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INSFEED – INTEGRATING INSECTS IN POULTRY AND FISH FEED IN KENYA AND UGANDA

IDRC PROJECT NUMBER: 107839

KENYA & UGANDA

ORGANIZATIONS IN KENYA: ICIPE, EGERTON UNIVERSITY, UNIVERSITY OF NAIROBI, KMFRI, KALRO, SANERGY, LASTING SOLUTION, KEBS, UNGA FEED, USIU

ORGANIZATIONS IN UGANDA: MAKERERE UNIVERSITY, NaLIRRI, NaFIRRI, UNBS, UGACHICK, FARM RADIO INTERNATIONAL

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FINAL TECHNICAL REPORT

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ACRONYMS

ACIAR: Australian Centre for International Agricultural Research

BSF: Black Soldier Flies (*Hermetia illucens*)

DM: Dry Matter

ICIPE: International Centre of Insect Physiology and Ecology

IDRC: International Development Research Centre

JOOUST: Jaramogi Oginga Odinga University of Science and Technology

KEBS: Kenya Bureau of Standards

KMFRI: Kenya Marine and Fisheries Research Institute

NaFIRRI: National Fisheries Resources Research Institute

NaLiRRI: National Livestock Resources Research Institute

SANERGY: A private company in sanitation based in Kenya

UGACHICK: A Ugandan private company in chicken and fish farming as well as feed production

UNBS: Uganda National Bureau of Standards

Unga Feed: A Kenyan private company in chicken and fish feed production

UoN: University of Nairobi

1. EXECUTIVE SUMMARY

The INSFEED project, funded through the CultiAF program and initiated in October 2014, aimed at demonstrating, in Kenya and Uganda, the feasibility of developing insect-based feeds for sustainable, safe and cost-effective poultry and fish production, and to verify that the idea is capable of being useful and demonstrates the attractiveness of taking it into commercial development.

The objectives were achieved, with the insect based feed technology proving to have a huge potential to contribute to job creation and income generation through establishment of insect mass rearing, processing and trading business; but also through improved egg and meet productivity as well as organic fertilizer commercialization.

A total of 1,701 farmers, feed processors and traders (452 females and 1249 males) were interviewed using questionnaires and engaged in focus group discussions. Poultry feed alone represents 60-70% of the mixed feed sector in Kenya and Uganda. Fish feed however, represents less than 1% of the local feed market size. This is because commercial fish farmers import feed due to the high protein requirement of fish feed, that leads to its frequent adulteration on local markets. Fish feed processors as well as fish farmers therefore find in the insect based feed enterprise, an opportunity to produce and source reliable fish feed locally.

The protein ingredient, specifically fishmeal, remains the most and increasingly expensive part of the feed. The cost of fishmeal is higher in Kenya than Uganda, at US$ 1.4/kg and US$ 0.47/kg respectively in 2015. The situation is however worsening in both countries, with an increase of up 122% between 2013 and 2015.

While in Kenya 70% of commercial poultry farmers purchase feed, in Uganda, 53.31% of poultry farmers mix their own feed. However, the demands for ingredients remain high in both countries. Female-headed households used commercially mixed feeds more frequently than their male counterparts and were therefore more affected by increase in protein ingredients and feed costs. The market demand sizes of silver cyprinid fish and soybean are high but available quantities are way below the demand, requiring importation. It was estimated that the replacement of 25% of protein in poultry feed alone in Kenya will require 27,000 to 32,000 tons of dried insects/year. Considering that 100% protein substitution with Black Soldier Fly (BSF) in layers yielded the best result and broilers' production is not affected by protein substitution up to 100%, demand for insect to substitute conventional protein source in feed in Kenya is estimated to 115,000 tons of dried insect annually for poultry feed alone. This would potentially result in 14,328 jobs for youth producing 2 tons fresh insect/month. Added to the potential for fish, poultry and pig industries, the business of insect production for animal feed has a brilliant future. In the short term, insect use as

protein source is estimated to reduce the protein cost in feed production by 25 to 37.5% and carries higher potential in the medium and long term where above 50% cost reduction could be envisaged.

Overall 16 insect species were reared, the most vibrant colonies being black soldier fly (BSF, *Hermetia illucens*), crickets (*Acheta domesticus* and *Gryllus bimaculatus)*, locust (*Schistocerca gregaria*), silkworm (*Bombyx mori*) and American cockroaches (*Periplaneta americana*). Based on colony growth rates and rearing inputs, four key species were retained for further evaluation: BSF, the 2 species of cricket and silkworm. Of these, BSF, which combined fastest population growth potential, absence of nuisance, waste management potential through conversion of a wide range of agricultural and municipal wastes into organic fertilizer and animal protein as well as low production costs, was selected for business development. The production of BSF in a screen house of 5 m x10 m could yield 2 tons fresh BSF/monthly, costing US$ 0.20/kg DM as production cost and sold on the market between US$ 0.90 and 1/kg DM.

The nutrient profiles of 28 insect species and instars were analyzed. Crude protein (CP) content of tested insects varied from 32.9% DM in termites (*Macrotermes subhylanus*) to 73.3% in *Gonimbrasia zambesia*. The CP content of fishmeal on Kenyan and Ugandan market is 40.3% DM and all the insect species reared under the INSFEED project were superior, with for instance, field cricket (67.21%), house cricket (62.57%), and BSF (49.5%). No aflatoxin was detected in these insects, and while various bacteria and fungi were found in fresh insects, steaming at 96 ^{o}C for 5 min or toasting at 150 ^{o}C for 2 min were enough to inactivate the microorganisms.

Fish and poultry feed formulations in which 25% to 100% of fish protein were substituted with BSF protein were evaluated. Tilapia fed for 22 weeks with 33% protein substitution by BSF showed 23.4% higher weigh gain than those fed on conventional feed. Broiler chicken fed on up to 100% substituted protein had similar weight gain as those fed conventionally. Layer chicken fed with up to 100% BSF protein substitution from 31st to 52nd week of age laid better quality eggs, had 2.1 times higher average egg production in last 10 weeks and significantly prolonged egg laying period above economic threshold compared to those fed on conventional feed.

A total of 25 students were trained. Various stakeholder workshops and advocacy meetings with policy makers enabled the development and approval of standards allowing and guiding the use of insect in feed in Kenya and Uganda. A total of 506 (293 males, 213 females) farmers, youth entrepreneurs, policy makers and Scientists were trained on insect rearing for integration into animal feed and radio based awareness programs prompted responses from 25,388 listeners. Insect commercialization for feed has been adopted in both countries. For instance, Sanergy Ltd., one of the private sector partners involved in the project is currently expanding its BSF production units with new investors joining the venture.

