SESSION 4.2:
SOLUTIONS FOR RESILIENT FOOD AND NUTRITION SYSTEMS OFF-FARM

Insect farming: a circular economy solution to create value for food loss and waste

Dr Fathiya Mbarak Khamis

Senior Scientist, International Centre of Insect Physiology and Ecology (*icipe*)

Abstract

The Food and Agriculture Organization (FAO) projects the global population to reach 9.7 billion by 2050. As such, food demand is expected to increase by 70% to meet food and nutritional security of the expanding population. Globally hunger is widely prevalent in the Africa, South Asia and in some Oceania islands. Therefore, population expansion and rapid urbanisation, coupled with the effects of the three Cs – COVID-19, climate change, and conflicts – are impacting food security in most of these regions. By 2050, 68% of the global population is anticipated to live in cities resulting in rising food prices, unemployment, and environmental degradation through massive accumulation of organic wastes, with only a very small proportion of it appropriately recycled in developing countries. Increasing income of urban dwellers has significantly increased the demand for crop and animal products, while lack of cost-efficient inputs such as fertilisers and feeds is constraining crop and livestock productivity. Ironically 33% of the food produced globally never manages to feed the people due to various post-harvest losses. These diverse and interlinked developmental challenges call for innovative solutions to address them. Use of insects such as black soldier fly, *Hermetia illucens*, for recycling organic wastes into nutrient-rich organic fertilisers for crop productivity, while also supplying high-quality insect biomass which is rich in crude proteins, fats, gross energy, well-balanced amino acids and vitamins for the feed sector to enhance livestock productivity, is one of these approaches. This is an innovative, eco-friendly and circular solution that contributes to environmental sustainability (mitigation of waste), food security (enhanced crop and livestock production) and has the potential to contribute to critically needed employment for youth and women in Africa, South Asia and the Pacific Islands. Furthermore, the high quality and locally produced insect protein and insect-based organic fertilisers can be excellent substitutes for often imported feed protein additives and synthetic fertilisers, and have the potential to reduce the import bills of several developing and underdeveloped nations.

In brief, *icipe* is the centre of excellence for research and capacity building in insect science and its application in Africa. The centre is an intergovernmental organisation (13 countries), over 50 years old, with over 570 staff of more than 30 nationalities. It has been governed by four directors and is currently under the stewardship of Dr Segenet Kelemu. Our head office is in Nairobi, Kenya.

The Food and Agriculture Organization of the United Nations (FAO) projects global population to reach 9.7 billion people by 2050, from the current 8 billion, and the effect of this will be a rise in food demand, though we are still grappling to meet SDG 2 (Figure 1). Agricultural production has to increase by 70% to meet food and nutritional security of the expanding population. Urbanisation, of course, will be rampant, and by 2050 seven out of ten people will be residing in the cities. Population expansion will lead to increased built environments for human settlements, which will drastically decrease land available

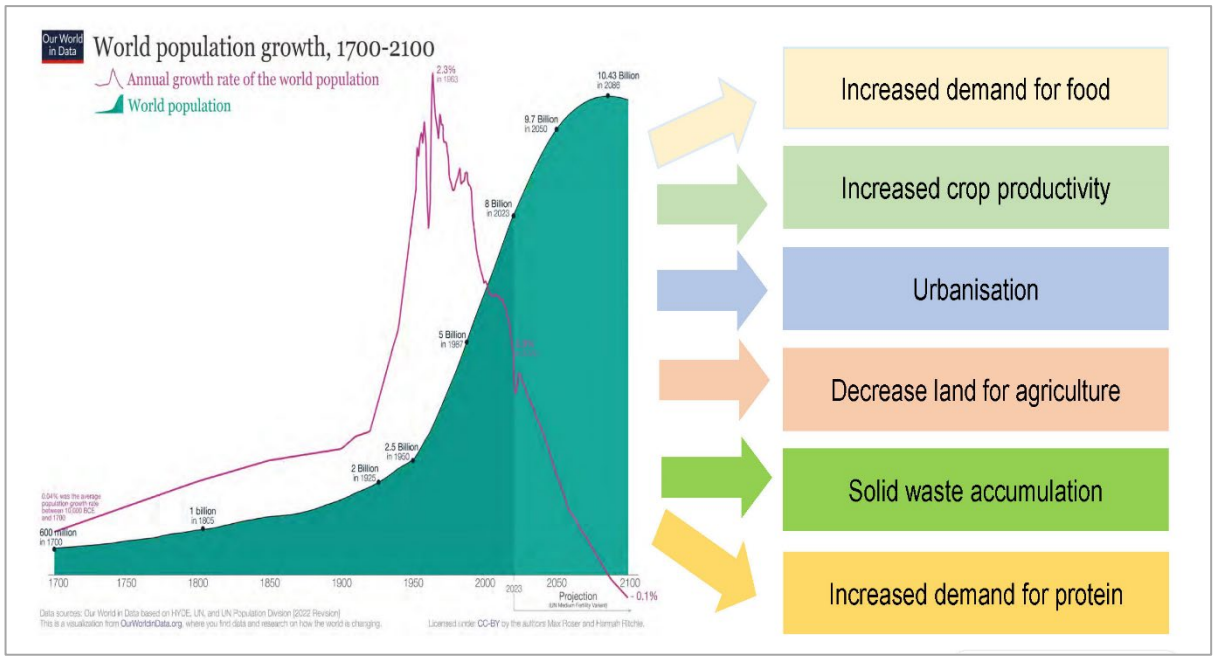

Figure 1. Population growth and food security.

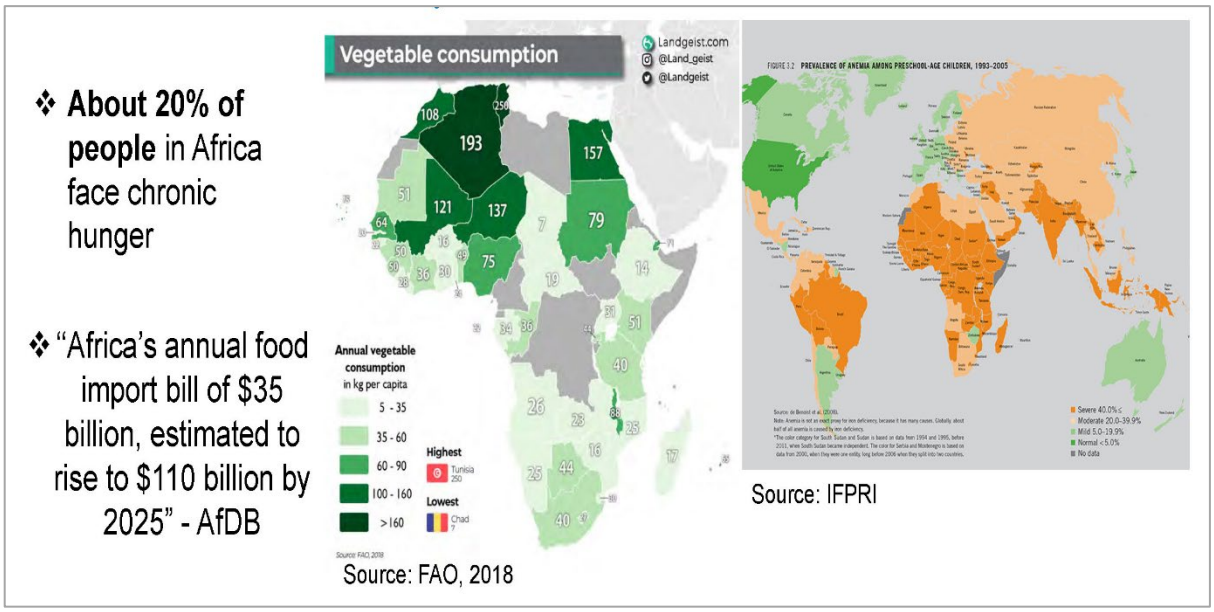

Figure 2. Challenge 1: Food and nutritional insecurity. Consumption of nutrient-rich vegetables vs hidden hunger in Africa. Anaemia across the world.

