barriers to scaling of CSPM technologies and practices				
1. Identification of barrier and opportunities to scale CSPM technologies.	Data on barriers and opportunities on scaling CSPM technologies available by 2020	A working paper on barriers and opportunities to upscale CSPM technologies produced and shared with partners by 2020	• Rapid baseline survey targeting 450 households was implemented in the districts of Mbale and Namutumba in Uganda	

2. Generate and document evidence on the benefits of CSPM technologies, practices and services to foster a learning environment and strengthen further the scaling process in other countries	Data on used for socioeconomic analysis of CSPM technologies and impacts of key pests available by mid-2022	At least two papers documenting benefits of CSPM technologies produced by mid-2022	NA	

(vi) Capacity Building and Institutional Development Programme: Results Based Management (RBM) Rolling Framework Report

Outputs	Outcomes	Performance Indicator	2020 Progress in Achieving Outcomes	2020 Lessons Learned
Objective or Specific Objective: Increase the number and quality of researchers and middle level practitioners required to respond to arthropod-related research and development challenges in Africa by 2020.				
1. Between 2014 and 2020, 60 PhD and 150 MSc postgraduate students (33% women) from at least 18 African countries representing all sub-regions of SSA, are at icipe at various stages of postgraduate training in arthropod and related sciences.	• At least 95% of students complete postgraduate training. • At least 75% of PhD students who complete their training each year during 2014–2020 contribute to research, development and higher education in Africa, dealing with reducing poverty, improving food and nutritional security, improving human, animal and environmental health; and work in Universities, National Research Systems, sub-Regional Organisations (SROs), International Research Centres (IRCs), and the private sector in Africa. • At least 50% of MSc graduates trained at icipe continue a career in R&D or higher education.	• Number of PhD and MSc students in the *icipe* postgraduate programmes at various stages of training, and number completing training with icipe, each year during the period 2021-2025. • Number of women in the programme each year. • Number of African countries represented in the postgraduate programmes each year. • Number of scientists trained at icipe engaged in research, development and higher education in Africa. • Number of researchers leading research and development projects or playing a leading role in higher education in Africa. • Number of research activities/projects implemented in African institutions by scientists trained at icipe during 2014–2020. • Number of graduates with positions of leadership in public & private organisations/enterprises in Africa.	• During 2020, there were 67 PhD fellows and 108 MSc fellows at various stages of their postgraduate training programme at *icipe*. In addition, *icipe* managed 82 Regional Scholarship and Innovation Fund (RSIF) PhD scholars at 11 African universities, 6 of whom are currently on a sandwich programme with Worcester Polytechnic Institute, USA (WPI) and 6 with the Korean Institute of Science and Technology (KIST), Korea. • In 2020, women represented 48% of all postgraduate fellows at icipe, and 37% of RSIF PhD fellows. • In 2020, 16 African nationalities, from all sub-regions of SSA were represented by postgraduate students at icipe (Benin, Burkina Faso, Cameroon, DR Congo, Ethiopia, Ghana, Kenya, Malawi, Nigeria, Rwanda, South Africa, Sudan, Togo, Uganda, Zambia, Zimbabwe). In addition to these nationalities, RSIF scholars also represented Chad, Côte d'Ivoire, Senegal and Tanzania, bringing the total to 20 African nationalities. • In 2020, 17 PhD and 18 MSc students completed postgraduate training with *icipe*. Of these, 14 PhD students (82%) are currently engaged in research, development or higher education in Africa; 2 (12%) are engaged in research outside Africa and 1 (6%) is currently seeking employment. Of the 18 MSc students, 7 (39%) are pursuing a career in R&D or higher education in Africa and 2 (11%) are undertaking a PhD. No data available for the remaining 9 MSc students who completed their studies with *icipe*. • 89 PhD and 162 MSc students completed training at *icipe* in 2014-2020. • 83 PhD students (93%) and 133 MSc students (82%) who completed training at *icipe* in 2014-2020 are engaged in research, development and higher education in Africa. • 36 *icipe* postgraduate students who completed training at *icipe* since 2014 are in senior positions or leadership roles in Africa.	Many African universities were closed for several months due to the Covid-19 pandemic, which slowed thesis defense and graduation of a number of postgraduate students. Capturing details of MSc and PhD students after completion of studies at *icipe* remains a challenge, particularly MSc students and students that pursue careers outside of R&D and higher education. Much information is gleaned from internet searches because many alumni do not respond readily to email surveys. Data on the number of research activities/projects implemented in African institutions has also been very difficult to obtain.

