https://doi.org/10.61308/LWHN4916

Black soldier fly larvae as animal feed

Ishaya Usman Gadzama
School of Agriculture and Food Sustainability, University of Queensland, QLD, Australia
National Animal Production Research Institute, Ahmadu Bello University, Zaria, Nigeria
Corresponding author: ishayausman@gmail.com

Citation: Gadzama, I. U. (2025). Black soldier fly larvae as animal feed. *Bulgarian Journal of Animal Husbandry, 62*(1), 48-64

Abstract: Black soldier fly (*Hermetia illucens* L.) larvae (BSFL) are a promising alternative to traditional animal feed sources due to their high nutritional value, including protein (8-60% DM), fat (18-40% DM), essential amino acids, minerals, and lauric acid, which has antimicrobial properties. The nutritional content of BSFL varies depending on the rearing substrate. Incorporating BSFL into the diets of various livestock species has led to improvements in growth performance, feed efficiency, product quality, and potentially animal welfare. The significance of BSFL in animal agriculture stems from the increasing demand for animal protein, which is expected to double by 2030, leading to a feed gap that BSFL can help address. BSFL farming offers a cost-effective and sustainable solution by converting organic waste into high-quality biomass, aligning with circular economy principles. However, further research is needed to better understand the effects of BSFL supplementation on animal responses, as a replacement for conventional feed sources like fish meal and soybean meal, which are costly, limited in supply, and environmentally impactful. This research will contribute to the development of more sustainable and efficient livestock production systems.

Keywords: black soldier fly larvae; animal feed; nutritional composition; rearing substrate; animal performance; insect protein

INTRODUCTION

The demand for higher-value foods, such as meat, eggs, and milk is expected to double by 2030, due to population growth and rising incomes, particularly in developing countries, where there is substantial potential for increased animal product consumption (FAO, 2017). The rising demand for animal protein is exerting pressure on traditional feed sources, such as fish meal and soybean meal, which are constrained by high costs, limited supply, and significant environmental impacts (Dörper et al., 2021; Raman et al., 2022; Gadzama et al., 2024). However, one of the major challenges facing animal agriculture today is sustaining the natural resource base (soil, water, air, and biodiversity), while meeting the increasing and changing demands for animal food products (FAO, 2017; Gadzama and Ndudim, 2019). Identifying new sustainable feed resources that minimize these impacts is crucial for long-term food security and environmental sustainability. Black soldier fly larvae (BSFL), scientifically known as *Hermetia illucens* L., have emerged as a promising alternative to address these challenges (Zulkifli et al., 2022; Raman et al., 2022; Gadzama and Panuel, 2024a,b). BSFL possess the unique ability to bioconvert organic waste into high-quality biomass, making them a sustainable and efficient option for animal feed production (Chia et al., 2021; Gadzama and Panuel, 2024a,b). This bioconversion process not only aids in waste management but also produces a nutrient-rich feed ingredient that can potentially replace conventional protein sources in livestock diets.

BSFL farming requires significantly less land than traditional livestock farming and can be conducted vertically in a smaller footprint, reducing the need for extensive grazing lands. Feeding trials with BSFL have been conducted in various animals, including chickens, pigs, rabbits, fish, cattle, sheep, and goats. While there are promising benefits, further research and development are needed to fully realize the potential of BSFL farming in addressing the challenges of livestock feed production. The main purpose of this paper is to review the nutrient composition of BSFL, integrate research findings from existing feeding trials, and improve our understanding of the effects of BSFL supplementation on animal production metrics and health.

NUTRITIONAL VALUE OF BLACK SOLDIER FLY LARVAE

The high protein content of BSFL, ranging from 8.0 to 60% DM (Table 1), positions it as a promising alternative to conventional protein sources, such as soymeal and fishmeal (Barragan-Fonseca et al., 2017; Shumo et al., 2019; Gadzama and Panuel, 2024a,b). This is particularly relevant in the context of the growing demand for protein for animal feed, coupled with the environmental concerns associated with traditional protein production. The wide variability observed in the nutritional content of BSFL emphasizes the need for standardized rearing practices to ensure consistent product quality. Factors, such as diet composition, rearing temperature, and harvesting time can significantly influence the final nutritional composition. For instance, BSFL raised on chicken feed, a protein-rich substrate, exhibit higher crude protein levels compared to those reared on other substrates (Table 2; Spranghers et al., 2018). This could be due to the defatting process, which has been shown to influence the protein levels in BSFL meal (Schiavone et al., 2017; Lu et al., 2022). The protein in BSFL is characterized by a well-balanced amino acid profile, exceeding soybean meal in leucine, lysine, and valine levels; particularly, valine levels in BSFL even surpass those in fish meal. BSFL protein contains a higher proportion of indispensable amino acids compared to common plant-based protein sources like rice and wheat, and even some animal-based proteins, including beef and chicken (Huang et al., 2019).

Full-fat BSFL has a fat content (18–40 % DM), and metabolizable energy (ME; 2–24 MJ/kg) (Table 1). While this high energy content can be beneficial for animals requiring elevated energy levels, it necessitates careful consideration during feed formulation (Lu et al., 2022). The main saturated fatty acids found in BSFL are Lauric acid (40.93%), palmitic acid (19.11%), oleic (17.34%), linolenic (8.79%), myristic (6.49%), and palmitoleic acids (3.89%) (Zabulionė et al., 2023; Gadzama and Panuel, 2024a; Shu et al., 2024). BSFL also serve as a source of essential polyunsaturated fatty acids, such as linoleic acid and linolenic acid (Gadzama and Panuel, 2024a,b). These essential fatty acids are crucial for various biological functions in animals, including growth, reproduction, and immune system function. The presence of these fatty acids in BSFL further contributes to their nutritional value (Lu et al., 2022).

BSFL is not merely a source of protein, but also a rich source of essential nutrients. The mineral composition of BSFL is an important consideration for their use as animal feed. Calcium (Ca) is the most abundant macromineral in BSFL, likely due to its presence in the exoskeleton (Chia et al., 2020; Gadzama et al., 2024). The significant levels of calcium, magnesium, phosphorus, and potassium underscore its potential as a valuable mineral supplement in animal feed and potentially even human diets. The abundance of lauric acid in BSFL, constituting 17.25% to 47.2% of total fatty acids, presents intriguing possibilities. Lauric acid is known for its antimicrobial and antiviral properties, suggesting its potential as a natural growth promoter in animal feed (Gadzama and Panuel, 2024a,b). This could contribute to reducing the reliance on antibiotics in animal agriculture, a practice that has raised concerns about antibiotic resistance. The presence of all essential amino acids, crucial for various physiological functions, further enhances the nutritional value of BSFL. The levels of lysine, methionine, phenylalanine, and valine are

Table 1. Summary of the chemical composition of Black Soldier Fly Larvae*

	Amount	Units
Proximate Composition		
Dry Matter (DM)	17.8–97.50	%
Organic Matter	87.2	%
Moisture	2.89–23.33	%
Protein (N x 6.25)	8.0–60	% DM
Fat	5.4–40	% DM
Crude Fibre	3.62–21.3	% DM
Ash	2.7–18.06	% DM
Carbohydrates (total)	7.24–17.41	% DM
Nitrogen free extract	4.90–20.5	% DM
Energy	2–24	MJ/kg
Minerals		
Calcium (Ca)	21000–37000	mg/kg
Magnesium (Mg)	2400–2700	mg/kg
Phosphorus (P)	6500–8200	mg/kg
Potassium (K)	8600–14000	mg/kg
Sodium (Na)	460–730	mg/kg
Zinc (Zn)	90–160	mg/kg
Copper (Cu)	10	mg/kg
Chitin	3.9–8.0	% DM
Fatty Acids		
Capric acid (C10:0)	1.0–1.7	% of total fatty acids
Lauric acid	17.25–47.2	% of total fatty acids
Myristic acid (C14:0)	2.65–8.0	% of total fatty acids
Palmitic acid (C16:0)	3.54–19.1	% of total fatty acids
Stearic acid (C18:0)	0.45–6.0	% of total fatty acids
Oleic acid (C18:1)	1.0–25.6	% of total fatty acids
Linoleic acid (C18:2)	1.73–23	% of total fatty acids
α-Linolenic acid (C18:3)	0.15–8.79	% of total fatty acids
Palmitoleic acid (C16:1)	1.05–3.89	% of total fatty acids
Vitamins/Carotenoids		
Provitamin A	0.0	µg/g
Thiamine (B1)	0.26	mg/g
Indispensable Amino Acids		
Lysine	26.30–29.00	mg amino acid/g
Methionine	7.40–8.30	mg amino acid/g
Phenylalanine	17.50–19.80	mg amino acid/g
Valine	23.20–24.70	mg amino acid/g
Dispensable Amino Acids		
Aspartic Acid	35.30–39.90	mg amino acid/g
Glycine	17.40–18.60	mg amino acid/g
Glutamic Acid	43.30–47.30	mg amino acid/g
Tyrosine	22.40–26.40	mg amino acid/g

Adapted from: Makkar et al. (2014); Al-Qazzaz et al. (2016); Benzertiha et al. (2020); Ognik et al. (2020); Tippayadara et al. (2021); Kozłowski et al. (2021); Zozo et al. (2022); Gadzama et al. (2023); Attia et al. (2023); Maranga et al. (2023); Loho & Lo (2023); Gadzama et al. (2024).

particularly noteworthy, as these amino acids are often limiting in plant-based protein sources. BSFL's ability to thrive on a wide range of organic waste materials, converting them into high-value protein, aligns with the principles of a circular economy. This aspect has significant implications for waste management and resource recovery, potentially contributing to a more sustainable food production system (Gadzama, 2024).