2. THE RESEARCH PROBLEM

Annual global turnover of commercial feed in 2015 alone is estimated at US$ 400 billion and production will have to increase by 70% to be able to feed the world in 2050, as meat and fish outputs are expected to double (van Huis *et al.*, 2013; IFIF, 2012; FAO, 2016). Ingredients for both poultry and fish feed include soybeans, fish oil, seed cakes and several other grains, with fishmeal being the major protein source. The growing scarcity of resources to produce these ingredients led to unbearable increases in their prices in recent years, while the feed cost is already prohibitive, representing 60-70% of production costs. It will therefore be an unsustainable option to continue to rely on fishmeal and soybean as main protein source in feed (van Huis *et al.*, 2013).

In many sub-Saharan Africa (SSA) countries, poultry and fish industries are among the fastest growing agro-businesses with women accounting for over 60% of the producers (Okitoi *et al.*, 2006). However, feed unavailability and poor quality have been rated as the most important constraints for growth of fish farming in several countries including Kenya and Uganda (Sithote *et al.*, 2012). The use of insect protein as a replacement for expensive protein sources from fish or plants is one potential solution. Indigenous free-range chicken which represent 75 to 90% of chicken consumed in most African countries are known to feed naturally on insects. However, insects have not been used in commercial feed production and standards for their use in feed still lack across the continent. Insects are often reported to have similar or higher protein content compared to conventional fish and soybean meals while their amino acid profiles are superior to those from plant supplements used in feed formulations (Bukkens, 2005; Anand *et al.*, 2008).

The overall objective of this project was therefore to demonstrate the feasibility of developing insect-based feeds for sustainable, safe and cost-effective poultry and fish production, verify that the idea is capable of being useful and demonstrates the attractiveness for commercial development. For this purpose, the project (a) Established strong scientific bases for the use of insects as feed in poultry and fish farming in Kenya and Uganda; (b) Tested the technical feasibility and economical profitability of the proposed technology with feed producers and farmers and (c) Created favourable social and political conditions for using the technology at large scale.

Reducing poultry and fish production costs should lead to lower prices enabling better access to more nutritious food. Finding an alternative to the fishmeal and soybean will reduce marine, lakes and land overexploitation. In addition, the potential of a new type of entrepreneurship in insect mass production for sell as source of protein to the feed industry is a new opportunity for job creation and income generation for the poor, unprivileged and unemployed, especially women and the youth.

3. PROGRESS TOWARDS MILESTONES

Table 1: INSFEED project progress towards milestones

Milestones	Progress	Comment
6 months after starting date: 1st TECHNICAL INTERIM REPORT Covering the first 6 months and reflecting on the following milestones (5-6 milestones – primarily processes)		
Inception workshop Organized	100%	• 1st from 29th to 31st October 2014 in Lusaka, Zambia and • 2nd from 9th to 11th December 2014 in Nairobi with 49 stakeholders (Annex1, Annex 2).
MOU Established with partners	100%	• All partners' MOU established and implemented successfully (Annex 3)
Students recruited	100%	• A total of 25 post graduate students are involved in the project (Annex 4).
Equipment purchased and functional	100%	• All equipment were purchased and operational
Sampling protocols finalized	100%	• Done and submitted in the first 6 months' report (Annex 5)
Communication and Gender strategies finalized and documented	100%	• strategy documents submitted in first 6 months' report (Annex 6) • Three gender trainings were held with total participation of 52 team members • Four team members attended communication training from 9th to 13th March 2015 in Nairobi, Kenya. This enabled preparedness for the various interviews, TV programs and printed media coverages also occurred during the 33 months' project implementation (Annex 2).
12 months after starting date: No official report but light reporting or skype follow-up to prepare 6-months updates Covering the last 6 months and reflecting on the following milestones (5-6 milestones – primarily activities)		
Insect rearing and harvesting systems are in place	100%	• Rearing protocols for 16 species and harvesting protocols for 6 wild species developed and tested (Annex 7) • Four species (black soldier flies, house crickets, field crickets and silkworm) were the leading candidates for mass rearing. However black soldier fly was prioritized for commercialization due to lower rearing cost and marketability of larvae and manure

Socio economic and marketing surveys carried out	100%	• Poultry and fish farmers as well as feed processors interviews finalized and data analyzed (Annex 8 & 9) • Market demand analyses finalized (Annex 10)
KAP results documented	97%	• Data fully analyzed and 1 paper submitted and 2 others in the pipeline (Annex 11)
Insect rearing substrates Identified	97%	• Effect of substrates finalized and most effective ones selected for mass rearing completed and publication in the pipeline (Annex 7).
3 MSc studies completed	95%	• One socio economic student submitted his thesis and two others are compiling their theses. (Annex 8)
18 months after starting date: 2nd TECHNICAL INTERIM REPORT Covering the last 12 months and milestones for period 6-12 months and 12-18 months (5-6 milestones/6 months – activities & results)		
Insect rearing and harvesting techniques completed	90%	• Insect rearing completed. Wild harvesting advanced but field activities were halted due to lack of funds (Annex 7)
Microbial profile and their risk factors identified	100%	• Microbial profiles analyzed and processing techniques assessed to ensure safety established (Annex 12).
Risk factors with regards to heavy metals established	100%	• Heavy metals and pesticide residues were not found in insect material. Publications being compiled. (Annex 12)
Nutritional profile of selected insects document	100%	• Completed and documented in various students' theses as well as papers submitted (Annex12)
4 additional MSc studies completed	85%	• Of the 25 postgraduate students, 1 defended his thesis, 18 others finalized their data collection are drafting papers and theses, while 6 were new and collecting their data.
24 months after starting date: No official report but light reporting or skype follow-up to prepare 6-months updates Covering the last 6 months and reflecting on the following milestones (5-6 milestones – primarily results/products)		
Different insect based feed formulations developed and processed	100%	• Fish and poultry feed formulations replacing up to 100% protein with BSF were developed for Nile Tilapia, Cat fish, broiler chicken and layer chicken (Annex 13)
Standards and regulation workshops completed	100%	• Completed, with the ultimate result of approved standards in Kenya and Uganda (Annex 14).
Cost benefit & cost effectiveness analysis completed	100%	• Cost of BSF and cricket production as well as current selling price on the market after standard approval were assessed (Annex 9).