2. Dissemination of research results by postgraduate students through 400 publications of research results (including theses, book chapters, peer-reviewed papers, conference abstracts and proceedings, training brochures and manuals, policy documents, print and online media) in the period 2014–2020	Research results disseminated in relevant formats at scientific community and policy maker levels	• Number of publications that result from research conducted by students at icipe (theses, book chapters, peer-reviewed papers, conference abstracts and proceedings, training brochures and manuals, print and online media). • Number of students contributing to policy documents. • Quality and relevance of icipe led-research results shared with scientific community determined by the number of citations in peer-reviewed publications. • Number of students participating in scientific meetings/conferences.	• In 2020, of the 153 peer-reviewed papers published by *icipe*, 85 (56%) were authored by postgraduate students, 76 (50%) as lead authors. • Citation metrics: Peer-reviewed publications by students in 2020 had an average 1.75 citations (range 0-12), and 128 downloads (range 0 to 1475) per publication. • 17 PhD and 18 MSc theses were completed and successfully defended in 2020. • In 2020, 9 postgraduate students participated in 10 international/regional scientific meetings & conferences. • In total, 450 peer-reviewed scientific papers were published by *icipe* Postgraduate students in 2014-2020. • 93 PhD and 167 MSc theses were completed by *icipe* postgraduate students in 2014-2020.	Postgraduate students continue to make a very significant contribution to the research and publication output of *icipe*.
3. Career development opportunities for at least 20 early career postdoctoral fellows implemented during the period 2014–2020	• At least 75% of postdoctoral fellows and visiting scientists on completion at icipe proceed to contribute to research, development and higher education in Universities, NARS, SROs, IRCs, and the private sector in Africa each year during the period 2014–2020. • At least 50% of postdoctoral fellows attract competitive research grants during their tenure at icipe. • At least 50 scientific publications in peer-reviewed journals are published by postdoctoral fellows and visiting scientists during the period 2014–2020.	• Number of postdoctoral fellows and visiting scientists trained. • Number of grants applied for and received by postdoctoral fellows each year. • Number of postdoctoral fellows trained contributing to research, development and higher education in Africa. • Number of research publications in peer-reviewed journals.	• 13 postdoctoral fellows were engaged in research at *icipe* in 2020. • 21 peer-reviewed articles were published by postdoctoral fellows (6 as lead author), representing 14% of all *icipe* peer-reviewed publications in 2020. • In 2020, *icipe* postdoctoral fellows participated in 52 grant applications; 9 were awarded and signed, 4 approved - awaiting contract, 8 are currently under review and 31 were unsuccessful (i.e., at least 25% success rate). • Of the 24 postdoctoral fellows recruited since 2014, 13 are currently postdocs at icipe, 2 are now scientists with *icipe*, 5 are working with national R&D systems, 3 are research consultants and 1 is deceased.	An important part of career development of postdoctoral fellows is the supervision of postgraduate students. This data will be captured in the RBM for 2021-2025. Also, more opportunities should be offered to postdocs to supervise postgraduate students, e.g., additional funding, such as postgrad scholarships, should be availed to postdocs.
4. At least 200 Science Interns (at least 40% women) trained during the period 2014–2020.	At least 50% of trained science interns progressing to research and	• Number of interns trained.	• 51 research interns were trained in 2020 (31 [61%] women). Average duration of an internship was 6 months.	Although the number of interns in R&D increased rapidly from 28 in 2017 to 80 in 2019, the number fell in