IMPACT OF REARING SUBSTRATE ON NUTRITIONAL COMPOSITION

The rearing substrate used for BSFL significantly influences its nutritional composition, making it a critical aspect of BSFL production for animal feed (Mwaniki et al., 2018; (Chia et al., 2020; Gadzama et al., 2023; Gadzama, 2024), which can be manipulated to tailor the nutritional value of BSFL to meet specific animal feed requirements (Zulkifli et al., 2022; Gadzama, 2024; Gadzama et al., 2024). Factors like temperature, humidity, and larval density during rearing can also impact BSFL growth and nutrient composition. Companies and research institutions are exploring various organic waste streams as feeding substrates, which shows the adaptability of BSFL and its potential in waste management (Table 2). BSFL can be easily reared and propagated on any nutrient-rich substrate, including plant residues, animal manure, and waste, food scraps, agricultural byproducts, or straws (Lu et al., 2022; Dou et al., 2024). Notable examples include pre-consumer recycled food, chicken feed, brewer's by-products, mixes of flour, water, and vegetable waste, food waste, chicken manure, and kitchen waste (Table 2). This approach aligns with the principles of circular economy, where waste is transformed into valuable feed resources.

IMPACT OF BSFL ON ANIMAL PERFORMANCE AND HEALTH

Research has shown that including BSFL in animal feed can improve animal growth, nutritional quality of animal products, and animal health and welfare. This means that animals fed BSFL grow faster and require less feed to reach a given weight. The improved growth performance is likely due to the high nutritional value of BSFL and its potential to enhance gut health, leading to better nutrient absorption. Furthermore, BSFL inclusion has been linked to an improvement in the quality of animal products. Moreover, the antimicrobial properties of lauric acid found in BSFL may contribute to improved animal health by reducing the risk of infections. This can lead to better overall animal well-being and potentially reduce the need for antibiotics in animal production.

Chickens

The effects of BSFL inclusion on broiler growth performance are inconsistent (Table 3). Some studies report positive outcomes, such as increased weekly weights in Ardennaise chickens fed 8% fresh BSFL (Moula et al., 2018). Conversely, other studies indicate potential downsides, including reduced body weight, weight gain, and feed intake in broilers fed diets containing 3-5% BSFL prepupae (Attia et al., 2023). However, a diet incorporating 60 g/kg of BSFL fat enhanced growth performance in broilers (Kierończyk et al., 2023). These findings suggest that the form and specific inclusion levels of BSFL are crucial for optimizing growth outcomes.

BSFL can be a valuable addition to laying hen diets. Studies demonstrate that appropriate amounts of BSFL (3% DM) can increase laying rates, decrease feed consumption per egg, and reduce cracked egg rates (Yan et al., 2023). Replacing conventional feed with BSFL meal up to 75% did not negatively impact meat quality (Makokha et al., 2023). However, excessive inclusion levels (24%) led to reduced feed intake, body weight, and egg production, highlighting the importance of determining optimal inclusion levels (Patterson et al., 2021). BSFL inclusion could improve poultry welfare. Broilers provided with live BSFL exhibited reduced fearfulness, a key welfare indicator, suggesting that the natural foraging behaviour stimulated by live BSFL may

Table 2. Nutritional composition and rearing substrates of Black Soldier Fly Larvae from various companies

Source	Rearing substrate	CP	Fat	ME	References
Enterra Feed Corp., Vancouver, BC, Canada	pre-consumer recycled food collected from local farms, food processors, and grocery stores	56.10	6.84	20.82	Mwaniki et al. (2018)[d]
Ghent University[p]	chicken feed	40.88	40.99	24.27	Spranghers et al. (2018)
Ghent University[p]	chicken feed	60.69	7.97	18.31	Spranghers et al. (2018)[d]
Foodyworm Inc. (Seoul, Republic of Korea)	NR	53.64	13.43	NR	Lei et al. (2019)
Nasekomo AD, Bulgaria	NR	18.01	6.75	13.27	Popova et al. (2020)
Hexafly (Co. Meath, Ireland)	brewer's by-product	49.10	36.60	NR	Campbell et al. (2020)
Shandong Wooneng Agricultural Science and Technology Co., Ltd., Liaocheng, China	mix of flour (35%), water (65%) and vegetable waste	34.97	35.49	NR	Chu et al. (2020)
Protix B.V. (Dongen, The Netherlands	NR	13.50	10.50	NR	Star et al. (2020)
HiProMine S.A., Robakowo, Poland	NR	40.40	33.50	NR	Ognik et al. (2020)
Department of Entomology, Chiang Mai University, Thailand	NR	26.12	36.47	1.93	Tippayadara et al. (2021)
HiProMine S.A. (Robakowo, Poland)	NR	42.40	28.00	NR	Kozłowski et al. (2021)
Entomics Biosystems (Cambridge, UK)	NR	8.07	1.93	6.76	Bellezza Oddon et al. (2021)[af]
INAGRO, Rumbeke-Beitem, Belgium	NR	14.39	9.56	8.69	Bongiorno et al. (2022)[af]
Guangzhou Feixite Aquatic Product Technology Co., Ltd, China	food waste	33.25	35.75	24.11	Ma et al. (2023)
Zhengzhou Bennong Agricultural Technology Co., Ltd. China	chicken manure	37.60	36.00	8.74	Yan et al. (2023)
ICIPE Nairobi, Kenya	kitchen waste	25.30	27.30	NR	Maranga et al. (2023)
Mobius Farms, Barossa Valley, South Australia	pre-consumer food waste (vegetables and fruits, and a small amount of chicken starter mash)	48.20	27.80	19.03	Gadzama et al. (2023)
Cyns, Piracicaba, Brazil	NR	54.30	9.53	21.80	Silva et al. (2024)

BSFL: Black soldier fly larvae, NR: Not reported, CP: Crude protein (% dry matter (DM)), Fat (% DM), ME: Metabolizable energy (MJ/kg), [d]Defatted BSFLM, [p](prepupae), ICIPE: International Centre of Insect Physiology and Ecology.

reduce stress levels (Ipema et al., 2020). In laying hens, live BSFL provision resulted in better feather conditions, further supporting its potential welfare benefits (Star et al., 2020).

BSFL can enhance the nutrient composition of poultry products. Broilers fed with increasing levels of BSFL showed a linear increase in meat redness, indicating improved pigmentation (Schiavone et al., 2019). However, some studies report undesirable changes in fatty acid profiles with high BSFL inclusion levels, necessitating a balanced approach to maximize nutritional benefits while mitigating potential negative impacts on product quality (Popova et al., 2020; Kierończyk et al., 2023). Variations in BSFL composition and processing methods impact research consistency. Further research is needed to standardize BSFL production and processing for reliable results. Most studies focus on short-term effects. Investigating the long-term implications of BSFL inclusion on poultry health, productivity, and product quality is crucial. More research is needed to understand consumer perceptions of poultry products derived from BSFL-fed animals.

