Annual Report 2021

icipe

Insects and birds have an intricate relationship. Insects are one of the major foods consumed by birds; and birds help to keep plant-eating insect populations under control. But birds are an endangered class of animals, threatened by deforestation and land use changes, agricultural intensification, predation, pollution and climate change, among other factors. Over the past several years, *icipe* has embarked on a greening initiative. One of the outcomes is that our Duduville Campus now has a thriving landscape that consists of numerous insect species; as well as bird species, some of which are featured in this report, courtesy of our resident macro photographer, Dr Svegan Subramanian, Principal Scientist and Head, Environmental Health Theme.

The African citril, *Crithagra citrinelloides*, male perched on acacia tree at the *icipe* Duduville Campus, Nairobi.

Annual Report
2021

May 2022

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We also recognise specific restricted project donors, as presented in each chapter of this report.

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The cover image is based on brilliant, insect-inspired artwork, created and installed at *icipe* by Kitengela Glass, a Kenyan company that applies the dalle de verre tableau technique on recycled glass.

All photos have been used with permission and unless otherwise specified, they belong to *icipe*.

Contents

Foreword

Prof. Kym Anderson
Chair, *icipe* Governing Council

In 2021, the *UNESCO Science Report 2021* was published by the United Nations Educational, Scientific and Cultural Organization. Subtitled: "The race against time for smarter development", the document underscores the global urgency to restrategise, in order to achieve the 2030 Agenda for Sustainable Development, adopted by the United Nations in 2015, and its 17 Sustainable Development Goals (SDGs).

According to that report, a smart development vision involves a dual, concurrent transition to digital and green economies. Digital technologies include artificial intelligence and robotics, big data and the Internet of Things (IoT), which intersect with nanotechnology, biotechnology and cognitive sciences, to underpin the Fourth Industrial Revolution. Thus, digital economies encompass smart manufacturing, smart finance, smart health care services and smart agriculture. Green economies are built around the premise of smarter production and consumption, with systems that reduce carbon emissions, are energy and resource efficient and socially inclusive, create employment and income, and improve biodiversity and ecosystem services.

Despite global willingness, the shift to digital and green economies is not without challenges. It requires large capacity building investments, and it will involve trade offs in product and labour markets that may exacerbate social inequalities during the transition period.

As evidenced in this Annual Report for 2021, *icipe* is contributing creatively to this transition. In smarter agriculture, our integrated pest management approaches show that it is possible to control crop pests and to increase yield without harming the Earth. Also, we sustainably exploit useful arthropods while conserving their diversity and survival. And the *icipe* programme that promotes insects for food and feed and other uses is a globally acclaimed model for the transformation of the food system into a greener, more sustainable and vibrant circular economy.

icipe supports smart consumption by disseminating knowledge on food value chains; expanding pathways to facilitate information flows; strengthening capacities of end-users and stakeholders; and impacting food systems governance by collaborating with policy and decision making institutions to design better policies, legislation and regulations. Further, we partner with the private sector to develop and market high-quality sustainable products; and intensively raise awareness to transform consumer demands.

Our efforts have led to an an extensive range of community-based small and medium enterprises that promote equality of opportunity and outcomes for women and men, especially the younger generation. For example, in 2021, 53 percent of the farmers we reached were women; over 70 percent of those trained through our insect for food and feed initiatives, and 30 percent of the push-pull farmers, are aged below 35 years.

We provide details in this Annual Report of how *icipe* is building its expertise in digital technologies, thus making our research processes smarter. We are also boosting digital technology capacities in Africa through both the Regional Scholarship and Innovation Fund (RSIF) and the BioInnovate Africa programme.

We believe that "The race against time for smarter development" can be won, and *icipe* will continue to contribute through sustainability science which mainstreams the study of the interactions between natural and social systems.

Preface

Dr Segenet Kelemu
Director General, *icipe*

The year 2021 began in hope; it staggered and stumbled, and then, the world started to pull itself up, aware that life will never be the same again, but determined to survive and thrive. As the global community counted its losses from the COVID-19 pandemic, especially the incredible human and economic toll, it was also compelled to acknowledge longstanding, intolerable inequities. The fragileness of our food and health systems; the importance of science, of global movements of collaboration and solidarity; the cracks and gaps in international research and knowledge systems; became evident.

This Annual Report reinforces this global awakening. The Management and Leadership chapter opens with a 2021 timeline; a snapshot of the events that *icipe* hosted or participated in, and the visitors to our Centre. The diversity of these activities reveals two things: the national, regional and global determination to reimagine the present and rethink the future; and the indispensable role of insect science and *icipe* in this process. This latter aspect is underscored by the rising investments in our Centre, as well as the increasing partnerships, visibility and recognition.

Four chapters are dedicated to the *icipe* 4H themes: Human, Animal, Plant and Environmental Health, which work closely with the Centre's Research Support Units. The highlights include two breakthroughs on malaria control: the progress towards spreading among mosquitoes, the malaria-parasite blocking microbe, *Microsporidia MB*, discovered from our earlier studies; and the potential of controlling mosquitoes by exploiting their relationship with the invasive *Parthenium* weed. Additionally, we have generated new knowledge on various vectors of arboviral and neglected tropical diseases in people and livestock. By tackling a plethora of agricultural pests, like the fall armyworm, the tomato leafminer *Tuta absoluta,* fruit flies, whiteflies, thrips and nematodes, we are impacting on food and nutritional security, as well as household and national economies.

Significantly, we have made huge advances in the development and commercialisation of biopesticides, especially from the insect-infecting *Metarhizium anisopliae* fungi. Also we have started to create next generation biopesticides from the fascinating endophytic fungi, like *Hypocrea lixii* and *Beauveria bassiana*. Concurrently, we are protecting and exploiting beneficial insects.

We have increased knowledge to harness pollinators in agriculture, including synergies between integrated pest and pollinator management; drivers and risks of pollinator decline; and stingless bees as more superior pollinators. Through the More Young Entrepreneurs in Silk and Honey (MOYESH) project, we have developed a model for holistic and inclusive development across Africa.

In the Insects for Food, Feed and Other Uses Programme chapter, we present breathroughs on the use of insect-based chitin and chitosan to manage plant diseases, and as the basis for novel antimicrobials against superbugs. We have also identified new insect species that could be employed to produce high quality frass fertiliser. Using cricket nutrients, we have transformed African porridge into a nutritious super-food; creating a blueprint for food-to-food biofortification.

Three chapters of this report focus on: the Social Science and Impact Assessment Unit, and its insights on the dissemination, adoption, economic benefits and gender inclusiveness of our technologies and strategies; the Technology Transfer Unit, which is scaling-out *icipe* technologies across Africa; and the Data Management, Modelling and Geo-Information Unit, a hub of cutting-edge expertise in decision making tools, machine learning and software and applications, for prediction and modelling of pests and vectors, and developmental thinking.

icipe's commitment to nurturing young African scientific talent and to strengthen research and innovation excellence in the continent, is captured under the Capacity Building and Institutional Strengthening Unit; BioInnovate Africa Programme; and Regional Scholarship and Innovation Fund (RSIF) chapters.

MANAGEMENT AND LEADERSHIP

Core donors: Swiss Agency for Development and Cooperation (SDC), Switzerland; Swedish International Development Cooperation Agency (Sida), Sweden; UK's Foreign, Commonwealth & Development Office (FCDO); Ministry of Education, State Department of University Education and Research, Kenya; and Government of the Federal Democratic Republic of Ethiopia.

2021 IN BRIEF

Timeline
A snapshot of events we hosted or participated in, and visitors to *icipe*.

Resource mobilisation
Overview of donor agreements; core donors; new donors and project donors.

Partnerships
New memoranda of understanding; project partner agreements; material transfer agreements; and contractual agreements.

Communications
News mentions; top stories; audience reach; geographical reach and social media reach.

Scientific publications
Peer-reviewed journal articles; and books, other publications and poster presentations.

Awards
External and internal awards and recognitions made to *icipe*, staff and students of the Centre.

Staff news
32 staff recruited, bringing the total to 569.

2021 Timeline

In 2021, *icipe* participated in and hosted a range of global, regional and national events. We also welcomed several visitors to our Centre.

JAN

icipe participated in the Global Forum for Food and Agriculture (GFFA); the fourth edition of the Future Investment Initiative (FII), a conference to reimagine the global economy amid the COVID-19 pandemic; and in a press conference on the launch of the TWAS-ICGEB-UNTBLDC programme of collaboration with LDCs.

FEB

We held discussions with Dr Beate Huber, Head, Department of International Cooperation, FiBL; and Dr Noah Adamtey, Senior Scientific Officer and Project Coordinator, FiBL; on the SysCom programme. We participated in the 24th Conference of OIE-World Organisation for Animal Health Regional Commission for Africa and in the Africa Nazarene University Creation Care Week.

MAR

In honour of International Women's Day (8 March), at the invitation of Her Excellency Sahle-Work Zewde, President of the Federal Democratic Republic of Ethiopia, *icipe* Director General, Dr Segenet Kelemu, participated in a virtual webinar of prominent Ethiopian women and women of Ethiopian origin. She also took part in a Stakeholder Engagement Workshop organised by IDRC on Women in STEM; and made a presentation titled: "My journey from tending the field to directing a leading science institution", as part of the Roedean IWD 2021 – Celebration of Inspiring Women.

Dr Kelemu made a presentation at a workshop on science diplomacy, convened by the US National Academies of Sciences, Engineering and Medicine; participated in a virtual public debate on vaccine equity, organised by SOAS University of London, in partnership with the African Research Universities Alliance (ARUA); and also attended the Annual Presidential Address to the Diplomatic Corps in Kenya.

APR

icipe participated in the SDC Agriculture and Food Security Network – Food Systems Dialogues; and took part in the 2021 Kenya Think Tanks Symposium by KIPPRA. The annual review meeting of BioInnovate Africa Programme was held with Dr Claes Kjellström, Senior Policy Specialist, Sida.

MAY

We commemorated the 20th Anniversary of the Stockholm Convention and celebration of the International Day for Biological Diversity (IDB); took part in the Sida Dialogue 3: Boost nature-positive food production – for people and the planet; participated in a session of the Global Action for Fall Armyworm Control, organised by FAO; deliberated on a joint research action plan for Africa with the French Agricultural Research Centre for International Development (CIRAD) and the French National Research Institute for Agriculture, Food and the Environment (INRAE). The DG gave a talk on 'Edible insects in circular economy' to Master's and PhD students at the University of Neuchâtel, Switzerland; and participated in discussions, including *icipe*'s insights and potential involvement in the One CGIAR.

JUN

We participated in the southern Africa subregional fall armyworm coordination group; in a webinar on challenges and solutions for global food security, hosted by University of Arizona, USA, co-sponsored by TWAS and IAP; and in an international digital forum titled 'Agriculture, guarantor of the One Health approach: Challenges, innovations, good practices' organised by Planet A.
We took part in the development of the Leishmaniasis Control Strategic Plan 2021 – 2025, organised by the Ministry of Health, Kenya; in a consultative meeting for the formulation of a continental plant health strategy for Africa organised by AU-IAPSC; in the KIPPRA annual regional conference on science, technology and innovation in Kenya; and the national stakeholder validation process of the draft national research system policy 2021.

icipe participated in the consultative meeting on climate change strategy planned by AU and UNECA. At the invitation of Springer Nature, we took part in Merck Curious 2021 – The Future of Food roundtable and panel discussion.

Visitors to *icipe* included: Dr Jan Wärnbäck (Coordinator of Sida's new regional hub for Environment and Climate Change in Africa) and Dr Katrin Aidnell (Regional Environment and Climate Change Specialist, Swedish Development Cooperation team for Environment and Climate Change in Africa (SwECCA)); Mr Michel Bernhardt (GIZ); and Prof. Hubert Gijzen, incoming Regional Director for Eastern Africa, UNESCO, accompanied by Dr Samuel Partey, Programme Specialist of Sciences.

We held a virtual meeting with The Stichting IKEA Foundation; took part in Ninth Conference on Climate Change and Development in Africa (CCDA-IX), which produced several recommendations for the COP26 meeting; participated in and made a presentation at the World Bioeconomy Forum.

The 2nd Eastern Africa Regional Bioeconomy Conference, organised by *icipe* and partners was held.

icipe in its capacity as the Regional Coordination Unit (RCU) of RSIF, in collaboration with Mohammed VI Polytechnic University convened an online workshop on building capacity for science, technology and innovation in Africa.

Dr Frank Eyhorn, Chief Executive Officer, Biovision Foundation for Ecological Development, Switzerland, visited *icipe*, accompanied by Ms Loredana Sorg (Co-Head of Development Projects); Dr Marie-Luise Matthys (Program Manager, Development Projects); Mr Fabian Kohler (Programme Officer Devolpment Projects); and Mr Danny Nef (Programme Officer, Development Projects).

JUL | **AUG** | **SEP** | **OCT** | **NOV** | **DEC**

We participated in a symposium on 'Insects for green growth and development' at the 31st International Conference of Agricultural Economists (ICAE); and in a conference on 'Science technology and innovation (STI) governance by the Kenya National Commission for Science, Technology and Innovation (NACOSTI).

We took part in the AGRF 2021 Summit Food Systems Innovators Session, where our DG reflected on insect-based technologies to recycle bio-waste into nutrient rich organic fertilizer, and production of insect-based feeds for poultry and fish. Dr Kelemu made an official visit to Ethiopia and toured selected various project sites being implemented by the MOYESH project and BioInnovate Africa Programme.

Meeting with Dr Marco Wopereis, Director General and Dr Ralph Roothaert, Country Director, Kenya, World Vegetable Center (WorldVeg); and Dr Tony Simons, Director General, World Agroforestry Centre (ICRAF).

Four early career scientists at *icipe* participated in the DIES/ CREST online training course for supervisors of doctoral candidates at African universities.

We attended the virtual 'Planet Explore 2021, Global Connection' conference.

Prof. Jeanick Brisswalter, President of the Université Côte d'Azur, Nice, France, visited *icipe*.

Prof Heikki Hokkanen and Dr Ingeborg Menzler-Hokkanen from the University of Helsinki, Finland, visited *icipe* to discuss new projects on integrated pest management.

icipe hosted a virtual annual general meeting of the Training Health Researchers into Vocational Excellence (THRiVE) initiative.

Resource Mobilisation

*All figures as of December 2021.

Overview

USD 36.7 million: Total value of *icipe* signed donor agreements for strategic long-term funding and restricted projects.

USD 7.9 million: Total value of contracts for restricted projects approved by donors, pending signatures.

USD 35.6 million: Total value of restricted projects proposals submitted to various donors, which were at various stages of review.

Core donors

Swiss Agency for Development and Cooperation (SDC), Switzerland; Swedish International Development Cooperation Agency (Sida), Sweden; UK's Foreign, Commonwealth & Development Office (FCDO); Ministry of Education, State Department of University Education and Research, Kenya; and Government of the Federal Democratic Republic of Ethiopia.

New donors 2021

African Technology Policy Studies Network; Chalmers University of Technology, Sweden; Children's Investment Fund Foundation (CIFF), UK; Code for Science & Society; German Aerospace Centre; IMC Worldwide Limited; Innovate UK; International Centre for Agricultural Research in the Dry Areas (ICARDA); Norwegian Refugee Council (NRC); Participatory Ecological Land Use Management (PELUM), Kenya; Remote Sensing Solutions; University of Bern, Switzerland; University of Leeds, UK.

Investors in RSIF

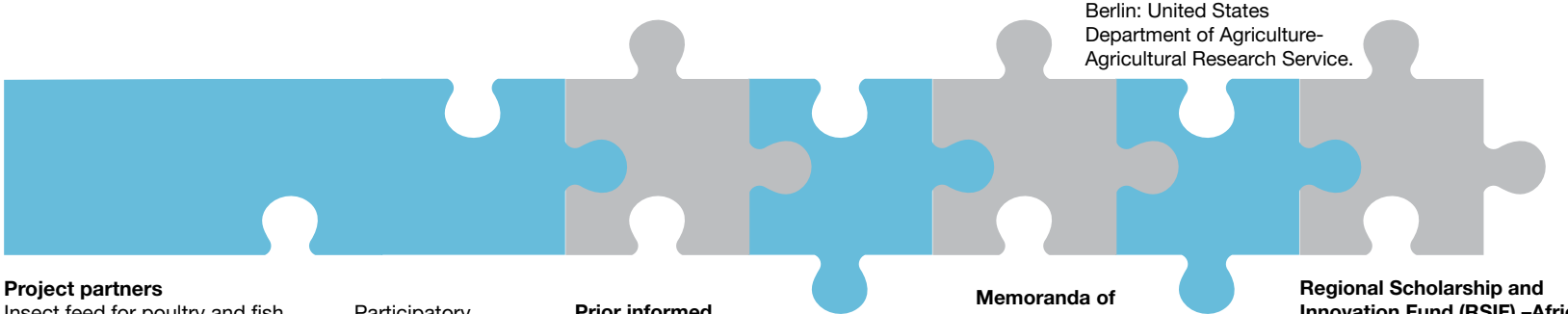
African governments: Benin, Burkina Faso, Côte d'Ivoire, Ghana, Kenya, Mozambique, Rwanda and Senegal. Other investors: World Bank; Government of South Korea; and ACP Innovation Fund of the European Union through the Organisation of African, Caribbean and Pacific States (OACPS).

Project donors

African Union; African Academy of Sciences; Bertha Foundation; Bill & Melinda Gates Foundation; BioInnovate Africa Programme; Biotechnology and Biological Sciences Research Council, UK, through Rothamsted Research and Keele University (both in the UK); Biovision Africa Trust; Biovision Foundation for Ecological Development, Switzerland; British Council-Newton Fund Institutional Links; Cambridge Africa ALBORADA Research Fund; Impaxio GMBH; Cultivate Africa's Future Fund (CultiAF), a partnership between the International Development Research Centre (IDRC) and the Australian Centre for International Agricultural Research (ACIAR); Danish International Development Agency (DANIDA); ETH Zurich; Ethiopian Catholic Church Social Development Commission (ECC-SDCBOM); European Union; Federal Ministry for Economic Cooperation and Development (BMZ), Germany, through the Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ); German Research Foundation (DFG); Food and Agriculture Organization of the United Nations (FAO); French National Research Institute for Sustainable Development (IRD); French Agricultural Research Centre for International Development (CIRAD); Bayer: Science for a Better Life; German Academic Exchange Service (DAAD); Global Challenges Research Fund (GCRF); Innovate UK; Institute of Research for Development (IRD); International Atomic Energy Agency (IAEA); International Development Research Centre (IDRC); International Fund for Agricultural Development (IFAD); JRS Biodiversity Foundation; Keele University, UK; LEAP-Agri (A Long-term EU-Africa research and innovation partnership on food and nutrition security and sustainable agriculture); Mastercard Foundation; Max Planck Institutes, Germany; Medical Research Council, UK; Mozilla Foundation; National Geographic Society; National Research Fund (NRF), Kenya; National Science Foundation (NSF), USA; Netherlands Organisation for Scientific Research (NWO); Norwegian Agency for Development Cooperation (Norad); Open Philanthropy; Pennsylvania State University, USA; Research Institute of Organic Agriculture (FiBL); The Rockefeller Foundation; Rothamsted Research, UK; Scottish Funding Council; Swedish International Development Cooperation Agency (Sida); Swedish University of Agricultural Sciences (SLU); Swiss Agency for Development and Cooperation (SDC); Swiss National Science Foundation (SNSF); The Curt Bergfors Foundation Food Planet Prize; The Royal Society, UK; The Royal Society to Future Leaders – African Independent Research (FLAIR); The Stichting IKEA Foundation through Biovision Foundation for Ecological Development; TWAS, The World Academy of Sciences through the Organization for Women in Science for the Developing World (OWSD); United Nations Environment Programme (UNEP); United Nations Office for Project Services (UNOPS); United States Agency for International Development (USAID); USAID-Partnerships for Enhanced Engagement in Research (USAID-PEER) Science program with funding from the National Academy of Sciences (NAS); United States Department of Agriculture (USDA); United States National Institutes of Health (NIH); University of Cambridge, UK; University of Glasgow, Scotland, UK; United States Agency for International Development (USAID)-funded IPM Innovation Lab (Feed the Future Innovation Lab for Integrated Pest Management) of Virginia Tech, USA; Wageningen University & Research, The Netherlands; Wellcome Trust, UK; World Bank Group; World Federation of Scientists; World Health Organization (WHO); World Trade Organization (WTO) – Enhanced Integrated Framework (EIF).

Partnerships

In 2021, *icipe* signed:



Project partners
Insect feed for poultry and fish production in sub Saharan Africa (INSFEED) project, phase 2: Treasure Industries Limited (TIL).

Integrated Pest and Pollinator Management (IPPM) project: Tropical Pesticides Research Institute (TPRI); Kenya Agriculture and Livestock Research Organization (KALRO) .

Community-based Fall armyworm Monitoring, Forecasting, and Early Warning System (CBFAMFEW II): Ministry of Agriculture, Machinga Agricultural Development Division, Malawi; Zambia Agricultural Research Institute (ZARI); Ethiopian Institute of Agricultural Research (EIAR); National Agricultural Research Organisation (NARO), Uganda; Rwanda Agriculture and Animal Resources Development Board (RAB).

Participatory beekeeping for ecological protection of mangrove forests in Zanzibar (Zanbee): Ministry of Agriculture, Irrigation, Natural Resources and Livestock, Zanzibar.

Integrated pest management strategy to counter the threat of invasive fall armyworm to food security in eastern Africa (FAW-IPM): RAB.

Long-term farming systems comparisons in the tropics (phase iv): KALRO.

Prior informed consent
Institut de Recherche pour le Development (IRD); Centre National de la Recherche Scientifique (CNRS); and University of Tours, all in France.

Contractual agreements under MOYESH
Suleyman Abera Building Contractor; Reis Muzemil Building Contractor; Kayof BC Partnership; Tesfaye Sofiya and Friends Building Works Partnerships; Ahmed Seid Building Contractor; Yadeta and Zelalem House Construction; Ashenafi Assefa and His Friends Construction Work; Kamiyu Building Road and Bridge GC; Meketwa Construction GC.

Service agreement
Bere Sericulture Production PLC.

Memoranda of understanding (MoUs)
mHealth Kenya Ltd; and Debre Markos University (DBU).

Material transfer agreements
Charite-Universitatsmedizin Berlin: United States Department of Agriculture-Agricultural Research Service.

Regional Scholarship and Innovation Fund (RSIF) –African Host Universities (AHUs)
International Institute for Water and Environmental Engineering (2iE), Ouagadougou, Burkina Faso.

RSIF – International Partner Institutes
University of Pretoria, South Africa; Telecom SudParis, France; IRD, France; University of Lisbon, Portugal; Regents of the University of Michigan, United States.

RSIF – tripartite partner agreements
Worcester Polytechnic Institute, USA and the African University of Science and Technology, Nigeria; University of Greenwich Natural Resources Institute, UK and Bayero University, Kano, Nigeria.

Communications

Media coverage

icipe appeared in 530 media items, published and broadcast, locally and internationally in 330 publications and in 52 countries.

The combined potential reach of the media coverage was 1.85 billion people.

The media outlets with the highest number of news items mentioning *icipe* were Springer; Multidisciplinary Digital Publishing Institute (MDPI); AllAfrica.com; Nature; Opera News; CABI; Daily Nation; Opportunities for Africans; People Daily Online; Alpha Galileo and Phys.org.

The potential advertising value of the media coverage was USD 17.17 million.

The top 10 countries in which the Centre appeared in the news were: United States, Switzerland, South Africa, Nigeria, Kenya, United Kingdom, France, China, Ghana, Australia.

On social media, *icipe* had 7,708 mentions: Twitter (6,352), Facebook (766) and blogs (530).

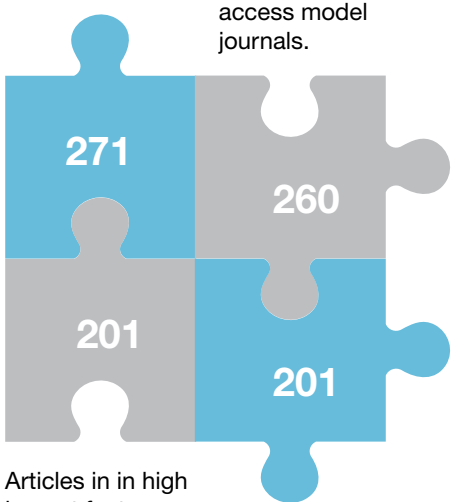
Approximately 78,200 visitors and 286,551 page views were registered on the *icipe* website. The top countries (ranked in order of visitor numbers) were: Kenya, United States, Indonesia, Ethiopia, Germany, United Kingdom, China, Nigeria, Uganda, Tanzania.

Scientific Publications

In 2021, *icipe* published and produced:

Peer-reviewed journal articles.

Articles in open access or open access model journals.



Articles in in high impact factor journals, including niche journals (impact factor above 2).

Articles in collaboration with national agricultural research systems.

Some of the top ranked 2021 papers based on online attention:

Dicks L.V. et al.; A global-scale expert assessment of drivers and risks associated with pollinator decline. *Nature Ecology and Evolution* 5, 1453-1461. https://doi.org/10.1038/s41559-021-01534-9
IF 15.46
ALTMETRIC 816
Ranked 3rd of 42 outputs of a similar age in *Nature Ecology and Evolution.*
This article is in the 99th percentile (ranked 610th) of the 282,539 tracked articles of a similar age in all journals.

Chemura A. et al.; Climate Change and Specialty Coffee Potential in Ethiopia. *Scientific Reports* 11 (1). https://doi.org/10.1038/s41598-021-87647-4
IF 4.379
ALTMETRIC 314
This article is in the 99th percentile (ranked 2,450th) of the 332,790 tracked articles of a similar age in all journals.