	development careers each year during the period 2014–2020.	• Number of women in the programme each year.	• In total 215 interns (131 [61%] women) were trained at *icipe* in 2014-2020. • Of those that were tracked since their training with *icipe*, 5 (3%) are currently completing BSc degrees, 22 (12%) are pursuing Diploma, MSc or PhD qualifications, 1 is completing an internship with another R&D organisation; and 20 (11%) have research assistant or consultancy positions with *icipe*.	2020 to 51 due to the Covid-19 pandemic, when *icipe* restricted intake for many months. Tracking of interns is challenging – many do not respond to requests for information.
5. Researchers, mid-level practitioners and extension workers (2000) from 30 national systems in Africa trained in non-degree professional development courses during the period 2014–2020.	• At least 50% of trained researchers, middle-level practitioners and extension workers applying acquired knowledge and expertise in Africa each year during the period 2014–2020.	• Number of training courses. • Number of trainees. • Number of organisations benefiting from training • Number of trainees applying acquired knowledge and expertise in Africa	• 69 training courses were held in 2020 for 5,430 researchers, mid-level practitioners and extension workers from 22 African countries (Benin, Burkina Faso, Burundi, Cameroon, Cape Verde, Chad, DR Congo, Ethiopia, Ghana, Ivory Coast, Kenya, Liswati, Malawi, Niger, Nigeria, Rwanda, Senegal, Sudan, Tanzania, Togo, Uganda and Zimbabwe) and 2 non-African countries.	As a result of the pandemic, a number of training courses that would have been conducted face-to-face, were conducted as live online training courses, especially for students and researchers. While this has been successful, we will continue to improve the delivery of online training.
6. At least 10 capacity building activities developed with national and regional research and higher education institutions during the period 2014–2020.	Research and training capacities strengthened at national and regional research and higher education institutions through the development of partnerships with icipe.	• Signed MoUs and collaborative agreements with partners. • Number of collaborative capacity building activities started with national and regional research and higher education institutions.	• In 2020 a MoU was signed with Jaramogi Oginga Odinga University of Science and Technology, Kenya, for training of postgraduate students. • In 2020, a service contract was signed with CABI for students to complete short research projects at icipe. • During 2014-2020: capacity building activities were developed with national and regional research and higher education institutions, including - KALRO (Kenya), Makerere University (Uganda), KEPHIS (Kenya), TARI-Selian (Tanzania), TARI-MARI (Tanzania), Amhara Regional State Bureau of Agriculture (Ethiopia) for CAP-Africa (Combatting Arthropod Pests for Better Health, Food and Climate Resilience) capacity building. - A postgraduate training programme was started with Egerton University, Kenya for training of students at *icipe* - An MoU with United States University in Africa, Kenya was signed for capacity building and joint research projects.. - RSIF capacity building agreements between icipe and 11 African universities were signed: University Felix Houphouet-Boigny, Cote d'Ivoire; University of Ghana, Legon, Ghana; Kenyatta University, Kenya; University of Nairobi, Kenya; African University of Science and Technology, Nigeria;	The program has continued to create effective capacity building partnership across Africa and beyond. Some capacity building activities with partners were restricted in 2020 due to the Covid pandemic, especially those that required international travel of partners and students.

			University of Port Harcourt, Nigeria; Bayero University, Nigeria; University of Rwanda, Rwanda; University of Gaston Berger, Senegal; The Nelson Mandela Institute of Science and Technology, Tanzania; Sokoine University of Agriculture, Tanzania. A call was published in 2020 for four additional African university PhD programs to join the RSIF project. - As part of the RSIF project, MoUs for capacity building at African universities were signed with a number of international partners: Korea Institute of Science and Technology (KIST); Korea Institute of Energy Research (KIER); Korea Research Institute of Chemical Technology (KRICT); Institute of Green Bio Science and Technology (GBST) of Seoul National University (SNU); Mohammed VI Polytechnic University, Morocco; Greenwich University, UK; International Livestock Research Institute (ILRI), Kenya; Worcester Polytechnic Institute (WPI), USA; Virginia Tech, USA; IMT Mines Albi, France; The Seoul National University Global Research & Development and Business Center (GRC), Korea; University of Pretoria, South Africa.	

(vii) BioInnovate Africa Programme: Results Based Management (RBM) Rolling Framework Report

