DOI:

Effects of Black Soldier Fly Larvae Supplementation in Ac Chickens' Feed: Impact on Meat Yield and Quality

Nguyen Thi Nhien[1], Tran Hoang Nam[2]

[1] *Faculty of Biotechnology, Vietnam National University of Agriculture, Trau Quy Ward, Gia Lam District, Hanoi 131000, Vietnam*

[2] *Research Center for Higher Education, Tokushima University, 1-1 Minami-Josanjima, Tokushima 770-8502, Japan.*

Correspondence to: Tran Hoang Nam, Research Center for Higher Education, Tokushima University, 1-1 Minami-Josanjima, Tokushima 770-8502, Japan
Phone: +81-88-656-9974
Email: tran@tokushima-u.ac.jp

ARTICLE INFO
Article History
Received:
Revised:
Accepted:

Key words: alternative livestock feed, amino acid content, BSFL meal, Hermetia illucens

ABSTRACT

This study investigated the effects of substituting bone meal with black soldier fly larvae (BSFL) in the feed of Ac chickens. A prospective randomized control design was employed on a total of 108 Ac chickens, which randomly divided into two experimental groups (EG1 and EG2) and one control group (CG) with equal number of chickens in each group. The chickens in CG were fed twice a day with 100% bone meal supplementation (feed inclusion rates of 12%), EG1 with 50% BSFL and 50% bone meal, and EG2 with 100% BSFL. The experiment started at 5 weeks of chickens' age and continued until 13 weeks of age. We found significant differences in average weight, with the EG2 exhibiting the highest weight at 738 g, followed by the EG1 at 736 g, and the CG at 603 g at 13 weeks of age. Chest circumference and body length were also significantly higher in the EG2 and EG1 compared to CG. The proportions of valuable meat portions, such as thigh meat and breast meat, were higher in the EG2 and EG1 compared to CG. Furthermore, the total amino acid content in the meat of Ac chickens was highest in the EG2 at 19.3%, while the CG had the lowest content at 18.8%. The essential amino acid content was also higher in EG1 and EG2 compared to CG. Substituting bone meal with BSFL in the feed of Ac chickens has positively influenced weight gain, body measurements, meat yield, and amino acid content.

INTRODUCTION

By the year 2050, it is projected that the global population will surpass 9 billion, raising significant concerns regarding the twin challenges of food security and environmental sustainability (Alexandratos et al., 2012). The exponential growth in population size inevitably translates into a surging demand for animal-derived products and livestock feed. This escalating demand for animal protein poses formidable challenges, particularly in the realm of livestock feed, which faces limitations in terms of natural resources, adverse impacts of climate change, and intensifying competition for limited supplies of food, feed, and fuel (FAO 2011). Consequently, the need to meet the rising demand for animal protein necessitates the allocation of substantial resources.

The increasing reliance on livestock production to satisfy the protein requirements of a growing population exacerbates the environmental burden, resulting in heightened levels of waste and environmental degradation. These trends further strain ecological systems and sustainability efforts, necessitating urgent attention and action (FAO 2011). Addressing these multifaceted challenges requires a comprehensive understanding of the complex interplay between population dynamics, resource availability, environmental impact, and agricultural practices. In light of these pressing concerns, it is crucial to explore sustainable and efficient strategies for livestock feed production, distribution, and utilization. Novel approaches, such as alternative feed sources, precision nutrition, and technological innovations, hold promise in enhancing feed efficiency, reducing resource consumption, and mitigating the environmental footprint of livestock production. Integrated efforts encompassing policy interventions, research advancements, and stakeholder collaborations are imperative to ensure the long-term viability and resilience of our food systems in the face of mounting population pressures and environmental constraints.

The Black Soldier Fly (*Hermetia illucens*) is a species of fly known for its distinctive black appearance and is widely recognized for its valuable role in waste management (Banks et al., 2014) and the production of high-quality protein through its larvae. The utilization of Black Soldier Fly larvae (BSFL) for organic waste management and the generation of nutrient-rich feed presents a viable avenue in the prevailing context. There has been a notable surge in the rearing and utilization of BSFL as animal feed in many Asian countries (Lu et al., 2022) including Vietnam. To provide timely and practical recommendations, several researchers have delved into this domain. A study conducted on quail (*Coturnix japonica*) has found no discernible differences in meat yield, breast meat weight, and meat yield between the control group and two groups supplemented with BSFL in their diet (Cullere et al., 2016). Moreover, it has been reported that incorporating BSFL into the diet of broiler chickens had no adverse effects on meat yield, carcass characteristics, or meat quality (Schiavone et al., 2017). Furthermore, it has been determined that supplementing laying hens' diets with 50% BSFL or replacing the entire soybean meal with them had negligible impact on hen health, meat yield, and egg weight and quality (Maurer et al., 2016). Taken together, these studies collectively underscore the potential of BSFL meal as a nutritious feed source suitable for poultry and aquaculture applications.