Pigs

Studies show that the inclusion of BSFL in pig diets can positively impact growth performance and feed efficiency (Table 4). A study by Chia et al. (2021) found that pigs fed a diet with 100% BSFL meal had significantly improved feed conversion efficiency. Eickleberry et al. (2022) demonstrated that BSFL oil, rich in lauric acid, improved final weight gain and average daily gain in pigs across all study phases. These findings suggest that BSFL, in both meal and oil forms, is a valuable ingredient for improving pig growth and feed utilization. However, it is important to consider the age of the pigs and the amount of BSFL included in the diet. Kawasaki et al. (2023) found that piglets fed 12.5% and 25.0% BSFL

Table 3. Summary of Studies on the Impact of Black Soldier Fly Larvae on Poultry

Species	Parameter	Summary of Results	References
Broilers	Performance	Feeding 8% fresh BSFL significantly increased weekly weights.	Moula et al. (2018)
		A diet of 3% BSFL prepupae (1-14 days) followed by 5% (15-42 days) reduced feed intake, body weight gain, and impaired feed conversion ratio.	Attia et al. (2023)
		Broilers fed BSFL fat at 60 g/kg diet showed better growth performance compared to the control group.	Kierończyk et al. (2023)
Hens		Feeding 24% BSFL meal reduced average daily feed intake, body weight, and egg production after 8 weeks.	Patterson et al. (2021)
Broilers	Welfare	Long-term access to live BSFL reduces fearfulness in broilers without impacting their health or performance.	Ipema et al. (2020)
Hens		Hens fed 12 g live BSFL per day using a larvae dispenser had significantly better feather condition after 12 weeks than the control.	Star et al. (2020)
	Product Quality	Substituting up to 75% of fish meal with BSFLM in hens' feed does not significantly affect meat quality.	Makokha et al. (2023)
Broilers		Broilers fed increasing levels of BSFL (50, 100, and 150 g/kg diet) showed a linear increase in meat redness and a linear decrease in meat yellowness.	Schiavone et al. (2019)
		Broilers fed BSFL meal had decreased PUFA, PUFA to SFA ratio (P/S), n-6/n-3 ratio, and hypo/hypercholesterolemic fatty acids (h/H) ratio in the meat.	Popova et al. (2020)
		Higher levels of BSFL fat reduced the omega-3 fatty acid content in the meat.	Kierończyk et al. (2023)

BSFL: Black Soldier Fly Larvae, TMR: Total Mixed Ration, Ca-soap: Calcium Soap, FCR: Feed Conversion Ratio, BSFLM: Black Soldier Fly Larvae Meal, PUFA: Polyunsaturated Fatty Acids, SFA: Saturated Fatty Acids, P/S: PUFA to SFA Ratio, n-6/n-3: Omega-6 to Omega-3 Ratio, and h/H: Hypo/Hypercholesterolemic Fatty Acids Ratio.

during the pre-weaning period had lower growth and feed conversion ratios compared to a control group after 28 days. This suggests there may be an age-dependent effect of BSFL inclusion. Conversely, van Heugten et al. (2022) found that BSFL oil supplementation (0%, 2%, 4%, or 6%) linearly improved pig body weight, daily gain, and FCR over 40 days.

Research suggests that BSFL inclusion can impact carcass traits and fat deposition in pigs. Chia et al. (2021) observed that pigs fed diets containing 50%, 75%, or 100% BSFL meal had greater fasted and carcass weights compared to those on control or 25% BSFL meal diets. Remarkably, pigs on the 100% BSFL diet had increased back fat depth at the 10th rib, indicating a potential influence of high BSFL inclusion levels on fat deposition. However, other carcass traits, such as dressing percentage and loin eye area, remained consistent across all BSFL inclusion levels.

Chia et al. (2021) reported that pigs fed BSFL meal had higher potassium levels in their spleen, liver, and loin muscle tissues compared to those on a control diet. Additionally, the study found increased iron and zinc concentrations in the loin muscle tissue of pigs fed a 100% BSFL meal diet. These findings suggest that BSFL could enhance the mineral content of pork products. The inclusion of BSFL in pig diets appears to influence the composition and function of the gut microbiome. Studies have shown positive changes in the intestinal microbiome of pigs fed BSFL after three weeks. However, research by Spranghers et al. (2018) demonstrated that BSF prepupae fat had an inhibitory effect on the growth of beneficial bacteria like lactobacilli and D-streptococci *in vitro* and a similar, but less pronounced, effect *in vivo*. These results suggest that BSFL can modulate the gut microbiome, which could have implications for pig health and nutrient digestion. Kar et al. (2021) found that pigs fed BSFL showed positive intestinal microbiome development compared to the control after 3 weeks.

While BSFL shows promise as a sustainable feed ingredient, some studies have indicated that

Table 4. Summary of Studies on the Impact of Black Soldier Fly Larvae on Pigs

Parameter	Summary of Results	References
Performance	Pigs fed 50, 75, and 100% BSFLM had significantly higher body weight gain as compared to the control group.	Chia et al. (2021)
	Pigs fed BSFL oil showed significantly higher final weight gain and ADG in all phases	Eickleberry et al. (2022)
	BSFL oil supplementation (0%, 2%, 4%, or 6%) linearly improved pig body weight, daily gain and FCR over 40 days.	van Heugten et al. (2022)
	Piglets fed 12.5% and 25.0% BSFL during the pre-weaning period had lower growth and FCR as compared to the control after 28 days.	Kawasaki et al. (2023)
Product Quality	Pigs fed diets with 50%, 75%, or 100% BSFL meal showed greater fasted carcass weights than the control.	Chia et al. (2021)
	A 100% BSFL diet increases back fat depth at the 10th rib compared to control	Chia et al. (2021)
	Pigs on BSFL meal diets had elevated potassium levels in the spleen, liver, and loin muscle tissues compared to the control.	Chia et al. (2021)
	Pigs fed a 100% BSFL meal diet showed increased iron and zinc concentrations in their loin muscle tissue.	Chia et al. (2021)
Health	Pigs fed BSF prepupae fat had a 0.5 log fold reduction of D-streptococci in their guts.	Spranghers et al. (2018)
	Pigs fed BSFL showed positive intestinal microbiome development compared to the control after 3 weeks.	Kar et al. (2021)

BSFLM: Black Soldier Fly Larvae Meal, BSFL: Black Soldier Fly Larvae, ADG: Average Daily Gain, FCR: Feed Conversion Ratio, and BSF: Black Soldier Fly.

BSFL oil can increase serum cholesterol levels in pigs (van Heugten et al., 2022; Kawasaki et al., 2023). The mechanism underlying this increase requires further investigation. Strategies to mitigate the potential rise in serum cholesterol levels associated with BSFL oil inclusion, such as dietary modifications or selective breeding of BSFL, warrant further research.

Rabbits

Research indicates that BSFL fat is a promising sustainable alternative to soybean oil in rabbit feed (Table 5). Replacing soybean oil with BSFL fat, even at 100%, does not negatively affect the growth performance of rabbits (Gasco et al., 2019a). Rabbits fed BSFL fat showed similar digestibility of dry matter, protein, ether extract, fibre fractions, and gross energy compared to control groups (Gasco et al., 2019a). This suggests that BSFL fat can be a suitable replacement for soybean oil in rabbit diets without compromising growth or nutrient utilization. However, some studies found slightly lower total tract apparent digestibility (TTAD) in rabbits fed BSFL fat compared to those fed linseed fat (Martins et al., 2018). This difference is likely due to variations in fatty acid composition.

Gasco et al. (2019b) found that rabbits fed BSFL fat have higher proportions of saturated fatty acids and lower proportions of polyunsaturated fatty acids in their meat compared to control groups. While this shift in fatty acid profile might raise concerns about the nutritional value of the meat, it's important to note that meat from rabbits fed BSFL fat was less prone to oxidation, indicating better preservation and shelf life (Gasco et al., 2019b). Despite changes in fatty acid composition, consumer acceptance of the meat remained unaffected (Gasco et al., 2019b). Replacing soybean oil with BSFL fat did not negatively affect gut morphometric indices or organ histopathology (Gasco et al., 2019a). Furthermore, BSFL fat supplementation increases the concentration of volatile fatty acids in the

Table 5. Summary of Studies on the Impact of Black Soldier Fly Larvae on Rabbits

Parameter	Summary of Results	References
Performance	Rabbits fed diets with 50% and 100% black soldier fly larvae (BSFL) fat instead of soybean oil for 42 days showed similar growth, health, and blood parameters.	Gasco et al. (2019a)
	Rabbits fed 50% and 100% BSFL fat for 42 days had similar nutrient digestibility (DM, protein, EE, fibre fractions, and gross energy) as the control.	Gasco et al. (2019a)
	Rabbits fed 30 g and 60 g/kg DM of BSFL fat for 5 weeks had slightly lower total tract apparent digestibility than those fed linseed.	Martins et al. (2018)
Product Quality	Rabbits fed 50% and 100% BSFL fat for 42 days had higher saturated fatty acids and lower polyunsaturated fatty acids compared to the control and mealworm groups.	Gasco et al. (2019b)
	Meat from rabbits fed 50% and 100% BSFL fat for 42 days was less prone to oxidation.	Gasco et al. (2019b)
	Rabbits fed 50% and 100% BSFL fat for 42 days had similar carcass traits, meat quality, and consumer acceptance compared to the control group.	Gasco et al. (2019b)
Health	Replacing soybean oil with 50% or 100% BSFL fat in the diet had no effect on gut morphometric indices or organ histopathology in growing rabbits after 42 days.	Gasco et al. (2019a)
	Supplementing rabbit diets with 1.5% BSFL fat for 41 days increased cecal volatile fatty acids compared to the control.	Dabbou et al. (2020)
	Dietary BSFL fat increased *Akkermansia* and *Ruminococcus* in the cecal microbiota of weaned rabbits after 41 days.	Dabbou et al. (2020)
	Rabbits fed 1.5% BSFL fat for 41 days had significantly lower *Yersinia enterocolitica* growth compared to the control and yellow mealworm groups.	Dabbou et al. (2020)

BSFL: Black Soldier Fly Larvae, DM: Dry Matter, EE: Ether Extract, and Yersinia enterocolitica is a type of bacteria.

cecum, which can benefit gut health and nutrient absorption (Dabbou et al., 2020). BSFL fat also changed the cecal microbiota composition, increasing the abundance of beneficial bacterial genera like *Akkermansia* and *Ruminococcus* (Dabbou et al., 2020). These findings suggest that BSFL fat may promote a favourable gut environment in rabbits. Research suggests that BSFL fat could also play a role in controlling pathogens in rabbits. Dabbou et al. (2020) found that rabbits fed BSFL fat had significantly lower *Yersinia enterocolitica* growth compared to control groups. However, there was no significant difference in *Salmonella* growth. Further research is needed to determine the specific mechanisms involved in the potential antimicrobial properties of BSFL fat and the range of pathogens that can be effectively controlled.