for agricultural productivity. And of course, all this leads to rising food prices, high levels of unemployment, and environmental degradation through massive accumulation of solid waste, especially organic waste.

Globally, hunger is widely prevalent in Africa, South Asia and in some Oceania Islands. About 20% of people in Africa are facing chronic hunger (Figure 2), with 90% of African countries yet to meet the average annual per capita vegetable consumption of around 88 kg. Across Africa the annual cost of importing food is US$35 billion, which is predicted to increase almost three-fold by 2050. Also, most of the regions of the world are currently facing anaemia.

Therefore, population expansion and rapid urbanisation, coupled with the effects of the three C's – COVID-19, climate change and conflict – are impacting food security. These effects will be intensified with the current trends in population growth.

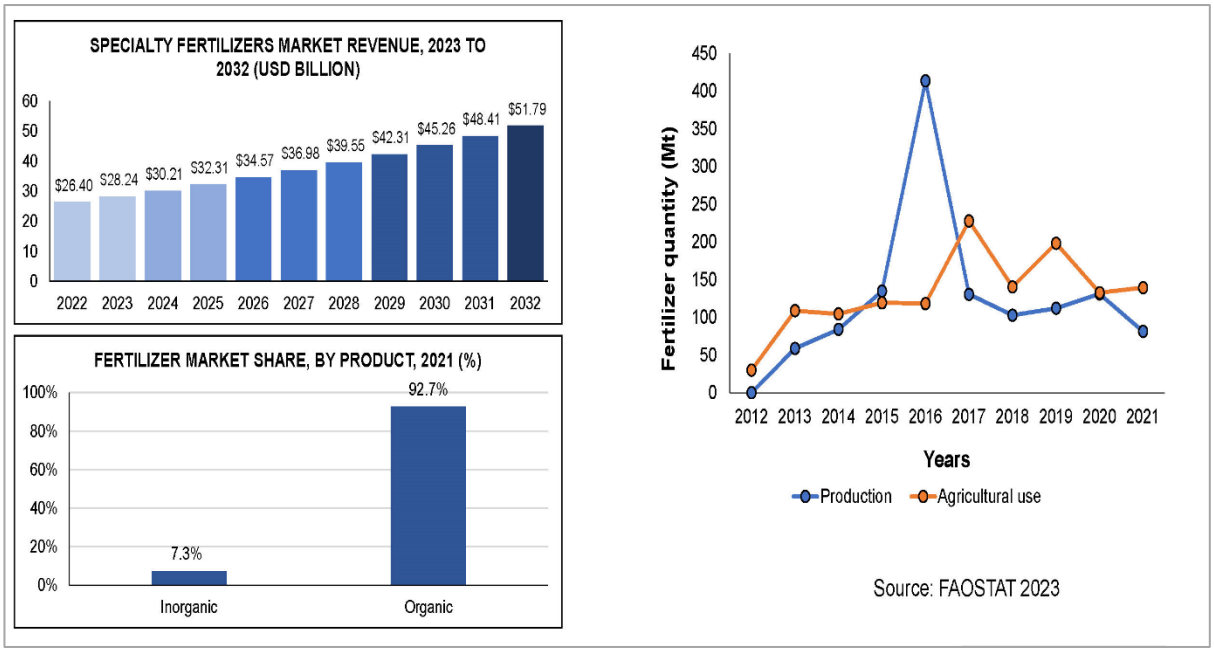

Figure 3. Challenge 2: Demand for fertiliser.

To increase agricultural productivity, demand for fertiliser is on the rise (Figure 3). Currently, demand is higher than supply due to political conflict. With the current shift towards regenerative agriculture, demand for organic fertiliser is rising and demand is expected to increase further.

Urbanisation and increasing incomes of urban dwellers will have significant effects on diets, with shifts especially towards animal-based proteins (Figure 4). The demand for animal products has drastically soared and is projected to almost double by 2050. This will in turn raise demand for feed for livestock production. Therefore, alternative sources have to be devised to meet this deficit and reduce reliance on sources such as soya bean, sunflower seed and fish.

A key challenge of population growth, urbanisation and increasing productivity is waste accumulation (Figure 5). Of the food produced globally, 33% never manages to feed people, due to various post-harvest losses, which means the bulk of municipal solid waste is foods and greens. Certainly this can also be used, and offers an opportunity when fully utilised.

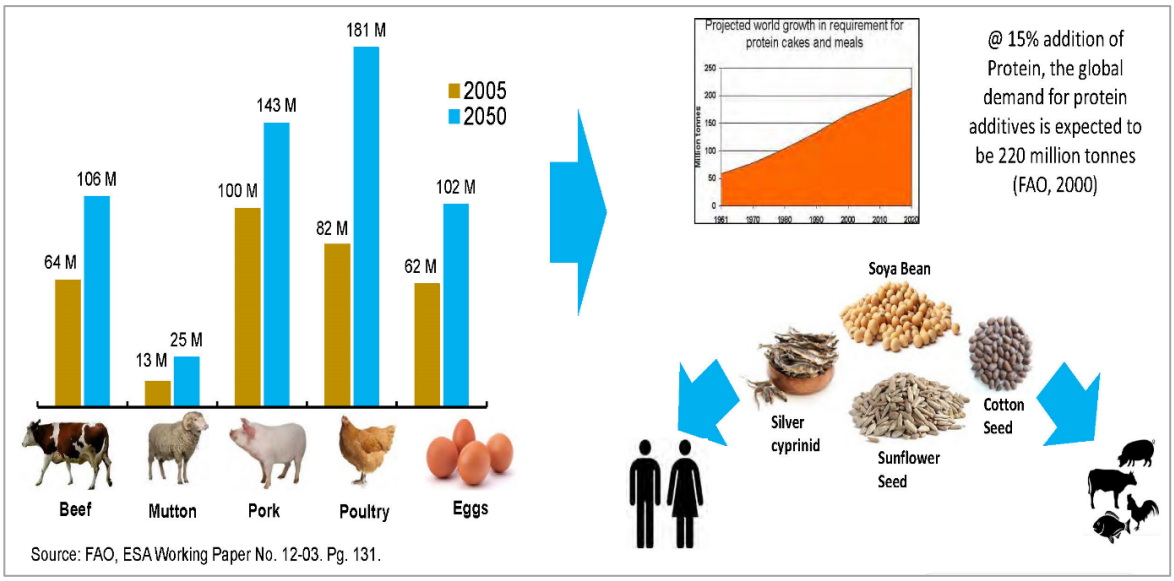

Figure 4. Challenge 3 (left): Global demand for meat protein (tons) (Alexandratos & Bruinsma 2012); Challenge 4 (right): Global demand for animal feed protein (FAOSTAT 2000).