Sterkel M. et al.; Repurposing the orphan drug nitisinone to control the transmission of African trypanosomiasis. *PLoS Biology* 19, e3000796. https://doi.org/10.1371/journal.pbio.3000796
IF 8.029
ALTMETRIC 131
Ranked 5th of 21 outputs of a similar age in *PLoS Biology.*
This article is in the 98th percentile (ranked 7,268th) of the 411,337 tracked articles of a similar age in all journals.

Bossert S. et al.; Phylogeny, biogeography and diversification of the mining beefamily Andrenidae. *Systematic Entomology*, 1–20. https://doi.org/10.1111/syen.12530
IF 3.844
ALTMETRIC 73
This article is in the top 5 percent of all research outputs scored by Altmetric. It is also among the highest-scoring outputs from *Systematic Entomology* (11th of 914).
Ranked 3rd of 16 outputs of a similar age in *Systematic Entomology*.
This article is in the 96th percentile (ranked 13,950th) of the 439,137 tracked articles of a similar age in all journals.

Nattoh G. et al.; Horizontal transmission of the symbiont *Microsporidia MB* in *Anopheles arabiensis*. *Frontiers in Microbiology* 12, 647183. https://doi.org/10.3389/fmicb.2021.647183
IF 5.64
ALTMETRIC 68
Ranked 3rd of 41 outputs of a similar age in *Frontiers in Microbiology*
This article is in the 96th percentile (ranked 11,962nd) of the 338,650 tracked articles of a similar age in all journals.

Magara et al.; Review: Edible crickets (Orthoptera) around the world: Distribution, nutritional value, and other benefits—A review. *Frontiers in Nutrition* 7, 537915. https://doi.org/10.3389/fnut.2020.537915
IF 6.576
ALTMETRIC 59
Ranked 17th of 178 outputs of a similar age in *Frontiers in Nutrition*
This article is in the 95th percentile (ranked 20,117th) of the 480,186 tracked articles of a similar age in all journals.

Schlum K.A. et al.; Whole genome comparisons reveal panmixia among fall armyworm (*Spodoptera frugiperda*) from diverse locations. *BMC Genomics* 22, 179. https://doi.org/10.1186/s12864-021-074str92-7
IF 3.969
ALTMETRIC 51
This article is in the 94th percentile (ranked 17,410th) of the 326,065 tracked articles of a similar age in all journals.

Awards and Recognitions

In 2021, *icipe* and several of the Centre's staff received a variety of external and internal awards and recognitions. These are:

Notable awards

In celebration of its 10-year anniversary, Ohio State University Global One Health initiative (GOHi) has selected *icipe* as one of its key partners.

Five current scientists and one former *icipe* researcher are in the "World Ranking of Top 2% Scientists" list. Created by Stanford University, the list identifies the top scholars in their own areas of specialty and the frequency with which their publications are cited by other authors around the globe. The scientists are: **Dr Sunday Ekesi**, Director of Research and Partnerships; **Prof. Baldwyn Torto**, Head, Behavioural and Chemical Ecology Unit; **Prof. Zeyaur Khan**, Leader, Push-Pull Integrated Pest Management Programme; **Dr Menale Kassie**, Head, Social Sciences and Impact Assessment Unit; **Dr Tadele Tefera**, Head, *icipe* Ethiopia Office and **Dr Jean Maniania**, former Head, *icipe* Arthropod Pathology Unit.

icipe **Director General, Dr Segenet Kelemu** has been selected as a member of the Scientific Board of the International Basic Science Programme (IBSP), the only international forum in the United Nations that makes recommendations to the Director-General of UNESCO and its Member States on the global situation of the basic sciences. Dr Kelemu was also recognised among brilliant women breaking barriers, improving global health, and inspiring others to pursue careers in science, a 'modern Marie Curie', by The Borgen Project, in honour of International Women and Girls in Science Day and International Women's Day, 2021.

Dr Ekesi was selected as a Fellow of the Entomological Society of America (ESA), the largest organisation in the world serving the professional and scientific needs of entomologists and individuals in related disciplines. He also received the Distinguished Scientist Award, one of four awards given annually by the ESA International Branches.

Dr Kassie was ranked among the top 5 percent authors in the field of Economics in IDEAS. **Dr Henri Tonnang**, Head, Data Management, Modelling and Geo-information Unit, has been nominated by the Director General of UNESCO as a member of the Advisory Committee in Open Science. **Dr Jeremy Herren**, scientist and leader of the *icipe* SymbioVector Project, has been selected as one of ten winners of the Falling Walls 2021, in the Life Sciences category. He spearheads the research that has discovered a microbe in malaria-transmitting mosquitoes, that can block transmission of the disease's parasites from the insects to people.

A baglafecht weaver, *Ploceus baglafecht*, perched on a hibiscus shrub at the *icipe* Duduville Campus, Nairobi.

HUMAN HEALTH THEME

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

Donors: Biovision Foundation for Ecological Development, Switzerland; Bill & Melinda Gates Foundation; German Academic Exchange Service (DAAD); Federal Ministry for Economic Cooperation and Development (BMZ), Germany, through the Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ); Foundation for the National Institutes of Health (FNIH), USA; German Research Foundation (DFG), Germany; Global Environment Facility (GEF)/United Nations Environment Programme (UNEP); Government of Kenya; Innovative Vector Control Consortium, UK; Kenya National Research Fund; National Institutes of Health (NIH), USA; National Science Foundation (NSF), USA; Norwegian Agency for Development Cooperation (Norad); Open Philanthropy Project, USA; Swiss National Science Foundation (SNSF); The Swedish Research Council, Sweden; Wellcome Trust, UK; World Health Organization-Regional Office for Africa (WHO-AFRO); Medical Research Council (MRC), UK; European Commission H2020 Model Grant Agreement for Marie Skłodowska-Curie RISE; Institute for Research and Development (IRD), France; Cambridge-Africa ALBORADA Research Fund.

A comprehensive list of partners is included in the annexes.

2021 IN BRIEF

Malaria transmission blocking
New breakthrough to spread *Microsporidia MB* among mosquitoes.

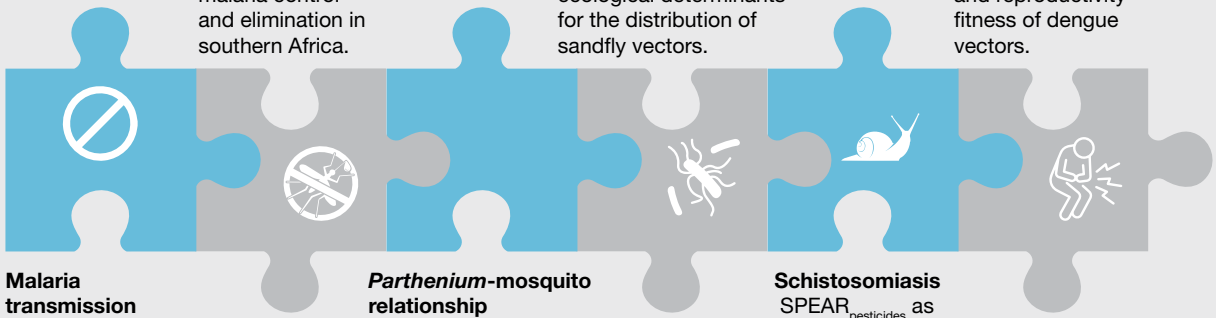
Integrated vector management
Contributing to malaria control and elimination in southern Africa.

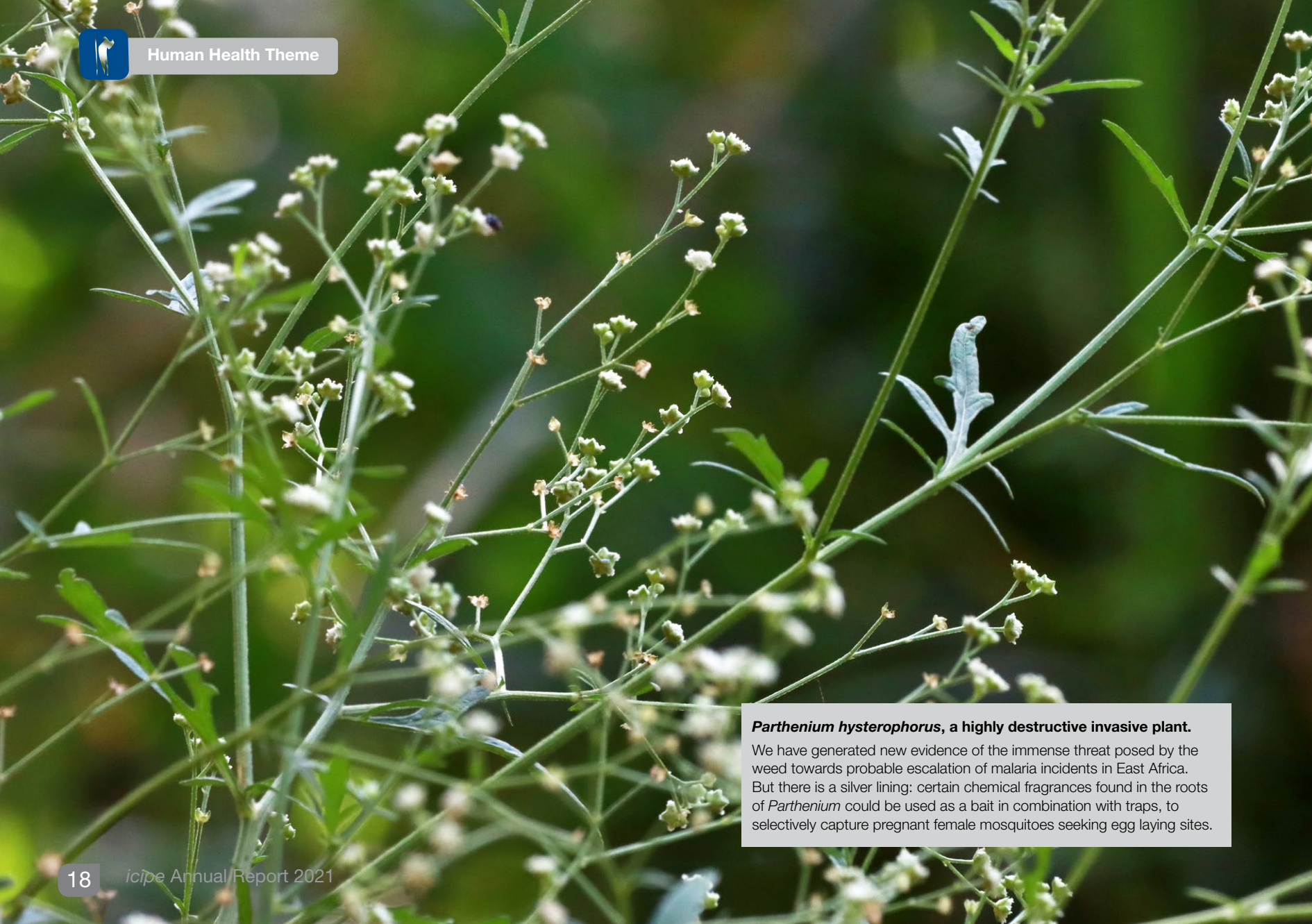
***Parthenium*-mosquito relationship**
New evidence and silver lining in possible use of chemical fragrances in the plant's roots as a mosquito bait.

Leishmaniasis
Leads for plant-derived attractants; and ecological determinants for the distribution of sandfly vectors.

Schistosomiasis
SPEAR$_{pesticides}$ as a cost-effective pesticide monitoring tool.

Arboviral diseases
Disease risk, arboviruses and insect-specific flaviviruses in mosquitoes; plant feeding ecology, and reproductivity fitness of dengue vectors.





***Parthenium hysterophorus*, a highly destructive invasive plant.**

We have generated new evidence of the immense threat posed by the weed towards probable escalation of malaria incidents in East Africa. But there is a silver lining: certain chemical fragrances found in the roots of *Parthenium* could be used as a bait in combination with traps, to selectively capture pregnant female mosquitoes seeking egg laying sites.

Malaria Research

Focus	Context	Progress in 2021	Way forward
Develop strategies to spread *Microsporidia MB* among mosquitoes	In 2020, *icipe* made the ground-breaking discovery of a microbe in *Anopheles* mosquitoes, which blocks transmission of the malaria parasite from the insects to people. The scientists found that the microbe, which they named *Microsporidia MB*, is passed on from female mosquitoes to their offspring at high rates and that it does not kill or cause obvious harm to the mosquito host.	In 2021, *icipe* conducted further research to investigate the natural ability of *Microsporidia MB* to spread among mosquitoes. We discovered a new transmission route of the microbe, this time between adult mosquitoes. These latest findings show that ***Microsporidia MB* can be transmitted sexually between mosquitoes.** Based on this knowledge, we are exploring the feasibility of releasing male mosquitoes laden with *Microsporidia MB* in areas of high malaria transmission.	As male mosquitoes do not bite people, they do not pose any malaria-transmission risk. Male mosquitoes with *Microsporidia MB* would continue with their natural life cycle, infecting wild female mosquitoes with the microbe. In turn, the females would convey to their offspring the malaria blocking trait. **The result would be a largely self-maintaining and sustainable strategy for malaria control.**
Contribute to malaria control and elimination in southern Africa	The aim is to demonstrate the potential benefits of integrating readily available, but not-widely used vector control tools like winter larviciding and house screening, in Botswana, Namibia, Mozambique, Eswatini, Zambia and Zimbabwe, to sustain malaria control and elimination.	We conducted assessments of our activities, as well as courses for community field workers on identification and sampling of adult mosquitoes in Zambia and Mozambique. We undertook initial bio-larviciding using *Bacillus thuringiensis israelensis* (Bti); and trained partners, community field workers and health workers on bio-larviciding and sampling of mosquito larvae in in Botswana, Eswatini and Namibia.	We have produced a brief **documentary on our activities in southern Africa,** which will be made available on various platforms.

Malaria Research

Focus	Context	Progress in 2021	Way forward
Explore potential of *Parthenium* in mosquito control	In 2015, we published a seminal study that made the **first global connection between *Parthenium hysterophorus*, and Anopheles mosquitoes.** We demonstrated that the weed is a preferred nectar source of the mosquitoes and it can sustain these insects by extending their lifespan even in the absence of a blood meal from people. Moreover, female *Anopheles* mosquitoes that feed on *Parthenium* survive longer, accumulate substantial energy reserves and they lay more eggs. Also, parthenin, a chemical in *Parthenium*, does not have the same toxic effect on adult female mosquitoes as it does on people and animals. This suggests that the insects can tolerate and possibly detoxify themselves of the compound.	In 2020, we **generated new evidence** that, unlike in people, the weed has contrastingly favourable effects on *Anopheles* mosquitoes. ***Parthenium* releases from its roots, chemicals known as terpenes that have a distinct blend of mosquito-attractive fragrances.** When these chemicals leak into stagnant water, they enhance its attractiveness as an egg laying site for female mosquitoes, in comparison to plain water. These chemicals enable mosquito larvae to emerge two to three days earlier and they also extend the lifespan of the adult mosquitoes arising from the contaminated breeding sites to a week longer than normal, thus boosting their chances to bite people and transmit the malaria parasite.	Our studies showed that only half of the eggs deposited in water containing the *Parthenium* chemicals hatched. We singled out parthenin as being responsible for the low egg hatch rate, indicating that the tolerance to the toxin by female mosquitoes is not passed on to the eggs. These findings provide a **silver lining in that the chemical fragrances in the roots of *Parthenium* could be used as a bait** in combination with traps, to selectively capture pregnant female mosquitoes seeking egg laying sites.

An *icipe* researcher sets up a sandfly trap near a termite mound in Nguruman, Kajiado County, Kenya, an emerging focus of leishmaniasis. Certain species of sandflies, the vectors of leishmaniasis, tend to breed in termite mounds. Thus, it is important to monitor such sites as part of vector surveillance.

Neglected Tropical Diseases

Focus	Context	Progress in 2021	Way forward
Plant-derived tools to control leishmaniasis	In previous studies, we showed that sandflies extensively feed on plants, imbibing sugar fructose in their foraging activities. The insects selectively feed on Acacia plants (Fabaceae family). We **identified organic compounds in the plants that could be exploited for odour-baited technologies** to control sand flies.	We investigated responses to the organic compounds by *Phlebotomus duboscqi*, the sandfly species that vector cutaneous leishmaniasis. Among these compounds, we noted those that are attractive to the sand flies, **which could be used as attractants** to trap the insects.	The results demonstrate the potential of plant-derived attractants for sandfly management.
Eco-epidemiology of leishmaniasis	Old world leishmaniasis, that found in the Eastern Hemisphere, is transmitted by sandflies of the *Phlebotomus* genus, which feed on multiple blood sources, including people. We studied sandflies in endemic focal points and in an emerging focus in Kenya.	We identified vector species of *Leishmania major*, the parasites that are the key cause of cutaneous leishmaniasis, and *L. donovani,* responsible for visceral leishmaniasis. We found ***Leishmania major* and *L. donovani* DNA in *Sergentomyia squamipleuris* sandfly species, which has not been described as a vector in these regions.** Also, **cutaneous leishmaniasis and visceral leishmaniasis were present in the non-endemic region.**	We continue studies on the ecological determinants for the distribution of sandfly vectors of leishmaniasis, and the competence of these insects to transmit the disease. This knowledge will support better surveillance by frontline disease management teams.
Pesticide monitoring to curb *Schistosomiasis* transmission	Our previous research established pesticide pollution as a risk factor in the occurrence of schistosoma-host snail and thus *Schistosomiasis* transmission. But detecting pesticide pollution in streams requires often expensive monitoring of peak concentrations during run-off events.	$SPEAR_{pesticides,}$ a technology developed in Central Europe helps to quantify pesticide-related changes in the macroinvertebrate community composition. With minimal adaptations, we were able to use the index to characterise pesticide pollution in streams in western Kenya and to estimate pesticide pollution through rapid macroinvertebrate sampling.	Against the urgent need to regulate pesticides in developing countries, $SPEAR_{pesticides}$ is a straightforward and cost-efficient tool.

Neglected Tropical Diseases

Focus	Context	Progress in 2021	Way forward
Management of tungiasis	Tungiasis is a painful, debilitating, parasitic skin disease caused by penetration of female sand fleas, *Tunga penetrans,* into the skin. It leads to physical disability and severe emotional and mental impacts. ***icipe*'s aim is to generate knowledge on the ecology of tungiasis in Kenya, investigating the environmental, social and individual determinants of health**.	Our surveys on domestic animals found no evidence of them as reservoirs that are involved in the tungiasis transmission cycle. We conducted care giver interviews and paternal mental health surveys. We also measured the association between tungiasis and cognitive development in children.	We are undertaking comprehensive data analysis. Activities have started on potential prevention intervention, testing of insect growth regulators on larvae development.
Develop biorational, cattle-targeted interventions for control of arthropod vectors of malaria and other diseases of people and livestock	Livestock are important blood-hosts of many biting arthropods. *icipe* aims to develop a tool to jointly target human and animal disease vectors. In selected sites in Kenya, we have mapped and engaged stakeholders in human and animal vector-borne diseases control. We have also studied and documented livestock keeping practices and challenges. **This knowledge lays the basis for us to design livestock-centred interventions strategies**.	We evaluated two strains of *Metarhizium anisopliae* of ICIPE 7, which is known for its action on ticks, and is constituent of an *icipe* bio-acaricide formulation that is under development; and ICIPE 30, which has demonstrated efficacy on malaria parasite transmitting mosquitoes. Additionally, two formulations of ICIPE 7, under the brand name Mazao TickOff, have been tested in the laboratory and under field conditions on their effect once applied on cattle on tick population and mosquitoes.	**We have selected a biopesticide formulation and an application strategy, and developed a proof-of-principle for pilot field trials**. We plan to **construct a 'healthy home' with improved features for disease reduction**. It will serve as a venue for training on prevention of malaria, ectoparasites, bacterial infections; and for training on proper hygiene, waste disposal, improved cooking, good animal husbandry; to inspire community members to implement some of the ideas in their own homes.

Arboviral Diseases

Focus	Context	Progress in 2021	Way forward
Understand disease risk, arboviruses and insect-specific flaviviruses in mosquitoes	*Aedes aegypti* and *Culex pipiens* mosquito complex are prolific vectors of arboviruses; genus of viruses that include the West Nile virus and dengue virus, which can emerge unexpectedly in human populations and cause potentially severe diseases, including epidemics. Insect-specific flaviviruses are distinct to their insect hosts and cannot replicate in people.	In recent studies on the two mosquito species, we did not detect classical viruses like dengue or chikungunya viruses. However, females of C. poicilipes tested positive for Sindbis virus, which causes febrile illness in humans.	The detection of a single Sindbis virus in a mosquito population with insect-specific flaviviruses is important. It calls for **further investigation on the role that insect-specific flaviviruses may play in modulating transmission of other classical arboviruses.**
Predictive surveillance of arboviruses in sandflies	Knowledge on the occurrence of sandfly-borne phleboviruses can help to understand their contributions to fevers of unknown origin in people.	We have discovered seven strains of four previously unknown phleboviruses: *Ntepes phlebovirus, Bogoria phlebovirus, Embossos phlebovirus, Kiborgoch phlebovirus, Perkerra phlebovirus,* in sandflies collected in the Kenyan Rift Valley. These findings led to a revision of the taxonomy of phylum *Negarnaviricota*, which has been ratified by the International Committee on Taxonomy of Viruses (ICTV). Our novel detected *Ntepes phlebovirus* is recognised as a species in the genus *Phlebovirus*, which is now expanded by six species including the new viruses that we detected in sandflies in Kenya.	Our findings suggest that diseases associated with sandfly-borne phlebovirus infections may also affect people in Kenya.

Arboviral Diseases

Focus	Context	Progress in 2021	Way forward
Investigate plant feeding ecology of *A. aegypti* mosquito	Plant sugar feeding behaviour of mosquitoes can enable the development of vector monitoring and control strategies of the vectors. But there is limited understanding of this trait in *A. aegypti* mosquito, the vector of dengue fever.	Our studies in dengue-endemic and non-endemic regions in Kenya showed that plant feeding in *A. aegypti* varies by sex and season; the mosquitoes acquire diverse plant-derived sugars; feed on various host plants mostly in Fabaceae (Acacia) and Malvaceae (mallows) families; and females have a greater selection of sugars and host plant species than males.	This knowledge allows **investigations on plants in dengue virus transmission dynamics**. This includes exploring the odours and compounds that attract *A. aegypti* mosquitoes to specific plants.
Explore plant nutrients and reproductive fitness of the dengue vector, *A. aegypti* mosquito	A recent study using DNA barcoding, identified the plants fed upon by four Afro-tropical mosquito species that vector dengue, malaria and Rift Valley fever. We investigated the role of three such plants, *Pithecellobium dulce* (Fabaceae), *Leonotis nepetifolia* (Lamiaceae), and *Opuntia ficus-indica* (Cactaceae), on the survival, fecundity and egg viability of *Aedes aegypti*.	Our studies show that *A. aegypti* females that had fed on *L. nepetifolia* laid more eggs; those fed on the other two plant diets laid fewer eggs compared to those fed exclusively on blood meals. **Egg hatching rates varied with the diet.** Analysis of gut contents of the mosquitoes had qualitative and quantitative differences in their amino acid levels.	These findings highlight the central role of plant nutrients in the reproductive fitness of dengue vectors, which may impact their disease transmission potential.

ANIMAL HEALTH THEME

The *icipe* Animal Health Theme aims to develop effective solutions to improve the health, productivity and sustainable farming of livestock in Africa. Our main research niche is disease transmitting insects and arthropods, primarily tsetse flies (vectors of human and animal trypanosomosis), biting flies and ticks. Through a One Health and multisectoral approach, our activities are geared towards profound understanding of the biology and population ecology of arthropod disease vectors; vector–host and vector–parasite interactions; and the epidemiology of vector-borne diseases. We develop locally-adapted technologies to manage vector-borne diseases, conduct operational research for vector-borne livestock diseases, and support capacity building and extension services.

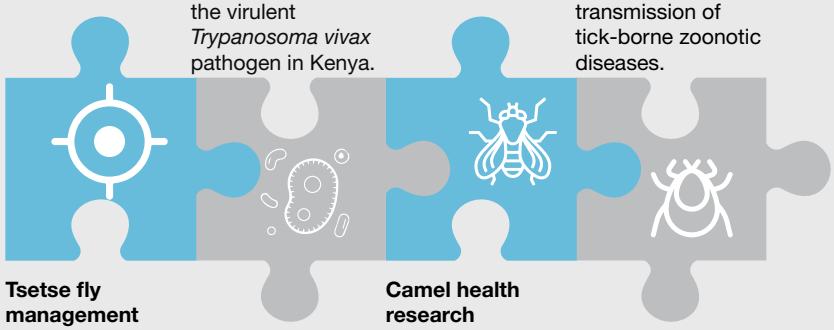
Donors: Biovision Foundation for Ecological Development, Switzerland; European Union; Federal Ministry for Economic Cooperation and Development (BMZ), Germany, through the Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ); German Research Foundation (DFG); International Atomic Energy Agency (IAEA); Max Planck Institutes, Germany; National Science Foundation (NSF), USA; Wellcome Trust, UK; United States Agency for International Development's Partnerships for Enhanced Engagement in Research (USAID-PEER) grants program.

A comprehensive list of partners is included in the annexes.

