INSFEED2: INSECT FEED FOR POULTRY, FISH AND PIG PRODUCTION IN SUB-SAHARAN AFRICA – PHASE 2

Cultivate Grant No: 108866-001

Organizations Involved in the Study
USIU-Africa, VACID-Africa, KALRO, KMFRI, Treasure Feed Industries Ltd, Makerere University

Location of Study
Kenya and Uganda

By

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FINAL TECHNICAL REPORT

01st August 2018 – 30th September 2021

31st November 2021

1. Executive Summary

In sub-Saharan Africa, poultry, pig and fish are fastest and most rapidly growing agricultural sectors. But these sectors are unable to realize their full potential due to the high cost of feed. This high cost of feed is attributed to the rising cost of major protein sources (fishmeal, soya bean, cotton seed cake, sunflower seed cakes and others), which represents over 70% of total production costs. This is further compounded by the lost of arable land and water of optimal production of these protein sources. Therefore, insects which are protein rich sources have been widely considered as alternative proteins for animal feeds. Due to the continuous growing interest to farm insects in sub-Saharan Africa, the INSFEED phase II project, funded by the International Development Research Centre (IDRC) and the Australian Centre for International Agricultural Research (ACIAR) partnership through the CultiAF program from August 2018 – September 2021. INSFEED 2 is aimed at scaling the achievements of the previous project phase based on increasing demands from the private sector, youth and small-scale farmers by evaluating the insect-based technologies under field conditions, testing different supply and upscaling pathways and developing a gender sensitive business model suitable for job creation and income generation for men, women and young farmers.

The traceability and capacity to reliably produce black soldier fly (BSF) larvae at commercial scale on various waste streams in Kenya and Uganda have been established. The crude protein (7 – 28%) of the organic waste have adequate nutrient to raise high-quality BSF larvae (crude protein: 38 – 62% on dry matter basis). The optimal conditions (25 - 33℃) for effective production in various agroecological zones showed over 80% of the larvae to marketable size. Safe processing options for the larvae revealed economically important pathogenic bacteria (*Campylobacter*, *Wohlfahrtiimonas* etc) and opportunistic fungus (*Cyberlindnera* sp. and *Trichosporon* sp.) that might pose health risks to both animals and humans. Thus, pre-treatment of waste is imperative for safe production of insect meal. The nutrient concentrations, fertilizing indices, nutrient supply potentials and compost maturity of nine insect frass fertilizers has been demonstrated. The impact on soil health and crop yield revealed that BSF frass fertilizers could be a complete or partial substitute of existing commercial fertilizers, with great potential to increase yields of French beans, kale, tomato, and maize by 41, 34, 26, and 32%, respectively, compared to applying inorganic fertilizers alone under field conditions. This has been reflected on the maize production with 29-44% higher net income to farmers. These findings justify the expansion of opportunities for future investments by the public private sectors, particularly in low- and middle-income countries.

The cost-effectiveness of BSF larvae meal (BSFLM) inclusion into broiler, layer, pig, and fish diets have been demonstrated on-station and on-farm with significantly higher gross profit margin, cost benefit ratio and return on investment following the increasing inclusion levels. Livestock and fish fed insect meal got ready to market size earlier, reducing cost of inputs and labour but increased profitability, if farmers decides to sell their pig, chicken or when the birds were allowed to lay eggs after being fed on diet with 50 and 75% BSFLM inclusion. The crude protein of the carcass of chicken, fish and pork were similar or superior in most cases when compared to animal fed on conventional fish meal-based feeds. Other carcass parameters measured included, fat content, ash, fiber, fatty acids (particularly omega- 3 fatty acids/ Omega -6 fatty acids), amino acids, minerals, and vitamins. The inclusion of BSFLM in broiler chicken diets significantly influenced the sensory and physicochemical properties of the meat, which accounted for the difference in organoleptic perception towards broiler meat. On-farm experiments set up revealed that the gut of broilers and layers fed diet with BSFLM (50 and 75% inclusion levels) significantly improved their gut health, which is attributed the presence of pre-biotic and probiotic bacteria (*Dysgonomonas*, *Morganella*, *Enterococcus*, *Pseudomonas*, *Actinomyces*, and *Providencia*). This might be a new shift away from the use of antibiotics in poultry production if there is wider adoption of insect-based feeds at commercial scale.

The economic viability studies to guide scaling up pathways, showed that between 65 - 85% of consumers are awareness and willing to pay for emerging insect-based protein, while 70-93% of the respondents showed preference and willingness to consume egg and meat products from animal fed diets with insect meal. Over 70% are willingness to pay a premium prices range between 0.31 – 3.05 US$ for either pellets or mash feed explicitly labelled as containing insect meal, insect meal mixed with soybean or fishmeal and dark-colored feed. Consumers were willing to pay 10% more for eggs with golden yellow yolk colour from layer chicken fed diet with insect-based feeds. Factors such as perceived benefits, ethics and traceability were observed to significantly influenced consumer intention to consume animal products when fed on diet containing insect meal. Household size, gender, awareness of insects as feed, off-farm income, household income, nature of buying place, and access to credit were important factors driving consumers perceptions. Other factors such feed *performance*, social *acceptability* of the use of insects in feed formulation, feed *versatility* and *marketability* of various products obtained from livestock and fish fed on diets with insect meal were identified as key attributes necessary to inform farmer purchase decisions. Also, awareness creation on insect-based feed attributes, group membership, off-farm income, wealth status and education level were the key factors that significantly

influenced farmers' perceptions. The findings provide evidence for multi-stakeholder collaborations to facilitate the creation of an inclusive BSFLM-based feed regulatory framework for sustainable feed and animal production.

Gender inclusive insect feed supply models adopted for production, marketing, and utilization of insect-based feed showed that farmers across gender were involved in cyclic business model (77%), market driven business models (18%) and out-grower business models (5%). Among these farmers, 69% were male and 31% women. Disaggregating businesses by gender, 78% of men versus 71% of women are involved in the cyclic model and 20% men versus 17% women in the market driven business models. The out-grower business model was more favored by women (12% women against 2% men). We observed that 36% women and 33% male respondents have been trained by other farmers. Majority of female farmers (64%) and male farmers (58%) got their training from *icipe*. Interestingly internet was also used as the source of training by men (9%) on how to farm black soldier fly. The mean age of the farmers was 37years with 42% of them practicing small scale production, while 35% and 23% of the farmers undertook medium and large-scale production, respectively. There was a positive correlation of 12% between years of enterprise establishment and tonnage of larvae production. Rearing substrate followed by labor are the most important running cost for insect mass production. A 1% increase in man-hours spent in the BSF farming enterprise led 0.34% reduction in the gross margin while 1% increase in the amount of waste used lead to 1.38% increase in the gross margin. These findings recommend that farmers should employ production options such as partial automation to reduce the number of man-hours spent in BSF production but at the same time significantly increase the utilization of more rearing substrate to improve profitability.

Pro-WEAI survey of 370 household-levels revealed that women are less empowered than men with 56% of the women disempowered (56 %) compared to 44% of men in dual households. Men performed better than women in dual households in all the 10 indicators. There is a huge gap between men and women in dual households in terms of work balance (women =54 %, men=74%) and self-efficacy (women=56%, men=82%). Only 56% of dual households (n=121) achieved gender parity. Approximately, 72% of the women had joint landowners and 5% sole landowners. For the men, 55% of them were joint landowners. Women reported a higher (26%) participation in decision making across all 12 decision-making domains than men (23%).

Socio-economic and environmental implications of replacing conventional poultry feed with insect-based feed in Kenya showed that 5-50% replacement of the major source of protein (fishmeal and soya bean meal) by BSFLM would generate a potential economic benefit of 69-687 million US$, if the entire poultry sector adopts BSFLM. These could translate to reducing poverty by 0.32-3.19 million people, increasing employment by 25,000-252,000 people, and recycling of 2-18 million tonnes of biowaste. The replacement of conventional fishmeal feeds by 5-50% BSFLM in the commercial poultry sector would increase the availability of fish and maize that can feed 0.47-4.8 million people at the current per capita of fish and maize consumption in Kenya. Similarly, the foreign currency savings would increase by 1-10 million US$ by reducing feed and inorganic fertilzer importation. These findings suggest that greater investment to promote BSFLM would boost economic, environmental and social sustainability.

Over 95% of the farms established during the project operate as microenterprises with opportunities to be transformed to large scale production. In Kenya and Uganda, over 978 black soldier fly farms have been established. The top ten insect farms can produce approximately 9780 metric tons of dried protein annually that can meet at least 7% of the crude protein needed to produce pigs, fish, and chickens. *icipe* continues to strengthen insect-based farming enterprises in the target countries with 11,200 farmers (38% females and 62% males) trained with increasing multiplier effects along the value chains. *icipe* played a leading role in the development of three new standards: (1) Production and handling of insects for food and feed – Code of practice; (2) Edible insects' products; and (3) Products containing edible insects. Similar standards have been drafted for Rwanda to be published soon. These new standards are an important milestone in supporting individual farmers, multinational companies and processing industry players interested in edible insects, who can now get accreditation to enable their products to be sold globally. Currently, over 9 out of 25 insect farming companies in Kenya have been issued with a Kenya Bureau of Standards (KEBS) certificates to market and sell their products both at the national and international fronts.

Throughout the project life cycle, a total of 1 PhD, 20 MSc (11 females + 9 males) and 5 BSc students (3 females and 2 males) have successfully completed their research work and submitted at least 1 manuscript for publication to internationally peer reviewed journal, which is a prerequisite for submission of their theses to the graduate board at the various universities for defence and graduation. A total of 35 articles have been published, 4 manuscripts accepted, 7 manuscripts submitted and 12 draft manuscripts under internal review by co-authors pending submission to credible journals.

2. The research problem

Increasing livestock and fish production in a sustainable manner has greater implication on food and nutrition security and poverty alleviation in developing countries. However, the conventional animal production is constrained by shortage of essential protein additives in their feed, in terms of quantity and quality. Further, available protein additives are costly increasing the feed costs substantially, which undermines the development efforts to boost production and to meet the food needs of growing population expected to reach 9.1 billion by 2050, while ensuring environmental sustainability. The Food and Agriculture Organization (FAO) of the UN estimates that the world will have to produce 200 million tonnes more meat by 2050 to feed the predicted 9.1 billion world population. This increase in meat production will require huge resources in terms of feed. Meeting the increased demand of conventional protein sources (fish, soya bean, cotton seed cake, sunflower seed cake among others) would requires developing cost-effective, socially, and environmentally sustainable alternative animal feed protein sources. Dependence on these major protein sources is becoming increasingly unsustainable, which accounts for over 70% of total production costs. Insect meal is widely accepted globally as an emerging, cost-effective, and sustainable protein alternative to fish, soya bean, cotton seed cake, sunflower seed cake among others in animal feed.