Fish

The growing interest in BSFL and its derivatives as sustainable alternatives to conventional fishmeal and fish oil in aquaculture is evident (Table 6). Some studies have shown that replacing fish meal with BSFL meal can support growth performance in certain fish species. For example, Nile tilapia fed with BSFL meal, even at 100% inclusion, showed no adverse effects on growth performance or feed utilization efficiency (Tippayadara et al., 2021). Similarly, juvenile golden pompano fed a diet with 25% BSFL meal exhibited increased feed intake without any negative impacts on growth or intestinal health (Yu et al., 2023). In African catfish, the inclusion of 50% BSFL meal did not significantly affect the feed conversion ratio, indicating efficient nutrient utilization from BSFL meal (Maranga et al., 2022). The authors note that the lack of statistical significance in this finding could be due to variations in experimental conditions or sample size. However, other studies suggest that high inclusion levels of BSFL meal (50% or more) can negatively impact growth in species like golden pompano (Yu et al., 2023). These findings highlight the importance of optimizing inclusion levels based on the specific requirements of the fish species being cultured.

BSFL oil inclusion can alter the digestibility of specific fatty acids. Gilthead seabream fed increasing levels of BSFL oil (up to 100%) showed similar overall lipid digestibility compared to the control group; however, the digestibility of saturated fatty acids (SFAs) increased, while that of unsaturated fatty acids decreased with increasing BSFL oil inclusion (Moutinho et al., 2023). Conversely, some studies report a decrease in polyunsaturated fatty acids (such as Oleic acid18:1n-9, Linoleic acid 18:2n-6, Eicosapentaenoic acid EPA 20:5n-3, and Docosahexaenoic acid DHA, 22:6n-3) with BSFL inclusion (Zhou et al., 2018). The fatty acid profile of BSFL differs from that of fish meal and fish oil, which can affect the fatty acid composition of fish tissues. BSFL oil is typically high in lauric acid, a medium-chain saturated fatty acid (Gadzama and Panuel, 2024a,b). Gilthead seabream fed BSFL oil showed a linear increase in lipase activity, which is responsible for the breakdown of dietary fats, potentially as an adaptation to the higher lauric acid content in the diet (Moutinho et al., 2023). In juvenile largemouth bass, dietary BSFL (up to 50%) increased the levels of DHA, EPA, and C22:5n-3 in the liver, indicating that BSFL can contribute to the accumulation of these essential fatty acids (You et al., 2024). While lower BSFL inclusion (25%) shows no adverse effects on gut health (Yu et al., 2023), higher levels (33 – 50% DM) can impair intestinal morphology in golden pompano (Yu et al., 2023) and largemouth bass (You et al., 2024). This suggests that the effects of BSFL on gut health are dose-dependent and that higher inclusion levels may have detrimental effects. BSFL inclusion can also induce oxidative stress in the gut, as indicated by increased malondialdehyde levels in juvenile largemouth bass (You et al., 2024). BSFL meal can enhance immune responses in fish, such as increased skin mucus lysozyme and peroxidase activities in Nile tilapia, contributing to innate immune defense (Tippayadara et al., 2021). Further research is needed to fully understand the long-term effects of BSFL inclusion on fish health, including gut health, immune function, and stress response.

Table 6. Summary of Studies on the Impact of Black Soldier Fly Larvae on Fish

Parameter	Summary of Results	References
Performance	Nile tilapia fed 0% to 100% BSFLM for 12 weeks had similar feed utilization efficiency, feed intake, and survival rates.	Tippayadara et al. (2021)
	Replacing 25% of fish meal with BSFLM increased feed intake and did not adversely affect the growth or intestinal health of juvenile golden pompano after 8 weeks	Yu et al. (2023)
	African Catfish fed 50% BSFLM at 5% and 3% BW for 4 months had similar FCR and survival rates compared to the control.	Maranga et al. (2023)
	Fish fed 50% BSFL meal for 8 weeks had reduced growth performance compared to the control.	Yu et al. (2023)
Product Quality	Gilthead seabream fed 0%, 42%, 84%, and 100% BSFL oil for 70 days had similar lipid digestibility, higher SFA digestibility, and reduced unsaturated fatty acid digestibility compared to the control.	Moutinho et al. (2023)
	Increasing BSFLM from 0% to 140 g/kg diet for 56 days significantly reduced polyunsaturated fatty acids in fish fillets.	Zhou et al. (2018)
	Lipase activity increased linearly in Gilthead seabream fed 0%, 42%, 84%, and 100% BSFL oil for 70 days.	Moutinho et al. (2023)
	Juvenile largemouth bass fed 16.67%, 33.33%, and 50% BSFL for 8 weeks increased liver levels of DHA, EPA, and DPA compared to the control.	You et al. (2024)
Health	Replacing 25% of fish meal with BSFLM did not adversely affect the intestinal health of juvenile golden pompano after 8 weeks.	Yu et al. (2023)
	Fish fed 50% BSFL meal for 8 weeks had impaired intestinal morphology compared to the control.	Yu et al. (2023)
	Fish fed 33.33% BSFL for 8 weeks had higher malondialdehyde levels in the foregut and liver than the control group.	You et al. (2024)
	Fish fed 10-100% BSFLM had improved skin mucus lysozyme and peroxidase activities than the control.	Tippayadara et al. (2021)

BSFLM: Black Soldier Fly Larvae Meal, BSFL: Black Soldier Fly Larvae, FCR: Feed Conversion Ratio, BW: Body Weight, SFA: Saturated Fatty Acids, DHA: Docosahexaenoic Acid, EPA: Eicosapentaenoic Acid, and DPA: Docosapentaenoic Acid.

Cattle

Protein supplementation is essential for enhancing the intake and digestion of low-quality forages in cattle (Köster et al., 1996). Recent research suggests that black soldier fly larvae can serve as an effective alternative protein supplement for cattle (Table 7), however, conflicting results were observed regarding the effects of BSFL on forage intake. Fukuda et al. (2022) reported a decrease in total dry matter intake (TDOMI) in steers supplemented with BSFL, while both Fukuda et al. (2022) and Carrasco et al. (2024) observed an increase in forage organic matter intake (FOMI) in steers fed BSFL. This discrepancy could be attributed to differences in the experimental design, BSFL processing methods, or other factors, which require further investigation. Black soldier fly larvae supplementation in beef steers generally led to increased energy intake but did not significantly affect digestibility or ruminal fermentation. Two studies by Fukuda et al. (2022) and Carrasco et al. (2024) found that steers fed BSFL had higher total gross energy intake compared to control groups. However, both studies also reported that BSFL supplementation did not significantly impact the digestibility of dry matter, organic matter, or neutral detergent fibre. Furthermore, Fukuda et al. (2022) observed that ruminal fermentation parameters, including ammonia-N, total volatile fatty acids, and pH, remained similar between steers fed BSFL and the control group. Carrasco et al. (2024) also specifically examined the effects of defatted BSFL and found no significant impact on ruminal ammonia-N, total volatile fatty acids, or pH. These findings suggest that BSFL supplementation, whether defatted or not, may not significantly alter the rumen environment in beef steers. In contrast, Jayanegara et al. (2017) reported lower ruminal ammonia concentration and reduced digestibility of dry matter and organic matter with BSFL meal compared to soybean meal diets.

Limited research is available on the effects of BSFL fat in dairy cows. Nekrasov et al. (2022) investigated the impact of BSFL fat supplementation on dairy cows and found that cows fed 10 g/head/day of BSFL fat produced slightly more milk than the control group. Moreover, cows fed 100 g/head/day of BSFL fat had increased serum lysozyme activity and bactericidal activity compared to the control. These results suggest that BSFL fat may have potential benefits for dairy cow health and milk production, but further research is needed to confirm these findings.