2021 IN BRIEF

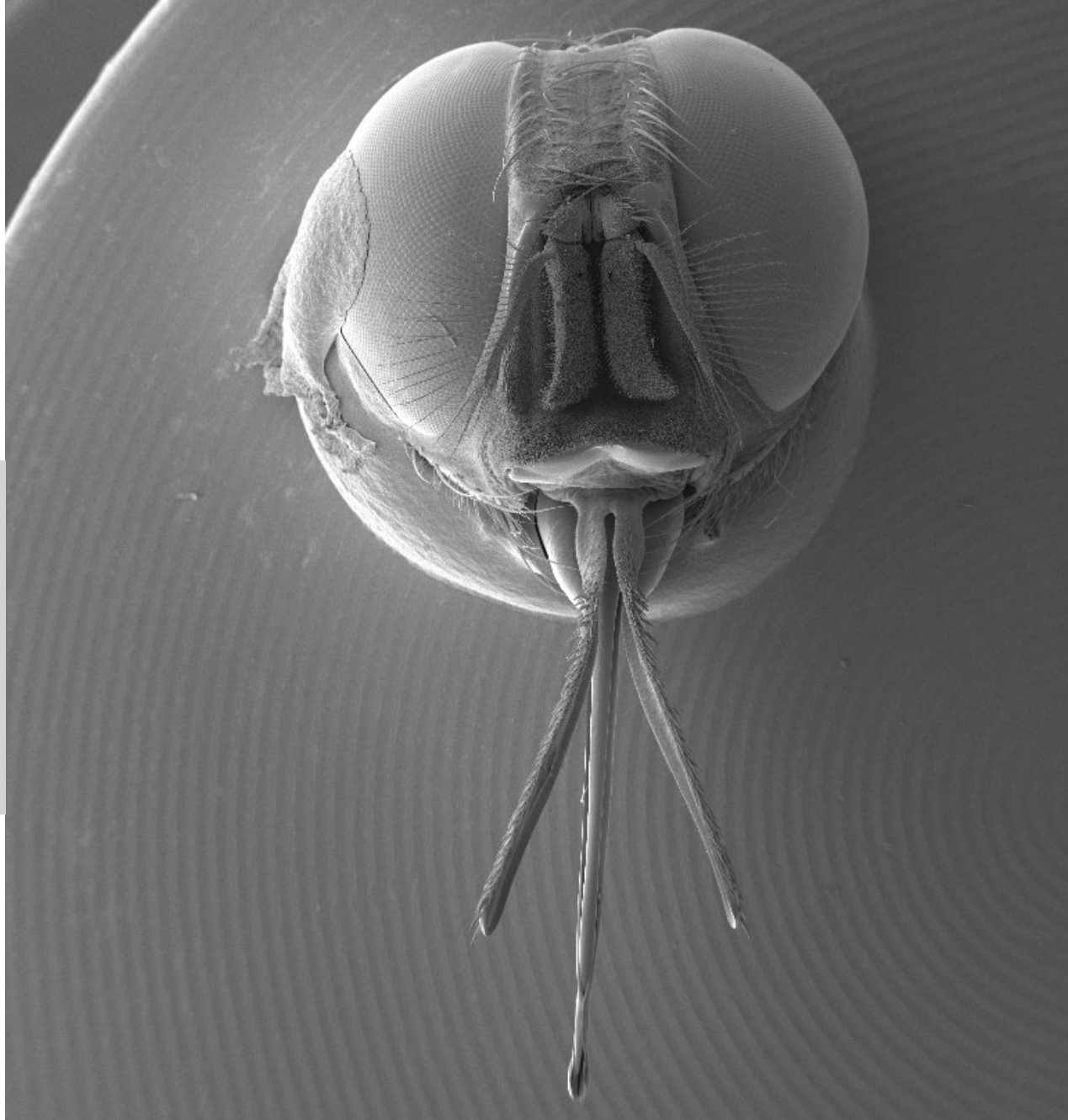
Trypanosomes
Presence of the virulent *Trypanosoma vivax* pathogen in Kenya.

Camel health research
Role of camels in transmission of tick-borne zoonotic diseases.



Tsetse fly management
Leads in zebra odours for control of *Glossina fuscipes fuscipe;* and silencing tsetse genes; and tsetse and trypanosomosis management technologies in Borana zone, Ethiopia.

Camel health research
Fertility boosting in stable flies.



Head of a tsetse fly.

The insect has a well developed visual, olfactory and mechano sensory system, which is a current area of our research to design control strategies. The tsetse fly antenna has olfactory sensilla with odour sensors; the eye is made up of many independent ommatidium with photo receptors, which act together for high resolution images; and its arista (the bristlelike appendage) has sensors for temperature and humidity. The sharp mouth parts are adapted to pierce the skin of the fly's host to access blood.

Tsetse Fly Management

Focus	Context	Progress in 2021	Way forward
Knowledge to develop control strategies for *Glossina fuscipes fuscipes*	Zebras are commonly present in areas infested by tsetse flies. But previous research has shown that **tsetse flies avoid and hardly bite zebras**. Common speculations were that the zebras' striped skin is a contributing factor for this evasion. In 2019, we published findings that **zebras produce certain scents that repel tsetse flies.**	We evaluated a three-component blend of these odours for repellency against the riverine tsetse fly, *Glossina fuscipes fuscipes*, a major vector of the trypanosome pathogens that cause human African trypanosomosis. We found that **the odour blend increases effectiveness of our existing *icipe* tsetse management tools like the tsetse repellent collar technology and NGU traps.**	These findings present the possibility of developing odour-based tools for *G. fuscipes fuscipe*, which has so far remained an elusive goal. Previously, traps and targets baited with visual cues have been used, but the development of olfactory-based tools has been challenging.
Possibility of silencing tsetse fly genes	As is the case with all other living things, in insects, the sense of smell is orchestrated at different stages, each involving various proteins.	We have investigated the role of odourant-binding proteins found inside the antennae of *G. fuscipes fuscipes*. Also, we have successfully **silenced a specific protein,** via the doublestranded RNA interference (dsRNAi) technique. As a result, **the tsetse flies were unable to interact with an attractant chemical in tsetse, and thus, they could not locate their hosts.**	These findings reveal the mechanisms of *icipe*'s successful repellent and attractant tsetse control tools. Moreover, **our success in conducting dsRNAi gene silencing is a milestone** that can be extended to plant and human health disease control through interference of genes in relevant pests and vectors.

Tsetse Fly Management

Focus	Context	Progress in 2021	Way forward
Investigate the presence of the virulent *Trypanosoma vivax* pathogen in Kenya	Trypanosomosis, one of the most life threatening diseases of livestock is caused by trypanosome parasites. *Trypanosoma vivax* **is the most prevalent trypanosome species in cattle** in Africa and Latin America. The parasite is mainly transmitted by tsetse flies. But *T. vivax* can also be mechanically transmitted by biting flies. Understanding the parasite's distribution, host range and prevalence is key step in trypanosomosis control.	We **identified for the first time, the presence of a virulent strain of *T. vivax*** in tsetse flies collected around Shimba Hills, a wildlife reserve along the Kenyan coast. This strain, designated Tvv4 genotype, was previously isolated in wildlife in Mozambique. We also confirmed that the Tvv4 strain in Shimba Hills consists of at least three closely related genotypes. We also demonstrated that tsetse flies are vectoring these highly pathogenic strains of *T. vivax*.	Our studies highlight the need for continued focus on tsetse fly control, especially in grasslands around the Shimba Hills National Reserve. Since *T. vivax* is also transmitted by biting flies, **further studies are needed to understand the parasite's distribution and determinants** in the region.
Tsetse and trypanosomosis management technologies in Borana zone, Ethiopia	Animal trypanosomosis caused by *Trypanosoma* spp, vectored by tsetse flies, is a key constraint in Borana zone, home to one of the most important indigenous cattle breeds that are named after the area. We are testing the *icipe* arsenal of tsetse control technologies in the zone. In partnership with communities and government agencies, we aim to build up, extend and incorporate these tools with other technologies that are already in use, **thus implementing an integrated tsetse control approach in various regions of Ethiopia.**	We have tested *icipe* tsetse repellent collars, odour-baited traps and targets. We have strengthened the skills and knowledge of local practitioners, with 816 pastoralists, 130 community-owned resource persons, 86 experts, 19 pastoralists, and small-scale micro-enterprises trained. A total of 204 agro-pastoralists have adopted the tsetse management technologies, leading to improved livestock health; reduction of tsetse fly abundance (82 percent), the prevalence of trypanosomosis in livestock (6 percent), cattle morbidity (56 percent), and mortality (50 percent). We are working with private sector partners to mass-produce and supply the tsetse control technologies.	We aim to consolidate the gains achieved thus far. In partnership, with the local government we will expand activities into new areas that have high infestation levels of tsetse fly. We have also found a high burden of other biting flies, mainly several Tabanids and Stomoxys, which could pose a challenge to livestock and transmit pathogens.

Camel Health Research

Focus	Context	Progress in 2021	Way forward
Fertility boosting flies	Stable flies, *Stomoxys calcitrans*, are a serious challenge for livestock and people across the world in general, and in Africa specifically. These blood-sucking insects transmit various pathogens, for example trypanosomes that cause the deadly trypanosomiasis. Over the past several years, *icipe* has built a wealth of knowledge, especially on the behaviour and ecology of these insects.	Our recent studies have revealed an ingenious habit used by stable flies to improve their fertility. These insects are obligate blood feeders, meaning that they must obtain blood to advance from one life stage to the next. Our research shows that, **surprisingly and perhaps deliberately, the flies also supplement their diet with nectar, which improves the quality of their eggs.**	We will establish the vector competence of various Stomoxys species for trypanosomes, and other blood pathogens transmission, including the **cellular and molecular basis of vector-host interactions.**
Ticks and tick-borne pathogens transmission of zoonotic diseases	Globally, ticks as vectors of diseases in people are considered second only to mosquitoes. Thus, establishing their roles in transmission of zoonotic and other emerging pathogens is important. Previously, dromedary (one-humped) camels have been implicated in tick-borne zoonotic diseases. But epidemiological data on tick and tick-borne pathogens in camels, which are also major constraints to the animals, are limited.	We conducted the **first detailed molecular study on tick species infesting camels in northern Kenya and on the tick-borne pathogens in blood and ticks from these camels and co-herded sheep.** Our findings suggest that camels and the ticks infesting them are reservoirs of various diseases including zoonotic ailments. The pathogens we found are: *Coxiella burnetii,* a bacteria that causes Q fever; *Rickettsia africae,* a causative agent of African tick-bite fever, and *Ehrlichia chaffeensis*, which is responsible for human monocytic ehrlichiosis. We also confirmed the presence of major livestock pathogens such as *Ehrlichia ruminantium,* circulating in camel herds and the ticks infesting them.	Further studies could focus on the role of camels in transmission of tick-borne zoonotic diseases.

PLANT HEALTH THEME

The Plant Health Theme conducts multidisciplinary research using a one health concept, working with a range of partners to benefit smallholder agriculture, nutrition, health and the environment in Africa. Our strategic objectives include basic and applied research on native and invasive, below- and above-ground, pre- and postharvest pests, under changing climate and habitats. We harness the synergies in plant-insect-soil interactions through integrated pest management (IPM) options that are ecologically sustainable and economically feasible. Our focus is on biological control using predators, parasitoids, microbes and habitat management strategies. Further, the Theme discovers, develops and pilots technological innovations, products and applications for pest management. We disseminate our research results, transfer technologies, influence policies and empower communities through partnerships with national agricultural research organisations, the private sector and other stakeholders. And we build excellence in plant health research in Africa through training of students and scientists.

Donors: African Union; French Agricultural Research Centre for International Development (CIRAD); Biotechnology and Biological Sciences Research Council (BBSRC), UK, through Rothamsted Research and Keele University (both in the UK); Biovision Foundation for Ecological Development, Switzerland; International Development Research Centre (IDRC), Canada; European Union; Federal Ministry for Economic Cooperation and Development (BMZ), Germany, through the Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ); Food and Agriculture Organization of the United Nations (FAO); French National Research Institute for Sustainable Development (IRD); International Atomic Energy Agency (IAEA), Austria; International Fund for Agricultural Development (IFAD); Norwegian Agency for Development Cooperation (Norad); Research Institute of Organic Agriculture (FiBL), Switzerland; Royal Society, UK; UK's Foreign, Commonwealth and Development Office (FCDO), UK; United States Agency for International Development (USAID), USA through the IPM Innovation Lab; United States Department of Agriculture (USDA).

A comprehensive list of partners is included in the annexes.

2021 IN BRIEF

Push-pull IPM
Sustainable intensification by integrating farmer-preferred vegetables; upscaling push-pull technology benefits.

Fall armyworm management
Push-pull technology and biopesticides to control fall armyworm.

Advocacy for agroecology (A4A)
Climate resilience of the push-pull technology; increasing push-pull adoption through community and private sector production of intercrop seeds.

Fruit pests management
Natural enemies and climate change; unlocking mango export; supporting policy for the management of fruit pests; and fruit fly control in Zanzibar.

Integrated pest and pollinator management (IPPM)
Key pests of avocado and curcubits established; progress in developing biopesticides for curcubits; assessment of the compatibility of biopesticides and IPPM; knowledge on flower strips and pollinators; and rectifying pollination deficit in smallholder avocado farms.

Vegetable IPM
Knowledge on lure-and-kill thrips management strategy; and precise identification of whiteflies.

Research on nematodes
'Wrap & plant' to protect potatoes from potato cyst nematodes (PCN); biocontrol options for nematodes; rapid diagnostic technique for PCN; nematode and nematology awareness and capacity building.

***Tuta absoluta* management**
Wasp becomes "the farmers' friend"; optimising and establishing efficacy and economic viability, and commercialisation of biopesticides for the control of *T. absoluta*.

A push-pull field planted with kale during maize off-season.

Known as ‘sukuma wiki’, which in Kiswahili means 'the vegetable that helps to push the week', the leafy vegetable is popular in East Africa due to its affordability and high nutrient content.

Push–Pull IPM

Focus	Context	Progress in 2021	Way forward
Push-pull sustainable intensification	Our previous studies have shown that *Desmodium*, a push-pull intercrop, repels vegetable pests. The legume also attracts beneficial arthropods, for example predators that prey on the vegetable pests, or parasitoids that parasitise and eventually kill them.	Working with partners we have begun to **integrate farmer-preferred vegetables** like kale, black nightshade, cabbage, cowpea, tomato and onion, into push-pull systems. The vegetables will **supplement household nutrition and provide income** during maize off-seasons. In line with our participatory approach, we are using a range of pathways, including innovative training materials for farmers, and cartoon books for school children, which have been widely distributed.	We aim to expand the integrated push-pull system across Africa.
Upscale push-pull benefits	In 2020, a five-year project titled 'Upscaling the benefits of push–pull technology for sustainable agricultural intensification in East Africa' (UPSCALE), was launched, co-led by *icipe* and Leibniz University Hannover, Germany. In collaboration with 17 partners in Africa and Europe, *icipe* will scale-up understanding; explore the potential to implement the push-pull technology concept in other cropping systems; and expand the adapted technology options across multiple scales.	In 2021, we **analysed agro-ecological and socio-economic challenges and solutions** that will enable the adaptation and sustainable intensification of push-pull. This knowledge includes the factors that determine the technology's effectiveness across farms, landscapes and climatic zones; its viability under future climate conditions; and likely consequences of spatial expansion of the technology. We have also **assessed the agro-economic, social, health and food security impacts** of the push-pull technology; and estimated the welfare effects (nutrition security, income) delineated in relation to male, female and youth farmers.	We will continue to conduct experiments and to generate large-scale data to expand knowledge on the potential expansion of push-pull beyond individual farms. We will also develop simulation and dissemination tools and multi-actor networks.

Advocacy for Agroecology (A4A)

Focus	Context	Progress in 2021	Way forward
Climate resilience of the push-pull technology	Over the past one decade, in response to the increasingly dry and hot conditions in many cereal-livestock farming systems in Africa, we have developed and disseminated a climate-smart version of the push–pull technology.	In 2021, using the Food and Agriculture Organization of the United Nations (FAO) Self-Evaluation and Holistic Assessment of Climate Resilience of Farmers and Pastoralists (SHARP), we **assessed the push-pull technology against 13 agroecosystem indicators of climate resilience,** in comparison to other farming systems. The results indicate that the push-pull farming system is more climate-resilient, with significant impact on 8 out of the 13 indicators.	As the climate-smart push-pull evolves, we will continue to generate knowledge, to boost the technology as an agroecological solution.
Increase push-pull adoption by ensuring availability of the seeds of its intercrops	A major constraint in the adaptation of the push-pull technology is inadequate availability of the seeds for its intercrops: *Desmodium* and *Brachiaria*. We aim to **increase community and private sector production of seeds,** through a variety of strategies including training, experience sharing and awareness creation.	In 2021, we trained 106 (80 male and 26 females) farmers; 20 extension staff and 18 private seed collectors, on seed production. About 142 kilogrammes of *Brachiaria* seeds and 35 kilogrammes of *Desmodium* seed were produced. As a result, 137 (108 male and 29 female) farmers were able to adopt the push-pull technology. They are reaping the benefits of the technology especially because of availability of high-quality fodder, which has had a major impact on livestock productivity.	Our outcomes show that we can r**educe dependency by push-pull farmers on imported seed.** We have started to establish a system for a recycling approach connecting seed growers, collectors and newly recruited farmers. Our activities are having a significant **impact on the seed value chain,** including resource flows, policies and market connections.

Fall Armyworm Management

Focus	Context	Progress in 2021	Way forward
Capacity of the push-pull technology to control fall armyworm	In 2017, based on reports from farmers as well as socio-economic studies, we established that the climate-adapted version of push–pull can control the fall armyworm. Since then, we have conducted various studies to determine the scientific underpinning of this capacity.	Our recent research shows that **greenleaf *Desmodium* provides the most effective control of fall armyworm within the push-pull technology.** The plant also has the capacity to recruit one of the fall armyworm's natural enemies, a wasp known as *Telenomus remusa*. Further the push-pull technology improves soil conditions, leading to higher maize growth rate, and it enables the plants to produce compounds that defend it from the fall armyworm, thus reducing infestation and damage by the pest.	We are evaluating grasses that can enhance the efficacy of the push-pull technology against the fall armyworm. With the intensification of the technology with vegetables, we will also evaluate how such crops can complement control of fall armyworm.
Biopesticides for fall armyworm management	In 2020, *icipe* tested the effectiveness of some of its biopesticides that had been previously commercialised for the control of diverse pests, in partnership with Real IPM Ltd, a Kenya-based biocontrol company. Two isolates of the insect-infecting *Metarhizium anisopliae* fungi: ICIPE 78 and ICIPE 7, which had been commercialised as Mazao Achieve® and Mazao Tickoff® respectively, were found to be effective against immature stages of the fall armyworm, and to work in synergy with the pest's natural enemies.	In 2021, in collaboration with Real IPM Ltd, we conducted trials, in alignment to the harmonised regional guidelines of the East African Community, and in partnership with regulatory agencies and private sector partners in the region. We have **received permits for the label extension and registration of Achieve OD® in Kenya. Towards the development of next generation fall armyworm biopesticides,** we have identified potential strains from endophytic fungi, a fascinating group that lives within plant tissues in a mutually beneficial relationship, without causing disease in their host plants.	Permits for label extension in Tanzania and Uganda, as well as final registration certificates of the two biopesticides are awaited in all the three countries. We have identified two endophyte strains, *Hypocrea lixii* F3ST1 and *Beauveria bassiana* G1LU3, that are effective against the fall armyworm, as well as the pea leafminer.

Based on success in eastern Africa, we are upscaling the *icipe* fruit fly IPM packages in Malawi, Mozambique, Tanzania, Uganda, Zambia and Zimbabwe. The impact of our interventions is evident, with farmers, like Mrs Rosemary Lungu of Mpwaya Camp in Zambia, now gradually re-entering mango trading.

Fruit Pests Management

Focus	Context	Progress in 2021	Way forward
Knowledge on natural enemies and climate change	In 2008, we imported from Hawaii, USA, two natural enemies (both wasps): *Fopius arisanus* and *Diachasmimorpha longicaudata,* for the management of various fruit fly species in Africa, from Hawaii, USA. We have released these wasps in Africa. We continue to increase knowledge on the natural enemies, to guide more effective releases.	*icipe* started to **release the two wasps in Malawi, Zambia, Mozambique and Zimbabwe.** Further, we conducted studies that show that *D. longicaudata* could successfully establish in tropical and sub-tropical regions under current and future climatic conditions. But a slight change in the suitable areas is expected by 2050 due to gradual rise in temperature.	Farmer groups have been formed to **accelerate spread of the natural enemies and adoption of the *icipe* fruit fly IPM** with emphasis on conserving the wasps. This will guide future releases of this wasp in Africa, and in designing strategies to limit the spread and impact of fruit flies.
Unlock mango export	Previously, we developed **protocols for postharvest disinfestation of *Bactrocera dorsalis*** in mango. In partnership with private sector partners, we have translated these protocols into technologies and commercial set-ups that are accessible to mango growers across Africa.	**The *icipe* protocols were recognised by the European Union as an effective post-harvest treatment for mango.** This facilitated re-access of mangoes from Africa into the EU. In July 2021, *icipe*, the Kenya Plant Health Inspectorate Service (KEPHIS), and Fresco Freshpro Ltd, Kenya, sent a pilot shipment of treated mango to Italy. The consignment satisfied all phytosanitary requirements. We also developed two more protocols for the Tommy Atkins mango cultivars in Uganda and Kenya.	The three protocols will be submitted to the International Plant Protection Convention (IPPC) for inclusion in International Standards for Phytosanitary Measures (ISPMs).
Support policy for the management of fruit pests	To realise the full potential of Africa's fruit production, policies are needed to enable design, dissemination, adoption and diffusion of strategies to manage pests, in compliance with local and international requirements.	We participated in two fora: the consultative technical meeting on the establishment of common user hot water treatment and fumigation facilities, at the invitation of the Horticultural Crops Directorate (HCD), Kenya; and the process to draft national phytosanitary policy, under KEPHIS.	Together with various stakeholders in Kenya, technical specifications have been compiled and plans are ongoing to establish a hot water treatment facility at HCD.

Fruit Pests Management

Focus	Context	Progress in 2021	Way forward
Reduce fruit fly populations in Zanzibar to an economically viable threshold	The *icipe* fruit fly control activities in Zanzibar commenced in 2018. Our previous studies identified the invasive fruit fly, *B. dorsalis* as the major species attacking mango, as well as other major fruit fly species in Zanzibar. We have provided farmers with several components of the *icipe* fruit fly IPM package, including lures and traps and approaches for orchard sanitation. Fruit growers in Zanzibar have also been involved in *icipe* field trials on fruit fly baits and biopesticides.	We **released the two fruit fly natural enemies:** *F. arisanus* and *D. longicaudata* for the management of *B. dorsalis*. Due to our interventions, **fruit fly densities have reduced dramatically,** with the catches in the traps down from a high of 25,000 fruit flies in 2018, to about 8,000 at the beginning of 2020, to a low of 2,300 by December 2021. We have established strong partnerships for example with the Zanzibar Ministry of Agriculture, Irrigation, Natural Resources and Livestock and Zanzibar Agricultural Research Institute (ZARI).	A committee and a mango growers association has been formed, as a link between the farmers and relevant government ministries and private sector partners, and as a **platform to seize opportunities and deal with challenges in the fruit value chain.** We have enhanced awareness creation in collaboration with Biovision Africa Trust, local media and through mobile phone apps, **reaching millions of people with information** on the *icipe* fruit fly IPM, management of fruit diseases, as well as postharvest handling of mangoes.

The *icipe* IPM packages to control the devastating tomato pest, *Tuta absoluta*, are enabling safe production of tomatoes. Women, like Ms Gladys Macharia and Ms Purity Wambui (from central Kenya), pictured staking their tomato crop, are benefiting especially due to the fact that our strategies require less labour, for example, by pre-empting constant and tedious spraying.

Tuta absoluta Management

Focus	Context	Progress in 2021	Way forward
Wasps to control the tomato pest, *Tuta absoluta*	In 2020, *icipe* achieved a landmark for tomato production in Africa, by releasing in Kenya, a parasitic wasp, *Dolichogenidea gelechiidivoris*, that will naturally control the notorious *T. absoluta* pest.	Our monitoring shows that the wasp has spread efficiently and is indeed established in Kenya. We also **determined the economically-viable rates for releasing the wasp in greenhouses,** with a ratio of 1 wasp to 100 caterpillars of *T. absoluta* being deemed appropriate.	We continue participatory trainings and farmers are now using environmentally-friendly pest management techniques that conserve **the wasp, widely known as "the farmer's friend".**
Optimise biopesticides to control *T. absoluta*	In 2020, we established that some of our commercially available biopesticides, *M.anisopliae* ICIPE 69 and *M. anisopliae* ICIPE 20, can protect tomato and nightshade against *T. absoluta*.	We have conducted modelling studies, a fundamental approach to optimise the efficacy of biopesticides prior to their deployment in the field. As a result, we have **identified suitable geographical locations** to use *M. anisopliae* ICIPE 18 and ICIPE 20 isolates against *T. absoluta* in Kenya, Tanzania and Uganda.	This knowledge will **guide decision and policy makers, private sector and farmers to choose specific strains for particular regions.**
Establish efficacy and economic viability of biopesticides for *T. absoluta*	We aimed to understand the impact of *M. anisopliae* ICIPE 20 on pest damage and yield loss reduction.	We noted significantly lower damage to crop, with yield gain of 72 percent and a benefit cost ratio of more than 4.	These findings prompted the registration, commercialisation and upscaling of *M. anisopliae* ICIPE 20.
Commercialisation of biopesticide for control of *T. absoluta*	A key goal of *icipe* is to **upscale and make accessible the Centre's biopesticides by as many end-users as possible.** This process involves public and private sector partnerships.	*icipe* has signed a license agreement with Russell Bio Solutions Ltd, UK, for the registration and commercialisation of *M. anisopliae* ICIPE 20. We have established a pilot biopesticide production facility to train farmers and through a partnership with Hottiserve East Africa Ltd, Kenya, a commercial biopesticide production plant has been launched in the country.	**These facilities will open up opportunities for business incubation for entrepreneurs and, overall, promote biopesticide use.**

Vegetable IPM

Focus	Context	Progress in 2021	Way forward
Lure-and-kill thrips management strategy	In previous studies, *icipe* and partners **discovered chemical odours, scientifically referred to as aggregation pheromones, released by male bean flower thrips** (*Megalurothrips sjostedti*), that attract male as well as female thrips. The pheromones cause bean flower thrips to assemble in a focal point on the plant, and can, therefore, be used to lure and trap the insects. The chemical odours could be integrated with other thrips management options, such as insect pathogenic fungal biopesticides.	We tested the field efficacy of two male-produced aggregation pheromones of the bean flower thrips. We also **determined the compatibility of these pheromones with two thrips attractants and the entomopathogenic fungus, *M. anisopliae* ICIPE 69.**	Our findings pave a way for **a lure-and-kill thrips management strategy** to control beanflower thrips using autoinoculation devices or spot spray application.
Precise identification of whiteflies	Closely related to aphids and mealybugs, whiteflies (*Aleyrodidae*), are soft-bodied, winged insects that are so tiny that they are usually camouflaged on plants, forming clusters on the undersides of leaves. A major **challenge in the development of sustainable management strategies for whiteflies is lack of knowledge on their diversity, including the different species and distribution.**	We have identified four whitefly species, *Aleyrodes proletella*, *Aleurodicus dispersus*, *Bemisia afer* and *Trialeurodes vaporariorum*, the latter being the most dominant species across all agroecologies in Kenya. Our studies show high climatic suitability of *T. vaporariorum* in Africa, Europe, Central America, parts of Southern America, parts of Australia, New Zealand and Asia.	Our findings will **guide biosecurity agencies on the protocols for precise identification of whitefly** species in Kenya. This is important in the development of early warning tools, especially against *T. vaporariorum* invasion into currently unaffected areas. This knowledge will also spport appropriate decision-making on the management of the pests.

