Sustainable Agriculture and Food Security

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Emerging Sustainable Aquaculture Innovations in Africa

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Sustainable Agriculture and Food Security

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Ndakalimwe Naftal Gabriel • Edosa Omoregie •
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Emerging Sustainable Aquaculture Innovations in Africa

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Preface

The global food production systems require expanding their capacity to produce almost twice the current levels to safeguard the food security of the burgeoning population worldwide. More than 800 million suffering from undernourishment worldwide pose a great risk to the attainment of sustainable development goal (SDG) 2 of the UN that targets "End hunger, achieve food security and improved nutrition and promote sustainable agriculture" within the next 7 years. The challenge is further exacerbated by the rising weather extremities and unpredictability in rainfall patterns and pest-pathogen dynamics associated with global climate change that has profound negative impact on the agricultural productivity and farm incomes worldwide. Also, the future targets of food production should be secured in a resource-constrained agricultural setting and with least environment footprint, thus calling for sustainable innovations in agri-farming systems and enhanced participation of women in agriculture. The challenge to reduce hunger is alarming in the case of developing nations particularly in Asia and Africa that house the largest proportion of people suffering from malnutrition and other nutrition-related issues. Furthermore, the agri-food systems in Asia and Africa are severely constrained by subsistence nature of farming, declining land and other agricultural resources, increasing environmental pollution, soil and biodiversity degradation, and climate change. Therefore, this book series, "Sustainable Agriculture and Food Security," has been planned to support the global efforts towards sustainability by providing timely coverage of the progress, opportunities, and challenges of sustainable food production and consumption in Asia and Africa. The series narrates the success stories and research endeavours from the regions of Africa and Asia on issues relating to SDG 2: Zero hunger. It fosters research in transdisciplinary academic fields spanning across sustainable agriculture systems and practices, post-harvest and food supply chains. The focus of the series is to provide a comprehensive publication platform and act as a knowledge engine in the growth of sustainability sciences with a special focus on developing nations.

As per the UN's Food and Agriculture Organization (FAO), aquaculture is defined as the '*farming of aquatic organisms including fish, molluscs, crustaceans* *and aquatic plants. Farming implies some sort of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated, the planning, development and operation of aquaculture systems, sites, facilities and practices, and the production and transport.*' Although aquaculture has been around for millennia, it started to contribute significantly to the global food supply and rural livelihoods about 30–40 years ago. In the context of target geographic regions of the book series, Asia dominates global aquaculture accounting for 92% of global production, and Africa has <2% share in global production. However, in the last 20 years, aquaculture production in sub-Saharan Africa (SSA) has grown by 11% annually on average, almost twice as fast compared with the rest of the world, and some African countries with a growth of 12–23% per year. However, due to fish disease triggered by poor water and farm management practices in the beginning of 2015, the high cost of local production, competition from cheap fish imports, and then the recent addition of the COVID-19 pandemic, the production level has been stagnated. As per an estimate, the projected increase in demand for aquatic foods in SSA required that aquaculture produces an additional 5 million tonnes by 2030 and 10.6 million tonnes by 2050. However, such growth must not come at the cost of aquatic ecosystem health, increased pollution, animal welfare, biodiversity, or social equality. This requires new, sustainable and equitable aquaculture development strategies.

According to a joint report of Agence Française de Développement (AFD), European Commission, and German International Development Agency (GIZ), '*the aquaculture value chain—whether it be the primary production stage or the subsequent product supply chain—can contribute to achieving SDGs at both national and regional levels.*'

Among different kind of aquaculture types—subsistence aquaculture, small-scale commercial aquaculture, SME aquaculture, and industrial aquaculture—the subsistence aquaculture has the potential to contribute to most of the relevant SDGs. This is due to the family level of operations, where work is well distributed, meaningful, and empowering. Small-scale commercial aquaculture in terms of its contribution to the SDGs also has a greater opportunity to directly contribute to family income, and thus address poverty issues. This will assist to achieve other SDGs at community level, including good health and education opportunities. It can also generate some jobs, and being local, can be undertaken on a part-time basis by women. In the majority of the aquaculture sector in Africa, the above-mentioned two types of aquaculture farming are more common in Africa, and therefore improving aquaculture in Africa will significantly contribute to achieving SDGs.

