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Review Article

Improving Poultry Production with Black Soldier Fly Larvae

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Abstract

Black soldier fly larvae (BSFL) are emerging as a promising alternative to traditional protein and fat sources in animal feed and pet food. Numerous studies have demonstrated the efficacy of BSFL meal as a partial or complete substitute for fishmeal and soybean meal in poultry diets, showing improvements in growth performance, feed efficiency, meat quality, and animal welfare. For laying hens, BSFL meal enhances egg production and quality and improves yolk fatty acid and amino acid profiles. These benefits are attributed to BSFL's rich protein content, balanced amino acid profile, essential fatty acids, and prebiotic properties. The nutritional composition of BSFL can be manipulated by varying their feed substrates, allowing customization to meet specific poultry species' needs and production goals. BSFL contain chitin, a prebiotic that supports a balanced gut microbiota, and lauric acid, a medium-chain fatty acid with antimicrobial properties, which can enhance gut health and potentially reduce antibiotic use in poultry production. Live BSFL can serve as environmental enrichment, promoting natural foraging behaviours and reducing stress-related behaviours. This enrichment improves leg health in broilers, enhances plumage status in layers and ducks, and reduces aggressive pecking in turkeys. The growing demand for BSFL in poultry feed has spurred commercial production efforts to provide sustainable and cost-effective protein sources. However, the optimal use of BSFL in poultry diets is still under investigation. This review aims to consolidate existing research on BSFL in poultry production, highlighting potential benefits and challenges. By identifying research gaps, this review provides valuable insights to guide future studies and support poultry farmers and researchers in optimizing BSFL use.

Keywords: Insect Protein; Black Soldier Fly Larvae; Poultry; Meat Quality; Eggs; Growth

Introduction

The increasing global demand for protein sources in animal feed has led to a search for sustainable and efficient alternatives. Traditional protein sources like soybean meal and fishmeal are becoming less viable due to their environmental impact and rising costs. This situation necessitates the exploration of alternative protein sources that are both sustainable and nutritionally adequate.

One promising solution is the use of black soldier fly larvae (BSFL) as an alternative feed ingredient. Black soldier fly larvae are highly nutritious, containing significant amounts of protein, fat, minerals, vitamins, and essential amino acids. Their nutrient composition, however, can vary significantly based on factors such as the type of organic waste used as feed, rearing conditions, and

processing methods [1-3]. This variability can pose challenges in ensuring a consistent and adequate nutritional profile for different animal species.

Nutritional composition of black soldier fly larvae

BSFL are an excellent source of protein, with crude protein levels ranging from 18% to 65.5% dry matter (DM), surpassing many conventional protein sources (Table 1) [1-6]. This wide range is influenced by the substrate the larvae are raised on and the stage at which they are harvested. BSFL protein is particularly rich in lysine, an essential amino acid often limiting in plant-based diets but may be deficient in methionine and cystine (Table 4).

Table 1: Chemical composition of black soldier fly larvae.

Parameter	Amount	Unit
Crude Protein	18-65.5	% DM
Fat	4.6-57	% DM
Ash	2.7-33	% DM
Gross Energy	8.7-24.1	MJ/kg DM

Adapted from Makkar., *et al*. [4], Barragan-Fonseca., *et al*. [7], Liu., *et al*. [8], Shumo., *et al*. [9], Alfiko., *et al*. [5], Zulkifli., *et al*. [1], Li., *et al*. [10], Loho., *et al*. [11], Gadzama., *et al*. [2], Macwan., *et al*. [12], and Lo., *et al*. [6].

The fat content of BSFL ranges from 4.6% to 57% DM (Table 1), with the fatty acid composition being manipulable through dietary adjustments [6,10]. BSFL are rich in lauric acid, a medium-chain saturated fatty acid known for its antimicrobial properties, which can make up as much as 51.8% of total fatty acids (Table 5). However, their ability to accumulate polyunsaturated fatty acids (PUFAs) from their diet is limited [10].

Black soldier fly larvae also contain significant amounts of essential minerals such as calcium, phosphorus, potassium, magnesium, and trace elements like iron, zinc, and copper (Table 2) [1,3]. They are a source of B vitamins, specifically thiamine and riboflavin, and vitamin C (Table 3), which are essential for various metabolic processes in animals [1].

Table 2: Mineral content of black soldier fly larvae.

Parameter	Amount	Unit
Ca	0.24-9.77	% DM
P	0.4-15	% DM
K	0.13-6.9	% DM
Na	0.06-1.3	% DM
Mg	0.18-3.9	% DM
Fe	300.75-689.24	mg/kg DM
Mn	134.93-246	mg/kg DM
Zn	108-1210	mg/kg DM
Cu	6.0-29.1	mg/kg DM

Adapted from Makkar., *et al*. [4], Barragan-Fonseca., *et al*. [7], Liu., *et al*. [8], Shumo., *et al*. [9], Alfiko., *et al*. [50], Zulkifli., *et al*. [1], Loho., *et al*. [11], Gadzama., *et al*. [3], Macwan., *et al*. [12], and Lo., *et al*. [6].

BSFL provide a good source of essential amino acids, including lysine, methionine, and threonine, which are often limiting in plant-based diets for poultry (Table 4). The amino acid profile of BSFL is comparable to that of fishmeal, containing all essential amino acids [13]. They are particularly high in glutamic acid and aspartic acid (Table 4).

Effects of black soldier fly larvae on broiler growth performance

Recent studies have shown varying effects of black soldier fly larvae on broiler chicken growth (Table 6). Some studies report improved growth performance with BSFL inclusion in broiler diets, while others find no significant impact on growth parameters. Additionally, certain studies indicate potential negative effects at higher inclusion levels. This variability may be attributed to factors such as BSFL processing methods, nutritional composition, inclusion levels, broiler breed, basal diet, experimental duration, and management practices. For instance, Lestari and Hanim [23] found that a 2:1 ratio of saponified BSFL oil to crude palm oil increased body weight and average daily gain in broilers over 35 days. This improvement may be due to the high lauric acid content of BSFL oil, which has antimicrobial properties that potentially enhance gut health and nutrient absorption. Similarly, Setiawan., *et al*. [24]

Table 3: The vitamin content of black soldier fly larvae.

Parameter	Amount	Unit
Vitamin B_1 (Thiamine)	1.98-2.00	mg/100g
Vitamin B_2 (Riboflavin)	5.00-24.74	mg/100g
Vitamin C (Ascorbic Acid)	0.19-0.37	mg/100g

Adapted from Zulkifli., *et al.* [1].

Table 4: Amino acid composition of black soldier fly larvae (% DM).