Outputs	Outcomes	Performance Indicator	2020 Progress in Achieving Outcomes	2020 Lessons Learned
Specific Objective 1: Develop value added goods and services from biological resources				
1. Innovative value-added goods that create value for customer segments in rural and urban communities.	Enhanced capacity of Eastern African universities and research organizations to translate modern biosciences into innovations targeting smallholder farmers and agro-process enterprises in the region	- % change in no. of bioscience value-added goods at different levels of development (undergoing value addition, ready for market, market tested)	1. Market-tested goods: i. Approx. 3,896,250 high quality clean & certified sweetpotato seeds were sold in Kenya, Rwanda, Tanzania & Uganda. ii. Over 7,500 bags (50 kg each) of nitrogen-enhanced organic fertilizer branded as 'Hakika' were sold in Tanzania. iii. Three (3) improved and branded cricket enriched products: extruded sweet and savoury snacks; cricket enriched cookies and ready-to-eat grasshoppers - were introduced to 3 community outlets in Uganda. iv. 769 mushroom substrate blocks and 48 kg of mushroom was sold in Tanzania. v. Two (2) tons of organic fertilizer generated from processing waste used for breeding Black Soldier Fly was sold in Tanzania. vi. 650 pieces of orange-fleshed sweetpotato chapati dough per day are being sold in Kenya. vii. Approx. USD 350 revenue was generated from selling honey-based toffees in Uganda. viii. 500 kg of striga resistant maize breeder seed variety, Maseno EH14 was sold to seed companies in Kenya.	The ongoing COVID-19 pandemic situation which intensified early in 2020, presented opportunities to: a. Maintain flexibility in programming activities b. Harness digital technology by way of virtual platforms to connect with partners and stakeholders. c. Initiate momentum for a bioeconomy by directly contributing to innovative solutions in response to COVID-19 in eastern Africa.
			2. Goods ready for market: i. 315 litres of sorghum syrup were produced in Kenya and Uganda for market-testing. ii. Tsetse repellent minimum viable products (MVPs) and masked odour blends customized for both human and livestock were developed. HDPE (High density polyethylene) fabric was incorporated with the repellent blends. iii. Potent biopesticides developed and tested:	

			• Four (4) against FAW (fall armyworm) namely: ICIPE 7, ICIPE 41, ICIPE 69 and ICIPE 78. • Two (2) against *Tuta absoluta* namely: ICIPE 18 & 20 • Two (2) endophytes against leaf miners, bean stem maggot, thrips, and Iris yellow spot virus & sugarcane mosaic virus. 3. Goods undergoing development: i. A reformulated mosquito-repellent catnip-based product is under development in Burundi with support from *icipe*. ii. Three (3) plant-based extracts with medicinal and immune properties addressing COVID-19 in eastern Africa.	
Specific Objective 1: Develop value added goods and services from biological resources				
2. Innovative value-added services that create value for customer segments in rural and urban communities.	Enhanced capacity of Eastern African universities and research organizations to translate modern biosciences into innovations targeting smallholder farmers and agro-process enterprises in the region.	- Number of bioscience services at different levels of development (undergoing value addition, ready for market, market tested)	1. Market-tested services: i. Three (3) tenders worth over USD 700,000 were awarded to BIOCON Africa Limited (a startup) in Tanzania for provision of integrated wastewater treatment services. ii. Viazi Vitamu mobile Application (App) for sweetpotato seed system is operational on Google Store. It is being used by over 60 sweet potato farmers in Uganda. 2. Services ready for market: i. Protocols for post-harvest hot-water treatment of Tommy Atkins mango variety and French beans (infested with thrips) are available (Kenya and Uganda) ii. A mobile field based molecular diagnostic kit for detecting sweetpotato viruses was validated under field conditions. iii. At EAGAADS Coffee factory in Kenya, 4 tons of coffee waste is being processed to produce 2 tons of vermicompost per month. iv. Protocols for drying (using refractance window drying technology) of pineapples, passion fruits,	

			mangoes, avocado and jackfruit are available in Kenya and Uganda. v. Protocols for processing hides and skins into finished leather using enzymes are available in Kenya. 3. <u>Service under development:</u> i. Commercial-scale rearing of long-horned grasshopper: The grasshopper colony at *icipe* grew from 2 to 9 cages with a 20% higher survival rate. ii. A fast and affordable diagnostic kit for testing COVID-19. iii. A data-driven model that combines COVID-19 data and data on food systems, environment among others, to predict the impact of COVID-19 in eastern Africa.	
Specific Objective 1: Develop value added goods and services from biological resources				
3. Bioscience knowledge that addresses the needs of smallholder farmers and agro-processors developed	Enhanced capacity of Eastern African universities and research organizations to translate modern biosciences into innovations targeting smallholder farmers and agro-process enterprises in the region.	- % change in no. of bioscience ideas emerging from the projects.	Two (2) bioscience ideas: i. It has been found that sorghum syrup may also be used as a dust suppressant on dusty roads. ii. Hydrothermal processing of grains may be used to preserve micronutrients. Six (6) manuscripts and two (2) articles were published as follows: i. Three (3) manuscripts and one (1) article on fungal biopesticides at *icipe*. ii. One (1) manuscript on PCR sweetpotato diagnostic kit at Makerere University iii. One (1) manuscript on enzymes at University of Nairobi iv. One (1) manuscript on tsetse repellents at KALRO v. One (1) article on the East African regional bioeconomy strategy. Two (2) manuscripts on sweet potato seeds are under development at JKUAT.	
			One (1) masters' thesis on ethnobotany is documented by University of Burundi.	

