***Photo 1** Fish farming at Lake Victoria, by Charles Mbauni Kanyuguto (FOSPA)*

The protein transition

How to operationalise use of black soldier fly larvae (BSFL) and spirulina as feed ingrediencies in Kenya and Uganda?

Authors

[1] Katrine Soma,[1] Adriaan Vernooij,[2] Maria Barbosa,[3] Mary Opiyo,[4] Jeroen Kals,[2] Rafael Cubero,[3] Hassan Pishgar Komleh,[2] Eugene Rurangwa,[5] Asaah Ndambi,[6] Raymond Schrijver,[7] Alwin Gerritsen[7]

Abstract[2]

Sub-Saharan Africa is confronted with complex interrelated problems of affordability and accessibility to feed and food for aquaculture, livestock, poultry and pig production for the larger share of the population. Moreover, drought, flooding and increasing commodity prices are accelerating the needs for more resilient food systems and strategies supporting trends of transitioning. Making use of locally cultivated insects and microalgae in feed supplied in the markets will not only enhance production potentials for local feed producers and small-scale farmers demanding the feed but will also provide high-quality affordable products for low-income consumers in Kenya and Uganda, if arrangements are implemented that will support such developments. In this Concept note, we introduce a series of trials with black soldier fly larvae (BSFL) and spirulina as replacement of soyabeans and fishmeal in feed that are carried out by KMFRI and WUR 2022, as well as a Footprint Analysis in Uganda and household survey of farmers in Kenya, with the **main aim to explore how to operationalise the use of fish feed containing black soldier fly larvae (BSFL) and spirulina for (fish) farmers in Kenya/Uganda, and to address challenges and opportunities for protein transition in the region of Lake Victoria**.

[1] [1]Wageningen Economic Research, [2]Wageningen Livestock Research, [3]Wageningen Bioprocess Engineering, [4]Kenya Marine and Fisheries Research Institute (KMFRI), [5]Wageningen Marine Research, [6]Wageningen Animal Science [7]Wageningen Environmental Research

[2] The Alternative fish feed sources from local resources in Lake Victoria region: Food loss and dialogues project (KB-35-008-015) and the Feeding cities and migration settlements project, followed up by the Food and nutrition security of low income groups in rural-urban food systems in the global south project (KB-35-002-001), are subsidised by the Dutch Ministry of Agriculture, Nature and Food Quality.

1 Introduction

Demand for animal protein for feed and human consumption is growing worldwide, and even more so in Sub-Saharan Africa, as a result of growing populations and increase in welfare among low-income groups (FAO, 2017). Alternative sources of protein are a necessity to meet this increasing protein demand in a sustainable way (Soma, 2022). At the same time, greenhouse gas emissions, such as carbon dioxide and methane, must decrease to reduce environmental footprints of future food systems, and to increase their resiliency through adaptation to climate change (IPCC, 2022).

In the Lake Victoria Region, efforts have been made to produce alternative feed ingredients locally, such as the production of black soldier fly larvae (BSFL) (*Hermetia illucens*) and spirulina (*Cyanobacteria*) for inclusion in formulated feeds, which are welcomed contributions to the regional protein transition. Fish farming in the Lake Victoria region is diverse in size and in application of different production systems, including cages, ponds and tanks (Obwanga et al. 2019). The fish-farmers share one challenge, namely that feeds claim a major share of the costs, often up to 70% of their income, and has been increasing in the last years due to increasing grain prices. If the protein transition could support fish farming by offering alternative feed ingredients with lower environmental footprints, and at the same time lower feed costs, this would allow fish farmers to extend investments in fish farming, and through extension of this sector, contribute even more to the protein transition by supplying affordable fish products to consumers. The use of BSFL, as well as a micro alga referred to as spirulina, as fish feed ingredients are currently investigated by WUR and local partner institutes in Kenya and Uganda, including KMFRI.

The main aim of this Concept note is to communicate to practitioners and policy makers how locally available waste materials can be upcycled, e.g., using BSFL. The Concept note further explains how to operationalise the use of fish feed containing BLSF and spirulina for fish farmers in Kenya and Uganda.

Photo 2 *Fish farming at Lake Victoria, by Charles Mbauni Kanyuguto (FOSPA)*

2 A Food system approach for protein transition

In Sub-Saharan Africa the population may increase from 1.15 billion to 3.8 billion from 2022 to 2100 (UN, 2022). While natural resources are threatened by degradation, and large numbers of people are living below the poverty line, an increase in the demand for animal-derived protein for human foods and animal feeds is taking place. Circular economy solutions with a re-use of organic waste and a shift towards the consumption of sustainable sources of protein, such as insects and single cell proteins are highly needed to increase living standards of low- and medium income groups (Soma, 2022). Making use of single cell proteins, insects or other animals to upcycle organic resources that are not suitable for human consumption can contribute to reducing organic waste and upcycling proteins to the maximal use.

A food system approach, as illustrated in Figure 1, points to the fact that food system activities, including the production of feed with insects and/or single cell proteins as ingredients, will have impacts in the whole food system and its outcomes. A protein transition will have large direct and indirect impacts on the Sustainable Development Goals addressing the environmental drivers, including on climate action (SDG13) as well as on natural resources on land (SDG15) and below water (SDG14). Moreover, the protein transition will contribute to fulfilment of a series of socio-economic related SDGs, including: GOAL 2: Zero Hunger, GOAL 8: Decent Work and Economic Growth, GOAL 10: Reduced Inequality, GOAL 11: Sustainable Cities and Communities, and GOAL 12: Responsible Consumption and Production (UN, 2015).

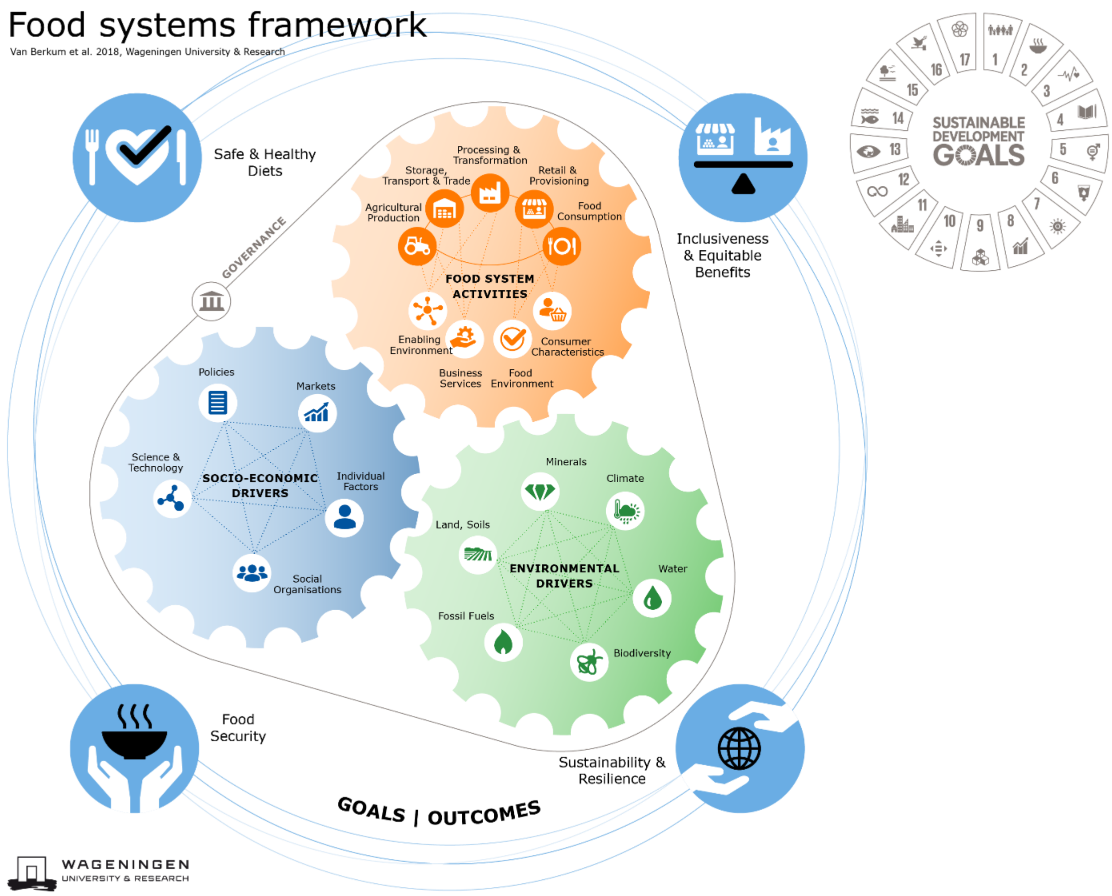

Figure 1 *A food system framework is applied focusing on the innovations of using insects or spirulina as protein source in food production systems*

3 The aquaculture sectors in Kenya and Uganda at a glance

Aquaculture

In 2020, global aquaculture production reached a record 122.6m tonnes, with a total value of $281.5bn (FAO, 2022). During the last years, the overall aquaculture production did not grow in Africa as a whole because of a decrease in the two major producing countries, Egypt and Nigeria (ibid.). This reduction in growth is foremost explained by low technology adoption, inadequate supply of fingerlings and high cost of fish feed (Kaleem and Sabi, 2021). In addition, challenges to growth relate to resource use conflicts (water and land) and energy consumption (Soliman and Yacout, 2016). Still, the rest of Africa, including Uganda and Kenya, contributed with 14.5% growth from 2019 (FAO, 2022*).*

Since 2000, Kenya and Uganda contributed with the highest annual growth rates of aquaculture production volumes of 22% and 23%, respectively (Ragasa et al., 2022).