Parameter	Amount
Alanine	3.0-7.8
Arginine	1.80-6.8
Aspartic acid	3.30-11.8
Cystine	0.1-1.3
Glutamic acid	4.59-14.2
Histidine	1.5-3.7
Isoleucine	1.69-5.1
Leucine	2.67-8.2
Lysine	2.1-7.4
Methionine	0.54-2.5
Phenylalanine	1.35-5.4
Proline	2.2-6.6
Serine	1.55-4.4
Threonine	1.42-4.7
Tryptophan	0.5-1.4
Tyrosine	1.71-6.9
Valine	2.2-3.18

Adapted from Tschirner and Simon [14], Liland., *et al.* [15], Barragan-Fonseca., *et al.* [7], DiGiacomo and Leury [16], Abd El-Hack., *et al.* [13], and Zulkifli., *et al.* [1].

reported that adding 100 g/kg or 150 g/kg of BSFL to Jawa Super chickens for 15 days increased their body weight. In contrast, El-lawidana., *et al.* [25] found that feeding broiler chickens diets with 2.5-10% BSFL full-fat meal or 2.5-10% BSFL defatted meal did not significantly affect body weight gain or feed conversion ratio compared to the control group. Similarly, El-Gendy., *et al.* [26] reported that including 6%, 12%, and 15% defatted BSFL meal in Cobb 500 broiler diets for 35 days did not significantly alter live weight. These findings suggest that BSFL, at certain inclusion levels and processing methods, may not provide additional growth benefits beyond conventional feed ingredients.

Table 5: Fatty acid content in black soldier fly larvae (% of total fatty acids).

Fatty Acid Category	Fatty Acid	Amount
Saturated Fatty Acids	Lauric (12:0)	11.9-51.8
	Myristic (14:0)	2.1-15.2
	Palmitic (16:0)	3.54-31.1
	Stearic (18:0)	0.45-5.7
Monounsaturated Fatty Acids	Palmitoleic (16:1n-7)	1.05-14.0
	Oleic (18:1n-9)	2.71-35.7
Polyunsaturated Fatty Acids	Linoleic (18:2n-6)	1.73-26.1
	Linolenic (18:3n-3)	0.08-23.2
	Eicosapentaenoic (20:5n-3)	0.03-5.6
	Docosahexaenoic (22:6n-3)	0.006-7.1

Adapted from St-Hilaire., *et al.* [17], Makkar., *et al.* [4], Oonincx., *et al.* [18], Liland., *et al.* [15], Starcevic., *et al.* [19], Ognik., *et al.* [20], Ewald., *et al.* [21], Sypniewski., *et al.* [22], Zulkifli., *et al.* [1], Alfiko., *et al.* [5], Li., *et al.* [10], Loho., *et al.* [11], and Lo., *et al.* [6].

La Mantia., *et al.* [27] found that feeding 100% BSFL meal to broilers led to significantly lower live weight and carcass weight compared to the control group and the 50% BSFL meal group. This could be attributed to potential anti-nutritional factors (such as chitin), or palatability issues associated with high levels of BSFL in the diet. Raju., *et al.* [28] also reported that feeding 7.5% and 10.0% BSFL to broiler chickens reduced body weight gain and feed intake during the first three weeks (Table 6). This suggests that there may be an optimal range for BSFL inclusion in broiler diets, beyond which growth performance may be compromised. Several factors could contribute to the inconsistent findings regarding the effects of BSFL on broiler growth. As evident from the studies discussed, the amount of BSFL included in the diet seems to play a crucial role. Lower inclusion levels (around 5-10%) may not significantly impact growth, while higher levels may lead to reduced growth due to potential anti-nutritional factors or palatability issues. The way BSFL is processed (e.g., full-fat meal, defatted meal, oil, etc.) can influence its nutritional composition and digestibility, ultimately affecting its impact on broiler growth. Different broiler breeds may also have varying nutritional requirements and digestive capacities, potentially leading to different responses to BSFL inclusion in their diets.

Table 6: Studies on the effects of black soldier fly larvae on broiler chicken growth performance.

Summary of results	References
10% BSFL full-fat meal increased feed intake (FI) but did not significantly affect body weight gain (BWG) or feed conversion ratio (FCR).	[25]
2.5-10% BSFL full-fat or de-fatted meal did not significantly affect BWG or FCR.	[25]
6%, 12%, and 15% defatted BSFL meal showed no significant differences in live weight.	[26]
15% BSFL meal did not significantly affect growth performance parameters.	[29]
2.5% and 5.0% BSFL increased BWG and FI; 2.5% increased FCR during weeks 0-3.	[28]
7.5% and 10.0% BSFL reduced BWG and FI during the first 3 weeks.	[28]
100g/kg or 150g/kg BSFL increased body weight.	[30]
5% and 10% live BSFL reduced FCR compared to a conventional diet.	[31]
5% and 10% BSFL meal and oil mix reduced FCR compared to the control.	[31]
50g/kg BSFL increased BWG after 35 days compared to the control.	[32]
12% full-fat BSFLM increased average daily gain (ADG) during the starter phase.	[33]
16% full-fat BSFLM decreased ADG across all phases.	[33]
15% BSFL increased body weight (BW) and BWG over 70 days compared to the control.	[34]
5% BSFL (dehydrated or live) increased final body weights and ADG by approximately 4%.	[35]
7.5% and 15% BSFL in finisher diets reduced BW, ADG, and FI but did not affect FCR.	[36]
12% BSFL improved live weight, ADG, and FCR over 35 days.	[37]

The duration of the experimental studies is another important factor. Short-term studies may not fully capture the long-term effects of BSFL on broiler growth, highlighting the need for longer-term studies to assess the sustainability of using BSFL as a feed ingredient. Further research is necessary to determine the optimal use of BSFL in broiler diets and to compare the effects of different BSFL processing methods on broiler growth performance, health, meat quality, and overall productivity.

Impact of BSFL on broiler carcass traits and meat quality

The influence of black soldier fly larvae on broiler chicken carcass traits and meat quality varies across studies, with some highlighting positive impacts, while others suggest no significant effects or potential drawbacks (Table 7). Regarding carcass weight, La Mantia., *et al*. [27] found that a diet of 100% BSFL meal resulted in significantly lower carcass weight compared to both the control group and a diet of 50% BSFL meal. This reduction may be due to anti-nutritional factors or palatability issues at high inclusion levels. However, Permana., *et al*. [36] observed that adding 7.5% and 15% BSFL to a finisher diet for 14 days did not significantly impact carcass weight compared to a commercial diet, suggesting that moderate BSFL inclusion levels may not negatively influence carcass weight. Conflicting results emerge regarding dressing percentage. El-Gendy., *et al*. [26] reported a significant decrease in dressing percentage when feeding 12% and 15% defatted BSFL meal to Cobb 500 broilers, while Permana., *et al*. [36] did not find any significant effect on dressing percentage when including 7.5% and 15% BSFL in finisher diets.

Research on the impact of BSFL on the yield of specific carcass cuts provides a varied picture (Table 7). Ellawidana., *et al*. [25] observed an improvement in breast weight, as well as thigh, back, neck, and heart weights, when feeding broilers a 5% BSFL full-fat meal diet. This finding contrasts with Baderuddin., *et al*. [38], who found a lower percentage of breast meat in broilers fed a 12% BSFLM diet for 28 days. These contrasting results could be due to differences in BSFL inclusion levels, processing methods (full-fat vs. defatted), or the duration of the study. The impact of BSFL on abdominal fat deposition in broilers appears to be negative. Raju., *et al*. [28] reported a significant increase in abdominal fat in broilers fed 5%, 7.5%, and 10% BSFL for six weeks compared to the control group (Table 7). This increase could be related to changes in lipid metabolism or hormonal profiles induced by BSFL consumption.