4 additional MSc studies completed	90%	• Of the 25 postgraduate students, 1 submitted his final thesis after defense and is awaiting graduation in October 2017, 3 submitted their papers for peer review publication as university requirement before thesis submission, 19 others have their papers being internally reviewed or being drafted for submission in peer reviewed journals while the remaining 2 just finished data collection and sorting their data for analysis.
Effect of formulated product on fish and chicken document	100%	• Performance studies of insect based feed on tilapia, cat fish, boiler chicken and layer chicken were completed (Annex 13)
At least 50 farmers trained in insect rearing per country	100%	• More than 75 farmers trained within first 18 months (Annex 4).
30 months after starting date: Final TECHNICAL REPORT Covering the last 12 months and milestones for period 18-24 months and 24-30 months (5-6 milestones/ 6 months – incidences/outcomes)		
Policy briefs developed and disseminated to policy makers in both countries	100%	• Advocacy strategy engaging policy makers through conferences, workshops and meeting was prioritized over policy briefs to achieve the ultimate result of approved standards in Kenya and Uganda. • The "*International Conference on Legislation and Policy on the use of Insects as food and feed in East Africa*" was held in Kisumu from 1st to 3rd March 2016, with 105 participants from 13 countries (Annex 14). • A total of 4 country specific stakeholders' workshops held in Uganda in December 2016, March 2017, May 2017 and June 2017 had total participation of > 300 stakeholders (Annex 14). • A total of 3 country specific stakeholders' workshops held in Kenya in November 2016, December 2016 and March 2017 with a total participation of > 100 stakeholders. (Annex 14). • Standards on dried insect meal for compounded animal feed were developed, approved and implemented in both Kenya and Uganda (Annex 14).
Dissemination workshop held	95%	• The "*International Conference on Legislation and Policy on the use of Insects as food and feed in East Africa*" was held in Kisumu from 1st to 3rd March 2016, with 105 participants from 13 countries (Annex 14). • The team presented also at various conferences in Kenya, Uganda, Canada, Benin and Madagascar attended by > 1,300 participants in total (Annex 14) • Final dissemination workshop held in Uganda (Annex 14). Kenyan workshop wasn't possible

		due to funds limitation.
At least 500 farmers reached with dissemination material	100%	• A total of 506 (293 males, 213 females) farmers, youth entrepreneurs, policy makers and Scientists were trained on insect rearing for integration into animal feed (Annex 4). • 25,388 listeners participated directly in radio programs on 2 stations by calling or smsing as well to exchange experience on insect use as animal feed • >20 web stories on the project (Annex 2).
Private sector take up technologies developed	100%	• Private sectors was imbedded in the project from the beginning in both countries • In Kenya Sanergy Ltd, one of the project private sector partners has started commercialization of BSF production for feed. They have so far sold 43 tons of dry BSF to various feed manufacturers (Annex 7). • The company also got 1.2 million Euro co-investment partnerships from FinFund for expansion that will enable them to produce 3,600 tons per year (Annex 7). • Various private companies and young entrepreneurs have requested to be trained on insect farming for business establishment
Project report compiled	100%	• All quarterly reports compiled and submitted (Annex 15). • Reports on standard development and gender outcome story compiled (Annex 15). • Final report compiled and submitted

4. SYNTHESIS OF RESEARCH RESULTS AND DEVELOPMENT OUTCOMES

Specific Objective 1: Establish strong scientific bases for the use of insects as feed in poultry and fish farming in Kenya and Uganda

1.1: Conduct survey of Small-scale poultry and fish farmers to gather data on current and potential insect species for feed (Annex 8 & 11).

In Kenya:

- A total of 388 poultry and 278 fish farmers participated in the survey in three counties Nakuru, Kisii and Kirinyaga. Majority of the poultry and fish farmer households, 87% and 86% respectively, were headed by males.
- The size of stock was above the threshold of 50 heads per farmer only in the intensive system, and this for layers (310 heads/farmer, 44.72% of poultry farmed through intensive system), broilers (241 heads/farmer, 34.78%), and local hens (120 heads/farmer, 17.32%). These are therefore the target groups for the insect based feed technology.
- Tilapia, catfish and milacap stock were 93.2%, 6.55% and 0.24% respectively.
- About 70% of the sampled farmers who practiced intensive system of production used purchased feeds, and only 6% used own mixed feeds.
- Purchased mixed feed for adult birds was the most highly demanded feed at 68,154 kg, followed distantly by growers' mash at 14, 087 kg and Chick and duck mash at 8,606 kg.
- Majority of poultry and fish farmers (91% and 81% respectively) expressed awareness of use of insect as feed and 93% were willing to buy insects based feeds.
- About 98% and 93% of the female and male farmers, respectively, indicated that insects can form a good source of feed (Annex 8).

In Uganda:

- A total of 287 poultry and 208 fish farmers were interviewed. Majority of households were headed by males, representing 76% and 93.75% for poultry and fish farmers respectively.
- The exotic breeds represent the most important proportion of chicken kept per farmer, with 60% represented by Layers and 26.8% for Broilers. In the semi-intensive system, local cocks (79 cocks/farmer), broilers (103) and layers (247) were above 50 heads per farmer while in intensive system, only broilers (158) and layers (514) are kept in reasonable numbers. Giving a wider target group insect based feed technology than found in Kenya.
- The three fish species reared were tilapia (82% of respondents), catfish (59%) and Milacap (7%). Under the open pond production system , tilapia recorded the highest average stock (76.4%).

- In regard to poultry feed, 53.31% of the farmers surveyed mainly relied on own mixed feeds and purchased feed represented only 28.85% of feed used.
- According to farmers who mixed own feed, fishmeal (silver fish, locally called Omena in Kenya and Mukene in Uganda) was the main source of protein in the feed formulation (54% of farmers), followed by sunflower (26%) and cotton seed cake (21%). Silver fish was the most expensive source of protein (at US$ 0.8/kg = USh. 2,275/kg) followed by cotton seed cake (US$ 0.54 = Ush. 1,800/kg) and sunflower (US$ 0.45 = Ush. 1500/kg).
- At least 90% of the farmers in each district surveyed reported that insects are a form of feed for poultry and 91% poultry farmers and 85% fish farmers are willing to use insect to feed their poultry and fish (Annex 8).

1.2: Conduct survey of livestock feed processors to collect data and describe all feeds currently used in poultry and fish farming, their rates, demand and availability (Annex 9).

This study examined the status of feed supply, local feed processing, and the profitability of poultry and fish feed enterprises.

In Kenya, primary data were collected from 152 traders and processors based in Kirinyaga, Kisii and Nakuru counties. Feed mixing is mostly done by traders/processors from Nakuru County; the traders surveyed in Kisii and Kirinyaga counties reported that they purchase and sell already mixed feed from processors located in Nakuru, Nairobi and Thika.

The mean quantity of major protein ingredients used to mix 100 kg of feed are: 17 kg of silver fish dust (reported by a negligible proportion of respondents), 15 kg of cotton seed cake (7.7%), 11 kg of sunflower (19%) or 10 kg of soy meal (13.5%). The protein ingredients constitute the most expensive component of feed formulation. The purchase prices of the various ingredients are: US$ 1/kg of silver fish, US$ 0.68/kg of soybean meal, US$ 0.48/kg of cotton seed cake, and US$ 0.29/kg of sunflower seed cake.

The average annual feed production is about 5,066 kg of fish feed per processor and 43,092 kg of poultry feed per processor.

With regard to profitability of feed trade and processing business, the survey results generally show that an average business is able to break even in all the sites except in Kirinyaga County.

Sensitivity analysis indicates that a 25-30 percent reduction in the cost of ingredients would result in the net positive revenue, underpinning the need for strategies to formulate and substitute protein feed ingredients for sustainable and cost-effective feed production.