In view of this, the present book, *Emerging Sustainable Aquaculture Innovations in Africa,* provides a platform to appreciate current efforts and plan future work on this important topic. The book contains 26 chapters written by various experts and practitioners in aquaculture in Africa. The chapters are written under four parts: Aquaculture Nutrition and Feed Management, Water Quality Management, Aquaculture Development and Innovations in Africa, and Aquaculture Animal Welfare. I would like to congratulate the editors, Ndakalimwe Naftal Gabriel, Edosa Omoregie, and Kenneth Prudence Abasubong, and all authors for their valued contributions. I am sure that this book is a great resource for students, researchers, aquaculture farmers, aquaculture educators and extension agents, policy makers, and other stakeholders engaged in transforming aquaculture in Africa and possibly other parts of the world.

I wish to extend my sincere thanks and gratitude to the Springer staff, particularly Aakanksha Tyagi, Senior Editor (Books), Life Sciences, and Naren Aggarwal, Editorial Director, Medicine, Biomedical and Life Sciences Books Asia, for their constant support for the accomplishment of this compendium. The cooperation received from my senior colleagues and research leaders such as David Morrison, Peter Davies, and Daniel Murphy and my laboratory colleagues Anu Chitikineni, Abhishek Bohra, and Vanika Garg from Murdoch University (Australia) is also gratefully acknowledged. I would like to thank my family members Monika Varshney, Prakhar Varshney, and Preksha Varshney for their love and support to discharge my duties as Series Editor.

Perth, WA, Australia Rajeev K. Varshney

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Chapter 3
Black Soldier Fly (*Hermetia illucens*) Larvae Meal as a Sustainable Protein Source for Fish Feed Production in Kenya

Mary A. Opiyo, Rita N. Nairuti, Charles C. Ngugi, and Gladys Mwaka Holeh

Abstract Aquaculture has been ranked as one of the fastest-growing food sub-sectors, providing quality protein to better the livelihoods of rural communities alongside curbing malnutrition and food security globally. Nonetheless, the industry's sustainability has been threatened by the high cost of fish feeds, which account for approximately 60–70% of the total operational costs. Fish meal (FM) has been extensively utilised as the main source of protein in the diets of farmed finfishes. However, due to declining capture fisheries and competing uses from other animal feed producers, the ingredient has become a scarce resource with limited availability and high prices. Black soldier fly larvae (BSFL) have been identified as a promising alternative protein source in fish feeds. BSFL are documented to have high nutritional content: crude protein (of up to 64% dry matter), essential amino acids, fatty acids, and other micro-nutrients which are vital for the growth of fish. BSFL meal has the potential success of replacing FM in the diets of various fish species. This chapter focuses on analysing recent research work in BSFL proximate and chemical composition, its current utilisation in fish feeds and gaps to be filled in its complete utilisation as an ingredient in commercial feed production. This information is expected to help both cottage and commercial fish feed producers utilise BSFL in feed production in Kenya and further will promote the sustainability of the aquaculture industry.

Keywords Aquaculture · Black soldier fly larvae · Fish feeds · *Oreochromis niloticus*

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3.1 Introduction

The aquaculture industry is faced with the challenge of the high cost of feeds which represents up to 60–70% of operational costs in fish production (Holeh et al. 2020). Fishmeal and fish oil have been the main source of protein and essential fats in the aquatic feed production (Betancor et al. 2016). This is due to the high nutritional value of fishmeal, balanced essential amino acids profile, high essential fatty acids, and phospholipids near to requirement levels of most cultivated aquatic organisms (Tacon 2018). However, high global demand and competition for fish meal (FM) from other animal feed manufacturers have increased the prices of the products, and the global supplies are on the decline (Montoya-Camacho et al. 2019; FAO 2020). These economic and sustainability concerns have led to the search for non-conventional ingredients from both plant and animal sources to replace fishmeal in fish diets (El-Sayed and Tacon 1997; El-Sayed 1998; Hasan and Chakrabarti 2009; Katya et al. 2017; Khalifa et al. 2018; Alfaro et al. 2019).