		- Number of intellectual properties (including patents) acquired at different levels of product development i.e., applied for, awarded, or in gazette	Awarded: 1. A utility model is registered in Uganda (UG/U/2021/12) for a hybrid electric and biomass powered Refractance Window Dryer (RWD). 2. A registration certificate for 'Hakika' organic fertilizer was awarded by Tanzania Fertilizer Regulatory Authority (TFRA) No. 0117 3. A trade mark certificate was awarded to Bomvitae Agro-Industries Limited (BAIL) in Uganda. Applied for: 1. A patent focusing on the novel invention of using a rocket stove to power the RWD has been filed in Uganda. 2. Initiated patent registration of ICIPE 41 and ICIPE 78 against fall armyworm (FAW) in Kenya and Tanzania, respectively. 3. Initiated patent registration of endophytic fungus *H. lixii* F3STI in Kenya.	
Specific Objective 2: Create new business prospects based on renewable biological resources				
4. Bio-based business models that help smallholder producers, and agro-processors to gain a competitive advantage in national and regional markets.	Increased linkages between research institutions, universities, and the private sector (including investors)	- Number of validated bio-based business models.	Six (6) validated business models: 1. Certified high quality sweetpotato seed 2. Hakika organic fertilizer 3. Striga-resistant maize breeder seed 4. Integrated wastewater treatment systems 5. Aroma Honey Toffees 6. Sorghum and millet instant porridge and flour	
5. Spin-off companies are developed and supported.		- Number of company registration certificates.	One (1) registration certificate for a newly created spin-off company 'Jazi Agroprocessing Solutions Ltd' in Uganda.	
6. Pipeline investors in biobased goods and services are linked to the programme		- Number of investor pitches and meetings organized with potential investors.	- One (1) meeting was held between BioBuu Kenya Ltd and a private equity investor. - One (1) partner (Guavay Company Ltd in Tanzania) received a grant of EUR 199,000 from Belgium Development Cooperation.	
Specific Objective 3: Support the development of local innovation ecosystems				

7. Institutional innovation frameworks are developed.	Improved prioritization and coordination of policy responses to promote bio-based innovation and entrepreneurship.	- Number of institutional innovation policies drafted.	The first bioscience innovation bootcamp was held on 26 November to 1 December 2020 in which 24 teams of entrepreneurial scientists participated.	
		- Innovation/technology transfer offices established.	None	
8. Networks and partnerships developed.		- Number of contracts and/or agreements signed to engage with various stakeholders.	i. A distribution agreement between Guavay Company Ltd and "Mtewele General Traders and Supplies" a leading fertilizer distributor in Njombe region. ii. A framework agreement was signed between Green Enzyme Technologies Ltd (GET) and Alpharama Tannery to pilot the enzyme technology in Kenya. iii. A Partnership agreement between Maseno University Seed Unit and Qualibasic Seed company was finalized. iv. The Kenya Port Authority has registered BioBuu Kenya as authorised to demolish its waste. v. A supplier contract was signed between Karire Products (Burundi) and Wuhan HDC Company for supply of 300 and 500 litre distillation equipment for essential oil extraction. vi. A partnership was initiated between *icipe*/BA and Villgro Africa to implement the first bioscience innovation bootcamp. vii. A partnership was initiated between icipe/BA and Thayer School of Engineering at Dartmouth USA for strengthen capacity for technoeconomic analyses in East Africa. viii. *icipe*/BA became a member of the Aspen Network of Development Entrepreneurs (ANDE) ix. A partnership was developed between *icipe*/BA and Growth Africa Foundation for business acceleration	