Black-bone chickens (*Gallus gallus domesticus*) can be found in China and other Asian countries including Japan, Taiwan, Vietnam, India, Indonesia, and Thailand (Huang et al., 2021; Khumpeerawat et al., 2021; Zhuang et al., 2023). Ac chicken is a native breed black-bone chicken in Vietnam, is highly in demand on the domestic market because of their meat quality traits, which has genetic, morphologic and meat quality characteristics different from other breeds. The Ac chicken exhibits distinct characteristics within the native chicken population, notably smaller in size from other broiler breeds. Newly hatched Ac chickens exceed 16.3 grams in weight, reaching 230 grams by the age of 60 days, and attaining a range of 600 to 750 grams by 120 days of age (Cuc et al., 2011; Le et al., 2023).

The current study is the first study in Vietnam on the effect of supplementation of dried BSFL meal in the diet of Ac chickens on meat quality. Moreover, this study aims to investigate the effects of different levels of dried BSFL meal on the growth, feed consumption, and meat quality of Ac chickens - one of the valuable and nutritionally rich chicken breeds with significant economic value, widely raised by farmers in Vietnam.

MATERIALS AND METHODS

Animal Preparation and Experimental Conditions

The study encompassed a cohort of 108 Ac chickens, which were supplied by a local farmer at the age of five weeks. The chickens were transferred to the research facility and maintained under standard conditions at 25-27°C and 60% humidity. The experimental process started at the age of 5 weeks and followed up until they reached 13 weeks of chicken's age. The experimental chickens were randomized into three groups, two experimental groups (EG1 and EG2) and one control group (CG) with 36 chickens in each group. The experimental diet formula for the chickens was applied according to a previous study, which investigated the nutritional value of some types of feed in raising Sao chickens in the Mekong Delta (Pham, 2014). All the three groups were fed on the same feed except for the composition of bone meal and BSFL meal as shown in Table 1. Other components such as the ratio of males to females, care regime, disease prevention procedures, and veterinary hygiene are all standardized. Feed and water are provided ad libitum, and the feeding regulations are followed according to the recommendations of the Thuy Phuong Poultry Research Center, Institute of Animal Husbandry.

Table 1: Ingredient composition (%) of the feed in the three groups

Ingredient	CG (%)	EG1 (%)	EG2 (%)
Bone meal	12	6	0
BSFL meal	0	6	12
Corn		39.6	
Rice bran		28	
Rice husk		8.4	
Soybean meal		12	
Mineral-vitamin premix		0.2	
Total		100	

Feeding

Table 2 shows the amino acid content in crude bone meal used in the current study, which was supplied by Thanh Duyen Trading and Import-Export Company.

Table 2: Amino acid content in crude bone meal*

Type of amino acid	Content (%)
Essential Amino Acids:	
Histidine	1.0
Threonine	2.5
Methionine	0.7
Valine	3.0
Phenylalanine	2.2
Isoleucine	2.6
Leucine	3.5
Lysine	4.7
Non-essential Amino Acids:	
Arginine	8.1

* Analysis was conducted at the Laboratory of Food Science and Technology, VNUA.

The BSFL utilized in this study were reared at the Animal Nutrition and Feed Science Experimental Farm, Vietnam National University of Agriculture (VNUA). These larvae were nourished with a diet comprising soybean bran and spoiled fruits and vegetables procured from a local market. Upon reaching the 5th instar stage, the larvae were harvested from the rearing trays and subjected to a thorough washing with clean water, followed by draining and subsequent drying at a temperature of 80°C until achieving crispness, which typically required approximately 4 hours. Subsequently, the larvae underwent meticulous grinding before being stored in hermetically sealed nylon bags. The processing of BSFL into meal was based on the method described by previous studies (Duong et al., 2017; Edwards et al., 1988; El Boushy et al., 2002). The amino acid content of the BSFL meal was analyzed according to the criteria listed in Table 3.

Table 3: Amino acid content in BSFL meal *

Type of amino acid	Content (%)
Essential Amino Acids:	
Histidine	0.48
Threonine	1.18
Methionine	0.95
Valine	1.78
Phenylalanine	1.34
Isoleucine	1.21
Leucine	1.93
Lysine	1.62
Non-essential Amino Acids:	
Aspartic acid	2.82
Serine	1.27
Glutamic acid	3.91
Proline	1.46
Glycine	1.97
Alanine	1.91
Cystine	0.02
Tyrosine	1.71
Arginine	1.18

* Analysis was conducted at the Laboratory of Food Science and Technology, VNUA

Data Collection

The chickens were slaughtered for evaluation on the 13th week. The research parameters, such as body weight throughout the weeks, and feed consumption, were determined using standard methods in poultry farming. To determine the percentages of different meat cuts such as breast meat and thigh meat,, the method described by the Poultry Board (Nguyen, 1979) was followed.