Studies show inconsistent findings on the effects of BSFL on broiler meat colour. Ellawidana., *et al*. [25] found no significant impact on meat colour with 2.5-10% inclusion of BSFL full-fat or defatted meal. Conversely, Sajjad., *et al*. [37] reported higher lightness (L*) and yellowness (b*) values in breast meat from broilers fed a 12% BSFL diet. The effects of BSFL on meat pH are also mixed. Some studies found no significant changes, while La Mantia., *et al*. [27] observed a lower ultimate pH in breast meat from quails fed BSFL. Lower pH can enhance shelf life and limit microbial growth, but excessively low pH might lead to undesirable meat qualities like pale, soft, and exudative (PSE) meat.

Several studies indicate a significant impact of BSFL on the fatty acid profile of broiler meat (Table 7). Both La Mantia., *et al*. [27] and Yalçin., *et al*. [39] reported increased saturated fatty acids (SFA) and decreased polyunsaturated fatty acids (PUFA) in thigh and breast meat from broilers fed BSFL diets. This shift in fatty acid composition is likely due to the high SFA content in BSFL, particularly lauric acid (Table 5). While this may raise concerns regarding the health implications of increased SFA intake, further research is needed to determine the specific types and ratios of SFA in BSFL and their potential effects on human health. Limited but promising data exists on the sensory aspects of broiler meat from birds fed BSFL. Ellawidana., *et al*. [25] found that a 5% BSFL full-fat meal diet resulted in higher scores for aroma, colour, flavour, and overall acceptability in sensory evaluations compared to the control. Yalçin., *et al*. [39] also reported no significant differences in consumer sensory scores for appearance, juiciness, flavour, texture, or overall liking when feeding broilers 5% dried BSFL meal. These findings suggest that incorporating BSFL into broiler diets, at least at moderate levels, may not negatively affect, or even potentially enhance, the sensory attributes of the meat.

The amount of BSFL in the diet seems to be a key factor influencing the results (Table 7). Higher inclusion levels may lead to more pronounced changes in carcass traits and meat quality, not always in a positive direction. Different BSFL processing methods (full-fat meal, defatted meal, oil) could affect the bioavailability of nutrients and the presence of anti-nutritional factors, leading to varied effects on carcass traits and meat quality. Additionally, different broiler breeds may respond differently to BSFL inclusion due to variations in their digestive physiology and nutritional requirements. To fully utilize BSFL in broiler production, further research should investigate the long-term effects of BSFL on broiler meat quality, with particular attention to factors such as shelf life, oxidative stability, and consumer acceptance. Additionally, it is crucial to consider the potential health implications of altered fatty acid composition in meat from BSFL-fed broilers, especially the specific types and ratios of SFA.

Table 7: Studies on the effects of black soldier fly larvae on broiler chicken carcass traits and meat quality.

Summary of results	References
100% BSFL significantly reduced carcass weight compared to control.	[27]
5% BSFL full-fat meal improved breast, thigh, back, neck, and heart weights.	[25]
5% BSFL (dehydrated or live) did not significantly affect slaughtering performance.	[35]
5%, 7.5%, 10% BSFL did not significantly affect dressing yield or relative weights of breast/liver.	[28]
12% and 15% defatted BSFL meal decreased dressing percentage.	[26]
12% and 15% defatted BSFL meal decreased breast weight (with bone).	[26]
5%, 7.5%, and 10% BSFL increased abdominal fat deposition.	[28]
2.5–10% BSFL full-fat or defatted meal did not significantly impact meat colour and pH.	[25]
12% BSFL diet increased lightness (L*) and yellowness (b*) values of breast meat.	[37]
5% dried BSFL meal decreased thawing loss but increased cooking loss.	[39]
12% and 15% defatted BSFL meal decreased meat tenderness compared to control.	[26]
12% defatted BSFL meal decreased malondialdehyde content in breast meat.	[26]
50% and 100% BSFL diets increased SFA in thigh and breast meat.	[27]
50% and 100% BSFL diets decreased PUFA, total omega-6, and omega-3 FAs in thigh meat.	[27]
50% and 100% BSFL diets decreased PUFA, total omega-6, and omega-3 in breast meat.	[27]

Impact of black soldier fly larvae on growth performance and egg production in layer chickens

Table 8 provides insights into how incorporating black soldier fly larvae in various forms and inclusion levels affects layer chickens across different life stages. Several studies observed no significant impact of BSFL on layer chicken growth and body weight. For instance, Facey., *et al*. [40] found that feeding 6.5% or 13% defatted BSFL meal (BSFLM) to Lohmann Brown-Lite hens for 20 weeks did not affect their body weight. Similarly, Cattaneo., *et al*. [41] reported that feeding 15% or 30% live BSFL to laying hens for 126 days did not influence their overall live weight. This suggests that, at these inclusion levels and with these specific BSFL forms, layer chickens can maintain healthy growth trajectories comparable to those fed conventional diets. However, some studies suggest a possible negative effect of BSFL, particularly at higher inclusion levels.

Facey., *et al*. [40] observed reduced feed intake and body weight in hens fed 13% defatted BSFLM compared to the control group. Similarly, Oddon., *et al*. [42] reported that Bianca di Saluzzo hens fed 6% live BSFL had higher body weight compared to the control group, while there was no difference in body weight between Bionda Piemontese hens fed 6% live BSFL and the control group. These findings suggest that there might be a threshold for BSFL inclusion, beyond which the nutritional balance or palatability of the diet might be compromised, potentially affecting feed intake and subsequent growth. In contrast, other research suggests that BSFL may positively influence growth, particularly in specific situations. Ahmad., *et al*. [34] found that feeding 15% BSFL to village chickens for 70 days resulted in significantly higher body weight and body weight gain compared to the control group. The reasons for these positive effects are not fully understood, but they could be related to the specific nutritional composition of BSFL, including its protein content, amino acid profile, and potential bioactive compounds, which might promote growth in certain chicken breeds or under specific environmental conditions.

Studies present a mixed picture of how BSFL affects the laying rate in hens (Table 8). Yi., *et al*. [43] reported an increased laying rate in hens fed a diet with 10% full-fat BSFL meal. Furthermore, Wang., *et al*. [44] observed a significant increase in laying rate after three weeks in Jinghong laying hens fed 50 g/kg, 100 g/kg, and 150 g/kg of BSFL after forced molting. These positive effects could be attributed to the nutritional value of BSFL, potentially providing essential nutrients that support egg production. However, other studies like Veldkamp., *et al*. [45], who fed 5% or 10% BSFL meal to Brown Nick laying hens, found no significant effect on laying rate. These varying results indicate that the impact of BSFL on laying rate may depend on factors like the inclusion level, BSFL processing method, hen breed, and physiological state. The impact of BSFL on egg weight also appears to be inconsistent across studies. Khan., *et al*. [46] found that feeding 21% BSFL to laying hens decreased average egg weight during weeks 48 to 52 of the trial. However, they also noted no significant difference in average egg weight between treatments during weeks 52 to 56. In contrast, Khan., *et al*. [47] observed a slight increase in average egg weight in Lohmann laying hens fed 9% BSFL meal with or without BSFL oil for eight weeks. These discrepancies highlight the complexity of the relationship between BSFL and egg weight, potentially influenced by factors like the duration of BSFL inclusion, the specific composition of the BSFL product, and the age of the hens.