Plant parasitic nematodes are a major problem for crop production. Once they infect plants roots, these microscopic, soil dwelling worms feed on, and migrate within the root. Compromised root systems are less able to access available water and nutrients.

Nematodes are difficult to identify and because they have high reproductive and short lifecycles; they build up population densities and spread rapidly. Moreover, climate change is altering their geographical spread. We have increased knowledge on the distribution and damage caused by various nematodes in eastern Africa including potato cyst nematode (PCN); root lesion nematodes (*Pratylenchus* spp.) in ensete, in Ethiopia; a range of nematode species in banana farms in Kenya; root knot nematodes (*Meloidogyne* spp.) in commercial and smallholder pineapple farms in Kenya.

Research on Nematodes

Focus	Context	Progress in 2021	Way forward
'Wrap & plant' to protect potatoes from potato cyst nematodes (PCN)	In 2015, PCN, a devastating a highly destructive nematode species was reported in East Africa, greatly threatening production of potato, one of the regions most important staple crops. Previous studies by the International Institute of Tropical Agriculture (IITA) showed that a simple technology, a paper made from banana-fibre, can improve the delivery and effectiveness of nematicides to control PCN. Known as 'wrap & plant', the solution involves enclosing potato seed before planting, in a protective sheet of paper that is made from the fibre of banana plants. When treated with ultra-low dosages of nematicide, **the paper releases the chemicals to the target root zone in a slow and sustained manner, in very low but effective concentrations; thus preventing contamination to non-target areas and organisms.**	In collaboration with the IITA team and other partners, *icipe* investigated a surprising but significant aspect of the 'wrap & plant' technology: that **even without the nematicides, the technology protects potato from PCN damage.** We established that the banana-fibre has unique sponge-like properties. Thus, through a process known scientifically as 'hydrogen bonding' the 'wrap & plant' paper soaks and physically binds to its surface and pores, the critical chemical signals released by potato crops that allow the PCN to hatch, find and infect plant roots. We recovered these chemicals from the paper and confirmed that they stimulate PCN hatching, in contrast to those that permeated through. As a result, the 'wrap & plant' technology provides a protective barrier for potato plants against damage by PCN. Whether treated with nematicides or not, and depending on the practice of individual farmers, **the technology can increase potato yield up to five-fold.**	Further studies are needed to understand the scientific underpinnings of the 'wrap & plant' technology. We are currently **exploring how to upscale the technology** in the region while also determining investor interest and assessing options to make it easy-to-use and accessible to farmers. Additionally, we have begun **assessments of 'wrap & plant' on other tubers, vegetables, seeds or seedlings,** with promising results against various nematode pests. The technology also presents multiple options to protect crops from **a range of soil pests and pathogens,** which we are exploring.

Research on nematodes

Focus	Context	Progress in 2021	Way forward
Biocontrol options for nematodes	Between 2017 – 2021, *icipe* and IITA were part of a five-year project that investigated how microbes can be used to control banana pests and diseases. ***icipe*'s focus was on endophytes and biocontrol agents (EBCAs)** against the burrowing nematode (*Radopholus similis*), the lesion nematode (*Pratylenchus* spp.) and the banana weevil (*Cosmopolitis sordidus*).	We found **three isolates of the endophytic fungus,** *B. bassiana* (ICIPE 648, ICIPE 660 and ICIPE 273), to be **highly effective against the banana weevil.** An isolate (V5w2) of the non-pathogenic endophytic fungus *Fusarium oxysporum* suppresses nematode infection and increases banana productivity in East African highland banana and the dessert banana, cv Grande Naine. We are testing compatibility and performance of the isolates with existing approaches, to develop an IPM strategy against banana weevil.	Ongoing trials will **optimise application of the fungi; illuminate mechanisms of nematode suppression and banana yield increase** through *F. oxysporum*; and reveal potential benefits of different applications of the endophytes on soil microbiome and soil health.
Rapid diagnostic technique for PCN	Across Africa, diagnostic capabilities for nematodes are limited, although the situation is gradually changing as expertise develops and more reliable scientific techniques become available.	Together with Agri-Tech Centre Crop Health and Protection and PES Technologies both in the UK, we have **developed a proof-of-concept for a diagnostic tool to identify and quantify PCN.**	We are **advancing this solution to provide more soil health indicators** from a soil sample than any other tool so far. We will analyse and advance sensor data.
Nematology capacity building and awareness creation	In Africa, nematology capacity is limited. Over the past five years, *icipe* and IITA have commenced efforts to **establish a critical mass in this sector, to create public awareness and understanding across the agricultural landscape; form networks and platforms for capacity building and research; and integrated knowledge on nematode management within agriculture, academia and policy.**	Our focus is on postgraduate undergraduate and internships training of young nematologists. We continue to coordinate the Kenya Track, which enables nematology MSc students from Gent University, Belgium, to undertake industrial training in Kenya, and the annual Basic Crash Course Nematology (BCCN). We participated in several key fora on nematology, and organised awareness events for practitioners and farmers, in partnership with universities and industry partners.	As partners in Nematology Education in Sub-Saharan Africa (NEMEDUSSA), we are establishing a pan-African nematology network (PANEMA), tipped to become the premier gathering of nematologists in the region.

A *Hypotrigona* stingless bee foraging on a female flower of cucumber.
Cucurbits, such as cucumber, are highly pollination dependent. They are also attacked by various pests. It is important to understand the interactions among various IPM strategies and pollinators such as bees.

Integrated Pest and Pollinator Management (IPPM)

Focus	Context	Progress in 2021	Way forward
Establish key pests of avocado and curcubits	The importance of avocado is fast rising in Kenya and Tanzania, with more than 400,000 metric tonnes of the fruit produced annually. About 85 percent of the produce is by smallholder farmers and 70 percent is consumed locally. Cucurbits include cucumber, butternut and pumpkin. In Kenya, more than 60,000 metric tonnes of pumpkin leaves, and 2,000 metric tonnes of cucumber, are produced per year.	We have established the **key pests of avocado to be the invasive fruit fly *Bactrocera dorsalis* and the false codling moth *Thaumatotibia leucotreta*.** The major fruit fly **pests of cucurbits include *Zeugodacus cucurbitae,* a recent invader into Africa and now the most serious pest of the crop.** Others are *Dacus bivittatus* and *D. ciliatus* fruit fly species.	Highlighting the importance of avocado and cucumber pests allows the development of eco-friendly IPM options. Some of the pests we identified are native. Others, like *B. dorsalis* are invasive, and to control this pest in avocado, we will adapt the IPM options developed for mango. In cucurbits, besides *Z. cucurbitae*, the other fruit flies also merit attention.
Develop biopesticides for curcubits	While several options – like wrapping the fruit with a cover and baited traps – are used globally to control *Z. cucurbitae,* biopesticides are not widely employed.	In screenhouse trials, we established that **the active ingredient in *M. anisopliae* ICIPE 69, is effective against *Z. cucurbitae*,** performing as well or better than commercially available options. In laboratory experiments, we found that ICIPE 69 is highly efficient against *Z. cucurbitae* and *D. bivittatus* pupae, which live in the soil.	We are now conducting multi-season screenhouse studies on squash **comparing biopesticide application on the plant and through soil drenching.**
Establish the usefulness of flower strips in pollination	Flower strips, a mixture of flowering plants, are being promoted in pollination-dependent crops. However, the jury is still out on flower strips; they may act as a source or as a sink of pollinators.	We investigated flower strips composed of coriander, sunflower and alfalfa in flowering season, in a large avocado plantation in Kenya. We found that flower strips act as pollinator sinks, although fruit set was not affected.	**Our findings open up studies on flower strips,** indicating amendments like the choice of flowers, size and placement. Other factors would be timing, for example, the introduction of inter-season and multi-year flower strips.

Integrated pest and pollinator management (IPPM)

Focus	Context	Progress in 2021	Way forward
Assess compatibility of biopesticides and IPPM	In comparison to their synthetic counterparts, biopesticides have numerous advantages: they do not leave toxic residue on produce; they pose minimal risk to the health of people and the environment; and they are less likely to induce pests and disease resistance. But against this general understanding of the safety of biopesticides, there is need for comprehensive knowledge on their interaction with pollinators.	We measured the effect of *icipe* biopesticides on honey bee survival, where basic information was available, and also on stingless bee survival, where such knowledge was lacking. Although all of the tested isolates are nontoxic according to the International Organization of Biological Control (IOBC) standards, some *M. anisopliae* isolates decreased survival of the African honey bee, *Apis mellifera*. In screenhouse trials, we demonstrated that **ICIPE 69 does not have any negative effect in terms of mortality, foraging behaviour and pollination success on the African stingless bee *Meliponula ferruginea*.**	We **established a novel protocol that will enable other researchers to conduct similar tests on bees.** Some biopesticides based on *M. anisopliae* merit further field studies on bee colonies, especially those of *A. mellifera*.
Establish pollination deficit in smallholder avocado farms	Pollination deficit is defined as the quantitative or qualitative inadequate pollen receipt, which decreases the sexual reproductive output of plants. In Africa, there is minimal knowledge about pollination deficits, on any crop.	Our studies in smallholder avocado farms showed the pollination deficit at 20.7 percent. However, we showed that, with just two **beehives in a smallholder farm, the pollination deficit reduced to 4 percent and can be eliminated.**	Pollination deficits in smallholder avocado farms are huge, and require supplementation with managed honey or stingless bees, or novel approaches to attract and preserve wild pollinators.

ENVIRONMENTAL HEALTH THEME

The focus of the Environmental Health Theme is to broaden knowledge on arthropods and their diversity and role in ecosystems, contribute to conservation and sustainable use of biodiversity, and develop strategies for climate change mitigation and adaptation. The Theme's research thrusts include: bee research; beneficial and commercial insects; bioprospecting, particularly for plant-based biopesticides and medicinal products; and habitat management to support biodiversity, pollination ecosystem services, and alternative hosts for pests and diseases.

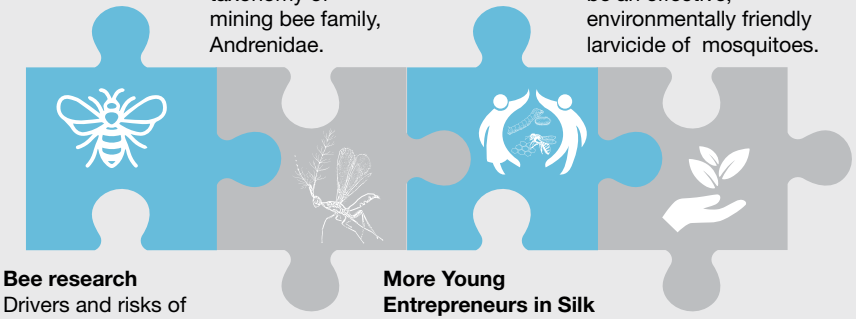
Donors: Bayer Bee Care, Germany; Biovision Foundation for Ecological Development, Switzerland; European Union; Federal Ministry for Economic Cooperation and Development (BMZ), Germany, through the Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ); Swiss National Science Foundation (SNSF); Fund for Scientific Research (FNRS), Belgium; German Science Foundation (DFG); International Fund for Agricultural Development (IFAD); JRS Biodiversity Foundation, USA; Kenya Agriculture and Livestock Research Organisation (KALRO); Mastercard Foundation; Nature Kenya; The Rockefeller Foundation; World Trade Organization (WTO) – Enhanced Integrated Framework (EIF); and Norwegian Agency for Development Cooperation (Norad).

A comprehensive list of partners is included in the annexes.

2021 IN BRIEF

Biosystematics
African weaver ants and their parasitoids; taxonomy of mining bee family, Andrenidae.

Bioprospecting
Emulsified formulation of *Ocimum kilimandscharicum* oil established to be an effective, environmentally friendly larvicide of mosquitoes.



Bee research
Drivers and risks of pollinator decline; knowledge on honey bees lineages in Comoros Islands; standards for stingless bees honey; superiority of stingless bees as greenhouse pollinators; first characterisation of the gut bacterial microbiota of African stingless bees.

More Young Entrepreneurs in Silk and Honey (MOYESH)
Strategic recruitment of partnering youth; gender equity in MOYESH; youth as business leaders; dynamism in job creation, enhancement of social capital, knowledge capital, finance and digital literacy; and advancement towards One Health hubs.

The stingless bee, *Meliponula bocandei*, collecting propolis and honey from a hive in a meliponiculture site at *icipe*.

Bee Research

Focus	Context	Progress in 2021	Way forward
Establish the drivers and risks associated with pollinator decline	Pollinator decline has attracted global attention, with substantial efforts being made to address this challenge through national pollinator strategies and action plans. These policies will be most effective if backed by knowledge on the drivers of pollinator decline and risks for society in various parts of the world.	***icipe* was part of a global team of pollination experts that reviewed the data and evidence for drivers of pollinator decline across six global regions.** Ten impacts of pollinator decline on human well-being were analysed. The drivers for regression in Africa were identified as: land cover and configuration; pesticide use; and climate change. However, there is not enough data to rank these three risk factors. The risks of pollinator decline for people (pollination deficits, wild pollinator diversity, yield instability, food system resilience) are higher in the global South.	Our results indicate that global policy responses should focus on **reducing pressure on land cover and configuration, land management and pesticides,** as these were considered important drivers in most regions.
Knowledge on honey bees lineages in the Comoros Islands	The honey bee, *A. mellifera*, is a globally distributed species that has spread both naturally and through human activity across the world resulting in many natural and secondary contact zones. The geographic isolation of honey bees is likely to contribute to genetic differentiation.	Our studies on wild honey bee populations in the Comoros Islands reveal **two coexisting mitochondrial lineages. One belongs to the typical African A-lineage. The second, which we have newly described, is the L-lineage closely related to *Apis koschevnikovi*, a honeybee species native to Southeast Asia.** It is possible that the Asian honey bee was transported from Southeast Asia to Madagascar and Comoros via human migrations 6,000 years ago. This species has hybridised with African honey bees at the nuclear genome, but its maternal ancestry can still be traced using the mitochondrial DNA markers.	This is the **first study to show the coexistence of the two honey bee mitochondrial haplotypes.** In all known cases, mitochondrial lineages replace indigenous bees that they encounter. The **findings are critical in conservation of bees and other pollinators** in the region and beyond. Also, this knowledge enhances our understanding on tackling invasive species amongst social insects.

Bee Research

Focus	Context	Progress in 2021	Way forward
Stingless bees species identity and harvesting methods	In Africa and other tropical regions, stingless bee honey is a premium product that has medicinal purposes. The quality of the honey varies, influenced by factors such as the bee species, ecosystems and processing methods. But there are inadequate assessments to link the quality characteristics of stingless bees honey and the influencing factors.	Through studies of six stingless bee species in Kakamega forest, Kenya, we established that the chemical composition and antiradical activity of honey significantly differed among the species. Harvesting methods, either by "punching holes" or "squeezing" did not influence the evaluated parameters. We observed a linkage between the antiradical activity and the phytochemicals (phenols and flavonoids) in the honey. Honey from *Liotrigona* sp. stingless bees exhibited the highest amounts of phenols, flavonoids and antiradical activity.	Our findings confirm the need to **establish separate standards for stingless bee honey** as it significantly varies from that by the African honey bee, *Apis mellifera,* in parameters such as moisture, free acidity, invertase, electrical conductivity and organic compounds. Also, there is need to establish **unique standards for honey from individual stingless bee species.**
Superiority of stingless bees as pollinators	Globally, there is a search for alternative indigenous pollinators, triggered by declines of honey bees and rapid expansion of protected cultivation of pollination dependent crops in greenhouses. In this quest, African stingless bees would be an effective option.	We demonstrated that **two *Meliponula* species that are endemic in Africa, *M. bocandei* and *M. ferruginea*, are superior pollinators of cucumber under greenhouse conditions.** They outperformed honey bees, with higher fruit volume, weight and seed number. *M. bocandei* is the most promising cucumber pollinator. Also, pollination by stingless bee species, *H. gribodoi*, *M. bocandei*, *M. lendliana* and *P. hildebrandti* results in uniform quality standards, roundness and ellipsoid ratios of sweet melon; as well as faster fruit maturation and higher seed counts compared to honey bee pollination.	Based on their superior pollination performance as well as their non-stinging nature, stingless bees are the most ideal pollinators in greenhouses. They are also more amenable for farmers. Also, the use of endemic stingless bee species for pollination may contribute to the conservation of the species in Africa.

Bee Research

Focus	Context	Progress in 2021	Way forward
First characterisation of the gut bacterial microbiota of African stingless bees	Beneficial microbes play a major role in insect host nutrition, detoxification, growth, activation of immune responses, and protection against pathogens. Previously, there has been no information on beneficial microbes in the gut of African stingless bee.	Our studies revealed the gut bacterial microbiota of eight stingless bee species from Africa. We found significant geographical and host intra-species-specific bacterial diversity. Each African stingless bee species have their own microbial composition with distinct dominant bacterial genus. This suggests host selective mechanisms among sympatric species and highlights host-microbe co-evolution and adaptation.	This study opens up research on the role of gut microbiota in the physiology, immune systems and behaviour of stingless bees in Africa and the tropics.

The mining bee, Andrena.

Biosystematics

Focus	Context	Progress in 2021	Way forward
Not so safe; African weaver ants and their recently discovered parasitoids	Aggressive weaver ant species (*Oecophylla longinoda*) are promoted for biological control of mango and cashew pests. Before 2020, parasitoids of the weaver ant were unknown in the Afrotropical region. That year, ***icipe* scientists discovered a cecidomyid fly as an endoparasitoid of the *Oecophylla*.** More detailed surveys at the south coast, Kenya revealed additional parasitoids.	*icipe* further surveys at the south coast, Kenya, revealed a second parasitoid species, a chalcidid pupae, within the abdomens of weaver ant workers. While clearly belonging to the Chalcididae, the specimens were different in morphological characters from other Afrotropical genera of the family. **We concluded that the pupae were Smicromorphinae, the first record of the subfamily from the Áfrotropics.** Details in the images of the pupae suggested that they represent an undescribed species. Molecular analysis by experts conducting DNA analysis using ultra-conserved elements, imply that the species represents a new genus.	Future work will focus on the **capture of adult parasitoids and the publication of the description of the species.** Because weaver ants are often used in the biological control of mango pests (particularly fruit flies), these parasitoids could influence the population dynamics of mango pest species. Monitoring the parasitisation rates of weaver ants will help to estimate the potential impact on their ability to control mango pests.
Phylogeny, biogeography and diversification of the mining bee family Andrenidae	The mining bees (Andrenidae) are a major bee family of over 3,000 described species with a nearly global distribution. They are a particularly significant component of northern temperate ecosystems and are critical pollinators in natural and agricultural settings. Mining bees belonging to genus Andrena are the second most species-rich genus of all bees. knowledge of the evolutionary history of Andrenidae is sparse.	*icipe* was part of a team of global taxonomic experts on Andrenidae, that developed a comprehensive genomic dataset of 195 species of Andrenidae, including all major lineages, to illuminate the evolutionary history of the family. The group found that **diversification rates of Andrenidae steeply increased over the past 15 million years, particularly in the genera Andrena and Perdita.**	There are only 14 species of *Andrena* known from Africa. An additional 18 species are known from the subfamily Panuginae, including *Mermiglossa,* Africa's only endemic andrenid genus. The limited sampling on Afrotropical Andrenidae from **our study has opened way for a comprehensive analysis of geo- and chrono- dispersal events of African andrenids.**

Bioprospecting

Focus	Context	Progress in 2021	Way forward
Expand the push-pull technology across Africa	*icipe*'s bioprospecting research aims to **discover, develop and commercialise natural products for pest and vector management** that are appropriate for use by rural communities. Central to this vision is the provision of new avenues for income generation by communities living adjacent to biodiversity-rich areas. One of *icipe*'s most outstanding bioprospecting initiatives is the development of a range of products from *Ocimum kilimandscharicum*, a plant of the mint family that is native to East Africa. Traditionally, the plant is used for various medicinal purposes, often harvested from forests. We have supported communities, especially around Kakamega Forest, Kenya, to domesticate the plant and to build thriving enterprises around it.	The development of products from *O. kilimandscharicum* is underpinned by scientific research, for example knowledge on the essential oils. We have **established an emulsified formulation of *O. kilimandscharicum* oil to be an effective, environmentally friendly larvicide of mosquitoes.** Under field conditions, the formulation, killed 98 percent of the larvae in 24 hours. When applied below sublethal doses (according to which standards?), the formulation caused malformation in the mosquito larva. The oil formulation is currently marketed as UZIMAX®.	The *O. kilimandscharicum* formulation is highly soluble on aqueous media; it is easy to produce, ecofriendly and affordable. Thus, there is **high potential to scale-up UZIMAX® including the cultivation and commercialisation of *O. kilimandscharicum.***

Young Entrepreneurs in Silk and Honey (YESH)


Sinore Solomon


Yenenesh Waketa


Alemnesh Shamana


Besufikad Hailu

The YESH project was implemented by icipe and the Mastercard Foundation in Ethiopia between 2015 and 2021. The project spawned jobs for 12,780 young men and women through honey and silk enterprises. A total of 1,060 youth business enterprises were established, and 121 tonnes of honey and 16 tonnes of silkworm cocoons were produced. Approximately USD 1.4 million was generated from beekeeping, silkworm farming and complementary side businesses.

Snapshot of YESH partners

It all starts with a silk moth! Sinore Solomon from Tadagi Sericulture YESH Enterprise in Mirab Abaya district, Southern Nations, Nationalities, and Peoples' Region, Ethiopia, knows this only too well.

In 2020, Yenenesh Waketa dropped out of university due to various circumstances. She returned home, in Chano Mille Village, Arba Minch, SNNPR, where she joined the YESH project. Yenenesh received support, including training, rearing inputs like feeding trays, plastic sheets, mountages to start silkworm rearing in a room in her house. In the first year she has produce around 20 kilogrammes of silk cocoons, inspiring her mother to join sericulture farming.

Alemnesh Shamana looks all set, with ready for sale balls of silk produced by Tadagi YESH Sericulture Enterprise, from Mirab Abaya district, Southern Nations, Nationalities, and Peoples' Region, Ethiopia.

Besufikad Hailu adorned in a silk scarf produced by Bere Sericulture Production PLC, a company founded by his father in 2004, which is based in Arba Minch, SNNPR, Ethiopia. The enterprise partnered with the YESH project, to produce high quality silk items for local and export markets. Besufikad is a Textile Engineering student at Bahir Dar University, Ethiopia. Alongside, he is leading the design and marketing arm of Bere Sericulture Plc, which uses locally obtained natural plants, as well as indigenous design and weaving skills.