Research on insects focuses on various species of Coleoptera and Diptera, including the Black soldier fly (*Hermetia illucens*) (Burtle et al. 2012), common houseflies (*Musca domestica)* (Awoniyi 2007) and beetles (*Tenebrio molitor*) (Khosravi et al. 2018) as a potential replacement of fishmeal in aquaculture nutrition have gained attention in the recent years. This is attributed to the fact that they contain high protein levels with high availabilities since they can be reared on low-grade bio-wastes to effectively convert organic wastes into high-quality proteins (Veldkamp et al. 2012; Shumo et al. 2019a, b). Black soldier fly larvae (BSFL) appear to be superior among other insects as a potential source of animal protein for use in fish feed formulations (Henry et al. 2015). BSFL contains up to 50% crude protein (CP) and up to 35% lipids and has an amino acid profile that is similar to that of the FM (Elwert et al. 2010; Henry et al. 2015; Katya et al. 2017; Shumo et al. 2019a, b). Its sustainability is due to ease in production using organic wastes (Barragan-Fonseca et al. 2017; Ewald et al. 2020). Moreover, the Black soldier fly (BSF) is neither a non-vector nor a pest, and it is known to reduce the presence of harmful bacteria, especially *Escherichia coli* and *Salmonella enterica,* from food substrates (Liu et al. 2017; Shumo et al. 2019a, b). In most studies, dietary inclusion of BSFL in fish diets has improved fish growth, yields and reduced production cost, thus promoting profitability and resource utilisation (Kroeckel et al. 2012; Li et al. 2017; Fawole et al. 2020; Wachira et al. 2021).

3.2 Basic Culture Method of Black Soldier Fly

3.2.1 Life History and Culture Conditions

The BSF occurs in the tropical and sub-tropical regions of the world and possesses holometabolous metamorphosis (Nairuti et al. 2022). Their life cycle starts from an

Table 3.1 Abiotic factors requirements for rearing black soldier fly larvae (Barragan-Fonseca et al. 2017)

Parameter	Minimum	Optimal	Maximum
Temperature (°C)	12	26–27	36
Relative humidity (%)	25	60–70	99
Substrate moisture (%)	40	52–70	70
Light intensity/m^2/s	60	135–200	–

egg, which marks the end of the previous life stage, i.e. the female dies after laying eggs (Shumo et al. 2019a, b). A female fly lays 400–800 eggs in tiny, dry and well-sheltered cavities and close to a food source, preferably decomposing organic matter. After hatching, the cream-like larvae take up large amounts of decomposing organic matter and increase from a few millimetres to approximately 2.5 cm in length and 0.5 cm in width (Dortmans et al. 2017). Larval development takes 14–16 days under optimal conditions (Shumo et al. 2019a, b) (Table 3.1).

The pupae stage is symbolised by replacing the larval mouthparts with a hook-shaped structure and changing colour from cream to dark brown-charcoal grey. The pupation stage takes 2–3 weeks and is marked by the transformation of the pupa into a fly. The emergent fly does not feed and is only dependent on water for development along the life cycle (Dortmans et al. 2017; Zurbrügg et al. 2018). During this phase, the adult searches for a partner and copulates and the female lays eggs. The flies have been found to prefer copulating during the morning light, and females lay their eggs in well-shaded areas near substrates. Light intensity affects mating and egg fertilisation of BSF (Zurbrügg et al. 2018). The insects have higher mating activities in shaded areas, with the females ovipositing eggs in dark crevices (Shumo et al. 2019a, b).

3.2.2 Culture Substrates for BSF Larvae

The growth, production and maturation of *H. illucens* are highly dependent on the quantity and nutritional quality of the culture substrate. Adult BSF does not take up any food (Tomberlin et al. 2002) but instead survives on the food reserves built up during the larval stage and water (Diener et al. 2011; Nguyen et al. 2015). The larvae of the BSF require food that is obtained from suitable substrates. Previous studies indicate that substrates rich in protein and carbohydrates result in good larval growth and translate to larvae with high Crude protein and fat content (Dortmans et al. 2017). However, culture substrates with high oily amounts produce larvae with high lipid levels, which subsequently translates to lower protein content, because of the inverse relation of proteins and lipids in animal tissues (Mohanta et al. 2016).