			of BA supported projects to transition to pilot commercial enterprises.	
Specific Objective 3: Support the development of local innovation ecosystems				
	Improved prioritization and coordination of policy responses to promote bio-based innovation and entrepreneurship.		x. Memoranda of Understanding between: a. Makerere University and Biofresh Uganda Ltd for commercial production of OFSP puree. b. Hawassa University and Dwame Bakery for commercial production of OFSP puree products.	
9. Relevant policy options to support scientists in their effort to promote bioscience innovations for smallholder farmers and agro processors evaluated.		- Strategies/policies put in place by governments to support and promote biosciences innovations.	1. The first regional eastern Africa Bioeconomy virtual conference was held on 21-22 October 2020 involving 397 regional and global stakeholders. A Bioeconomy Observatory portal was launched during the conference. 2. A Draft Bioeconomy strategy was presented to EASTECO (East African Science and Technology Commission) Governing Board technical committee on policy and Regulations.	
		- Enabling regulations put in place by governments to support and promote biosciences innovations.	1. A new BSF standard was issued by the Kenya Standards Body KEBS. The standard focuses on: Production and handling of insects for food and feed (KS 2921:2020) 2. The edible Insect standard for Uganda was approved for use. 3. Inspection reporting forms by Uganda's Ministry of Agriculture were adopted for use on the Viazi Vitamu Mobile App.	

(viii) Partnership for skills in Applied Sciences, Engineering and Technology (PASET) - Regional Scholarship and Innovation Fund (RSIF): Results Based Management (RBM) Rolling Framework

Outputs	Outcomes	Performance Indicator	2020 Progress in Achieving Outcomes	2020 Lessons Learned
Overall Objective: To strengthen the institutional capacity for quality and sustainable doctoral training, research and innovation in transformative technologies in Sub-Saharan Africa (SSA) by 2025				
Specific Objective 1: To develop the capacity for growth and management of a scholarship, research and innovation fund				
Specific Objective 2: To establish scholarships, research and innovation grants for ASET by 2025				
Endowment Fund established with contributions from SSA governments, private sector, donors	Growth in endowment fund for sustained financing of scientific and technical talent development in Africa	Permanent fund established and growing over time	• Endowment fund feasibility study completed. Framework agreed, with funding strategy, governance arrangement & implementation plan. Board charter, investment policy and fund manager TORs drafted.	• Considering setup and running costs, feasibility study recommends registration in Mauritius upon having secured a minimum of USD 8 million. • A key challenge remains the impact of COVID-19 pandemic, including how it might influence investment decisions.
Capacity for operation and management of doctoral training scholarships and research grants built	Increased capacity to operate and manage doctoral training scholarships and research grants	Number of scholarships and grants successfully administered	• 82 doctoral scholarships and 6 research grants successfully administered	• As scholarships and grants are set to double, MIS and staff capacities are being aligned accordingly.
Increased capacity of RSIF African Host Universities for improved quality of doctoral programs and research in ASET	Quality of doctoral programs and research in ASET enhanced at RSIF African Host Universities	At least 10 agreements signed with RSIF African Host Universities by 2023 At least 10 RSIF African Host Universities with an online application system in place by 2023	• Agreement with the 11th RSIF AHU[2] signed in 2020. • 9[3] RSIF AHUs with an online application system in place • 6[4] RSIF AHUs that have started international accreditation process	• Addendum to the AHU-*icipe* agreements prepared to respond to key lessons including on strengthening university supervisor reporting, accounting and timeliness of research funds. • Due to increasing number of students a call was launched for additional RSIF African Host

[2] The current 11 African Host Universities (AHUs) include: Nelson Mandela African Institution of Science and Technology (NM-AIST-Tanzania), African University of Science and Technology (AUST-Nigeria), Sokoine University of Agriculture (SUA-Tanzania), University of Ghana (UG-Ghana), University of Port Harcourt (UNIPORT-Nigeria), University of Nairobi (UoN-Kenya), Gaston Berger University (GBU-Senegal), University of Rwanda (UR-Rwanda), Bayero University (BUK-Nigeria), University Félix Houphouët-Boigny (UFHB-Côte d`Ivoire) and Kenyatta University (KU-Kenya). https://www.rsif-paset.org/partners/#host-institutions

[3] Links to university online application portals: (1) University of Ghana; (2) NM-AIST; (3) KU; (4) BUK; (5) UoN; (6) UNIPORT; (7) UR; (8) SUA ; (9) UGB and; (10) Universities of Félix Houphouët-Boigny (Côte d`Ivoire). RSIF also has a central online application system used for this call and accessible to all 11 universities, here.

