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Practice Abstracts - Batch 1

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Abstract	This document reviews the insect production landscape as a route to producing sustainable protein as part of the NESTLER grant. This report covers Deliverable 2.2, led by MANA Biosystems Limited ('FlyBox') and supported by ICIPE. The assessment of BSFL in Livestock Feed is covered in Section 1. This deliverable also contains the practice abstracts that will be published in EU CAP Network for broad dissemination to practitioners. Specifically, there are 3 practice abstracts: 1. Assessment of controlled livestock breeding 2. Assessment of controlled fishery breeding *3.* Assessment of frass fertilizer for crop immunity and harvesting

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Definitions, Acronyms and Abbreviations

BSFL	Black Soldier Fly Larvae
BSFFF	BSF frass fertilizer
BSFLM	Black Soldier Fly Larvae Meal
FAO	Food and Agriculture Organization
ICIPE	International Centre of Insect Physiology and Ecology

Executive Summary

This document (along with D2.1) reviews the insect production landscape as a route to produce sustainable protein as part of the NESTLER grant.

This report covers Deliverable 2.2, led by Mana Biosystems Limited (FlyBox) and supported by ICIPE. The report focuses on Black Soldier Fly Larvae (BSFL) as this is the primary insect used globally to improve human nutrition.

The practice abstracts outline how a farmer could use BSFL to supplement feeding of their animals for Livestock and Fish, as well as the use of Frass - a form of organic fertiliser - for use on land as part of arable agriculture.

1. Assessment for feeding livestock with BSFL

1.1. Overview

Feeding black soldier fly (BSF) meal to livestock is becoming more recognised as a viable sustainable practice in animal nutrition. BSF are in the family of Stratiomyidae and their larvae (BSFL) are high in lipids and proteins, providing a good alternative protein source for livestock feed. Using BSF meal can have several benefits in addition to sustainability,

1.1.1. Nutrition

BSF meal is very nutritious, with a well-balanced amino acid profile and contains vital nutrients required for animal growth and development. It is high in protein, with roughly 40-60% crude protein, depending on the rearing conditions, as well as the feedstock used to grow them. Protein in BSFL meal is easily digested by the gut of livestock, making it a good alternative for other animal based proteins.

1.1.2. Sustainability

BSFL can be grown on a range of organic waste materials, such as food waste, animal manures and waste meat products. By valorising these waste streams using BSFL meal production, it has the effect of reducing food waste and offering an environmentally friendly waste solution that up-cycles waste. BSFL production also uses far less water and produces less greenhouse gases than the production of other proteins.

1.1.3. Feed Efficiency

BSFL have an exceptional feed conversion efficiency (FCR). They can bioconvert a large range of organic waste products into protein and lipid far more efficiently than traditional livestock feed sources. BSF larvae consume various organic wastes, including low-quality waste like manure, that are not suited for direct consumption by livestock. When converting these materials into protein rich feed, BSF meal can improve feed efficiency and lessen the overall demand for traditional protein sources, with the potential to reduce feed costs.

1.1.4. Disease prevention

BSFL have shown the ability to break down pathogens present in organic waste materials within their gut. The warm environment within the BSF larvae gut, coupled with antimicrobial peptides, helps to reduce the number of pathogens and could contribute to disease management in livestock. Using BSFL meal in livestock diets can reduce the risk of pathogen transmission and enhance animal health through providing essential vitamins and minerals.

1.1.5. Regulatory Considerations

When using BSFL meal in livestock feed, it is subject to specific regulations to ensure its safe usage. As the use of BSFL meal gains traction, regulators are working to establish appropriate standards, legal framework and protocols for BSF farming, larvae processing, and its use in feed. Collaboration between farmers, government, and regulatory bodies are essential to ensure the safe and effective use of BSFL meal in livestock feed.

Whilst it’s clear that there are a number of benefits of using BSFL meal, there are a number of challenges to address. These include establishing efficient and scalable BSFL production systems, ensuring consistent quality control and safety standards, the production of larvae in a cost effective manner, and improving the customer acceptance of its use in livestock feed. In addition to this, the regulations need to be addressed and brought to the attention of regulatory bodies in order to remove red tape that is currently blocking the scalability of the industry in some regions.

The main section of this document will touch on these points in more detail, whilst assessing and reviewing best practice for the inclusion of BSFL meal in animal feed in the EU and Africa.

Figure 1: Black soldier fly larvae meal (Photo; Protix 2020)

1.2. Evaluating nutrient quality and maturity of BSF frass fertilizer products

Before analysing the value of BSF for feeding livestock, we provide an analysis of the nutritional quality of different solid and liquid chitin-fortified BSF frass fertilizer (BSFFF) products. Results showed that liquid BSFFF products had higher concentrations of macronutrients, secondary nutrients and micronutrients required for optimal crop growth (Table 1).

Table 1: Nutrient quality (mean ± standard deviation) of different solid and liquid BSFFF products

Formulation	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	C/N ratio
			Solid frass fertilizers (%)			
BSFFF	3.6 ± 0.09	0.53 ± 0.02	2.3 ± 0.07	0.7 ± 0.01	0.28 ± 0.01	11.1 ± 0.3
BSFFF + Chitin 1	3.8 ± 0.19	0.53 ± 0.02	2.4 ± 0.04	1.3 ± 0.03	0.30 ± 0.01	11.2 ± 0.8
BSFFF + Chitin 2	5.6 ± 0.24	0.57 ± 0.03	1.5 ± 0.05	3.1 ± 0.11	0.30 ± 0.02	7.3 ± 0.2
BSFFF + Chitin 3	5.0 ± 0.14	0.44 ± 0.02	1.4 ± 0.04	2.3 ± 0.05	0.25 ± 0.01	8.4 ± 0.4
			Liquid frass fertilizers (mg/L)			
BSFFF	1010 ± 65	1090 ± 10	7946.7 ± 74	332.7 ± 3	508 ± 7	10.8 ± 0.3
BSFFF + Chitin 1	603.3 ± 25	610.7 ± 5	4050.0 ± 27	347.3 ± 4	299.3 ± 2	6.7 ± 05
BSFFF + Chitin 2	1433.3 ± 170	656.0 ± 13	4810.0 ± 66	532.0 ± 6	431.7 ± 6	8.7 ± 0.9
BSFFF + Chitin 3	1063.3 ± 158	552.0 ± 2	3833.3 ± 32	435.0 ± 4	361.3 ± 3	8.5 ± 0.6

Comparative assessments showed that liquid frass fertilizers container higher (1.5 – 11-fold) nitrogen, phosphorus and potassium compared to commercial liquid fertilizer. We noted that the inclusion of BSF chitin increased the concentrations of nitrogen (6 – 42%) and calcium (up to 4.4-fold) in frass fertilizers, but there was no consistent trend for potassium and magnesium. It was noted that amendment of frass fertilizer with chitin improved compost maturity and stability in terms of carbon to nitrogen (C/N) ratio. Further studies have shown multiple benefits of these fertilizers in boosting yield, pest and disease control and soil health {1].