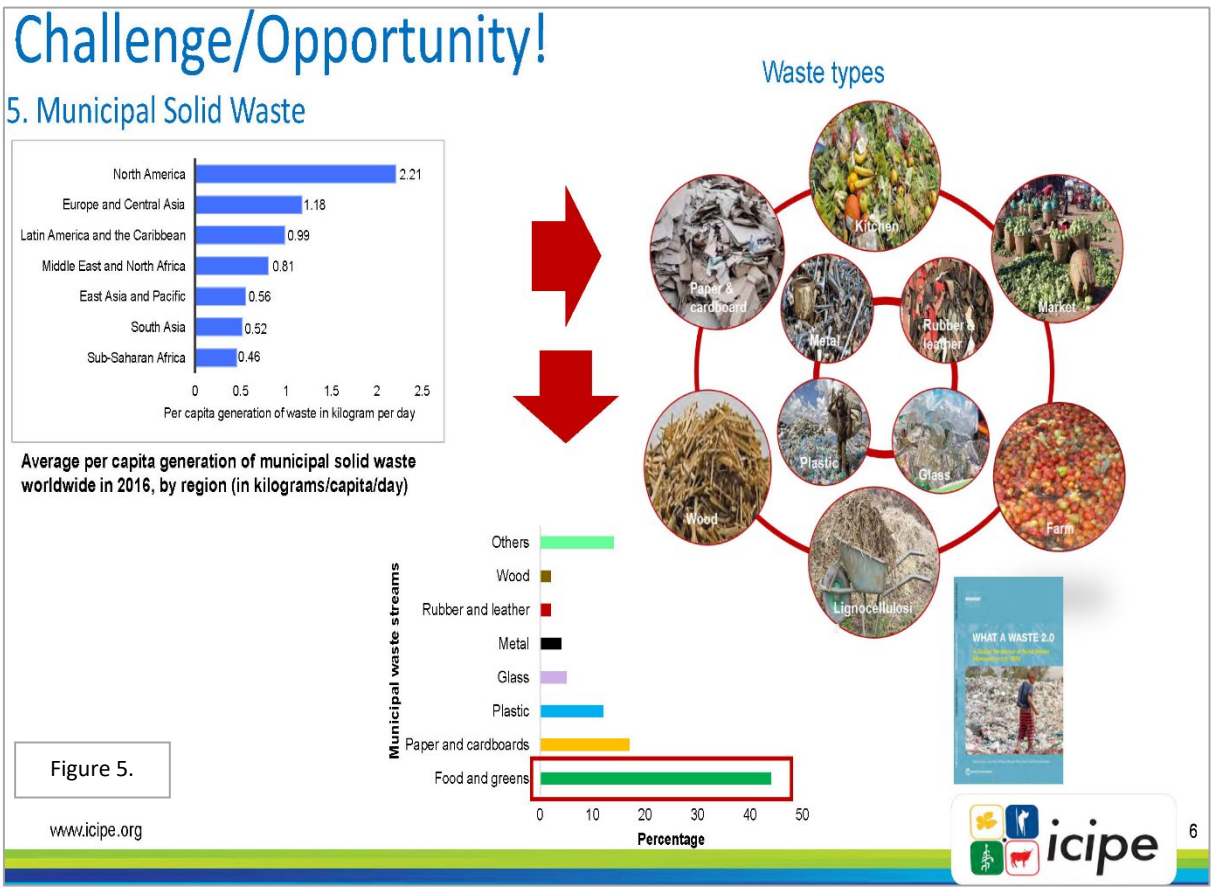

Figure 5.

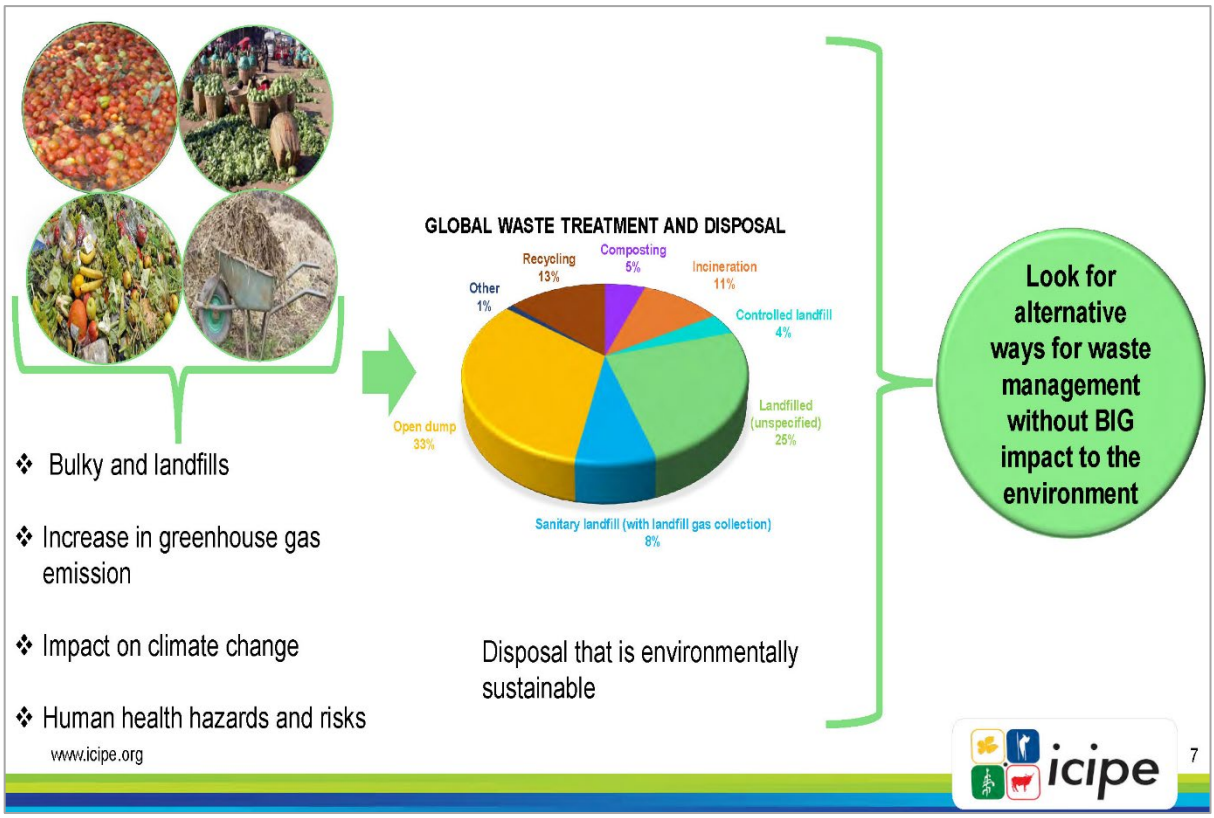

Figure 6. Need to manage waste in a sustainable way.