BSFL fat supplementation in dairy cows appears to have positive effects on milk composition and yield. Nekrasov et al. (2022) reported that milk from cows fed 100 g/head/day of BSFL

Table 7. Summary of Studies on the Impact of Black Soldier Fly Larvae on Cattle

Parameter	Summary of Results	References
Performance	Beef steers fed BSFL at 88 mg nitrogen per kilogram of body weight (N/kg BW) for 14 days had higher forage organic matter intake than the control.	Fukuda et al. (2022)
	Steers fed defatted BSFL had significantly higher forage organic matter intake (FOMI) compared to the control over 14 days.	Carrasco et al. (2024)
	BSFL intake significantly reduced TDOMI in beef steers (60.1 g/kg MBW) compared to the control (62.2 g/kg MBW).	Fukuda et al. (2022)
	Steers supplemented with BSFL had higher total gross energy and digestible energy intake compared to the control.	(Fukuda et al., 2022).
	Feeding beef steers defatted BSFL significantly increased total gross energy intake compared to the control over 14 days.	Carrasco et al. (2024)
	Steers supplemented with BSFL had similar digestibility of dry matter, organic matter, and neutral detergent fibre compared to the control.	Fukuda et al. (2022)
	Steers fed defatted BSFL had comparable dry matter digestibility, organic matter digestibility, and neutral detergent fibre digestibility after 14 days.	Carrasco et al. (2024)
	Cattle fed BSFL showed similar ruminal fermentation parameters, including ammonia-N, total volatile fatty acids, and pH, compared to the control.	Fukuda et al. (2022)
	Feeding beef steers defatted BSFL as protein supplements had no significant effects on ruminal ammonia-N, total VFA, or pH over 14 days.	Carrasco et al. (2024)
	Diets with BSF larvae meal reduced ruminal ammonia concentration and the digestibility of dry and organic matter compared to control.	Jayanegara et al. (2017)
	Dairy cows fed 10 g/head/day of BSFL fat produced slightly more milk than control.	Nekrasov et al. (2022)
Health	Cows fed 100 g/head/day of BSFL fat of BSFL fat showed increased serum lysozyme activity and bactericidal activity than control.	Nekrasov et al. (2022)
	Cows fed BSFL fat had comparable biochemical blood profiles.	Nekrasov et al. (2022)
Product Quality	Milk from cows fed 100 g/head/day of BSFL fat had a higher fat yield than the control.	Nekrasov et al. (2022)
	Milk fatty acid composition increased in dairy cows fed 10 g/head/day of BSFL fat.	Nekrasov et al. (2022)

BSFL: Black Soldier Fly Larvae, N/kg BW: Nitrogen per Kilogram of Body Weight, FOMI: Forage Organic Matter Intake, TDOMI: Total Digestible Organic Matter Intake, MBW: Metabolic Body Weight, VFA: Volatile Fatty Acids, and BSFLM: Black Soldier Fly Larvae Meal.

fat had a higher fat yield than the control group. Additionally, milk fatty acid composition increased in dairy cows fed 10 g/head/day of BSFL fat. These findings suggest that BSFL fat supplementation could be a viable strategy for enhancing the nutritional value of milk. Nekrasov et al. (2022) also reported that BSFL fat supplementation did not negatively impact the biochemical blood profiles of dairy cows. This suggests that BSFL fat is a safe and potentially beneficial feed ingredient for dairy cows.

While BSFL appears to be a viable protein supplement for beef cattle consuming low-quality forage, further research is needed to optimize its use and compare its efficacy to other insect-based supplements like mealworm larvae. Carrasco et al. (2024) suggested that mealworm larvae might be even more effective in promoting forage utilization in beef cattle. Nevertheless, both BSFL and mealworm larvae are considered viable protein supplements. Further research is essential to fully understand these effects and optimize the use of BSFL in cattle diets.

Sheep

The use of black soldier fly larvae in sheep nutrition is an emerging area of research with initial findings highlighting both potential benefits and challenges (Table 8). For instance, ewes fed 25% BSFL in their total mixed ration showed increased nutrient intake, but lower digestibility (Fernandez-Mora et al., 2024). However, replacing soybean meal with 5% BSFL didn't significantly impact ram performance metrics, such as weight gain, feed consumption, or feed conversion ratio (Rahman et al., 2021). BSFL inclusion appears to influence water intake and excretion. Ewes on a 25% BSFL diet exhibited higher water consumption and faecal excretion (Fernandez-Mora et al., 2024). In contrast, rams receiving 8% calcium soap derived from BSFL oil maintained consistent water intake (Sudarman et al., 2024).

Table 8. Summary of Studies on the Impact of Black Soldier Fly Larvae on Sheep

Parameter	Summary of Results	References
Performance	Ewes fed 25% BSFL in TMR had higher nutrient intakes than the control after 21 days.	Fernandez-Mora et al. (2024)
	Yearling Florida native ewes fed 25% BSFL in TMR had lower digestibility of nutrients.	Fernandez-Mora et al. (2024)
	Ewes fed BSFL in TMR had higher CP intake, lower CP digestibility, and increased EE.	Fernandez-Mora et al. (2024)
	Rams fed 5% BSFL as soybean meal replacement had comparable growth performance after 12 weeks.	Rahman et al. (2021)
	Ewes fed 25% BSFL had higher faeces excretion and water consumption.	Fernandez-Mora et al. (2024)
	Rams fed 8% calcium soap from black soldier fly larvae oil had similar water intake across treatments.	Sudarman et al. (2024)
Health	Male Garut sheep fed 8% Ca-soap from BSFL oil had lower morning respiration rates, with no significant effects on rectal temperature and heart rate over 9 weeks.	Sudarman et al. (2024)
	Rams fed 8% Ca-soap from BSFL oil had higher lymphocyte counts and lower N/L ratios, with other haematological parameters unaffected over 9 weeks.	Sudarman et al. (2024)
	Rams fed 5% BSFL and 2.5% BSFL + 10% bioconverted cocoa pod husk had similar haematological responses to the control after 12 weeks.	Rahman et al. (2021)

BSFL: Black Soldier Fly Larvae, TMR: Total Mixed Ration, CP: Crude Protein, EE: Ether Extract, Ca-soap: Calcium Soap, and N/L: Neutrophil/Lymphocyte ratio.

Preliminary evidence suggests potential benefits of BSFL on certain health parameters, including immune response and respiration rate. Sudarman et al. (2024) found that rams fed 8% calcium soap from BSFL oil had lower respiration rates in the morning compared to a control group, although their rectal temperature and heart rate remained unaffected. Additionally, these rams showed an increase in lymphocyte count and a decreased neutrophil/lymphocyte ratio, signifying potential immune modulation. However, feeding rams 5% BSFL, or a combination of 2.5% BSFL and 10% bioconverted cocoa pod husk did not significantly alter their red blood cell count, haemoglobin levels, or haematocrit compared to a control group (Rahman et al., 2021). These findings highlight the complex and varied effects of BSFL on sheep. Further research is needed to fully understand the optimal inclusion rates and potential long-term consequences of using BSFL in sheep diets.

Goats

Research into the response of goat production to dietary black soldier fly larvae (BSFL) is still in its early stages (Table 9). Studies consistently show that incorporating BSFL meal into milk replacers significantly increases dry matter intake, compared to traditional commercial milk replacers (Sepriadi et al., 2022; Sadeli et al., 2024). This increase in DMI is likely due to the enhanced palatability of BSFL meal, making it more appealing to young goats and encouraging higher consumption (Sepriadi et al., 2022). Despite the increased DMI, the average daily gain in goat kids fed BSFL meal remains comparable to those fed the control diet (Sepriadi et al., 2022; Sadeli et al., 2024). This suggests that the increased feed intake does not directly translate into enhanced growth performance. One possible explanation is the higher initial body weight in the control group and increased stress levels in the BSFL group (Sadeli et al., 2024). Importantly, studies indicate that BSFL meal is safe and well-tolerated by goat kids, with no adverse effects on their physiological responses when included in their milk replacer (Sepriadi et al., 2022; Sadeli et al., 2024). This supports the potential use of BSFL meal as a safe ingredient in goat diets. From an economic perspective, using BSFL-based milk replacer can lead to lower feed costs per gain in Peranakan Etawa goat kids, highlighting a potential economic advantage (Sadeli et al., 2024). In conclusion, while BSFL meal increases DMI, it does not necessarily translate to improved ADG. Further research is needed to understand the underlying reasons and to explore how to maximize the growth potential of goats fed BSFL. Additionally, investigating the potential impact on milk production in lactating goats would be beneficial.