Lake Victoria has a total area of 68,000 km^2, shared between Uganda (45%), Tanzania (49%) and Kenya (6%) (FAO, 2022). Uganda is a land-locked country endowed with waters and lakes. Uganda is the second largest aquaculture producer in Sub-Saharan Africa after Nigeria, and the third in Africa, with Egypt on the very top of the list (Adeleke et al 2020). Aquaculture production in Uganda increased from just over 800 tonnes (2000) to 123,897 tonnes in 2019. In Kenya, through a government programme called the Economic Stimulus Program (ESP), the aquaculture production got a jumpstart from 2009/2010, increasing from less than 5,000 tonnes to more than 24,000 tonnes in a peak reached in 2014, before decreasing and again increasing from 2017 (KNBS, 2021).[3] ESP support contributed to a higher number of small-scale fish farmers (roughly estimated at around 30,000). In Uganda, it was estimated that 28,236 were involved in fish farming in 2019 (FAO, 2022). In both countries, there is a shift of fish farming in ponds to fish farming in cages.

Both in Kenya and Uganda, aquaculture production is mostly composed of Nile tilapia *(Oreochromis niloticus)* (75% in Kenya and 69% in Uganda) and Catfish *(Clarias gariepinus)* (18% in Kenya and 30% in Uganda). Whereas in Uganda the annual per capita consumption of fish was estimated at about 11.2 kg (2016), in Kenya this is a lot lower, at 4.3 kg per capita (Farm Africa, 2018). Uganda is a net exporter of fishery products. The total fish and fishery product exports in Uganda were valued at $160 million in 2019, mostly Nile perch sold to European countries as fillets. The same year the imports were valued at $10 million.

Photo 3 *Fish farming in Nyeri, by Charles Mbauni Kanyuguto (FOSPA)*

Feed

In Kenya there are currently 24 approved feed suppliers of pellets for fish production (e.g., Sigma Ltd, UngaFarmcare Ltd, Lenalia Feeds Ltd), of which six import the feed (Obwanga, 2018). Only 7% of the total amount of the high-quality fish feed needed in Uganda is currently locally produced. The remainder consists of imported or low-quality home-grown mixtures, compromising the effectiveness of fish production in Uganda (Khan et al*.,* 2021). The high-quality feed sold as pellets still makes use of soya as main protein source, which has been criticised for contributing to natural resource degradation and CO_2 footprint of the industry. When available, fishmeal, which is a commercial product made from bycatch or fish by-products, is the preferred protein ingredient in fish feed. Fishmeal production around Lake Victoria is usually of a low quality due to poor drying methods and adulteration with sand and shells. Therefore, in this project ingredients from BSFL and

3 LINK: FILM HATCHERY LAKE VICTORIA

spirulina are tested and evaluated as alternatives or complementary ingredients for fish feed. In Table 1, an overview of some core national figures of aquaculture in Uganda and Kenya is provided.

Table 1 *Overview of national figures of aquaculture and feed in Uganda and Kenya**

Per year	Uganda	Kenya	Source
Production of farmed fish per year (tonnes)	123,897 tonnes	19,945 tonnes	*FAO (2022b)/ KNSB (2021)*
Annual growth rate of aquaculture	23%	22%	*Ragasa et al. 2022*
Consumption of farmed fish per year (per capita)	11.2 kg per capita	4.3 kg per capita	*FAO (2022b)/ FarmAfrica (2018)*
Export of fish	19,039 tonnes	2,000 tonnes	*FAO (2022b)/ KNSB (2021)*
Import of fish	11,200 tonnes	19,000 tonnes	*FAO (2022b)/ KNSB (2021)*
Manufactured feed		988.7 tonnes	*KNSB (2021)*
Import of fish feed	26,885 tonnes	n.a	*Larive (2021)*
Commercial feed usage	69,058 tonnes	n.a	*Larive (2021)*
No of fish farmers	28,236	30,000	*KMFRI*

* The figures are meant to be indicative and stem from different years and references.

Photo 4 *Fish farming in Nyeri, by Charles Mbauni Kanyuguto (FOSPA)*

Small-scale fish farmers in Kenya

The aquaculture sector in Kenya uses multiple production systems, including cages located on lakes and dams and ponds on agricultural land. Some 30,000 small-scale fish farmers using ponds operate in Kenya, for which most are low or medium commercialised (Jacobi, 2013). An average small-scale fish farm operates with one, two or three ponds of about 300m^2. The fish farmers using ponds foremost cultivate Nile tilapia and African catfish. The farming of fish using ponds in a semi-intensive way demands the input of feed, which can be commercial fish feed, the use of pig pellets, poultry feeds or farm-made feeds. The latter three, which are most common as commercial fish feeds are often out of reach are not optimal to feed the fish which result in less effective results. The lowest income fish farmers use their own labor, and consume the fish at the household level, while others sell at the farm gate to neighbors or other customers. Given low opportunities for making choices of investments because micro-credits mostly are not available, the small-scale fish farming often operate below optimal performance and may incur losses. A basic profit-loss statement of small-scale fish farmers is shown in Table 2. The table shows that for one pond the net revenue per year has been estimated to an average of €235. Note that the revenue is about three times higher (€725). Because the variable costs are relatively high, the net income is low. Of the total variable costs, on average of about 70% is spent on feed. The example shows how much impact the feed costs have on the small-scale fish farmers' business models.

Table 2 *A basic profit-loss statement of the small-scale pond fish farmers in Kenya**

Yearly net income		**One Pond (€)**	**Share feed costs**
Revenue	207 kg per pond * €3.50 per kg	725	
Variable costs	Sum of the costs below	489	
Costs feed	*Economic feed conversion rate: 2 kg feed per 1 kg fish; Total feed needed p.a. 414 kg; Price feed 0.79 per kg*	*326*	*67%*
Costs fingerlings	*Price €0.09 per piece; 6 fingerlings per m^3; no. of fingerlings needed per pond ($300m^2$) per year are estimated to be 1815*	*163*	
Net revenue		**235**	

* Numbers are averages based on the Nyeri Fish Farmer Cooperative Society LTD in Kenya, January 2022.

Feed costs across aquaculture categories.
An analytical farm household survey of 300 farmers was conducted in the counties of Kiambu (60), Kakamega (80), Siaya (80), Nyeri (45) and Kirinyaga (35) in August 2018 (Obwanga et al., 2018). While a large share of fish farmers used cages in Siaya, in the other counties, pond farming is dominating (Figure 2A). Moreover, the level of commercialisation is higher among cages than ponds (Figure 2B).

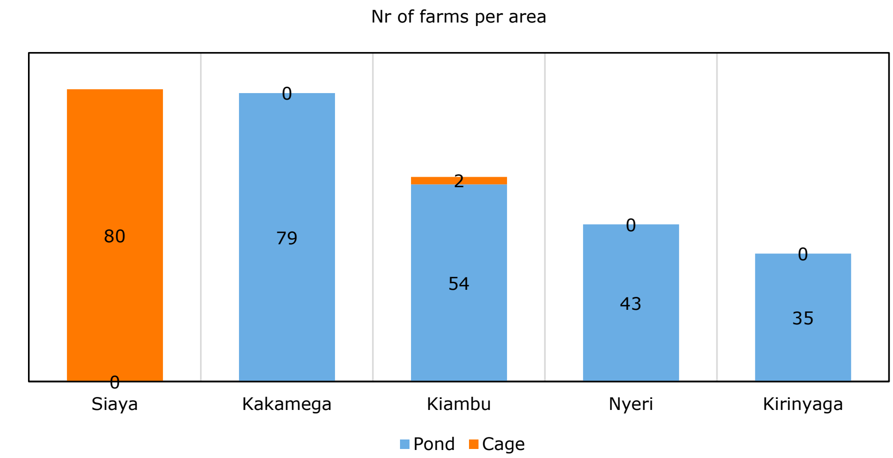

Figure 2A *Sample of interviewees of pond and cage farmers across counties in Kenya*

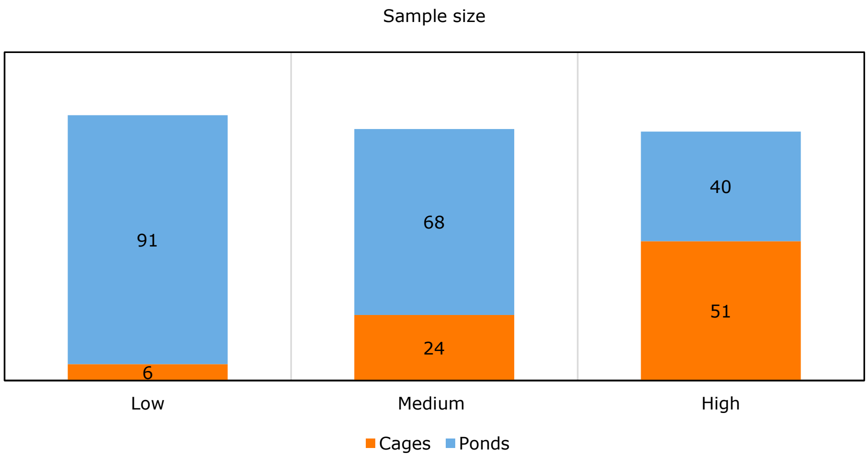

Figure 2B *Relative commercialisation levels of pond and cage fish farmers in Kenya*

The diversity within fish farming in Kenya is further demonstrated by the large differentiation in yearly gross margin[4] (€). Whereas the low-income pond fish farmers on average earns around €528, the most profitable cage farmers earns a gross margin of an average of €3,149 based on this survey (Figure 3A) (Obwanga et al. 2018). Moreover, looking at the share of feed costs of total variable costs, although it is high to all the differentiated segments of this survey, it is the highest for medium commercialised pond farmers (63%) and lowest for the medium commercialised cage farmers (38%). This is slightly lower than the estimate provided in Table 2 (i.e., 69%)

The overall message is, if the costs of feed get lower for high quality feed, the gross margin will increase substantially for all the different categories (Munguti et al. 2021).