Waste disposal methods (Figure 6) can have many repercussions for the environment. For instance, open dumping can be hazardous to the environment and can pose serious health risks to humans and animals. So, alternative methods should be employed that are ecologically sound.

Black soldier flies: so many uses

One versatile approach that is plausible is the use of black soldier flies (BSF) *Hermetia illucens* (Figure 7). They can be used to recycle organic waste into nutrient-rich organic fertiliser for crop productivity, while also supplying high quality insect biomass that is rich in crude proteins, fats, well-balanced amino acids and vitamins.

The insect has so many advantages: it is cheap to maintain on various organic waste streams, reducing microbes; it has a short lifespan and a high reproductive rate; and is easy to rear and maintain. BSF has a global distribution with a wide introduced range. Many farmers are rearing BSF for farm use and also for small-scale sales especially to their peers and to big players in the field. It has been adopted by many key global players in all regions of the world (Figure 8), including the Asia-Pacific region, for various uses – such as protein additive for feed, for fertiliser, for oil production and waste streams.

A key development in insect farming is that recently *icipe* collaborated with development partners AgriFutures Australia and ACIAR (Australian Centre for International Agricultural Research) and created the Emerging Insect Technology Hub (EIT-Hub). The aim of the platform is to foster

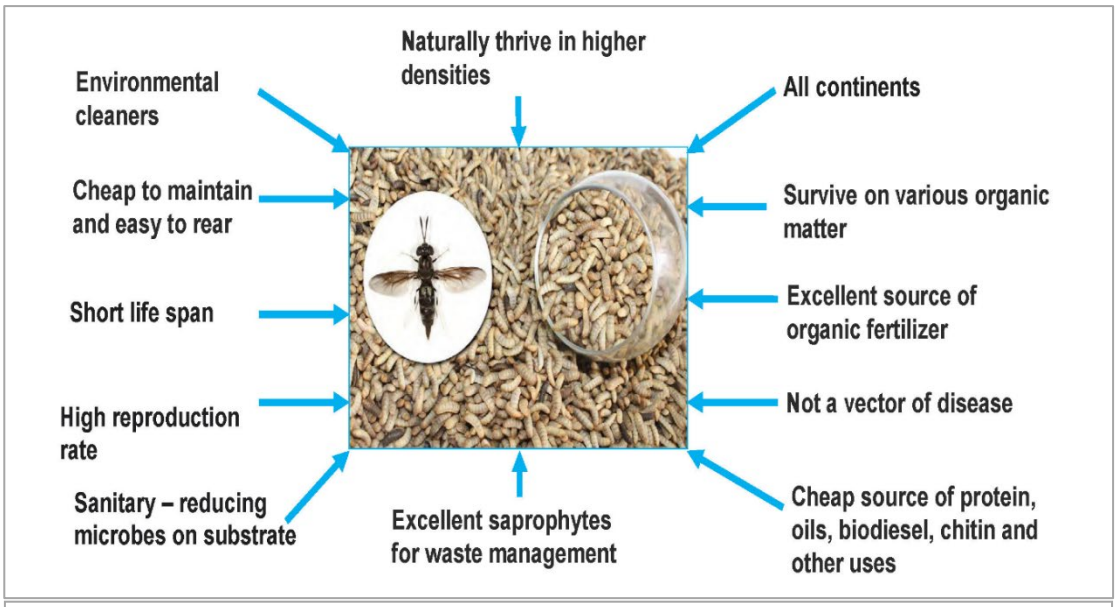

Figure 7. Black soldier fly, *Hermetia illucens*.

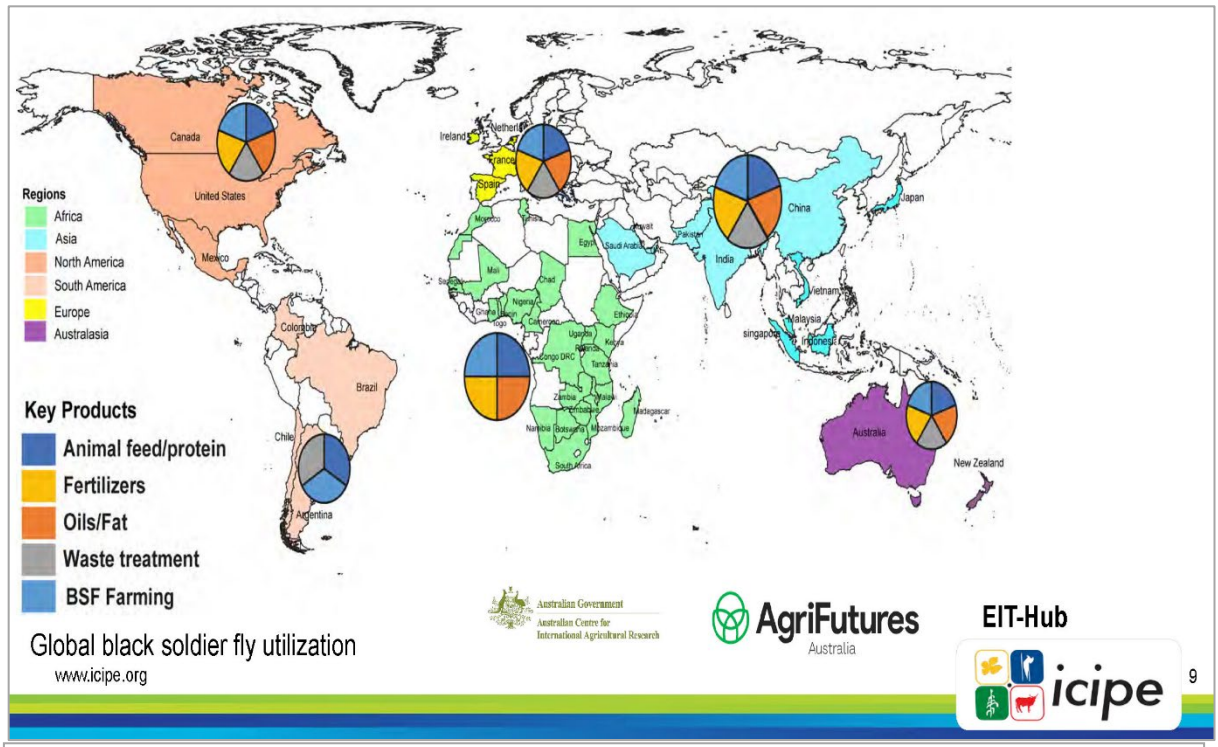

Figure 8. Current global distribution of black soldier fly.

collaboration and knowledge-sharing among research and industry partners, scientists and investors in Africa and Australia. The Hub is capitalising on the goal of promoting insect farming in Australia by AgriFutures.

