Original scientific paper
DOI: /10.5513/JCEA01/27.1.4693
Journal of Central European Agriculture, 2026, 27(1), p.57-68

Black soldier fly (*Hermetia illucens*) larvae meal as an innovative feed source: analysis of its effect on broiler thigh quality

Hmyzia múčka z lariev muchy čiernej (*Hermetia illucens*) ako inovatívny zdroj krmiva: analýza jej vplyvu na kvalitu stehien brojlerov

Stanislava DROTÁROVÁ, Branislav GÁLIK (✉), Milan ŠIMKO, Miroslav JURÁČEK, Michal ROLINEC, Ondrej HANUŠOVSKÝ, Mária KAPUSNIAKOVÁ, Matúš DŽIMA, Eva MIXTAJOVÁ, Kristína KOLBASKÁ

Institute of Nutrition and Genomics, Faculty of Agrobiology and Food Resources, Slovak Agriculture University in Nitra, Trieda Andreja Hlinku 2, 949 76 Nitra

✉ Corresponding author: branislav.galik@uniag.sk

Received: February 3, 2025; accepted: October 1, 2025

ABSTRACT

The increased demand for poultry meat production, linked to the ever-growing global population, is exerting pressure on poultry meat producers. However, current trends emphasize sustainable, low-impact organic production. Consequently, the circular economy and the use of insects in production are coming to the fore as a potential for reducing biowaste and producing an alternative high-protein feed. The objective of the experiment was to observe the impact of varying concentrations of partially defatted insect meal from black soldier fly larvae (*Hermetia illucens*) on the qualitative and quantitative attributes of thigh muscle and bone in broiler poultry. The objective was to utilize an alternative protein source and to replace commercially fed soybean protein in the diets at replacement levels of 50% and 100%. A total of 131 Cobb 500 hybrid broilers were fattened for a period of 37 days. At the conclusion of the fattening period, 30 birds were selected for laboratory analysis and evaluation of baseline parameters. The effect of feeding the alternative protein source was found to have a statistically significant impact on the growth parameters of thigh muscle and bone length in broilers ($P<0.05$). The highest mean weight of thighs was observed in the experimental group, which received 100% of the alternative protein source, at 279.23 g, while the longest tibia bone was 91 mm in the same group. No significant changes were noted in the qualitative composition of the diet. The highest levels of lauric acid (C12:0) (6.45) and saturated fatty acids (38.44) were found in the 100% group.

Keywords: circular economy, insect meal, black soldier fly, broiler thigh quality, fatty acids

ABSTRAKT

Zvýšený dopyt po produkcii hydinového mäsa súvisí so stále rastúcim počtom obyvateľov na svete a vyvíja tlak na výrobcov hydinového mäsa. Súčasné trendy však kladú dôraz na udržateľnú ekologickú výrobu s nízkym vplyvom na životné prostredie, preto sa do popredia dostáva obehové hospodárstvo a využívanie hmyzu vo výrobe ako potenciálny prostriedok na zníženie biologického odpadu a výrobu alternatívneho krmiva s vysokým obsahom bielkovín. Cieľom experimentu bolo sledovať vplyv rôznych koncentrácií čiastočne odtučnenej hmyzej múčky získanej z lariev muchy čiernej (*Hermetia illucens*) na kvalitatívne a kvantitatívne vlastnosti stehennej svaloviny a kostí u brojlerovej hydiny. Cieľom bolo využiť alternatívny zdroj bielkovín pochádzajúci z lariev muchy čiernej a nahradiť komerčne skrmované sójové bielkoviny v krmivách na úrovni náhrady 50 % a 100 %. Celkovo bolo vykrmovaných 131 brojlerov hybridu Cobb 500 počas 37 dní. Na konci výkrmu sa vybralo 30 jedincov na laboratórnu analýzu a vyhodnotenie základných parametrov. Zistilo sa, že vplyv skrmovania alternatívneho zdroja bielkovín mal štatisticky významný vplyv na rastové parametre stehennej svaloviny a dĺžky kostí brojlerov ($P<0,05$). Najvyššia priemerná hmotnosť sa zaznamenala v pokusnej skupine, ktorá dostávala 100 % alternatívny zdroj bielkovín, a to 279,23 g, pričom najdlhšia holenná kosť bola v tej istej skupine 91 mm. V kvalitatívnom zložení krmiva sa nezaznamenali žiadne významné zmeny. Najvyššie hodnoty kyseliny laurovej (C12:0) (6,45) a nasýtených mastných kyselín (38,44) sa zistili v skupine so 100 % podielom.