Results from the previous project (INSFEED 1) revealed that men and women poultry and fish farmers knew of many insect species that could be fed raw to their animals because these insects were most preferred in nature. It also clearly demonstrated that over 28 species of insects were rich source of crude protein ranging between 32.9 – 73.3% in dry matter basis. This is superior to the crude protein content of fishmeal (40.3%) and soya bean meal (38%) in Kenya and Ugandan market. INSFEED 1 also showed that no aflatoxin was found reared insects when preserved in clean containers. Also, steaming the insects at 96°C for 5 min or toasting at 150°C for 2 min inactivated all bacteria and fungi that could pose health risk to livestock and fish. The project showed that female livestock farmers were the most affected by increase in feed prices in comparison with male counterparts (Macharia et al., 2016), which is further compounded by the general lack of adequate cash flow to afford purchased feed. Thus, these women resorted to home-made livestock feed rations, of uncertain quality. INSFEED 1 project also showed that relative to men, women livestock farmers lack access to institutional support services such as extension, training, and credit to help improve productivity of the enterprise, though they were more involved than men in livestock production, while men dominated fish production in ponds. Particularly purchasing and provision of feed to the livestock were women dominated activities. On-station feeding trials with insect-based diets showed that 100% replacement of fishmeal with insect meal in layer diets yielded the highest egg production and quality, while broiler growth performance was not affected by 100% insect protein inclusion in the diet.

Based on the excellent data generated in INSFEED 1 project, several new gaps were identified and need to be addressed: (1) fine-tune or optimize the mass rearing procedures of these insects to ensure traceability and effective yield under commercial scale of production by the private sector partners; (2) develop a more comprehensive business model with a robust capacity planning potential on-farm that enables proper planning and successful and timely delivery (in quality and quantity) of insect-based protein to customers needs; (3) generate information on substrate and insect larvae product quality when reared in different agro-ecological zones; (4) evaluate the quality of the frass fertilizer and their contribution towards solving the increasing acute soil infertility and improved crop yield in the region; (5) determine the economic benefits of insect farming and insect based feed for poultry, fish and pig production systems along the value chain; (6) predict the long-term potential impact of insect based feed technologies on food and nutrition security; (7) assess economic viability of insect based feed supply chain models to guide scaling up pathways; (8) develop and test gender inclusive insect feed supply models and build capacity along the value chain; (9) create awareness through various dissemination channels targeting the different actors; (10) develop, test and compare different supply chain models linking insect production with feed manufacturing.

The proposed project will contribute to closing the gender gaps by equitably availing appropriate and sustainable technological options in poultry, fish, and pig farming as well as the feed industry, thus empowering women. The new entrepreneurship opportunities through small and medium-scale insect rearing, feed production as well as poultry, fish and pig farming will create jobs and empower the youth in Uganda and Kenya. By increasing the food supply, reducing hunger and increasing income generation opportunities for small-scale farmers in a sector dominated by women and youth, the project will contribute towards meeting the goals of Pillar 3 (increase food supply and reduce hunger across the region by raising smallholder productivity and improving responses to food emergencies) of the Comprehensive Africa Agricultural Development Plan (CAADP), the Sustainable development Goals 1 (no poverty), SDG2 (no hunger), SDG4 (promote gender equality) and SDG 8 (decent work and economic growth). The project will also contribute to Kenya vision 2030 and Uganda vision 2040 through the reduction of extreme poverty, job creation for youth, gender equity and environmental sustainability (GoK, 2007; NPA, 2010).

3. Progress towards milestones

Table 1: INSFEED-Phase 2 project progress towards milestones

Milestones	Progress	Comment
Updates Covering the last 42 months and reflecting on the following milestones		
INSFEED Phase II - Inception and planning workshop organized	100%	• The inception meeting was held on Monday 10th – Tuesday 11th December 2018 at Safari Park Hotel & Casino, Nairobi, Kenya.
MoU established with all partners	100%	• All partners' MoU established and implemented successfully
Students recruited	100%	• A total of 1 PhD, 20 MSc (11 females + 9 males) and 5 BSc students (3 females and 2 males) were involved in the project (**Annex 1**)
Objective 1: Fine-tune and deploy rearing techniques under small- and medium-scale on-farm conditions to improve capacity planning to meet customer demand for insect-based protein and fertiliser		
Activity 1.1: Improve traceability and capacity planning for reliable and timely meetings of customers' demands.	100%	• Two articles published on the biosafety of BSF larvae grown on the most commonly available waste - Tanga CM, Waweru JW, Tola YH, Onyoni AA, Khamis FM, Ekesi S and Paredes JC (2021) Organic waste substrates induce important shifts in gut microbiota of black soldier fly (*Hermetia illucens* L.): Coexistence of conserved, variable, and potential pathogenic microbes. *Front. Microbiol.* 12:635881. doi: 10.3389/fmicb.2021.635881. - Khamis F. M., Fidelis L O Ombura, Komivi S. Akutse, Sevgan Subramanian, Samira A. Mohamed, Komi K.M. Fiaboe, Weerachai Saijuntha, Joop J.A. Van Loon, Marcel Dicke, Thomas Dubois, Sunday Ekesi, Chrysantus M. Tanga (2020) Insights in the global genetics and gut microbiome of black soldier fly, *Hermetia illucens*: Implications for animal feed safety control. Frontiers in Microbiology 11:1538. https://doi.org/10.3389/fmicb.2020.01538. • One article on the nutritional quality of larvae raised on different waste in Kenya published - Chia SY, Tanga M.C., Osuga I, Ekesi S, Van Loon JJA, Dicke M. (2020). Nutritional composition of black soldier fly larvae feeding on agro-industrial by-products. *Entomologia Experimentalis et Applicata*. doi: 10.1111/EEA.12940. • One article on the global genetic structure of BSF raised on various waste has been established. - Kaya, C., T.N. Generalovic, G. Ståhls, M. Hauser, A.C. Samayoa, C.G. Nunes-Silva, H. Roxburgh, J. Wohlfahrt, E.A. Ewusie, M. Kenis, Y. Hanboonsong, J. Orozco, N. Carrejo, S. Nakamura, L. Gasco, S. Rojo, C.M. Tanga, R. Meier, C. Rhode, C.J. Picard, C.D. Jiggins, F. Leiber, J.K. Tomberlin, M. Hasselmann, W.U. Blanckenhorn, M. Kapun and C. Sandrock (2021) Global population genetic structure and demographic trajectories of the black soldier fly, *Hermetia illucens*. BMC Biology, 19:94. https://doi.org/10.1186/s12915-021-01029-w. • One article on potential natural enemies posing risk of BSF colony collapse - Gérard Delvare, Robert S. Copeland & C.M. Tanga (2019) Description of *Eniacomorpha hermetiae* Delvare sp. n. (Hymenoptera, Chalcidoidea, Chalcididae) a pupal parasitoid of *Hermetia illucens* (L.) (Diptera, Stratiomyidae), and a potential threat to mass production of the fly as a feed supplement for domestic animals. Zootaxa 4638 (2): 237–254. • One draft report on the effect of waste on the quality of BSF larvae fed on 12 different substrates in Uganda developed (**Annex 2**).
Activity 1.2: Develop quality organic fertiliser for enhanced crop production alongside high yielding insect production.	100%	• A total of 8 articles on frass fertilizer production and on-farm testing on vegetables and maize published. - Anyega AO, Korir NK, Beesigamukama D, Ghemoh CJ, Nkoba K, Subramanian S, van Loon JJA, Dicke M and Tanga CM (2021) Black Soldier Fly-Composted Organic Fertilizer Enhances Growth, Yield, and Nutrient Quality of Three Key Vegetable Crops in Sub-Saharan Africa. Front. Plant Sci. 12:680312. doi: 10.3389/fpls.2021.680312. - Beesigamukama D., B. Mochoge, N. Korir, C.J. Ghemoh, S. Subramanian and C.M. Tanga (2021) In situ nitrogen mineralization and nutrient release by soil amended with black soldier fly frass fertilizer. Scientific Reports, 11:14799. https://doi.org/10.1038/s41598-021-94269-3. - Tanga C.M., D. Beesigamukama, M. Kassie, P.J. Egonyu, Changeh J. Ghemoh, Kiatoko Nkoba, S. Subramanian, A.O. Anyega, and S. Ekesi (2021) Performance of Black Soldier Fly Frass Fertilizer on Maize (*Zea mays* L.) Growth, Yield, Nutritional Quality, and Economic Returns.

		Journal of Insects as Food and Feed (in press), 0 (0)- Pages: 1 – 12. https://doi.org/10.3920/JIFF2021.0012. - Beesigamukama D., B. Mochoge B, N.K. Korir NK, K.K.M. Fiaboe KKM, D. Nakimbugwe D, Khamis FM, Subramanian S, Wangu MM, Dubois T, Ekesi S, Tanga CM. (2021). Low-cost technology for recycling agro-industrial waste into nutrient-rich organic fertilizer using black soldier fly. *Waste management Journal.* Waste Management 119 (2021) 183–194. - Dennis Beesigamukama, Benson Mochoge, Nicholas Korir, Martha W. Musyoka, Komi K. M. Fiaboe, Dorothy Nakimbugwe, Fathiya M. Khamis, Sevgan Subramanian, Thomas Dubois, Sunday Ekesi and C.M. Tanga (2020). Nitrogen Fertilizer Equivalence of Black Soldier Fly Frass Fertilizer and Synchrony of Nitrogen Mineralization for Maize Production. Agronomy, 10, 1395; doi:10.3390/agronomy10091395. - Beesigamukama, D., Mochoge, B., Korir, N.K., Fiaboe, K.K., Nakimbugwe, D., Khamis, F.M., Dubois, T., Subramanian, S., Wangu, M.M., Ekesi, S. and Tanga, C.M. (2020). Biochar and gypsum amendment of agro-industrial waste for enhanced black soldier fly larval biomass and quality frass fertilizer. *PloS one*, *15*(8), p.e0238154. - Beesigamukama D, Mochoge B, Korir NK, Fiaboe KKM, Nakimbugwe D, Khamis FM, Subramanian S, Dubois T, Musyoka MW, Ekesi S, Kelemu S and Tanga C.M. (2020) Exploring Black Soldier Fly Frass as Novel Fertilizer for Improved Growth, Yield, and Nitrogen Use Efficiency of Maize Under Field Conditions. Front. Plant Sci. 11:574592. doi: 10.3389/fpls.2020.574592. - Beesigamukama, D., B. Mochoge, N. Korir, K. Menale, B. Muriithi, M. Kidoido, H. Kirscht, G. Diiro, C.J. Ghemoh, S. Sevgan, D. Nakimbugwe, M.W. Musyoka, S. Ekesi and C.M. Tanga (2021) Economic and ecological values of frass fertiliser from black soldier fly agro-industrial waste processing. *Journal of Insects as Food and Feed,* 0 (0)- Pages: 1 – 10. https://doi.org/10.3920/JIFF2021.0013. • One manuscript on the fertilizer quality of nine insects have been demonstrated and manuscript submitted. - Beesigamukama, D., S. Sevgan and C.M. Tanga (2021) Organic waste recycling by nine edible insects into quality frass fertilizers: The key to boosting soil fertility and crop productivity. *Scientific Reports* (submitted) (**Annex 3**) • One elsevier book chapter on frass fertilizer and impact on soil pathogenic bacteria submitted - Beesigamukama, D., María Gómez-Brandón and C.M. Tanga (2021) Potential of entomocomposting towards organic waste and soil pathogen suppression. *Elesiver Book Preparation for Fate of Biological Contaminants During Recycling of Organic waste.* (submitted) (**Annex 4**)
Activity 1.3- Establish insect rearing on-farm and assess performance and constraints based on rearing model, gender, age, scale and agro-ecology	100%	• One article on the circular economy of black soldier fly farming in East Africa with indications of the impact of waste streams on the nutrient quality of the larvae and state of production has been published. - Tanga C. M, James P Egonyu, Dennis Beesigamukama, Saliou Niassy, Kimathi Emily, Henlay JO Magara, Evanson R Omuse, Sevgan Subramanian and Sunday Ekesi (2021) Edible insect farming as an emerging and profitable enterprise in East Africa. Current Opinion in Insect Science 2021, 48:64–71. https://doi.org/10.1016/j.cois.2021.09.007. • One report on lessons learnt on black soldier fly farming under on-farm conditions in Kenya has been established (**Annex 5**) • One article on the determinant of profitability of black soldier fly farming enterprise and potential constrain in Kenya has been established. - Mutuku K.V., A.W. Mukhebi, M.A. Orinda and C.M. Tanga (2021) Determinants of profitability of black soldier fly farming enterprise in Kenya. *Journal of Insects as Food and Feed,* 0 (0)- Pages: 1 – 8. https://doi.org/10.3920/JIFF2021.0066.
Objective 2- Assess the cost-effectiveness and potential livelihood effects of insect-based feed technologies through gender lens along the value chain		