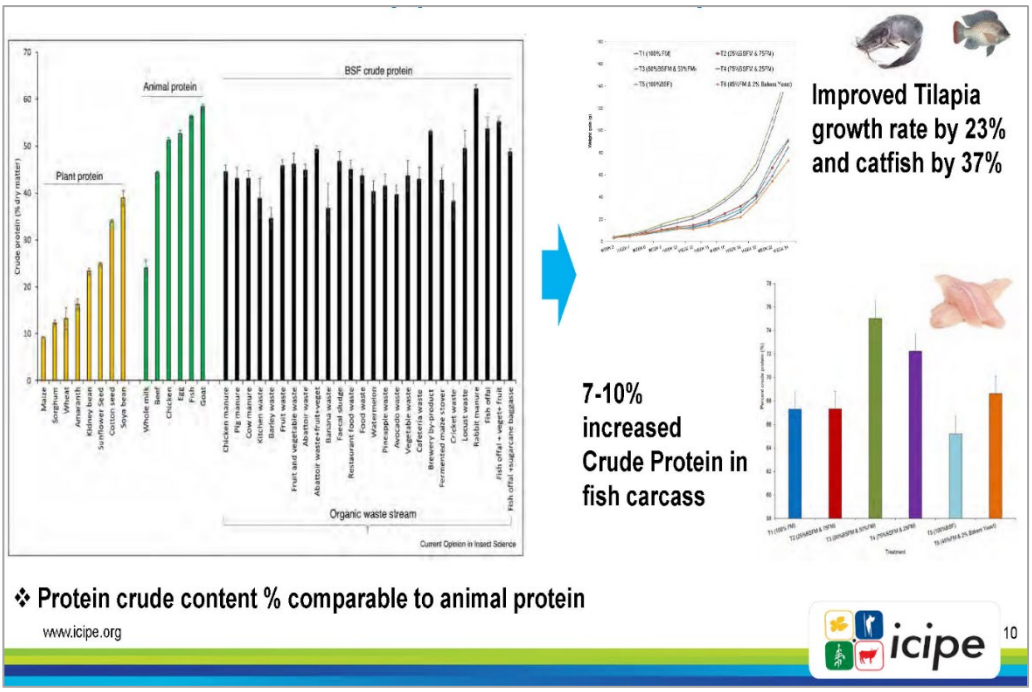

Figure 9. Crude protein – application in aquaculture.

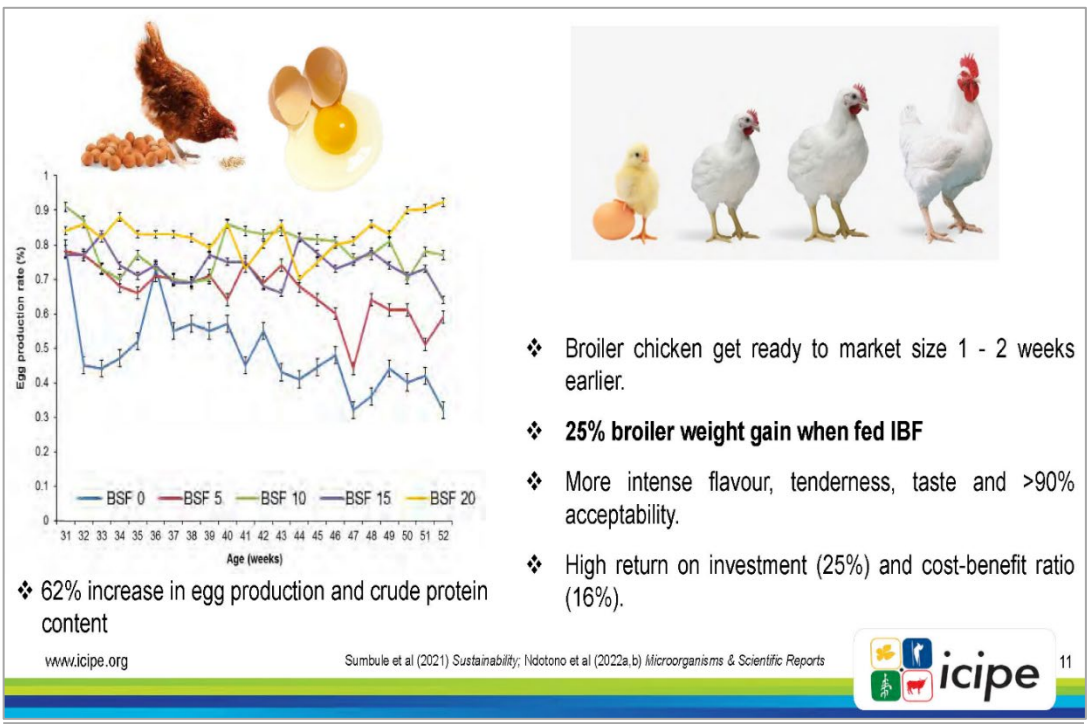

Figure 10. Application in poultry farming (Sumbule *et al*. 2021; Ndotono *et al*. 2022a,b).