[4] Links to institutions handling university international accreditation processes: African University of Science and Technology completed the process by HCERES, University of Ghana started the process with AQAS), Germany, University of Port Harcourt initiated the process with HCERES, University of Rwanda initiated the process with ZEvA, Bayero University initiated the process with HCERES, Université Félix Houphouët-Boigny completed the process with HCERES.

		At least 10 RSIF African Host Universities that start international accreditation process for the PhD programmes by 2023 • 10 cross-cutting training courses/workshops held for RSIF scholars and researchers by 2023 • 10 implemented networks between RSIF African Host Universities and RSIF international partners for PhD training and research collaboration	• 12[5] cross-cutting training courses/workshops held for RSIF scholars and researchers • 11 AHUs and 13 RSIF IPIs as of end 2020 with student matching and network formation in progress	Universities to be selected early 2021. • There is inadequate funding within the project to directly cater for international accreditation costs and concept note is being prepared.
Capacity for the operation and management of innovation grants built	Improved research and innovation capacity in ASET including transformative technologies in SSA Increase in productivity More industry university partnerships More patents filed More enterprises developed More employment opportunities created	• Number of Innovation grants successfully managed • 10 firms co-finance innovations grants by 2023 • 6 innovations grants awarded to RSIF African Host Universities by 2023 • 5 innovation grants awarded to faculty at RSIF African Host Universities by 2023	• 8 innovation grants successfully managed • 2 firms co-finance innovation grants.[6] • 6[7] innovation grants awarded to RSIF AHUs • 2[8] innovation grants awarded to faculty at RSIF AHUs	• First round of calls showed need for flexibility on private sector co-funding requirements and supporting AHUs in the partnership development.
RSIF PhD scholars enrol in selected PhD programs at RSIF African Host Universities	Increased number of PhD scholars with full scholarships enrolling in selected PhD	At least 90 (30 female and 60 male) RSIF scholars enrol in selected PhD	• 82 (30 female and 52 male) scholars enrolled in selected PhD programs at RSIF AHUs	• Women applicants and those from Francophone and Lusophone countries remain in

[5] Courses include: (1) Introduction to Research Communications; (2) Introduction to Digital Storytelling; (3) Introduction to Research Ethics; (4) Introduction to Information Literacy and Reference Management; (5) Grant Writing; (6) Introduction to Grievance address mechanisms, Sexual harassment; (7) Strategies for a Successful PhD; (8) Introduction to PhD proposal writing; (9) Introduction to research methods and statistics, data analysis and management; (10) Introduction to communication and social media for RSIF scholars as RSIF Ambassadors. Two (2) additional courses delivered in August and September 2020: (1) In-depth Information literacy and Reference Management; (2) Monitoring and Evaluation.

[6] Two private companies are co-applicants to Cooperability Grants approved for award to applicants from the University of Rwanda and University of Felix Houphouet-Boigny. The companies will offer in-kind support to the project teams to commercialize their products.

[7] Six Institutional Innovation Capacity Building Grants (Innovation Type 1) were approved for award by the PASET EB on May 29,2020. Project Grant Agreements have been signed between *icipe* and all grant project teams. Implementation of the Yr.1 workplan activities has commenced albeit slow due to in country COVID-19 related movement restrictions.

[8] Two Cooperability Grants (Innovation Grants Type 2) which require collaboration with the private sector were approved by the PASET EB on May 29, 2020. Project Agreement has been signed with the University of Rwanda and activity implementation was initiated for the Year 1 workplan of the Project.

	programs at RSIF African Host Universities	programs at RSIF African Host Universities		minority among applicants. Targeted outreach and calls for proposals could be pursued.
RSIF scholars graduate from PhD programs	Increased number of scientists (at least 32% women) at doctoral level in ASET fields	At least 82 (26 female and 56 male) RSIF scholars graduate from PhD programs by 2025	N/A[9]	• Covid-19 have caused some delays and plans are underway to support affected scholars graduate on time.
Increase in quality of research publications on ASET in Africa	Quality of doctoral programs and research in ASET including transformative technologies enhanced at RSIF African Host Universities	At least 20,000 scientific and technological journals can be accessed by RSIF scholars and RSIF African Host University researchers by 2023 At least 35 research papers submitted by staff members or scholars supported by the project for publication to internationally indexed journals by 2023 (of which at least 10 by female authors or co-authors) At least 10 implemented networks between RSIF African Host	• 184,014 scientific and technological journals and databases that can be accessed by RSIF scholars and researchers[10] • 26[11] research papers (of which 5 by female authors or co-authors) • Four RSIF networks initiated, and partnership agreements under review[12]. • 470[13] student/staff that take cross-cutting courses, entrepreneurship and / or research commercialization courses supported by the project • 6[14] research grants awarded to faculty of RSIF AHUs.	