Table 9. Summary of Studies on the Impact of Black Soldier Fly Larvae on Goats

Parameter	Summary of Results	References
Performance	Feeding BSFL meal in milk replacers significantly increased DMI in goat kids compared to the control.	Sepriadi et al. (2022)
	Two-week-old male Peranakan Etawa goat kids fed a BSFL flour milk replacer had similar body weight gain, ADG, and weaning weights as the control group.	Sadeli et al. (2024)
	Goat-fed BSFL meal in their milk replacer had similar ADG as the control group	Sepriadi et al. (2022)
Health	Feeding BSFL milk replacer did not negatively affect the physiological responses of goats.	Sadeli et al. (2024)
	Feeding a BSFL meal in a milk replacer had no adverse effects on the physiological responses of goat kids.	Sepriadi et al. (2022)
Economic Benefits	Peranakan Etawa goat kids fed BSFL-based milk replacers had lower feed costs per gain.	Sadeli et al. (2024)

BSFL: Black Soldier Fly Larvae, DMI: Dry Matter Intake, ADG: Average Daily Gain.

CONCLUSION

Black soldier fly larvae are a promising new feed resource to support future animal production needs. They are a highly nutritious and sustainable food source. Trials incorporating BSFL into the feed rations of many agriculturally significant animal species have shown improvements in productivity, health, product quality and potentially animal welfare.

REFERENCES

Al-Qazzaz, M. F. A., Ismail, D., Akit, H. & Idris, L. H. (2016). Effect of using insect larvae meal as a complete protein source on quality and productivity characteristics of laying hens. *Revista Brasileira de Zootecnia*, *45*, 518-523.

Attia, Y. A., Bovera, F., Asiry, K. A., Alqurashi, S. & Alrefaei, M. S. (2023). Fish and Black Soldier Fly Meals as Partial Replacements for Soybean Meal Can Affect Sustainability of Productive Performance, Blood Constituents, Gut Microbiota, and Nutrient Excretion of Broiler Chickens. *Animals*, *13*(17), 2759. https://doi.org/10.3390/ani13172759.

Barragan-Fonseca, K. B., Dicke, M. & van Loon, J. J. (2017). Nutritional value of the black soldier fly (*Hermetia illucens* L.) and its suitability as animal feed–a review. *Journal of Insects as Food and Feed, 3*(2), 105-120.

Bellezza Oddon, S., Biasato, I., Imarisio, A., Pipan, M., Dekleva, D., Colombino, E., Capucchio, M. T., Meneguz, M., Bergagna, S., Barbero, R., Gariglio, M., Dabbou, S., Fiorilla, E., Gasco, L. & Schiavone, A. (2021). Black Soldier Fly and Yellow Mealworm live larvae for broiler chickens: Effects on bird performance and health status. *Journal of Animal Physiology and Animal Nutrition*, *105*(Suppl 1), 10–18. https://doi.org/10.1111/jpn.13567.

Benzertiha, A., Kierończyk, B., Rawski, M., Mikołajczak, Z., Urbański, A., Nogowski, L. & Józefiak, D. (2020). Insect fat in animal nutrition–a review. *Annals of Animal Science*, *20*(4), 1217-1240. https://doi.org/10.2478/aoas-2020-0076.

Bongiorno, V., Gariglio, M., Zambotto, V., Cappone, E. E., Biasato, I., Renna, M., Forte, C., Coudron, C., Bergagna, S., Gai, F. & Schiavone, A. (2022). Black soldier fly larvae used for environmental enrichment purposes: Can they affect the growth, slaughter performance, and blood chemistry of medium-growing chickens?. *Frontiers in Veterinary Science*, *9*, 1064017. https://doi.org/10.3389/fvets.2022.1064017.

Campbell, M., Ortuño, J., Stratakos, A. C., Linton, M., Corcionivoschi, N., Elliott, T., Koidis, A. & Theodoridou, K. (2020). Impact of Thermal and High-Pressure Treatments on the Microbiological Quality and *In Vitro* Digestibility of Black Soldier Fly (*Hermetia illucens*) Larvae. *Animals*, *10*(4), 682. https://doi.org/10.3390/ani10040682.

Carrasco, M. N. & Drewery, M. L. (2024). Mealworm larvae and black soldier fly larvae as novel protein supplements for cattle consuming low-quality forage. *Translational Animal Science*, *8*, txae122. https://doi.org/10.1093/tas/txae122.

Chia, S. Y., Tanga, C. M., Osuga, I. M., Alaru, A. O., Mwangi, D. M., Githinji, M., Dubois, T., Ekesi, S., van Loon, J. J. A. & 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. https://doi.org/10.3920/JIFF2020.0072.

Chia, S. Y., Tanga, C. M., Osuga, I. M., Cheseto, X., Ekesi, S., Dicke, M. & van Loon, J. J. (2020). Nutritional composition of black soldier fly larvae feeding on agro-industrial by-products. *Entomologia Experimentalis et Applicata, 168*(6-7), 472-481. https://doi.org/10.1111/eea.12940.

Chu, X., Li, M., Wang, G., Wang, K., Shang, R., Wang, Z. & Li, L. (2020). Evaluation of the Low Inclusion of Full-Fatted *Hermetia illucens* Larvae Meal for Layer Chickens: Growth Performance, Nutrient Digestibility, and Gut Health. *Frontiers in Veterinary Science*, *7*, 585843. https://doi.org/10.3389/fvets.2020.585843.

Dabbou, S., Ferrocino, I., Gasco, L., Schiavone, A., Trocino, A., Xiccato, G., Barroeta, A. C., Maione, S., Soglia, D., Biasato, I., Cocolin, L., Gai, F. & Nucera, D. M. (2020). Antimicrobial Effects of Black Soldier Fly and Yellow Mealworm Fats and Their Impact on Gut Microbiota of Growing Rabbits. *Animals*, *10*(8), 1292. https://doi.org/10.3390/ani10081292.

Dörper, A., Veldkamp, T. & Dicke, M. (2021). Use of black soldier fly and house fly in feed to promote sustainable poultry production. *Journal of Insects as Food and Feed*, *7*(5), 761-780. https://doi.org/10.3920/JIFF2020.0023.

Dou, Z., Dierenfeld, E. S., Wang, X., Chen, X. & Shurson, G. C. (2024). A critical analysis of challenges and opportunities for upcycling food waste to animal feed to reduce climate and resource burdens. *Resources, Conservation and Recycling*, *203*, 107418.

Eickleberry, C., Koutsos, E., McComb, A. & van Heugten, E. (2022). PSV-2 Beneficial Impact of Black Soldier Fly (*Hermetia Illucens*) Larvae Oil on Growth Performance of Nursery Pigs. *Journal of Animal Science*, *100*(Suppl 2), 156–157. https://doi.org/10.1093/jas/skac064.266.

Food and Agriculture Organization of the United Nations. (2017). *The future of food and agriculture: Trends and challenges*. FAO.

Fernandez-Mora, B. M., NinoDeGuzman-Cerna, C., Salas-Solís, G. K., Arriola, K., Arce-Cordero, J. A. & Vyas, D. (2024). Inclusion of black soldier fly (*Hermetia illucens*) larvae frass as an alternative protein source in the diet of Florida native yearling ewes. *Journal of Animal Science*, *102*(Supplement_1), 86-87. https://doi.org/10.1093/jas/skae019.097.

Fukuda, E. P., Cox, J. R., Wickersham, T. A. & Drewery, M. L. (2022). Evaluation of Black Soldier Fly larvae (*Hermetia illucens*) as a protein supplement for beef steers consuming low-quality forage. *Translational animal science*, *6*(1), txac018. https://doi.org/10.1093/tas/txac018.

Gadzama, I. U. (2024). *Influence of rearing substrate on black soldier fly larvae nutritional value for animal feed*. *Wikifarmer*. Retrieved from https://www.researchgate.net/publication/383121796*Influence*of*Rearing*Substrate*on*Black*Soldier*Fly*Larvae*Nutritional*Valu*e*for*Animal*Feed*.

Gadzama, I. U., Malcolm, J. & Malcolm, C. (2024). Mineral composition in black soldier fly larvae: A promising alternative to fishmeal and soybean meal in livestock feed. In: *Proceedings of the 35th Biennial Conference of the Australian Association of Animal Sciences and the 20th Asian-Australasian Association of Animal Production Societies*, 35, 334-335. Retrieved from https://www.researchgate.net/publication/383122248_Mineral_composition_in_black_soldier_fly_larvae_A_promising_alternative_to_fishmeal_and_soybean_meal_in_livestock_feed.

Gadzama, I. U. & Panuel, P. (2024a). *Combatting antimicrobial resistance in livestock with BSFL antimicrobial peptides*. *Wikifarmer*. Retrieved from https://www.researchgate.net/publication/383948084_Combatting_Antimicrobial_Resistance_in_Livestock_with_BSFL_Antimicrobial_Peptides.