Kľúčové slová: obehové hospodárstvo, hmyzia múčka, mucha čierna, kvalita stehien brojlerov, mastné kyseliny

INTRODUCTION

The production, processing and marketing of poultry meat have undergone significant modifications in recent years, most notably changes in consumer preferences. 80% of poultry is sold largely as cut parts and processed products, rather than whole cuts (Barbut and Leishman, 2022). In addition to processing technology, a variety of other factors, such as rearing conditions, pathogen-induced infections, genetics, and feed composition and ration setting, affect the quality, composition, and consumption of poultry meat (Choi et al., 2023). Petracci et al. (2015) reported a global increase in demand for chicken due to its affordable price range, suitable nutritional profile and its suitability for subsequent processing and consumption. However, this increasing demand requires increasing the efficiency of broiler poultry production. The intensity of increasing production requires fast-growing hybrids with slaughter weights of around 2.5 kg and fattening duration of maximum 42 days (Kralik et al., 2018). Valenta et al. (2022) report requirements for fast-growing modern hybrids to reach a minimum weight of 2 kg in 35 days. The growth of broiler poultry is influenced by different rearing technologies, environment and nutrition; genetics also play an important role. At the same time, the protein content and concentration of the feed mix also play a major role. However, protein in compound feed is a costly item, and therefore it is very important to pay increased attention to this feed component (Chodová et al., 2021). A very valuable source of protein in broiler diets is a potentially new feedstuff, insect meal produced from different approved insect species. Due to its content of essential amino acids, fatty acids and antimicrobial peptides, it meets the demanding nutritional requirements of fattening new modern broiler hybrids (Slimen et al., 2023). Insects as a new alternative feed meet the current requirements for sustainable circular farming (de Jong and Nikolík, 2021).

Circular economy in livestock production

Livestock production and its production considering environmentally sustainable production, reducing production and production costs and adapting to the demands of the consumer market are part of the modern world economy (Ramirez et al., 2021). Livestock production is influenced by aggregate factors that are difficult to influence, predict and change. The production of livestock products depends on climatic conditions (rainfall, temperature, drought), economic factors (market, input costs), consumer factors, and commercial market demands and labor sufficiency (Thorton et al., 2010). Current new consumer and production requirements include overseeing environmental sustainability and reducing emissions and greenhouse gas production. Depending on this, the EU Green Deal challenge has been adopted with the aim of reducing emissions and improving and streamlining the sustainable management of natural resources by 2050 (Doyeni et al., 2023). The authors Thornton et al. (2010) report a global increase in human population to as high as 9.15 billion by 2050. They cite the need for increasing food production but warn of the possibility of decreasing food quality and safety. Due to the continuous increase in world population associated with the increasing need for production, it is crucial to ensure the environmental sustainability of livestock production (Ramirez et al., 2021). An alternative and sustainable source of feed in the diet of primarily monogastrics is insects and their processing products (Gasco et al., 2023). de Jong and Nikolík (2021) report an estimate of increasing demand for insect products from the current 120 000 metric tons to a quantity of 500 000 metric tons by 2030, whereby the use of insects in circular management can help recycle bio-waste and agro-food unusable materials and translate them into high-value protein feeds. The production of insects for food and feed purposes has ecological importance in addition to its sustainable significance. The production of insect protein produces significantly lower emissions than other livestock production sectors. The production of 1 kg of insect protein produced from mealworm (*Tenebrio molitor*) produces 1.3-2.7 times lower emissions (kg CO_2-eq/kg edible protein) compared to the poultry industry (Spatola et al., 2024).