The results also indicate that women have smaller enterprises in terms of capital as compared to their male counterparts and had lower performance levels in terms of capacity utilization. However, they were operating at a higher level of profitability than their male counterparts (Annex 7a).

In Uganda 71 small scale feed processors/traders were surveyed in Gulu, Masaka and Tororo districts.

The main sources of protein used by the traders to mix 100 kg of feed include fish meal, cotton seed cake, soybean and sunflower meal.

All feed processors (100%) used fish meal to make layers' mash, and about 71% used it to make broilers mash. Cotton seed cake was only used to make layer's mash (by about 59% of the feed processors). Soybean was used by about 33% of the processors for broilers mash and by about 18% of the processors to make layers' mash. Other notable sources of protein include blood meal.

Protein sources were the most expensive components in feed formulation. The mean prices for the various proteins sources reported are: US$ 0.72/kg of fish meal, US$ 0.61/kg of soymeal, US$ 0.30/kg of sunflower meal and US$ 0.44/kg of cotton seed cake. The average annual production is about 4,980 kg of poultry feed and about 1,560 of fish feed/processor (Annex9).

1.2: Carry out market demand analysis for insects as feed ingredients for poultry and fish (Annex 10).

Market demand analyses were conducted in both Kenya and Uganda. The growing commercial poultry Industry in Kenya and Uganda currently produces over 6.8 and 4.8 million commercial birds per year respectively compared to 34 and 34.8 million indigenous birds per year respectively. Commercial poultry is however one of the fastest growing agri-business sectors and has risen steadily since 2010.

In Kenya, the commercial layers' sector is far more developed than broilers but in both cases, feeds represent the single costliest input accounting for 67 to 75% of production cost. Poultry feed represents 60 to 70% of all feed produced in both countries. Only 1% of the feed produced locally is currently used in aquaculture. However, the sector grew quickly from 4,000 MT/year in 2009 to > 20,000 MT in 2014, and a market value of US$ 56 million per year in 2014. The main fish feed in commercial aquaculture is imported to ensure quality. Indeed, fish feed requires far more protein than poultry feed and unavailability of protein in both countries often leads to low quality fish feed, forcing commercial fish producers to simply import expensive but reliable feed. Fish feed producers as well as commercial fish farmers expect such situation to change once protein levels are high in the regions to ensure reliable and quality fish feed.

Small scale feed producers have an estimated 1,000 MT/ year while the largest can reach > 90,000 MT annually. Currently, the mixed feed industry produces between 400,000 and 550,000 MT of poultry feed in Kenya alone.

Acquisition of needed inputs for feed formulations is a significant challenge that limits the quality and quantity of finished feed in Kenya. The majority of both carbohydrate and protein rich ingredients are imported which raises the price and creates a trade balance deficit.

Protein cost represents 70% of ingredients used in feed production and primary sources of feed protein are soybeans and meals, oilseed cakes, and Omena/Mukene fish (silver cyprinid fish, *Rastrineobola argenta*), the latter being the most similar to insect protein. The silver fish is particularly challenging to acquire as price fluctuations and quality issues are common and purchased via brokers with links to Lake Victoria fishermen. Broad national estimates of silver fish used in feed production fall between 22,000 and 38,000 MT resulting into a value between US$ 24 million and US$ 42 million.

Silver fish prices have been volatile and rising in recent years. While in Uganda the silver fish cost in 2015 US$ 0.47/kg, in Kenya, its prices reached USD 1.44/kg at their highest point, hovering around USD 1.1-1.2/kg on average for the same year. However, in 2013, the fish cost in Kenya was as low as USD 0.65/kg, showing a worsening scenario.

In both countries, most feed producers reacted positively to the idea of including insect protein in their formulations provided a reliable availability, good value for money, consistent quality and proper policy and standards are in place.

It is estimated that a 25% conventional protein substitution with BSF, for the poultry sector alone, will require the production of 27,000 to 32,000 tons of dry BSF/year in the short term in Kenya. Considering therefore that up to 100% substitution in poultry is possible, the total national demand for BSF to substitute 90% of omena is estimated at 115,000 tons dry BSF/year. This represents 14,328 potential jobs for youth producing 2 tons of fresh BSF/month, and a conservative market value of US$ 103.5 million at the current market sell price of US$ 0.9 to 1/Kg dry BSF.

Specific Objective 2: Test the technical feasibility and economical profitability of the proposed technology with feed producers and farmers

2.1: Development, adaptation and optimization of insect rearing techniques in small scale farming systems (Annex 7).

Various insects' species were reared and studied in facilities in ICIPE, SANERGY, UoN and Makerere University. These include: Black Soldier Fly (*H. illucens*), crickets (*G. bimaculatus*, *A.*

domesticus, *T. chopard* and *B. membranaceus*), grasshopper (*R. nitidula*, *R. differens*), locust (*S. gregaria*), fruit flies (*C. cosyra*, *C. capitata*, *B. dorsalis*), leafworms (*S. littoralis*), silkworm (*B. mori*), cockroach (*P. americana*) and the blue calliphora flies (*C. vomitoria*).

Various studies were conducted in Kenya and Uganda to compare black soldier flies rearing substrates based on performance of colony.

In a first experimental set up, 5 substrates were compared, composed of swine waste, chicken waste, bovine waste, decomposing avocado, and brewery waste. Brewery waste produced the best colony performance, followed by decomposing avocado, kitchen waste, bovine waste and swine waste.

In a second set of experiment where chicken waste, kitchen waste and rabbit waste were compared, results indicated a better performance of colony reared on chicken waste.

A third experimental set up compared banana peels, brewery waste, coffee ground, kitchen waste, market waste and human fecal sludge and found the brewery waste to be the best performing rearing substrate.

A fourth experimental set up comparing brewery waste with pig waste indicated a further higher performance of pig waste compared to the brewery waste, with 4% heavier larvae when reared on pig waste compared to barley waste.

Brewery waste was the best rearing substrate for calliphora fly (*C. vomitoria*) while cassava and pumpkin leaves were the best out of nine food plants tested on the house cricket *A. domesticus*.

On another hand, rearing of crickets (both *A. domesticus* and *G. bimaculatus*) in cages containing empty egg trays and fed with wheat bran and kale gave excellent results. Different substrates tested for the purpose of oviposition and egg survival included topsoil, sand, gravel, fine sawdust, coarse sawdust and wheat bran. The number of eggs deposited in the dry substrates was significantly lower compared to the wet substrates. The highest numbers of eggs hatched were recorded on coarse sawdust followed by topsoil and fine sawdust.

2.2: Development, adaptation and optimization of wild insect harvesting technologies (Annex 7).

Four traps (Ngu, Pyramidal, Biconical and Nzi traps) commonly used to trap tsetse (Glossina) were selected and their performance with respect to harvesting biting flies and other insects compared in natural and peri-domestic habitat in Makueni County.