2.1: Determine the economic benefits of insect farming and insect-based feed for poultry, fish and pig production systems along the value chain.	100%	• A total of 8 articles were published on the cost-effectiveness on insect farming and insect-based feeds - Beesigamukama, D., B. Mochoge, N. Korir, K. Menale, B. Muriithi, M. Kidoido, H. Kirscht, G. Diiro, C.J. Ghemoh, S. Sevgan, D. Nakimbugwe, M.W. Musyoka, S. Ekesi and C.M. Tanga (2021) Economic and ecological values of frass fertiliser from black soldier fly agro-industrial waste processing. *Journal of Insects as Food and Feed,* 0 (0)- Pages: 1 – 10. https://doi.org/10.3920/JIFF2021.0013. - Okello, A.O.; Nzuma, J.M.; Otieno, D.J.; Kidoido, M.; Tanga, C.M. (2021) Farmers' Perceptions of Commercial Insect-Based Feed for Sustainable Livestock Production in Kenya. *Sustainability*, *13*, 5359. https://doi.org/10.3390/su13105359. - Khaemba C.N., M. Kidoido, G. Owuor and C.M. Tanga (2021) Consumers' perception towards eggs from laying hens fed commercial black soldier fly (*Hermetia illucens*) larvae meal-based feeds. *Poultry Science*, doi:https://doi.org/10.1016/j.psj.2021.101645. - Chia S. Y., Macharia J., Diiro G.M., Kassie M., Ekesi S., van Loon J. J. A., Dicke M. and Tanga C. M. (2020) Smallholder farmers' knowledge and willingness to pay for insect-based feeds in Kenya. *PLOS One* 15, e0230552. https://doi.org/0230510.0231371/journal.pone.0230552. - Sumbule, E.K.; Ambula, M.K.; Osuga, I.M.; Changeh, J.G.; Mwangi, D.M.; Subramanian, S.; Salifu, D.; Alaru, P.A.O.; Githinji, M.; van Loon, J.J.A.; Marcel Dicke and C. M. Tanga (2021) Cost-Effectiveness of Black Soldier Fly Larvae Meal as Substitute of Fishmeal in Diets for Layer Chicks and Growers. Sustainability, 13, 6074. https://doi.org/10.3390/su13116074. - Wachira, M.N.; Osuga, I.M.; Munguti, J.M.; Ambula, M.K.; Subramanian, S. and Tanga, CM (2021) Efficiency and Improved Profitability of Insect-Based Aquafeeds for Farming Nile Tilapia Fish (*Oreochromis niloticus* L.). *Animals*, 11, 2599. https://doi.org/10.3390/ani11092599. - Mutisya M.M., Agbodzavu K. Mawufe, John N. Kinyuru, C.M. Tanga, Mathew Gicheha, Girma Hailu, Daisy Salifu, Zeyaur Khan, Saliou Niassy (2020) Can Black Soldier Fly Larvae-*Desmodium intortum* based Diets enhance the Performance of Cobb500® Broiler Chickens and Smallholder Farmers' Profit in Kenya? *Poultry Science* 100(8) DOI: 10.1016/j.psj.2020.11.021. - Mutisya M.M., Agbodzavu K. Mawufe, John N. Kinyuru, C.M. Tanga, Mathew Gicheha, Girma Hailu, Daisy Salifu, Zeyaur Khan, Saliou Niassy (2022) Effect of *Desmodium intortum* and black soldier fly larvae *Hermetiaillucens* based meal on sensory and physicochemical properties of broiler chicken meat in Kenya. Journal of Insects as Food and Feed: 0 (0)- Pages: 1 – 14. https://doi.org/10.3920/JIFF2021.0103 . • Ten drafted or submitted manuscript on the economic viability of insect-based feeds. - Mawai H., G.M. Diiro, I. Macharia, P. Irungu, J. Mburu, J.J. A. van Loon, J. Nabikyu, M. Dicke and C.M. Tanga (2022) Gender specific preference and willingness to pay for meat derived from chicken fed insect-based feeds (**Annex 6**). - Mwangi J.K., J.N. Kinyuru, P. Kahenya, I.M. Osuga, D. Salifu, C.J. Ghemoh, E.K. Sumbule, J. J. A. van Loon, T. Dubois, S. Subramanian, M. Dicke and C.M. Tanga (2021) Benefits of Incorporating Black Soldier Fly Larvae Meal into Laying Hen Diet on the Nutritional Quality of Eggs. *Frontiers in Nutrition* (Submitted) (**Annex 7**). - Sumbule E.K., M.K. Ambula, I.M. Osuga, D.M. Miano, D. Salifu, P.A.O. Alaru, M. Githinji, S. Ekesi, J.J. A van Loon, M. Dicke and C. M. Tanga (*2022*) Black soldier fly larvae-based diet boost laying hen egg production and profit: Overcoming major protein source dependence in Africa. *Animal Feed Science and Technology*. (**Annex 8**). - Okello A.O., D.J. Otieno, J.M. Nzuma, M.M. Kidoido and C.M. Tanga (2021) Farmers' willingness to pay for commercial insect-based chicken feed. *Food policy* (Submitted) (**Annex 9**) - Okello A.O., C.M. Tanga, M.M. Kidoido and I.M. Osuga (2022) Economic performance of insect-based feeds for broiler chicken production under smallholder farmers production systems in Kenya (**Annex 10**) - Khaemba C.N., M. Kidoido, G. Owuor and C.M. Tanga (2021) Economic viability of eggs production from hen fed insect-based feeds under smallholder farming systems. (**Annex 11**) - Wamai L.K., L.M. Munga, I.M. Osuga, C.M. Tanga and M. Kidoido (2021) Growth performance and economic analysis of substituting soybean and sunflower cake with black soldier fly larval meal in chicks and grower chicken diets. *Animal Feed Science and Technology*. (**Annex 12**)

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		- Wamai, L.K., L.M. Munga, I.M. Osuga, M. Kidoido and C.M. Tanga (2021) Laying performance and cost effectiveness of laying hen fed diet containing black soldier fly larval meal. *Animal Nutrition*. (**Annex 13**) - Wamai L.K., L.M. Munga, I.M. Osuga and C.M. Tanga (2021) Laying hen fed diet with black soldier fly larvae meal produced improved quality eggs: Implications in human nutrition and health. *Food Quality and Preference*. (**Annex 14**) - Makatiani B.C., Kirscht, H. and C.M. Tanga (2021) Smallholder pig and poultry farmers' awareness of black soldier fly (*Hermetia illucens*) farming in, Kenya. **(Annex 15)**
Activity 2.2: Predict the long-term potential impact of insect-based feed technologies on food and nutrition security.	100%	• One article on the socio-economic and environment impact of replacing fishmeal in animal feed has been published. - Zewdu A., M. Kassie, C.M. Tanga, D. Beesigamukama and G. Diiro (2020) Socio-economic and environmental implications of replacing conventional poultry feed with insect-based feed in Kenya. *Journal of Cleaner Production*. 265: 121871.
Activity 2.3: Assess economic viability of insect-based feed supply chain models to guide scaling up pathways.	95%	• One draft report on determinants of investor's preference for business models in insect-based feed value chains in Kenya. (**Annex 16**) • A draft report on the impact of COVID 19 on male and female BSF entrepreneurs in Kenya (**Annex 17**).
Objective 3 - Develop and test gender inclusive insect feed supply models and build capacity along the value chain		
3.1: Awareness creation.	100%	• INSFEED activities have been mentioned in 494 articles produced in 15 major languages across 40 countries in 4 continents. The estimated reach is anticipated to 3 billion people (http://www.icipe.org/sites/default/files/Insfeed-Media-Coverage.pdf) (**Annex 18a,b&c**) • Over 87 web-based stories on the project activities in the target countries (**Annex 18a, b & c**). • The INSFEED research outputs have been presented several international conferences 1. Entomological Society of America Annual Meeting - Entomology 2020 (3,200 entomologists) and the Insects to Feed the World 2020 Virtual Conference (450 participants from 45 countries) 2. Keynote speaker: Insects to Feed the World 2020 Virtual Conference, November 23-26, 2020. Journal of Insects as Food and Feed 6 Supplement 1. SSN 2352-4588 online, DOI 10.3920/JIFF2020.S1. 3. Eleven (11) presentations at the Insects to Feed the World 2020 Virtual Conference, November 23-26, 2020. 4. Four (4) presentations at the Animal Production Society of Kenya (APSK) meeting, April 9 -11, 2019 at Hotel Waterbuck Nakuru, Kenya. 5. Nine (9) presentation at the 1st African Conference on Edible Insects; 14–16 August 2019, Harare, Zimbabwe. 6. An oral presentation in the INSECTINOV 3: Insect Production for Human and Animal Nutrition held on the 26th – 28th November 2019 - Adebiotech, Paris France. 7. An oral presentation at the 23rd Meeting and Conference of the African Association of Insect Scientists (AAIS), 18–22 November 2019, National institute of Public Health, Côte d'Ivoire 8. An oral presentation at the INSECTA 2019 International Conference, 05th – 06th September 2019, Potsdam, Germany. 9. An oral presentation on the 13th International Congress of Orthopterology, March 24–28, 2019, Agadir, Morocco. 10. Two virtual presentations at the 31st International Conference of Agricultural Economists (ICAE 31), held during 17-31 August 2021 online • An on-line mobile interactive platform (DuduTalk) for BSF farmers and feed processors has been developed to be anchored on the INSFEED website under construction. • Three policy briefs have been developed for publication on activities related to the project. (**Annex 19a, b & c**) • A total of 3562 certificates of participation have developed, printed and distributed to those who successfully completed the training of trainer (ToT) course on "Organic waste recipes, BSF production, processing, and animal feed formulation. (**Annex 20**)