1.2.1. Agronomic effectiveness of insect frass fertilizers on different crops

Crop response to fertilizer inputs varies with the type and quality of fertilizer, and agroecological zone in terms of rainfall, soil types and test crops. The levels of frass fertilizer included in the soil amendment for different crops are shown in Table 2. These studies carried out in different agro-ecological zones of Kenya have revealed that insect frass fertilizers increased the yields of maize, potatoes, and bell pepper by 26 – 50%, 53 – 149%, and 2.3 – 5.3 folds, respectively, compared to unfertilized soil. The highest agronomic nitrogen use efficiency of maize production was achieved using the lowest rate, indicating that lower rates of frass fertilizer are effective for maize production. For bell pepper, we found that cricket frass yielded 1.5 – 3.9-fold higher agronomic nitrogen use efficiency compared to NPK and other frass fertilizers. We noted that the agronomic nitrogen uses efficiency of potatoes increased with rate of chitin inclusion.

Table 2: Yield benefits of different insect frass fertilizer products

Test crop	Treatment	Yield tonnes/ha	Agronomic use efficiency (kg/kg)
Maize	Control	2.53 ± 0.72	-
	30BSFFF	3.58 ± 0.32	35.0
	60BSFFF	3.20 ± 0.32	11.1
	100BSFFF	3.81 ± 0.69	12.74
Potato	Control	9.3 ± 1.8	
	BSFFF	20.5 ± 2.4	74.6
	BSFFF+ Chitin 1	20.4 ± 3.1	73.9
	BSFFF+ Chitin 2	22.1 ± 2.2	85.1
	BSFFF+ Chitin 3	21.6 ± 1.5	81.7
	BSFFF+ Chitin 4	20.5 ± 1.2	74.8
	BSFFF+ Chitin 5	23.1 ± 2.0	92.2
Bell pepper	Control	1.39 ± 0.00	
	NPK	2.94 ± 0.02	6.9
	BSFFF	3.17 ± 0.02	7.9
	Locust frass	5.51 ± 0.03	18.3
	Cricket frass	7.38 ± 0.03	26.7

Furthermore, the yields of bell pepper grown using BSFFF, locust frass fertilizer and cricket frass fertilizer were higher than those achieved using synthetic NPK fertilizer by 8%, 88% and 152%, respectively. It was noted that maize grown using BSFFF had bigger and well filled cobs with bigger grain sizes. Studies to assess the profitability and nutritional quality of cereal and vegetable crops grown using different insect frass fertilizer products are ongoing.

Studies involving bush beans revealed that application of BSF frass fertilizer boosted flowers (7 – 8%), pods (4 – 9%) and seeds (9 – 11%) production compared and increased bean seed yield by 43 – 67% compared to commercial organic and inorganic fertilizers. We found that the application of BSFFF with daily irrigation, significantly increased the yields of kale and Swiss chard, compared to unfertilized treatment, under the wonder multi-storey gardening system. The yields of kale and Swiss chard achieved using a combination of BSFFF and daily irrigation were 14 – 69% and 13 – 56% higher than the values achieved using synthetic NPK, respectively.

1.2.2. Leveraging insect frass fertilizer to suppress soil-dwelling pests

Soil-borne pests are a major challenge, with potential to cause upto 100% yield loss. The lack of affordable and quality pesticides has caused a continuous decrease in crop yields, pushing a large fraction of farmers into abject poverty, hunger, and food insecurity. We assessed the potential of chitin-fortified BSF frass fertilizers on the control of cabbage and onion root maggots and root knot nematodes, key pest of bananas, vegetables and fruits, to generate recommendations for use of BSFFF as a biopesticide.

Findings revealed that chitin-fortified liquid BSFFF suppressed root knot nematodes by 89 – 95% within a short period of 24 hours and achieved suppression rates (89 – 95%) that was as good as that of the synthetic nematicide (96%). Furthermore, chitin fortified BSFFF inhibited the hatchability of cabbage and onion root fly by 65%. In another study, we found high potential of BSFFF to reduce the incidence and severity of key crop pests such as aphids, diamondback moth, whiteflies and leaf miners under climate-smart vertical farming systems. The chitin-fortified BSFFF amendments significantly reduced the number of potato cysts nematodes (PCN) in soil by 32 – 87% and caused 31– 98% reduction in reproduction rate compared to the unamended soil (Table 3).

Table 3: Effect of chitin-fortified BSF organic fertilizer on potato cyst nematode suppression

Test crop	Treatment	Fertilizer rate (kg/ha)	Yield (tonnes/ha)	Agronomic use efficiency (kg/kg)
Maize	Control	0	2.53 ± 0.72	
	30BSFFF	1304	3.58 ± 0.32	35.0
	60BSFFF	2609	3.20 ± 0.32	11.1
	100BSFFF	4247	3.81 ± 0.69	12.74
Potato	Control	0	9.3 ± 1.8	
	BSFFF	5535	20.5 ± 2.4	74.6
	BSFFF+ Chitin 1	5590	20.4 ± 3.1	73.9
	BSFFF+ Chitin 2	5646	22.1 ± 2.2	85.1
	BSFFF+ Chitin 3	5701	21.6 ± 1.5	81.7
	BSFFF+ Chitin 4	5756	20.5 ± 1.2	74.8
	BSFFF+ Chitin 5	5812	23.1 ± 2.0	92.2
Bell pepper	Control	0	1.39 ± 0.00	
	NPK	1283	2.94 ± 0.02	6.9
	BSFFF	7500	3.17 ± 0.02	7.9
	Locust frass	10714	5.51 ± 0.03	18.3
	Cricket frass	9782	7.38 ± 0.03	26.7

1.2.3. Evaluating the benefits of BSF frass fertilizer on soil fertility rejuvenation

Multidisciplinary studies showed that soil amendment with BSF frass fertilizer increased the pH, highlighting a critical role in reducing soil acidity. We also found that frass fertilizer application caused increased available nitrogen (2 – 4-fold), phosphorous concentration (54 –107-fold), calcium (7 – 18%), potassium (10 – 52%), magnesium (7 – 36%) and cation exchange capacity (1 – 4-fold) compared to the unamended soil (control) (Table 4). We have also demonstrated the superiority of frass fertilizer in pathogen suppression and increasing resilience to climate change.