Naturally, the BSF is found in faecal waste piles of livestock, poultry, swine and humans (Dortmans et al. 2017). Further, they are found colonizing domestic and wastes from industrial by-products, including kitchen vegetable and fruit wastes, decaying coffee pulp wastes and municipal organic wastes (Barragan-Fonseca et al. 2017). The presence of bacterial and fungal communities in these wastes acts as

Table 3.2 Nutritional composition of BSFL cultured in the different substrates in Kenya (Shumo et al. 2019a, b)

Parameters (% dry matter)	Chicken manure	Kitchen waste	Spent grain
Dry matter	80.7	87.7	83.1
Ash	9.3	9.6	11.6
Crude protein	41.1	33	41.3
Neutral detergent fibre	21.9	20.4	28.6
Acid detergent fibre	12.6	13.2	15
Ether extract	30.1	34.3	31

decomposition aids to further breakdown of organic matter making it easier for the larvae to access the nutrients (Dortmans et al. 2017). For the culture of BSF, the larvae can be fed on a wide range of organic food substrates rich in nitrogen and calcium (Ca) (Dortmans et al. 2017) and has a moisture content between 52 and 70% (Sophie et al. 2007; Shumo et al. 2019a, b). However, the wastes used as substrates should be free from potential pathogens, which can be harmful to human beings. They should not have food safety hazards as per the EU regulation of 2017 and must contain "products of non-animal origin" with those substrates made of flesh and manure (human food waste) explicitly excluded (EU Commission Regulation of 2017). In the United States of America, the Food and Drug Administration (FDA) also approved dried larvae of *Hermetia illucens* cultured in substrates comprising exclusively of feed grade materials containing not less than 34% CP and 32% fat for use in feeding salmonid fishes. These restrictions were implemented to fulfil the safety conditions for insect production for farmed fish and animal feed (Wang and Shelomi 2017). However, in Kenya, no regulations have been implemented to regulate the substrate used for BSFL production. The nutritional composition of cultured BSFL differs depending on the culture substrate. Substrates documented for use for BSFL culture include chicken manure, kitchen waste and spent grains (Table 3.2).

3.3 Biochemical Composition of BSF Larvae as a Feed Ingredient

3.3.1 Crude Protein and Fat Content

The protein and fat content of BSFL depends highly on the quality and quantity of the substrate used for the culture of the larvae (Nguyen et al. 2015; Barragan-Fonseca et al. 2017; Shumo et al. 2019a, b; Ewald et al. 2020). A study by Spranghers et al. 2017 reported significantly higher CP levels in larvae reared in restaurant waste (43.1%) compared to chicken feed and vegetable waste. Nguyen et al. (2015) also recorded higher protein and low fat in larvae fed on kitchen waste than those fed chicken feed. Previous studies have also reported higher fat content in

Table 3.3 Content of crude protein and crude fat (CF) of BSF larvae reared on different substrates. (Modified from Barragan-Fonseca et al. (2017)

Substrate	% Crude protein[a]	% Crude fat
Cattle manure	42.1	34.8
Chicken manure	40.1; 41.1	27.9
Swine manure	43.6; 43.2	26.4
Palm kernel meal	42.1; 45.8	27.5
Restaurant waste	43.1	39.2
Chicken feed	47.9	14.6
Liver	62.7	25.1
Fruits and vegetables	38.5; 30.84	26.63; 33.10
Fish	57.9	34.6

[a] All values are expressed on a dry matter basis

larvae reared on cattle manure (34.8%) in comparison to chicken (27.9%) and swine manure (26.4%) (Table 3.3).

3.3.2 Amino Acid Content

Essential amino acids (AA) are important in fish feeds and should be considered when selecting a fish feed ingredient. The AA content in BSFL is mainly influenced by the processing efficiency of the larvae. Defatting, which involves the mechanical or chemical removal of fat from the larvae, has been found to help increase the amino acid content of dried BSFL meal (Renna et al. 2017). Most studies have shown that the amino acid contents of the BSFL do not differ much based on the culture substrate (Table 3.4). However, some AA, like methionine, have been reported to be relatively low in BSFL meal compared to FM. Generally, BSFL meal has a good protein quality compared to FM and has higher contents of arginine, isoleucine, alanine, valine histidine and tryptophan (Barragan-Fonseca et al. 2017).