		• Six educative and training videos on BSF production have been developed to be anchored on the Insect for Food and Feed website at *icipe*: https://youtube.com/playlist?list=PL9gX8_3YU6k_LGuTQ9Euqv_OBgp92WHZ_ • Workshops and meeting engaging policy makers were organized to finalize the development and approval of three new standards in December 2020 (1) Production and handling of insects for food and feed – Code of practice; (2) Edible insects' products & (3) Products containing edible insects) in Kenya and Uganda. (**Annex 21 a, b & c**)
3.2: Develop, test, and compare different supply chain models linking insect production with feed manufacturing and financial institutions.	90%	• One draft manuscript on business model has been developed. - Bulinda C., K. Holger and C.M. Tanga (2021) Gender inclusive investor's preference for business models in insect-based feed value chains in Kenya. (**Annex 16**) • Training workshop on insect for food and feed product certification requirements and procedures to acquire KEBS Permit to use the Standardization Mark was organized on 23 July 2021 with a total of 25 SMEs involved. (**Annex 22**) • Out of the 25 SMEs, fifteen (15) (Wayan Consultancy Ltd, ProteinMaster Ltd, InsectiPro Ltd, BugPicture Ltd, R.O. Urban Farm, Ecodudu Ltd, FAM Feed Ltd, Sanergy Ltd and NutriEnto Ltd) have successfully received permission to use the KEBS standardization mark (certification) to market insect-based feed products in Kenya and beyond (**Annex 23**). • There are over 1000 well-established young insect-based enterprises in Kenya and Uganda run by youths and women (https://doi.org/10.1016/j.cois.2021.09.007) (Annex…) and the first top ten (10) of these companies produces approximately 9780 metric tons of dried insect protein annually for the market. • One of the entrepreneurs (InsectiPro Ltd) developed within the project has been able to secure substantial financial grant from Dutch Sustainable Trade Initiative (IDH) ($US 200,000) and Bill & Melinda Gates Foundation (BMGF) ($US 2.1 million). The BMGF project is implemented in partnership with *icipe*. • Six insect-based enterprises within the project (Zihanga Ltd, The Insectary Ltd, NutriEnto Ltd, The Bug Picture Ltd, Biobuu Ltd and Bug Life Ltd) got financial support of $US 10,000 from Rockefeller Foundation and Dalberg. • One of the entrepreneurs (InsectiPro Ltd) was among the finalist for the new Sustainable Food Systems Solver Class 2020. (https://solve.mit.edu/articles/meet-the-solver-teams-sustainable-food-systems#). • The International Centre of Insect Physiology and Ecology (www.*icipe*.org) and Sanergy Ltd were jointly awarded the prestigious, USD 1 million Curt Bergfors Foundation Food Planet Prize, from about 650 global nominations, in recognition of the Centre's pioneering research and development (R&D) activities on insects for feed and other uses. See link: https://www.the-star.co.ke/news/2020-12-15-icipe-sanergy-among-2020-food-planet-prize-winners/ • Several enterprises in Kenya (Sanergy, Biobuu Ltd, InsectiPro Ltd among others) and Uganda (Marula Proteen Ltd, Protein Kapital Ltd, Bobo Eco Farm Ltd and others) have secured both national and international market outlets for their insect-based products. For example, Sanergy Ltd anticipates producing the highest yield (250 MT/month) of dried BSF product in sub-Saharan Africa for regional (feed manufacturers) and export market, particularly in the UK market. • Sanergy Ltd and *icipe* won a £100,000 grant from the Foreign, Commonwealth & Development Office (FCDO) to undertake a project titled: "Validation of low-cost sensors for optimal insect protein production" to help scale up BSF larvae production as sustainable protein to boost livestock and fish farming. • BioBuu Ltd, Kenya, which a medium scale insect-based enterprise got financial support of $US 750,000 from BioInnovate Africa to scale up the BSF production in Kenya and Uganda. • The County government of Busia and Nyandarua in an attempt to supported youth groups involved in BSF farming with 1 million Kenyan shillings.

1. Synthesis of research results to date:

Work Package 1: Fine-tune and deploy rearing techniques under small- and medium-scale on-farm conditions to improve capacity planning to meet customer demand for insect-based protein and fertiliser.

- Selection of potential waste streams for reliable production of black soldier fly larvae and traceability of their quality for marking revealed single and combined substrates in Kenya (26) and Uganda (12). The crude protein of available waste in the target countries ranged between 7 – 28%, while that of the BSF larvae raised on these wastes range between 38 – 62% on dry matter basis. This implies that majority of the waste types in the target countries had adequate nutrients to sustain the development (9 –23 days) and survivorship (>80%) of the larvae to marketable size (**Annex 2**).

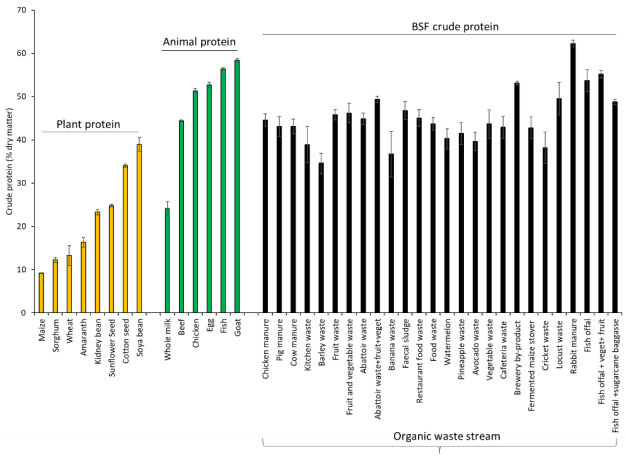

Figure 1: Comparative analysis of BSF larvae protein raised on various organic waste and existing major plant and animal-based protein sources

- The mean fecundity per female raised on the various waste types ranged between 285–924 eggs. The most effective eggs harvesting devices used in BSF "love" or laying cages were corrugated cardboard and wooden stacks with over 90% egg laying achieved. The optimal temperature for egg hatching and larvae growth ranged between 25 - 33℃ under room conditions with substrate temperature of 33-35℃. At 70 - 80% relative humidity, over 85% hatchability of the eggs, >90% survival of larvae and emergence of adult flies was observed. Larvae mortality rate increased at temperatures above 37 - 47℃. Both male and female adult flies lived on average 11–16 days when provided water. The fat, ash, fatty acids (especially omega-3 fatty acids), amino acid profiles, vitamins (riboflavin, thiamine, folic acid, vit E and A) and mineral (iron, calcium, zinc, and potassium etc) contents of BSF larvae grown on waste and other insects (crickets, locust etc) were identified.
- Safety analysis of the BSF larvae collected in six continents and raised on varied waste showed economically important pathogenic bacteria (*Campylobacter*, *Wohlfahrtiimonas* etc) and opportunistic fungus (*Cyberlindnera* sp. and *Trichosporon* sp.) that might pose health risks to both animals and humans. This study recommends pre-treatment of feedstocks and postharvest measures of the harvested BSF larvae to minimize risk of pathogen contamination along the insect-based feed value chain.
- In another study on larvae reared on brewers' spent grain, kitchen food waste, poultry manure, and rabbit manure, we observed six conserved bacterial members in 99.9% of our samples, namely, *Dysgonomonas*, *Morganella*, *Enterococcus*, *Pseudomonas*, *Actinomyces*, and *Providencia*. However, BSF larvae fed on rabbit manure induced a dysbiosis with higher loads of the pathogenic bacteria, such as *Campylobacter*. This study provides the first comprehensive analysis of bacterial and fungal communities of BSF gut across untreated substrates and highlights conserved members, potential pathogens, and their interactions. This information contributes to the establishment of safety measures for future processing of BSF larval meals and the creation of legislation to regulate their use in animal feeds.

- Insect-based feeds were fed to broiler and layer chicken, showed many beneficial bacteria (*Enterococcus*, *Pseudomonas*, *Dysgonomonas*, *Actinomyces* among others) in their gut. Our findings unravel complex gut microbial shift in laying hen and broiler gut when fed BSF larvae meal and underpins the potential roles of beneficial bacteria that could be exploited as promising prebiotics and probiotics in reshaping of the gut microbiota of layer chickens to enhance gut health and food safety.
- Two important postharvest pests particularly *Necrobia rufipes* DeGeer (A) and *Tribolium castaneum* Herbst (B) were observed in dried and stored BSF larvae products in many insect-based enterprises established in Kenya and Uganda (e.g., Sanergy Ltd, InsectiPro Ltd, Eco Dudu Ltd, Marula Proteen Ltd, Protein Kapital Ltd, Eco Bobo Farm, The bug Picture Ltd, BugLife Ltd among others.

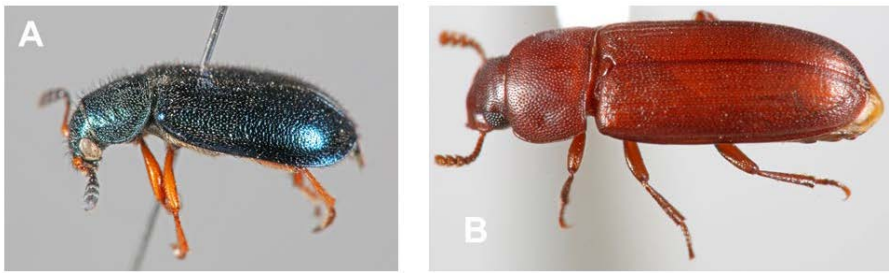

Figure 2: Two major postharvest pest infesting dried and stored dried black soldier fly larvae in Kenya and Uganda

- Other key natural enemies attacking BSF during rearing include the newly described pupal parasitoid, *Eniacomorpha hermetiae* Delvare, which inflicted over 70% pupal parasitism and suppressing adult emergence from the pupae.

Figure 3: Pupal parasitoid attacking black soldier fly pupae during storage for emergence to adult flies in many insect-based enterprises in Kenya and Uganda.

- Also, phoretic mite *Macrocheles muscaedomesticae* (Scopoli), were commonly observed cling on the body of adult flies in poorly managed insect farms causing high mortality (>80%), no mating of adult, low or no egg production by afflicted female flies.

Figure 4: Adult female black soldier fly heavily infected by phoretic red mites across insect-based enterprises in Kenya and Uganda

- Our findings showed that crickets are excellent source of protein (*Scapsipedus icipe* = 56.8 and *Gryllus bimaculatus* = 56.9%), minerals (particularly iron, zinc and potassium contents), and vitamins (Riboflavin, thiamine, and folic acid concentrations are superior to that of the conventional sources) for animal feed compared to many plant and animal protein sources. Protein digestibility of both insects (*S. icipe* and *G. bimaculatus*) ranged between 80 - 88%, which is comparable to that of common plant foods but slightly lower than that of animal proteins. Thus, integrating cricket flours into feed products will help to address the most pressing nutritional challenges observed in animal feed industry.
- The quality of insect oil as rich source for animal feed has been established. Profiling of oils from ten insect species revealed that they are rich in all types of omega-3 fatty acids compared to plant sources (Olive and Sesame oils) with only one form. The peroxide, iodine, saponification, and acid values of some of these insects ranged between 1.92-2.49 mEq O_2/Kg, 103.44-104.94 g I_2/100g, 234-246 mg KOH and 1.10-2.19 mg KOH, respectively. Antinutritional properties (oxalates, phytates and tannins) of insect oils ranged between 95.99-97.01 mg/100g, 3.85-10.33 mg/100g and 0-1.56 mg/100g. These findings suggest that insect oils can be utilized as alternative ingredients in feed and pharmaceutical industries.