Table 4: Effect of chitin-fortified BSFFF on selected soil chemical properties

Treatments	pH(H_2O)	Available nitrogen (ppm)	Available phosphorus (ppm)	Exchangeable potassium (Cmol kg^{-1})	Exchangeable calcium (Cmol kg^{-1})	Exchangeable magnesium (Cmol kg^{-1})	Cation exchange capacity (Cmol kg^{-1})
Control	7.6 ± 0.1bc	10.0 ± 1.7a	2.4 ± 0.1c	0.87 ± 0.1ab	9.4 ± 0.3b	2.2 ± 0.1b	15.0 ± 0.60c
BSFFF	7.7 ± 0.1bc	13.3 ± 1.0a	56.7 ± 5.8b	0.76 ± 0.1ab	9.4 ± 0.3b	3.0 ± 0.1a	17.2 ± 0.71abc
BSFFF + chitin 1	7.6 ± 0.0c	27.7 ± 1.1a	109.5 ± 13.0a	0.97 ± 0.1a	9.2 ± 0.4b	3.4 ± 0.2a	17.7 ± 0.68ab
BSFFF + chitin 2	7.6 ± 0.1ab	18.2 ± 1.7a	89.2 ± 10.6ab	0.50 ± 0.1ab	9.5 ± 0.2b	3.2 ± 0.1a	17.3 ± 0.35abc
BSFFF + chitin 3	7.9 ± 0.1ab	22.4 ± 1.0a	70.5 ± 8.2ab	0.54 ± 0.1b	9.7 ± 0.2ab	3.1 ± 0.1a	17.5 ± 0.51abc
BSFFF + chitin 4	8.0 ± 0.0a	21.5 ± 0.7a	64.5 ± 4.4ab	0.55 ± 0.1b	10.2 ± 0.4ab	3.0 ± 0.1a	18.2 ± 0.65ab
BSFFF + chitin 5	7.7 ± 0.0abc	39.6 ± 1.3a	92.0 ± 3.1ab	0.47 ± 0.0ab	11.0 ± 0.1a	3.2 ± 0.1a	19.4 ± 0.28a

1.3. Nutritional value of BSFL meal vs alternatives

Insects can be fed whole live, whole dried, as a pulp, and as a meal. However, in order for livestock to get the complete and consistent nutrition they require, it is necessary for insects to be provided in the form of insect meal that can be formulated into a complete feed.

1.3.1. Variability

The nutritional value of BSFL meal can vary quite heavily depending on the waste type that was used to feed them, as well as the genetics of the colony used to produce the insect meal. This can be a problem for some farmers since some waste substrates may cause high growth for the larvae but produce a low quality insect meal. For example, highly starchy wastes can cause high and fast growth for BSFL but will produce an insect meal that is lower in protein content.

For this reason, it is important for farmers to carry out nutritional/proximate analysis of their larvae (and waste) alongside growth trials in order to get the most valuable product in the shortest time. With this data producers can calculate important KPIs such as protein conversion rate that will tell them how much of the protein from the waste is actually being converted into the larvae.

1.3.2. Average nutritional values

The table below shows the average nutritional value of BSF meal taken from a number of different sources, fed on a range of different substrates [1,2,3,4,5,6]:

Table 5: A number of different proximate analyses of BSF meal used to create average values

Feed	% Protein	% Lipids	%Fibre	% Ash	Water %	Carbohydrate %	Calcium %
BSFL (Fed on Chicken Manure)	41			9.3			
BSFL (fed on Swine Manure)	43.6	23.4					
BSFL (fed on palm kernal meal)	42.1	27.5					
BSFL (fed on Chicken Feed)	47.9	14.6					
BSFL (fed on Liver)	62.7	25.1					
BSFL (fed on fruit and veg waste)	38.5	34.6					
BSFL (fed on kitchen waste)	33			9			
BSFL (fed on spent grain)	41			11.3			
BSFL (Control Diet)	37.7		8.7	10.7	8.3		
BSFL (chicken Manure) SHING YANG		9					
BSFL (Control diet)	44	21		13			
BSFL **wet** (Sagel oink ventures)	12						
BSFL (feed on chicken manure)	41.1			9.3	19.3		3.2
BSFL (fed om kitchen waste)	33			9.6	12.3		2
BSFL (fed on spent grain)	41.3			11.6	16.9		1.7
BSFL (spray dried)	48.2	25.7	10	8.3	7.1		
BSFL (oven dried)	47.5	28.4	9.5	8.2	3.2		
BSFL (oven dried)	39.4	38.4	7.4	7.3	5.3		
BSFL							
Average	**39.9**	**26.4**	**9.0**	**10.0**	**9.2**		**2.3**

The table below shows the average nutritional value of Soy meal taken from a number of different sources.[7,8,9,10,11,12,13]

Table 6: A number of different proximate analyses of soymeal used to create average values

Feed	% Protein	% Lipids	%Fibre	% Ash	Water %	Carbohydrate %	Calcium %
Soymeal							
Soybean Meal	44.4	2.18	6.8	6.6			
Soybean Meal (full fat)	37.5	20.5	2.3	5.7			
Soybean Meal (de-fatted)	42	3.5	6.5	6			
Soybean Meal	46.4		5.9	10.3			
Soybean Meal	48.12	1.23		6.04			
Soybean Meal	20.5		2.1	5.9			
Soybean	39.2	30.3	6.8	4.61			
Soybean	48	6.8	7	6.5			
Soybean seed	37.1	18.8	5.12	4.86			
Soymeal	49.5	8.6		6.8			
Soybean	39.2	30.1	6.84	4.61			
Soybean Meal					12		
Soybean Meal						36	
Soybean Meal	40.8		3.03	5			0.35
soy meal (raw, defatted)	49.2	2.4			6.9	35.9	0.24
soya bean meal	47		8.2	7.2		14.5	0.3
soy beans	36.5	19.9	9.3	4.9	8.5	30.2	0.28
soymbean meal	47.5			6			
Average	**41.1**	**13.6**	**5.5**	**6.1**	**9.5**	**36.0**	**0.30**

The nutritional values of BSF meal are comparable to that of soymeal as shown in *Table 1* and *Table 2*. However, BSF meal contains a much higher percentage of lipid in comparison with soymeal. Therefore, it is important to consider whether or not the BSF meal is defatted or not since this can have a big impact when replacing protein sources such as soy with BSF meal.