3.3.3 Fatty Acids Content of BSF Larvae

The BSF larvae meal is rich in monounsaturated fats but has lower polyunsaturated fatty acid percentages compared to other insects, such as housefly maggots, meal-worms and adult crickets used in animal feed (Ghosh et al. 2017). BSFL contain between 58 and 72% saturated fatty acids and 19 and 40% mono- and polyunsaturated fatty acids (Table 3.5) (Larouche 2019). The quality and quantity of fatty acid content in the BSFL are highly influenced by the type of substrate used. They tend to accumulate more lipids when the larvae are fed on a lipid-rich animal diet (Wang and Shelomi 2017). Larvae fed on fish by-products and fish wastes have increased levels of n-3 polyunsaturated fatty acids (n-3 PUFA), a-linolenic acid (ALA), eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) in their tissues

Table 3.4 Amino acid profile of the BSF larvae. (Source: Spranghers et al. (2017)

Parameter (g/kg dry matter)	Chicken feed	Digestate	Vegetable waste	Restaurant waste
Essential amino acids				
Isoleucine	17.2	18.4	17.3	19.1
Leucine	28.6	29.5	28	30.6
Lysine	23.4	25.7	22.6	23
Arginine	20.3	20.3	20	19.9
Methionine	7.6	8.7	7.6	7.1
Histidine	13.6	13.5	12.4	3.8
Phenylalanine	17	18.7	16.3	16.4
Threonine	16.4	16.8	15.4	16.2
Non-essential amino acids				
Alanine	25.2	24.3	24.2	27.8
Cystine	2.5	2.4	2.1	2.2
Glutamic acid	41.9	39.8	41.3	45.8
Glycine	22.6	22.6	22.2	25.2
Proline	22.5	22.1	21.4	25.1
Serine	16.6	15.5	15	15.9
Aspartate	37.8	33.6	35.9	36.9
Tryptophan	6.7	6.2	5.8	5.4
Valine	24.1	24.9	24.8	28.2

Table 3.5 Fatty acid profile of the black soldier fly larvae. (Data adapted and modified from (Larouche 2019))

Parameter (% lipid)	Content in BSF larvae (Oonincx et al. 2015; Liu et al. 2017)
Lauric (C12:0)	29–61
Myristic (C14:0)	7–10
Palmitic (C16:0)	8–17
Palmitoleic (C16:1n-7)	3–7
Stearic (C18:0)	1–3
Oleic (C18:1n-9)	8–18
Linoleic (C18:2n-6)	4–17
Alpha-linolenic (C18:3n-3)	0–2
Unsaturated fatty acid	18–37
Saturated fatty acid	58–80

(Sophie et al. 2007; Renna et al. 2017). This indicates that BSFL provide the necessary fatty acids requirements to meet the different nutritional requirements of different fish species, which is 0.5–1% (Andersen et al. 2016).

3.3.4 Mineral Content of BSF Larvae

The mineral content of the BSFL larvae is profoundly influenced by the type of substrate used for feeding the larvae and the stage of development (Table 3.6). For instance, a study by Shumo et al. (2019a, b) reported higher phosphorus levels in BSFL reared on spent grain compared to kitchen waste and cattle manure. High Ca has been reported in larvae fed on digestate compared to chicken feed, vegetable and restaurant waste. The high Ca concentration and ash contents (9 and 28% dry matter, respectively) reported in the larvae were attributed to the secretion of calcium carbonate ($CaCO_3$) by the epidermis (Finke 2013). On the other hand, the low Ca content (0.03%) in the newly emerged adults has been attributed to the fact that the pupal cuticle that is concentrated with Ca is shed off to give rise to the adult fly, indicating that the Ca levels are affected by the larvae stage of development (Finke 2013; Spranghers et al. 2017).