Research provides interesting insights into how BSFL might influence specific egg quality parameters (Table 8). Cattaneo., *et al*. [41] reported that feeding 15% or 30% live BSFL to laying hens for 126 days did not affect the physical attributes of the whole egg, egg yolk weight, Haugh unit, egg surface, yolk colour, eggshell quality characteristics, or chemical composition of the yolk and albumen. This suggests that, at these inclusion levels, BSFL might not compromise these critical quality parameters. Several studies highlight BSFL's potential to alter the fatty acid composition of eggs. Cattaneo., *et al*. [41] observed higher levels of saturated fatty acids (SFAs), particularly lauric acid (C12:0) and myristic acid (C14:0), and polyunsaturated fatty acids (PUFAs), like linoleic acid (C18:2n6) and α-linolenic acid (C18:3n3), in egg yolks from hens fed live BSFL. These changes reflect the fatty acid profile of BSFL itself, potentially leading to nutritional implications for consumers. Similarly, Dalle Zotte., *et al*. [48] reported increased SFAs and decreased PUFAs in eggs from quails fed diets containing 10% and 15% defatted BSFLM. These findings underscore the importance of understanding the specific fatty acid composition of BSFL products and their potential impact on egg quality and consumer health.

Beyond growth and egg performance, some studies explore the impact of BSFL on other aspects of layer chicken health and well-being. Oddon., *et al*. [42] found that Bionda Piemontese hens fed 6% live BSFL had better total integument scores, suggesting improved plumage status. Both Bionda Piemontese and Bianca di Saluzzo hens fed live BSFL showed higher preening frequency and lower severe feather pecking incidence. These findings indicate

that BSFL, particularly in live form, might positively contribute to layer hen welfare. Oddon., *et al*. [42] also observed that hens fed live BSFL spent more time walking compared to the control groups. This increased activity level might be linked to the foraging behaviour stimulated by the presence of live BSFL in the environment. Research suggests that BSFL might influence the gut microbiota composition of chickens.

Effects of black soldier fly larvae on layer chicken egg quality parameters

The impact of black soldier fly larvae on egg quality parameters in layer chickens is presented in Table 9. Some studies show no impact on certain parameters, while others suggest improvements or negative consequences, often depending on the form of BSFL and the inclusion level. For instance, Cattaneo., *et al*. [41] found no significant difference in eggshell quality characteristics when feeding laying hens 15% or 30% live BSFL for 126 days. Similarly, Cattaneo., *et al*. [51] observed no significant effect on eggshell thickness in Lohmann Brown hens fed 15% or 30% live BSFL over 14 weeks, although they did note a higher eggshell breaking strength in the 30% BSFL group at week 34. Conversely, Anas., *et al*. [52] observed a positive impact on eggshell quality when feeding laying hens 2% black soldier fly larvae oil calcium salt (BSFLO-SCa) for 8 weeks, reporting increased eggshell weight and thickness. The calcium salt form of BSFL oil might be particularly beneficial for enhancing calcium deposition in the eggshell, leading to improved strength and thickness.

Regarding albumen quality, Cattaneo., *et al*. [41] observed no significant changes in the chemical composition of the egg albumen when feeding laying hens 15% or 30% live BSFL for 126 days. In contrast, Anas., *et al*. [52] found that feeding 2% BSFL oil calcium salt (BSFLO-SCa) to laying hens for 8 weeks led to increased egg albumen weight, height, and ratio. This suggests that BSFL oil, particularly in a calcium salt form, might enhance protein synthesis or deposition in the albumen, leading to larger and potentially more nutritious albumen. Several studies have reported conflicting information regarding the effects of BSFL on yolk colour. Cattaneo., *et al*. [41] found no significant difference in yolk colour when feeding laying hens 15% or 30% live BSFL for 126 days. However, Dörper., *et al*. [50] observed darker yolk colours in laying hens fed either high inclusion of live larvae or low or high inclusion of BSFL meal and oil compared to a control group. Anas., *et al*. [52] found that feeding 2% black soldier fly larvae oil calcium salt (BSFLO-SCa) to laying hens for 8 weeks increased yolk lightness (L*) and yellowness (b*), but decreased yolk redness (a*). These variations might be attributed to differences in BSFL forms, inclusion levels, the presence of pigments like carotenoids in BSFL, and their transfer to the yolk.

Table 8: Studies on the effects of black soldier fly larvae on layer chicken growth and egg performance.

Summary of results	References
15% or 30% of live BSFL did not affect live weight in laying hens over 126 days.	[41]
13% defatted BSFLM reduced body weight in Lohmann Brown-Lite hens over 20 weeks.	[40]
15% BSFL increased body weight in village chickens over 70 days.	[34]
13% defatted BSFLM reduced feed intake in Lohmann Brown-Lite hens over 20 weeks.	[40]
10% or 20% of live BSFL did not affect feed intake in Bovans White hens over 12 weeks.	[49]
5% or 10% BSFL reduced feed intake in Brown Nick hens, improving FCR.	[45]
5% or 10% live BSFL reduced total dry matter intake by 6.5% in Brown Nick hens.	[50]
BSFL meal and oil mimicking 5% or 10% live larvae reduced total dry matter intake by 6.5%.	[50]
6% live BSFL reduced daily feed intake in Bionda Piemontese hens over 90 days.	[42]
6% live BSFL did not affect daily feed intake in Bianca di Saluzzo hens compared to controls.	[42]
9% and 18% BSFL meal, with or without BSFL oil, reduced feed consumption in Lohmann hens over 8 weeks.	[47]
6.5% or 13% defatted BSFLM resulted in similar FCR across all treatment groups.	[40]
BSFL products reduced FCR per dozen eggs by 4.7%.	[50]
10% full-fat BSFLM increased laying rate over 35 days.	[43]
50 g/kg, 100 g/kg, and 150 g/kg BSFL increased laying rate post-molting, with 100g/kg showing higher rates on days 36-42.	[44]
7%, 14%, and 21% BSFL linearly increased laying rate over 8 weeks.	[46]
18% BSFL meal without BSFL oil reduced laying rate over 8 weeks.	[47]
21% BSFL decreased average egg weight by 0.93 g during weeks 48-52, with no significant difference during weeks 52-56.	[46]
9% BSFL meal, with or without BSFL oil, slightly increased average egg weight over 8 weeks.	[47]
18% BSFL meal with BSFL oil significantly reduced average egg weight over 8 weeks.	[47]
BSFL meal and oil reduced egg weight during the last two weeks of the experiment.	[50]