However, fish meal is a traditionally used protein source for animal feed, which BSF meal can be used to replace. Fish meal has a high-quality protein content and essential amino acid profile. However, there are fears about its sustainability, overfishing, and the rapidly increasing cost of fish meal, which have led to the exploration of alternative protein sources such as black soldier fly meal. Insects are able to accumulate a high amount of Omega 3 fatty acids in their bodies, which can make them useful in replacing fishmeal, which usually provides this for fishmeal in aquaculture.

The table below shows the average nutritional value of fishmeal taken from a number of different sources:[14,15,16,17,18]

Table 7: A number of different proximate analyses of fishmeal used to create average values

Feed		% Protein	% Lipids	%Fibre	% Ash	Water %	Carbohydrate %	Calcium %
Fish Meal								
Fishmeal		61.9	8.9		22.4			
Fishmeal (mixed species)		52.9	5.78	3.1	21.9			
Fishmeal		70.1	9.2		17			
Fishmeal		65	3.65	1	12.6			
Fishmeal		70.7	7.8		18.3			
Fishmeal		64.4	9.8		10.2			
Fishmeal		65	9.2	0	19.8	7.9		
Fishmeal								2.65
Fishmeal		42.5		1.85	24.11			4.2
fishmeal (anchovy)		64.6			15			
fishmeal								
Average		**61.9**	**7.8**	**1.5**	**17.9**	**7.9**		**3.4**

When substituting fish meal with BSFL meal in livestock feed feed, it's necessary to consider the specific nutritional requirements of the animal that it will be used for. Formulating a balanced diet requires that the other ingredients are balanced in accordance to ensure that all essential nutrients are provided in the necessary amounts for that animal. As shown in Table 3, fishmeal contains a higher percentage of protein than BSF meal and soymeal. However, it has a lower lipid content.

One of the most important things to think about when replacing fishmeal or soymeal with BSFL meal in livestock feed is the amino acid profile. BSFL meal is in general a high-quality protein source due to its well balanced amino acid profile. However, it is quite low in certain essential amino acids when compared to traditionally used protein sources. Below are some essential amino acids that are often relatively lower in BSFL meal:

- **Methionine:** Methionine is an essential amino acid that is usually limited in plant-based protein sources, such as soy. While BSFL meal does contain methionine, its levels may be relatively lower compared to traditional animal based protein sources, such as fish meal or bone meal.
- **Lysine:** Lysine is another essential amino acid that is essential for growth in animals. BSFL meal contains lysine, but its levels may again be slightly low when compared to traditional protein sources like soy and fish meal.
- **Tryptophan:** Tryptophan is an essential amino acid needed for the synthesis of proteins. BSFL meals may have lower levels of tryptophan than fishmeal and soymeal.

It's important to take into consideration that whilst BSFL meal may be relatively lower in these specific amino acids, it is still a valuable source of protein and can be used in animal feed formulations to good effect. By combining BSFL meal with other protein sources that complement its amino acid profile, a well-balanced diet can be created that meets the nutritional requirements of animals. Feed formulations should consider the specific needs of livestock to ensure all essential amino acids are provided in the right amounts.

1.4. Benefits of using BSFL meal in feed

This document includes a list of sources that highlights studies that demonstrates the advantages of feeding BSFL to livestock, including those seen improved growth, health and cost reductions:

1.4.1. Chickens (Broilers)

Growth

- Chickens fed on a control diet took 32 days to reach the desired size of 1.3Kg, whereas those fed with a 3% BSFL in the feed only took 30 days.[19]
- With a 4% inclusion of BSFL to a controlled diet, the overall daily weight gain was found to increase from 20.13g/day to 23.8g/day (increase of 18.2%).[20]

Quality

- BSFL oil improves feed conversion ratio and increases the incorporation of medium-chain fatty acids into abdominal fat pad and serum antioxidant capacity in broiler chickens.[21]

1.4.2. Laying hens

- When added to feed, black soldier fly was found to increase the average weight of eggs, and the content of polyunsaturated fatty acids, while decreasing cholesterol levels[22]
- The protein-lipid concentrate in the diets of laying hens contributed to an increase in the average weight of eggs in the first experimental group by 1.7 g (3.26%), and in the second experimental group – by 2.1 g (4.39%) compared to control[22]
- Replacement of 20% fishmeal in conventional poultry feed with BSF resulted in higher (53%) egg production and improved quality compared to conventional feed[23].

Cost benefits:

- Replacing soy or fish meal in poultry feed with insect meal (up to 42 percent in the starter diet and 55 percent in the finisher diet) did not have any adverse effects on weight gain, body composition, or flavour of chickens. But it did reduce the cost of feed and improved the cost-benefit ratio by 16 percent and the return on investment by 25 percent.[24]

Health benefits:

- There was a linear increased frequency of CD4+ T lymphocyte, serum lysozyme activity, and spleen lymphocyte proliferation with a linear increase in BSFL inclusion in feed. Serum lysozyme concentration in BSFL-fed groups (1, 2 and 3% BSFL: 4.07, 4.46 and 4.70, respectively) was significantly higher than that in the control group (3.76)[25]
- There was also an increase in survivability in broiler chicks against *S. Gallinarum*, a pathogenic bacteria that causes death in chickens. Final survival rates in 1, 2 and 3% BSFL-fed groups were 67, 75 and 85%, respectively. However, the survival rate of the control group was only 50%[73] [25]
- A study showed a benefit to birds in terms of improved leg health and long-term elevated levels of foraging behaviour and general activity in broilers receiving black soldier fly larvae, and this effect was largest and most consistent for broilers receiving the larvae in the highest amount and frequency tested (10% of their dietary dry matter, 4 times a day.[26]

1.4.3. Swine

BSFL inclusion in feed provides a range of benefits to swine including, growth, health and cost efficiency.