3.4 Utilisation of BSF Larvae in Fish Feed Formulation

Earlier studies have documented the utilisation of BSFL in fish feed formulation (Henry et al. 2015; Barragan-Fonseca et al. 2017; Katya et al. 2017; Dietz and Liebert 2018; Fawole et al. 2020; Wachira et al. 2021). BSFL have attracted enormous attention due to their higher reproductive capacity, short life cycle, ability to convert organic matter into high-quality protein and their capacity to thrive in a wide array of environments (Barragan-Fonseca et al. 2017). Additionally, the high protein content, digestibility, and amino acid profiles of the BSFL have been the selling point for this meal in fish diets. The BSFL meal has successfully replaced conventional protein sources in the diets of salmon (*Salmo salar*) (Weththasinghe et al. 2021), African catfish (*Clarias gariepinus*) (Fawole et al. 2020), European sea bass (*Dicentrarchus labrax*) (Moutinho et al. 2021), Nile tilapia (*Oreochromis*

Table 3.6 Mineral composition of BSF larvae reared on three different rearing substrates. (Data adapted and modified from Tschirner and Simon (2015) and Shumo et al. (2019a, b))

Mineral composition g/kg DM)	Cattle manure	Kitchen waste	Spent grain	Sugar beet pulp	Requirements by fish (National Research Council (NRC) 2011)
Phosphorus	3.9	4.1	4.6	1.3	7 g
Potassium	4.9	5.7	4.4	1.9	1–3 g
Calcium	3.2	2.0	1.7	6.2	5 g
Magnesium	4.0	3.3	3.5	0.5	500 mg
Iron	0.6	2.2	0.3	0.02	50–100 mg
Copper	0.4	0.2	0.5	1.2	1–4 g
Manganese	1.4	0.9	1.1	0.05	20–50 mg
Zinc	0.3	0.3	0.3	0.01	30–100 mg

niloticus) (Nairuti et al. 2021; Wachira et al. 2021), rainbow trout (*Oncorhynchus mykiss*) (Sophie et al. 2007) and turbot (*Psetta maxima*) (Kroeckel et al. 2012).

3.5 BSF Larvae Meal Effect on Fish Growth Performance

The inclusion of BSFL meals in the diets of *O. niloticus* do not lead to any negative effect on the body weight gain (BWG) and specific growth rate (SGR) of the fish (Devic et al. 2018; Toriz-Roldan et al. 2019). Similarly, a partial or total dietary replacement of FM with BSFL meal did not lead to differences in the BWG and SGR of juvenile Japanese bass (*Lateolabrax japonicus)* and rainbow trout (*Oncorhynchus mykiss*), respectively (Wang and Shelomi 2017). A study carried out by Fawole et al. (2020) recorded better final weight and BWG when 50% FM was replaced by BSFL meal in the diets of *C. gariepinus*. Similarly, Muin et al. (2017) reported the highest weight gain and SGR values when BSFL meal was used to replace 50% FM in the diets of Nile tilapia (Table 3.7). Additionally, BSFL meal has been demonstrated to be a promising FM replacement in the diets of the pacific white shrimp (*Litopenaeus vannamei*) at a 25% inclusions level (Cummins et al. 2017).

3.6 Cost Reduction of Fish Feeds Using Black Soldier Fly Larvae Meal

Reducing feed costs is critical to the profitability and sustainability of aquaculture production since fish feeds account for more than half of the operating cost (Holeh et al. 2020). BSF larvae have lower prices than other animal-based products, like fish and soybean meals in Kenya. The cost of dry BSFL ranges from 0.5 to 0.7 USD, while the FM is from 0.9 to 1.2 USD and soybean meal is from 1.5 to 1.7 USD in Kenya (Nairuti et al. 2022). These low costs of BSFL could be because they are produced and fed on low-value organic wastes, which are readily available (Shumo et al. 2019a, b). Previous studies have reported a reduction in the cost of feed when BSF meal was used to replace primary conventional sources of proteins, especially soybean meal and FM (Onsongo et al. 2018; Wachira et al. 2021). Abdel-Tawwab et al. (2020) reported decreased diet costs at increasing levels of BSFL meal in European sea bass diets from 0.71 to 0.60 USD kg^{-1}. Similarly, Wachira et al. (2021) recorded 14.4% cost reduction in feed production when the FM was replaced by a BSFL meal at 100% for Nile tilapia diets and a cost–benefit ratio of 2.172 when 33% of FM was replaced with BSFL meal. This indicates that the utilisation of BSFL reduces the cost of feeds used in fish production.