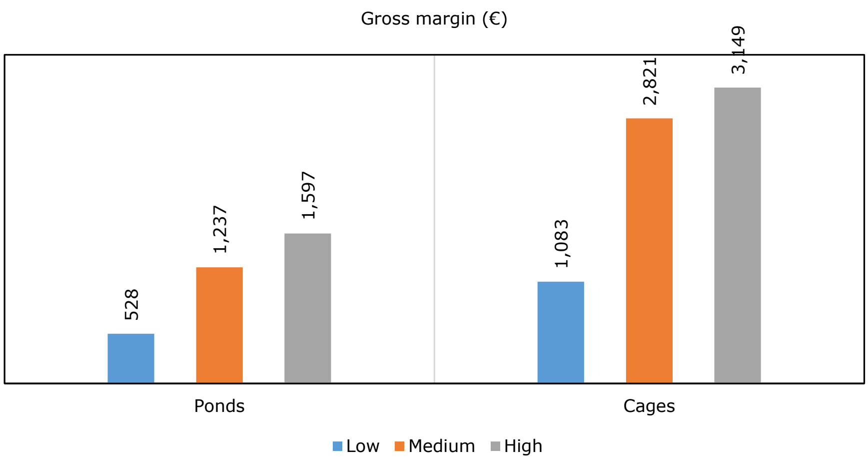

Figure 3A *Gross margin (€) across different commercialisation levels of cage and pond fish farming in Kenya*

[4] Gross margin is estimated by subtracting average total variable costs from the average gross sales.

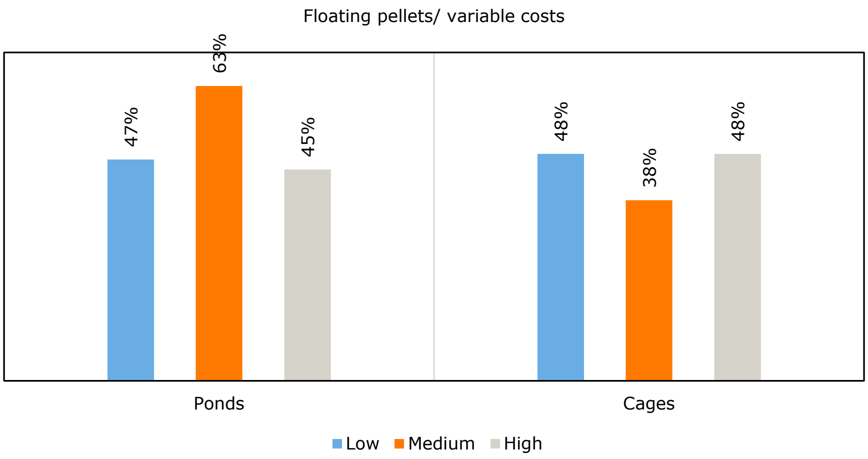

Figure 3B *Floating pellet costs as share of variable costs across commercialisation levels of cage and pond farmers in Kenya*

4 Exploring BSFL as protein source in feed in a trial measuring growth of fingerlings in Kenya and Uganda

In 2022, a project was carried out at Wageningen University & Research (WUR) within a strategic programme called Protein Transition Investment Theme[5], on 'Alternative fish feed ingredients from local resources in Lake Victoria region'. This project lays at the interface between the science themes biochemical processes and complex transition networks, focusing on microalgae and insects. Improving the productivity and environmental performance of aquaculture and ensuring it provides safe, affordable, and nutritious food/proteins to millions of people around the world is an important item for a sustainable food future. In order to grow sustainably, the project results must be made available to fish farmers, suitable to the region's needs for operationalisation under local market conditions.

Black soldier fly larvae (BSFL)

In Kenya many businesses have begun culturing the BSFL larvae, both on small and large scale. In most cases the BSFL larvae are grown on local waste and by-products and seen as a sustainable way of producing protein. The black soldier fly larvae (BSFL) possess a series of properties making it possible to convert urban food waste into animal feed. The BSFL is suited to feed a variety of animals including poultry, pigs and fish. During larval stages, the BSFL has a great appetite for organic waste including everything that begins to rot. The BSFL have been shown to effectively digest a wide range of organic waste products such as offal, kitchen waste, fruit and vegetable waste, but also for conversion of chicken manure. (Tanga et al. 2017)

The cycle of a BSFL lasts for a total of 38 days. Newly hatched larvae have a dull white to cream colour and are about 1.8 mm long. A larva goes through five larval stages and completes development by around 13 - 18 days with favourable conditions. Optimal moisture content for the feed (60% - 90%), and optimal temperatures for efficient processing (27 - 33°C) must be met. The BSFL is reared under shade, as they bury themselves in the substrate when exposed to light. When the BSFL has grown to roughly 27 mm in length and 6 mm in width, they have a pale white colour with a small black head containing their mouthparts. It takes about six months for a larva to reach a maturity as a black soldier fly (BSF).

The benefits of BSFL include that it is easy to harvest. In the last stage of the BSFL's life cycle, the larvae develop a large fat store, empties its gut, and then seeks a place away from the waste to pupate, which makes it simple to collect the larvae. Moreover, after the food waste has been

[5] WUR Protein transition investment theme: https://intranet.wur.nl/Project/ProteinTransitionInvestmentTheme

processed by the BSFL, the leftover biomass is nutrient-rich, low-odour, humus that can be added to soils as an amendment to increase organic matter and fertility. Bottlenecks include the changing composition of protein in the feed depending on what the BSFL are fed, which depends on the defatting process (production of high quality defatted BSFL meal). Challenges of formulating feed based on BSFL also refers to high fat levels compared with high quality fish meal pellets.

WUR together with Kenyan and Ugandan partners, including Kenya Marine and Fisheries Research Institute (KMFRI) and an aquaculture farm called 'Bukani Aqua Park' in Kenya and NARO Kajjansi ARD Centre in Uganda, investigate ways in which the production of dried larvae can be used as feed directly.

BSFL trials Uganda & Kenya

Protein from locally produced BSFL meal has the potential to be a sustainable alternative to protein from local fishmeal. Investigating whether protein from locally grown BSFL is a suitable alternative for the fishmeal component in fish feed for Nile tilapia is therefore relevant. To determine this, conducting experiments with feeds in which different amounts of fishmeal protein are exchanged with locally grown BSFL protein will provide important information about important parameters, such as growth, feed conversion and survival.

Fingerling trail in Uganda

Six experimental diets were formulated, of which the protein fraction of the fishmeal is replaced for 0%, 25%, 50%, 75% and 100%, respectively, by protein from a locally produced defatted BSFL meal (Proteen, Kampala, Uganda). In addition to these five experimental feeds, a commercial feed is included as a reference. The composition of the feeds have the same amount of dietary nitrogen (i.e. iso-nitrogenous) and have the same, or constant, energy (i.e. iso-energetic). The diets were tested in triplicate, resulting in 18 experimental units. Tilapia fingerlings were obtained from a local producer, and were randomly allocated to the 18 tanks integrated into a flow through aquaculture system. After acclimation, the fingerlings were fed to apparent satiation with the experimental diets in order to achieve maximum feed intake. The average fish weight per tank is determined at the beginning, in between and at the end of the experiment. At the end of the trial growth, economic feed conversion rate and survival rate are determined across the fingerlings fed with different diets. The obtained data is analysed using ANOVA to test dietary effects, with tests of p-value < 0.05 indicating a significant difference. When an effect is significant, any difference between individual treatments is tested using a so-called post hoc test.

Fingerling trial in Kenya

For the trial at Bukani Aquapark, Nile tilapia fingerlings were bought from local hatcheries, graded, weighed and randomly allocated to the ponds at a density of three fish per m^2. After seven days, fish were fed with the different experimental treatments randomly allocated to the ponds. The fish were fed by hand to apparent satiation three times a day in order to achieve maximum feed intake. The average fish weight per pond was determined at the beginning, in between and at the end of the experiment. At the end of the trail, the results are presented in the form of dry matter, and biomass per pond, number of fish per pond, average fish weight, growth and the economic feed conversion rate are determined. The obtained data is analysed using ANOVA to test dietary effects. Tests with a p value < 0.05 indicate a significant difference. When an effect is significant, any difference between individual treatments is tested using a post hoc test. Table 3 shows an overview of the BSFL trials carried out in the Lake Victoria region, as well at KMFRI Sagana, by WUR and local partners.