Growth benefits:

- Average daily weight gain of finisher pigs increased (500g D0 to 625g D100) significantly with the replacement of fishmeal with BSF.[27]
- In male pigs, they saw nearly a 30% increase in carcass weight when all the fishmeal in the diet was replaced with BSFL meal.
- Pigs fed with a standard diet (administered *ad libitum*) with the addition of 0.3% and 0.9% BSFL showed a higher average daily weight gain (between 8.2% and 9.1%) than the control group fed with a standard substrate[28]

Health benefits:

- Diversity of microbiota greatly increased in the small intestine (jejunum) of pigs fed with BSF rather than soy meal. This is shown by the Shannon index.[29]
- In addition the BSF meal increased the amount of Alpha-aminobutyric acid, which is a key intermediate in the synthesis of a tripeptide analog of glutathione (i.e., ophthalmic acid) with antioxidative properties that can support health of pigs.[29]
- Taurine (β-aminoethanesulfonic acid) is an AA derivative, present in various tissues of different insect species, including BSF. Taurine supplementation is also proposed to be a potential nutritional intervention strategy to increase growth performance in pigs.[30]
- Dietary replacement of FM with BSFLM at the rates of 50%, in pig diet increased RBC (red blood cells), and haemoglobin number by 27%.[31]

Cost benefits:

- The cost–benefit ratio and return on investment were similar across diets. The cost of BSFLM will also decrease as production increases, whereas fishmeal prices will increase.[32]

1.4.4. Fish

BSFL inclusion in feed provides a range of benefits to swine including, growth and health per below

Growth:

- A study on Nile Tilapia (Devic et al. 2017) used the white larvae dry meal to formulate isonitrogenous and isoenergetic diets with maggot meal inclusions at 0, 30, 50 and 80 g/kg substituting gradually three conventional expensive feedstuffs: fish meal, fish oil and soybean meal. Results showed no significant difference in growth parameters (final weight; weight gain and SGR), feed utilisation efficiency (FCR and PER and feed intake) between treatments.
- Performance studies in catfish fingerlings revealed that a 37% higher growth rate and 23% higher weight gain was achieved from BSF-based feed, compared to conventional feed.[33]

Health:

- Total replacement of fish meal with black soldier fly (Hermetia illucens) larvae meal does not compromise the gut health of Atlantic salmon (Salmo salar).
- BSFL meal can improve the disease resistance of aquatic animals against pathogens.[34]

1.4.5. Shrimp

- In a shrimp feed study all the trial treatments using BSF meal had more desirable results than the control. The best result came from a diet which had a 25% fishmeal replacement inclusion (a total 6.6% BSF meal). This led to a 14% higher survival rate, 17% higher live yield and a better feed conversion rate of 20%, when compared to the control diet. The inclusion of Nutrition Technologies' BSF meal in this treatment

increased the total cost of the diet by 3.3%, but due to the improved performance, resulted in an overall shrimp feed that was 14.4% better value for money[35]
- The use of BSF in shrimp diets should be controlled at a dosage of 20% of the FM, which can improve the intestinal microbiota without causing any negative effects.

1.5. Nutritional Requirements

1.5.1. Livestock

Black Soldier Fly meal is most commonly used in non-ruminant feed when it comes to livestock. In particular, there has been most research into its use in swine feed and chicken feed (both layers and broilers). The nutritional requirements for swine feed can vary upon the age, as well as the purpose of the livestock.

1.5.2. Target nutritional requirements for chickens:

Figure 2: From right to left - chick mash, chicken crumb and chicken pellets

The nutritional requirements for broiler chickens and layer chickens differ significantly due to their differing physiological functions and production outputs.

Broilers are raised for meat production, with production targets that aim for fast growth and efficient feed conversion into biomass (feed conversion ratio, FCR). To reach these targets, broilers need high levels of energy, protein, and amino acids in their feed. Their diet needs to be rich in digestible carbohydrates and high-quality protein inputs to support muscle development and improve weight gain.

On the other hand, layers are specifically bred to produce eggs. Their nutritional requirements focus on supporting egg formation, shell quality, and overall reproductive health. Layers require a diet which is well-balanced for nutrients such as energy, protein, vitamins, and minerals. Calcium is particularly important for layers because they need significant amounts of it to produce eggshells. Layer feeds are formulated to meet the needs of producing eggs efficiently, which includes adequate levels of calcium, phosphorus, and other micronutrients that are essential for reproductive functions.
The comparative required nutritional/micro nutritional values for chicks, broilers and layer hens are shown below[36,37,38]:

Table 8: Average of recommended % of key nutrients and minerals taken from multiple studies.

	Animal	Nutrients				Minerals				
Nutrient/Mineral %		Protein	Fat/oil	Fibre	Ash	Calcium	Sodium	Magnesium	zinc	Phosphate
	Chicken feed (chick)	21.4	4.25	3.5	6	0.98	0.18			0.45
	Chicken feed (grower)	18.5	4.5	3.5	5.5	0.95	0.18			0.415
	Chicken feed (Layer)	17	3.35	4.5	12.5	4.12				0.55

Important things to note include:

- The higher protein content for chicks and broilers as they are required to put on weight faster.
- The higher fat content for chicks and broilers as they are required to put on weight faster.
- The higher calcium levels in the layer feed, which is required for the egg shells to be strong and healthy.
- Layer birds can cope with a higher amount of fibre than broilers. It's thought this is due to lower daily food intake and higher fibre utilisation.

1.5.3. Target nutrition requirements for swine

Pigs have fairly similar nutritional requirements to chickens in a more general sense, but there are important differences to be aware of:

- **Protein:** Both poultry and swine require similar amounts of dietary protein, but the sources of that protein may differ, and the required amino acids may also differ slightly. Chickens are omnivorous and need high-quality protein sources, such as animal-based protein and plant-based protein (e.g., soybean meal). Pigs are also omnivorous but in general have greater protein requirements in comparison to chickens. They can efficiently digest and use soybean meal, corn, wheat, and other cereal grains
- **Energy:** Pigs have greater energy requirements in comparison to chickens because of their larger body size and their increased metabolic rate. Pigs grow most effectively when fed energy-rich diets containing carbs and fats from sources like grains and vegetable oils.
- **Fibre:** Pigs have a well-developed digestive system that enables them to digest a large variety of fibre, including the hulls of soybean, wheat bran, and other fibrous materials. In contrast, chickens have a lower ability to digest dietary fibre. Their digestive systems are adapted for processing grains and protein-rich foods, and therefore fibre rich diets can hinder nutrient absorption.