Table 3.7 Growth performance of different species of fish fed diets with different BSFL meal levels. (Adapted and modified from Nairuti et al. (2022))

Fish species	Attribute/element tested	Replacement levels (%)
Jian carp (*Cyprinus carpio*) (Li et al. 2017)	Substitution of 100% FM by defatted BSFL meal in diets for Jian carp had a negative effect on growth performance and feed utilisation efficiencies	0, 25, 50, 75, **100**
Meagre (*Argyrosomus regius*) juveniles (Guerreiro et al. 2020)	10% of *Hermetia illucens* can be included in Meagre diets without major adverse effects on growth, feed utilisation, whole-body composition and fatty acid profile; further increase in the substitution rates leads to negative effects on the growth performance parameters	**10,** 20, 30
Nile tilapia (*Oreochromis niloticus*) (Dietz and Liebert 2018)	Replacement of soy protein concentrate by partly defatted BSFL meal up to a level of 50% had no negative effect on growth performance and improved the dietary protein quality of tilapia feeds under study	25, **50,** 100
Siberian sturgeon *(Acipenser baerii*) (Caimi et al. 2020)	Overall, this study showed that it is possible to replace up to 25% of FM with BSFL meal in the diet of Siberian sturgeons (equal to 18.5% HIM inclusion level) without affecting the growth performance	**25**, 50, 100
Rainbow trout (*Oncorhynchus mykiss*) (Dumas et al. 2018) Nile tilapia (*Oreochromis niloticus*) (Muin et al. 2017)	The maximum inclusion of BSFL meal recommended in rainbow trout diets is 13%; further increase in the substitution leads to a decrease in the growth parameters The study suggests that substitution of FM with BSFL up to 100% is possible without any negative effects on the growth performance, feed utilisation efficiency, body composition	0, 6.6, **13.2**, 26.4 0, 25, 50, 75, **100**
European sea bass (*Dicentrarchus labrax*) (Abdel-Tawwab et al. 2020)	With the 3 substitution levels of FM with BSFL meal at (25, 35 and 50%), BSF larvae meal can effectively replace FM up to 50% without any negative effects on the growth performance	25, 35, **50**
Rice field eel (*Monopterus albus*) (Hu et al. 2020)	Lower substitution rates (5.26, 10.52%) of FM by BSFL meal in the diets of Rice field eel exhibited low values of the growth performance parameters as compared to higher substitution rates of FM by BSF larvae meal made at 15.78%	5.26, 10.52, **15.78**
African catfish (*Clarias gariepinus*) (Fawole et al. 2020)	Substitution of FM by BSFL up to 75% leads to no negative effects on the growth performance and nutrient utilisation	0, 25, 50, **75**
Juvenile turbot (*Psetta maxima*) (Kroeckel et al. 2012)	The maximum inclusion of BSFL meal recommended in Juvenile turbot diets is 33%; further increase in the substitution	0, 17, **33,** 49, 64, 76

(continued)

Table 3.7 (continued)

Fish species	Attribute/element tested	Replacement levels (%)
	leads to a decrease in the growth performance parameters and nutrient utilisation	

*Values in bold represent the recommended replacement or inclusion levels

3.7 Conclusion

The BSF larvae have shown very promising results in aquaculture due to their high levels of CP, balanced amino acid profile and fatty acid profile, together with high mineral contents, which makes them suitable as a dietary component in fish feed. Different studies have reported that it can replace FM up to100% in diets of several fish species. However, in some cases, levels above 50% have resulted in a negative effect on growth performance. This is probably due to the high chitin and fat content of the larvae. Therefore, proper culture systems for the BSFL and further processing by defatting and removing the chitin contents can improve the utilisation of BSFL by a wide range of fish species to improve fish growth performance and reduce aquaculture production costs. Further work to promote BSFL rearing and commercialisation in Kenya is needed to achieve the full potential of its use as a protein feed ingredient. BSFL rearing will also provide additional ecosystem services through municipal and organic waste management leading to environmental ecological balance.

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