Several studies show that BSFL can alter the fatty acid composition of egg yolks (Table 9). Cattaneo., *et al*. [41] reported higher levels of saturated fatty acids (SFAs), particularly lauric acid (C12:0) and myristic acid (C14:0), in egg yolks from hens fed live BSFL. Similarly, Dalle Zotte., *et al*. [48] found increased SFAs in eggs from quails fed diets containing 10% and 15% defatted BSFLM. The increase in SFAs might be directly related to the high lauric acid content in BSFL, which is transferred to the yolk. Furthermore, Cattaneo., *et al*. [41,51] observed higher polyunsaturated fatty acid (PUFA) levels, including linoleic acid (C18:2n6) and α-linolenic acid (C18:3n3), in egg yolks from hens fed live BSFL. This increase may be due to the fatty acid profile of the BSFL itself or to changes in the hen's metabolism that affect fatty acid synthesis and deposition in the yolk. Conversely, Cattaneo., *et al*. [41,51] found lower levels of monounsaturated fatty acids (MUFAs), mainly oleic acid (C18:1n9), in yolks from hens fed live BSFL. This decrease might be a compensatory mechanism in response to the increased SFAs and PUFAs or a result of the hen's altered fat metabolism. These shifts in the fatty acid profile might have implications for the nutritional value and health benefits of eggs. While increased levels of certain PUFAs, like omega-3 fatty acids, are desirable, higher SFAs could raise concerns about potential cardiovascular health impacts. More research is needed to fully understand the long-term consequences of BSFL-induced fatty acid changes in egg yolks on human health. Other yolk parameters, such as chemical composition, were found to be unaffected by BSFL inclusion. Cattaneo., *et al*. [41] found no significant difference in the chemical composition of the egg yolk when feeding laying hens 15% or 30% live BSFL for 126 days. However, Anas., *et al*. [52] reported decreased egg fat and cholesterol content when feeding laying hens 2% black soldier fly larvae oil calcium salt (BSFLO-SCa) for 8 weeks (Table 9).

Table 9: Studies on the effects of black soldier fly larvae on layer chicken egg quality parameters.

Summary of Results	References
9% BSFL meal with or without BSFL oil slightly increased average egg weight.	[47]
18% BSFL meal with BSFL oil significantly reduced average egg weight.	[47]
21% BSFL decreased average egg weight by 0.93 g during weeks 48-52, with no significant difference during weeks 52-56.	[46]
2% BSFL oil calcium salt increased eggshell weight and thickness after 8 weeks.	[52]
2% BSFL oil calcium salt increased egg albumen weight, height, and ratio after 8 weeks.	[52]
15% or 30% of live BSFL did not affect physical attributes, egg and yolk weights, Haugh index, egg surface, yolk colour, eggshell quality, or chemical composition.	[41]
High inclusion of live larvae or meal and oil darkened egg yolk colour compared to control.	[50]
2% BSFL oil calcium salt decreased yolk colour score and redness (a*) after 8 weeks.	[52]
2% BSFL oil calcium salt increased yolk lightness (L*) and yellowness (b*) after 8 weeks.	[52]
2% BSFL oil calcium salt decreased egg fat and cholesterol compared to control.	[52]
15% or 30% live BSFL increased SFA (lauric acid, myristic acid) in egg yolk.	[41]
15% or 30% live BSFL increased PUFA (linoleic acid, α-linolenic acid) in egg yolk.	[41]
15% or 30% live BSFL decreased MUFA (oleic acid) in egg yolk compared to control.	[41]

Impacts of black soldier fly larvae on duck growth performance

Studies showed that feeding BSFL to ducks generally does not negatively affect growth performance parameters (Table 10). In some cases, BSFL inclusion may even lead to improvements in certain parameters, such as feed conversion ratio (FCR). This variation is likely due to differences in BSFL forms (live, partially defatted meal, full-fat meal), inclusion levels, duck breed, and experimental durations. More research is needed to fully understand the effects of BSFL on duck growth performance and to determine the optimal inclusion levels for different duck breeds and production systems. Gariglio., *et al*. [53] reported that feeding 5% live BSFL to female Muscovy ducks for 55 days did not affect live weight, average daily gain (ADG), average daily feed intake (ADFI), or FCR. Similar observations were made by Colombino., *et al*. [54], who found no significant differences in these parameters when feeding 5%

live BSFL to Muscovy ducks for 55 days, or when providing BSFL and yellow mealworm larvae at 5% of expected ADFI for 52 days. This suggests that at moderate inclusion levels, live BSFL may not provide additional growth benefits compared to standard diets. In contrast, Gunawan., *et al*. [55] observed that supplementing a low-protein diet (13.43%) with 40 g/head/day of live BSFL to Alabio ducks for six weeks resulted in similar egg mass production to ducks fed a high-protein diet (18.29%). This indicates that live BSFL might contribute to improved protein utilization, potentially supporting growth even when dietary protein levels are suboptimal. However, direct growth parameters were not reported in this study, warranting further investigation.

Gariglio., *et al*. [56,57] conducted studies on Muscovy ducks fed 0%, 3%, 6%, and 9% partially defatted BSFL meal. They found that BSFL inclusion did not significantly influence live weight, ADG, DFI, or FCR over the entire experimental period (3-50 days of age). This suggests that partially defatted BSFL meal, at least within the tested inclusion levels, may not be an effective growth promoter in Muscovy ducks. Aldis., *et al*. [58] found that using BSFL meal as a protein source in diets with varying protein levels (14%, 16%, 18%) for 42 days decreased feed intake, body weight, weight gain, ADG, and increased FCR in male hybrid ducks compared to the control group (Table 10). This suggests that full-fat BSFL meal, when used as the primary protein source, might negatively impact growth, possibly due to differences in protein digestibility or amino acid profile compared to traditional protein sources. Nha and Thuy [59] reported that replacing up to 60% of fishmeal protein with BSFL protein in Muscovy duck diets resulted in similar weight gain compared to the control diet over a five-week period (7-12 weeks old). However, replacing 80% of fishmeal protein with BSFL protein reduced average weight gain. This indicates a possible threshold for BSFL inclusion in duck diets, beyond which growth performance might be compromised.

The varied growth outcomes observed in these studies can be attributed to several factors. BSFL contains chitin, a complex carbohydrate that can be difficult for ducks to digest. High inclusion levels of BSFL, particularly full-fat meal, might increase the chitin content in the diet, potentially hindering nutrient absorption and ultimately impacting growth. Moreover, the amino acid profile of BSFL differs from conventional protein sources like soybean meal or fishmeal. While BSFL is generally rich in essential amino acids, certain amino acids might be limiting in duck diets, particularly at high inclusion levels. This imbalance could affect protein synthesis and growth performance.

The current research on the effects of BSFL on duck growth performance provides an incomplete picture. While some studies demonstrate no adverse effects, others suggest potential growth reduction, particularly with high inclusions of full-fat BSFL meal. The inclusion of BSFL, especially in high amounts, might alter the palatability of the diet. Ducks may find the taste or texture of BSFL-based diets less appealing, leading to reduced feed intake and consequently affecting growth. Furthermore, BSFL might contain anti-nutritional factors like chitinase inhibitors or tannins, which can interfere with nutrient digestion and absorption. Further research is needed to identify and quantify potential anti-nutritional factors in BSFL and their impact on duck growth.

Influence of black soldier fly larvae on duck carcass traits, meat/egg quality, and behaviour/welfare

Table 11 presents a detailed analysis of the effects of incorporating black soldier fly larvae into duck diets on various parameters, including carcass traits, meat and egg quality, as well as behaviour and welfare. While certain findings remain consistent across studies, others highlight the importance of considering factors like BSFL form and inclusion levels. Research suggests that BSFL inclusion, at least at the levels studied, generally does not significantly alter carcass traits in ducks. Gariglio., *et al*. [57] observed a quadratic response in slaughtering weight, hot and chilled carcass weights, and abdominal fat weight of Muscovy ducks when fed 6% partially defatted BSFL meal for 47 days. However, no significant differences were noted when feeding up to 9% partially defatted BSFL. This suggests that moderate inclusion levels of partially defatted BSFL meal may not substantially impact these carcass characteristics.