The table below shows the nutritional /micro nutritional requirements of both weaner pigs and pigs during the growth stage[39,40,41]:

Table 9: Average of recommended % of key nutrients and minerals taken from multiple studies.

	Animal	Nutrients				Minerals				
Nutrient/Mineral %		Protein	Fat/oil	Fibre	Ash	Calcium	Sodium	Magnesium	zinc	Phosphate
	Swine feed (Weaner)	18.5	3.18	3.58	12.5	1.54	0.33	0.04		0.43
	Swine feed (Growth)	17	3.00	4.63		0.52	0.10	0.04		0.46

Important points to note include;

- Protein requirement is higher for weaner pigs as they are growing at a faster rate.
- Mineral requirements are generally higher in weaner pigs, as they are crucial for health and development in young pigs.
- Older pigs can generally cope with more fibre in their diet compared to younger pigs. As pigs mature, their digestive systems develop and adapt to handle a wider range of dietary fibre sources. The microbial population in the gut of older pigs becomes more diverse and efficient in fermenting fibre.

1.5.4. Amino Acid target values for chickens and pigs

The most important amino acids to provide in the suitable amounts are the essential amino acids. These are amino acids that cannot be created by the animals themselves in their bodies. Out of these the most significant in terms of growth and health are methionine, lysine, isoleucine, threonine and leucine.

In general, the requirements for these essential amino acids is higher in younger livestock that need to develop (chicks, weaners) and higher in the broilers rather than layer hens.

Target requirements for essential amino acids can be seen in the table below for pigs and chickens[42,43,44,45,46,47]:

Table 10: Average of recommended % of key nutrients and minerals taken from multiple studies.

Animal	Amino Acids						
	lysine (Lys),	threonine (Thr),	tryptophan (Trp),	methionine (Met)	Cystein (cys)	valine (Val)	Leucine (leu)
Chicken feed (chick)	1.17	0.77	0.2	0.45	0.37	0.9	1.2
Chicken feed (grower)	1.02	0.65	0.18	0.385	0.32	0.82	1.09
Chicken feed (Layer)	0.865	0.59		0.39	0.35		
Swine feed (Weaner)	1.31	0.77	0.24	0.41	0.38	0.89	1.7
Swine feed (Growth)	0.99	0.64	0.17	0.25	0.25	0.65	1

1.6. Aquaculture

This document will only focus on the two most commonly farmed types of fish in Africa. This includes the Nile Tilapia (*Oreochromis niloticus*) and the African Catfish (*Clarias gariepinus*) respectively.

The main nutritional differences between feed for livestock and feed for fish are due to their physiological needs, the way in which they feed, and diets. Below are some key of the key differences:

1.6.1. Protein Sources

Fish feed normally contains greater amounts of protein when compared to feed for livestock. Fish can be carnivorous or omnivorous, and tend to require more protein for growth and development. Protein sources usually used in fish feed include fish meal, fish oil, and plant-based protein concentrates. Whereas livestock feed can contain a combination of plant-based protein sources such as soy, corn meal, and animal-derived proteins like fishmeal and bone meal.

1.6.2. Fats and Oils

Fish feed contains greater levels of marine-derived oils and fats, such as fish oil, because of the need for omega-3 fatty acids which are essential for fish health and development. Such oils are rich in long-chain omega-3 fatty acids, specifically eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). Livestock feed may contain vegetable oils, animal fats, or both, but are generally much lower in omega-3- fatty acids than fish feed. However, it has also been shown that BSF can accumulate high amounts of omega-3 fatty acids in their bodies which can make BSF oil a useful replacement for this if fishmeal is omitted from the diet.

1.6.3. Carbohydrates

Fish feed typically contains fewer carbohydrates compared to livestock feed. Fish have limited ability to digest complex carbohydrates, and their natural diets consist mainly of protein and fat. Livestock, such as cattle and poultry, can efficiently metabolise and utilise carbohydrates, so their feed may include a higher proportion of grains and other carbohydrate sources.

1.6.4. Vitamins and Minerals

Both fish and livestock feed require essential vitamins and minerals for optimal growth and health. However, specific needs can be different. For example, fish feed often requires higher levels of vitamins C and E to reduce the effects of oxidative stress in aquatic environments. Livestock feed can require greater levels of vitamins A and D, which are necessary for their bone development and immunity.

It's important to note that the specific composition of both livestock and fish feed will vary depending on the species, production systems, and nutritional targets.

The target nutritional/micro nutritional values for key nutrients and minerals for both Nile Tilapia and African Catfish are listed below[48]:

Table 11: Average of recommended % of key nutrients and minerals taken from multiple studies.

	Animal	Nutrients				Minerals				
Nutrient/Mineral %		Protein	Fat/oil	Fibre	Ash	Calcium	Sodium	Magnesium	zinc	Phosphate
	Fish feed (Talapia)	30	8.5	8		0.7		0.07		0.9
	Fish feed (Catfish)	28	5	4		0		0		0.3

Important points to note:

- Almost double the proportion of protein is required for fish nutrition than livestock.
- Similarly, the fat content is roughly twice as great for fish feed than livestock feed. This fat is also expected to contain omega-3 fatty acids as explained above. This can be provided through insect oils.

1.6.5. Amino Acid target values for aquaculture

As for livestock, the most important amino acids for aquaculture are the essential amino acids. However, for aquaculture, they are generally required in a greater amount.

Table 12: Average of recommended % of key amino acids taken from multiple studies.

Animal	Amino Acids						
%	lysine (Lys),	threonine (Thr),	tryptophan (Trp),	methionine (Met)	Cystein (cys)	valine (Val)	Leucine (leu)
Fish feed (Talapia)	1.98	1.11	0.84	0.1		1.34	2.15
Fish feed (Catfish)	1.6	0.7	0.2	0.6	0.3	0.8	1.3

1.7. Feed formulation with insect meal - concept and methodology

When incorporating BSFL meal into feed formulation, it is similar to the process for incorporating conversional feed, but with additional considerations. Below is an overview of the methodology used when carrying out feed formulation with insect meal:

1.7.1. Define nutritional requirements

Identify what the specific nutritional requirements are for the animal, taking factors such as age, weight, growth rate, and production targets into account. Determine the required nutrients, including proteins, carbs, fats/oils, vitamins, minerals, and amino acids, that are needed for optimal growth and animal health.