During the dry period (September 2015), a total of 2,127 insects were harvested in the natural habitat (Kibwezi forest), out of which 2,096 were tsetse (12 *Glossina brevipalpis* and 2,084 *Glossina pallidipes*). During the same period, only 23 insects (15 *Stomoxys*, 8 *Haematopota*) were captured in the peri-domestic habitat.

During the rainy season, trap catches were much higher than in the dry season, with a total of 6,092 insects harvested. Out of these, 5,030 were biting flies. A total of 4,998 biting flies were caught in the natural habitat versus 705 in the peri-domestic habitat. Majority of the biting flies caught were *Glossina pallidipes* (4,948). Other biting flies caught were *Tabunus gratus* (6), *Stomoxys calcitrans* (12*), Glossina brevipalpis* (36) *Tabanus taeniola* (22), *Stomoxys niger* (1), *Haematopota pluviaris* (1) *Stomoxys innornatus* (2) *Tabanus leucostomus (*1) and *Tabanus coniformis* (1).

Lake flies' traps were improved to enable overnight harvesting with minimal fishermen involvement. Field trials were however hampered by financial limitations as a result of exchange loss and this work was not completed.

2.3: Nutritional profiles of selected insects and conventional feeds (Annex 12).

The most important components sought through the use of insect as feed ingredient is the protein content and the quality of amino acid profile. For this purpose, the crude protein content as well as the critical amino acid composition of various insects were assessed and compared to fishmeal, sunflower meal and cotton seed meal (Fig 1). In addition to protein content and amino acid profile quality, other critical nutrients such as vitamins, fatty acids, flavonoids, fiber, minerals were assessed. Various processing as well as effect of rearing techniques were assessed.

A total of 28 insect species and instars, including *A. domesticus, Anaphe panda, B. dorsalis, B. invadens, B. mori, B. membranaceus, Bunaea alcinoe, C. vomitoria, Cameraria ohridella, Chaoborus pallidipes, C. cosyra, Corcyra cephalonica, Deanolis sublimbalis, Gonimbrasia belina, Gonimbrasia zambesia, Gynanisa maiya, G. bimaculatus, H. illucens, Macrotermes subhylanus, Melanocera menippe, Nudaurelia krucki, P. Americana, R. differens, R. nitidula, S. gregaria* and *S. littoralis*.

Crude protein (CP) content of tested insects varied considerably from 32.9% DM in termites *M. subhylanus* to 73.3% in *G. zambesia*. All the species reared under the INSFEED project were superior to fishmeal in terms of CP content in dry matter (Fig1). This demonstrates the potential of insects to replace the 3 conventional protein sources depending on cost efficiency and good feed performance in poultry and fish.

With regards to protein quality (amino acids profile), tryptophan and threonine, which are commonly purchased by farmers to complement vegetable based feed, are far higher in insects than in fishmeal, sunflower meal and cotton seed meals. For instance, tryptophan concentrations in mg/g DM in silkworm and BSF were 147.3 and 68.4 respectively compared to 4.3, 3.2 and 4.4 respectively in fishmeal, sunflower and cotton seed meals. Threonine concentrations in silkworm and *A. panda* were 599.5, and 525.5 respectively compared to 16.1, 8.2 and 11.6 respectively in the three conventional protein sources.

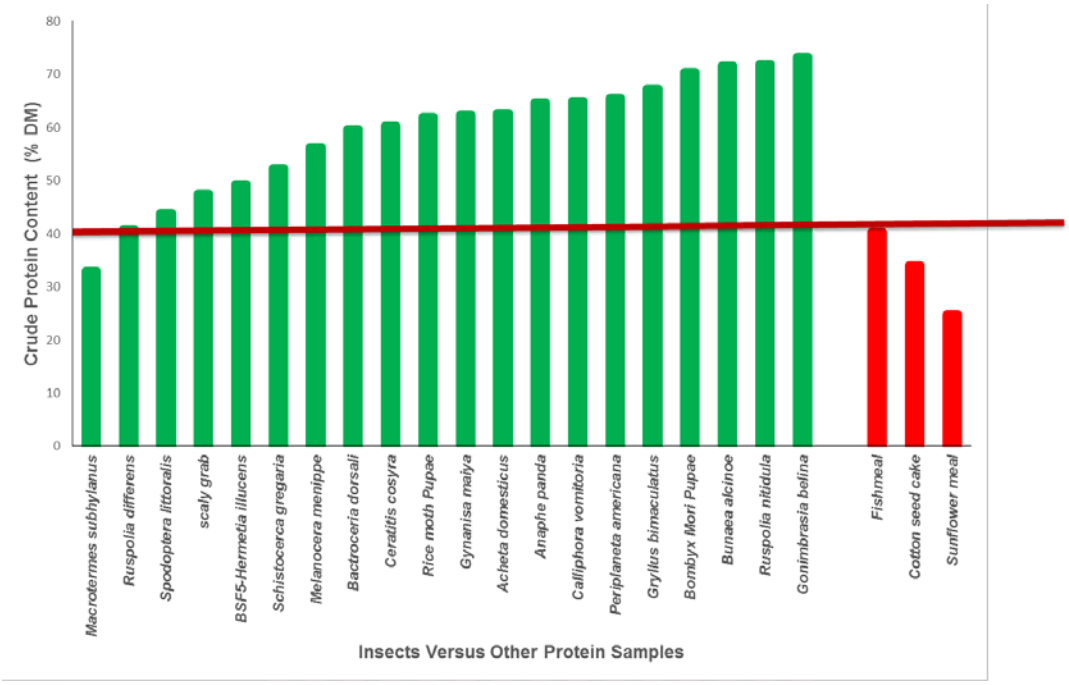

Figure 1: Crude Protein (CP) content of various insect samples in comparison to conventional feed protein sources.

Insects were found also rich in macro and micro-minerals. For instance, the three most critical macro-nutrients in poultry feed were particularly high in BSF larvae, with 44.2, 124.4 and 7.1 g/kg DM for potassium, sodium and magnesium respectively. Similarly, the three most crucial micro-minerals required in poultry feed were high in BSF larvae with 213.4, 716.7 and 16.6 mg/kg DM for iron, manganese and copper.

Four drying methods (a) 1-week sun drying, (b) 24 h oven drying at 105 ^{0}C, (c) 48 h oven drying at 60 ^{0}C and (d) 24 h oven drying at 70 ^{0}C, were evaluated. All yielded products with 91.8 and 95.4% DM, which is safe for storage. The simplicity of processing methods implies adaptability to small scale farming conditions.

Significant differences in CP were found between BSF reared on kitchen waste (36.63%) on one side and brewery waste (50.11%) and market waste (51.11%) on the other hand. The developmental stage of the insect was also crucial for CP content.

2.4: Processing and formulation of insect based poultry and fish feeds (Annex13).