Table 3 *Overview of BSFL trials carried out in the WUR supported project on protein transition in Uganda and Kenya*

Trials	Aim	Who, where & what
1. Uganda fingerling feed trial	In this trial the aim is to determine whether protein from locally grown BSFL meal is a suitable and cost-effective alternative to the protein from local fishmeal in feed for Nile tilapia to decrease fishing pressure on the lake. • Determine growth, apparent feed conversion and survival rate of fingerlings given the different types of feed.	**Who:** (Margaret Aanyu and colleagues), WUR (Eugene Rurangwa, Adriaan Vernooij, and colleagues) **Where:** NARO Kajjansi ARD Centre. **What:** Six experimental feeds are formulated, of which the protein fraction of the fishmeal is replaced by 1) 0%, 2) 25%, 3) 50%, 4) 75% and 5) 100% by protein from locally grown BSFL, and 6) a commercial feed is included as a reference. The six diets are tested in triplicate, resulting in 18 experimental units. The fish are fed to apparent satiation in order to achieve maximum feed intake.
2. Kenya fingerling feed trial (ponds)	The aim is to determine whether feeding partly a supplementary diet of chopped dried BSFL and chopped dried Caridina to on-growing Nile tilapia in ponds owned by small-scale farmers are suitable and cost-effective alternative feeding strategies compared to feeding a commercial diet only. • Determine growth, economical feed conversion rate and survival rate of fingerlings given the different types of feeding strategies.	**Who**: KMFRI (Mary Opiyo and colleagues), WUR (Adriaan Vernooij and colleagues) **Where**: The experiment is being undertaken at Bukani Aquapark, Busia, involving 9 ponds owned by different farmers. **What**: Three different treatments of fingerlings: 1) 100% commercial feed; 2) 80% commercial + 20% BSFL; 3) 80% commercial + 20% *Caridina niloticus*

Results of fingerling trial in Uganda

Growth of fish was lower than expected due to large variation in temperature during day and night and frequent power shutdowns. At day 30 no differences were found in growth expressed in the specific growth rate (SGR) in % BW d^{-1} ($p > 0.05$) (Figure 4a). However, when leaving out the commercial diet, which is used as a benchmark, the exchange of fishmeal protein by protein from defatted BSFL meal affects the specific growth rate of the fish (Figure 4b, $p < 0.05$). From the preliminary results, with the low growth, it seems that replacing protein from fishmeal with protein from defatted BSFL meal in the range of 50-75% positively affected growth.

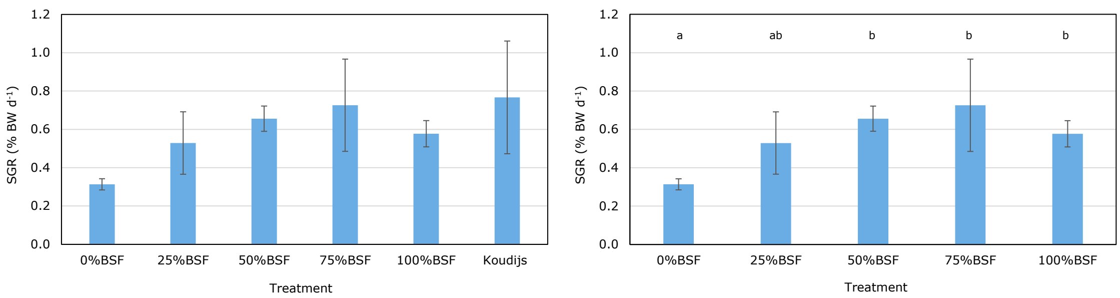

Figure 4 *Left (a): The specific growth rate (SGR) expressed in % BW d^{-1} of fish fed with different diets at day 30, showing that numerically growth of fish fed with the 75% BSFL feed is almost as high as growth of the commercial feed (Koudijs), so there is no significantly difference in growth. Right (b): The specific growth rate (SGR) expressed in % BW d^{-1} of fish fed with different diets at day 30, excluding the commercial diet. Means with a common superscript are not significantly different using the Fisher LSD post hoc test ($p < 0.05$).*

Results of fingerling trial in Kenya

The preliminary results show that there are no significant differences in the feed given and specific growth rate (SGR) between the different diets or feeding strategies ($p > 0.05$). Numerically, the growth of fish fed the commercial diet with dried BSF or Caridina freshwater shrimp as a supplementary diets is higher than feeding the commercial diet only (See Figure 5). These are preliminary results. The final results will be published in 2023 and distributed to Workshop participants.

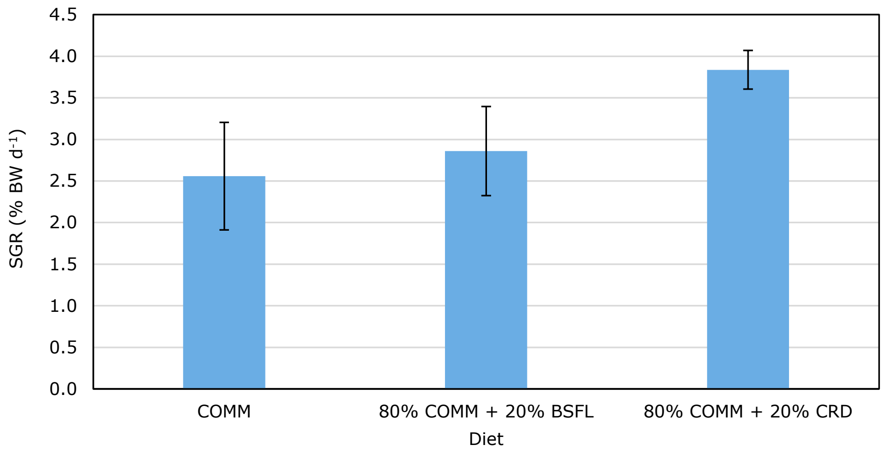

Figure 5 *The specific growth rate (SGR) in % BW d^{-1} at day 42, comparing commercial feed diet (COMM), a diet with 80% COMM + 20% dried BSFL, and a diet with 80% COMM + 20% dried Caridina shrimp (CRD). Although not significant ($p > 0.05$), a small difference in growth can be seen.*

Spirulina trials

Currently, KMFRI is performing experiments on the use of spirulina biomass for fish feed on Nile tilapia fingerlings. These outcomes will be used as a cornerstone for developing new aquaculture feed formula options in Kenya and Uganda. Spirulina is a well-known alkaline cyanobacteria (but industrially referred to as a microalgae) characterised by high content in proteins (up to 60% dry weight) with a profile of amino acids that covers essential amino acids such as Leucine, Lysine, Phenylalanine, Isoleucine, Valine, Threonine, Methionine, and non- essential amino acids like Arginine, Aspartic acid, Cysteine, Serine, Tyrosine, Glycine, Proline and Glutamic acid (Alagawany et al*.*, 2021). In addition, spirulina is a rich source of polyunsaturated fatty acids (PUFAs) and vitamins. Currently, the powder of spirulina has been used as a nutrient supplement in human consumption but lately, research has been focused on its potential use in feed formulas for livestock and aquaculture (Alofa et al*.,* 2020).

Our working hypothesis is to check whether the inclusion of different levels of spirulina powder in the diets of the Nile tilapia fingerlings shows a difference in growth, feed conversion and survival rates of Nile tilapia fingerlings. Therefore, four experimental feeds have been formulated, of which the protein fraction of the fishmeal is replaced for 0, 10, 20 and 30% respectively by the spirulina protein. As a positive control, a commercial feed is included as a reference. The composition of the feeds are isonitrogenous and isoenergetic, based on the composition of the commercial diet. The five diets are tested in triplicate, resulting in 15 experimental units. Thus, 35 tilapias of ± 2 grams are used per unit. The expected duration of the trial is 12 weeks. The fish are fed to apparent satiation in order to achieve maximum feed intake. The optimal inclusion of spirulina powder will be estimated based on the performance of the fish in relation to the inclusion level of the spirulina protein (dose-response). The treatments are shown in Table 4.

__Table 4__ The experimental design: five diets in triplicate, with 35 fish per tank (experimental unit)

Treatment	Number of fish	Diet
-	35	T(0). Analysis proximate analysis initial samples
A	35*3=105	Reference diet with 0% of the fish protein replaced by spirulina protein.
B	35*3=105	Reference diet with 10% of the fish protein replaced by spirulina protein.
C	35*3=105	Reference diet with 20% of the fish protein replaced by spirulina protein.
D	35*3=105	Reference diet with 30% of the fish protein replaced by spirulina protein.
E	35*3=105	Commercial reference diet (40/8).
-	560	Total number of fish needed.

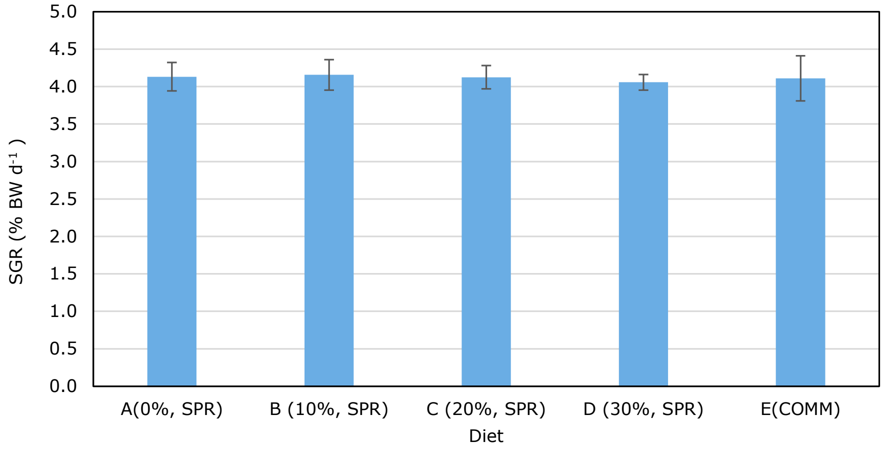

__Figure 6__ The specific growth rate (SGR) in % BW d^{-1} at day 42, for the fish fed the commercial diet (COMM) and the experimental diets with 0%, 10%, 20%, 30% spirulina protein replacing fish meal protein in the feed

Preliminary results of the experiment are provided in Figure 6 comparing the growth rate of the fingerlings fed diet with different inclusion levels of spirulina at day 42. The specific growth rate expressed in % BW d^{-1} at day 42 is similar between treatments ($p > 0.05$). From these preliminary results, nutritionally, protein from Spirulina seems a suitable ingredient to replace fish meal protein in diets for juvenile tilapia up to at least 30%.