Albeit BSFL inclusion does not appear to dramatically alter overall meat quality, some studies point to subtle changes in fatty acid profiles and oxidative stability. Gariglio., *et al*. [57] found that incorporating 9% partially defatted BSFL meal increased the saturated fatty acid content in the thigh meat of Muscovy ducks. However, the same study reported no impact on the monounsaturated and polyunsaturated fatty acid content in the breast meat, though the ratio of polyunsaturated to saturated fatty acids decreased in both breast and thigh meat with increasing BSFL inclusion. This suggests that BSFL, specifically in a partially defatted meal form, may contribute to a shift towards a higher proportion of saturated fatty acids in duck meat.

Gariglio., *et al*. [57] also found that feeding up to 9% partially defatted BSFL meal to Muscovy ducks for 47 days did not influence

Table 10: Studies on the effects of black soldier fly larvae on duck growth performance.

Summary of Results	References
0%, 3%, 6%, and 9% partially defatted BSFL meal did not affect live weight (LW) at 38 days.	[56]
0%, 3%, 6%, and 9% partially defatted BSFL meal did not affect LW over 47 days.	[57]
5% live BSFL did not affect LW over 55 days compared to control.	[53]
5% live BSFL on top of basal diet did not affect final LW over 55 days.	[54]
5% BSF and YMW live larvae did not affect final LW over 52 days.	[54]
BSFLM as a protein source in diets with 14%, 16%, 18% protein decreased LW over 42 days.	[58]
Replacing 20%, 40%, 60% of fishmeal with BSFL did not affect LW over 5 weeks.	[59]
Replacing 80% of fishmeal protein with BSFL reduced LW over 5 weeks (7-12 weeks old).	[59]
BSFLM as a protein source in diets with 14%, 16%, 18% protein decreased LW over 42 days.	[58]
BSFL + high-protein diet (18.29%) increased duck day production than low (13.43%).	[55]
Average daily gain (ADG) not affected except at 18–38 days compared to the control.	[56]
0%, 3%, 6%, and 9% partially defatted BSFL meal did not affect ADG over 47 days.	[57]
5% of live BSFL did not affect ADG over 55 days compared to the control.	[53]
5% live BSFL on top of basal diet did not affect ADG over 55 days.	[54]
5% BSF and YMW live larvae did not affect ADG over 52 days.	[54]
BSFLM as a protein source in diets with 14%, 16%, 18% protein decreased ADG over 42 days.	[58]
Daily feed intake (DFI) not affected at any feeding phase or overall (3-50 days).	[56]
BSFLM as a protein source in diets with 14%, 16%, 18% protein decreased DFI over 42 days.	[58]
0%, 3%, 6%, and 9% partially defatted BSFL meal did not affect DFI over 47 days.	[57]
5% of live BSFL did not affect DFI over 55 days compared to the control.	[53]
5% live BSFL on top of basal diet did not affect DFI over 55 days.	[54]
5% BSF and YMW live larvae did not affect DFI over 52 days.	[54]
Feed conversion ratio (FCR) not affected at any feeding phase or overall (3-50 days).	[56]
40 g/head/day of live BSFL for 6 weeks did not affect feed consumption or FCR.	[55]
0%, 3%, 6%, and 9% partially defatted BSFL meal did not affect FCR over 47 days.	[57]
5% live BSFL did not affect FCR over 55 days compared to the control.	[53]
5% live BSFL on top of basal diet did not affect FCR over 55 days compared to the control.	[54]
5% BSF and YMW live larvae did not affect FCR over 52 days compared to the control.	[54]
BSFLM as protein source in diets with 14%, 16%, 18% protein increased FCR over 42 days.	[58]

thiobarbituric acid-reactive substances (TBARS) values in either the breast or thigh meat. TBARS are a common indicator of lipid oxidation, which can lead to undesirable flavour changes and reduced shelf life. This suggests that incorporating partially defatted BSFL meal at moderate levels may not negatively impact the oxidative stability of duck meat. Additionally, Gariglio., *et al*. [57] observed a slight effect on the mineral profile of the meat, with a linear increase in the copper content of the thigh meat with increasing partially defatted BSFL meal inclusion. This finding hints at the possibility of BSFL influencing the mineral composition of duck meat, but further investigation is needed to confirm this and understand the potential implications.

The effects of BSFL on duck egg quality are complex, with some studies reporting benefits and others highlighting potential drawbacks (Table 11). Gunawan., *et al*. [55] found that supplementing a low-protein diet with live BSFL led to a significant increase in egg weight and yolk weight in Alabio ducks. This suggests that BSFL might contribute to improved nutrient utilization in laying ducks, resulting in larger and potentially more nutrient-rich eggs.

Several studies have provided compelling evidence for the positive impact of BSFL on duck behaviour and welfare. These findings

are particularly relevant in addressing common welfare concerns in intensive duck farming. Gariglio., *et al*. [53] observed that ducks fed 5% live BSFL spent more time eating and drinking and showed lower attack behaviour compared to those fed yellow mealworm larvae or a control diet over 55 days. This suggests that live BSFL might enrich the environment and stimulate natural foraging behaviour, reducing boredom and stress, and potentially leading to lower aggression levels.

Gariglio., *et al*. [53] also reported reduced excreta corticosterone metabolites (ECM) and a lower heterophil-to-lymphocyte ratio in ducks fed 5% live BSFL at 55 days of age compared to controls. ECM levels and the heterophil-to-lymphocyte ratio are commonly used indicators of stress in birds. These findings strongly indicate that live BSFL might contribute to a reduction in stress levels, possibly by providing environmental enrichment and promoting natural behaviours. In addition, Oddon., *et al*. [42] found that Bionda Piemontese hens fed live BSFL at 6% of their daily feed intake for 90 days had better total integument scores, suggesting improved plumage status. They also observed a higher frequency of preening behaviour and a lower incidence of severe feather pecking in both Bionda Piemontese and Bianca di Saluzzo hens fed live BSFL compared to controls. These findings indicate that incorporating live BSFL could potentially contribute to improved feather condition and reduce feather pecking, a common welfare concern in laying hens.

Effects of black soldier fly larvae on turkey's growth performance

Table 11: Studies on the effects of black soldier fly larvae on carcass traits, meat/egg quality and welfare of ducks.

Summary of Results	References
40 g/head/day BSFL with a high-or low-protein diet had similar egg mass production	[55]
Slaughtering weight, hot and chilled carcass weights, and abdominal fat weight showed a quadratic response at 6% BSFL meal after 47 days.	[57]
Up to 9% BSFL meal did not affect pH, colour, proximate composition, or TBARS values in breast or thigh meat.	[57]
9% BSFL meal increased saturated fatty acids in thigh meat compared to the control.	[57]
9% BSFL meal resulted in similar monounsaturated and polyunsaturated fatty acids in breast meat; ratio decreased linearly in both breast and thigh meat.	[57]
Up to 9% BSFL meal slightly increased Cu content in thigh meat compared to control.	[57]
Live BSFL increased egg weight and yolk weight compared to control.	[55]
5% live BSFL increased eating and drinking time compared to yellow mealworm larvae or control diet.	[53]
5% live BSFL reduced attack behaviour over 55 days compared to control.	[53]
5% live BSFL reduced excreta corticosterone metabolites (ECM) and heterophil to lymphocyte ratio at 55 days compared to control.	[53]

Table 12 summarizes the findings of various studies on the effects of black soldier fly larvae on turkey growth performance, including feed intake, body weight, and feed conversion ratio. The results of the studies vary, likely due to differences in the form of BSFL used (live larvae, full-fat meal, defatted meal, whole larvae meal), inclusion levels, and the duration of the experimental period. In some cases, BSFL inclusion improved growth performance, while in other cases, no significant differences were observed compared to the control groups. Some studies reported minimal or negative impacts on growth performance when BSFL was included in the diet. More research is needed to determine the optimal inclusion levels and form of BSFL for maximizing turkey growth performance.