Basing on the nutritive values of BSF larvae and Adult Cricket, various diets were formulated for different growth stages of poultry and fish by substituting current conventional feed protein with BSF and crickets at the rates of 25% to 100%. The main conventional protein sources substituted were fishmeal and soybean which also represent the most expensive and scarce protein sources and are mostly imported due to limited national quantities produced. The substitution was carried out based only on protein requirement, making sure the recommended protein content is met for each feed. Table 2 shows for instance the 25%, 50% and 100% BSF protein substitution in layer feed, while Table 3 shows the nutrient profile of the different modified diets. Similar links were identified between protein substitution levels and effect on nutritive profile of Nile Tilapia feed, cat fish and broiler chicken. Considering the cost of US$ 1.2 to 1.44 /kg of fishmeal on the market in 2015 and the US$0.9/kg BSF currently on the market, a reduction of 25 to 37.5% per kg of protein cost is already achieved in the short term. With increased volumes of insect production nationwide, further considerable protein cost reduction could be reached in the medium and long term. In the medium term, protein cost saving in production of 100 kg bags of feed can be estimated at 14.6% for tilapia feed and 19.9% for layer poultry feed (Annex10 & 13).

Table 2: Layer chicken diets' ingredients and corresponding black soldier fly larvae protein contribution

Feed Ingredients	**Conventional**	**BSF 25%**	**BSF 50%**	**BSF 75%**	**BSF 100%**
Maize Grains	49.1	46.95	46.08	45.2	46.82
Pollards	29.11	28.94	29.08	28.2	24.91
Bone Meal	0.39	2	0.38	0.45	0.01
Soya Bean Meal	7.83	8.53	4.96	3.6	0
Fish Meal	7.51	3.07	2.59	0.17	0
DCP	1.27	1.42	2.32	2.87	3.46
Calcium carbonate	4.44	2.81	4.06	3.89	4.18
Vitamin Premix	0.35	1.27	0.52	0.62	0.62
Insect meal	**0**	**5**	**10**	**15**	**20**
Total diet	100	100	100	100	100
CP Contribution by BSF	0%	25%	50%	75%	100%

Table 3: Layer diets nutritional composition as affected by source of protein

Diet	**DM**	**% DM**				
		ASH	**EE**	**CP**	**NDF**	**ADF**
Conventional	89.6	7.9	3.5	16.7	38.3	11.2
BSFL 25%	90.1	8.6	5.5	17.5	55.2	15
BSFL 50%	89.6	11.5	7.6	17	45.3	9.4
BSFL 75%	89.6	9.8	6.8	16.6	51.3	3.9
BSFL 100%	89.2	9.7	6.4	16.7	53.3	13.5

The cricket powder exhibited higher sorption capacity, whereas the BSFL powder was more sensitive to temperature variation. In the two substrates, transition from bound to free water begins at ~5 g/100 g. Shelf-life of up to one year is achieved if the cricket and BSFL powders are dried to ~6.5 g/100 g and ~6 g/100 g moisture contents, respectively and packaged in 80 μm thick polyethylene

bags that have low permeability to water vapour. Combination of temperature, type of packaging and duration of storage was found to significantly affect all the chemical and microbial parameters examined. Our findings demonstrate that semi-processed BSF larvae can be stored for a relatively longer period of time if postharvest contamination is avoided and the product is refrigerated in plastic packages with lid.

2.5: Risk factors associated with chemical and microbial contamination (Annex 12).

No aflatoxins were detected in a total of 13 insect samples analyzed. This implies the insects would be safe for use in poultry and fish feed even when reared on waste materials as substrates, provided proper post-harvest handling is ensured (Annex10a).

Fresh BSF and crickets were positive for the key microbes screened: *Escherichia coli*, *Salmonella typhi, Staphylococcus aureus,* fecal coliform and, yeasts and molds. Similar results were obtained when boiled at 96 ^{o}C for 1 or 2 min or toasted at 150 ^{o}C for 1 minute. However, when boiled from 5 min or more or toasted for 2 min and above, the insect materials were free from microbes. This implies that simple post-harvest handling like boiling or toasting can reduce or even mitigate the risk of microbial contamination through the value chain. Proper storage conditions are however required to maintain quality of the insect material since re-contamination was observed and increased with storage time where proper post-harvesting handling methods were not followed.

2.6: Performance of insect based feed on fish and poultry (Annex 13).

Various insect based feeds were tested on tilapia, cat fish, broiler chicken and layer chicken in both countries. Results showed that the performances, in terms of feed intake, growth rate and/or egg production, of all the animals fed insect based feed, were at least equal to and in majority of the cases, outperformed those fed on conventional feed. Conventional protein substitution with insect protein ranged from 25 to 100%. Broiler chicken was the only one for which BSF based feed performed just equally in all parameters (growth rate and feed intake) compared to conventionally fed ones. Nile Tilapia fed for 20 weeks with diets where 33% of fish protein was substituted with BSF larvae protein showed 23.4% higher weigh gain and 28.4% better feed conversion than that fed on conventional feed. Performance studies in catfish fingerlings revealed a 37% higher growth rate and 23% higher weight gain was achieved from BSF-based feed, compared to conventional feed. Layer chicken fed from 31st to 52nd week of age on BSF based protein up to 100% substitution laid better quality eggs, with egg yolks scoring 15 on a scale of 16 compared to a score of 3 to 4 for conventionally fed layers. They also produced 2.1 times higher average egg in their last 10 weeks

and prolonged significantly the egg laying period above economic threshold compared to eggs from layers fed with conventional diet (Fig 2).

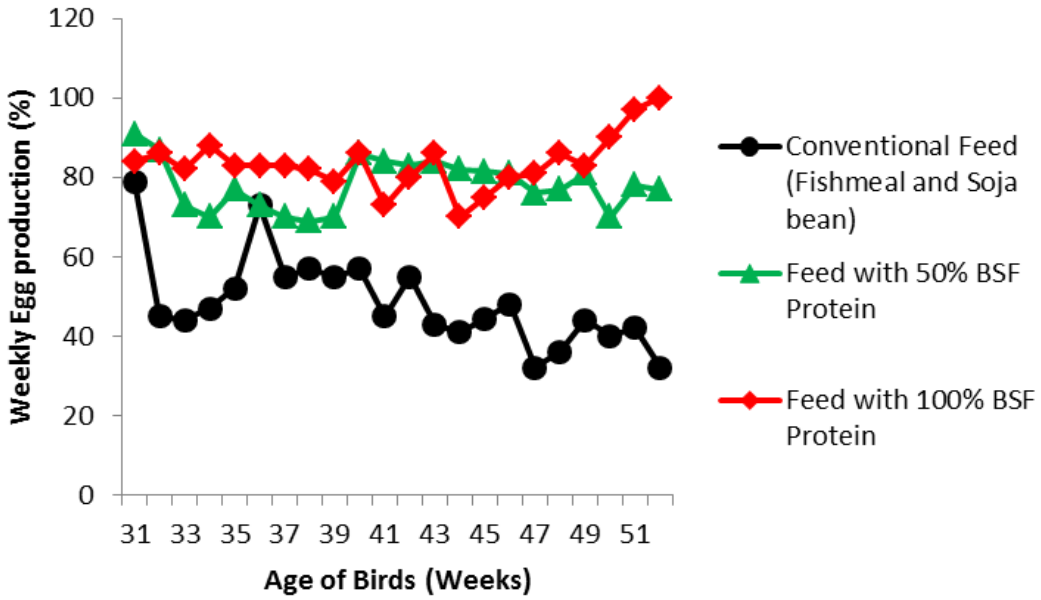

Figure 2: Effect of Black Soldier Fly Larvae inclusion in diet on weekly egg production of KALRO improved indigenous chicken.