Insects as new sustainable feed

Entomophagy is a worldwide phenomenon. Approximately 2100 insect species are commonly consumed and used in either human or animal nutrition in more than 110 countries worldwide (Bingqian et al. 2023). In recent years, also due to the pressure to produce sustainable feeds, the interest in producing insect products for feed purposes has been increasing year by year. Due to this, the high price of insect protein is projected to decrease from approximately EUR 3 500 – 5 000 (the price of a metric ton) in 2020 to EUR 1 500 to 2 500 (the price of a metric ton) in 2023 (Gasco et al., 2023). The rearing of insects within a circular economy is considered beneficial for environmental improvement due to their ability to decompose organic waste and convert it into valuable protein-rich sources of food and feed (van Huis, 2022). In addition to these properties, insects provide positive health benefits for humans, animals and as soil and plant substrate quality improvers due to their specific compounds (Gasco et al., 2023). Due to the pressure on sustainability and environmental impact, there is at the same time pressure to improve legislation within the production and processing processes to produce insect products. However, this pressure needs to be exerted by society, academia, as well as governmental and non-governmental organizations (van Huis, 2022). Black soldier fly (*Hermetia illucens*), yellow mealworm (*Tenebrio molitor*) and common housefly (*Musca domestica*) are among the most commonly involved insect species globally for food and feed production (Gasco et al., 2023), with the domestic cricket (*Acheta domesticus*) and locust (*Locusta migratoria*), for example, also among the insect species approved as Novel Foods by EU legislation (Spatola et al., 2024).

Black soldier fly (Hermetia illucens) as an alternative protein source and quality animal feed

Black soldier fly (BSF) is classified as a saprophytic insect, capable of decomposing any organic materials and wastes into ecological products with a wide range of applications in various industries. The meal obtained from BSF is one of the high-quality protein feeds used in livestock and companion animal nutrition (Liu et al., 2019). The utilization of BSF in the circular economy also allows the use of the end waste product related to insect production, namely the feces obtained from the breeding (frass), which can be used as a quality organic fertilizer in agriculture (Lopes et al., 2022). Another possible segment where BSF can be exploited is the use of BSF larvae and their products as biofuels. The insect is a valuable species capable of high dry matter conversion of organic wastes (depending on the quality and dry matter of the substrate) and production of high-quality protein feed (Bosch et al., 2019). Insect meal is a potential feed with high nitrogen content, antinutrients and specifically active substances suitable for both animal and human nutrition. The use of insect meal from BSF larvae is a potentially suitable feed in the diet of broiler poultry, for which insects are a natural source of nutrients and nitrogen. Insect meal from BSF larvae has a more optimal amino acid composition than soybean meal, while larvae are a rich source of protein (37-63% DM) and fat (7-39%). Depending on its processing (defatted-no fat, defatted-100% fat and partially defatted-50% fat), insect meal can be fed to broiler poultry in the ratio of inclusion in the feed mixture of 25-50% with positive physiological effects (better enzymatic microbial intestinal activity) and positive growth and production parameter (fattening, egg production) (Murawska et al., 2021). In addition to high nitrogen, lipid (lauric acid), mineral and vitamin content, insect meal is characterized by specifically effective lytic substances with antimicrobial, antifungal, anticancer, antiviral, antioxidative and anti-inflammatory effects. The content of essential nutrients and specifically active compounds depends on the growth stage of the insect, its processing and the nutritional composition of the rearing substrate (Bingqian et al. 2023).