More Young Entrepreneurs in Silk and Honey (MOYESH)

Focus	Context	Progress in 2021	Way forward
Strategic recruitment of partnering youth	The MOYESH project takes a very diverse approach in the recruitment of partnering youth. For example, we seek to engage not just unemployed youth, but those who are either underpaid or working as unpaid labour.	The total number of recruited youth stood at 42,467 (60 percent female), which is **43 percent of the total target of 100,000** for the entire lifetime of the project.	Across Ethiopia and indeed Africa, **youth unemployment remains a massive challenge that requires innovative approaches backed by strong, effective partnerships.** We will continue to work with private and public sector actors in the recruitment of deserving youth.
Enable more women to enter and thrive in the MOYESH project	The MOYESH project has set itself a **target where 60 percent of the partnering youth will be women.** But there are a number of challenges. Although Ethiopia has a long beekeeping tradition, this sector has historically not been considered a female occupation. Other barriers include cultural perceptions that create difficulties for women to join the labour market.	So far, we have **achieved our gender target, through several adjustments** in beekeeping technologies, for example more female-friendly apiary designs; and model female beekeepers to serve as an inspiration for others. Also women partners can choose the most convenient sites for their apiaries, for instance in their backyards, and work in all-female teams, should they so opt. Further, we have introduced child care facilities for nursing mothers to use during training and group work sessions. This enables the female partners to dedicate quality time to the training, and to have peace of mind that their children are being cared for close by.	We will continue to develop engendered processes in our activities. **Our thriving community of female youth partners is the best testament to MOYESH as an ideal platform for holisitic, gender inclusive development, and its transformative power on all segments of the community.**

More Young Entrepreneurs in Silk and Honey (MOYESH)

Focus	Context	Progress in 2021	Way forward
Enable MOYESH youth to become business leaders	The MOYESH project aims to transform partnering youth into successful entrepreneurs, by providing them with technical skills in beekeeping and silk farming; and in entrepreneurship.	In 2021, a total of 3,800 (38 percent female) youth partners, project and local extension teams were trained. Topics covered include gender in value chains; online data management systems; business development strategies (financial and marketing management); harvesting and postharvest handling of honey. The youth also received appropriate equipment for beekeeping and silk farming. This support has enabled the partnering youth to establish and run their own businesses. A total of 4,026 youth-led enterprises have been registered and they have been allocated land by local governments, to practice beekeeping, silkworm farming and complementary side businesses. The enterprises have produced 46 tonnes of honey and 60 kilogrammes of silkworm cocoons worth ETB 8.7 million (USD 170,000). The youth have earned a total of ETB 5.2 million (USD 27,500) from complementary side businesses.	The MOYESH project has brought a dynamic change in job creation. A major outcome is the enhancement of the social capital of partnering youth. Many of them testify that they have gained confidence in themselves, a 'can-do' attitude, as well as leadership skills. Their transformation has impacted other untargeted youth groups. We believe that the **MOYESH project provides a model that can be upscaled across Africa, in the goal of holistic and inclusive development.**

More Young Entrepreneurs in Silk and Honey (MOYESH)

Focus	Context	Progress in 2021	Way forward
Create knowledge capital across the value chains	Among the objectives of the MOYESH project are to strengthen the capacity of local institutions; establish strong private-public partnerships; and create opportunities for stakeholders, beyond the partnering youth, along honey and silk value chains.	By 2021, the MOYESH project had created employment for an estimated 4,760 people along the value chain. This is through the establishment of small and medium-sized enterprises (SMEs) to manufacture and supply beekeeping and sericulture inputs like frame beehives, protective clothing for beekeepers, silkworm rearing trays and cocoon mountages. This initiative is also providing insights into development models, for example, the value chain approach; socioeconomic information on behaviour change of partners, as well as knowledge capital. Overall, the MOYESH project has increased the number and diversity of partners collaborating with *icipe.* These include various agencies along the honey and silk value chain -- government, non-government, financial institutions, private sector actors and communities.	We foresee more opportunities to establish more SMEs that produce inputs like honey bee colonies and beeswax, and provide services such as product aggregation, value addition and practical training, thereby creating dignified jobs directly and indirectly.

More Young Entrepreneurs in Silk and Honey (MOYESH)

Focus	Context	Progress in 2021	Way forward
Bolster finance and digital literacy of partnering youth; market development; and financial inclusion in MOYESH	We aim to increase access of finance by the youth from the private sector; and create platforms for business to business (B2B), and marketing information services. We are also supporting construction of marketplaces that will serve as trading points and knowledge transfer hubs.	A major outcome of is a growing savings culture in the youth enterprises. By end of 2021, through various strategies, the youth enterprises had saved and deposited in banks a total of USD 936,000. This enabled them to obtain loans amounting to USD 93,000 from microfinance partners. We leveraged the capacity of partnering private banks to deliver loanable funds to our collaborating micro-finance institutions, to be accessed by youth enterprises at village level. We are also tapping into emerging opportunities for uncollaterilised loans through the micro-finance institutions.	We are working with stakeholders to **develop financial products that are accessible and specific to the MOYESH partners.**
Create One Health hubs	The MOYESH project is not only enabling partnering youth to engage beekeeping and silk farming, but to also become part of a thriving economy.	In addition to bees and silk products, the partnering youth have commenced sideline income-generating activities like vegetable farming, production of multipurpose tree seedlings and development of feedlots for meat animals. Indeed, the **enterprises have evolved into One Health hubs that amalgamate knowledge and technologies from the *icipe* 4H themes while also embracing novel, transformative elements.**	This evolution reveals the **MOYESH project as a model for disruptive development.** Our challenge and vision is to scale-up and to integrate systems thinking into our activities.

INSECTS FOR FOOD, FEED AND OTHER USES PROGRAMME

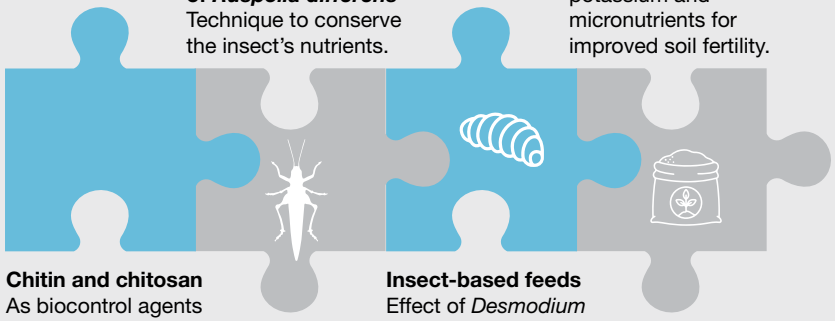
The *icipe* Insects for Food, Feed and Other Uses (INSEFF) programme aims to translate the latent benefits of insects in transforming the food system into a more sustainable and vibrant circular economy. Currently, much of our food system is wasteful, polluting or toxic; thus, impacting air, land and water. It contributes to about a quarter of global greenhouse gas emissions. The world uses about half of available land on Earth for food production and about 70 percent of the freshwater consumption is directed to agriculture. Insects have a better ecological footprint and lower greenhouse gas emissions. They are also an alternative, more affordable and nutritious source of food for people and livestock; are efficient in bioconverting waste; and are a basis of organic fertiliser and pest control products.

Donors: Australian Centre for International Agricultural Research (ACIAR) and International Development Research Centre (IDRC) through the Cultivate Africa's Future (CultiAF) programme; Bioinnovate Africa; Federal Agency for Food and Agriculture (BLE), Germany; Federal Ministry for Economic Cooperation and Development (BMZ), Germany, through the Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ); Danish International Development Agency (Danida); Netherlands Organization for Scientific Research (NWO); The Rockefeller Foundation; Norwegian Agency for Development Cooperation (Norad); UK's Foreign, Commonwealth and Development Office (FCDO); Scientific Cooperation Grant Initiative for Eastern Africa; Biotechnology and Biological Sciences Research Council, UK Research and Innovation (UKRI); World Bank.

2021 IN BRIEF

Blueprint for food biofortification through cricket-nutrients biofortified porridge.
Postharvest treatment of *Ruspolia differens*
Technique to conserve the insect's nutrients.

Frass fertiliser from insects
Eight insect species with adequate concentrations of nitrogen, phosphorus, potassium and micronutrients for improved soil fertility.



Chitin and chitosan
As biocontrol agents of bacterial wilt of tomato; and novel antimicrobials for superbugs.

Insect-based feeds
Effect of *Desmodium intortum* and black soldier fly larvae-based meal on broiler chicken meat

Consumers perception on eggs from hens fed with black soldier fly larvae meal-based feeds.

Scapsipedus icipe.

Widely farmed across Kenya, the cricket, *S. icipe*, was discovered by the Centre in 2018 as a new species in science. *icipe*'s studies have shown that the cricket is significantly rich in crude protein and fat, which, respectively, make up 57 percent and 36 percent of its dry body weight mass. The insect is also rich in essential amino acids, minerals and vitamins, with 88 percent of its nutrients being digestible by the human body. Often cultivated for its leaves or grains, amaranth is known for its high levels of vitamin C and pro-Vitamin A, as well iron, zinc and calcium. Its grains are also rich in protein, lysine (an essential amino acid) and calcium.

Insects for Food, Feed and Other Uses Programme

Focus	Context	Progress in 2021	Way forward
Cricket biofortified porridge	African porridge, which is made from cereal grains, is one of the most popular staple foods in Africa. Although the predominant African porridge cereals, like sorghum and finger millet, are rich in carbohydrates, they are extremely low in energy and nutrient densities. This is partly because they contain anti–nutrient compounds that block the absorption of certain essential nutrients in the body.	In a game-changer for nutritional security in Africa, *icipe* has used insect nutrients to transform African porridge from a basic, often low-nutrient meal, into a super-food that meets and exceeds micronutrient requirements for people. We fortified finger millet with high-quality nutrients from an edible African cricket known as *Scapsipedus icipe*; and the grain of amaranth, an indigenous vegetable that is widely grown across the continent. To counter the anti-nutrient factors in finger millet and amaranth, we tested several traditional grain processing techniques: sun drying, roasting, germination and fermentation. We found that the germination and fermentation techniques improve the availability of nutrients in the two grains. The result of is a flavour-full, fortified porridge flour that has twice as much protein, three to four times more crude fat and double the amount of iron and zinc. Depending on the processing technique, the cricket-fortified porridge contains up to 17 times more vitamin B5; almost one and a half times more vitamin B9; and twelve times more vitamin B12; than commercially available brands. The product also has the three essential omega-3 fatty acids.	The cricket-fortified porridge is nourishing, acceptable, appealing and accessible to a wide range of consumers. *icipe* has provided a model for harnessing indigenous resources in combination with scientifically validated processing methods, to address the malnutrition challenge, not just in Africa but in other low-and middle-income countries as well.

Insects for Food, Feed and Other Uses Programme

Focus	Context	Progress in 2021	Way forward
Postharvest treatment of the edible long-horned grasshopper, *Ruspolia differens*	The long-horned grasshopper, *R. differens,* is a tasty delicacy in over 20 African countries. The preparation methods of the insect, for example blanching, boiling, toasting and deep-frying, may affect the nutrients, total flavonoid content and sterols preservation in the insect's products.	A recent *icipe* study has demonstrated that deep-frying *R. differens* drastically reduces its crude protein, ash and fibre content. But blanching increased Omega-3, Omega-6 fatty acid and sterols, and flavonoids by two to three-folds. The iron and zinc content rose significantly in blanched and boiled products of *R. differens*.	These findings indicate that nutrients, total flavonoid content and sterols in *R. differens,* can be conserved through the blanching technique, which is also less expensive and time-consuming.
Test the effect of *Desmodium intortum* and black soldier fly larvae-based meal on broiler chicken meat	Over the past one decade, *icipe* and partners have promoted insect-based feeds for poultry rearing, leading to a thriving industry on the incorporation of such products as an alternative source of protein to fish and soybean meals in poultry farming. In broiler chickens, the impact has been demonstrated through increased yield, optimal growth performance and carcass quality and improve the sensory, physicochemical attributes of the meat.	We have established that broiler chickens fed on a diet that incorporates a combination of *Desmodium intortum* and black soldier fly larvae meal produce meat that is preferred by consumers for its flavour and tenderness, juiciness, colour, flavour, taste and overall acceptability. The fatty acid content is improved and the cholesterol profiles of the meats are reduced.	Further research will focus on feed modulation for broiler production in relation to consumers' preference and potential health benefits.

Insects for Food, Feed and Other Uses Programme

Focus	Context	Progress in 2021	Way forward
Consumers perception on eggs from hens fed commercial black soldier fly larvae meal-based feeds	In layer chicken, incorporation of insect-based meal in feed for improved nutrition, sustainable egg production and quality and profitability for farmers.	In a recent study, we found that 65 percent of the interviewed consumers are aware of the benefits of integrating insect protein in poultry feed. Over 70 percent of them showed preference and willingness to consume egg products from hens fed on diets that include black soldier larvae-based feeds. Perceived benefits, ethics and traceability are the key aspects that influence consumer intention to consume eggs.	These findings will enable us to continue to work with partners to increase awareness and evidence-based demonstrations of the benefits of insect-based feeds in poultry and other livestock. This will help to improve consumer perception and uptake, and pave way for further linkages between farmers, public private partners, policy makers and consumers.
Evaluate frass fertilizer from edible insects as a potential soil booster	Globally, there is growing interest in using insects to recycle organic waste into high-quality frass fertiliser, thus creating a circular economy approach. *icipe* research has demonstrated the superiority of frass fertilizer developed using black soldier larvae in improving crop yield and soil fertility. We are now conducting studies to identify other farmed insects that can used to develop high quality frass fertiliser.	Recent *icipe* studies have focused on eight insects: two crickets (*Gryllus bimaculatus* and *Scapsipedus icipe*); silk moth (*Bombyx mori*); edible saturniid caterpillar (*Gonimbrasia krucki*); mealworm (*Tenebrio molitor*); desert locust (*Schistocerca gregaria*); African fruit beetle (*Pachnoda sinuata*) and rhinoceros beetle (*Oryctes rhinoceros*). We confirmed that all these insect species have adequate concentrations of nitrogen, phosphorus, potassium and micronutrients for improved soil fertility.	Although the frass fertiliser obtained from the eight insects species showed medium to high phytotoxicity, it requires further composting to improve its maturity and stability. We will also conduct agronomic studies to establish the optimal amendment rates of the fertilisers to ensure high nutrient release and synchrony for crop uptake, improved yield, and nutritional quality of food crops.

Insects for Food, Feed and Other Uses Programme

Focus	Context	Progress in 2021	Way forward
Chitin and chitosan as biocontrol agents of bacterial wilt of tomato	Bacterial wilt, one of the major diseases of tomato and other solanaceous plants, is caused by *Ralstonia solanacearum* bacterium, one of the most damaging pathogens globally. The disease is difficult to control, and novel strategies are needed for its management. Chitin and chitosan, naturally occuring products in the skeletons of insects, are known to have the potential to control plant diseases.	Recent studies by *icipe* show that chitin and chitosan extracted from the husks of black soldier fly larvae, significantly inhibits the growth of *R. Solanacearum*. Soil amended with chitin and chitosan from the larvae reduced the incidence bacterial wilt disease by 30.3 percent and 34.9 percent, respectively. In inoculated plants, the two products diminished the severity of the disease by 22.6 percent and 23.7 percent.	We will continue studies to explore IPM options that include insect-based chitin and chitosan to manage the bacterial wilt of tomato disease. Also, these findings give value to black soldier fly larvae pupal shells, which are often discarded as waste.
Chitosan as novel antimicrobials for superbugs	Antimicrobials, which include antibiotics, antivirals, antifungals and antiparasitics, are medicines used to prevent and treat infections in people, animals and plants. Antimicrobial resistance is a rising challenge worldwide, with a growing list of so-called superbugs: strains of bacteria, viruses, parasites and fungi that are resistant to most available medications. This scenario has led to a global search for novel antimicrobials.	*icipe* has pioneered studies on chitosan extracted from black soldier fly pupal exuviae as a potential source of antimicrobials. We made the first report of chemical and biological extraction of chitin. Our findings demonstrate that chitosan from black soldier fly pupal exuviae is a promising and novel therapeutic agent. It inhibits the growth of several superbugs, including *Escherichia coli*, *Bacillus subtilis, Pseudomonas aeruginosa, Staphylococcus aureus*, and *Candida albicans*.	Further studies will investigate the mode of action of chitosan on various microbes. These results also show the high economic impact of chitin and chitosan extracted from black soldier fly pupal exuviae and their potential application in the pharmaceutical, food, cosmetics, textile, wastewater treatment, and agricultural sectors.

Ms Monica Nyakonyo, a member of Githunguri Youth Group, Kiambu County, Kenya, tending to black soldier fly larvae. The group is receiving training and support from *icipe* through the FAO youth capacity building programme on black soldier fly rearing and insect-based feed for poultry production.

SOCIAL SCIENCE AND IMPACT ASSESSMENT UNIT

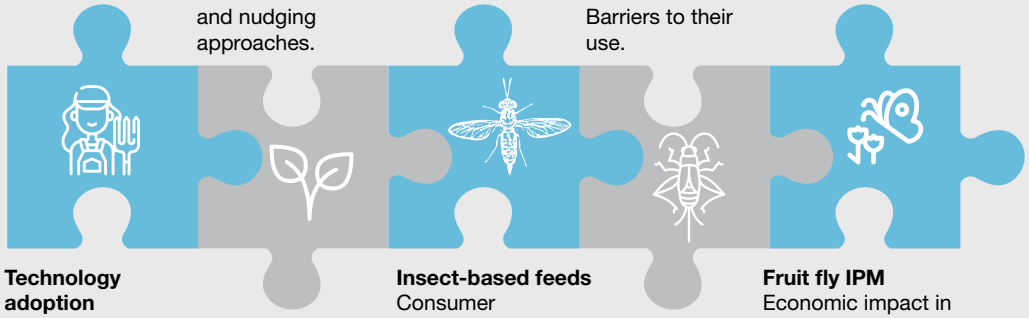
The *icipe* Social Sciences and Impact Assessment (SSIA) Unit focuses on generating evidence on the drivers of technology adoption, impact assessment, gender analysis, and scaling-up of strategies. The Unit also has the responsibility for implementing the *icipe* monitoring and evaluation, and gender strategies.

Donors: Australian Centre for International Agricultural Research (ACIAR); Bill & Melinda Gates Foundation (BMGF); BioInnovate Africa Programme; Biovision Foundation for Ecological Development, Switzerland; European Union; Federal Ministry for Economic Cooperation and Development (BMZ), Germany, through the Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ); German Research Foundation (DFG); Impaxio GmbH, Switzerland; International Development Research Centre (IDRC), Canada; Mastercard Foundation (MCF); National Research Fund (NRF), Kenya; Norwegian Agency for Development Cooperation (Norad); The Rockefeller Foundation; Tel Aviv University, Israel; United States Agency for International Development (USAID); University of Bern, Switzerland; and Wageningen University and Research Centre, The Netherlands.

2021 IN BRIEF

Disseminating agricultural innovations
Advantages of incentives and nudging approaches.

Insects as food
Barriers to their use.



Technology adoption and women empowerment
Increases in benefits for women and children through push-pull technology.

Insect-based feeds
Consumer perceptions on eggs produced using such products.

Fruit fly IPM
Economic impact in relation to production scales.

Pollinator-dependent crops and impact on nutritional security and poverty.

Social Science and Impact Assessment Unit

Focus	Context	Progress in 2021	Way forward
Impact of technology adoption on women empowerment	Considerable research has been conducted on why female farmers have lower technology adoption rates than male farmers. However, there are gaps in knowledge about what happens within a household after technology uptake.	**Using the *icipe* push-pull technology as a model, we investigated the intra-household distribution of benefits and costs of agricultural technology adoption in Kenya.** Through gender-disaggregated data, we found that adopting the push-pull technology increases consumption expenditure associated with female preferences and spending on children's education. Although less than for men, the accrued labour savings due to adoption of the technology by rural women may empower them through reduced workload, especially during weeding, ploughing and planting activities.	We intend to use this evidence to support scaling-up of the push-pull technology beyond Kenya.
Incentives and nudging and dissemination of information on agricultural innovations	Low technology adoption in developing countries is one of the constraining factors for agricultural productivity. One reason is the lack of information and appropriate scaling-up mechanisms. A typical approach to extension and scaling-up of technologies in many developing countries involves targeting and training lead (or model) farmers. The assumption is that these farmers will transfer knowledge to fellow farmers. But, teaching one's peers involves an opportunity cost that not all lead farmers are willing or able to incur.	We used a randomised control trial to study how incentives can be combined with a nudge (loss-framed messaging) to promote knowledge diffusion of the push-pull technology among farmers groups in Ethiopia. We provided incentives for group leaders to share knowledge with members through the conditional provision of material or social prestige rewards. **We found that incentives increase diffusion effort. Also, combining incentives with loss-framed messaging further boosts attempts.**	We aim to generate knowledge on the dynamic impact of these scaling-up strategies, their cost-effectiveness and replicability across different settings and countries.

Social Science and Impact Assessment Unit

Focus	Context	Progress in 2021	Way forward
Understand barriers to the use of insects as food	Insects are increasingly becoming valued as green, more affordable and nutritious sources of food for people. To translate this potential into reality, it is important to **understand factors that encourage or hinder entomophagy (eating of insects).**	*icipe* researchers analysed the role of psychological and cultural factors in entomophagy in western Kenya. We found that **psychological factors, such as social norms and perceived personal barriers,** affect the intention to eat insects. Also, **cultural factors** affect the decision on insects that are considered edible and affects the preference of insects for other sources of proteins.	This knowledge will facilitate design of effective campaign messages
Consumers perception and eggs production using an insect-based feeds	Increased demand for animal protein has motivated the search for more efficient livestock production systems. There has been growing interest in incorporating insect meal as an alternative source of protein to fish and soybean meal in chicken feed for improved nutrition, sustainability and animal welfare benefits. Black soldier fly larval-based feeds have been shown to increase egg production cost-effectively.	The *icipe* team conducted a study to understand the perceptions of poultry consumers towards the consumption of eggs from layers fed diet integrated with such products. About 65 percent of the consumers were aware of the benefits of integrating insect protein in poultry feed. Over 70 percent of the respondents showed preference and willingness to consume egg products produced using black soldier fly larval-based feeds. **Perceived benefits, ethics and traceability are the key aspects influencing intention to consume the eggs.** Consumer characteristics such as household size, gender, awareness of insects as feed, off-farm income, household income, buying place and access to credit were important factors driving the perceptions of consumers.	We recommend **increased efforts on awareness creation and evidence-based demonstration on the benefits of black soldier fly larval-based feeds in poultry production.** This will improve consumer perception and foster uptake of this rapidly growing and emerging technology.

Social Science and Impact Assessment Unit

Focus	Context	Progress in 2021	Way forward
Estimate economic impact of *icipe* fruit fly IPM packages in relation to production scales	The *icipe* IPM packages for control of fruit pests have been widely promoted across all scales of mango farmers. It is important to assess if all the different practices are equally profitable to all mango farmers.	We conducted a study to understand the heterogeneous impact of the *icipe* fruit fly IPM packages across small-, medium- and large-scale producers. Results showed that, while all the IPM practices reduce the quantity of mangoes damaged due to fruit flies, the **impact on net income is more pronounced among small- and medium-scale farmers.** The study also showed that all practices are profitable, but that orchard sanitation is only profitable to farmers with a minimum of 17 trees (or when farmers with fewer trees share the practice). We also found that most of the IPM practices are not profitable to very large farmers (those with more than 320 trees).	A study to understand barriers to adoption along the value chain is under way. **Further research is needed to understand why the fruit fly IPM packages are less profitable for the large-scale farmers.**
Assess the impact of pollinator-dependent crops on reducing nutrition poverty	Many developing countries promote a calorie economy, where cereal production dominates the cropping system, contributing to malnutrition. Less attention is given to fostering high-quality pollinator-dependent crops to reduce the huge economic cost of malnutrition in sub-Saharan Africa (SSA). We assessed the impact of pollinator-dependent crops in reducing nutrition deficiency using large data from four SSA countries.	We found that **increasing the proportion of pollinator-dependent crops cultivated area relative to pollinator-independent crops reduces the likelihood of nutrient deficiencies and increases household incomes.** The impact is non-linear, and benefits accrue only if the pollinator-dependent crop proportion is below a certain threshold. Our findings show that adjusting the existing cropping system and investing more in the production of pollinator-dependent crops can serve as a complementary pathway to nutrition security without economic trade-offs.	This information will be useful for policymakers and development partners towards making adjustments in existing cropping systems and investing in nutrient-dense crop production, as a pathway to close the micronutrient deficiency gap.

The streaky seedeater, *Crithagra striolata,* perched on a lantana shrub at the *icipe* Duduville Campus, Nairobi.

TECHNOLOGY TRANSFER UNIT

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

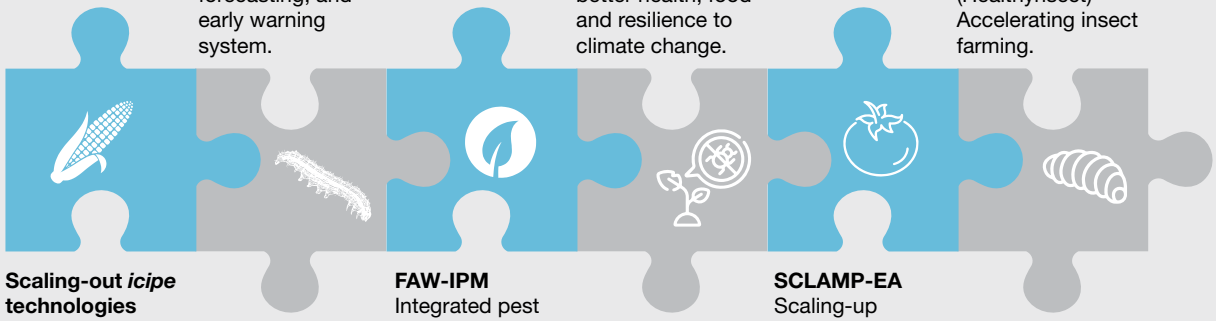
Donors: European Union; Bertha Foundation; Danish International Development Agency (DANIDA); Federal Ministry for Economic Cooperation and Development (BMZ), Germany, through the Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ); International Development Research Centre (IDRC), Canada; Norwegian Agency for Development Cooperation (Norad); UK's Foreign, Commonwealth & Development Office (FCDO); and United States Agency for International Development (USAID).

2021 IN BRIEF

CBFAMFEW II
Community-based fall armyworm monitoring, forecasting, and early warning system.

CAP-Africa
Combating arthropod pests for better health, food and resilience to climate change.

Insect Farming for Health and Livelihoods
(Healthynsect)
Accelerating insect farming.



Scaling-out *icipe* technologies
Focused on:
the push-pull technology;
management of the fall armyworm, fruit fly and *Tuta absoluta* pests.

FAW-IPM
Integrated pest management strategy to counter the threat of invasive fall armyworm to food security in eastern Africa.

SCLAMP-EA
Scaling-up climate-smart pest management approaches for enhanced maize and tomato systems productivity in eastern Africa.