1.7.2. Assess insect meal characteristics

Evaluate the proximate composition, digestibility, and purity of the BSFL meal being considered. Different insect species may vary in terms of their protein content, amino acid profile, fat content, and mineral composition. Understand the inherent nutritional value and any potential anti-nutritional factors associated with the specific insect meal.

1.7.3. Evaluate ingredient compatibility

Determine how BSFL meal combines/interacts with the other feed inputs in terms of nutrient digestibility, palatability, and potential processing challenges. Some BSFL meals may have a higher fat content or variations in texture, which can alter feed processing and feed uptake by the animal.

1.7.4. Inclusion levels

Identify the appropriate inclusion levels of the BSFL meal in the feed formulation. begin with lower inclusion levels and slowly increase them while monitoring animal growth/development and feed uptake. Consider the nutritional contribution of BSFL meals to meet the target nutrient requirements, as well as any practical constraints in terms of cost and input availability.

1.7.5. Adjust formulation

Use feed formulation software or mathematical modelling to calculate the nutritional values when using different ingredient combinations, including BSF meal, to achieve the desired nutritional profile. Fine-tune the formulation by adjusting the quantities of other feed inputs in order to achieve a balanced diet.

1.7.6. Analyse and test

Conduct laboratory analysis or cross reference with validated nutritional databases to work out the predicted nutritional profile of your feed. Verify the nutrient levels, in particular it is important to do this for the protein quality and amino acid balance, to ensure they meet the required standards. Lab analysis can also help identify any nutrient deficiencies or excesses.

1.7.7. Animal performance

Feeding trials and animal monitoring can be used to assess the effectiveness of the BSF meal in combination with the other ingredients to meet the requirements of the animals. Assess parameters such as growth rate, feed conversion ratio, and overall animal health.

1.7.8. Quality control and monitoring

Create quality control measures to ensure consistent nutrient content and quality of BSFL meal used in the feed. Regularly test the BSFL meal samples for nutritional composition, potential contaminants, and the presence of any pathogens, as well as anti-nutritional factors.

1.7.9. Summary

It is important to keep up-to-date with scientific research and industry protocols regarding the use of BSFL meal in animal feed. It is also important to make sure that you are complying with regulations within your region related to feeding animals.

1.8. Feed formulation recipes with insect meal based on local feedstock availability

1.8.1. EU

When formulating feed with insect meal it is important to remember that the nutritional content of the insect meal is highly dependent on the waste substrate that was fed to the larvae. As a result, feed formulation recipes are different according to the region you are in. Differences in waste substrates used between regions are dependent on:

- Regulation for feeding BSFL in that region - Some waste feedstocks are prohibited for use when producing BSF for animal feed in certain regions. This is particularly true of the EU, UK and North America.
- Waste stream availability - Some waste streams are more readily available in some regions than others. Or those waste streams may already be used in other industries or directly for the feed industry.

In this report the focus is mainly on East Africa, where Flybox have been conducting waste trials and waste mapping exercises.

1.8.2. East Africa

In East Africa there is an existing legal framework surrounding insect farming. It is permissible to use any viable waste source as a waste feedstock for BSFL. This includes manures, meat products and pre-consumers waste, none of which are permitted for use in the EU. This provides a wider number of waste sources that can be used. However, these waste sources are not always easy to collect or access.

NESTLER consortium has been able to compile a comprehensive report on organic waste availability and distribution in Kenya, Uganda and Rwanda and Tanzania, as well as the costs associated with its collection, dumping and potential use as a feedstock for BSF. The types of waste that we focused on researching for feedstock included;

- Market waste
- Fruit and vegetable processing/export waste
- Animal manure
- Brewery waste/spent grains
- Slaughterhouse waste
- Fish processing waste

1.8.3. Market waste

There were several common themes throughout all the 4 countries visited during the study: The waste tends to be very mixed in with a lot of dirt and inorganic waste and is almost never sorted. Therefore, to use this waste it would be necessary to provide sorting bins and to employ people to ensure this is done properly. Quantities of waste do not vary too much seasonally because there is such a great variety of produce.

It is important that you form a good relationship with the market leaders and local council when using market waste. In particular, it is key that these parties can trust that you are taking all the waste to be processed at your site and you are not dumping elsewhere. There may also be claims from local authorities or businesses that once the waste is sorted, it is a commodity and therefore should be paid for, which you should try to avoid.

Finally, the private waste companies are often the companies that manage market waste, so it would be valuable to form relationships with these companies. They charge fees to remove this waste, which is something we could do too.

1.8.4. Fruit and vegetable waste processing / exporter waste

This form of waste is the most seasonally variable of the types of waste listed. Pineapples in particular have a very short season. Seasonality is particularly an issue if the exporter or processor uses a small range of fruits/vegetables.

However, these companies do have large amounts of organic waste in a centralised location, such as packhouses. Facilities are often used by several companies, with a huge variety of fruit waste. Additionally, these companies often pay a waste dumping fee so will happily give it to BSF producers for free.

1.8.5. Animal Manure

Our main focus here has been on information regarding pig and chicken manure as they are the better feedstocks for BSF. During this study, we have seen that cattle and goats are often farmed through grazing practices, but pig and chickens are increasingly farmed more intensively and indoors. Intensive chicken farms often do not use the manure for anything, freeing it up for use as a BSF feedstock. However, some farmers use it on their plantations for fertiliser if they have them.

1.8.6. Brewery waste / spent grain

Brewery waste includes spent grains and yeast. This study has shown us that the yeast would be a much feasible waste source in this case because spent grain already has value as animal feed. This is particularly clear in Kenya where the government has ensured that the dairy industry has priority of this resource. Yeast is a high protein substrate, so a small amount can be in a very small amount to supplement the protein levels. We have found that spent grain and brewers yeast is expensive when you can buy it.

1.8.7. Slaughterhouse waste

We have found it difficult to communicate with slaughterhouses during this study, as they have not often been open to calls and often do not have websites or contact info. However, from online research it is clear that these companies do have large issues with waste management as this is an issue that often comes up in local community newspapers and reports. Some chicken farms process their own chickens and often have a large amount of waste from this.