Statistical Analysis

The analysis of amino acid composition in the meat was conducted according to the method described by Aronal et al., 2012 using a high-resolution liquid chromatography-mass spectrometry system (Shimadzu Japan). Data was processed and organized using Microsoft Excel. Statistical analysis was performed by using the one-way ANOVA test in Minitab 16 software.

RESULTS AND DISCUSSION

Growth performance

It has been reported that the Ac chickens exhibit favorable heat tolerance; however, they demonstrate decreased tolerance to cold temperatures. In the experimental conditions, the Ac chickens may achieve a survival rate ranging from 93.6% to 96.9%. In the current study, by ensuring appropriate provisions of warmth during the early weeks, the survival rate achieved 100%.

The findings presented in Table 4 demonstrate that the inclusion of BSFL meal in Ac chicken feed at levels of 6% to 12% resulted in enhanced growth rates compared to the CG. Significant differences in body weight among all three groups emerged from week 7 onwards until week 13, representing the conclusion of the meat rearing phase (p<0.05). Notably, in EG2, where BSFL meal was supplemented at a rate of 12%, the average body weight reached 738.1 g, which was significantly similar to the average body weight in EG1 (736 g), and notably surpassed that of the CG (603 g), which exhibited the lowest weight. Therefore, both the 6% and 12% inclusion levels of BSFL meal in the feed had a positive impact on the growth performance of the chickens. This observation aligns with a previous literature (Schiavone et al., 2019), which reported an improvement in body weight development as the inclusion level of BSFL meal in the feed increased, as well as a linear increase in chicken weight when supplemented with BSFL meal ranging from 10% to 15% in the feed.

Table 4: Body weight (g) of Ac chickens throughout the weeks

Week	CG	EG1 (6 %)	EG2 (12 %)
5th	$452^a \pm 9.87$	$437^b \pm 2,55$	$452^a \pm 3,94$
6th	$416^b \pm 4.74$	$416^b \pm 6,94$	$427^a \pm 5,36$
7th	$409^c \pm 3.63$	$422^b \pm 7,74$	$465^a \pm 2,10$
8th	$432^c \pm 4,19$	$458^b \pm 6,47$	$504^a \pm 2,89$
9th	$448^c \pm 6,82$	$493^b \pm 2,5$	$532^a \pm 10,2$
10th	$464^c \pm 12,0$	$524^b \pm 4,59$	$573^a \pm 14,2$
11th	$514^c \pm 12,5$	$610^b \pm 14,6$	$639^a \pm 14,3$
12th	$553^c \pm 8,34$	$667^b \pm 8,01$	$708^a \pm 6,25$
13th	$603^b \pm 10,8$	$736^a \pm 13,4$	$738^a \pm 3,47$

[abc] Means in the same row without common letter are different at $p < 0.05$

These results are also consistent with previous reports (Kaya et al., 2015; Lee et al., 2008), which highlights the nutritional benefits of insects, such as the BSF, for poultry, as well as their potential to enhance the avian immune system through key components like chitin and antimicrobial peptides found in their bodies. During the larval stage of the BSF, chitin serves as the primary constituent of their exoskeleton, and its derivatives have been shown to positively impact animal health. It has been demonstrated that the supplementation of chitin in the feed of meat chickens significantly increased the relative weight of immune organs like the bursa of Fabricius and the thymus (Chi et al., 2017). Moreover, chitin derivatives can act as substrates for beneficial intestinal bacteria in chickens. Alterations in the microbial community within the intestine have profound implications for chicken health, as these microorganisms play a critical role in immune system development (Li et al., 2007). Importantly, no indications of illness were observed in the chickens throughout the entire experimental duration, and the mortality rate across all groups was zero.

Feed intake

The daily feed intake reflects the health status of the chicken flock, the quality of the feed, and the care and management practices. Additionally, it directly affects the growth and meat yield of the birds. The daily feed intake is also related to the energy and protein levels in the feed, which in turn influence the growth and product yield of poultry. Moreover, daily feed intake is influenced by various factors such as climate, temperature, environment, and health conditions.

In Table 5, the feed intake of chickens across the weeks did not show significant differences among the experimental and control groups. From the 7th week to the 12th week, the feed intake increased linearly in all three treatments, but the feed intake in the control group was lower compared to EG1 and EG2. This indicates that the addition of BSFL meal at 6% and 12% did not affect the palatability of the feed for the chickens. Furthermore, although there were no significant differences in feed intake among the treatments, the weight gain of the chickens in the experimental groups was higher than that of the control group. This further confirms that BSFL meal contributes to the balance of nutrients, especially essential amino acids, in the chicken feed. These findings are consistent with several previous studies (Attivi et al., 2020; M. Khan et al., 2018; S. Khan et al., 2016).