The outcomes of the experiments can be used for the implementation of an industry for aquaculture feed production based on microalgae in the region. This might be challenging because currently only a few enterprises are in the area. These small companies/NGOs are concentrated mainly on the production of spirulina for human consumption. As a part of our scope in the project, some of the industries have been contacted but only a few of them as shown a positive response to our efforts to be involved. Among them, Nasio Trust Spirulina and Thriving green have been interested and they would like to explore the idea of using spirulina biomass for feed formulas in aquaculture industry. We hope that this will represent a game changing point in the current situation and more spirulina producers will be settled in the area. For that, our goal in the future will be to isolate and study local spirulina strains from Lake Victoria and characterise their amino acid profile. It is important to notice that spirulina is a fast grower microalga with a specific growth rate up to 0.8 per day. The isolation of new spirulina strains from Lake Victoria and its surroundings will provide microorganism already adapted to climate conditions and water quality of the area. A technical and economic feasibility study of the project will be developed to boost and favour the establishment of an incipient industry based on spirulina production for aquaculture feed.

5 Using BSFL instead of soya in feed will reduce GHG emissions with at least 68%

A Footprint analysis has been conducted to assess the environmental impacts of black soldier fly larvae (BSFL) in a production unit of Marula agribusiness located in Kampala, Uganda (Pishgar-Komleh et al. 2022). The analysis investigated greenhouse gas (GHG) emissions in the larvae production process. Both environmental burdens and benefits were determined. The obtained results showed that the production of one kg dried larvae emits 3.1 kg CO_2eq would prevent 9.7 kg CO_2eq by replacement of other activities causing emissions, i.e., avoiding emissions from landfill, replacing livestock feed ingredients and replacing chemical fertiliser (Figure 7). The figure shows emissions (red bars) by producing BSFL and reduced emissions (green bars) by replacing other protein sources. As it is seen, use of energy to do the machinery operations (such as shredding, separation etc.) contributed most to the total GHG emissions, followed by transport emissions and the emissions during rearing BSFL. Among the sources of avoided emissions, use of organic waste in the rearing process of larvae had the highest share (5.09 kg CO_2eq per kg final product), followed by final product (replacing animal feed meal by BSFLs) and BSFL manure.

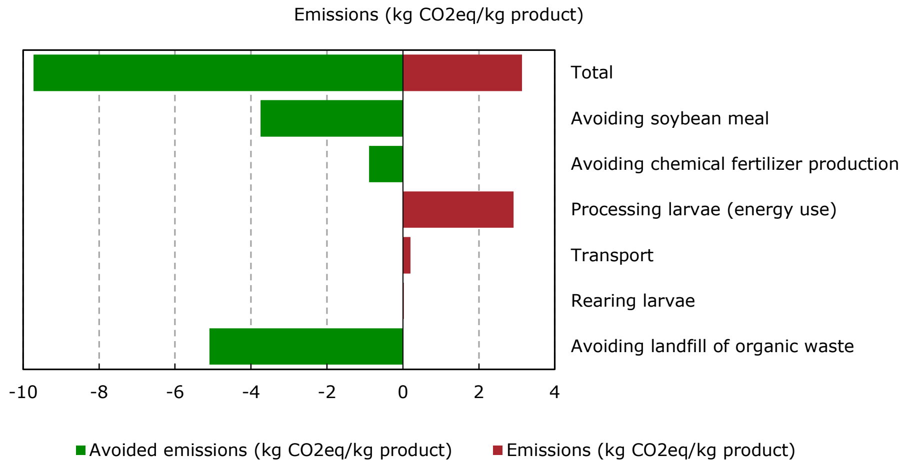

Figure 7 *Environmental impacts (emissions and avoided emissions) of black soldier fly larvae production*

Moreover, in addition to replacing soybean meal with BSFL, replacement of fishmeal by the BSFL was determined (Figure 8). The avoided emissions for replacing soybean meal and fishmeal resulted in 3.8 kg CO_2eq per kg BSFL for soybean meal and 0.52 kg CO_2eq per kg BSFL for fishmeal. The lower carbon footprint of fishmeal and the lower protein content of the soybean meal were main contributing factors for the lower emissions. The protein content of soybean meal and fishmeal were 453 and 630 g protein per kg, respectively. The GHG emissions associated with the production of the soybean meal was 2.7 kg CO_2eq per kg soybean (including land use change) while production of one kg fishmeal results in 0.85 kg CO_2eq.

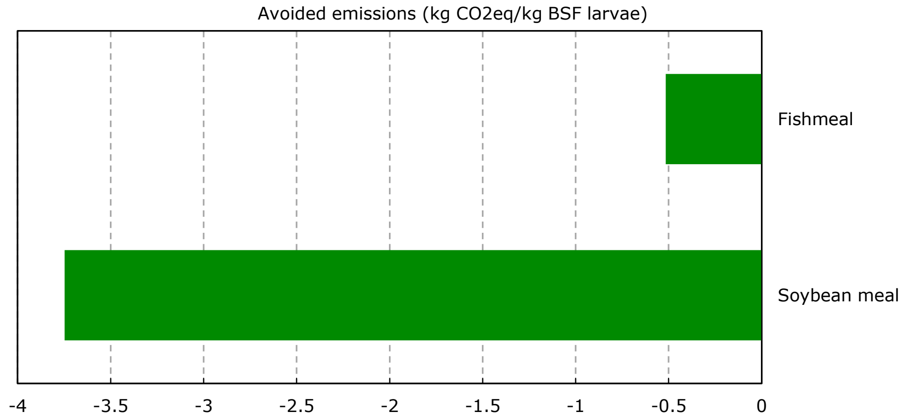

Figure 8 *The avoided emissions of replacing soybean meal and fishmeal by BSFL*

Higher GHG emissions per unit produced show the potential for improvements in the BSFL production in this region. Our findings show positive environmental impacts of BSFL products to feed livestock. Increasing the efficiency of rearing process (by increasing the larvae growth rate) and reducing the transportation distances of soyabean and fishmeal has large impacts on reduction of environmental impacts with BSFL production. Replacing the soybeans with the BSFLs has larger positive environmental impact than replacement of fish meal.

6 Small-scale farmers highly demand spirulina and BSFL as ingredients in feed

In this chapter three examples of operationalisation of BSFL and spirulina are provided. First from the supply side, thereafter from the demand side. Whereas the supply side examples are based on interviews with some core actors in the sector supplying the feed locally, the demand side examples are provided based on a series of interviews of small-scale farmers in the region of Nyeri. The third section is addressing some suggestions for future opportunities for small-scale farmers to benefit from affordable, accessible and acceptable high-quality feed in future.

Supply of BSFL and spirulina based feed in Kenya and Uganda

Domestic companies, such as Proteen LTD in Uganda and Biofit LTD in Kenya have invested in production systems using insects to produce a protein source for feed. The business models of the companies Proteen LTD (Uganda) and Biofit LTD (Kenya) are targeting small-scale farmers by selling them the baby BSFL. The farmers get an opportunity to earn extra revenue after having fed the BSFL on waste materials on their farm and selling the grown-out BSFL back to the companies. The farmers also benefit because the waste used to grow the larvae is transformed into high-quality fertiliser. This cooperation between feed producers and BSFL farmer as business model is still in an early stage but looks promising and full of potential for the future. Still, to date, it has been difficult to produce the BSFL-based feed to affordable prices.

Table 5 *Two examples of successful BSFL and spirulina feed producers in Uganda and Kenya*

Feed producers	Product	Who, where & what
1. Proteen LTD, Uganda (https://weareproteen.com/).	Currently produces 10,000- 15,000 kg p.a. floating pellets fed by waste from markets (e.g., cabbage)	Waste to feed the BSF is selected at the markets and at coffee farms. They need a total of 60,000 tonnes per year, as well as 1.5 tonnes of fertilisers. Chicken farmers are involved in the rearing of larvae (now 900, could easily be extended to 2,000). Need to invest in own warehouse, now they just got 3 years of extension to use the municipality owned for free. Carbon credit and certification scheme are part of the Proteen business model. Challenge if warehouse is 40 km away from Kampala –an increase from the 14-km drive at present. BSF replaces use of silverfish from the Lake, which is a lot better given the high share of sand (40-60%) being replace with protein. Interested in working with cooperatives to reach out to small-scale fish farmers, who can train the farmers to feed the larvae.
2. Biofit LTD, Kenya (https://biofit.co.ke/)	Currently produces 240,000 kg p.a. with a protein share: 49% BSF, 50% soya bean, 60% fish meal	Is using water hyacinth as a raw material in manufacturing livestock feed, and thereby contributing to solving a series of problems caused by this plant, for instance, it is of hindrance of water transport, contributes with contamination of the lake and thus declining fish population and fishing activities. The protein shares are as follows: 48.9% in BSF, 50% in soya bean, and 60% in fish meal, however, share differ per target group. The BSF larvae – has two sources: Intensive production at Biofit, growth based on bloodmeal collected from slaughterhouses. One slaughterhouse has as average 5 cows per day, for which each produce 5-liter blood. This is 25 kg per day per slaughterhouse. Out growers – targeting youth (20 people involved) and women (7 people involved) in particular, which are not using the feed themselves for feed. This is going slow, with low impact on the feed production.
3. Tiwani Spirulina (http://www.tiwanispirulina.com/) Secteur 10 (https://www.secteur10.fr/kugawana-spirulina/) Thriving green (https://thriving-green.com/en/spirulina/)	Spirulina is a microalga known to be very rich in vitamins, minerals, proteins and other nutrients. Because it has no cell wall like plants and animals, it is very digestible.	Spirulina is used for human consumption, with the knowledge that with only 3 to 5 g intake of spirulina per day, children suffering from malnutrition can become healthy again in just a few weeks. Natural superfoods can become shortcuts to better overall nutrition. Spirulina can play a critical role to future diets, while reducing negative impacts on our planet's finite resources. Spirulina used for animal production is still at a very early stage. It is restrained by regulations and extremely high price given that it is used for food only.