Nutritional importance of poultry meat intake

Poultry meat is a valuable source of high-quality, easily digestible protein in the human diet. In addition, it is also characterized by a low concentration of saturated fat, which makes it suitable for consumption by people of all ages (Kralik et al., 2018). Dowarah (2013) states that 3 g fat/100 g of meat, about half of which are monounsaturated fats and only one third are saturated fats, therefore it is suitable for consumption by people prone to cardiovascular disease. The composition of poultry meat and its fatty acid content can be influenced by several factors affecting its quality. For example, the composition of the feed mixture, the addition of feed additives, the use of feed oils, and the addition of vitamins and minerals are the most crucial factors (Kralik et al., 2018). Poultry meat is characterized by a high content of polyunsaturated fatty acids (PUFA), the content of which can be increased by modifying the feed mixture (Bordoni and Danesi, 2017). PUFAs are characterized by their positive properties against diseases such as osteoarthritis, autoimmune diseases, and blood pressure regulation. They can dampen inflammatory processes in the body and regulate cellular metabolism (Kapoor et al., 2021). The study hypothesised that the dietary insect intake will growth rate of chicks, as well as affect the crude fat content and fatty acids composition in experimental groups.

MATERIALS AND METHODS

The above experiment aimed to investigate the effect of feeding different diets with different concentrations of insect meal from BSF larvae on the growth and quality characteristics of thighs (essential nutrient content of thigh muscle, fatty acid content of thigh muscle fat, femur strength - Tibia) of Cobb 500 broiler hybrids. Insect meal from BSF presented an alternative source of protein, replacing soy protein in the experimental diets. The course of the whole experiment was divided into three basic steps (1. Preparation of the experiment and formulation of feed formulas, 2. Implementation of the experiment, 3. Analysis and evaluation of the results). The experiment was conducted for a total of 37 days on 131 broiler poultry of hybrid Cobb 500 in two phases (Phase I and Phase II/III). The experiment took place on a farm focused on poultry production - Gazdovská Hus farm, in the village Sobotište, the Slovak Republic.

Experiment preparation and feed formulation

The first step of the experiment was to provide the breeding facilities, experimental animals, and experimental feed mixtures and to determine the different stages of the experiment. In formulating the feed formulations, we focused on maximizing the potential of an alternative protein source - insect meal (IM) from BSF larvae, which we substituted for the commonly fed soy protein. BSF from larvae was included in the experimental feed mixtures at 50% and 100% replacement ratios for soybean meal extract, while nothing was replaced in the control feed mixture at 0%. Feed formulations were compiled using the QuickChick Calculator program (Evonik-Degussa, GmbH, Germany), with amino acids reported as standardized ileal digestible amino acids. The feed mixtures are present in Table 1 (I. and II.stage of the experiment). The content of fatty acids is reported as present in the fat sample for each feed mixture out of all fatty acids determined in Table 2. (%). Due to its fast growth potential and high feed conversion ability, the hybrid Cobb 500 was found. Insect meal from BSF larvae was sourced from Bioconvert, Ltd. (Nitra, Slovak Republic).

Experiment implementation

The experimental work lasted for 37 days (standard fattening period of experimental farm), with stage I. taking place on day 0-12 of the experiment duration and stage II taking place from day 12-37 of the experiment duration. Stage I of the experiment was carried out in a 90 x 200 cm rearing room with an infrared radiator (light regime 20 lx during the first 7 days, after that reduced to 10 lx). The average number of animals per 1 m^2 was 25. The number of animals in each group at the beginning of the stage was: 0% IM - 44, 50% IM - 44, 100% IM - 43 and at this stage, the feed mixture designed for the first stage of the experiment - BR-I was fed. Stage II was carried out in a 300 x 300 cm room (light regime 10 lx till the age of 21 days). The average number of animals per 1 m^2 was 5 broilers. In each group, the number of animals at the beginning of the stage was: 0% IM - 44, 50% IM - 39, 100% IM - 42 and at the end: 0% IM - 41, 50% IM - 37, 100% IM - 41 and at this stage, the feed mixtuwas re

Table 1. Composition of experimental compound feeds (%)