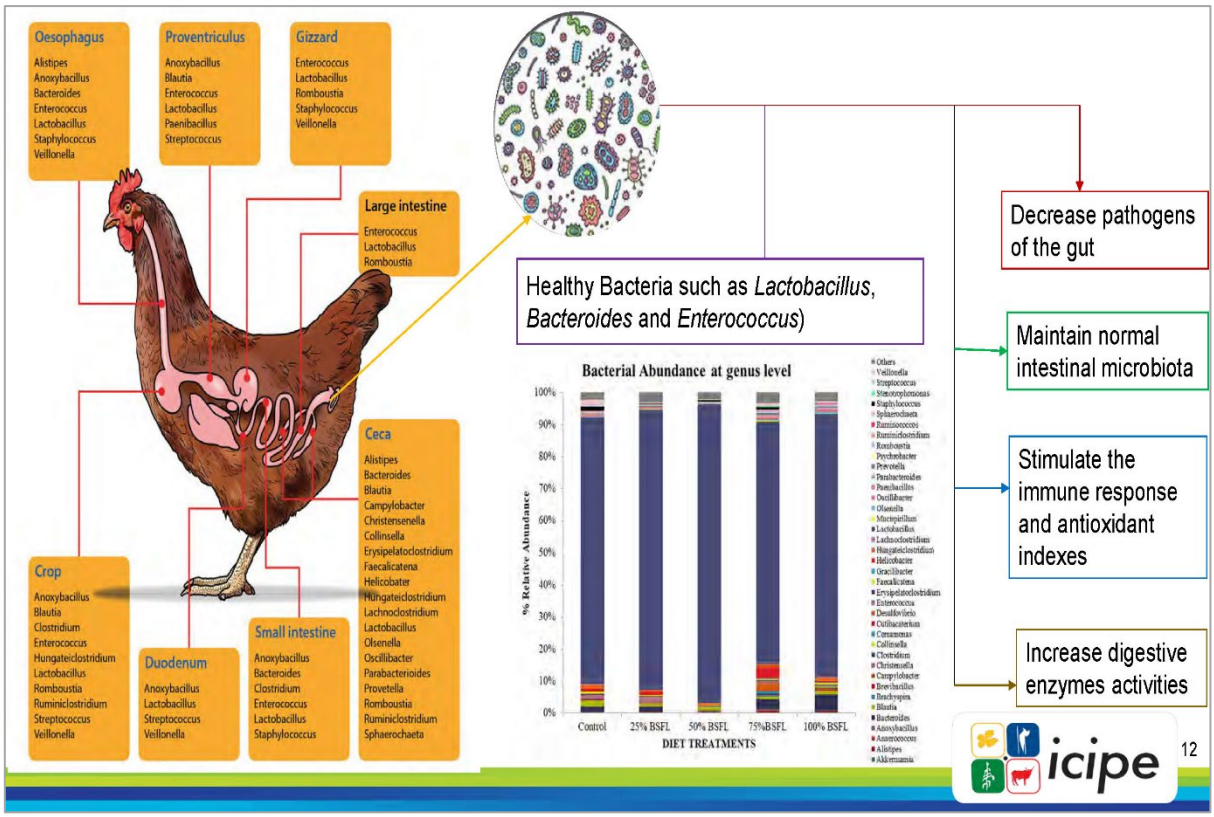

Figure 11. Insect-based feed improves chicken gut health.

While utilising and valorising organic wastes into usable fertilisers, we can produce BSF larval biomass with high protein content which is comparable to animal protein. This can be used as feed, for example in aquaculture (Figure 9). Our previous research has shown that insect-based feeds improve the growth of fish and increase the crude protein content of fish carcasses.

Similarly, in the poultry industry (Figures 10, 11), inclusion of BSF-based meal increases egg production by over 62% and raises the crude protein content of the eggs. It also increases the weight of broiler chickens by 25% while improving the quality and flavour of the chicken carcass. BSF also improves the gut health of poultry through increasing the abundance of beneficial bacteria such as *Lactobacillus* in the chicken gut, thereby promoting health and also growth without reliance on antibiotics.

Furthermore, soil amendments using insect chitin fertiliser suppress pests and diseases in vegetable cropping systems, while frass fertiliser improves yields of vegetables such as tomato, French bean, kale and staple crops such as maize (Figure 12). Those are the areas we have done experiments on, so far, and in general profitability increased by over 44%.

BSF larvae are a good and affordable source of excellent oil that can be used in the beauty industry, pharmaceuticals, for food and for biodiesel production (Figure 13).

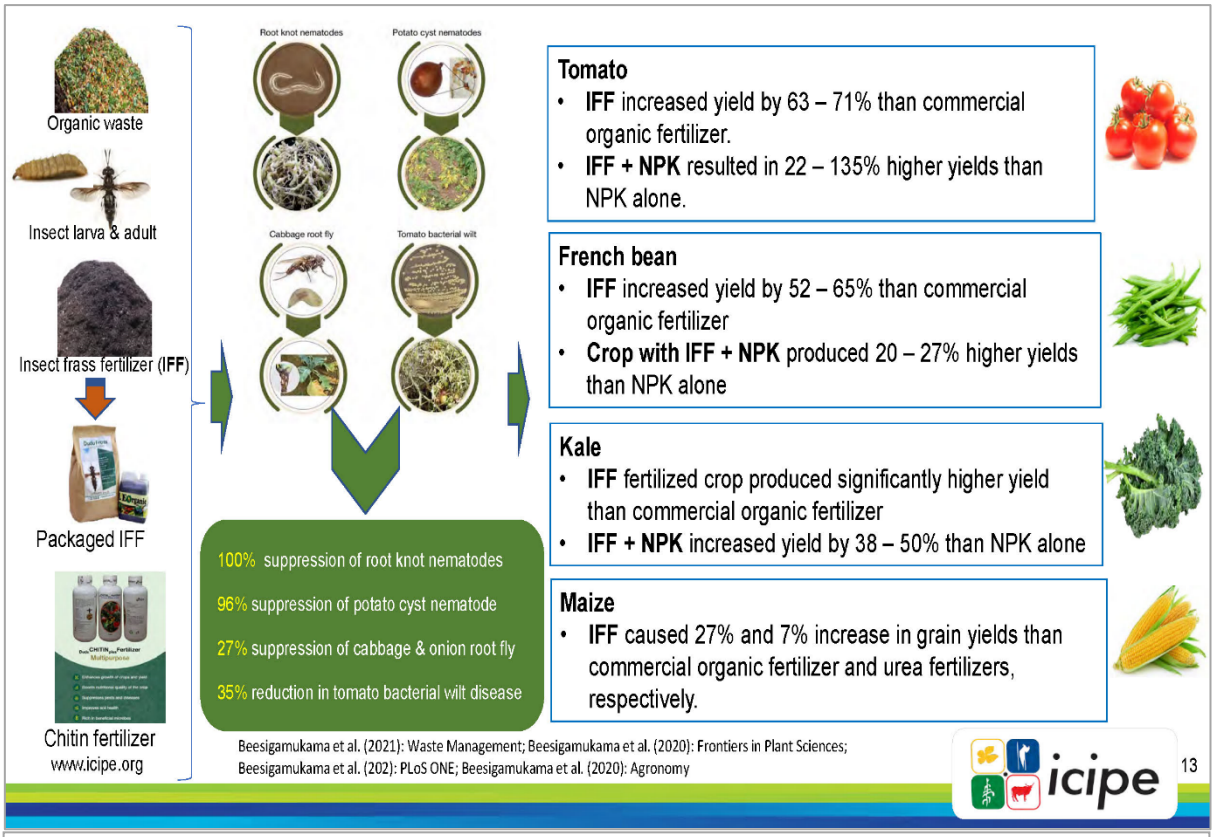

Figure 12. Chitin fertiliser and insect frass fertiliser, IFF (Beesigamukama *et al*. 2020, 2021).