Gadzama, I. U. & Panuel, P. (2024b). *Black soldier fly larvae: A sustainable solution to antimicrobial resistance in livestock farming*. *Wikifarmer*. Retrieved from https://www.researchgate.net/publication/383877561_Black_Soldier_Fly_Larvae_A_Sustainable_Solution_to_Antimicrobial_Resistance_in_Livestock_Farming.

Gadzama, I. U., Malcolm, J. & Malcolm, C. (2023). Impact of drying methods on the nutritional composition of black soldier fly larvae as animal feed ingredient. In: *Recent Advances in Animal Nutrition - Australia (RAAN-A) Conference*, Gold Coast, Australia. Retrieved from https://www.researchgate.net/publication/374544950_Impact_of_drying_methods_on_the_nutritional_composition_of_black_soldier_fly_larvae_as_animal_feed_ingredient.

Gadzama, I. U. & Ndudim, R. K. (2019). Nutritional composition of housefly larvae meal: a sustainable protein source for animal production–a review. *Acta Scientific Agriculture*, *3*(4), 74-77. https://actascientific.com/ASAG/pdf/ASAG-03-0388.pdf.

Gasco, L., Dabbou, S., Trocino, A., Xiccato, G., Capucchio, M. T., Biasato, I., Dezzutto, D., Birolo, M., Meneguz, M., Schiavone, A. & Gai, F. (2019a). Effect of dietary supplementation with insect fats on growth performance, digestive efficiency and health of rabbits. *Journal of Animal Science and Biotechnology*, *10*, 4. https://doi.org/10.1186/s40104-018-0309-2.

Gasco, L., Dabbou, S., Gai, F., Brugiapaglia, A., Schiavone, A., Birolo, M., Xiccato, G. & Trocino, A. (2019b). Quality and Consumer Acceptance of Meat from Rabbits Fed Diets in Which Soybean Oil is Replaced with Black Soldier Fly and Yellow Mealworm Fats. *Animals*, *9*(9), 629. https://doi.org/10.3390/ani9090629.

Huang, C., Feng, W., Xiong, J., Wang, T., Wang, W., Wang, C. & Yang, F. (2019). Impact of drying method on the nutritional value of the edible insect protein from black soldier fly (*Hermetia illucens* L.) larvae: amino acid composition, nutritional value evaluation, in vitro digestibility, and thermal properties. *European Food Research and Technology*, *245*, 11-21.

Ipema, A. F., Bokkers, E. A. M., Gerrits, W. J. J., Kemp, B. & Bolhuis, J. E. (2020). Long-term access to live black soldier fly larvae (*Hermetia illucens*) stimulates activity and reduces the fearfulness of broilers, without affecting health. *Scientific Reports*, *10*(1), 17428. https://doi.org/10.1038/s41598-020-74514-x.

Jayanegara, A., Novandri, B., Yantina, N. & Ridla, M. (2017). Use of black soldier fly larvae (*Hermetia illucens*) to substitute soybean meal in ruminant diet: An *in vitro* rumen fermentation study. *Veterinary World*, *10*(12), 1439–1446. https://doi.org/10.14202/vetworld.2017.1439-1446.

Kar, S. K., Schokker, D., Harms, A. C., Kruijt, L., Smits, M. A. & Jansman, A. J. M. (2021). Local intestinal microbiota response and systemic effects of feeding black soldier fly larvae to replace soybean meal in growing pigs. *Scientific Reports*, *11*(1), 15088. https://doi.org/10.1038/s41598-021-94604-8.

Kawasaki, K., Zhao, J., Takao, N., Sato, M., Ban, T., Tamamaki, K., ... & Yano, K. (2023). Sustenance trial to analyze the effects of black soldier fly larvae meal on the reproductive efficiency of sows and the haematological properties of suckling and weaning piglets. *Animals*, *13*(21), 3410.

Kierończyk, B., Rawski, M., Mikołajczak, Z., Szymkowiak, P., Stuper-Szablewska, K. & Józefiak, D. (2023). Black soldier fly larva fat in broiler chicken diets affects breast meat quality. *Animals*, *13*(7), 1137. https://doi.org/10.3390/ani13071137.

Köster, H. H., Cochran, R. C., Titgemeyer, E. C., Vanzant, E. S., Abdelgadir, I. & St-Jean, G. (1996). Effect of increasing degradable intake protein on intake and digestion of low-quality, tallgrass-prairie forage by beef cows. *Journal of Animal Science*, *74*(10), 2473-2481.

Kozłowski, K., Ognik, K., Stępniowska, A., Juśkiewicz, J., Zduńczyk, Z., Kierończyk, B., Benzertiha, A., Józefiak, D. & Jankowski, J. (2021). Growth performance, immune status and intestinal fermentative processes of young turkeys fed diet with additive of full fat meals from *Tenebrio molitor* and *Hermetia illucens*. *Animal Feed Science and Technology*, *278*, 114994. https://doi.org/10.1016/j.anifeedsci.2021.114994.

Lei, X. J., Kim, T. H., Park, J. H. & Kim, I. H. (2019). Evaluation of Supplementation of Defatted Black Soldier Fly Larvae Meal in Beagle Dogs. *Annals of Animal Science*, *19*(3), 767-777. https://doi.org/10.2478/aoas-2019-0021.

Lu, S., Taethaisong, N., Meethip, W., Surakhunthod, J., Sinpru, B., Sroichak, T., ... & Paengkoum, P. (2022). Nutritional composition of black soldier fly larvae (*Hermetia illucens* L.) and its potential uses as alternative protein sources in animal diets: A review. *Insects*, *13*(9), 831.

Ma, T. T., Zhu, S. P., Chen, A. L., Zhong, Y. J., Fu, Z. Q., Deng, S., Huang, Y. H. & Fu, J. (2023). Effects of black soldier fly larvae meal on production performance, meat quality, antioxidant capacity and serum biochemical indices of squabs. *Journal of Insects as Food and Feed*, *10*(2), 1-13. https://dx.doi.org/10.1163/23524588-20230053.

Makkar, H. P., Tran, G., Heuzé, V. & Ankers, P. (2014). State-of-the-art on use of insects as animal feed. *Animal Feed Science and Technology*, *197*, 1-33.

Makokha, M. P., Muliro, P. S., Ngoda, P. N., Ghemoh, C. J., Xavier, C. & Tanga, C. M. (2023). Nutritional quality of meat from hen fed diet with full-fat black soldier fly (*Hermetia illucens*) larvae meal as a substitute to fish meal. *Journal of Functional Foods*, *101*;105430. https://doi.org/10.1016/j.jff.2023.105430.

Maranga, B., Kagali, R., Mbogo, K., Orina, P., Munguti, J. & Ogello, E. (2022). Growth Performance of African Catfish (*Clarias Gariepinus*) Fed on Diets Containing Black Soldier Fly (*Hermetia Illucens*) Larvae Under Aquaponic System. *Aquaculture Studies*, *23*(5). http://doi.org/10.4194/AQUAST910.

Martins, C., Cullere, M., Zotte, A. D., Cardoso, C., Alves, S. P., De Bessa, R. U. I. & Bengala Freire, J. P. (2018). Incorporation of two levels of black soldier fly (*Hermetia illucens* L.) larvae fat or extruded linseed in diets of growing rabbits: effects on growth performance and diet digestibility. *Czech Journal of Animal Science*, *63*(9), 356-362. https://doi.org/10.17221/22/2018-CJAS.

Moula, N., Scippo, M. L., Douny, C., Degand, G., Dawans, E., Cabaraux, J. F., Hornick, J. L., Medigo, R. C., Leroy, P., Francis, F. & Detilleux, J. (2018). Performances of local poultry breed fed black soldier fly larvae reared on horse manure. *Animal Nutrition*, *4*(1), 73–78. https://doi.org/10.1016/j.aninu.2017.10.002.

Moutinho, S., Oliva-Teles, A., Pulido-Rodríguez, L., Magalhães, R., Monroig, Ó., Parisi, G. & Peres, H. (2023). Black soldier fly larvae oil as an alternative lipid source in diets for gilthead seabream (*Sparus aurata*) juveniles. *Aquaculture*, *574*, 739705. https://doi.org/10.1016/j.aquaculture.2023.739705.

Mwaniki, Z., Neijat, M. & Kiarie, E. (2018). Egg production and quality responses of adding up to 7.5% defatted black soldier fly larvae meal in a corn–soybean meal diet fed to Shaver White Leghorns from wk 19 to 27 of age. *Poultry Science*, *97*(8), 2829-2835. https://doi.org/10.3382/ps/pey118.

Nekrasov, R. V., Ivanov, G. A., Chabaev, M. G., Zelenchenkova, A. A., Bogolyubova, N. V., Nikanova, D. A., Sermyagin, A. A., Bibikov, S. O. & Shapovalov, S. O. (2022). Effect of Black Soldier Fly (*Hermetia illucens* L.) Fat on Health and Productivity Performance of Dairy Cows. *Animals*, *12*(16), 2118. https://doi.org/10.3390/ani12162118.