Body size growth

Body size is one of the indicators that reflects growth, representing characteristics of each growth stage and distinguishing different breeds, thereby contributing to the differentiation of different breeds. Understanding the body size of chickens at different growth stages not only provides insights into the biological characteristics of the breed but also helps determine their growth requirements. This knowledge enables the development of appropriate feeding regimes tailored to different chicken breeds, creating the optimal environment for their growth and development.

The results of Table 6 show that the body size indicators of Ac chicken in terms of chest circumference and body length tend to increase linearly with the supplementation of BSFL meal in the diet. When completely replacing bone meal with BSFL meal (12%), the chest circumference and body length of the chickens are the largest ($p < 0.05$), measuring 20.6 cm and 15.9 cm, respectively, compared to the other two experimental diets.

The wing length index in all three diets does not show differences ($p > 0.05$). This can be explained by the fact that supplementing BSFL meal at a level greater than 10% stimulates the development of muscle tissue, which is concentrated in the chest region. This is consistent with the findings of a previous study, where the supplementation of BSFL improved the meat yield of chicken breast (Schiavone et al., 2019). Another report also confirmed that BSFL meal enhances the quality of feathers, breast meat, and thigh meat in poultry (Okah et al., 2012).

Table 5: Feed intake (g) of Ac chickens.

Week	Feed intake (g/bird/day)		
	CG	**EG1**	**EG2**
5th	25.8	30.6	32.1
6th	20.7	25.6	27.4
7th	31.6	38.6	44.5
8th	34.4	42.9	46.6
9th	35.4	44.6	49.6
10th	38.8	46.7	51.6
11th	40.4	52.1	56.1
12th	45.1	61.2	63.7
Average	34.0	42.8	46.4

Table 6: Indicators of body size (cm) in Ac chickens

Measurement (cm)	CG	EG1	EG2
Chest circumference	$19.1^{b} \pm 0.35$	$20.0^{a} \pm 0.08$	$20.6^{a} \pm 0.62$
Body length	$15.4^{b} \pm 0.11$	$15.6^{ab} \pm 0.13$	$15.9^{a} \pm 0.18$
Wing length	14.5 ± 0.20	14.8 ± 0.46	14.9 ± 0.40

abc Means in the same row without common letter are different at $p < 0.05$

Meat yield and meat quality

Meat yield and meat quality are crucial indicators for assessing the meat production capacity of poultry. The thigh meat and breast meat are the main and highest-quality meat portions of poultry in general. To evaluate the meat yield and meat quality, the Ac chickens were slaughtered and analyzed at the 13th week of the birds' age. The results are presented in Table 7.

The ratios of carcass meat, thigh meat, and breast meat are important indicators for evaluating the meat yield capability. From Table 7, we can observe that supplementing BSFL meal at 6% and 12% levels in the diet of Ac chickens contributed to an increase in valuable meat ratios (thigh meat and breast meat). The ratios of thigh and breast meat yield in the experimental treatments, corresponding to the 6% and 12% supplementation levels, were 33.7% and 34.6%, respectively, higher than the control formula ratio of 30.3%. Our research results are consistent with the findings of a previous study regarding the supplementation of 6-8% BSFL to increase the thigh meat yield in turkeys (Schiavone et al., 2019). Another study also has affirmed that replacing soybean meal with BSFL meal significantly improves growth performance, carcass characteristics, and meat quality (Elahi et al., 2022). These findings preliminarily demonstrate that incorporating BSFL meal into the diet of Ac chickens can enhance meat production efficiency.

The chemical composition of meat partly reflects its quality. Breast meat and thigh meat constitute a significant portion of the body's meat mass and are important indicators for evaluating meat quality and the meat yield capability of the breed. The main parameters evaluated through thigh meat and breast meat include the amino acid profiles of the chickens at 13 weeks of age in the experimental treatments.

Total amino acids comprise both free amino acids and peptide-bound amino acids. Free amino acids are hydrophilic amino acid groups that are tightly bound to the aqueous environment and often form hydrogen bonds with the environment and between amino acids themselves. Peptide-bound amino acids are hydrophobic amino acid groups that are insoluble or poorly soluble in water (TCVN12621, 2019). The analysis results show that the highest total amino acid content is observed in EG2, accounting for 19.3%. It is followed by EG1 with 19.1%, and the lowest content is found in the CG at 18.8%. The content of each amino acid type in Ac chicken meat across the different treatments is presented in Table 8.