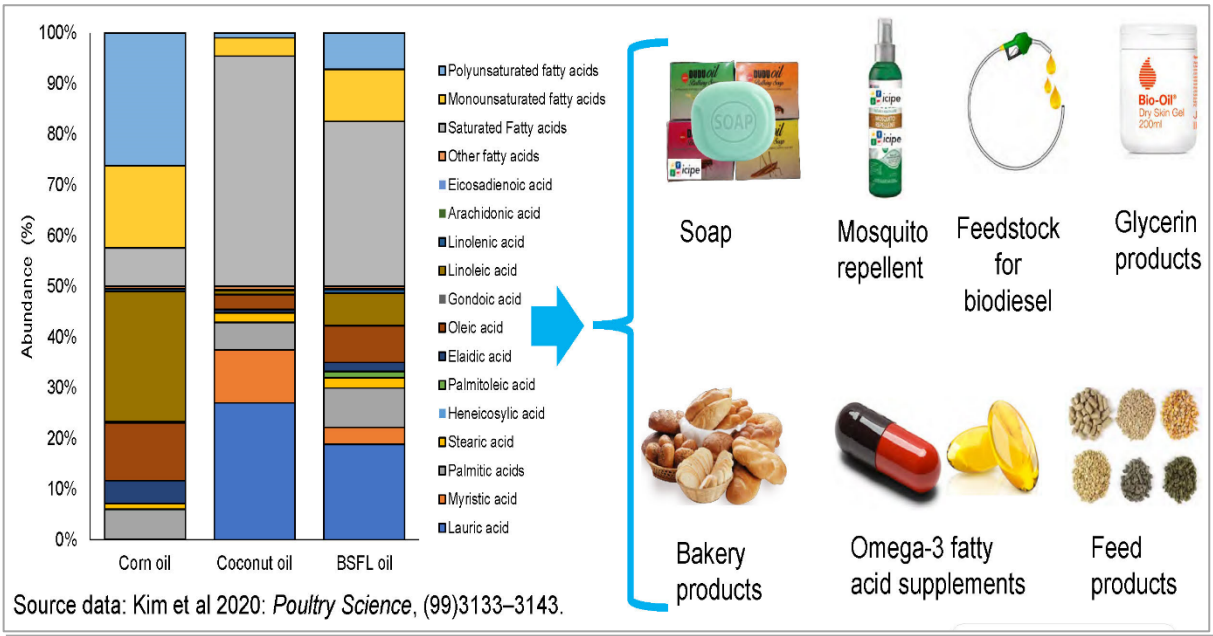

Figure 13. Excellent source of oils for various applications (Kim *et al*. 2020; Cheseto *et al.* 2020).

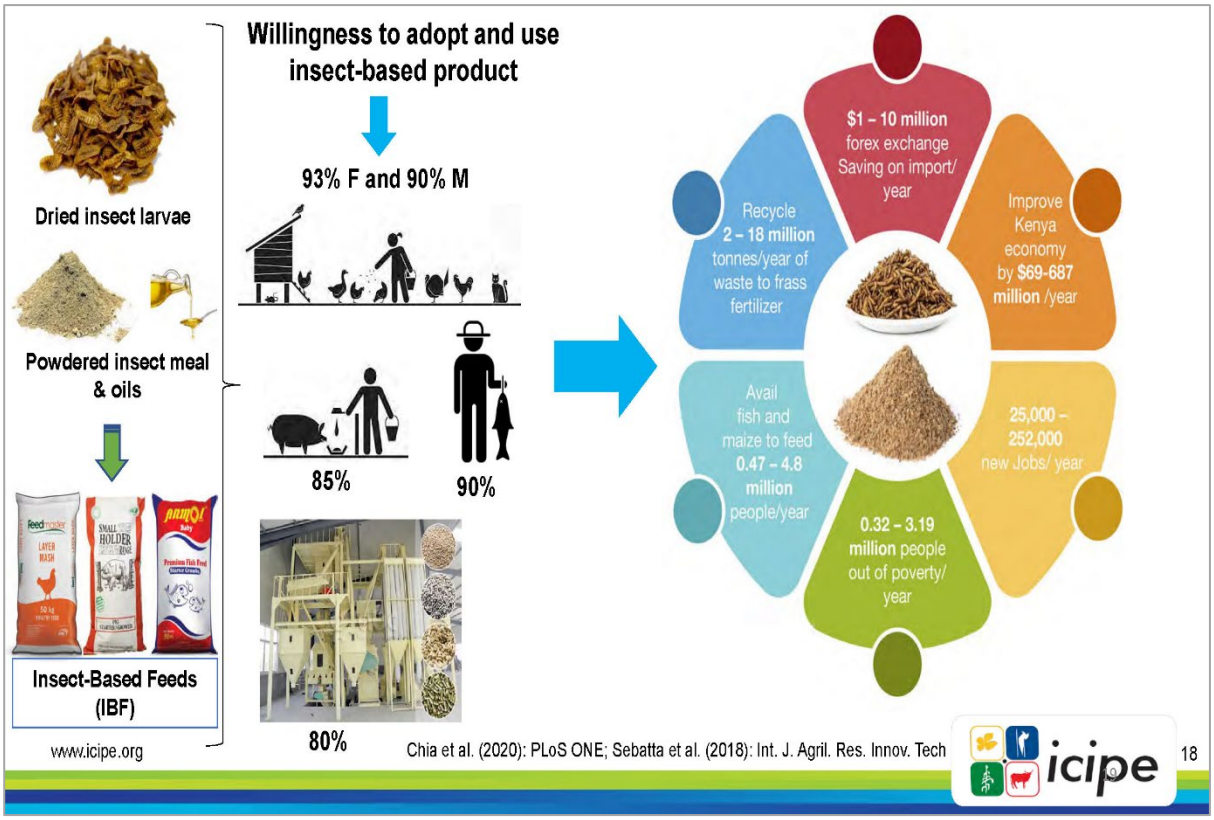

Figure 14. Socioeconomic and environmental impact of insect-based feeds in Kenya (Sebatta *et al*. 2018; Chia *et al*. 2020).

Capacity building and widescale promotion

icipe has built capacity at different levels on BSF. We have trained MSc students, PhD students and postdoctoral fellows. We have also trained trainers, developed training materials and issued starter kits to stakeholders to improve dissemination and adoption of this technology. And we have published widely for the scientific community on BSF and its research in our INSEFF (Insects for Food and Feed) program.

Through demonstration partners and networks of stakeholders, we have built capacity of farmers and small, medium and large-scale stakeholders interested in BSF production and value chains. We have done media engagement for visibility and wider acceptability of the technology.

At the start of our project we suggested using BSF for waste management, and by now the uses have increased to include feed and other uses. This has happened through policy engagement for enabling environments. *icipe* and partners have developed standards for certification of insect-based feed products and we are currently in collaboration with the African Organisation for Standardisation to develop standards for Africa.

Although insect-based feeds have gained traction in most parts of the world, socio-economic assessment is important for policy development (Figure 14). We assessed farmers' knowledge on edible insects as feed, and the acceptance and willingness to pay for the same in Kenya and other countries in East Africa. Our study revealed that farmers are aware and consider insects as a good ingredient for feed, and are willing to buy insect-based feeds for their livestock. And the impact has been tremendous in the economy of the country, through job creation, enhancing food and nutrition security, and improving the general livelihoods of the population.

Summary

In conclusion, BSF farming fits well within the context of the regenerative circular economy for waste valorisation and better agri-business livelihoods. Furthermore, BSF anchors well within the One Health framework where it serves to link all paradigms of health, from plant to human to animal and environment, working towards SDGs 1,2,3,4,5,6,7,8,10,11,13,14,15,16 and 17.

This insect has the potential to accomplish the global quest of transitioning to a greener environment. We have seen that BSF can be used for waste management, while at the same time the insect uses the waste as feed for its growth. The insect biomass can be utilised as sources of various high value products, such as oils, chitin and chitosan, frass fertilisers, antimicrobial peptides, enzymes and biodiesel, among others, which have diverse uses in the energy industry, pharmaceutical, food and crop protection sectors, while safeguarding the environment. All these products offer enterprise lines for creating jobs and sustaining livelihoods. *icipe* in this context won a Food Planet Prize in 2020.