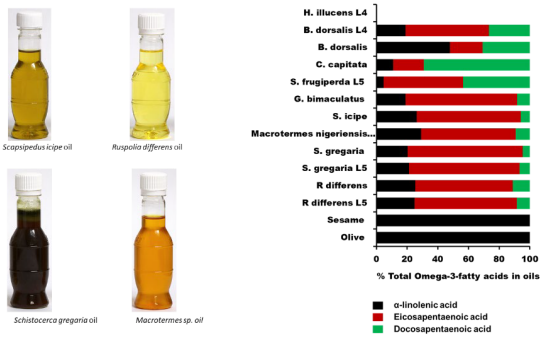

Figure 5: Omega-3 fatty acids content of edible insects for feed

- Nutrient quality and maturity status of frass fertilizer from nine (9) insect species, comparing the nutrient concentrations, fertilizing indices, nutrient supply potentials and compost maturity has been completed. The frass fertilizer from all the insect species had adequate concentrations of nitrogen (N), phosphorus (P), potassium (K) and micronutrients. The fertilizing indices of the frass fertilizers were above 3, which indicates good quality products. However, BSF frass fertilizer was the best with significantly higher N (20 – 130%) and K (17 – 193%) concentrations compared to others. The highest seed gemination rate (> 90%) and germination index (267%) were observed in seeds treated with BSF frass fertilizer. Frass fertilizer obtained

from the other eight insect species require further composting for maturity and stability. These findings demonstrate that insect frass fertilizers are promising alternatives to existing commercial fertilizers (i.e., mineral, and organic) for improved soil health and crop yield.

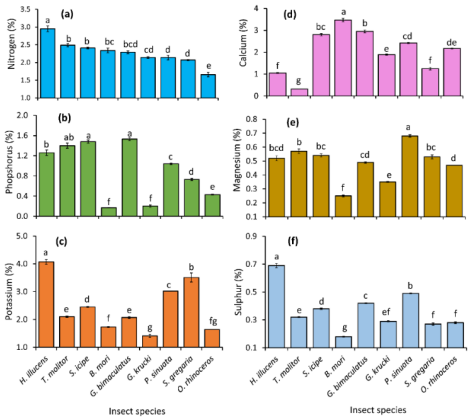

Figure 6: Total concentrations of nitrogen (a), phosphorus (b), potassium (c), calcium (d), magnesium (e) and sulphur (f) in frass fertilizer generated by different edible insects. Per panel, means (±standard error) followed by the same letters are not significantly different at $p \leq 0.05$.

- On-farms trials demonstrate that the use of BSF frass fertilizer in vegetable cropping systems at the recommended rate would improve soil health, boost yield and nutritional quality of vegetable crops and maize. Farming with BSF frass fertilizer increased yields of French beans, kale, tomato, and maize by 41, 34, 26, and 32%, respectively, compared to the sole application of other commercial fertilizer.
- The effectiveness of BSF frass fertilizer can be attributed to shorter periods of net immobilization of nitrogen (N) (30 – 60 days) compared to commercial organic fertilizer (SAFI) treated soils (60 – 95 days). There is increased rates of mineralization (3 – 10 times) and nitrification (2 – 4 times) in soils treated with BSF frass fertilizer. Application of frass fertilizer increased N release by 3 folds, with increased populations of bacteria and fungi, reduced soil acidity, increased phosphorus (2-folds) and magnesium (2 – 4-folds) release compared to other commercial organic fertilizer (SAFI). These findings highlight the benefits of using BSF frass fertilizer, particularly in addressing the challenges associated with soil acidity, phosphorus fixation and nutrient mining which are characteristic of most soils in sub-Saharan Africa and beyond.
- The economic analysis showed that maize grown on plots treated with BSF frass fertilizer yielded 29-44% higher net income than maize harvested from plots amended with commercial organic fertiliser. Direct use of frass fertilizer by insect farmers for maize production would generate 30-232% higher net income than farmers purchasing similar products.

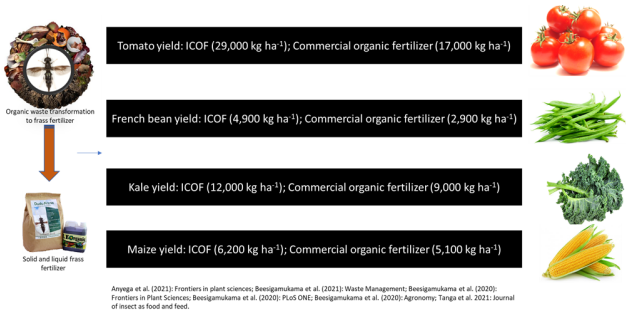

Figure 7: Insect composted organic fertilizer (ICOF) enhances crop yield

Work Package 2: Assess the cost-effectiveness and potential livelihood effects of insect-based feed technologies through gender lens along the value chain.

- Layer chicken fed insect-based feed showed a linear reduction in daily feed intake with increasing inclusion of BSF larvae meal (BM) to substitute fish meal (FM). Egg production showed a quartic response with maximum production estimate at 89.9% inclusion rate with an extended egg production period. Egg weight showed a cubic response with maximum estimated at 73.1% inclusion rate. Gross profit margin, cost benefit ratio and return on investment were significantly higher with increasing inclusion levels of BM in hen diets compared to those fed diet with 100% FM (Table 1). These results suggest that BM would be a sustainable substitute of FM in the diet of Isa Brown laying hens.

Table 3: Economic analysis of replacing FM with BSFL as cheaper feed protein ingredient in exotic layer diets

	Diet (100% FM)	Diet 2 (25%BM+75%FM)	Diet 3 (50%BM+50% FM)	Diet 4 (75%BM+25%FM)	Diet 5 (100%BM +0%FM)	P value
Cost of feed (US$/kg)						
Layer	0.456	0.447	0.439	0.430	0.421	-
Total feed intake (g/bird)						
Layer	1520.4	1420.4	1252.0	1142.4	1036.6	-
Cost of feed consumed (US$ per bird)						
Layer	24.16±0.1^{a}	22.74±0.1^{b}	20.67±0.1^{d}	22.16±0.2^{c}	19.62±0.1^{e}	<0.0001
Total number of eggs laid/bird	312±0.5^{c}	347±0.5^{a}	315±0.4^{c}	340±0.4^{b}	343±0.5^{b}	<0.001
Gross profit margin	16.27±0.1^{d}	22.25±0.2^{b}	20.42±0.1^{c}	21.91±0.2^{b}	24.98±0.1^{a}	<0.0001
CBR	0.67±0.1^{c}	0.98±0.1^{b}	0.99±0.1^{b}	0.99±0.1^{b}	1.27±0.1^{a}	<0.0001
RoI	67.3±08^{c}	97.9±1.0^{b}	98.9±0.9^{b}	98.9±1.8^{b}	127.3±0.2^{a}	<0.0001

Currency exchange rate at the time of study (1 US$ for 100 Ksh). Cost (US$ /kg) of protein ingredients: Soya bean: 0.90, FM (*omena*) 1.20, BSFL 0.85. CBR = Cost benefit ratio, RoI = Return on investment.

- On-farm smallholder farmers feeding trial with broiler chicken fed insect-based feeds showed that partial replacement with 75% BM inclusion had the lowest feed convention ratio of 2.0 against 2.5 for the birds fed diet with %FM. The most profitable diet was 25% BSFLM with 147% rate of return which is 112% less than that recorded for conventional feed, and a gross margin of US$ 8.25 against US$ 7.79 of the control diet. This implies diet with BM would be the most preferred and profitable diet for commercial broiler chicken production, which gets ready for market size 1 – 2 weeks earlier following higher inclusion levels of BM

Table 2: Marginal and gross margin analysis (US$/bird)

- Hybrid pigs (crossbreeds of purebred Large White and Landrace) fed diet with 50%BM inclusion had higher platelet counts,

Dietary treatment	Total variable costs	Marginal cost	Net benefit	Marginal net benefit	Marginal rate of return (%)	Gross margins	Opportunity cost
100% BM	3.22	-	11.24	-	-	8.04	0.25
75% BM	3.44	0.22	11.54	0.30	136	8.10	0.31
25% BM	3.76	0.32	12.01	0.47	147	8.25	0.46
50% BM	4.08	0.29	11.84	-	-	7.76	-0.03
100%FM	4.47	0.71	12.26	0.25	35	7.79	-

which might explain why pigs did not show any visual signs of illness or abnormal behavior throughout the experiment. Dietary inclusion of BM did not affect blood total cholesterol and low-density lipoprotein, thus reducing the predisposition of the pigs to heart diseases. The cost-benefit ratio and return on investment were similar when the various diet types were fed to the pigs. This implies that insect-based feed remains a suitable and cost-effective alternative protein to fishmeal in feed for growing pigs.

- The growth of growing pigs to market size (finishers) was 1.2 to 2 months earlier when fed diet with BM. Carcass weight of finisher pigs fed diets with BM at the inclusion rate of 50, 75 and 100% (w/w) was significantly higher than pigs fed diet with 100% FM. The crude protein content of the pork tissues was higher (65-93% on dry-matter basis) for pigs fed diet with BM. Additionally data on enhanced nutrient quality (proximate composition, fatty acids, amino acids, minerals and vitamins) of pork meat derived from pig fed diet with BM for improved human nutrition and health was determine.
- On-farm feed efficiency of substituting soybean meal and sunflower cake with BM in chick and pullet (grower) diet showed that the cost of feed formulation with FM was higher (US$ 0.46) compared to diet with BM (US$ 0.42). Chick fed diet with 75% BM had the highest overall live body weight gain and low average daily feed intake. For pullets diet containing 50% BM was the best. Diet containing 75 and 100%BM were the most cost-effective, if farmer decided to sell the pullets at farm gate price due to higher cost benefit ratio (CBR), return to investment (ROI)and marginal rate of return (MRR) of 1.19, 19.37 and 429 %, respectively (**Figure 8**).

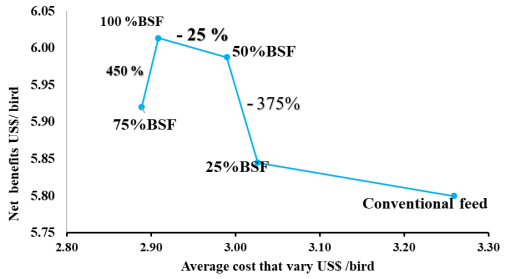

Figure 8: Net benefit curve for layers pullets fed on diets containing BSFLM. (US$ = 106.7).