Table 8 presents the results of the analysis of 17 commonly synthesized amino acids for body proteins, including 8 out of 9 essential amino acids: Histidine, threonine, methionine, valine, phenylalanine, isoleucine, leucine, lysine. Among them, the content of non-essential amino acids in the two formulations supplemented with BSFL (6% and 12%) is higher than in the control formulation. Previous studies have also investigated the supplementation of fresh BSFL in the diet of broiler chickens as a replacement for soybean meal, showing that BSFL provide essential amino acids methionine and lysine, improving the quality of chicken meat (Makkar et al., 2014; Willemen et al., 2012). Furthermore, when studying the supplementation of 8% BSFL in the diet of laying hens, it has been shown to improve the quality of eggs, specifically increasing the yolk proportion compared to non-supplemented diet (Agunbiade et al., 2007).

Table 7: Thigh and breast meat yield (%) in Ac chickens (Provide the chickens age, please)

Category	CG (n = 9)	EG1 (n = 9)	EG2 (n = 9)
Live weight (g)	$592^{c} \pm 37.0$	$713^{b} \pm 22.4$	$751^{a} \pm 52.6$
Carcass weight (g)	$359^{c} \pm 28.5$	$453^{b} \pm 33.2$	$481^{a} \pm 53.0$
Carcass yield (%)	$60.6^{b} \pm 2.99$	$63.5^{a} \pm 3.71$	$63.9^{a} \pm 3.09$
Thigh meat weight (g)	$61.3^{c} \pm 11.3$	$81.1^{b} \pm 8.49$	$88.7^{a} \pm 14.4$
Thigh meat yield (%)	$17.0^{b} \pm 1.97$	$18.0^{a} \pm 2.09$	$18.4^{a} \pm 2.00$
Breast meat weight (g)	$47.8^{c} \pm 6.74$	$71.3^{b} \pm 9.43$	$77.6^{a} \pm 28.5$
Breast meat yield (%)	$13.3^{b} \pm 1.00$	$15.7^{a} \pm 1.54$	$16.1^{a} \pm 5.54$
Average weight of thigh and breast meat (g)	$54.6^{c} \pm 8.79$	$76.2^{b} \pm 6.48$	$83.1^{a} \pm 19.6$
Thigh and breast meat yield (%)	$30.3^{b} \pm 2.71$	$33.7^{a} \pm 2.42$	$34.6^{a} \pm 7.01$

abc Means in the same row without common letter are different at $p < 0.05$

Table 8: Amino acid content in Ac chicken meat by different treatments

	Amino acid content %)		
Type of amino acid	**CG (*n* = 9)**	**EG1 (*n* = 9)**	**EG2 (*n* = 9)**
Essential amino acids			
Methionine	0.85	0.89	0.92
Histidine	1.32	1.30	1.27
Threonine	0.87	0.90	0.93
Valine	0.06	0.05	0.04
Phenylalanine	0.78	0.81	0.84
Isoleucine	0.97	0.96	0.94
Leucine	0.63	0.58	0.53
Lysine	1.07	1.09	1.11
Sub-total	6.55	6.58	6.58
Non-essential amino acids			
Alanine	0.61	0.63	0.64
Tyrosine	1.83	1.81	1.79
Glutamic	2.23	2.38	2.52
Serine	1.23	1.32	1.41
Cystine	1.82	1.86	1.89
Glycine	0.95	0.94	0.93
Aspartic acid	1.48	1.51	1.54
Arginine	1.12	1.10	1.07
Proline	1.02	1.00	0.97
Sub-total	12.3	12.6	12.8
Total amino acids	18.8	19.1	19.3

In addition, the supplementation of BSFL also improves the flavor and sweetness of the meat, as reflected in the higher content of glutamic acid. EG2 has the highest glutamic acid content (2.52%) compared to EG1 (2.38%) and the lowest in the control formulation (2.23%). Glutamic acid plays a leading role in current food as it contributes to the sweetness and deliciousness of meat (Nguyen 2010). Another study has investigated the relationship between energy metabolism, crude protein, and amino acids in broiler chickens and has found that the quality of crude protein depends on essential amino acids, especially lysine, methionine, cystine, threonine, and some amino acids interact with each other such as methionine and cysteine, phenylalanine and tyrosine (Vo, 2019). In this study, the crude protein of bone meal has high levels of essential amino acids such as lysine and threonine, but the quantity and ratio of amino acids are imbalanced compared to BSFL, which is a crucial aspect in formulating the diet for poultry. Furthermore, it was found that if the ratio of amino acids in the protein is balanced according to the animal nutritional needs, the protein oxidation to provide energy will be lower, and if the crude protein content is high but the amino acids, especially essential amino acids, are unbalanced, the requirements for each amino acid will also change (Le et al., 2014). The current study reemphasized the importance of finding a protein source with balanced quantities and ratios of amino acids. Interactions exist among amino acids. In chickens, the lysine requirement increases when the diet is low in methionine, arginine, and B-group vitamins.