Technology Transfer Unit

Project	Context	Progress in 2021	Way forward
Scale-out *icipe* technologies in Africa and beyond	*icipe* places great emphasis on the effective transfer of the Centre's technologies, by instituting strategies to translate research into tangible products; building indigenous capacity to use and adapt them to local conditions; and working with public and private partners to create relevant and effective value chains.	The Technology Transfer Unit (TTU) **increased efforts to the scale-up and scale-out *icipe* technologies in Eastern and Southern African regions.** We focused on: the push-pull technology; and the management of the fall armyworm, fruit fly and *Tuta absoluta* pests. We used multiple dissemination pathways: farmers exchange visits, field days, demonstrations, digital platforms, media and communications materials. We reached more than three million people.	We will continue to translate and package *icipe's* research knowledge, tools and technologies, and to diversify our dissemination pathways, to reach more end users more effectively.
Community-based Fall armyworm Monitoring, Forecasting, and Early Warning System (CBFAMFEW)	The CBFAMFEW project is an initiative coordinated by the Food and Agriculture Organization of the United Nations (FAO), with *icipe* and CABI as partners. The first phase was implemented from January 2018 – June 2019. The second phase, which commenced in 2022, focuses on Ethiopia, Uganda and Rwanda, aiming to strengthen community capacity, while also introducing actionable IPM options.	We produced several communication materials on fall armyworm occurrence, distribution and management. These materials were distributed in Malawi, Rwanda, Ethiopia, Uganda and Zambia. Tools, including mobile phones and their accessories, were provided to community members for data collection and field scouting of the pest. Pheromone trapping was conducted using the FAW Monitoring and Early Warning System (FAMEWS), a mobile application from FAO. Training of trainers (ToT) was undertaken in Ethiopia, Malawi, Rwanda, Uganda and Zambia, for 543 (172 female and 371 male), extension officers, research assistants, community focal persons. Collaboration agreements have been made with national agricultural research institutions.	Activities to **collate data for better fall armyworm predictions** are ongoing. We will partner with private sector actors to disseminate fall armyworm management tools. We will also **produce an analytical report on fall armyworm, since its arrival in Africa was first reported six years ago.** Also, we are conducting baseline surveys and studies to support the development of biopesticides and the search for more natural enemies of the fall armyworm.

Technology Transfer Unit

Project	Context	Progress in 2021	Way forward
Integrated pest management strategy to counter the threat of invasive fall armyworm to food security in Eastern Africa (FAW-IPM)	The FAW-IPM project aims to develop and scale-out IPM approaches for the fall armyworm. In the **immediate term, we are focusing on available IPM options; in the medium to long term, adaptive research is being conducted to generate Africa-specific solutions** for fall armyworm management.	More than 3,500 smallscale maize growers (70 percent female) and about 500 (45 percent female) technology disseminators have been trained on fall armyworm monitoring and management. Approximately three million people in Kenya, Ethiopia and Tanzania, Rwanda and Uganda, have been reached indirectly through the media and other outreach efforts. We have developed various digital materials, including a video series on fall armyworm IPM, which have been disseminated through various channels. We have also conducted awareness campaigns, in partnership with Biovision Africa Trust, including radio programmes reaching more than two million people. Farmer exposure and experience visits have also been conducted.	These activities will be enhanced in partnership with national agricultural institution and private sector partners. We will conduct on-farm validation and efficacy trials for emerging technologies for the management of the fall armyworm. **Multilocational demonstrations, and awareness creation for *icipe* biopesticides and use of natural enemies are planned.**
Combating Arthropod Pests for Better Health, Food and Resilience to Climate Change (CAP-Africa)	CAP-Africa focuses on: Global health – malaria and emerging infectious diseases (in Ethiopia and Kenya); climate change ecosystem services focusing on invasive species (in Kenya) and climate smart push-pull technology (in Kenya, Uganda and Tanzania).	We conducted eight training workshops in Kenya, Uganda, Tanzania and Ethiopia involving 289 stakeholders, including extension, policymakers and private sector. Representatives from 19 institutions, among them government, non-governmental and private sector partners were trained on the knowledge and transfer of various IPM and IVM technologies. We established nine technology learning sites in Kenya and Uganda, enabling us to conduct six field days; and train 2,083 farmers (1,045 females; 1,038 males) on fall armyworm management.	We will **use the training sites to build capacity of stakeholders and researchers using the One Health concept.**

Technology Transfer Unit

Project	Context	Progress in 2021	Way forward
Scaling-up Climate-Smart Pest Management Approaches for Enhanced Maize and Tomato Systems Productivity in Eastern Africa (SCLAMP-EA)	The SCLAMP-EA project aims to facilitate large-scale adoption of proven and piloted climate smart pest management technologies and practices by smallholder farmers, for key insect pests of maize and tomato.	The unit developed three manuals on the biology and management of fall armyworm and *Tuta absoluta*, and maize IPM, which were distributed to end-users.	We intend to organise training and digital scaling up of the technologies, as well as simplified methods to guide suitable for lead farmers and community focal persons.
Insect Farming for Health and Livelihoods (Healthynsect)	The overall aim of Healthynsect project is to generate new knowledge to accelerate insect farming and insect consumption in Africa for improved nutrition, health and livelihoods.	We developed a manual on cricket rearing, and a video series on black soldier fly, including: introduction; waste sourcing; bait preparation; larvae feeding; larvae harvesting; and frass fertilizer.	We will strengthen collaboration with partners in Kenya, Ghana and Uganda, and develop more dissemination pathways to promote healthy insect farmers.
African Association of Insect Scientists (AAIS)	The Technology Transfer Unit uses this platform for information sharing among scientists and practitioners, introduces new technologies or approaches for experience sharing and networking.	We conducted five lecture series to promote insect science and its application on the following topics: the science of neem; potential distribution of fall armyworm in Africa and beyond; harnessing butterflies for environmental and socioeconomic sustainability; end-to-end value chain of palm larvae in Ghana; and exploring behavioural complexities in honeybee colonies.	Inspired by the feedback from the association, we will continue to develop the forum as spaces for deliberation.
Knowledge Centre for Organic Agriculture in Africa (KCOA)	We are supporting the development and validation of products to expand access to knowledge on organic agriculture and agroecology. We are collecting, validating and converting the information into suitable formats and languages, as well as making it available on a centralised database.	We developed manuals on biological control of stemborers and fall armyworm, and on maize IPM, which were disseminated to partners.	We will develop methods guide for lead farmers and community focal persons.

The African Citril, *Crithagra citrinelloides* (Fringillidae: Passeriformes), female, perched on an Amaranthus plant at the *icipe* Duduville Campus, Nairobi.

DATA MANAGEMENT MODELLING AND GEO-INFORMATION UNIT

The *icipe* Data Management, Modelling and Geo-Information Unit was launched in 2019 as part of the Centre's efforts to boost capacity for the development of the next generation of decision-making tools, models, software and mobile phone applications for crop, pest and disease management. The goal is to integrate advanced data analytics and approaches (such as data and model fusion), to strengthen all *icipe*'s R&D activities.

Donors: Bill & Melinda Gates Foundation; BioInnovate Africa Programme; European Union; Federal Ministry for Economic Cooperation and Development (BMZ), Germany, through the Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ); International Development Research Centre (IDRC), Canada.

A comprehensive list of partners is included in the annexes.

2021 IN BRIEF

Instituting FAIR Data Principles
Enhance ability of machines to automatically find and use data.

Post-COVID-19 pandemic thinking
Generate decision making tools, models, software and mobile phone applications for crop, pest and disease management; modelling impact of pandemic on food supply chains.

Machine learning models
Integrate into insect morphometrics for insect identification.

Researcher's Manual
for Non-metric Multi-Dimensional Scaling with R, for analysis of volatile compounds from GC-MS.

Landscape characterisation
to understand pollinators and pests

Land-use and land-cover classifications
Adoption of Sentinel-2 satellite imagery recommended; maps generated, and ecological niche model to predict the suitable habitat of invasive fruit developed.

Desert locust breeding sites
Model to predict and assess damage developed.

Data Management Modelling and Geo-information Unit

Focus	Context	Progress in 2021	Way forward
Institute FAIR Data Principles	Across all its activities, *icipe* generates considerable amounts of data in various knowledge domains. It is important to consolidate this data for easy access by the Centre's teams and partners. Our goal is to institute FAIR Data Principles, to **enhance the ability of machines to automatically find and use data, and support its reuse by individuals.**	We developed a master data engineering and pipelines workflow in alignment to research data management and archival (RDMA) policy. We also set up various data management resources: the meta-data template (for collecting legacy data); data collectors (ODK, REDCap); source code sub-version platform; the data repository; and service request form.	We will **mainstream the RDMA policy implementation; and build the capacity of *icipe* teams to use it.** We will develop other modules and components and bridge the gap between the *icipe* ICT and DMMG units for efficiency and better coordination.
Use data science to assess COVID-19 pandemic impact	*icipe* is joining the African and global communities in contemplating the path beyond the COVID-19 pandemic. Among other contributions, we aim to **use our expertise in developing next generation decision making tools, models, software and mobile phone applications for crop, pest and disease management.** This expertise will allow us to design a "systems thinking" approach that captures diverse elements and components of the COVID-19 pandemic.	Our team estimated cases and fatalities due to the pandemic and the impact of governmental interventions in Burundi, Ethiopia, Kenya, Rwanda, South Sudan, Tanzania and Uganda, using time-series data collated from the repository of Johns Hopkins University, USA. We developed and validated an extended susceptible-infected-removed (e-SIR) compartmental model incorporating additional compartments on quarantine and vaccination. Thus, we were able to forecast the transmission dynamics of the epidemic based on the basic reproduction number. We also developed and validated a stochastic model using Bayesian approach to estimate the rates of transmission, the number of transmitters, and the number of infected people at a given time.	We are preparing a modelling protocol to assess the potential impact of environmental conditions on the transmission dynamics of the COVID-19 pandemic.

Focus	Context	Progress in 2021	Way forward
Machine learning models for insect morphometrics	Alongside DNA barcoding, analyses of landmark-based morphometric measurements on insects have been a useful taxonomic approach in insect identification. At *icipe*, statistic analyses have used traditional statistical methods and approaches. Advancements in computing power creates a paradigm shift to apply modern tools like machine learning.	We assessed predictive performance of four machine learning classifiers on fruit fly morphometrics and concluded that Support Vector Machine and Artificial Neural Network models are best in discriminating fruit fly species. These findings are useful for future studies in determining variables to be measured.	**We will integrate machine learning models for insect identification into insect morphometrics at *icipe*.** These algorithms could be used to develop an integrated and smart application software for insect discrimination and identification.
Researcher's Manual: Non-metric Multi-Dimensional Scaling with R: Analysis of Volatile Compounds from GC-MS	Volatile collection and characterisation using gas chromatography - mass spectrometer (GC-MS) is an important stage in understanding host - insect behavioural science. GC-MS results in large number of variables – chemical compounds identified and measured – which require appropriate multivariate techniques to mine and extract useful information.	A manual was developed to demonstrate a step-by step, rank-based technique called non-metric multi-dimensional scaling (NMDS) for analysis of such multivariate GC-MS data using R software.	The NMDS is already in use, and **the manual is available for public acess across the Centre.** We will also build the capacity of *icipe* postgraduate scholars to use this tool.
Landscape characterisation to understand pollinators and pests	A key aspect of the integrated pest and pollinator management (IPPM) project implemented recently by *icipe,* was the effort to understand the effect of landscapes, for example cropping patterns and farming systems, on pollinators and pests' distribution and densities.	Through mapping of vegetation productivity, landscape structure and cropping systems, combined with climatic indicators, **we developed a generalised model to predict the habitat suitability and density of avocado pests and pollinators.** We found that cropping patterns are the most influential variable in the distribution of avocado pests and pollinators.	The gauged parameters are generally difficult to measure. By testing and applying cross-cutting geospatial tools and techniques, **we have developed innovative methodologies to understand cropping patterns, farming systems and their impact on pests and pollinators.**

Focus	Context	Progress in 2021	Way forward
Modelling the impact of COVID-19 on food supply chains	Disruptions in the food supply chains caused by the COVID-19 pandemic have destabilised the balance between production, supply, transport, distribution and consumption, thus affecting food and nutritional security all over the world.	**We conceptualised a framework with several systemic properties: susceptible, exposed, infected, recovered and death (SEIRD), which we used to characterise the infectious component of the COVID-19 pandemic.** We applied causal loop and stock and flow diagrams, to map the links and interactions between variables from the contagion, health, and food supply chains of the entire system. We demonstrated the level of impact of COVID-19 pandemic to food and nutritional security in Eastern African countries (Burundi, Ethiopia, Kenya, South Sudan, Tanzania, Rwanda, and Uganda).	**We recommend a shift towards direct food supply from producers to consumers.** This will shorten the food supply chain, enhance food self-sufficiency and reduce severe disruptions on food and nutritional security. This will require collaborations among governments in food production innovations, and national and inter-regional trade, infrastructure and fully equipped food aggregation and commercialisation centres.
Predict potential fall armyworm invasion	The fall armyworm, *Spodoptera frugiperda,* was first reported in Africa in 2016 and it has since become established across the continent where it poses a serious threat to food and nutritional security. It is vital to assess the invasion threat of the pest, especially the risk of transient and permanent population establishment, in Africa under current and predicted future climates, considering irrigation patterns.	Our aim was to develop an ecological niche model at a regional scale to predict the distribution of the fall armyworm in Ethiopia, Kenya, Rwanda, Tanzania and Uganda. We re-parameterised the existing CLIMEX model, a computational tool for studying the effects of climatic conditions on species distribution and relative abundance. This approach resulted in **a systems thinking model on the interactions among fall armyworm, maize stemborers and parasitoids.** We also applied data science tools and algorithms. Our findings suggest that **the fall armyworm will retract its invasion from both northern and southern regions towards the equator. But a large area in eastern and central Africa will have an optimal climate for the pest's persistence.**	The **identified areas will serve as fall armyworm 'hotspots',** from where the pest may migrate to the north and south during cooler seasons. This knowledge will guide decision making for timely control of the fall armyworm.

Focus	Context	Progress in 2021	Way forward
Develop land-use and land-cover classifications	In Africa, knowledge on the structure of smallholder agroecological subzones and accurate land-use and land-cover classifications is needed, to design biodiversity and ecological conservation processes.	We have explored the use of multisource satellite datasets to map coffee-based landscapes in central Kenya. **We recommend adoption of Sentinel-2 satellite imagery, which are freely available, to support generation of information for land-use planning in smallholder agroecosystems.** We have conducted further land use/ land cover studies in Zambia, Zimbabwe and Malawi, where we generated various maps. We also developed an ecological niche model to predict the suitable habitat of invasive fruit flies in Zambia and produced a satellite-based model for mapping mango crop in Zimbabwe.	The information generated in these studies can guide stakeholders to manage coffee berry borer and the invasive fruit fly that attacks mango crop.
Predict desert locust breeding sites	Since late 2019, several eastern African countries, especially Ethiopia, Kenya and Somalia, have been devastated by catastrophic locust swarms, with adverse implications for livelihoods, food security, environment and socioeconomic development. Previously, using desert locust occurrence records and machine-learning algorithms, we have helped to predict potential breeding sites of the insect in East Africa using key bioclimatic (temperature and rainfall) and edaphic (sand and moisture contents) factors.	**We developed a model for predicting desert locust breeding grounds in the Sahel-Maghreb region in Northwest Africa.** We also created a model to assess damage caused by the insects in Kenya.	A **model to assess the effect of climate change on desert locust outbreak is under development.** The modelling routine will guide operations in desert locust surveillance and monitoring processes in recession areas.

CAPACITY BUILDING AND INSTITUTIONAL DEVELOPMENT PROGRAMME

Building the capacity of people and institutions to respond to arthropod-related developmental needs in Africa is a major commitment of *icipe*. This goal is achieved through: world-class postgraduate and postdoctoral training; nurturing and strengthening of African research and development organisations and institutions; dissemination of technologies to national agricultural and health research and extension systems.

Donors: Scholarships and fellowships are provided by: Scholarships and fellowships are provided by: German Academic Exchange Service (DAAD); Welcome Trust; THRiVE-2 Fellowships; Fogarty International Centre – NIH, USA, through the Eastern Africa Network of Bioinformatics Training (EANBiT) network; Norwegian Agency for Development Cooperation (Norad) through the Combatting Arthropod Pests for better Health, Food and Climate Resilience (CAP-Africa) project.

Further support for scholars, through *icipe* project funds from:
African Union; Agence Nationale de la Recherche (ANR), and HORTINET CI funded by PreSed/CI; African Development Bank, through Technologies for African Agricultural Transformation (TAAT); Bill & Melinda Gates Foundation; BioInnovate Africa Programme; Biovision Foundation for Ecological Development, Switzerland; European Union Horizon 2020 programme; European Union; Food and Agriculture Organization of the United Nations (FAO); French Agricultural Research Centre for International Development (CIRAD); French Development Agency (AFD); German Ministry of Economic Cooperation and Development (BMZ) through Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ); German Research Foundation (DFG); Good Venture Foundation; International Development Research Centre (IDRC); JRS Biodiversity Foundation; Kenya Medical Research Institute –Wellcome Trust Programme; Newton Fund; Norwegian Agency for Development Cooperation (Norad); The Rockefeller Foundation; Swedish Research Council; UK's Foreign, Commonwealth & Development Office (FCDO); United States Agency for International Development (USAID); United States Department of Agriculture – Agricultural Research Service (USDA-ARS); World Health Organization (WHO); World Health Organization/Regional Office for Africa (WHO-AFRO).

***icipe* core donors:** Swiss Agency for Development and Cooperation (SDC), Switzerland; Swedish International Development Cooperation Agency (Sida), Sweden; UK's Foreign, Commonwealth & Development Office (FCDO); Ministry of Education, State Department of University Education, Kenya; and Government of the Federal Democratic Republic of Ethiopia.

2021 IN BRIEF

Geographical representation
A total of 19 African countries and eight non-African are represented in the *icipe* capacity building programmes.

Awards, recognitions, grants and presentations
icipe scholars made 29 presentations at various fora. They received 15 external awards; 8 internal awards; and 2 grants.

Gender equity
Of the combined number of PhD and MSc scholars, and interns at *icipe*, 46 percent are women.

Postdoctoral and postgraduate training
A total of 257 fellows and scholars were undertaking their research at *icipe* in 2021.

Research and development impact
Of all journal articles published by *icipe,* 87 were lead-authored by postgraduate scholars; 11 by postdoctoral fellows. A total of 51 postgraduate scholars completed their studies, impacting on activities across the Centre's four themes.

Institutional strengthening
A total od 140 training events conducted, reaching 9,464 participants (48 percent women) from 30 African countries.

Eastern Africa Network for Bioinformatics Training (EANBiT)
Strengthening bioinformatics training in eastern Africa.

Capacity Building and Institutional Development Programme

Focus	Context	Progress in 2021	Way forward
Nurture and mentor young African scientists	The *icipe* postdoctoral fellowship programme provides opportunities for doctoral graduates to undertake research at *icipe* to develop their research skills and careers, and collaborative research programmes. The Centre's postgraduate training is conducted through the African Regional Postgraduate Programme in Insect Science (ARPPIS); and the Dissertation Research Internship Programme (DRIP); with support from German Academic Exchange Service (DAAD) and other donors. The *icipe* internship programme provides opportunities for hands-on professional skill development.	A total of 257 fellows and scholars were undertaking their research at *icipe*. They included 21 postdoctoral fellows; 59 PhD; 102 MSc students; and 75 research interns.	We are focused on the sustainability of the Centre's capacity building and institutional development programme, strengthening the relationship with our traditional donors while working towards attracting more donors, increasing the participation of women while also expanding collaboration to like-minded partners.

Focus	Context	Progress in 2021	Way forward
Foster research and development impact of *icipe* scholars	The postdoctoral fellows and postgraduate scholars are integrated into projects across the Centre. Their research extends from strategic basic research, technology development and validation, through community-based adoption. As a result, they make outstanding discoveries and contribute to the global knowledge hub, and also to sustainable development.	In 2021, of the 271 peer-reviewed journal articles published by *icipe,* 106 were lead-authored by postgraduate scholars; and 16 by postdoctoral fellows. A total of 51 *icipe* postgraduate scholars completed their studies, contributing knowledge on: control of the vectors of leishmaniasis, genetics of *Aedes aegypti* mosquitoes, host seeking behaviour of Anopheles mosquitoes, pest population dynamics, sand flies, surveillance of Afrotropical disease vectors, viral hemorrhagic fevers outbreaks, chemical analysis on organic micropollutants in water, human rhinovirus transmission pathway, human metapneumovirus and respiratory syncytial virus; epizootic and zoonotic pathogens in camel; management of fall armyworm, fruit flies, *Tuta absoluta*, tsetse flies and eastern Africa finger millet and the rice blasts; biosafety of mycopesticides on selected pollinators of avocado and cucurbits microbe-based strategies for bee health; locust mass culture, pesticide residues in edible insects, black soldier fly frass fertiliser, and cricket-based fish rearing.	We will **measure the socio-economic impact of the scholars' contribution to research and development,** modelled on previous tracer studies as graduants establish themselves in academia, research sector, government and industry.

Focus	Context	Progress in 2021	Way forward
Enhance geographical representation in the *icipe* capacity building programmes	As the only institution in Africa working primarily on insects and other arthropods, ***icipe* is committed to ensuring that as many as possible talented and interested young African scientists, from diverse regions of the continent benefit from the Centre's capacity building initiatives.** Moreover, *icipe* stands out as a model for insect science training, not just in Africa, but across the world.	Currently, a total of 19 African countries are represented in the *icipe* capacity building programmes: Benin, Burkina Faso, Cameroon, DRC, Ethiopia, Ghana, Kenya, Liberia, Malawi, Mali, Nigeria, Rwanda, South Africa, Sudan, Tanzania, Togo, Uganda, Zambia and Zimbabwe. Eight non-African countries are currently represented in *icipe* postgraduate and postdoctoral training programmes. They are: Belgium, Cambodia, Colombia, Costa Rica, Ecuador, Germany, The Netherlands and United States of America.	In recent years, concern has been raised about the global slump in certain fields of science, entomology included. *icipe* intends to **sustain its efforts in enhancing Africa's, and indeed global, entomological capacity.**
Pursuing gender equity	*icipe* recognises that holistic and inclusive development will not be possible without the participation of all sectors of communities. Thus, the Centre continues to **mainstream engendered approaches across all its activities, including in capacity building.**	Currently, **46 percent of the combined number of PhD and MSc scholars, and interns at *icipe* are women.** The breakdown of women representation by programme is: 33 percent of ARPPIS PhD scholars; 43 percent of DRIP PhD scholars; 46 percent of DRIP MSc scholars and 64 percent of interns. Among the postdoctoral fellows, 14 percent are women.	Gender equity will continue to be a key focus of the *icipe* capacity building activities.
Awards, recognitions, grants and presentations	The *icipe* capacity building programmes **pivot the young researchers, through world class training and skills, and also enables them to access the global reward system,** which includes resources, knowledge and recognition.	In 2021, *icipe* scholars made 29 presentations at various fora. They received 15 external awards; 8 internal awards; and 2 grants.	Boosting visibility of our scholars is important, and we will provide support and incentives for academic excellence, and competition for national, regional and global opportunities.

Focus	Context	Progress in 2021	Way forward
Institutional strengthening	The *icipe* capacity building activities include the enhancement of capabilities of end-user stakeholders to effectively adopt our technologies. The Centre conducts a range of courses, workshops and other training events for our teams, research and development collaborators, farmers and extension workers, among others. The training covers a range of activities, from basic strategic research, technology development and validation, and technology implementation and commercialisation.	In 2021, we conducted 140 training events, and reaching 9,464 participants (48 percent women) from 30 African countries: Benin, Botswana, Burkina Faso, Burundi, Cameroon, Chad, Comoros, Congo, C te d'Ivoire, Eritrea, Eswatini, Ethiopia, Ghana, Kenya, Liberia, Malawi, Mozambique, Namibia, Nigeria, Rwanda, Senegal, Seychelles, Somalia, South Sudan, Sudan, Tanzania, Togo, Uganda, Zambia and Zimbabwe. The trainings were held in 13 countries in Africa: Botswana, Comoros, Ethiopia, Eswatini, Kenya, Malawi, Mozambique, Namibia, Rwanda, Tanzania, Uganda, Zambia and Zimbabwe.	*icipe* will continue to structure the institutional strengthening activities, in tandem with the Centre's research and technology breakthroughs, local and regional developmental initiatives and aspirations, as well as emerging training strategies, especially in the digital space.

Focus	Context	Progress in 2021	Way forward
Strengthening bioinformatics training in eastern Africa	Through the Eastern Africa Network for Bioinformatics Training (EANBiT), *icipe* is also coordinating a network of three universities and four research institutes in Kenya, Tanzania and Uganda, established to **develop a critical mass of practitioners in these regions who can develop and use bioinformatics approaches to biosciences.**	Between 2018 and 2021, 44 MSc in Bioinformatics fellowships have been awarded in four cohorts from. From cohort one, all nine fellows have successfully defended their thesis; three are undertaking their PhD studies – at the University of Leicester, UK, the Swedish University of Agricultural Sciences and the Forschungszentrum Jülich, Germany. Three are working as Computational Biologists, at Glasgow University, Scotland, UK, University of Chicago and Uganda Virus Research Institute. From cohort two, one fellow is undertaking a PhD at the University of Bristol, UK, and two have received PhD fellowships to Oxford University, UK and University of Oldenburg, Germany. One fellow has received an offer from the International Sustainability Academy, Hamburg, Germany for a nine-month fellowship in 2022. One six weeks Bioinformatics Residential Training was conducted as a blended training (in-person and virtual), for a total of 14 participants.	In July 2022, EANBiT will conduct a blended Residential Training course. A Students' Symposium will be held as a side event of the Residential Training course, bringing together all EANBiT fellows, faculty members, Steering Committee, and the independent Scientific Advisory Board (iSAB). We expect cohort two and cohort three fellows to complete their studies.