- The impact of substituting soybean meal and sunflower cake with BM on egg production showed layers fed diet with 75%BM had low feed intake, highest live body weight and highest number of eggs produced. The most profitable diet was 75 % BM with higher CBR, ROI and MRR of 2.07, 106.75 and 471% (Figure 9). Diet with 75% BM inclusion would be the best to be recommended to smallholder farmers (Figure 9).

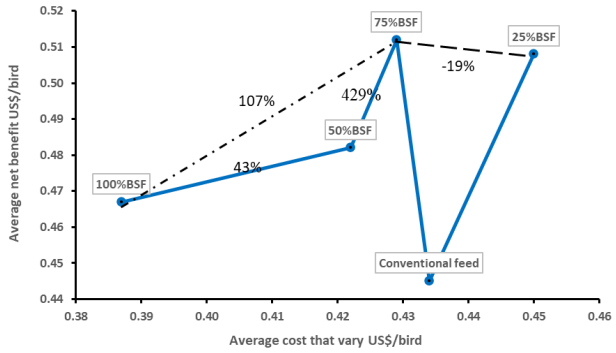

Figure 9: Net benefit curve of layers fed from week 19 to week 60 with different diets containing different soya bean meal and sunflower cake substitution levels with BM and conventional feeds (US$ = 106.7.

- Eggs obtained hen fed diet with increasing inclusion levels of BM had significantly increased egg white and egg yolk weight as well as increase in crude protein content compared to those fed diet with 100%FM. The calcium, iron, phosphorous and zinc coentent of eggs from hen fed diet with 100% inclusion levels of BM was significantly higher. Vitamin A content in whole egg and yolk varied considerably, whereas vitamin E content was similar. Omega-6 and Omega-3 ratio of the eggs collected from hen provided the various diet types were unaffected. Monounsaturated fatty acids content significantly increased with increasing levels of BM. These findings highlights the potential marketing quality of the eggs derived from layers fed diet with insect-based meal.
- Cobb500 broiler chickens fed diet containing plant-based proteins (*Desmodium intortum* (DI) and BM showed enhanced growth performance with better profit margins to smallholder farmers. Diet type did not show any significant effect on average daily body weight gain, average daily feed intake, feed conversion ratio and weights of internal organs when compared to those with 100%FM. Smallholder farmers would make more profit when chicken fed on diet with DI-BM were sold as assorted parts or at retailed price or as whole chicken at farm gate.
- Consumers showed preference for meat from chicken fed diet with 75%BM:25%DI due to its flavour and tenderness, 50%BM:50%DI due to its juiciness and 25%BM:75%DI for its colour, flavour, taste, and overall acceptability scores. Meat from chicken fed diet with BM had significantly lower moisture content and higher water holding capacity than the control diet (100%FM). Additional research focus on the potential benefits of such meat to consumers' health is crucial.
- The nutritional profiling of spent hen meat powder from hens fed on diet with varying inclusion levels of BM had no significant differences in terms of the crude protein (86 – 87%), crude fat (8 – 9%), minerals (except for Ca, K and Al), and amino acids (except isoleucine, methionine, lysine and aspartic acid) compared to those fed diet with 100% FM. Omega- 6 fatty acids/ Omega -3 Fatty acids (n-6/n-3) was reduced by 0.9 folds in layer fed diet with 100%FM compared to those fed diet with 100%BM. Therefore, the inclusion of BM up to 100% had no adverse effect on spent hen meat quality.
- Evaluation of the gut health of broilers and layers fed diet containing BM at 50 and 75% inclusion levels showed significantly improved their gut health. This was attributed to the presence of pre-biotic and probiotic bacteria (*Dysgonomonas*, *Morganella*, *Enterococcus*, *Pseudomonas*, *Actinomyces*, and *Providencia*) in the gut of the birds.
- The cumulative abundance of antibiotic resistance genes in the gut of layer chicken (Figure 10) fed diet with 75 and 100% inclusion levels of BM reduced significantly. This implies BM is a good source of antimicrobial peptides that might have acted against pathogenic bacteria suppressing the presence in the gut of the birds. These findings implies that there might be a new shift away from the use of antibiotics in poultry production, if there is wider adoption of insect-based feeds at commercial scale.

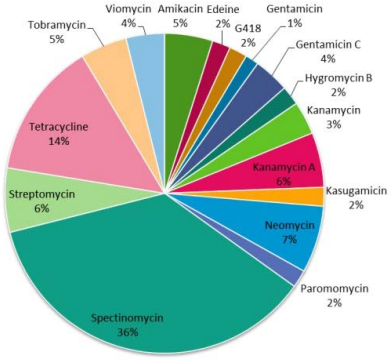

Figure 10: Cumulative abundance of antibiotic resistance genes in the gut of layer chicken fed diet with insect-based meal.

- African catfish (*Clarias gariepinus*) fed diet with BM revealed that 50% BM and 75%BSFLM inclusion enhanced the growth and carcass crude protein content (72 – 75%). The lipid content of the carcass obtained fish fed diet 50 and 75% BM was 40 and 42%, respectively. The concentration of essential amino acids and fatty acids of carcass from fish fed diet with BM was significantly higher compared to those fed diet with 100%FM. The economic returns of fish fed diet with 50 and 75% inclusion levels of BM was significantly higher compared to that with 100% FM.
- Tilapia fish (*Oreochromis niloticus* L.) fed diet with BM showed a 14% increase in body weight gain. However, the return on investment and the cost–benefit ratio was not affected by the diet type used, suggesting that BM is a suitable and cost-equivalent dietary protein to substitute FM in aquafeed for growing tilapia fish in earthen ponds for the market.
- Black soldier fly larvae meal substitution at the rates of 50 and 75% significantly increases growth performance, increase weight gain as well as improved carcass quality and profit margins of the farmers **(Annex 24)**.
- To establish the determinants of profitability of black soldier fly farming enterprise, a survey in six counties in Kenya revealed that organic waste and household size were positively and significantly correlated to the enterprise gross margin. Labour was significantly and negatively correlated to the enterprise gross margin. This implies that 1% increase in man-hours spent in the BSF farming enterprise would result in 0.34% reduction in the gross margin while 1% increase in the amount of waste used would lead to 1.38% increase in the gross margin (**Annnex 25**).
- Dietary inclusion of vegetative diet protein and BSF larvae meal in broiler feed significantly affected the fatty acid and cholesterol profiles of the meats with distinct sensory and physicochemical properties that account for the difference in organoleptic perception of consumers (**Annex 26**).
- Interview of 200 consumers on their preference and willingness to pay for eggs from hen fed insect-based feed revealed over 65% awareness among the farmers with > 70% of them showing preference and willingness to consume these egg products. Factors such as perceived benefits, ethics and traceability were observed to significantly influenced consumer intention to consume eggs. Household size, gender, awareness of insects as feed, off-farm income, household income, nature of buying place, and access to credit were important factors driving consumers perceptions (**Annex 27**).
- Out of 310 farmers interviewed, > 90% were ready and willing to use insect-based feeds (IBF) and factors such as feed *performance*, social *acceptability* of the use of insects in feed formulation, feed *versatility* and *marketability* of various products were key attributes that farmer purchase decisions (**Annex 28**).
- Interview of 314 chicken farmers showed that 93% of them were willingness to pay (WTP) for attributes of BM-based commercial chicken feed and the premium prices range between Ksh 35 - Ksh 345 for either pellets or mash feed explicitly labelled as containing insect meal, insect meal mixed with soybean or fishmeal and dark-colored feed (**Annex 29**).

Work Package 3: Develop and test gender inclusive insect feed supply models and build capacity along the value chain.

- Project-level Women's Empowerment in Agriculture Index (pro-WEAI) survey of 370 households (poultry, pig and fish farmers) in Kiambu County revealed that in dual households, women were less empowered than men. We found that 56% of the women interviewed were disempowered compared to 44% of men in dual households particularly in terms of work balance (women =54 %, men=74%) and self-efficacy (women=56%, men=82%).
- Socio-economic survey on potential business models adopted by farmers for production, marketing, and utilization revealed that 77% of the farmers across gender, were involved in the cyclic business model, 18% in market driven business models and 5% in out-grower business models. Disaggregating businesses by gender showed that 78% of men versus 71% of women are involved in the cyclic model and 20% men versus 17% women in the market driven business models. Out-grower business model was more favored by women (12% women against 2% men). Majority of female farmers (64%) and male farmers (58%) got their training from *icipe*, while 36% women and 33% male were trained by other farmers. We recommend the need to develop gender responsive business model incubations that adopts specific needs and capacities of male and female farmers.
- A mixed methods approach used to evaluate the effect of women's and men's perceptions on women's sole/joint land ownership on women's intra-household decision making showed that 72% of the women were joint landowners and 5% sole landowners. Among the men, 55% of them were joint landowners. Over 90% of the men reported high decision-making power while 96% of women attributed high decision-making power to themselves. However, only 26% of women reported a higher participation in decision making across all 12 decision-making domains than men (23%). These results highlight the opportunities available for informing the adoption of insect farming by both men and women.
- Over 65.5% of consumers were aware that insect meal could be an integral part of layer chicken feed. Among the respondents 70.5% showed preference towards consuming eggs from hen fed insect-based feed. Over 85% of the consumers expressed remarkably preference for eggs with golden yellow yolk colour and were willing to pay a premium cost (i.e., 10% of the normal cost) of Ksh. 18 compared to eggs from chicken fed diet with 100% FM. (**Annex 30**).
- Economic analysis revealed that sourcing and processing of organic waste a substrate for rearing BSF accounted for 81-90% of total cost of production. However, the production and utilisation of frass fertilizer as an additional value-added product would increase farmer's net income by 5-15 folds compared to sales of dried larvae only.
- Maize grown on plots treated with frass fertilizer would give 29-44% increase in the net income of farmers compared to when commercial organic fertilizer is used. The direct use of frass fertilizer by insect farmers for maize production would generate 30-232% higher net income than farmers purchasing frass fertilizer for maize production. These findings justify the expansion of opportunities for future investments by the public private sectors.
- The adoption of 5-50% insect-based feed in Kenya by the entire poultry sector as substitute to fish meal in poultry diet has been projected to generate potential economic benefit of 69-687 million US$, which will translate to reducing poverty by 0.32-3.19 million people, increasing employment by 25,000-252,000 people, and recycling of 2-18 million tonnes of biowaste.
- The replacement of 5-50% of fishmeal with insect meal in the poultry sector in Kenya would increase the availability of fish and maize that can feed between 0.47-4.8 million people at the current per capita of fish and maize consumption.
- Mapping exercise in the target project sites showed that 95% of the 978 black soldier fly farms operate as microenterprises with opportunities to be transformed into partial or more automated systems as the market for insect protein continues to grow in the region. The current production of the top ten BSF farms [Sanergy Ltd; InsectiPro Ltd; Marula Proteen Ltd; Biobuu Ltd (Kenya); Bugslife Protein Ltd; The Bug Picture Ltd; The Insectary Ltd; Protein Kapital Ltd; Eco Dudu Ltd and Bobo Eco Farm Ltd) is estimated at approximately 9780 metric tons of dried protein annually at the market of US$ 1.1–1.4 kg[1]. This insect protein resource is enough to meet 7% of the crude protein needed to produce pigs, fish, and chickens.
- Over the 3 years, *icipe* has trained 11,200 farmers (38% females and 62% males) with varying multiplier effects along the value chains. A total of 167 (98 males and 69 females) government agricultural extension officers have been trained on all aspects related to insect farming, processing, and integration into animal feed. Across the BSF farming enterprises, 1,325 youths (954 females and 371 males) have secured dignified and fulfilling employment in the sector.