Veldkamp and Van Niekerk [60] found that live BSFL at 12% of the daily ration significantly increased feed intake and final body weight in male turkeys over 35 days. This improvement might be linked to the larvae's palatability and nutritional content, potentially stimulating appetite and enhancing nutrient absorption. However, it is crucial to consider the practical challenges and costs associated with incorporating live larvae into commercial turkey diets.

Jankowski., *et al*. [61] observed a linear increase, albeit not statistically significant, in final body weight and daily body weight gain in turkeys fed 50 g/kg, 100 g/kg, or 150 g/kg full-fat BSFL meal for four weeks. This suggests that BSFL meal, especially at higher inclusion levels, might contribute to improved growth performance in turkeys. The non-significant result could be due to the limited duration of the study. Similarly, Ognik., *et al*. [20] reported a linear upward trend, approaching statistical significance (P = 0.056), in

the final body weight of turkeys fed 5%, 10%, or 15% BSFL meal for four weeks (Table 12). This further supports the possibility of BSFL meal positively influencing turkey growth.

Kierończyk., *et al*. [62] found that diets containing 5% BSFL fat as the sole fat source or a 2.5% BSFL fat and 2.5% soybean oil blend did not significantly affect body weight, body weight gain, feed intake, or feed conversion ratio in turkeys over 28 days compared to a soybean oil control diet. This suggests that replacing soybean oil entirely with BSFL fat might not be beneficial for turkey growth. Similarly, Sypniewski., *et al*. [22] observed no significant difference in body weight gain, feed intake, or feed conversion ratio in turkeys fed a diet where 100% of soybean oil was replaced with BSFL fat compared to the control group over 28 days. This reinforces the hypothesis that the complete replacement of soybean oil with BSFL fat might not improve turkey growth performance.

A consistent finding across many studies is the potential for BSFL to improve feed conversion ratio, a key indicator of feed efficiency. A lower FCR indicates that less feed is required to produce a unit of weight gain. Veldkamp and Van Niekerk [60] reported a significantly lower FCR in turkeys fed live BSFL at 12% of the daily ration for 35 days. Jankowski., *et al*. [61] observed a linear decrease in FCR in turkeys fed increasing levels of full-fat BSFL meal (50g/kg, 100g/kg, or 150g/kg) for four weeks. Ognik., *et al*. [20] reported a linear decrease in FCR in turkeys fed 5%, 10%, or 15% BSFL meal for four weeks. This trend of improved FCR suggests that BSFL, regardless of form, might enhance nutrient utilization in turkeys, leading to more efficient growth. This could be attributed to factors like BSFL's balanced amino acid profile (Table 4), high digestibility, and potential prebiotic effects that promote gut health.

Incorporating BSFL into turkey diets might have positive implications for turkey welfare and behaviour, particularly in terms of reducing aggression and promoting natural foraging behaviours. A key welfare concern in turkey production is aggressive pecking, which can lead to injuries, stress, and reduced productivity. Several studies indicate that BSFL inclusion in turkey diets might mitigate this problem. Veldkamp and Van Niekerk [60] found that providing live BSFL at 10% of daily feed intake for 35 days reduced aggressive pecking behaviour (at the back and tail base) in turkeys. This suggests that the larvae's presence in the diet might provide an outlet for turkeys' natural foraging instincts, reducing their motivation to engage in damaging pecking behaviours. In addition, Gariglio., *et al*. [53] reported lower attack behaviour over 55 days in Muscovy ducks fed 5% live BSFL compared to a control group. While this study involved ducks, it provides further support for the potential of BSFL to reduce aggression in poultry.

The inclusion of live BSFL in turkey diets appears to promote natural foraging behaviours, potentially enriching their environment and improving their overall well-being. Veldkamp and Van Niekerk [60] observed that early life feeding with live BSFL at 10% of daily feed intake stimulated more natural foraging behaviour in the first week compared to turkeys fed commercial diets. This suggests that BSFL might offer a more stimulating and engaging feeding experience for turkeys, allowing them to express their natural foraging instincts.

Table 12: Studies on the effects of black soldier fly larvae on turkey growth performance.

References	Form of BSFL, dosage, duration	Key findings
[60]	Live BSFL 12% of daily feed ration (35 days)	Higher final body weight and feed intake.Lower FCR compared to control. Early life feeding stimulated natural foraging behaviour.
[62]	BSFL fat 5% (sole fat source), 2.5% + 2.5% soybean oil (28 days)	No significant differences in body weight, weight gain, feed intake, or FCR compared to the control. Higher fat digestibility and lipase activity with 100% BSFL fat.
[22]	BSFL fat (replacing soybean oil) 50%, 100% (28 days)	No significant differences in body weight gain, feed intake, or FCR. No significant effects on muscle triglyceride or cholesterol content.
[61]	Full-fat BSFL meal 50 g/kg, 100 g/kg, 150 g/kg (4 weeks)	No significant differences in feed intake. Linear increase in body weight and ADG (not statistically significant). Linear decrease in FCR, lowest at 150 g/kg.
[20]	BSFL meal 5%, 10%, 15% (4 weeks)	Linear upward trend in body weight (approaching significance). Linear decrease in FCR, lowest at 15% BSFL.
[63]	BSFL 3 g/kg (28 days)	Lower body weight and weight gain. Higher FCR compared to control.
[64]	Defatted BSFL meal, Whole BSFL larvae meal 10% (78 days)	Defatted BSFL meal: 7.35% weight increase at day 78, ~8% at day 114. Whole BSFL larvae meal: 9.05% weight increase at day 78, ~8% at day 114. FCR of 2.45 (56-114 days) compared to 3.00 in control.

Impact of black soldier fly larvae on turkey carcass traits and meat quality

Table 13 presents a limited but intriguing picture of how incorporating BSFL into turkey diets might affect carcass traits and meat quality. While some studies suggest minimal impact, others point to potential modifications in fatty acid profiles and meat characteristics, warranting further investigation. Lalev., *et al*. [64] found that incorporating 10% defatted BSFL meal into turkey diets for 78 days did not lead to differences in carcass weight or yield. This finding suggests that BSFL meal, at least at this inclusion level and for this duration, may not substantially alter overall carcass characteristics in turkeys. However, more research is needed to confirm this observation across various BSFL forms and inclusion levels.