The African yellow-warbler, *Iduna natalensis,* making a call to its mates in the evening, at the *icipe* Duduville campus.

BIOINNOVATE AFRICA PROGRAMME

In 2016, the Swedish International Development Cooperation Agency (Sida) and *icipe* reached an agreement for the Centre to host and manage the Bioresources Innovations Network for Eastern Africa Development (BioInnovate Africa) Programme, Phase II (2016–2021). One of Africa's largest regional science and innovation-driven initiatives, BioInnovate Africa was established in 2010 with support from Sida, its first phase running up to 2015. The Programme provides grants to enable scientists, researchers, innovators and entrepreneurs in eastern Africa (Burundi, Ethiopia, Kenya, Rwanda, Tanzania and Uganda), to work together to turn innovative ideas and technologies based on biological sciences into viable businesses.

Donors: Swedish International Development Cooperation Agency (Sida), Sweden.

A comprehensive list of partners is included in the annexes.

2021 IN BRIEF

Development of a bioeconomy in Africa
Efforts by BioInnovate Africa and partners help advance development of a bioeconomy in eastern Africa; to serve as a model for the rest of the continent.

Entrepreneurial capacity of partners
Bolstered through various strategies.

Commercial enterprises
Eight projects supported by BioInnovate Africa fully transition into commercial biobased enterprises.

Gender participation in the African bioeconomy
By 2021, 34 women fellows from the six partnering eastern African countries had undertaken fellowships through BioInnovate Africa.

Ms Ann Kitisya, Manager, Mimea International Kenya Ltd, inspects tissue culture blooms to develop virus free sweet potato vines, in a project supported by BioInnovate Africa Programme. Other partnering organisations in this initiative include: Makerere University, Uganda; Senai Farm Supplies Limited, Uganda; Jomo Kenyatta University of Agriculture and Technology, Kenya; Mikocheni Agricultural Research Institute, Tanzania; and Rwanda Agriculture Board.

BioInnovate Africa Programme

Focus	Context	Progress in 2021	Way forward
Transition of initiatives into commercial enterprises	BioInnovate Africa's ultimate goal is to move biobased research outputs and inventions along the innovation chain into the market. This process involves **supporting partners to generate visionary ideas, address bio-based barriers and risks, improve supply chains for raw materials, understand customer preferences, and develop competitive products and enterprises.**	**Eight projects supported by BioInnovate Africa fully transitioned into commercial biobased enterprises.** They will produce: virus free sweet potato vines using tissue culture; *Striga* tolerant maize and finger millet varieties; nitrogen enhanced biofertilizer from municipal waste; biofertilizers through waste vermicomposting; protein-rich feed supplements for fish and poultry; an integrated solution for industrial effluents management; bakery products enriched with orange-fleshed sweet potato puree; sorghum and millet nutrient dense instant flours and healthy honey toffees.	This progress is valuable for the advancement of biobased businesses in eastern Africa. It serves as an **inspiration and a model** for other BioInnovate Africa-supported initiatives. It offers **lessons learnt and best practices** on how to overcome complexities in the innovation chain, insights into opportunities and areas of advantage for African bioinnovators; all in support of a sustainable bioeconomy in Africa.
Strengthen entrepreneurial capacity of partners	Biobased enterprises require capacity strengthening, for example in business incubation especially during the critical stages of starting up their ventures. The incubation decreases the chances of a startup to fail, shortens the establishment process, and reduces the cost of establishing and growing the business. Entrepreneurs also need business acceleration support through mentors and investors, who help their enterprises to become stable, self-sufficient businesses.	BioInnovate Africa conducted a bioscience innovation bootcamp in partnership with Inclusive Business Sweden and Villgro Africa, early stage business incubators and impact investors. We held a biobusiness acceleration webinar on intellectual property in research and innovation in partnership with Growth Africa. With the Thayer School of Engineering, USA, we are building capacity for technoeconomic analysis (TEA) of innovation projects in eastern Africa. Eight students were trained and together with counterparts in the USA, they conducted a TEA on selected BioInnovate Africa-supported projects.	We will continue to bolster the biobased innovation capacity across Africa, and to support their translation into successful enterprises through a range of approaches.

Focus	Context	Progress in 2021	Way forward
Enhance gender participation in the African bioeconomy	In Africa, a critical factor for the development of a sustainable and resilient bioeconomy is that it should be holistic and inclusive, encompassing various sections of the community like the youth and women. Specifically, **women are custodians of biological resources in most of the Africa communities.** Therefore, it is important to increase their participation in bioinnovation and bioentreprenuership.	In 2019, BioInnovate Africa launched a **Women Scientists Fellowship, to provide opportunities for early and mid-career female researchers** to work with, and learn from the Programme's projects and networks in the region. By 2021, 34 women fellows from the six partnering eastern African countries, had undertaken training within the initiative. Their research areas included: phytomedicine/ biopharmaceuticals, food, feed and nutrition, biofuels, biopesticides, biofertilizers, industrial enzymes, insect-based proteins and bioeconomy policies.	BioInnovate Africa will continue to evolve the Women Scientists Fellowship initiative into a **regional network of women scientists and bioenterprenuers.**
Fostering the development of a sustainable bioeconomy in Africa	While funding bio-based innovation projects remains the core activity of BioInnovate Africa, the Programme's strategy also includes the development of a sustainable and circular bioeconomy in eastern Africa. This is built on the premise that Africa, with its rich biological diversity, and a relatively large proportion of arable land, is well positioned to tap into these opportunities, and build a competitive, sustainable bioeconomy.	BioInnovate Africa is partnering with the East African Science and Technology Commission (EASTECO), Stockholm Environment Institute (SEI)-Africa Centre, and Biosciences eastern and central Africa-International Livestock Research Institute (BecA-ILRI) Hub in a number of activities towards the development of a bioeconomy. In 2021, the partners convened the Second Eastern Africa Bioeconomy Conference, under the theme: "Building a Sustainable and Resilient African Bioeconomy." The forum brought together 625 regional, continental and global participants including policymakers, academia, scientists, innovators, funders, investors, business professionals and the media. It provided institutions to capitalise on advances and to address persisting challenges and risks in the development of a bioeconomy.	**Through the efforts of BioInnovate Africa and partners, the eastern Africa region is arguably the most advanced in the development of a bioeconomy in Africa.** This is evidenced by the completion of a regional bioeconomy strategy, partnerships among stakeholders and the evolution of the region's annual bioeconomy conference as one of the largest convenings on bioeconomy on the continent. As such, the eastern Africa can serve as a model for bioeconomy development across the continent.

Her Excellency Caroline Vicini, Swedish Ambassador to Kenya, delivering a keynote address at the second eastern Africa Bioeconomy Conference, held from 10 – 11 November 2021.

REGIONAL SCHOLARSHIP AND INNOVATION FUND

The Regional Scholarship and Innovation Fund (RSIF – www.rsif-paset.org), was launched in 2015 as the flagship programme of the Partnership for Skills in Applied Sciences, Engineering and Technology (PASET), an initiative established in 2013 by African governments and partners. As a competitive grants scheme, the mission of RSIF is to strengthen the institutional capacity for quality and sustainable doctoral training, research and innovation in sub-Saharan Africa in five priority thematic areas identified by PASET as strategic economic sectors for growth and development in Africa. In 2018, *icipe* was appointed as the Regional Coordination Unit (RCU) of RSIF.

Donors
Governments of Benin, Burkina Faso, Côte d'Ivoire, Ghana, Kenya, Mozambique, Rwanda and Senegal.

Further investments have been provided by the World Bank, Government of South Korea, and ACP Innovation Fund of the European Union through the Organisation of African, Caribbean and Pacific States (OACPS).

African Host Universities (AHUs): African University of Science and Technology, Nigeria; Bayero University Kano, Nigeria; Haramaya University, Ethiopia; Institut International d'Ingénierie de l'Eau et de l'Environnement (2iE), Burkina Faso; Kenyatta University, Kenya; Makerere University, Uganda; Sokoine University of Agriculture, Tanzania; Nelson Mandela African Institution of Science and Technology, Tanzania; Université d'Abomey-Calavi, Benin, Université Félix Houphouët-Boigny, Côte d'Ivoire; Université Gaston Berger, Senegal; University of Ghana; University of Nairobi, Kenya; University of Port Harcourt, Nigeria; and University of Rwanda.

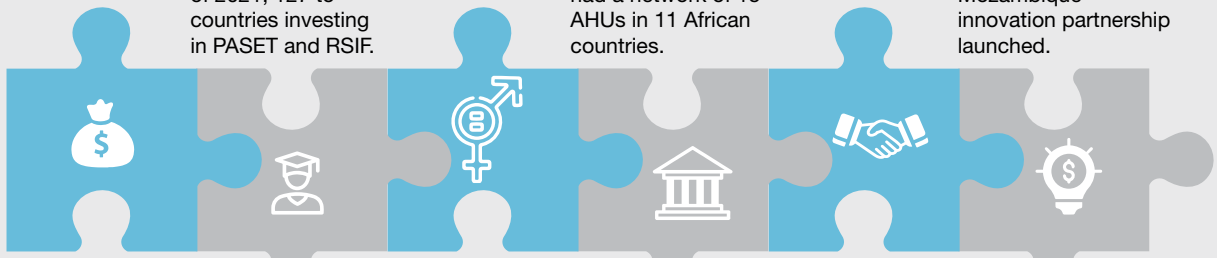
International Partner Institutions (IPIs): Ben-Gurion University of the Negev, Israel; Ghent University, Belgium; IMT Mines Albi, France; Institutes of Green-bio Science & Technology (GBST), South Korea; Institut de Recherche pour le Développement (IRD), France; International Cooperation Group of Brazilian Universities (GCUB), Brazil; International Livestock Research Institute (ILRI), Kenya; Karlsruhe Institute of Technology, Germany; Korea Institute of Energy Research (KIER), South Korea; Korea Institute of Science and Technology (KIST), South Korea; Korea Research Institute of Chemical Technology (KRICT), South Korea; Maastricht University, The Netherlands; Mohammed VI Polytechnic University (UM6P), Morocco; Seoul National University Global Research & Development and Business Center (GRC), South Korea; Télécom SudParis, France; University of Greenwich, Natural Resources Institute, UK; University of Lisbon, Portugal; University of Michigan, USA; University of Pretoria, South Africa; Virginia Tech College of Agriculture and Life Sciences, USA; Worcester Polytechnic Institute (WPI), USA.

2021 IN BRIEF

RSIF scholarships
A total of 2,000 applications received in 2021; cumulatively, 184 scholarships awarded by end of 2021; 127 to countries investing in PASET and RSIF.

African Host Universities (AHUs)
As of 2021, RSIF had a network of 15 AHUs in 11 African countries.

Research and innovation
A total of 27 research and innovation grants; Research Award Grants for RSIF PhD graduates established; RSIF-Mozambique innovation partnership launched.



Resource mobilization
A total of 9 African governments; the World Bank, Government of Korea, and the Organisation of African, Caribbean and Pacific States (OACPS), through the European Union; Nestlé South Africa, Samsung Dream Scholarship Foundation, among others, investing in RSIF.

Gender diversity
Currently, 38 percent (a total of 66 scholars) of the 173 RSIF scholars are women.

International partner institutions (IPIs)
As of 2021, RSIF had 21 IPIs, three in African countries and the rest spread in Europe, America and Asia.

Regional Scholarship and Innovation Fund

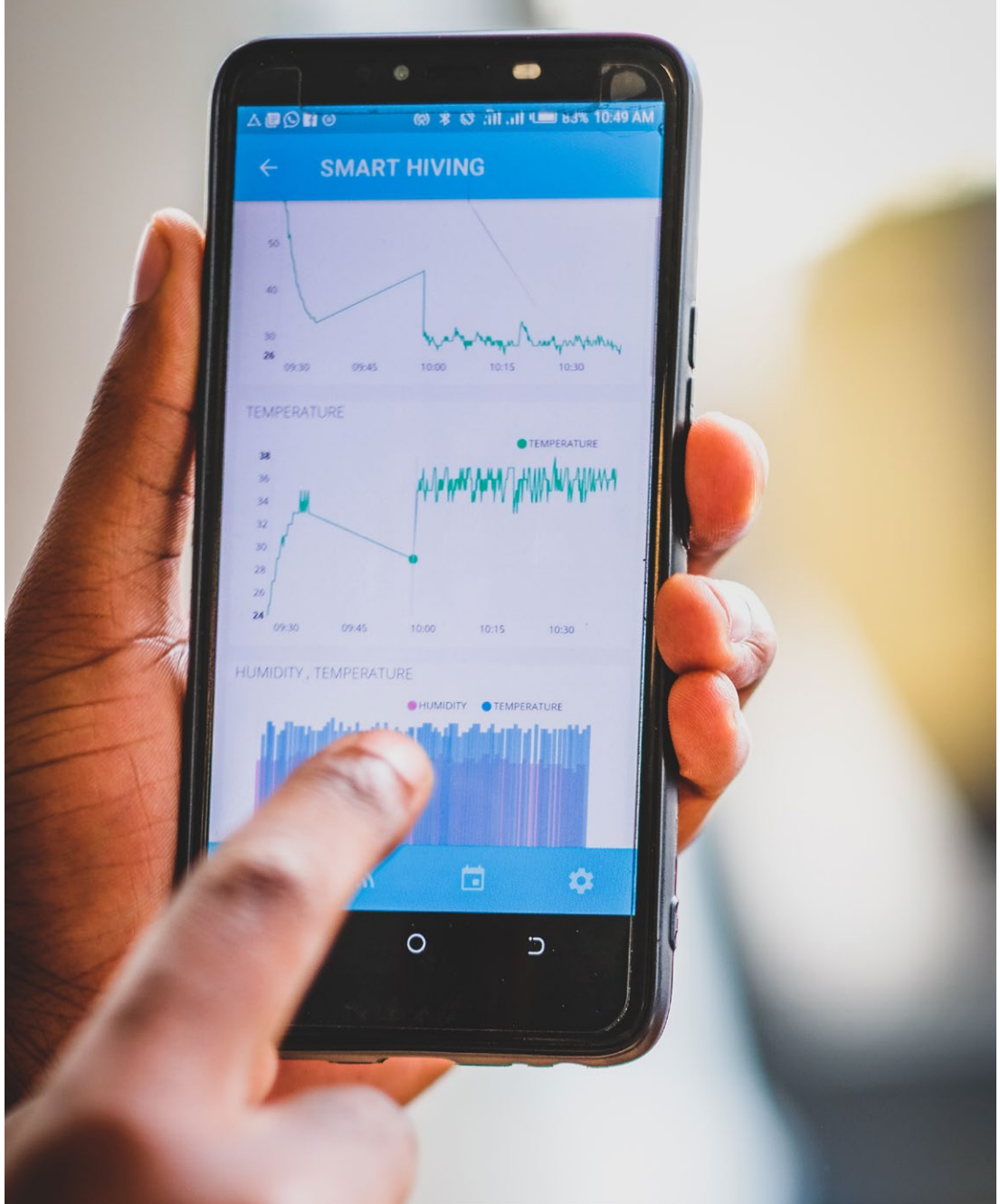
Focus	Context	Progress in 2021	Way forward
Foster RSIF as a sustainable pan-African science fund	Over the past two years, **RSIF has gained incredible momentum with rapid evidence of the Fund as an outstanding platform for socio-economic transformation in Africa for example by embracing the fourth industrial revolution.** Indeed, many stakeholders are appreciating RSIF as an effective channel for resources to achieve continental visions and agendas, as well as acceleration of the sustainable development goals (SDGs).	The most significant outcome of the appreciation of RSIF is growing support by African governments. By end of 2021, the governments of Benin, Burkina Faso, Côte d'Ivoire, Ghana, Kenya, Mozambique, Nigeria, Rwanda and Senegal had committed investments in RSIF. In addition, the Government of Korea, the World Bank, and the Organisation of African, Caribbean and Pacific States (OACPS), through the European Union, are supporting RSIF. Private sector partners including Nestlé, South Africa; and the Samsung Dream Scholarship Foundation, who are also financing various aspects like research activities. Several other private sector partners are involved in collaborative research activities to co-create knowledge related to their for-profit activities. We have also completed the feasibility study for establishment of the RSIF permanent fund, including a fundraising strategy and implementation plan.	In 2022, we plan to hold a series of strategic events, underpinned by communication and marketing activities to support resource mobilisation. A technical advisory group on the establishment of the RSIF endowment fund will be set up.

(Left – right): Linda Bih Numfor (Cameroon) and Ruth Lorivi Moirana (Tanzania), are both RSIF PhD scholars at the Nelson Mandela African Institution of Science and Technology, Tanzania. Linda's research is on heavy metal removal in biowaste material, while Ruth is investigating ways to detect contaminants, like fluoride, in the soil and their impact on crop yield.

Focus	Context	Progress in 2021	Way forward
Increase interest and inclusivity in RSIF scholarships	The goal of RSIF is to **attract the best and brightest talent from across Africa, ensuring geographic and thematic representation.** Thus, we have made several improvements in the RSIF Scholarship Calls, including dissemination strategies.	The growing interest in RSIF scholarships is evidenced by the soaring number of applicants. For example, in the 2021 call, we received close to 2,000 applications. The number of RSIF scholars has risen rapidly, with 184 scholarships awarded by end of 2021. Of these scholarships, 127 have gone to countries investing in PASET and RSIF, while the rest have been allocated to other African countries, with geographical diversity across sub-Saharan Africa.	We will continue to implement strategies to enhance geographic and thematic representation in RSIF.
Achieve gender diversity in RSIF	In Africa, women constitute 30 percent of researchers in science fields, about the same as the global average of 28 percent. Still, this means that only a fraction of women's potential contribution to science and technology is currently being harnessed. Therefore, the issue of gender is very central to PASET and to RSIF.	Currently, 39 percent (a total of 72 scholars) of the 184 RSIF scholars are women. This is good progress, but we keep aiming higher. **RSIF appreciates that achieving gender equity requires a holistic approach that brings together numerous actors.**	We have recently published a study titled 'Making it to the PhD: Gender and Student Performance in Sub-Saharan Africa', which illuminates obstacles and opportunities in higher learning. These findings will inform the RSIF gender strategy while also supporting efforts of likeminded stakeholders and opening up avenues for collaboration.

Focus	Context	Progress in 2021	Way forward
Strengthen RSIF's unique training model	RSIF has **a unique approach that combines intra-Africa exchange and international training.** The Fund incorporates a network of African Host Universities (AHUs); competitively and rigorously selected universities that offer a PhD programme in any one of RSIF's thematic areas. RSIF also has a network of international partner institutions (IPIs) – globally recognised universities, research institutes, public and private companies.	The RSIF hybrid model takes scholars from their home countries to an AHU where they are initiated into research working directly on challenges facing the continent. The scholars then proceed to an IPI for sandwich placements where they have access to state-of-the-art research and training facilities, advance their scientific skills, broaden international networks, and strengthen industry linkages, among other outcomes. **As of 2021, RSIF had a network of 15 AHUs in 11 African countries and 21 IPIs, three in African countries and the rest spread in Europe, America and Asia.**	Based on the importance of the sandwich model, we intend to **extend our network of IPIs,** especially those with a strong culture of research to innovation.
Boost knowledge generation and thought leadership through RSIF	One of RSIF's goals is to contribute to the mentoring and nurturing of doctoral students. This enables them to not only complete their programmes, but to do so with **excellent research that augments the global knowledge hub and impacts regional and global thinking on key developmental issues.**	We conduct a series of **skills strengthening trainings and events for the RSIF scholars.** The monthly RSIF student seminars enable them to make presentations and obtain feedback on their projects from experienced researchers. The guest webinars have evolved into **think spaces that attract distinguished speakers** like Prof Donna Strickland, Nobel Prize in Physics 2018 winner; Dr Codou Diaw, Lead, Education, at the Mastercard Foundation; and Aicha Evans, Chief Executive Officer, ZOOX, a US based driverless car company. By the end of 2021, RSIF scholars had authored 64 peer reviewed journal articles.	These trainings and webinars are a suitable platform for nurturing and establishing academic and career mentoring initiatives and will be explored further as drivers for career development. RSIF scholars will be linked with a mentorship platform that is being developed.

Focus	Context	Progress in 2021	Way forward
Boost research and innovation excellence in AHUs	One of RSIF's key goals is to promote research excellence, as well as capacity for innovation and entrepreneurship in Africa, by providing grants to faculty in AHUs to implement projects aligned to the PASET Priority thematic areas.	A total of 27 research and innovation grants have so far been awarded to faculty in AHUs. Of these, 16 grants are targeted at developmental issues. Three prototypes have been developed: one is for drying fruits and vegetables using solar heater. The other two are Internet of Things (IoT) devices, to assess indoor air pollution; and to monitor bee hives using smart technology. Six AHUs are receiving support to strengthen innovation ecosystems through the Institutional Capacity Building Program Grants. Five innovative projects are developing prototypes and business plans for commercialisation through the Cooperability Grants.	We intend to increase efforts to enable more female scientists access research and innovation opportunities within RSIF, for example through partnerships with AHUs leadership. Within the pan-African vision of RSIF, we recognise the need to create synergies among organisations, initiatives, sectors and researchers. This will be a key goal as it will lead to stronger research networks and innovation capacity across the continent.
Support RSIF PhD graduates to launch research careers	RSIF focuses on strengthening doctoral training in applied sciences, engineering and technology (ASET) through a virtuous cycle that will lead to increased, and more qualified PhD faculty capacity, able to undertake high quality and impactful research and innovation; and to mentor and nurture doctoral students.	Towards this goal, RSIF has launched a Junior Investigator **Research Award Grants for RSIF PhD graduates who obtain employment and postdoctoral positions in universities and research institutions in Africa.** A total of 10 grants of up to USD 800,000 are available, targeting the first cohort of RSIF scholars.	Our aim is to enable applicants to prepare high quality proposals, for example through support and linkages with international partners and regular online events.
RSIF-Mozambique innovation partnership	RSIF is rapidly gaining acceptance among African countries, as an important actor in national development. In 2021, the government of Mozambique channelled funds from its World Bank-funded project on Improvement for Skills (MozSkills) into RSIF.	In the first Call for Proposals; seven projects in Mozambique are receiving support for research and initiatives that include commercialisation of bio energy digester. Two universities are being funded to strengthen their innovation environments through the Institutional Capacity Building Program Grants.	Awarded grants will receive technical support during implementation including knowledge sharing with existing opportunities with on-going projects by AHUs.



The Smart Bees Hiving Technology, being developed through an RSIF research and innovation grant.

Its development is being led by University of Rwanda. Collaborating partners are: Narada Electronics Ltd and Seed Technology Engineering and Science Group both in Rwanda; University of Malawi; Copperbelt University, Zambia; and Sodertorn University, Sweden.

The technology will help to monitor an entire range of parameters on the conditions that negatively impact the life cycle and functions of bees. The tool will increase efficiency in managing beekeeping and forestation, and also increase the viability of the industry. It will also boost smart bee farming and entrepreneurship.

2021, 2020 AND 2019 FINANCIAL STATEMENTS

Statement of Financial Position

DESCRIPTION	2021 "USD 000"	2020 "USD 000"	2019 USD "000"
Non-Current Assets	8,270	9,087	9,830
Current Assets	62,337	41,664	42,656
Total Assets	70,607	50,751	52,486
Liabilities	46,583	26,704	29,087
Total Assets less Total Liabilities	**24,024**	**24,047**	**23,399**
Financed By:			
Capital Fund and Reserves	**24,024**	**24,047**	**23,399**

Statement of Comprehensive Income & Activities

DESCRIPTION	2021 "USD 000"	2020 "USD 000"	2019 "USD 000"
Income			
Unrestricted Grants	3,592	4,977	4,320
Restricted Grants	32,150	25,128	24,959
Other	2,164	2,107	2,441
Total Income	**37,906**	**32,212**	**31,720**
Appropriation			
Research	34,219	27,630	26,501
Institutional	5,649	5,929	6,267
Overheads	(2,491)	(1,859)	(1,563)
Transfer to Reserves	**529**	**512**	**515**
Total Appropriations	**37,906**	**32,212**	**31,720**

Note: The detailed Financial statements are available at www.icipe.org

Annexes

Annex A: Awards

Centre-wide recognition

In celebration of its 10-year anniversary, Ohio State University Global One Health initiative (GOHi) has selected *icipe* as one of its key partners.

External awards to staff

Five current scientists and one former *icipe* researcher are in the "World Ranking of Top 2% Scientists" list. Created by Stanford University, the list identifies the top scholars in their own areas of specialty and the frequency with which their publications are cited by other authors around the globe. The scientists are: **Dr Sunday Ekesi**, Director of Research and Partnerships; **Prof. Baldwyn Torto**, Head, Behavioural and Chemical Ecology Unit; **Prof. Zeyaur Khan**, Leader, Push-Pull Integrated Pest Management Programme; **Dr Menale Kassie**, Head, Social Sciences and Impact Assessment Unit; **Dr Tadele Tefera**, Head, *icipe* Ethiopia Office and **Dr Jean Maniania**, former Head, *icipe* Arthropod Pathology Unit.

icipe **Director General, Dr Segenet Kelemu** has been selected as a member of the Scientific Board of the International Basic Science Programme (IBSP), the only international forum in the United Nations that makes recommendations to the Director-General of UNESCO and its Member States on the global situation of the basic sciences. Dr Kelemu was also recognised among brilliant women breaking barriers, improving global health, and inspiring others to pursue careers in science, a 'modern Marie Curie', by The Borgen Project, in honour of International Women and Girls in Science Day and International Women's Day, 2021.