- Three new standards on insect-based feed were developed and published in December 2020: (1) Production and handling of insects for food and feed – Code of practice; (2) Edible insects' products; and (3) Products containing edible insects.
- The partnership between Kenya Bureau of Standards (KEBS) and *icipe* has been very instrumental in working closely with the private sector (insect-based enterprises) to deliver 15 insect-based product certifications with Standardization Mark out of the 25 applications submitted. This will support individual farmers, multinational companies and processing industry players interested in edible insects, who can now get accreditation to enable their products to be sold globally.
- A total of 1 PhD, 20 MSc (11 females + 9 males) and 5 BSc students (3 females and 2 males) have successfully completed their research work and submitted at least 1 manuscript for publication to international peer reviewed journal, which is a prerequisite for submission of their theses to the graduate board in their various Universities.
- A total of 38 articles have been published, 4 manuscripts accepted, 23 draft manuscripts under review for submission to credible international recognized journals.

Awareness creation and trainings

- During this period, scientists, PhD, and MSc students were ensured to participated in at least one international conference to present the research findings generated from their work. The total audience in these conferences can be estimated to be over 10,000 participants, which provided a platform to create awareness among the various stakeholders in the edible insect value chain.
- Project activities were extensive covered by several media outlets with over 87 web-based stories across the world. Tracking on INSFEED activities showed that the progress of the project has been mentioned in 494 articles produced in 15 major languages across 40 countries in 4 continents. Several big international media houses like **BBC Deutsche Welle** (**DW**) (https://www.dw.com/en/food-security-sustainable-agriculture-farming-tech-larvae-africa-kenya-soy/a-54354145); **Reuters** (https://www.reuters.com/article/us-kenya-environment-insects-idUSKCN26E1DK); **World News** (https://www.reuters.com/article/instant-article/idAFL8N2GA069); **Oman Daily Observer** (https://www.omanobserver.om/kenya-harnesses-fly-larvaes-appetite-to-process-food-waste/); **Agroklub** (https://www.agroklub.com/poljoprivredne-vijesti/stocnu-hranu-prave-od-licinki-vojnickih-muha-hrane-ih-otpadom-iz-trgovina-i-trznica/63267/).
- Entrepreneurs from the project have been instrumental in training other farmers and promoting black soldier fly farming: For example: Meet Kenyan farmer rearing Fish and Black Soldier Fly using the smallest available space (https://africaclimateconversations.com/rearing-fish-black-soldier-fly-using-smallest-available-space/)
- Several blogs on black soldier fly farming have been reported by the IDRC/ACIAR to expand on the visibility of project activities (e.g., Kenyan agripreneurs fly high with black soldier flies - https://www.aciar.gov.au/media-search/blogs/kenyan-agripreneurs-fly-high-black-soldier-flies among others (Annex 15)
- Many proejct activities were broadcasted in various popular national media stations especially K24TV:

  Kilimo Na Biashara/Black soldier fly farming (https://youtu.be/wyHqa1zlKE8) aired on K24 TV which has over 1.18 million subscribers. The video has been viewed by 21,146 subscriber in less 4 months; KamemeTV: https://www.youtube.com/watch?v=UJuqqJZpdpg with about 7,013 views

- Three policy briefs have been developed for publication and dissemination to the wider audience (Annex …).
- Over 3562 certificates of participation have developed, printed, and distributed to those who successfully completed a 5-days hands-on training course on "Organic waste recipes, BSF production, processing, and animal feed formulation.
- Several video on the role of insects in the feed sectors and training videos on BSF production have been developed to be anchored on the Insect for Food and Feed website: https://youtube.com/playlist?list=PL9gX8_3YU6k_LGuTQ9Euqv_OBgp92WHZ_
- The engagement of policy makers in Kenya and Uganda lead to the development and approval of three new standards in December 2020 (1) Production and handling of insects for food and feed – Code of practice; (2) Edible insects' products & (3) Products containing edible insects), which are an expansion of the 2017 standards on the integration of insect meal in compounded animal feed. These new standards have created an enabling policy environment for over 1000 BSF farmers to be

established on feed in Kenya and Uganda. Through a circular economy approach, the top 10 insect farmers are estimated to produce approximately 9780 metric tons of dried protein annually, which is sufficient to substitute fish or soyabean meal in animal feeds with the capacity to produce 4.7 million chickens.

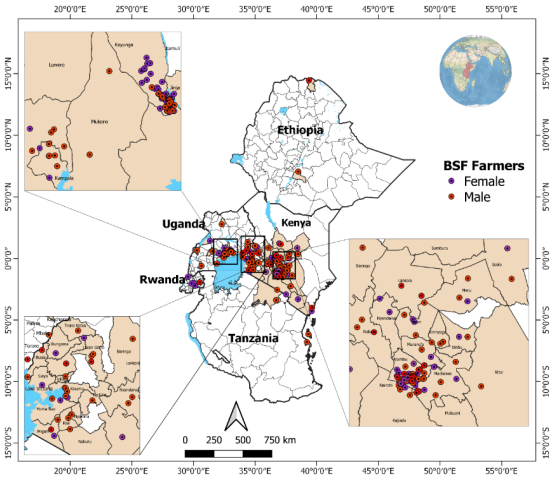

Figure 11: Distribution of BSF farmers in East Africa that received technical backstopping from *icipe* through IDRC/ACIAR and other donor support.

- An on-line mobile interactive platform called DuduTalk was developed and will be anchored the Insects for Food and Feed website, which will go operational in the coming months. The interactive platform is intended for effective sharing and tracking information on substrate availability, insect-based protein production, feed production and marketing among key stakeholders to improve networking within insect-based protein supply chain.
- Several success stories have been reported in the field: Here are some examples of farmer accounts on the revolutionary changes brought about insect farming in the animal feed sector in Kenya [*https://ecomumkenya.wordpress.com/2018/07/13/black-soldier-fly-larvae-farming-and-the-future-of-food-in-kenya/*; (2) Brown live Gold - The Black Soldier Fly agripreneur: https://www.youtube.com/watch?v=3Zv9b5E3ocs; (3) *https://www.thikatowntoday.co.ke/2018/02/save-money-and-earn-millions-with-this_17.html* - Save money and Earn millions with this Insect Farming; (4) Smart Farm: Focus on the black soldier fly in Kenya (https://www.youtube.com/watch?v=MFu6qVQmAVs): Farmer in Rongai rearing insect for its larva for feed.
- Other success stories include that of a female poultry farmer, who said "*Insect farming turned my life around: Generating income, satisfying family needs*"

Figure 12: "*No one believed that a woman could increase earnings so much through insect farming and poultry production. This was possible because of the help I received from the IDRC/ACIAR project*"

3.4: Global research partnership on insects for feed

- From the beginning of this project, the partnerships established extends to 247 public and private sector organisations, spread in 61 countries in 5 continents (**Annex 31**).
- Beside the INSFEED 2 project, many donor initiatives supporting insects as feed have been established. These new projects have been instrumental in complementing the activities of INSFEED 2 and played a key role in improving the dissemination of insect-based feed through increasing the numbers youth and women entrepreneurs across Africa. Additional donor supports that continues to build capacity in upscaling insects for food and feed include: (1) SipFEED with $US 600,000 funded by the Rockefeller Foundation; (2) INSBIZ with $US 750,000 funded by Bio Innovate Africa program and implemented by ICIPE and Makerere University; (3) Validation of low-cost sensors for optimal insect protein production funded (£100,000) by the Foreign, Commonwealth & Development Office (FCDO), implemented by ICIPE and Sanergy Ltd (private sector partner) to expand on the insect-based commercial feed sector; (4) INSFeedFish funded ($US180,000) by the World Bank and GoK; (5) Innovating the Feed Market in Rwanda supported (£329,000) by FCDO; (6) Climate-smart waste recycling funded (3,768,007 NOK) by NORAD; (7) Insect oils funded by Bio Innovate Africa program; (8) Insects for food and feed funded ($US 2.2 million) by Bill & Melinda Gates Foundation and implemented by ICIPE and InsectiPro Ltd (private sector partner); (9) Locust control funded ($US 300,000) by NRF; (10) Cricket breeding programme funded by BBSRC, UK; (11) SipFEED Phase 2 funded ($US 500,000) by Rockefeller Foundation; (12) PROTeinAfrica funded (AUD 3 million) by ACIAR; (13) FLYgene (11,999,759 DKK) funded by DANIDA and (14) NESTLER funded (Euro 5,254,562.5) by European Union.

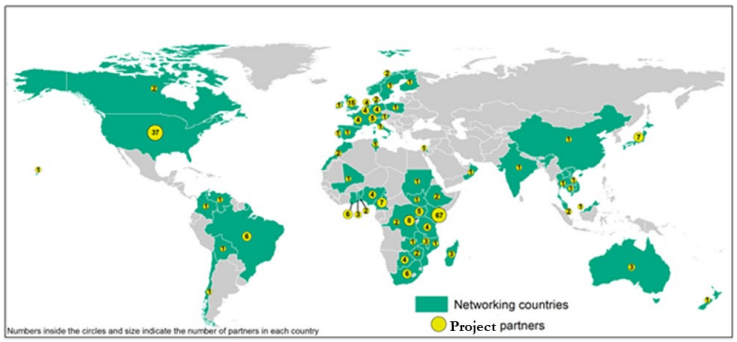

Figure 13: Global partnership on insects for feed

- The INSFEED 2 team received institutional recognition for it outstanding performance and its support staff (Ms Faith Nyamu Wamurango) got the 2021 year award while the Principal Investigator (Chrysantus M. Tanga) was promoted in November 2021 to Senior Scientist and Head of the Insects for Food, Feed and Other Uses Programme (INSEFF) at ICIPE, for his leadership, scientific contribution and strong networking demonstrated through this project. Furthermore, Dr. Dennis Beesigamukama, who was the PhD student in the INSFEED 2 working on Frass fertilizer has been recruited as a Postdoctoral fellow to prosecute research with a view to the same area.
- Six of insect-based enterprises run by entrepreneurs within the project (Zihanga Ltd, The Insectary Ltd, NutriEnto Ltd, The BugPicture Ltd, InsectiPro Ltd and BugLife Ltd) got financial support of over $US 10,000 from Rockefeller Foundation via Dalberg business initiative.
- InsectiPro Ltd, one of the successful entrepreneurs within the project was among the winners of the new Sustainable Food Systems Solver Class 2020. (https://solve.mit.edu/articles/meet-the-solver-teams-sustainable-food-systems#).
- The Insects for Food, Feed and Other Uses (INSEFF) programme at ICIPE and Sanergy Ltd won the prestigious, USD 1 million Curt Bergfors Foundation Food Planet Prize, from about 650 global nominations, in recognition of the Centre's pioneering research and development (R&D) activities on insects for feed and other uses. See link: https://www.the-star.co.ke/news/2020-12-15-icipe-sanergy-among-2020-food-planet-prize-winners/

Governance

- At the inception of the project, the roles and responsibilities of the various partners in the project were clearly defined and commensurate to their respective budget allocations. Clear boundaries were set as to when to approach sponsors, escalate concerns or get change approved in a considerable process. Gender equality was built at all stages of INSFEED 2 implementation with women making > 50% of trained postgraduate students. The project was well planned to ensure that the various work packages were talking to the other workstreams. Both PIs from the Kenya (male) and Uganda (female) ensured that the project technical reporting was jointly carried out together while financial reporting from the various country partners were channeled through ICIPE to the donor (IDRC/ACIAR) to allow direct communication, transparency, sound financial management and accountability between the country coordinators of the projects. The project had a well establish and strong culture of identifying, reporting, and tracking risks and issues in a way that crosses projects and workstream boundaries and created practical mitigations. Given the novelty of the insect-based feed technologies, the project was aligned to strategic business models and during implementation there was regular check back to the priorities of the project to ensure that the benefits of the outcomes were still relevant with increase consumer design.