Specific Objective 3: Create favorable social and political conditions for using the technology at large scale.

3.1: Stakeholders workshops and advocacy meetings to create favorable social and political conditions (Annex 14).

The "*International Conference on Legislation and Policy on the use of Insects as food and feed in East Africa*" held at Kisumu with effective participation of 105 participants enabled the formulation of recommendations to the scientific community, governments, donors and private sector (Annex 3a & b). Furthermore, the conference enabled establishment of a common roadmap with policy makers in regards to the development and approval of a standard for the use of insect in feed in Kenya and Uganda.

A total of seven follow up advocacy meetings and stakeholders' workshops were held in the two countries in the scope of developing, reviewing and approving standards for insect inclusion in animal feed.

3.2: Standard developed and approved (Annex 14).

The project team organized various international and national stakeholder's workshops in Kenya and Uganda between March 2016 and June 2017. The team also filed applications with and

submitted proposals to the Kenyan Bureau of Standard (KEBS) and Ugandan National Bureau of Standard (UNBS) in September 2016. With assistance of the respective national Technical Committees (TC) for animal feed, standards were drafted in December 2016 and March 2017 in Kenya and Uganda respectively. The drafts were submitted for public review in each country, followed by balloting and submission to each national Standard Approval Council (SAC). The "*Dried insect meal for compounding animal feed*" standard that, at the same time allows inclusion of insect in animal feed and guides its application, was approved in March 2017 and June 2017 in Kenya and Uganda respectively. This created an enabling policy environment for commercialization of insect for feed. For instance, in Kenya Sanergy Ltd., one of the project's private partners, has started commercialization of insect production for feed and has so far sold 43 tons of dry BSF to various Kenyan feed manufacturers just between April and May after standard approval in Kenya. The huge demand that followed this standard approval enabled the company to secure co-investment funding with FinFund from Finland, in order to expand their insect production capacities to >3,600 tons of dry insects/year for the feed sector.

3.3: Awareness creation and trainings (Annex 4)

The project team participated in various international fora, to present research findings and to create awareness among various stakeholders in Kenya, Uganda, Canada, Benin and Madagascar with a cumulative audience of above 1,200 participants. The team also received a high demand from youth, farmers and private companies for training on insect rearing as well as its use as feed or feed component. Being a proof of concept phase, a limited number of these demands were attended to. The total number trained during the project life time was 506 (293 males and 213 females). Awareness was also created through the partnership with another CultiAF funded project named Radio Reaching Farmers with Research Results (4R), implemented through Farm Radio International (FRI), broadcast of insect for feed related radio programs in Uganda. The "*Lutabanjaliire*" radio program is a platform where community members discuss farming-related issues. Radio Simba airs the program every Saturday and Sunday in the central while Mega FM airs it on Tuesdays and Thursdays in the northern region of Uganda. The programs have high listenership, and the total number of listeners who called directly to participate in the radio programs was 25,388. It is therefore evident that a far higher listeners' reach was achieved.

3.4: Research Partnership

The INSFEED project team led the International Legislation conference for East Africa. The majority of the local committee comprised of INSFEED project team and above 80% of the core

costs of the event was covered through the project. In addition, the team was also instrumental in creating synergy between other projects currently involved in the agenda of insect use as feed and food in Africa as whole but also in Europe, Asia and America.

Since the initiation of the project, two other projects were funded through the same donor in order to improve on dissemination of insect based feed potential as well as upscaling to young entrepreneurs in Uganda and Kenya through Farm Radio International (FRI) and the United States International University (USIU).

The INSFEED project also gave the necessary visibility and capacity building in the area of use of insect for food and feed to all the institutes involved and particularly ICIPE and Makerere University that lead the project as well as other partners. For instance, at ICIPE, two other projects were funded: ILIPA with €600,000 funded by the Dutch NWO and EntoNUTRI with €1,200,000 funded by the German GIZ/BMZ. The latter project, which also involves Makerere University, specifically focus on insect for food to complement the insect for feed aspect carried out within INSFEED. SANERGY Ltd., the main private partner in Kenya was able to secure a co-investment partnership with FinFund from Finland in order to expand on their insect production capacities for the feed sector.

A world bank funded regional center of excellence project estimated at US$ 7,500,000 and involving all the institutes currently in INSFEED project is approved for funding and led by JOOUST University who co-organized the international conference.

INSFEED project team presented the project's research findings in Canada on invitation from the Aquaculture Association of Canada (AAC) and NewFoundLand Aquaculture Industry Association (NAIA). Through this conference the project team built network with the Global Affair Canada, the Canadian Costal Zones Research Institute (CZRI). These networks also enabled the INSFEED project team to exchange experience and maintain contact with two Canadian private companies specialized in edible insect commercialization: Enterra Feed Ltd. which is specialized in production of BSF for feed and Entomofarms Ltd. specialized in insect based food production.

The project team was also invited by the Madagascar Biodiversity Centre to share the INSFEED experience and establish partnership with institutions interested in undertaking research and commercialization of insect as feed or food.

The Kenyan INSFEED PI has been promoted since January 2016 as Program leader as a result of the INSFEED project and in charge of the Insect for Food, Feed and other uses (INSEFF) program of ICIPE while the Ugandan PI was promoted to Associate Professor in 2017 following, among others, the leadership, scientific contribution and strong networking demonstrated through this project.

3.5: Governance

Gender equity was built in the project implementing strategies, with women making 52% of trained postgraduate students. Both PIs from the two countries alternate leadership in project technical reporting while financial reporting is done directly to IDRC by each PI.

3.6: Research Ethics

Respondents and small-scale farmers participating in this study are selected based on their informed consent and free willingness to be interviewed and/or be involved in the project activities; and their confidentiality and anonymity are fully respected. Data collection is impartial and done with total integrity and quality.