Ognik, K., Kozłowski, K., Stępniowska, A., Listos, P., Józefiak, D., Zduńczyk, Z. & Jankowski, J. (2020). Antioxidant Status and Liver Function of Young Turkeys Receiving a Diet with Full-Fat Insect Meal from *Hermetia illucens*. *Animals*, *10*(8), 1339. https://doi.org/10.3390/ani10081339.

Patterson, P. H., Acar, N., Ferguson, A. D., Trimble, L. D., Sciubba, H. B. & Koutsos, E. A. (2021). The impact of dietary Black Soldier Fly larvae oil and meal on laying hen performance and egg quality. *Poultry Science*, *100*(8), 101272. https://doi.org/10.1016/j.psj.2021.101272.

Popova, T. L., Petkov, E. & Ignatova, M. (2020). Effect of black soldier fly (*Hermetia illucens*) meals on the meat quality in broilers. *Agricultural and Food Science*, *29*(3), 177-188. https://doi.org/10.23986/afsci.88098.

Rahman, R., Laconi, E. B., Jayanegara, A. & Astuti, D. A. (2021). Effect of dietary black soldier fly larvae (*Hermetia illucens*) and bioconversion product of cocoa pod husk on performance and haematological profile of sheep. In IOP Conference Series: *Materials Science and Engineering*, *1098*(6),062058. IOP Publishing. https://iopscience.iop.org/article/10.1088/1757-899X/1098/6/062058/pdf.

Sadeli, A., Hanafi, N. D. & Sepriadi, S. (2024). Performance and Physiological Responses of Pre-Weaning Peranakan Etawa Goats Fed Milk Replacer with BSF Maggot Flour. *Journal Agripet*, *24*(2), 156-161.

Schiavone, A., De Marco, M., Martínez, S., Dabbou, S., Renna, M., Madrid, J., ... & Gasco, L. (2017). Nutritional value of a partially defatted and a highly defatted black soldier fly larvae (Hermetia illucens L.)

meal for broiler chickens: apparent nutrient digestibility, apparent metabolizable energy and apparent ileal amino acid digestibility. *Journal of Animal Science and Biotechnology*, *8*, 1-9.

Schiavone, A., Dabbou, S., Petracci, M., Zampiga, M., Sirri, F., Biasato, I., Gai, F. & Gasco, L. (2019). Black oldier fly defatted meal as a dietary protein source for broiler chickens: effects on carcass traits, breast meat quality and safety. *Animal, 13*(10), 2397–2405. https://doi.org/10.1017/S1751731119000685.

Sepriadi, S., Hanafi, N. D. & Sadeli, A. (2022). The effect of milk replacer containing black soldier fly on pre-weaned Ettawa crossbreed goats on performance and physiological response. In *IOP Conference Series: Earth and Environmental Science*, *977*(1), 5. IOP Publishing. https://iopscience.iop.org/article/10.1088/1755-1315/977/1/012132.

Shu, M. K., Li, C. M., Furtado, W. E., Huang, Q., St-Hilaire, S. & Kenéz, Á. (2024). Antibacterial properties of oil extracts of black soldier fly larvae reared on bread waste. *Animal Production Science*, *64*(8), AN23394**.** https://www.publish.csiro.au/an/pdf/AN23394.

Shumo, M., Osuga, I. M., Khamis, F. M., Tanga, C. M., Fiaboe, K. K., Subramanian, S., ... & Borgemeister, C. (2019). The nutritive value of black soldier fly larvae reared on common organic waste streams in Kenya. *Scientific Reports*, *9*(1), 10110.

Silva, B. C. R., Paulino, M. T. F., da Silva, L. A. L., de Moura Andrade, J. M. & Marcato, S. M. (2024). Black soldier fly (*Hermetia illucens*) larvae meal improves quail growth performance. *Tropical Animal Health and Production*, *56*(2), 1-8. https://doi.org/10.1007/s11250-024-03899-y.

Raman, S. S., Stringer, L. C., Bruce, N. C. & Chong, C. S. (2022). Opportunities, challenges and solutions for black soldier fly larvae-based animal feed production. *Journal of Cleaner Production*, *373*, 133802. https://doi.org/10.1016/j.jclepro.2022.133802.

Spranghers, T., Michiels, J., Vrancx, J., Ovyn, A., Eeckhout, M., De Clercq, P. & De Smet, S. (2018). Gut antimicrobial effects and nutritional value of black soldier fly (*Hermetia illucens* L.) prepupae for weaned piglets. *Animal Feed Science and Technology*, *235*, 33-42. https://doi.org/10.1016/j.anifeedsci.2017.08.012.

Star, L., Arsiwalla, T., Molist, F., Leushuis, R., Dalim, M. & Paul, A. (2020). Gradual provision of live black soldier fly (*Hermetia illucens*) larvae to older laying hens: effect on production performance, egg quality, feather condition and behaviour. *Animals*, *10*(2), 216. https://doi.org/10.3390/ani10020216.

Sudarman, A., Kirana, K. C., Ningsih, R. H. C. & Fassah, D. M. (2024). Supplementation Effect of Black Soldier Fly (*Hermetia illucens*) Larvae Oil Calcium Soap on Physiological Responses and Hematology of Male Garut Sheep. In *IOP Conference Series: Earth and Environmental Science*, *1359*(1),012118. IOP Publishing. https://iopscience.iop.org/article/10.1088/1755-1315/1359/1/012118.

Tippayadara, N., Dawood, M. A. O., Krutmuang, P., Hoseinifar, S. H., Doan, H. V. & Paolucci, M. (2021). Replacement of Fish Meal by Black Soldier Fly (*Hermetia illucens*) Larvae Meal: Effects on Growth, Haematology, and Skin Mucus Immunity of Nile Tilapia, *Oreochromis niloticus*. *Animals*, *11*(1), 193. https://doi.org/10.3390/ani11010193.

van Heugten, E., Martinez, G., McComb, A. & Koutsos, L. (2022). Improvements in performance of nursery pigs provided with supplemental oil derived from Black Soldier Fly (*Hermetia illucens*) larvae. *Animals*, *12*(23), 3251.

Yan, Y., Zhang, J., Chen, X. & Wang, Z. (2023). Effects of Black Soldier Fly Larvae (*Hermetia illucens* Larvae) Meal on the Production Performance and Cecal Microbiota of Hens. *Veterinary Sciences*, *10*(5), 364. https://doi.org/10.3390/vetsci10050364.

You, C. H., Li, H. W., Zhou, M., Lin, L., Dong, Y. W., Tan, X. H. & Huang, Y. H. (2024). Replacing Different Proportions of Fishmeal with *Hermitia illucens* Meal on the Growth, Health and Muscle Quality of Micropterus Salmoides. *Acta Hydrobiologica Sinica*, *48*(3), 372-383. http://dx.doi.org/10.7541/2024.2023.0159.

Yu, Z., Sun, Z., Ou, B., Zhou, M., Huang, Y. & Tan, X. (2023). Effects of partial replacement of fish meal with black soldier fly (*Hermetia illucens*) larvae meal on growth performance, lipid metabolism and hepatointestinal health of juvenile golden pompano (*Trachinotus ovatus*). *Aquaculture Reports*, *33*, 101824. https://doi.org/10.1016/j.aqrep.2023.101824.

Zabulionė, A., Šalaševičienė, A., Makštutienė, N. & Šarkinas, A. (2023). Exploring the antimicrobial potential and stability of black soldier fly (*Hermetia illucens*) larvae fat for enhanced food shelf-life. *Gels*, 9(10), 793. https://doi.org/10.3390/gels9100793.

Zhou, J. S., Liu, S. S., Ji, H. & Yu, H. B. (2018). Effect of replacing dietary fish meal with black soldier fly larvae meal on growth and fatty acid composition of Jian carp (*Cyprinus carpio* var. Jian). *Aquaculture Nutrition*, *24*(1), 424-433. https://doi.org/10.1111/anu.12574.

Zozo, B., Wicht, M. M., Mshayisa, V. V. & van Wyk, J. (2022). The Nutritional Quality and Structural Analysis of Black Soldier Fly Larvae Flour before and after Defatting. *Insects*, *13*(2), 168. https://doi.org/10.3390/insects13020168.

Zulkifli, N. F. N. M., Seok-Kian, A. Y., Seng, L. L., Mustafa, S., Kim, Y. S. & Shapawi, R. (2022). Nutritional value of black soldier fly (*Hermetia illucens*) larvae processed by different methods. *PloS one*, *17*(2), e0263924.

Received: **November, 27, 2024**; *Approved*: **January, 10, 2025;** *Published:* **February, 2025**