[9] 15 & 67 scholars recruited in Cohort 1 & 2. Cohort 3 and 4 to be recruited in 2021. Cohort 1, 2, 3 & 4 students are expected to graduate in 2022, 2023, 2024 & 2025 respectively.

[10] The 11 RSIF AHUs signed agreements with the Research4Life (R4L) program that allows them to access ~140,000 resources including peer-reviewed international scientific journals, books and databases provided by leading science publishers. These include around 30,000 journals, books, and reference works that focus on ASETs. In addition, the AHUs accessed more than 8,000 articles following most journals granting access to articles during the COVID-19 pandemic. RSIF is also supporting subscription of over 40,803 e-books and 3,210 journals for the 11 AHUs. The total access through R4L and RSIF supported subscriptions is ~184,014 resources.

[11] Links to publications: https://www.rsif-paset.org/wp-content/uploads/2021/03/RSIF-Scholars-publications.pdf

[12] These include (i) Artificial Intelligence and Big Data led by the University of Rwanda and the University of Gaston Berger, (ii) Dryland related issues led by Bayero University, (iii) Materials and Mining Science and Technologies (MaST) led by the Nelson Mandela African Institute of Science and technology, (iv) Solar Energy network led by the University of Nairobi.

[13] In May 2019, 15 Cohort 1 scholars were trained in Kigali. In January 2020, RCU-RSIF organized and hosted a grant writing capacity building workshop targeting 32 faculty of AHUs and their partners; an orientation and training workshop was organized for 64 RSIF Cohort II scholars. In August 2020, RCU-RSIF organized an Information Literacy and Reference Management training attended by 71 RSIF participants; in September 2020, RCU-RSIF organized an M&E training course for RSIF scholars and AHU local tutors attracting 82 participants (RSIF-71, *ICIPE* and Others 11) ; in October 2020, RCU-RSIF organized a Safeguarding training for RSIF AHU coordinators, *icipe* and AHU Committees, attracting 18 RSIF participants; in November 2020, RCU-RSIF organized: a) Science Communications-Posters and Presentations training attended by 112 participants (RSIF-72, *ICIPE* and others-40) and b) Research Methods Data Management and Analysis training attended by 76 participants (RSIF-62, *ICIPE* and Others -14).

[14] Six RSIF Research Awards (Research Grants Type 1) to faculty of RSIF Host institutions were approved by the PASET EB on May 29, 2020, Project Agreements have been signed with all project teams. Projects have initiated Year 1 workplan activity implementation albeit slow due to in-country and university COVID 19 restrictions.

		Universities and international partners for PhD training and research collaboration by 2023 At least 120 student/staff that take cross-cutting courses, entrepreneurship and / or research commercialization courses supported by the project by 2023 At least 10 grants awarded to faculty of RSIF African Host Universities by 2023 At least 16 research grants awarded to RSIF scholars by 2023	• First call for Research Award to RSIF scholars is scheduled to open in 2022[15]	Since a potential maximum 15 RSIF scholars will have graduated in 2022, the plan is to instead do a call to award 10 grants and reallocate balance to Type 1 grant category (TBC)

[15] The Call for Proposals for the award of research grants to RSIF Scholars (RSIF Junior Investigator Research Award) will be published in 2022 on graduation of 1st cohort of scholars to meet the eligibility requirements for the Call.

SECTION 4: LIST OF JOURNAL ARTICLES (PEER REVIEWED) (JANUARY – DECEMBER 2020)

KEY: GOA – Gold Open Access; S - Subscription based; and IF – Impact Factor

2020 (153)
(Note: Author names shown in italics are *icipe* staff)

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icipe

International Centre of Insect Physiology and Ecology
P.O. Box 30772-00100 Nairobi, Kenya
Phone: +254 (20) 8632000 | Fax: +254 (20) 8632001/2
Email: icipe@icipe.org | Website: www.icipe.org