3.7: Use of research results

The INSFEED project results were the backbone of data used by policy makers in Kenya and Uganda for establishment of standards for the use of insects in animal feed. The standards developed in both countries in turn was the major trigger of demand for insect for feed production by mainly the medium scale feed processors while large scale feed producers still await reliable countrywide productions. More than 200 agripreuneurs were trained in insect rearing to target this emerging market and while at the current phase of the project training was limited to a hands-on approach of less than a week, agripreuneurs that had poultry, fish or pig farming activities before receiving the training started their own small-scale insect productions. The demand for a consistent training is growing in both countries and the project team even receives requests from neighboring countries like Rwanda, Tanzania and Ethiopia as well as from distant countries like Ghana, Togo, Benin and Nigeria. Insect production for feed has started to gain ground in both Kenya and Uganda and led by partners involved in the project as well as farmers trained in the project. Business and funding partners have shown interest in implementing joint ventures with enterprises involved in insect rearing and the aforementioned case of Sanergy and FinFund is surely just the beginning.

5. SYNTHESIS TOWARDS AFS THEMES

Increasing Agricultural Productivity (Availability)

The ever-growing cost has driven vulnerable small-scale poultry and fish producers out of business, with the resource poor youth and women being most affected. The use of insect in feed has proven to not only provide an alternative protein source in livestock and aquaculture and therefore lift this burden but also has the potential of reducing the protein cost by 25 to 37.5% in the short term and by 41.7 to 51.4% in the medium term. Such cost reduction is expected to promote youth and women adoption of poultry and fish farming and increase the use of quality feed in poultry and

fish rearing, which in turn, will increase productivity as well as production levels. Furthermore, the high yield in terms of weekly egg production coupled with the prolonged economic profitability period in layers fed with BSF based feed will increase egg productivity and production where insect will be adopted for inclusion in feed. Higher growth rates in Tilapia and catfish also provide the potential for increased productivity in the aquaculture sector.

Improving Access to Resources, and/or Markets and Income (Accessibility)

Establishing cost effective and sustainable insect rearing facility for feed market represents on its own a fertile ground for job creation and income generation. In Kenya alone current market value of commercial poultry and fish are US$ 133 million/year and US$ 56 million/year. The current volume of poultry mixed feed alone in the country is estimated between 400,000 and 550,000 MT/year and, with the increasing population this is expected to increase. The substitution of current protein with BSF in poultry feed alone in Kenya has a potential demand of 115,000 tons of dry insect per year, translating into a market value of US$ 103.5 to 115 million/annum and >14,328 jobs. It is estimated that the fish and pig feed will triple this demand, market size and job creation potential levels to 345,000 tons, 310.5 to 345 million and 43,000 jobs respectively. In a growing industry and a more and more urbanized population in search of meat, insect mass rearing for sell to the feed sector is therefore a suitable opportunity for income generation for the enterprises that will embrace this business. This will empower the youth and women as well as men, and improve the access of all to wealth while reducing gaps.

Improving Nutrition (Utilization)

The quality of egg obtained from insect based feed was constantly superior to eggs from conventionally fed chicken. An orange yolk compared to the whitish-yellow yolk in egg from conventionally fed layer chicken implies higher nutritional value derived from pigments such as carotenoids. Some carotenoids, like beta-carotene, contain high nutritional values for humans' consumption. Human bodies convert beta-carotene into vitamin A, therefore a wide spread use of insect based feed for layers' feed will therefore translate into an improved human nutrition.

Informing Policy

In an attempt to influence policy, the various stakeholders meeting where KEBS, UNBS, Kenya Wildlife, Uganda National Environment Management Authority (NEMA), the Kenyan Museum were represented at director level and where world renown enterprises like Unilever, various arms of government from both countries, FAO, and participants from Africa, America, Asia and Europe contributed in creating the necessary momentum required to take this agenda further and ensure

upscaling and uptake of technology. Further advocacy meetings with policy makers in the animal feed sector, coupled with various stakeholders' workshops in both countries created the in-depth awareness required to create favorable condition for the use of insect in animal feed. Before the inception of the INSFEED project, insect was not allowed in animal feed and even considered as contamination in both countries. The knowledge generated through the project informed policy about the potential insect has as alternative protein source. Through continuous engagement of and dialogue with policy makers, a standard for use of insect in animal feed was developed, disseminated for public review and input then finally approved in both countries to guide the agenda.

6. PROJECT OUTPUTS

Various outputs were achieved through the INSFEED project. Key outputs include two standards for insect based feed developed, processed and fully approved, data generated to demonstrate feasibility and profitability of the use of insect as protein source in feed and nutritive potential of insects as well as their mass rearing techniques developed. Furthermore, through the various training approached, 25 students were trained, 506 farmers and youth were trained, 25,388 radio program listeners were actively engaged in the dialogue on insect as feed, >20 media and web coverage, at least 15 key note speeches and presentations at international and national fora. Project results were also being disseminated with 6 papers submitted for peer review publications, 1 gender story of change paper, > 25 draft peer reviewed papers being internally reviewed. Through results generated in the present project, insect production as business has been taken up in both countries and the market demand is paramount.

7. PROBLEMS AND CHALLENGES

Key challenges faced were:

- Survey tools were supplemented with gender related aspect, leading to a longer time of data collection and a more robust socio-economic data analysis than initially planned.
- There was delay in setting insect colonies at the beginning of the project and that affected the timely delivery activities depending on insect availability. The colonies were later successful and the 3 months no cost extension enabled successful project completion.
- Certain project components were initially not budgeted for in Uganda. A revised budget approved by the donor enabled smooth running of project.
- The high reduction in CAD exchange rate compared to USD led to a loss of equivalent of USD 260,763 on the Kenyan side. Field activities scheduled for the last 6 months

(awareness creation, wild harvesting and conferences) were reduced to bare minimum to fit costs where possible.

8. OVERALL ASSESSMENT AND RECOMMENDATIONS

The achievements of the INSFEED project were beyond expectation. Initially designed to be just a proof of concept, the thrilling results obtained, coupled with the dare need of alternative protein, the motivation of youth to produce insect as feed ingredient for income generation, the support from policy makers, strong and highly relevant partnerships … made the project a highly successful one. Insect rearing techniques were developed, standard developed and policy makers even at the high levels in both countries are passionate about the initiative, the insect rearing as business is being taken up by private sector, the job creation and income generation potentials proven throughout the potential use of insect in feed, from the new business itself, to increased productivity in existing industries, are some of the far reaching successes of the INSFEED project.

In regards to risk management, none of the foreseen risks have impeded the smooth running of the project. No major political instability was faced and farmers, private sectors, policy makers and scientific community strongly supported the initiative. However, the approach of technical report submission on same date of project ending was a concern for all partners in the project, and the unforeseen unfavorable exchange rate affected the project.

All stakeholders are unanimous in recommending that this initiative be taken to full accomplishment, not only in the 2 countries when the project was implemented, but also beyond, to make tangible impact on the livelihood of the billions of vulnerable populations in developing countries. For this to be achieved, a second phase of the INSFEED project will be necessary to disseminate project findings, take it from proof of concept to pilot stage, fine tune and scale up the technologies, incubate youth and promote on the ground business development and job creation.