Research Ethics

- During the lifespan of INSFEED 2, several ethical principles were put in place to in order to minimize the risk of harm. One of the foundations of INSFEED 2 was to ensure that in all research activities participants understood (a) they were taking part in specific research and what the research required of them. They were provided with the purpose of the research, methods to be used, possible outcomes of the research, as well as associated demands, discomforts, inconveniences, and risks that the participants may face. This implies that all the participants were volunteers taking part without having been coerced and deceived.
- The project protected the anonymity and confidentiality of the research participants, especially information that were of a private or sensitive nature (e.g., names, medical history, geographical cues, ID numbers among others).
- INSFEED 2 project ensured no deceptive practice was undertaken during implementation. This was avoided through the structuring of the informed consent.
- INSFEED 2 project also provided the participants the right to withdraw at any stage in the research process. The project did not pressurize or coerced in any way to try and stop them from withdrawing.
- The project ensured that data collection was impartial and done with total integrity and quality using a well-trained team of enumerators from the Social Science and Impact Assessment Unit (SSIAU), ICIPE.

Use of research results

- All the results of INSFEED 2 project generated from the laboratory has been transferred to the field under farmer settings. The grassroot communities have been trained on all aspects related to suitability of organic waste for insect farming, low-cost wild harvesting of insects for feed, processing of insect-based products such feed for livestock and fish, economic viability of developing insect-based enterprises, management of postharvest pest in stored insect-based products, oil and chitin extraction, frass fertilizer development and impact on improve soil fertility and crop yield etc.
- The results on the nutrient and antinutrient profile of the larvae raised on various waste stream, biosafety of insect products and shelf life has been very instrumental in informing policy makers in Kenya and Uganda to allow the development of three new standards that promote the commercialization of insect farming in all its forms for both national and international markets.
- Based on the evidence-based generated information in the project, over 15 entrepreneurs have got permits to use the standardization mark (certification) for the first time in Africa. These new certifications of insect-based products are important milestone in supporting individuals and industry players interested in edible insects. The insect harvesters, farmers and feed processing industries can now get accreditation as their products are issued with a Kenya Bureau of Standards certificates to enable them market and sell them globally.
- Data on economic viability of insect-based feed formulation at the feed miller and utilization at the smallholder poultry, pig and fish farmer production systems now serves as a guide for effective production and marketing of egg and meat products derived from animal fed insect-based feeds. These results have incentivized many farmers to trust in insect-based feeds as alternative high-quality diets. This has subsequently increased their demand for these new products.
- Effective hands-on training provided to the youths and women has strongly empowered them as agripreuneurs on insect farming targeting the emerging market. Thus, there is consistent increase in demand from many people in the target countries and beyond requesting to be trained from neighboring countries and beyond such as Rwanda, Tanzania, Ethiopia, Senegal, Morocco, Zimbabwe, Zambia, Cameroon, Ghana, Togo, Benin, and Nigeria among others.
- The certificate of participation and successfully completion of the 5-days hands-on trainings during the project served as a testimonial for the skills acquired by youths and women. For examples, the emergence of youth entrepreneurs and enterprises played a key role in generating additional dignified and fulfilling employment and income generation opportunities along the value chain, modernizing the insect farming sub-sectors and contributing towards a youth-led rural and urban transformation.

Figure 14: Increase job creation for the youth and women in the insect enterprise.

- The establishment of insect-based enterprises had a significant positive spill-over effects along the value chain to benefit thousands of people indirectly through trainings offered by SMEs for a fee. The various communities in the project areas benefited through skills, services, and income transfers and spontaneous adoption of technologies
- There was increased agricultural productivity (vegetable and maize) through organic fertilizers and animal feed, with further potential contributions to food security and income
- There are several well-established insect-based enterprises which have demonstrated the potential to scale were exposed to financial platform and got financial assistance from many donors' initiative. For example, six SMEs were supported by

Rockefeller Foundation via Dalberg initiative. For example, InsectiPro Ltd got support from the Sustainable Trade Initiative (IDH) and Bill & Melinda Gates Foundation. Sanergy Ltd won the Foreign, Commonwealth & Development Office (FCDO). Mana Biosystems a pan African insect farming company was involved in a newly approved project supported by the European Union. The interest in foreign investment into the emerging insect-based enterprises in the target countries continue to grow each day.

Synthesis towards AFS themes

- *Increasing Agricultural Productivity (Availability)*
  - The development of low-cost insect-based value-added products such as insect protein meal to substitute the expensive major protein sources in animal feed have strengthen the livelihoods resilience of many farmers, especially the vulnerable segment of the communities who are the youths and women. On-station and on-farm trials of the effects of insect-based feed on pig, poultry and fish have demonstrated highly positive impact in terms of fast growth rate, increased weight gain and better carcass quality that is comparable or superior to animals fed conventional fishmeal-based feeds. Layer fed insect-based feeds produce significantly higher numbers of eggs with intensive egg york colour, higher crude protein with increasing inclusion of insect meal etc. This implies that the use of insect-based feed does not only overcome the total dependence of major protein sources (fish, soya bean, cotton seed cake, sunflower seed cake etc) but increases the profit margin of farmers. The frass fertilizer from insect farming has been demonstrated to improve soil fertility and crop yield. Such cost reduction is expected to increase potential economic benefit and GDP of the country, reducing poverty, increasing employment of youth and women as well as recycling of wastes reducing environmental pollution. The foreign currency savings would increase following the reduction in feed and inorganic fertilizer importation. Promotion of insect-based feeds has the potential to boost livestock and fish productivity as well as crop productivity through the use of frass fertilizer. Layer fed insect-based feed produced higher number of eggs and spent-hen meat quality. The economic profitability of broilers fed BSF based feed can be attributed to fast growth rate and higher weight gain. The broilers get ready for market 1 – 2 weeks earlier reducing cost of input and labour. Increased productivity and carcass quality has been observed for Nile tilapia and African catfish. This will help to reduce food and nutritional security.

- *Improving Access to Resources, and/or Markets and Income (Accessibility)*
  - The emerging and fast-growing insect-based enterprises developed within the project provides a platform for new job markets for income generation and livelihood improvement. The demand for alternative protein in Kenya and Uganda is huge, though the supply can't meet the market demand of the products. Studies conducted in Kenya revealed that replacing 5-50% of the conventional feed sources by insect meal would generate a potential economic benefit of 69 – 687 million USD (0.1 – 1% of the total GDP) and 16-159 million USD (0.02-0.24 of the GDP) if the entire and commercial poultry sector alone adopt insect meal. The substitution of current protein with insect meal in the poultry sector has potential to create 25,000 – 252,000 and 3300-33,000 new jobs for the entire and commercial poultry sector, respectively. This translates to reduced poverty by 0.32 – 3.19 million people, especially in the fast-growing industries and urbanized areas. Thus, development of business model with a circular economy perspective would be a sustainable opportunity for income generation for the insect enterprises, thus empowering the youth and women as well as men and improve the access of all to wealth while reducing gender gaps.

- *Improving Nutrition (Utilization)*
  - The crude protein quality of pork, poultry meat, eggs and fish fillets derived from livestock and fish fed insect-based feed was constantly superior to those fed on conventional fishmeal-based feeds. The various products were also rich in iron, zinc and vitamins like E and A, which are important for improved human nutrition.

Informing Policy

- *icipe* and partners have been working in very close collaboration with influential policy makers, such as KEBS, UNBS, Kenya Wildlife Services, National Environment Management Authority (NEMA) and the Kenyan Museum. Several virtual meetings have been organized with policy makers in the animal feed sector, coupled with various stakeholders' workshops in both countries to create in-depth awareness to provide favorable condition for the use of insect in animal feed. All these policy makers were embedded in the project implementation right from the very start to have a buy-in into the project. The knowledge generated through the project has helped to inform policy on the immediate and long-term benefits of insect-based products as such three new standards have been gazette and published to regulate the production, handling and processing of insects for food and feed in Kenya and Uganda. The standards include: (1) Production and handling of insects for food and feed – Code of practice, KS 2922-l:2020 Kenya; (2) Standard Edible Insects Specification Part t: Edible insects' products, and KS 2922-2:2020 Kenya; (3) Standard Edible Insects Specification – Part 2: Products containing edible insects. These new standards are an important milestone in supporting individuals and industry players interested in edible insects. This implies insect harvesters, farmers and processing industries can now get accreditation and their products will be issued with a Kenya Bureau of Standards certificates to enable them market and sell them globally. Over 25 SMEs have received certification for the products, which can now get the Standardization Mark of KEBS.

Challenges encountered / Actions taken

Key challenges faced were:

- Due to the Covid-19 pandemic some slight delays were experienced setting up the demonstration facilities in Busia, Siaya and Bungoma. However, much progress has been made since the travel bans were lifted. Also, a lot of on-site trainings by experts trained at icipe were undertaken in each target project sites.
- Another major challenge faced by the farmers is getting their insect larvae dried for extended shelf life before marketing. The project in collaboration with other project have purchase a communal dryer to be used by over 100 SMEs.

Overall assessment and recommendations

- The INSFEED 2 has been a great success with outstanding achievements beyond the goal that were set at the beginning. The uptake of the technologies has been remarkable couple with the urgent need to overcome the protein. The project created a platform whereby committed youths and women could produce insect as protein feed ingredient for income generation. The policy makers have been extremely supportive and strongly worked together with several other partners to create an enabling environment for the promotion and scaling of insects as alternative protein in animal and frass fertilizer for improved soil fertility and crop yield. Insect farming has been widely taken up by passionate actors along the value chain particularly the private sector partners and farmers (poultry, pig and fish farmers), thus creating new dignified and fulfilling jobs and income generation.
- Given the massive growing interest across the continent of Africa, all the stakeholders are of the opinion that the benefits of this project should be extended to countries. This will help to expand project activities with greater and wider impact on the livelihood of billions of vulnerable populations in the developing countries. Therefore, continuous support to disseminate project findings and scale up insect technologies for business is highly recommended beyond the traditional boundaries of the current project.