The research suggests that BSFL inclusion, particularly in the form of fat, might induce subtle but significant changes in turkey meat quality, especially concerning fatty acid profiles and other parameters (Table 13). Sypniewski., *et al*. [22] found that replacing soybean oil entirely with BSFL fat in turkey diets did not significantly affect the triglyceride or cholesterol content of breast or thigh muscle tissue. However, this study did not examine other fatty acids, leaving room for potential differences in the overall fatty acid composition of the meat. Srikha., *et al*. [65] reported a higher meat pH at 24 hours post-mortem in Thai native chickens fed 50% or 75% BSFL oil compared to a control group. While this study focused on chickens, it hints at the possibility of BSFL oil influencing meat pH in poultry, which could affect meat tenderness and other quality attributes. Furthermore, Sajjad., *et al*. [37] observed higher lightness (L*) and yellowness (b*) values in breast meat from broiler chickens fed a 12% BSFL diet compared to the control group. This suggests that BSFL inclusion might influence meat colour, potentially affecting consumer perception and acceptability. However, it is important to consider the potential variation in colour depending on the BSFL form and processing methods. Srikha., *et al*. [65] also found lower shear force, indicating greater tenderness, in meat from Thai native chickens fed 50% BSFL oil compared to the control group and a 75% BSFL oil group. This finding suggests that moderate inclusion of BSFL oil might enhance meat tenderness.

Table 13: Studies on the effects of black soldier fly larvae on turkey carcass traits and meat quality.

References	Form of BSFL, Dosage, Duration	Key Findings
[64]	Whole larvae meal 10% (78 days)	Increased live weight by 9.05% at 78 days and 8% by day 114. Smaller gizzard weight (1.34% of carcass weight) compared to the control group (1.72%). Feed conversion ratio of 2.45 compared to 3.00 in the control group—no difference in carcass weight.
[64]	Defatted BSFL meal 10% (78 days)	Increased live weight by 7.35% at 78 days and 8% by day 114. No difference in carcass weight or yield after 74 days.
[66]	BSFL and Silkworm meals 10% (74 days)	Improved water holding capacity and reduced cooking loss in breast meat. Increased lipid and iron levels in thigh meat. No changes in protein, lipid, or mineral content of breast meat.
[20]	BSFL meal 5%, 10%, or 15% (4 weeks)	No significant differences in carcass weight or yield, or meat quality.
[22]	BSFL fat 50% or 100% (28 days)	No significant effects on the triglyceride or cholesterol content of breast or thigh muscle tissue.

Impact of black soldier fly larvae on quail growth, carcass traits, and meat quality

There is limited information on the effects of BSFL on meat quality parameters. Most of the research primarily focuses on carcass traits and egg quality in quails fed with BSFL (Table 14). While the research is still developing, the findings highlight BSFL's potential as a sustainable protein source in quail production, prompting further investigation to optimize its application and benefits. Studies examining the effects of BSFL on quail growth performance present a mixed picture, suggesting that the impact might depend on factors such as the BSFL inclusion level and processing method. Silva., *et al*. [67] reported that feeding BSFL meal to quail for 42

days resulted in a quadratic effect on body weight and body weight gain, with maximums observed at 62.3 and 62.4 g/kg, respectively. This study also observed a linear reduction in FCR with increasing BSFL meal inclusion. This finding suggests that moderate inclusion levels of BSFL meal might enhance quail growth performance, although higher inclusion levels could lead to diminishing returns. Conversely, Cullere., *et al*. [68] found that quails fed 10% and 15% defatted BSFL meal for 28 days had similar final weight and FCR compared to the control group, indicating that incorporating defatted BSFL meal at these levels might not significantly impact growth performance. Cullere., *et al*. [68] observed no significant differences in breast meat weight and yield between quails fed 10% and 15% defatted BSFLM and the control group, suggesting that defatted BSFL meal, at least at these levels, might not substantially alter carcass composition in quails. More studies are needed to investigate the effects of different BSFL forms (live larvae, full-fat meal, defatted meal, and oil) and inclusion levels on a wider range of carcass traits, such as dressing percentage, abdominal fat deposition, and organ weights. This information will be crucial for assessing the overall suitability of BSFL as a feed ingredient in quail production.

Research suggests that BSFL inclusion in quail diets could potentially influence meat quality parameters, particularly meat pH and fatty acid composition (Table 14). Cullere., *et al*. [68] found that feeding quails 10% and 15% defatted BSFL meal for 28 days resulted in a lower ultimate pH in the meat compared to the control group (Table 14). Ultimate pH is an important indicator of meat quality, as it can affect factors such as water-holding capacity, colour, and tenderness. Lower pH values are generally associated with improved shelf life and reduced microbial growth. However, excessively low pH values can lead to pale, soft, and exudative (PSE) meat, affecting meat shelf life. The practical implications of this pH reduction in quail meat require further investigation. Moreover, Dalle Zotte., *et al*. [48] reported that quails fed diets containing 10% and 15% defatted BSFL meal had increased saturated fatty acids and decreased polyunsaturated fatty acids in the eggs compared to the control group. This finding suggests that BSFL inclusion might alter the fatty acid profile of quail products, potentially affecting their nutritional value and sensory characteristics. However, further studies should investigate the effects of BSFL on a broader range of meat quality parameters, including colour, texture, water-holding capacity, and sensory attributes. In addition, consumer sensory evaluations are essential to assess the acceptability of quail meat from birds fed BSFL diets. These evaluations will guide industry adoption and ensure that consumer preferences are met.

Table 14: Studies on the effects of black soldier fly larvae on quail growth, carcass traits and meat quality.

Parameter	Summary of Results	References
Growth	Quails fed 10% and 15% defatted BSFL meal for 28 days had similar final weight, FCR, and mortality compared to the control group.	[48, 68]
	Feeding 0-100 g/kg BSFL meal for 42 days showed a quadratic effect on body weight and gain, with peaks at 62.3 and 62.4 g/kg.	[67]
	BSFL meal increased body weight and gain, reduced FCR, and decreased small intestine weight linearly over 42 days.	[67]
	Protein deposition and retained energy showed a quadratic effect with peaks at 71.4 and 66.7 g/kg BSFL meal.	[67]
Egg Quality	10% and 15% defatted BSFL meal improved egg shape, eggshell thickness, weight, and yolk colour.	[48]
	Increased saturated fatty acids and decreased polyunsaturated fatty acids in eggs.	[48]
	Similar egg sensory qualities, except higher off-flavour in the 15% group.	[48]
	10% defatted BSFL meal improved egg oxidative stability after 28 days of storage.	[48]
Carcass Traits	Similar carcass traits and breast meat weight/yield with 10% and 15% defatted BSFL meal for 28 days.	[68]
	No significant effect on dry matter, crude protein, ether extract, mineral matter, or fat deposition with 0-100 g/kg BSFL meal for 42 days.	[67]
Meat Quality	Lower ultimate pH in meat with 10% and 15% defatted BSFL meal for 28 days.	[68]
Other	Similar digestibility of dry matter, crude protein, starch, energy, and microbial composition of excreta with 10% and 15% defatted BSFL meal for 28 days.	[68]

Conclusion

Black soldier fly larvae are emerging as a promising alternative feed resource to support future animal production needs. Studies have shown that incorporating BSFL into poultry diets can enhance productivity, welfare, and product quality. These improvements highlight the potential of BSFL as a valuable ingredient in feed rations. As research and technology advance, BSFL is likely to become an increasingly important component in poultry production systems.

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