Dr Ekesi was selected as a Fellow of the Entomological Society of America (ESA), the largest organisation in the world serving the professional and scientific needs of entomologists and individuals in related disciplines. He also received the Distinguished Scientist Award, one of four awards given annually by the ESA International Branches.

Dr Kassie was ranked among the top 5 percent authors in the field of Economics in IDEAS. **Dr Henri Tonnang**, Head, Data Management, Modelling and Geo-information Unit, has been nominated by the Director General of UNESCO as a member of the Advisory Committee in Open Science.

Dr Jeremy Herren, scientist and leader of the *icipe* SymbioVector Project, has been selected as one of ten winners of the Falling Walls 2021, in the Life Sciences category. He spearheads the research that has discovered a microbe in malaria-transmitting mosquitoes, that can block transmission of the disease's parasites from the insects to people.

Dr Clifford Mutero, Consultant Scientist, Human Health Theme was appointed by the Principal Secretary, Kenya Ministry of Health to a 10-member Kenya-Cuba Malaria Vector Control Task Force.

Dr Joel Bargul, Postdoctoral Fellow, Animal Health, was ranked in first place (Partners only category) in the ILRI CapDev Grand Challenge, a vibrant contest where young and upcoming livestock researchers made exciting pitches on their research, to engage with donors and policymakers.

A paper co-authored by **Dr Robert Copeland,** Biosystematics Unit, won the Science Achievement Award of the United States National Museum of Natural History (NMNH), Smithsonian Institution's 2020 committee.

External awards to scholars

Stella Muthoni Gachoki (PhD scholar), has received a grant from the Royal Netherlands Academy of Arts and Sciences (KNAW) to support her research on the transferability of *Glossina pallidipes* occurrence models beyond Shimba Hills National Reserve, Kenya.

Kavengi Kitonga, Ruth Kihika, Maysoon Omar and Trizah Milugo (PhD scholars) were selected to participate in the inaugural Mawazo Learning Exchange (MLEx) Fellowship Programme, to receive training, mentorship and networking with national, regional and international researchers and experts.

On 20 August 2021, World Mosquito Day, **Trizah Koyi Milugo** (PhD scholar, BCEU), was featured in a blog on Frontiers Science News, on her research that aims to contribute to the development of novel tool for controlling malaria transmission.

Ruth Najala (Fellow, Eastern Africa Network of Bioinformatics Training – EANBiT), was the winner of the speed presentations category at the 17th meeting of the H3Africa Consortium held in April 2021.

Three *icipe*-affiliated female students: **Sylvia Wairimu Maina** (Kenya); **Susan Ojochide** (Nigeria); and **Fatoumata Thiam** (Senegal); all scholars of the Regional Scholarship and Innovation Fund (RSIF); were featured by the United Nations Economic Commission for Africa (ECA), under the banner: International Women's Day 2021: Future Women Leaders.

Bester Mudereri (Zimbabwe), a PhD scholar within the Push-Pull for sub-Saharan Africa project, funded by Biovision Foundation for Ecological Development, Switzerland, received the best PhD award in the University of the Western Cape for the 2020–2021 academic year.

Mukundi Mukundamago (South Africa), ARPPIS PhD scholar was nominated as an Africademics Scholarships Ambassador.

Three members of the Nematology Research Group won awards during the Horticultural Association of Kenya workshop (29 November – 3 December 2021): **James Kisaakye**, Best Oral presentation (Endophytic non-pathogenic *Fusarium Oxysporum* improves banana); **Calvince Orange**, Best Poster presentation (Assessment of cv. Shangi-like potato lines with potato cyst nematode resistance – PCN); and **Ivy Nyambura**, First-runner up, poster presentation (Biological control of PCN using banana fibre paper).

Journal appointments

Dr Menale Kassie, Head, Social Science and Impact Assessment Unit: Member, Editorial Board to manage the Insect Economics section, *Frontiers in Insect Science*.

Dr Michael Lattorff, Senior Scientist, Bee Research Programme: Managing Editor, International Journal of Tropical Insect Science Associate; and as Editor; (Insect Health and Pathology section), *Frontiers in Insect Science*.

Dr Henri Tonnang, Head Data Management, Modelling and Geo-information (DMMG) Unit: Associate Editor, *Frontiers in Tropical Diseases.*

Dr Elfatih M. Abdel-Rahman, Scientist, DMMG Unit: Guest Editor, Special Issue on 'Environmental Sustainability with Remote Sensing in Africa', *ISPRS Journal of Photogrammetry and Remote Sensing.*
Dr David Tchouassi, Scientist, Behavioural and Chemical Ecology Unit: Editor, Vectors and medical and veterinary entomology section of *Current Opinion in Insect Science* (Vol. 52).

Amanuel Tamiru, Scientist, Plant Health Theme: Associate Editor, *Physiological Entomology of the Royal Entomological Society.*
Dr Saliou Niassy, Head, Technology Transfer Unit; and **Dr James Egonyu,** Scientist, Insects for Food and Feed and other uses programme: Guest Editors of a Special Issue on Advances in Insects for Food and Feed, in the *International Journal of Tropical Insect Science*.

Dr Beatrice Muriithi, Postdoctoral Fellow, Social Sciences and Impact Assessment Unit: Member of the Editorial Board, *African Journal of Agricultural and Resource Economics* (AfJARE)/*Journal Africain d'Economie Agricole et des Ressources* (JAEAR).
Dr Komivi Akutse, Scientist, Plant Health Theme: Member, Scientific Advisory Board of the *Journal of Applied Entomology*.

Internal staff awards

Outstanding Employee of the Year (2021)
Dr Julius Ecuru

Outstanding Employee of the Year (2021)
Mr Jimmy Pittchar

Outstanding Professional Scientist of the Year (2021)
Dr Workneh Ayalew

Outstanding Support Staff of the Year (2021)
Ms Faith Nyamu Wamurango

Outstanding Publication of the Year (2021)
Mitogenomic analysis of diversity of key whitefly pests in Kenya and its implication to their sustainable management. *Scientific Reports* 11, 6348. Khamis F.M., Ombura F.L., Ajene I. J., Akutse K.S., Subramanian S., Mohamed S., Dubois T., Tanga C. and Ekesi S. (2021) https://www.nature.com/articles/s41598-021-85902-2

Outstanding Partner of the Year (2021)
Mastercard Foundation

Outstanding Team of the Year (2021)
Institutional Occupational Health and Safety Committee members
Jimmy Pittchar, Scientist Plant Health Theme and ITOC Station Administrative Coordinator (Chair); Nelson Suchi, Facilities and Assets Manager (Secretary); Marita Dieling, Manager People and Organisation Development; Baldwyn Torto, Principal Scientist, Behavioural and Chemical Ecology Unit; Franceen Amutallah, Guest House Manager; Moses Ndotono, Laboratory Manager; James Lelesara, Security Coordinator; Getachew Wudu, Human Resources Manager.

icipe Governing Council Student Awards Winners

BEST PUBLISHED SCIENCE PAPER

Winner
Ayaovi Agbessenou (PhD, Togo)
Registered in: University of Pretoria, South Africa
Paper: Agbessenou A., Akutse K.S., Yusuf A.A., Ekesi S., Subramanian S. and Khamis F. (2020) Endophytic fungi protect tomato and nightshade plants against *Tuta absoluta* (Lepidoptera: Gelechiidae) through a hidden friendship and cryptic battle. *Scientific Reports* 10, 22195. Paper link

First runner up
Trizah Koyi Milugo (PhD, Kenya)
Registered in Tumaini University, Tanzania
Paper: Milugo T.K., Tchouassi D.P., Kavishe R. A., Dinglasan R. R. and Torto B. (2021) Root exudate chemical cues of an invasive plant modulate

oviposition behavior and survivorship of a malaria mosquito vector. *Scientific Reports* 11, 14785. Paper link

Second Runner Up
Rose Nyakemiso Sagwe (PhD, Kenya)
University of Würzburg, Germany
Paper: Sagwe R.N., Peters M., Dubois T., Steffan-Dewenter I. and Lattorff H.M.G (2021) Pollinator supplementation mitigates pollination deficits in smallholder avocado (*Persea americana* Mill.) production systems in Kenya. *Basic and Applied Ecology*, 56, 392-400. Paper link

BEST SCIENCE POSTER

Winner
Dorcus Omoga (PhD, Kenya)
Registered in: University of Pretoria, South Africa
Poster title: One Health surveillance: Evidence of known and new zoonotic arboviruses circulation in multiple hosts with potential impact to Human
Supervisors: Dr Rosemary Sang and Dr David P. Tchouassi (*icipe*); Dr Marietjie Venter (University of Pretoria); Prof. Sandra Junglen, Institute of Virology, Charité —Universitätsmedizin, Berlin, Germany

First runner up
Ayaovi Agbessenou (PhD, Togo)
Registered in: University of Pretoria, South Africa
Poster title: Temperature-dependent modelling approach and spatial prediction reveal suitable areas for deployment of two *Metarhizium anisopliae* isolates for sustainable management of *Tuta absoluta*
Supervisors: Dr Komivi S. Akutse and Dr Fathiya M. Khamis (*icipe*); Dr Abdullahi A. Yusuf (University of Pretoria)

First runner up
Rose Nyakemiso Sagwe (PhD, Kenya)
Registered in: University of Würzburg, Germany
Poster title: Pollination efficiency and visitation frequency of avocado (*Persea americana*) flower insect visitors
Supervisors: Dr Michael Lattorff and Dr Thomas Dubois (*icipe);* Dr Ingolf Steffan-Dewenter and Dr Marcell K. Peters, (University of Würzburg)

First runner up
Evanson Omuse (MSc, Kenya)
Registered in: University of Nairobi, Kenya
Poster title: Safety of Biopesticides on the Honeybee *Apis mellifera* and African stingless bee *Meliponula ferruginea*
Supervisors: Dr Thomas Dubois and Dr Saliou Niassy (*icipe*); Dr John Maina Wagacha and Dr George Otieno Ong'amo (University of Nairobi)

First runner up
Tracy Maina (MSc, Kenya)
Registered in: Jomo Kenyatta University of Agriculture and Technology, Kenya
Poster title: Horizontal transmission of *Plasmodium*-blocking symbiont *Microsporidia MB* in *Anopheles Arabiensis*.
Supervisors: Dr Jeremy K. Herren and Dr Tullu Bukhari (*icipe)*

Annex B: Partners

Human Health Theme

Addis Ababa University (Aklilu Lemma Institute of Pathobiology), Ethiopia; agricultural research institutes, non-governmental organisations, private sector partners, farmers and farmer groups; Ceva Santé Animale (CEVA), France; Dabaso Tujengane Self Help Group – Watamu Marine Association, Kenya; Duke University, USA; Durham University, UK; Egerton University, Kenya; Elimination 8 Programme (E8); Free University of Berlin and Charité–Universitätsmedizin, Berlin, Germany; Helmholtz Centre for Environmental Research (UFZ), Leipzig, Germany; Ifakara Health Institute, Tanzania; International Livestock Research Institute (ILRI); Johns Hopkins University, USA; Kenya Medical Research Institute (KEMRI); Kenya Wildlife Service (KWS); Kilimanjaro Christian Medical University College (KCMUCo), Moshi, Tanzania; KTH Royal Institute of Technology in Stockholm, Sweden; Liverpool School of Tropical Medicine, UK; London School of Hygiene & Tropical Medicine (LSHTM), UK; Makerere University, Uganda; Millennium Institute, USA; Ministries of Health in Kenya and Ethiopia; Ministry of Agriculture, Livestock and Fisheries, Kenya (Directorate of Veterinary Services); Ministry of Public Health and Sanitation (Division of Disease Surveillance and Response), Kenya; Mosquito Control in Nyabondo (MOCON) community group, Nyabondo, Kenya; national malaria control programmes of Botswana, Mozambique, Namibia, Swaziland, Zimbabwe and Zambia; National Center for Agricultural Utilization Research, USDA-ARS, Peoria, Illinois, USA; National Museums of Kenya (Institute of Primate Research); Northeastern University, Boston, USA; Ohio State University, USA; Pennsylvania State University, USA; Radboud University, Nijmegen, the Netherlands; RWTH Aachen University, Germany; Sumitomo Chemical, Japan; Swedish University of Agricultural Sciences (SLU); Swiss Tropical and Public Health Institute, Switzerland; Kenya Medical Research Institute (KEMRI) (Wellcome Trust Research Programme, Kenya, and Centre for Virus Research); Ultimate Products (Aust) Pty Ltd, Australia; Umeå University, Sweden; University of Bonn, Germany; University of Glasgow, UK; University of Nairobi, Kenya; University of Pretoria, South Africa; United States Department of Agriculture (USDA), USA; Wageningen University, the Netherlands; Wellcome Sanger Institute, UK; World Health Organization-Regional Office for Africa (WHO-AFRO); Institute of Molecular Biology & Biotechnology (Foundation for Research & Technology Hellas), Heraklion, Crete, Greece; University of Cambridge, UK; University of Canterbury, Christchurch, New Zealand; University of Georgia, USA; University of Florida, Gainesville, FL, USA.

Animal Health Theme

African Union Inter-African Bureau for Animal Resources (AU-IBAR); county governments of Marsabit and Isiolo, Kenya; Director of Veterinary Services (DVS) (Kabete Veterinary Research Laboratories), Nairobi, Kenya; Kenya Livestock Producers Association (KLPA); Kenya Tsetse and Trypanosomiasis Eradication Council (KENTTEC); Kenya Wildlife Service (KWS); Marsabit County Livestock Office, Kenya; Max Planck Institute for Chemical Ecology, Jena, Germany; Ministry of Agriculture, Livestock & Fisheries and Department of Veterinary Services in Kwale County; Mount Kenya University, Kenya; National Museums of Kenya; Smithsonian Institution, USA; Sokoine University of Agriculture, Tanzania; Tanzania National Parks; Tanzania Wildlife Research Institute (TAWIRI); University of Maryland, USA; University of Würzburg, Germany; Yale School of Public Health (USA).

Plant Health Theme

A to Z Textiles Limited, Arusha, Tanzania; Academy of Sciences of the Czech Republic (Institute of Organic Chemistry and Biochemistry); African Academy of Sciences; African Conservation Tillage Network, Malawi and Zambia; Agrarian Systems Ltd, Uganda; Agricultural Research Corporation (ARC), Wad Medani, Sudan; Agricultural Research for Development (CIRAD), France; Agroscope, Switzerland; Anglican Development Services, Kenya; Anglican Development Services Eastern (ADSE), Kenya; Austin Investment Ltd; Avocado Growers Association, South Africa; Biocontrol Research Laboratories, India; Bioversity International, Italy; Busitema University, Uganda; CABI Africa; Crop Health and Protection (CHAP), UK; Citrus Research International, South Africa; Conservation Farming Unit (CFU), Zambia; Dschang University, Cameroon; Division of Plant Industry, Florida Department of Agriculture and Consumer Services, USA; Dudutech Ltd, Kenya; East African Seed Co. Ltd, Kenya; Éléphant Vert Kenya; Embu University, Kenya; Ethiopian Institute of Agricultural Research (EIAR); Ethiopian Agricultural Transformation Agency; Farmer groups and mango growers; Farmtrack Consulting Ltd, Kenya; Forum for Agricultural Research in Africa (FARA); French National Research Institute for Sustainable Development (IRD), France; Hawassa University, Ethiopia; Heifer International – Kenya and Tanzania; Horticultural Research and Training Institute-Tengeru (HORTI Tengeru), Tanzania; HottiServe East Africa Limited, Kenya; Humboldt-Universität zu Berlin, Germany; Institute for Sustainable Development (ISD), Ethiopia; International Center for Tropical Agriculture (CIAT); International Crops Research Institute for the Semi-Arid Tropics (ICRISAT); International Institute of Tropical Agriculture (IITA); International Livestock Research Institute (ILRI); International Maize and Wheat Improvement Center (CIMMYT); International Potato Center (CIP); International Water Management Institute (IWMI); Jaramogi Oginga Odinga University of Science and Technology (JOOUST), Kenya; Jomo Kenyatta University of Agriculture and Technology (JKUAT), Kenya; Julius Kühn-Institut (Institute for Biological Control), Germany;

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Social Science and Impact Assessment Unit

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Environmental Health Theme

Addis Ababa University, Ethiopia; African Union Inter-African Bureau for Animal Resources (AU-IBAR); Agricultural Sector Development Programme, Zanzibar, Tanzania; Aklilu Lemma Institute of Pathobiology, Ethiopia; Bahir Dar University, Ethiopia; Biovision Africa Trust; Debre Berhan University, Ethiopia; Debre Markos University, Ethiopia; East Usambara Farmers Group; Ethiopian Ministry of Trade and Industry; Ethiopian Institute of Agricultural Research; Faculty of Agriculture, University of Kinshasa (DR Congo); Federal Ministry of Health, Ethiopia; French Agricultural Research Centre for International Development (CIRAD), France; French National Institute for Agricultural Research (INRA), France; Food and Agriculture Organization of the United Nations (FAO); German Centre for Integrative Biodiversity Research (iDiv), Germany; Holeta Bee Research Centre, Ethiopia; Iziko South African Museum, South Africa; Jimma University, Ethiopia; Kamaki Beekeepers Cooperative Society Limited, Kenya; Kenya Agricultural and Livestock Research Organization (KALRO) (National Sericulture Research Centre); Kenya Marine and Fisheries Research Institute (KEMFRI - Nyabondo);

Kenya Medical Research Institute (KEMRI); Martin Luther University, Halle-Wittenberg, Germany; Milba Brands Associates Limited, Kenya; Millennium Institute, USA; Ministry of Agricultural Development and Food Security, Botswana; Ministry of Agriculture (MoA-Nyabondo); Ministry for Animal Resources and Fisheries, Burkina Faso; Ministry of Agriculture, Livestock and Fisheries (Directorate of Livestock Production), Madagascar; Ministry of Agriculture, Ethiopia; Ministry of Agriculture, Fisheries, Environment, Land Use and Urban Planning, Comoros; Ministry of Agriculture, Liberia; Ministry of Agriculture, Natural Resources, Livestock and Fisheries, Zanzibar; Ministry of Agro-industry and Food Security (Entomology Division), Mauritius; Ministry of Health, Municipal Council of Malindi, Kenya; Ministry of Livestock, Fisheries and Animal Industries, Cameroon; Ministry of Public Health and Sanitation (Nyabondo); Muliru Farmers Conservation Group (MFCG), Kenya; Museum für Naturkunde, Berlin, Germany; National Agriculture and Food Research Organization, Japan; National Beekeeping Station, Kenya; National Institute of Medical Research (NIMR), Tanzania; National Museum, Bloemfontein, South Africa; National Museums of Kenya; Pangani Basin Water Board, Tanzania; Pennsylvania State University, USA; Royal Museum for Central Africa, Tervuren, Belgium; Ruhr-Universität Bochum, Germany; Schmalhausen Institute of Zoology, Ukraine; Seychelles Agricultural Agency; Smithsonian Institution, USA; Smithsonian National Museum of Natural History, USA; Sokoine University of Agriculture, Tanzania; Stellenbosch University, Department of Conservation Ecology and Entomology, South Africa; Strand Life Sciences, India; Taita Environmental Research and Resource Arc (TERRA), Kenya; Tanzania Farmers Conservation Group (TFCG); Tropical Entomology Research Center, Viterbo, Italy; Tuscia University, Viterbo, Italy; United States Department of Agriculture (USDA), USA; University of Bonn, Germany; University of California, Davis, USA; University of Dar es Salaam, Tanzania; University of Helsinki, Finland; University of Kansas, USA; University of Lausanne, Switzerland; Umeå University, Sweden; University of Würzburg, Germany; University of York, UK; Wageningen University and Research (Resource Ecology group), the Netherlands; Yeungnam University, South Korea.

Technology Transfer Unit
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Annex C: Abbreviations and Acronyms

A4A	Advocacy for agroecology
ACIAR	Australian Centre for International Agricultural Research
AFD	French Development Agency
AHUs	African Host Universities
ANR	Agence Nationale de la Recherche / French National Research Agency
ARPPIS	African Regional Postgraduate Programme in Insect Science
AU	African Union
AU-IAPSC	African Union Inter-African Phytosanitary Council
BBSRC	Biotechnology and Biological Sciences Research Council, UK
BCCN	Basic Crash Course Nematology
BecA-ILRI Hub	Biosciences eastern and central Africa – International Livestock Research Institute Hub
BioInnovate Africa Programme	Bioresources Innovations Network for Eastern Africa Development
BLE	German Federal Agency for Food and Agriculture
BMZ	Federal Ministry for Economic Cooperation and Development, Germany
CAP-Africa	Combating arthropod pests for better health, food and resilience to climate change
CBFAMFEW II	Community-based fall armyworm monitoring, forecasting, and early warning system (phase II)
CIRAD	French Agricultural Research Centre for International Development
COP26	26th UN Climate Change Conference of the Parties
COVID-19	Coronavirus disease 2019
CultiAF programme	Cultivate Africa's Fund, a partnership between Future Australian Centre for International Agricultural Research (ACIAR) and International Development Research Centre (IDRC).
DAAD	German Academic Exchange Service
Danida	Danish International Development Agency
DFG	German Research Foundation
DRIP	Dissertation Research Internship Programme
e-SIR	Extended susceptible-infected-removed compartmental model
EANBiT	Eastern Africa Network for Bioinformatics Training
EASTECO	East African Science and Technology Commission
EBCAs	Endophytes and biocontrol agents
ESA	Entomological Society of America
FAO	Food and Agriculture Organization of the United Nations
FAW-IPM	Integrated pest management strategy to counter the threat of invasive fall armyworm to food security in eastern Africa
FCDO	UK's Foreign, Commonwealth & Development Office
FiBL	Research Institute of Organic Agriculture
FII	Future Investment Initiative
FNIH	Foundation for the National Institutes of Health
GC-MS	Gas chromatography – mass spectrometer
GFFA	Global Forum for Food and Agriculture
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
GOHi	Ohio State University Global One Health initiative
IAEA	International Atomic Energy Agency
IAP	InterAcademy Partnership
IBSP	Scientific Board of the International Basic Science Programme
ICAE	International Conference of Agricultural Economists
ICGEB	International Centre for Genetic Engineering and Biotechnology
ICTV	International Committee on Taxonomy of Viruses
IDB	International Day for Biological Diversity
IDRC	International Development Research Centre, Canada
IF	Impact factor
IFAD	International Fund for Agricultural Development
INRAE	French National Research Institute for Agriculture, Food and the Environment
INSFEED	Insect feed for poultry and fish production in sub Saharan Africa

IPIs	International partner institutions
IPM	Integrated Pest Management
IRD	French National Research Institute for Sustainable Development
IWD	International Women's Day
KCOA	Knowledge Centre for Organic Agriculture in Africa
KIPPRA	Kenya Institute for Public Policy Research and Analysis
KTH	Kungliga Tekniska Hogskolan, Sweden
LDCs	Least Developed Countries
LED	Liechtenstein Development Service
MOYESH	More Young Entrepreneurs in Silk and Honey
MRC	Medical Research Council
NACOSTI	National Commission for Science, Technology and Innovation, Kenya
NEMEDUSSA	Nematology Education in Sub-Saharan Africa
NIH	National Institutes of Health, USA
NMDS	Non-metric multi-dimensional scaling
Norad	Norwegian Agency for Development Cooperation
NRF	National Research Fund
NSF	National Science Foundation
NWO	Netherlands Organization for Scientific Research
OACPS	Organisation of African, Caribbean and Pacific States
PANEMA	Pan-African nematology network
PASET	Partnership for Skills in Applied Sciences, Engineering and Technology
PCN	Potato cyst nematodes
RCU	Regional Coordination Unit
RDMA	Research data management and archival
RSIF	Regional Scholarship and Innovation Fund
SCLAMP-EA	Scaling-up climate-smart pest management approaches for enhanced maize and tomato systems productivity in eastern Africa
SDC	Swiss Agency for Development and Cooperation
SEI	Stockholm Environment Institute Africa Centre
SHARP	Self-Evaluation and Holistic Assessment of Climate Resilience of Farmers and Pastoralists
Sida	Swedish International Development Cooperation Agency
SNNPR	Southern Nations, Nationalities and Peoples' Region
SNSF	Swiss National Science Foundation
STEM	Science, technology, engineering and mathematics
SwECCA	Swedish Development Cooperation team for Environment and Climate Change in Africa
SRC	Swedish Research Council
TAAT	Technologies for African Agricultural Transformation
TEA	Technoeconomic analysis
THRiVE	Training Health Researchers into Vocational Excellence
TWAS	The World Academy of Sciences
UKRI	UK Research and Innovation
UNECA	United Nations Economic Commission for Africa
UNEP-GEF	United Nations Environment Programme / Global Environment Facility
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNTBLDC	United Nations Technology Bank for Least Developed Countries
UPSCALE	Upscaling the benefits of push–pull technology for sustainable agricultural intensification in East Africa
USAID	United States Agency for International Development
USAID-PEER	United States Agency for International Development's Partnerships for Enhanced Engagement in Research
USDA-ARS	United States Department of Agriculture-Agricultural Research Service
WHO	World Health Organization
WHO-AFRO	World Health Organization/ Regional Office for Africa
WTO–EIF	World Trade Organization – Enhanced Integrated Framework
ZARI	Zanzibar Ministry of Agriculture, Irrigation, Natural Resources and Livestock and Zanzibar Agricultural Research Institute

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A pair of Kenya Rufous Sparrows, *Passer rufocinctus*, perched on a fence in one of *icipe*'s field sites in Kitale, Rift Valley, Kenya.

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icipe was established in 1970 in direct response to the need for alternative and environmentally friendly pest and vector management strategies. Headquartered in Nairobi, Kenya, *icipe* works through the 4Hs Themes – Human Health, Animal Health, Plant Health and Environmental Health – a holistic and integrated framework aimed to improve the overall well-being of communities in Africa, with sustainable development as its basis.

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

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