Demand for BSFL and spirulina based feed among small-scale farmers
WUR[6], in cooperation with Laikipia University and the Nyeri Fish Farmer Cooperative, are currently carrying out a survey in the Nyeri County about small-scale farmers demands for BSFL and spirulina. They are all visited on farm and interviewed in person. Until now, 95 of the 200 farmers have been interviewed. Based on this work in progress, the following can be reported on the demand side of the feed in Kenya.

First, the characteristics of the interviewees are provided in the Figure 10 a-c. Although most small-scale farmers have many different activities, they have in this survey been selected based on their membership in a cooperative representing the dairy farmer, the poultry farmers, the aquaculture farmers and the pig farmers. Until now, a total of 46% are represented as poultry farmer (Figure 9a). Because it in this survey is of interest to know whether a small-scale farmer is member of a group, because this will provide opportunities to make investments not possible for a small-scale farmer alone, this was one of the selection criteria. It appears that so far, the interviewees are mostly a member of a community groups (53%), or a women group (37%) (Figure 9b). It was also a desire to have women highly represented in the sample, and this has been reached so far, representing a total of 58% of interviewees (Figure 9c).

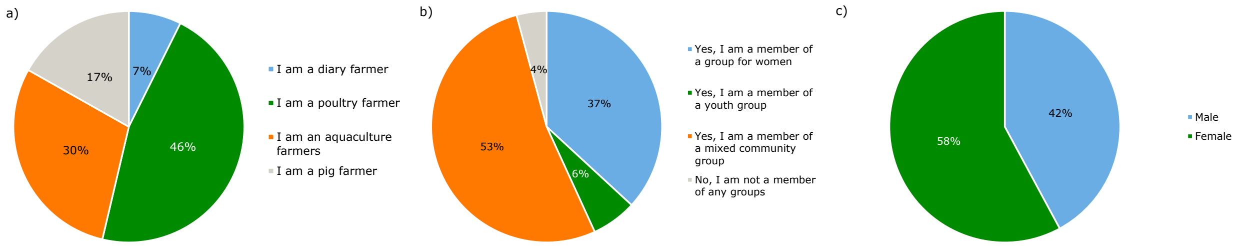

Figure 9a-c *Characteristics of the interviewees; a) Representative for farming activity in this survey, b) Membership of farmer group, c) Gender*

Second, regarding small-scale farmers use of feed at present, Figure 10 presents from which source the feed stems (a), and how many kilos per week the farmers use (b). It appears most farmers use Kenyan produced commercial feed (90%), and about 30% use more than 50 kg per week. Further, 16% 41-50 kg per week, 22% use 31-40 kg per week, 17% use 21-30 kg per week, and only 6% use 6-10 kg per week.

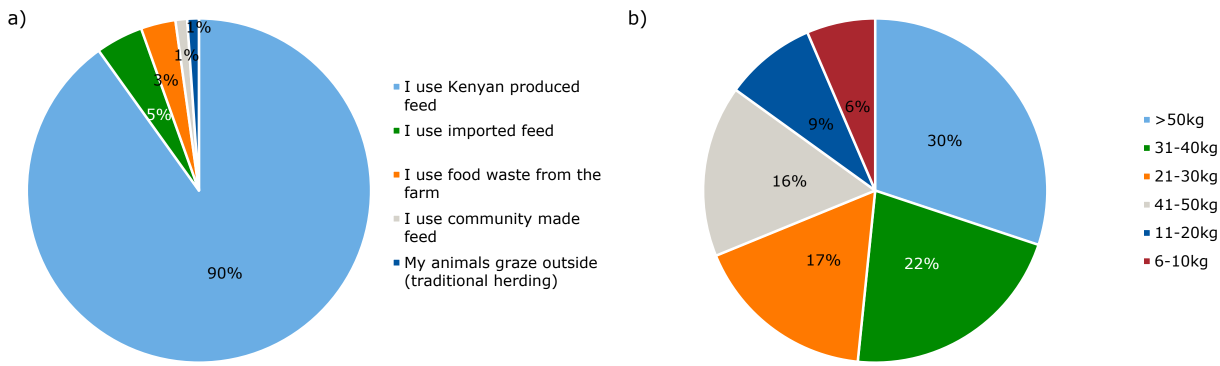

Figure 10a-b *Current use of feed among interviewed farmers; a) Main source of feed on your farm at present, b) Feed needed for animal production per week*

[6] The survey is carried out in the project: Feeding cities and migration settlements 2019-2022. The analyses of the data collected will by a follow-up project: Food and nutrition security of low-income groups in rural-urban food systems in the global south (2023-2024).

Figure 11 gives some few market figures of feed, including the current cost of feed for animal production as share of income (a), and the access to feed (b). It appears that 51% of the farmers spend 61-70% of income on animal feed.

Another 18% spend 71-80% of income on animal feed, and yet another 16% spend 51-60% of income on animal feed. The last 15% spend more than 80% of income on feed.

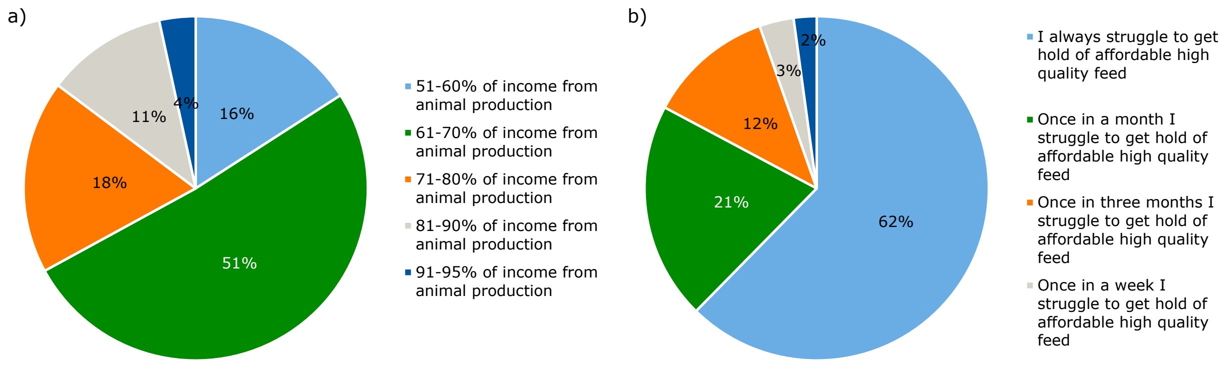

Figure 11 a-b *Market figures on feed; a) Cost of feed for animal production as share of income, b) Levels of feed shortage in the market*

According to Figure 12 is the most accessible waste for the interviewees at this stage is on-farms vegetables fruit waste, followed by access to local market vegetables and fruit waste. Note that on-farm animal waste, such as blood, manure, fish and animal waste also are available, followed by access to slaughterhouse waste and waste by schools and restaurants. A total of 14% inform that they also can access factory waste, if need to be.

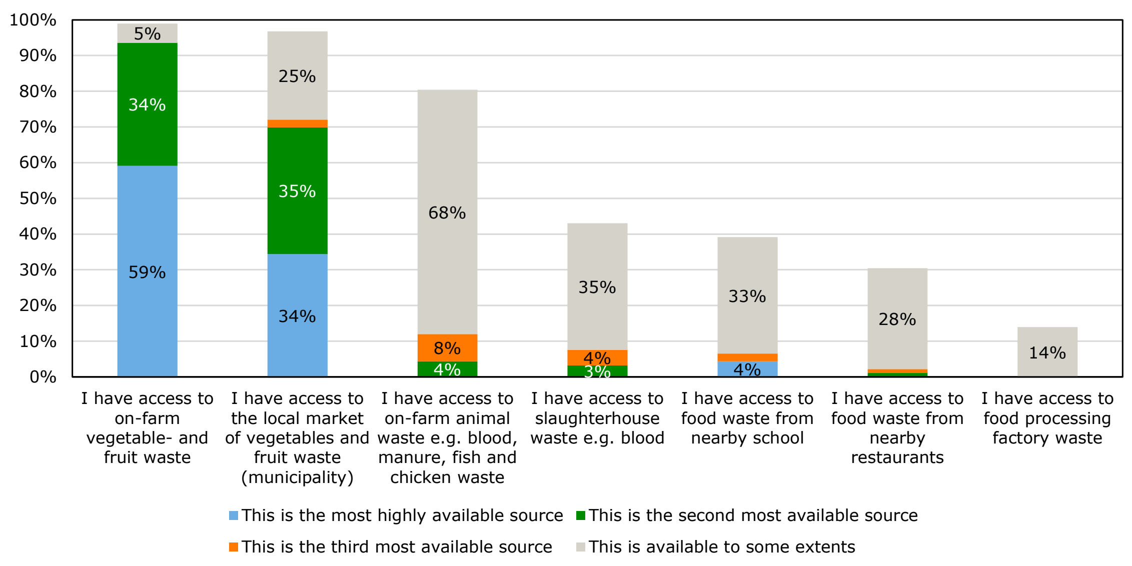

Figure 12 *The main potential sources of waste to feed the BSFL at this stage*

Moreover, Figure 13 informs that given a good quality of feed made of insects, almost everybody (98%) would be interested in buying it. This is also the case given that the price is low (97%). More than half of the interviewees are interested in contributing to producing the larvae themselves. With no support in terms of accessing finance or instructions about how to do it, 37% are interested in investing in hatcheries and 32% in growth of larvae. Only 10% is interested in producing the feed with BSFL if it is only for their own farm feed needs.