This interaction occurs because one amino acid is converted into another. If the diet lacks cystine or its exchange form cysteine, cystine will be synthesized from methionine. Thus, the methionine requirement depends on the cysteine or cystine content in the diet, and these two amino acids always go together. Hence, the term "methionine + cystine requirement" is used. However, methionine is not synthesized from cystine, so methionine must always be present in part to meet the animal's needs. Phenylalanine and tyrosine have a similar relationship. In chickens, glycine and serine can be converted into each other. If protein is used for energy production, the amino acid requirements will also change. The most amino acid used in establishing nutritional requirements is lysine. The amino acids in the diet always exceed the desired ratio, so they are deficient compared to the requirements. These deficient amino acids are called limiting amino acids. Lysine and methionine are the first two limiting amino acids in most types of animal feed in Vietnam (Le, 2002). Since cysteine can be synthesized from methionine, cysteine (or cystine) can meet 50% of the requirement for the total amount of sulfur-containing amino acids (methionine + cysteine). In this way, cysteine can reduce the requirement for methionine. Similarly, for the group of aromatic amino acids, phenylalanine can meet the requirement for the total amount of phenylalanine and tyrosine (aromatic amino acids) because the conversion of phenylalanine can generate tyrosine. Tyrosine can meet at least 50% of the total requirement for these two amino acids, but it is not the only source and cannot replace phenylalanine because it cannot be converted into phenylalanine (Ho et al., 2006). The relationship between amino acids and protein reflects the protein's quality. An ideal protein is considered as the one that balances essential and non-essential amino acids, providing a complete and appropriate ratio of essential amino acids required by the animal (Le et al., 2014). Therefore, the analyzed ratio and content of amino acids in BSFL in this study are well-suited and a reasonable choice for poultry farming in general and Ac chickens in particular.

The findings of this research on the effects of substituting BSFL in the feed of Ac chickens have significant importance and several implications. Firstly, the study demonstrates that incorporating BSFL into the diet of Ac chickens resulted in notable improvements in weight gain. The EG2 group, which received 100% BSFL as substitution of bone meal, exhibited the highest average weight, indicating the potential of this dietary substitution to enhance chicken growth and productivity. Moreover, the increased chest circumference and body length in the EG2 group suggest that BSFL supplementation may contribute to overall body development and size.

Additionally, the higher proportions of valuable meat portions, such as thigh meat and breast meat, in the supplemented groups highlight the potential for improved meat yield, which is of great significance in the poultry industry. Furthermore, the higher total amino acid content and essential amino acid content in the meat of chickens receiving BSFL emphasize the nutritional benefits of this dietary alternative. These findings have implications for sustainable animal feed production, as BSFL offer a promising source of protein and can help reduce reliance on traditional feed ingredients. The research outcomes provide valuable insights for poultry farmers, feed manufacturers, and policymakers, supporting the exploration and adoption of alternative and sustainable protein sources in animal nutrition.

While the study on the effects of substituting bone meal with BSFL in the feed of Ac chickens provides valuable insights, it also has certain limitations. Firstly, the study only focused on one specific breed of chicken (Ac chickens), which may limit the generalizability of the findings to other chicken breeds. Additionally, the sample size of 108 chickens, divided into three groups, is relatively small, which could affect the statistical power and reliability of the results. Furthermore, the study duration from 5 weeks to 13 weeks of age may not capture the long-term effects of the dietary changes on the chickens. It would be beneficial to observe the effects over a more extended period. Moreover, while the study measured weight gain, body measurements, meat yield, and amino acid content, it did not investigate other important parameters such as cost-effectiveness, feed conversion ratio and efficiency, and potential effects on gut health and immune response in chickens. Therefore, long-term studies are needed to assess the extended effects of BSFL meal on chicken growth, carcass composition, and overall health. Such investigations will provide more comprehensive insights into the practical application and potential benefits of BSFL meal in poultry production systems.

CONCLUSION

This study highlights the significant benefits of incorporating BSFL meal as a highly nutritious feed for Ac chickens. The addition of up to 12% of BSFL as a partial feed ingredient resulted in improved weight gain, body measurements, meat yield (thigh and breast meat), and amino acid content in the meat of Ac chickens. These findings underscore the potential of BSFL as a sustainable and efficient protein source for poultry nutrition.

REFERENCES

Agunbiade JA, Adeyemi OA, Ashiru OM, Awojobi HA, Taiwo A, Oke DB & Adekunmisi AA. **(2007)**. Replacement of Fish Meal with Maggot Meal in Cassava-based Layers' Diets. The Journal of Poultry Science, **44(3)**, 278–282. https://doi.org/10.2141/jpsa.44.278

Alexandratos N & Bruinsma J. **(2012)**. World Agriculture Towards 2030/2050: The 2012 Revision (No. **12**; 03). FAO.