1.8.8. Fish processing waste

As a high protein waste source, this was a target during the study for which we found out some valuable information. Large fish such as Nile Perch, processed around Lake Victoria, produce much more waste than smaller fish such as Tilapia. However, the skin of these fish is already bought directly as feed for pigs at 300TSh per/kg, but the guts could be used as BSF feedstock. In addition, fish processors that export should be target partners because they fillet the fish (producing more waste), whereas when sold locally it is normally sold as whole fish.

2. Practice Assessment

2.1. Practice Abstract – Livestock

Majority of the work done in BSF application is for poultry and pigs although some interesting new work has been done on the viability of BSF as a probiotic creep feed/milk replacer. Chickens are natural scavengers and have a palatability preference for BSF. The high levels of calcium in BSF products are favourable for bone growth and development and is a considerable advantage in layer chicken diets. Other advantages include increased yolk and albumin mass and higher protein quality. The cholesterol content of the eggs can also be successfully reduced.

The added natural antibacterial and antioxidant attributes of BSF products are a nutritive tool to reduce traditional medicinal inclusions to support flock health and welfare in poultry diets. Broiler formulations have seen inclusion levels of up to 20% full fat larvae, successfully improving growth parameters, carcass characteristics and gut health.

The use of BSF meal and oil in pig diets has supported improved piglet viability, growth rates and reduced incidence of disease. Live or whole dried larvae can be fed to piglets to improve feed conversion ratios, either inside their feed ration or as a supplement to reduce total feed consumption whilst maintaining growth rate. The lauric acid in BSFL oil can be consumed by sows and then carried over as an additional immunity boost to sucking piglets, reducing their vulnerability to pathogens. A better understanding of insect products allows for reduced skepticism and higher acceptance of sustainable ingredient inclusions.

2.2. Practice Abstract – Aquaculture

The advantages of using Black soldier fly (BSF) larvae in fish farming are nutritional, functional (antibacterial and antiviral) and sustainable. Applicable products for aquaculture diets include whole BSF, BSF Oil, Protein Hydrolysates and BSF protein powder. Using BSF as a functional ingredient allows for not only good growth and production performance, but also improved health status as a natural antibiotic. BSF oil (naturally high in lauric acid) can successfully substitute fish oil (up to 95%) in aquaculture diets as well as be used as a high quality pellet coating.

Utilizing these additional benefits of BSF ingredients means that the breeding success, survival rates and FCR of fish is improved. Farmers can substitute up to 60% of fishmeal (around 30% of the diet) with BSF and achieve a balanced and immune-boosting formulation. Alternatively, BSF can be added whole (live or dried) as a nutritional supplement to boost fish health and growth efficiency. This allows for EPA and DHA optimizations in BSF through production inputs for a specific fish species. Usually, for example Seabass, formulations include around 14% fish oil and 40% fishmeal, which can successfully be partially replaced by BSF to increase animal health and improve Fish in-Fish out metrics. By understanding the benefits of insect supplementation, farmers can make successful substitutions for carbon heavy feed ingredients and medicinal inclusions being used.

2.3. Practice Abstract – FRASS

Soil degradation is a major challenge to food security in sub-Saharan Africa (SSA), yet synthetic fertilizer use is hampered by high cost and limited access. Nonetheless, rejuvenating the highly degraded soils requires organic fertilizers to replenish organic matter and micronutrients and ameliorate soil acidity. Yet, the uptake of organic fertilizers is limited by poor quality, long production time and scarcity of organic matter on the farm. The use of saprophytic insects to recycle organic waste into affordable and high-quality insect-composted organic fertilizer products (ICOF) has attracted rapid attention globally. Our research aimed to determine the quality of ICOF generated from various waste streams and assess ICOF impacts on soil fertility, crop yield and nutritional quality, and suppression of soil-borne pests and pathogens. Data were collected using laboratory, greenhouse and field experiments involving ICOF, commercial fertilizers, and various test crops in Kenya. Our findings revealed that insects require only 5 weeks to recycle organic waste into nutrient rich, mature and stable organic fertilizer, compared to 12 – 24 weeks required for conventional composting methods. We found that ICOF contains 3 – 9 folds higher macronutrients, and adequate secondary nutrients and micronutrients required for adequate crop growth compared to conventional organic fertilizers. Agronomic studies revealed that soil amendment with ICOF significantly increased the yields of crops such as maize (6 – 27%), kales (20 – 27%), tomatoes (22 –135%), French beans (38 – 50%), spinach (13 – 56%), bell pepper (8 – 151%), and Amaranthus dubius (10 – 11%) compared to commercial fertilizers. Use of ICOF increased crude protein (6 – 190%) and mineral contents of food crops, net income (10 – 154%) and return on investment (5 – 156%) better than commercial fertilizers. Furthermore, we found that ICOF application increased soil water storage, nutrient release and synchrony for plant uptake, microbial populations, and reduced soil acidity compared to conventional organic fertilizers. Soil amendment with ICOF suppressed potato cyst and root knot nematodes, cabbage and onion root fly pests, and tomato bacterial wilt by up to 100%, 65%, and 35%, respectively. Our results highlight the positive role of ICOF in improving soil fertility and crop yield and nutritional quality by addressing the challenges of soil acidity, nutrient deficiency, soil-borne pets and diseases which is characteristic of most tropical soils. These findings indicate that adoption of high-quality, affordable and multipurpose fertilizers such as ICOF will immensely contribute towards sustainable soil health management and transformation of food production systems for improved food security.

3. Conclusion

This report highlights the key considerations in livestock nutrition as related to BSFL meal, as well as other key aspects such as sustainability, feed efficiency and impacts on disease prevention.

BSFL offers a more sustainable alternative to current feed inputs such as fishmeal and soya, whilst also offering an opportunity to address issues with poor quality feed in some locations, such as SSA, where these inputs are often lacking vs. the idea feed formulation quantities.

BSFLM offers great opportunity for improvements to feed formulations for Chickens, Swine and Fish, with Chickens being a prime target for initial output of the sector (due to being able to eat BSFL whole). Fish offer a similarly substantial opportunity over the medium term however require more processing (some smaller fish cannot eat BSFL whole thus it has to be BSFL meal) and focus on highly species dependent feed formulations.

Overall BSFLM and BSFL offer a substantial opportunity across both the EU and SSA to address issues with feed stock quality and sustainability.

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