Looking at the interest in Spirulina (Figure 14), the demand would be high if price was low (92%) and if it gets available on the market (87%). Note, that it is less demanded if just one of many ingredients in commercial feed (70%). Spirulina is also of high interest as on-farm production possibility (73%), especially with access to financing (66%) or instructions about how to do it (58%). With none of these measures, a total of 52% would be interested in producing it on the farm. Only 2% informed they had no interest in Spirulina as feed ingredient.

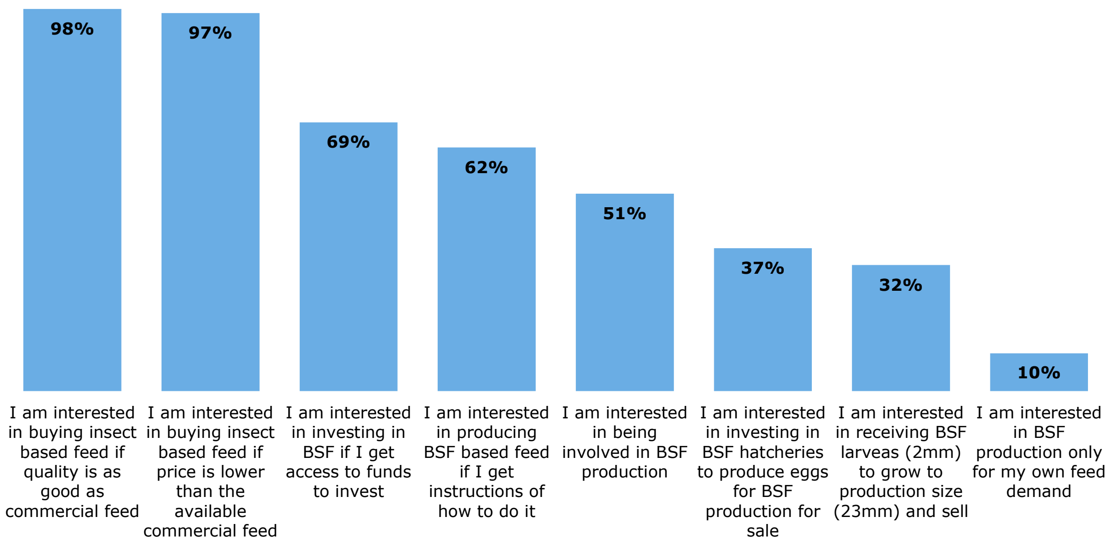

Figure 13 *Level of interest in BSFL at this stage*

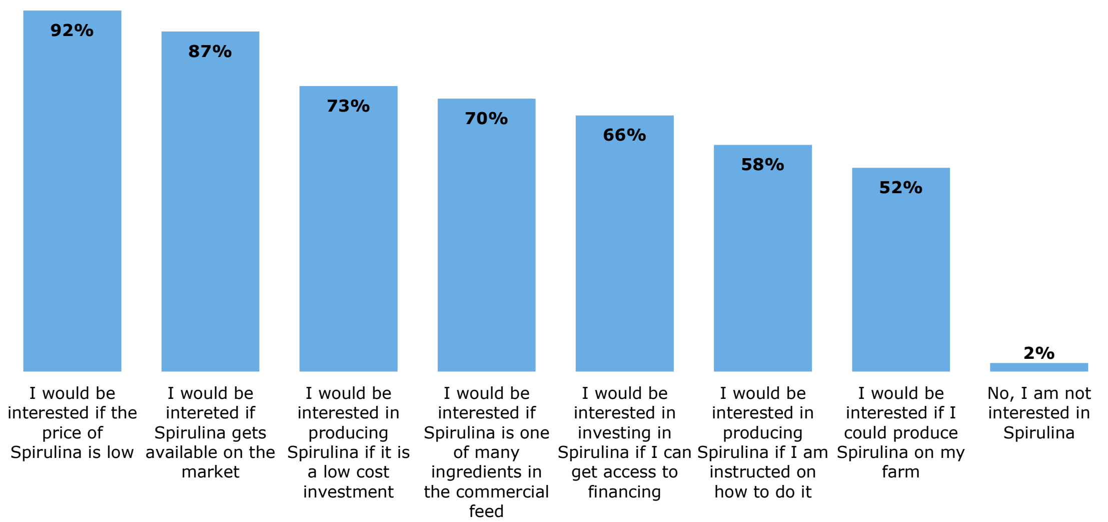

Figure 14 *Level of interest in spirulina at this stage*

Some possible business applications of feed containing BSFL and/or spirulina
The trials in this study give information about:

1. Uganda: whether protein from locally grown BSFL meal is a suitable and cost-effective alternative to the protein from local fishmeal in formulated feed for Nile tilapia. This would decrease fishing pressure on Lake Victoria and provide optimal inclusion level of the BSFL meal.
2. Kenya: whether feeding partly a supplementary diet of chopped dried BSFL and chopped dried freshwater shrimp (*Caridina nilotica*) to fingerlings of Nile tilapia in ponds at small-scale farms is a suitable and cost-effective alternative feeding strategy compared to feeding a commercial diet

only. This is to deal with one of the most critical feed bottlenecks and to provide small-scale farmers with affordable high-quality feed containing BSFL or spirulina.

For sustainable aquaculture development in Sub-Saharan Africa including Uganda and Kenya, it is advised that small-scale farmers have access to affordable and acceptable feed (Ragasa et al. 2022). In Figure 15 some opportunities for provision of affordable, accessible and sustainable feed are sketched out. While spirulina is judged expensive at this stage in time, this could change if new opportunities for feed production become available.

The most advanced option at this stage is to produce floating pellets on a large scale to sell to cooperatives in larger quantities, to make it available to small-scale farmers.

With a BSFL-hatchery production system run by the small-scale farmers themselves, the profit margin would not need to be shared among a feed company and the fish farmer and can be operated at lower costs. Such insect-based feed production business model could be combined with a fish farming system or be operated by farmers who decide to concentrate only on BSFL production in the communities. This highly locally animal circular practice would target the exact needs of the fish farmers by balancing quality and needs, although not providing standards similar to laboratory made feed. Because the farmers do not yet know how to operate a hatchery, and will need some micro-credit to invest, community based BSFL hatcheries have not yet been scaled to date.

An alternative or complementary approach could be that small-scale BSFL producers or fish farms that produce the BSFL on-site could feed the larvae dried or fresh as a supplementary diet next to the local available commercial diet or farm-made feed. If this approach is working, it will promote the decentralised production and use of BSFL grown on small-scale fish farms improving the value chain of BSFL and possibly improve the social economic position of the small-scale farms.

A comparable option could be the use of dried freshwater shrimp (*Caridina nilotica*). *Caridina nilotica* is a freshwater shrimp species thriving in Lake Victoria. It is an important by-catch of the local omena fishery. Using a by-catch as a protein source supports the resource use efficiency of local ingredients. As with BSFL meal several studies using Caridina meal in formulated diets for fish have shown that Caridina meal is an interesting ingredient. Similarly, if dried freshwater shrimp can be fed directly as a supplementary diet next to the local available commercial diet or farm made feed it could improve its application and the social economic position of the small-scale farms. In addition, the expanding population of Caridina have resulted in a simplified food web which may have negative consequences for sustainable fish production in Lake Victoria. An increase of using Caridina as fish feed could contribute to solve this problem'.

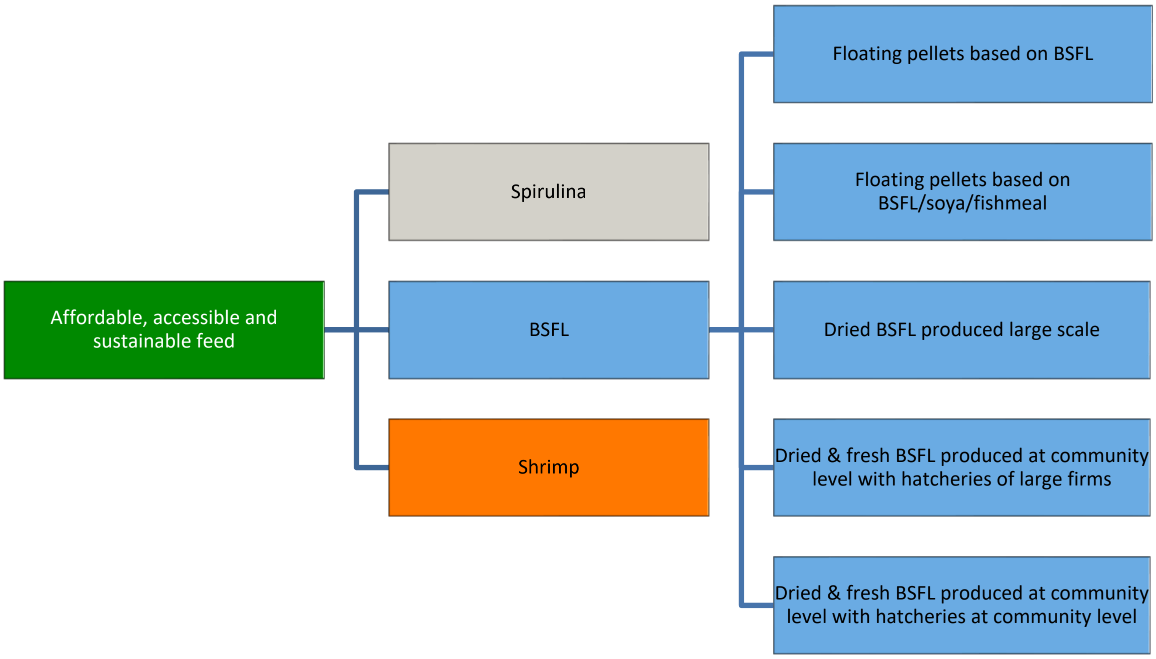

Figure 15 *Opportunities for operationalise affordable, accessible and sustainable feed opportunities for small-scale farmers*

Challenges to the spirulina is that it is presently used for Human consumption as 'superfood', i.e., as source of proteins, vitamins, minerals, and trace elements, and is therefore extremely expensive at this stage. Scaling up production and diversifying the use of spirulina for feed purposes will need new administrative and regulative measures. This might represent a barrier for small-scale farmers, with the inherent risk of solely benefiting large investors and produces and exclusion of small-scale farmers.