Aronal A, Huda N & Ahmad R. **(2012)**. Amino Acid and Fatty Acid Profiles of Peking and Muscovy Duck Meat. International Journal of Poultry Science, **11(3)**, 229–236.

Attivi K, Agboka K, Mlaga G K, Oke O E, Teteh A, Onagbesan O & Tona K. **(2020)**. Effect of Black Soldier Fly (Hermetia Illucens) Maggots Meal as a Substitute for Fish Meal on Growth Performance, Biochemical Parameters and Digestibility of Broiler Chickens. International Journal of Poultry Science, **19(2)**, 75–80. https://doi.org/10.3923/ijps.2020.75.80

Banks IJ, Gibson WT & Cameron MM. **(2014)**. Growth rates of black soldier fly larvae fed on fresh human faeces and their implication for improving sanitation. Tropical Medicine \& International Health, **19(1)**, 14–22. https://doi.org/https://doi.org/10.1111/tmi.12228

Chi X, Ding X, Peng X, Li X & Fang J. **(2017)**. Broilerlerde kitosan olisakkarit ilavesinin immun organlarda hücre siklusu üzerine etkileri. Kafkas Universitesi Veteriner Fakultesi Dergisi, **23(6)**, 1003–1006. https://doi.org/10.9775/kvfd.2017.17997

Cuc NTK, Weigend S, Tieu HV & Simianer H. **(2011)**. Conservation priorities and optimum allocation of conservation funds for Vietnamese local chicken breeds. Journal of Animal Breeding and Genetics, **128(4)**, 284–294. https://doi.org/10.1111/j.1439-0388.2010.00911.x

Cullere M, Tasoniero G, Giaccone V, Miotti-Scapin R, Claeys E, De Smet S & Dalle Zotte A. **(2016)**. Black soldier fly as dietary protein source for broiler quails: apparent digestibility, excreta microbial load, feed choice, performance, carcass and meat traits. Animal□: An International Journal of Animal Bioscience, **10(12)**, 1923–1930. https://doi.org/10.1017/S1751731116001270

Duong NK, Tran TV, Le TH, de Caters A & Crielaard G. **(2017)**. Ruoi Linh Den: Loai con trung an toan, huu ich cho chan nuoi cong nghiep (Black soldier fly (*Hermetia illucens*): A safe and useful insect for industrial livestock). Quoc Gia TP Ho Chi Minh Publisher.

Edwards C & Niederer A. **(1988)**. The production and processing of earthworm protein. In C. Edwards & E. Neuhauser (Eds.), Earthworms in waste and environmental management (pp. 169–180). The Hague, Netherland.

El Boushy ARY & van der Poel AFB. **(2002)**. Handbook of Poultry Feed from Waste: Processing and Use. Springer Dordrecht.

Elahi U, Xu CC, Wang J, Lin J, Wu SG, Zhang HJ & Qi GH. **(2022)**. Insect meal as a feed ingredient for poultry. Animal Bioscience, **35(2)**, 332–346. https://doi.org/10.5713/ab.21.0435

FAO. 2011. World Livestock. **(2011)**. Livestock in food security. Retrieved April 1, 2023, from https://www.fao.org/3/i2373e/i2373e00.htm

Ho TT, Le VA, Nguyen TL, Do QH & Cao DN. **(2006)**. Giao trinh Hoa Sinh Dong Vat (Textbook of Animal Biochemistry). Nong Nghiep Publisher.

Huang X, Weng Z, He Y, Miao Y, Luo W, Zhang X, Zhong F & Du B. **(2021)**. Mitochondrial DNA diversity and demographic history of Black-boned chickens in China. Mitochondrial DNA Part B: Resources, **6(4)**, 1462–1467. https://doi.org/10.1080/23802359.2021.1912668

Kaya M, Erdogan S, Mol A & Baran T. **(2015)**. Comparison of chitin structures isolated from seven Orthoptera species. International Journal of Biological Macromolecules, **72**, 797–805. https://doi.org/10.1016/j.ijbiomac.2014.09.034

Khan M, Chand N, Khan S, Khan RU & Sultan A. **(2018)**. Utilizing the house fly (Musca domestica) larva as an alternative to soybean meal in broiler ration during the starter phase. Revista Brasileira de Ciencia Avicola, **20(1)**, 9–14. https://doi.org/10.1590/1806-9061-2017-0529

Khan S, Khan RU, Sultan A, Khan M, Hayat SU & Shahid MS. **(2016)**. Evaluating the suitability of maggot meal as a partial substitute of soya bean on the productive traits, digestibility indices and organoleptic properties of broiler meat. Journal of Animal Physiology and Animal Nutrition, **100(4)**, 649–656. https://doi.org/10.1111/jpn.12419

Khumpeerawat P, Duangjinda M & Phasuk Y. **(2021)**. Factors affecting gene expression associated with the skin color of black-bone chicken in Thailand. Poultry Science, **100(11)**, 101440. https://doi.org/10.1016/j.psj.2021.101440

Le DN. **(2002)**. Giao trinh dinh duong gia suc (Animal nutrition course). Nong Nghiep Publisher.