Figure 15 shows the team working on our Insects for Food and Feed program INSEFF. I would like to acknowledge the groups in Figure 16 for funding various aspects of the program and I also acknowledge our institutional donors (Figure 17).

References

Alexandratos N., Bruinsma J. 2012. *World agriculture towards 2030/2050: the 2012 Revision.* ESA Working Paper No.12-03. FAO, Rome. https://www.fao.org/3/ap106e/ap106e.pdf (page 131, table 4.18)

Beesigamukama D. *et al*. 2020. Exploring black soldier fly frass as novel fertilizer for improved growth, yield, and nitrogen use efficiency of maize under field conditions. *Frontiers in Plant Sciences* **11** https://doi.org/10.3389/fpls.2020.574592

Beesigamukama D. *et al*. 2020. Nitrogen fertilizer equivalence of black soldier fly frass fertilizer and synchrony of nitrogen mineralization for maize production. *Agronomy* **10**(9): 1395. https://doi.org/10.3390/agronomy10091395

Beesigamukama D. *et al*. 2020. Biochar and gypsum amendment of agro-industrial waste for enhanced black soldier fly larval biomass and quality frass fertilizer. *PLoS ONE* **15**(8): e0238154. https://doi.org/10.1371/journal.pone.0238154

Beesigamukama D. *et al*. 2021. Low-cost technology for recycling agro-industrial waste into nutrient-rich organic fertilizer using black soldier fly. *Waste management* **119**: 183–194. https://doi.org/10.1016/j.wasman.2020.09.043

Cheseto X. *et al*. 2020. Chemistry and sensory characterization of a bakery product prepared with oils from African edible insects. Foods **9**(6), 800. https://doi.org/10.3390/foods9060800

Chia S.Y. *et al*. 2020. Smallholder farmers' knowledge and willingness to pay for insect-based feeds in Kenya. *PLoS ONE* **15**(3): e0230552. https://doi.org/10.1371/journal.pone.0230552

Kim Y.B. *et al*. 2020. Black soldier fly larvae oil as an alternative fat source in broiler nutrition. *Poultry Science* **99**(6): 3133-3143.

Ndotono E.W. *et al*. 2022a. Insights into the gut microbial communities of broiler chicken fed black soldier fly larvae-*Desmodium*-based meal as a dietary protein source. *Microorganisms* **10**(7): 1351. https://doi.org/10.3390/microorganisms10071351

Ndotono E.W. *et al.* 2022b. Gut microbiota shift in layer pullets fed on black soldier fly larvae-based feeds towards enhancing healthy gut microbial community. *Sci Rep* **12:** 6714. https://doi.org/10.1038/s41598-022-20736-0

Sebatta C. *et al*. 2018. *International Journal of Agricultural Research, Innovation and Technology* **8**(2): 32–41. DOI: 10.3329/ijarit.v8i2.40553

Sumbule E.K. *et al*. 2021. Cost-effectiveness of black soldier fly larvae meal as substitute of fishmeal in diets for layer chicks and growers. *Sustainability* **13**(11): 1–20.

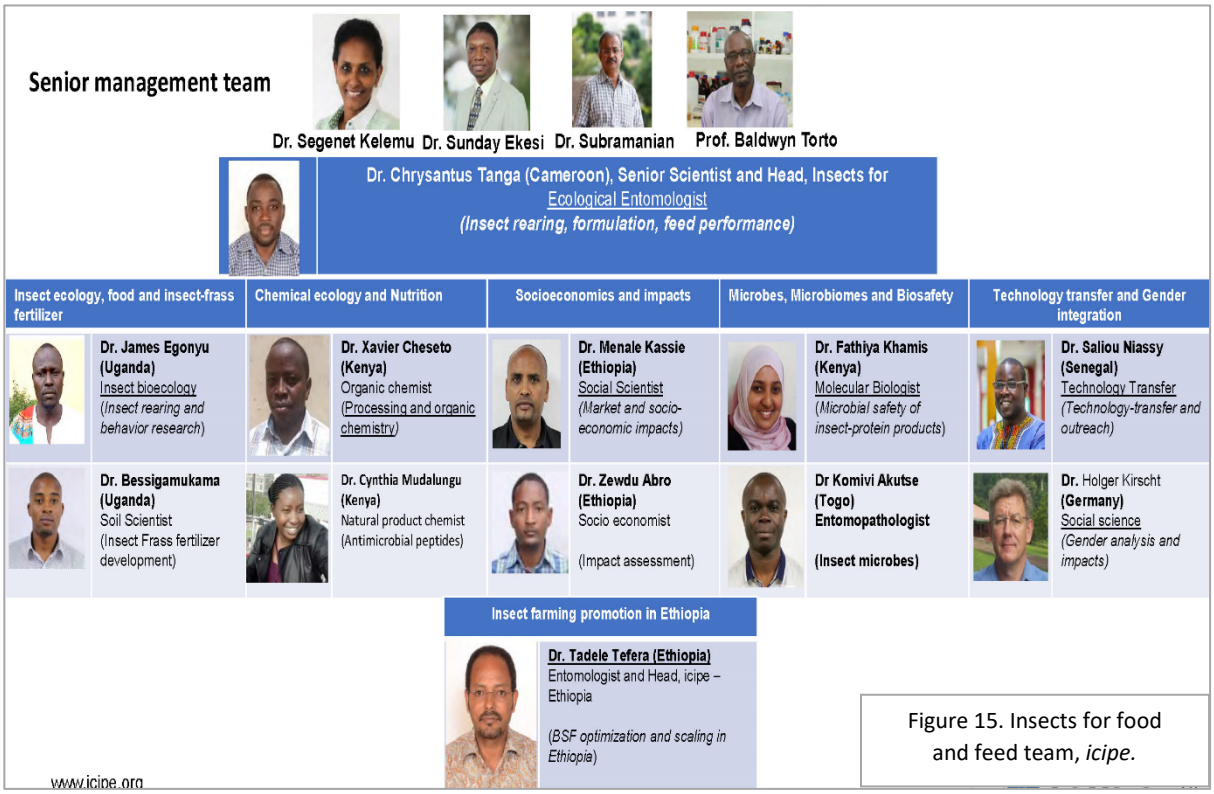

Figure 15. Insects for food and feed team, *icipe*.

Figure 16. These groups fund aspects of the program.

Figure 17. Institutional donors to *icipe*

Fathiya Khamis is a Molecular biologist and a Scientist in the Plant Health Theme of *icipe* working on native and invasive insect pests of fruits and vegetables that are of economic importance for food security in Africa and beyond. Fathiya applies molecular biology techniques for insect pest identification and understanding variabilities in pest populations – essential for the development of sustainable, integrated pest management systems. Fathiya also applies molecular techniques to assess the safety of insects as a sustainable source of nutritious food for humans and feed for livestock. Furthermore, she is advancing her research skills in microbiome analyses to enhance control of crop pests, improve biocontrol and reduce pesticide resistance in pest population. Fathiya is also active in building research capacity in Africa and has contributed significantly to the body of scientific knowledge through authoring and co-authoring more than 100 articles in international peer-reviewed journals and four book chapters.