For BSFL the challenges are many. 1) Only few companies exist competing at a large scale, but this may increase in future. Although it can be beneficial with competition because the more competition could lead to higher demand if accessibility and affordability benefit new user groups. 2) Feed price is still relatively high – the economy of scale for the large importing businesses manage to keep prices low of imports (e.g., vitamins and soybean). 3) For firms dependent on waste from market, the cold chain that is being set up in marketplaces in Nairobi can become a threat, as then waste will be less available. 4) Restrictions to scaling the production from present level are related with getting new customers, materials and inventories. 5) Out-growers of BSFL is going slow.
6) Transportation of waste is expensive and polluting, given that 10 times waste is needed to produce BSF. It is therefore a good option to work with the Government. 7) Insects are regularly attached by pests, aunts, etc., which harm the BSFL production.

7 Use of alternative protein sources in feed produced locally, such as BSFL and spirulina, can become a gamechanger if inclusion is ensured

The main aim of this Concept note is to explore how to operationalise the use of fish feed containing black soldier fly larvae (BSFL) and spirulina for (fish) farmers in Kenya/Uganda, and to address challenges and opportunities for protein transition in the region of Lake Victoria. The trials presented in this Concept note show the potential by the growth feed conversion and survival of Tilapia fingerlings with different feed composition, using BSFL, spirulina and Caridina shrimp, often in combination with the commercial feed. This implies there is a high potential to scale up in future, to supply Sub-Saharan Africa with high quality and sustainable feed.

Currently, companies in Uganda and Kenya are scaling up the BSFL ingredient in feed. Some producers inform that it is already possible to reduce price of feed without reducing quality, while others struggle to come below the market price of imported feed because of the economy of scale using soya and fishmeal in feed.

The feed containing BSFL currently brings high costs to the small-scale farmers. This does not need to be the case in the future. Different opportunities exist for supplying the small-scale farmers with affordable protein rich feed based on BSFL, including feed companies producing high quality feed, feed companies cooperate by larvae production on farms, or on-farm hatchery and feed production. Also, different compositions of homemade and pellets based on BSFL and hatcheries not only at large scale but also at small-scale farmer community level, are relevant options to consider. As the surveys presented on this Concept note explains, although the small-scale farmers are highly interested, they lack the knowledge and finance to invest to start such small-scale production. Because of these bottlenecks, trials are planned with spirulina and BSFL on small-scale farms as pilots. This will take place in the project **KB35: Food & nutrition security of low-income groups in rural-urban food systems in the global south' (2023-2024),** subsidised by the Dutch Ministry of Agriculture, Nature and Food Quality, carried out by WUR in cooperation with KMFRI, Laikipia University and other network partners in Kenya. This includes the cooperatives, who are critically important for capacity building of farmers, on farms, from farmer to farmer. Also, the cooperatives can allow large feed producers to sell larger quantities at a time. Following the trials presented in this Concept note, a possibility is to feed 20% dried BSFL, and 80% commercial feed which consist of sustainable protein sources, such as BSFL, spirulina, Caridina shrimp. Different strategies can be combined to achieve optimal solutions to serve the small-scale fish farmers in future.

Providing small-scale farmers with affordable high-quality feed (ingredients) will not only enhance the income of the families involved but will also supply a larger share of the population with affordable and high-quality healthy protein as source of food. As such, depending on the outcomes of the trials and the applicability to farmers, the expansion of affordable BSFL and spirulina based feed can contribute to the protein transition and fulfilment of a series of socio-economic-related SDGs. This includes climate action (SDG13), preservation of natural resources on land (SDG15) and life below water (SDG14), as well as zero hunger (SDG2), decent work and economic growth (SDG8), reduced inequality (SDG10), sustainable cities and communities (SDG11), and responsible consumption and production (SDG12). Whereas in this study the focus has been on the feed side, thus at an early stage of the value-chain, this is highly connected to the rest of the food system, including the producers, the midstream and the consumers. Because affordable, accessible and acceptable feed is a critical bottleneck in the food system, solving it will impact the whole chain, including the new fish value-chain established previously to this project, which was tackling yet another bottleneck of supply of affordable and accessible fish to low-income consumers living in informal settlements.[7] The protein transition pathway will require food system interventions and assessments of their outcomes, as well as activities of targeted aid, inclusiveness, circularity, trade and commercialisation.

[7] Link: A NEW FISH VALUE CHAIN NYERI-KIBERA

Photo 5 *Fish pond construction in Nyeri, by Charles Mbauni Kanyuguto (FOSPA)*

Sources and literature

Adeleke, B., Robertson-Andersson, D., Moodley, G., and Taylor, S. (2020). Aquaculture in Africa: A comparative review of Egypt, Nigeria, and Uganda vis-a-vis South Africa. Reviews in Fisheries Science & Aquaculture, 29(2), 167-197.

Chia, S. Y., Tanga, C. M., Osuga, I. M., Alaru, A. O., Mwangi, D. M., Githinji, M., ... & Dicke, M. (2021). Black soldier fly larval meal in feed enhances growth performance, carcass yield and meat quality of finishing pigs. Journal of Insects as Food and Feed, 7(4), 433-447.

FAO. (2017). The future of food and agriculture – Trends and challenges. Rome

FAO. (2022). The State of World Fisheries and Aquaculture 2022. Towards Blue Transformation. Rome, Italy. https://doi.org/10.4060/cc0461en.

FAO. (2022b). Fishery and Aquaculture Country Profiles, Uganda. Rome, Italy. https://www.fao.org/fishery/en/facp/uga?lang=en.

IFAD. (2018). Development of Kenya's aquaculture sector could reduce rural poverty and tackle chronic malnutrition and food insecurity. In: IFAD. Cited 22 November 2021. www.ifad.org/en/web/latest/-/news/development-of-kenya-s-aquaculture-sectorcould-reduce-rural-poverty-and-tackle-chronic-malnutritionand-food-insecurity.

IPCC. (2022). Summary for Policymakers. In: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.001.

Jacobi, N. (2013). Examining the Potential of Fish Farming to Improve the Livelihoods of Farmers in the Lake Victoria Region, Kenya: Assessing Impacts of Governmental Support [University of Akureyri]. In MSc Thesis (Issue May). https://skemman.is/handle/1946/15901.

Kaleem, O., Sabi, A.F.B.S. (2021). Overview of aquaculture systems in Egypt and Nigeria, prospects, potentials, and constraints. Aquaculture and Fisheries, 6(6), 535-547.

Kenya National Bureau of Statistics (KNBS). (2021) Economic Survey 2021. Nairobi, Kenya, pp 428.

Munguti J., Obiero, K., Orina, P., Mirera, D., Kyule, D., Mwaluma, J., Opiyo, M., Musa, S., Ochiewo, J., Njiru, J. Ogello, E., Hagiwara, A. (Eds) (2021). State of Aquaculture in Kenya 2021: Towards Nutrition Sensitive Fish Food Production Systems. Techplus Media House, Nairobi, Kenya. 190 pp.

Obwanga, B., Soma, K., Ayuya, O.I., Rurangwa, E., van Wonderen, D., Beekman, G., and Kilelu, C. (2020). Exploring enabling factors for commercializing the aquaculture sector in Kenya (No. 3R Research report 011). Centre for Development Innovation.

Pishgar-Komleh, S.H., Vernooij, A., and Straub, P.T. (2022). Carbon footprint of processing city market waste for animal feed with Black Soldier Flies in Kampala, Uganda. Wageningen Livestock Research. Report 1382. Wageningen. The Netherlands. p26.

Ragasa, C., Charo-Karisa, H., Rurangwa, E., Tran, N., and Shikuku, M.K. (2022). Sustainable aquaculture development in sub-Saharan Africa. Nature Food 3, 92-94.

Soliman, N.F. and Yacout, D.M. (2016). Aquaculture in Egypt: status, constraints and potentials. Aquaculture international, 24(5), 1201-1227.

Soma, K. (2022). Ensuring accessibility of insect-based feed to small-scale fish farmers in Kenya and Uganda. Eds. Editors: Sanne Stroosnijder, Bas Hetterscheid & Bob Castelein A journey into the world's food systems in search of losses, waste and ways to solve them, 58-62. Wageningen, the Netherlands. Wageningen University & research. DOI number 10.18174/571395.

Tanga, C.M., Fiaboe, K.K.M, Niassy, S., van Loon, J.J.A., Ekesi, S. and Dicke, M. (2017). A field guide to commercially produce low-cost, high-quality novel protein source to supplement feeds for poultry, pig and fish industries and the valorization of organic by-products. A handbook for extension staff and trainers. ICIPE, Nairobi, Kenya. 31 pp.

UN. (2022). World Population Prospects 2022: Methodology of the United Nations population estimates and projections. Department of Economic and Social Affairs, Population Division (2022). (UN DESA/POP/2022/TR/NO. 4).

More information
Dr. Katrine Soma
T +31 (0)623259872
E katrine.soma@wur.nl
www.wur.eu/economic-research

2023-008