Le DN, & Du TH. **(2014)**. Giao trinh dinh duong vat nuoi (Animal nutrition curriculum). Hue University Press.

Le TP, Tran TT & Nguyen TN. **(2023)**. Genetic variants of INHA/PstI and VIPR1/HhaI and their relationship with reproductive traits in Ac chicken (Gallus gallus domesticus Brisson). Veterinary Integrative Sciences, **21**(3 SE-Research Articles), 831–841. https://he02.tci-thaijo.org/index.php/vis/article/view/263857

Lee CG, Da Silva CA, Lee JY, Hartl D & Elias JA. **(2008)**. Chitin regulation of immune responses: an old molecule with new roles. Current Opinion in Immunology, **20(6)**, 684–689. https://doi.org/https://doi.org/10.1016/j.coi.2008.10.002

Li XJ, Piao XS, Kim SW, Liu P, Wang L, Shen YB, Jung SC & Lee HS. **(2007)**. Effects of chito-oligosaccharide supplementation on performance, nutrient digestibility, and serum composition in broiler chickens. Poultry Science, **86(6)**, 1107–1114. https://doi.org/10.1093/ps/86.6.1107

Lu S, Taethaisong N, Meethip W, Surakhunthod J, Sinpru B, Sroichak T, Archa P, Thongpea S, Paengkoum S, Purba RAP & 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)**, 1–17. https://doi.org/10.3390/insects13090831

Makkar HPS, 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. https://doi.org/https://doi.org/10.1016/j.anifeedsci.2014.07.008

Maurer V, Holinger M, Amsler Z, Früh B, Wohlfahrt J, Stamer A & Leiber F. **(2016)**. Replacement of soybean cake by Hermetia illucens meal in diets for layers. Journal of Insects as Food and Feed, **2(2)**, 83–90. https://doi.org/10.3920/JIFF2015.0071

Nguyen CB. **(1979)**. Co so sinh hoc cua nhan giong va nuoi duong gia cam (Biological basis of poultry breeding and rearing). Khoa Hoc & Ky Thuat Publisher.

Nguyen TH. **(2010)**. Nghien cuu kha nang san xuat cua giong ga thit long mau Sasso nuoi tai mien Bac Vietnam (Research on the production capacity of Sasso colored broiler chickens raised in North Vietnam). Thai Nguyen University Press.

Okah U & Onwujiariri EB. **(2012)**. Performance of finisher broiler chickens fed maggot meal as a replacement for fish meal. International Journal of Agricultural Technology, **8**, 471–477.

Pham TN. **(2014)**. Nghien cuu gia tri dinh duong cua mot so loai thuc an trong chan nuoi ga Sao giai doan sinh truong o Dong Bang Song Cuu Long (Study on the nutritional value of some types of feed in raising Sao chickens in the Mekong Delta). Hue University Press.

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

Schiavone A, De Marco M, Martínez S, Dabbou S, Renna M, Madrid J, Hernandez F, Rotolo L, Costa P, Gai F & 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)**, 1–9. https://doi.org/10.1186/s40104-017-0181-5

TCVN12621. **(2019)**. Xac dinh ham luong axit amin bang phuong phap sac ky long hieu nang cao (Determination of amino acids by high performance liquid chromatography) Retrieved April 1, 2023, from https://tieuchuan.vsqi.gov.vn/tieuchuan/view?sohieu=TCVN+12621%3A2019%C2%A0

Vo VH. **(2019)**. Moi quan he giua nang luong trao doi, protein tho va cac axit amin doi voi ga thit (Relationship between metabolic energy, crude protein and amino acids for broilers). https://agr.htu.edu.vn/gioi-thieu/moi-quan-he-giua-nang-luong-trao-doi-protein-tho-va-cac-axit-amin-doi-voi-ga-thit.html

Willemen L, Veldkamp A, Verburg PH, Hein L & Leemans R. **(2012)**. A multi-scale modelling approach for analysing landscape service dynamics. Journal of Environmental Management, **100**, 86–95. https://doi.org/https://doi.org/10.1016/j.jenvman.2012.01.022

Zhuang Z, Zhao L, Zong W, Guo Q, Li X, Bi Y, Wang Z, Jiang Y, Chen G, Li B, Chang G & Bai H. **(2023)**. Genetic diversity and breed identification of Chinese and Vietnamese local chicken breeds based on microsatellite analysis. Journal of Animal Science, **101**, skad182. https://doi.org/10.1093/jas/skad182