Component	Stage I.			Stage II.		
	0%	50%	100%	0%	50%	100%
Wheat	19.5	48.40	50.45	20.55	40.70	45.60
Maize	40.0	20.0	19.0	48.0	33.0	28.0
Extracted Soya bean meal	29.0	12.40	-	20.0	10.80	-
Wheat DDGS	-	-	3.0	-	-	4.0
Albumex 102-Broiler	3.15	3.5	7.0	3.40	0.42	2.50
Insect meal (*Hermetia illucens*)	-	12.40	17.5	-	10.80	17.0
Rapeseed Oil	3.50	0.20	-	3.50	1.60	0.40
Calcium 37.8%	1.03	0.80	0.52	0.94	0.85	0.72
Salt	0.27	0.28	0.3	0.25	0.28	0.28
Su Minfos 22.7% P, Ca, L	0.6	0.35	0.3	0.55	0.35	0.35
Premix Treonin 20	0.45	-	-	0.65	-	-
Premix Lysine 40	0.95	0.60	0.85	0.83	0.20	0.15
Premix Methionie 40	0.55	-	-	0.33	-	-
NTR Chicken uni	1	1	1	1	1	1

% – per cent; DDGS – Dried Distillers Grains with Solubles

Table 2. Selected fatty acids present in the fat sample of the experimental compound feed out of all fatty acids determined (%)

Trivial name	Formula	Stage I.			Stage II.		
		0%	50%	100%	0%	50%	100%
Lauric acid	C12:0	-	13.33	19.16	-	7.32	15.26
Myristric acid	C14:0	-	3.05	4.37	-	3.81	2.24
Palmitic acid	C16:0	12.90	14.05	14.04	6.66	11.91	12.21
Palmitoleic acid	C16:1	0.14	1.21	1.70	0.18	4.46	1.29
Stearic acid	C18:0	4.05	4.09	3.93	1.81	2.20	2.25
Oleic acid	C18:1cis n9	24.09	19.74	18.28	50.53	26.04	27.14
Linoleic acid	C18:2cis n6	52.21	38.98	33.30	30.12	34.71	44.02
α -linolenic acid	C18:3 n3	4.29	3.29	2.75	6.0	2.36	2.62
Arachic acid	C20:0	0.41	0.35	0.29	0.51	0.33	-
				Fatty acid profile			
Polyunsaturated fatty acids	PUFA	56.50	42.28	36.18	36.24	37.07	46.64
Monounsaturated fatty acids	MUFA	24.61	21.26	20.38	51.84	27.91	28.44
Saturated fatty acids	SFA	17.80	35.50	42.57	9.41	33.93	24.03

% – percent

designed for the second stage of the experiment - BR-II. /III. was fed. Throughout the duration of the experiment, deep straw litter, feeders and water drinkers were used for ad libitum intake of feed and water. Fat-soluble vitamins A, D3 and K were administered to all animals in potable, safe water throughout the course of the experiment. Poultry were cared for throughout the experiment by an experienced caretaker, and the entire experiment was conducted in accordance with Directive 2010/63 EU of the European Parliament and of the Council of 22 September 2010 on the protection of animals used for scientific purposes. At the end of the experimental period, 10 individuals (30 in total) were randomly selected from each group and were then humanely re-introduced according to the requirements and destined for further analyses. In the average, feed consumption per head and day in the I. stage was 193.53 g (control), 161.7 g (50%) and 117.6 g (100%). In the II. stage 109.9 g (control), 114.2 (50%) and 124.5 g (100%). During the trial, mortality in the control group 6.8%, in the group with 50% supplementation 5.9% and in the group with 100% supplementation 4.7% was respectively.

Analyzing and evaluating results

After the completion of the experimental phase of the experiment, a concrete evaluation of the results took place. In the experiment, we focused on quantitative parameters - thigh muscle uncleaned (with fat and skin) with and without bone and qualitative parameters - and the basic nutrient content and fatty acid content. We also focused on the femur - tibia and its length and strength (shear strength). The analyses (except for bone strength) were carried out at the Slovak University of Agriculture in Nitra, at the Institute of Nutrition and Genomics. The analyses focused mainly on the following basic nutrient parameters: dry matter, crude protein, crude fat, crude ash, nitrogen free extract and analysis of selected fatty acids of interest to the consumer: lauric acid (C12:0), palmitic acid (C16:0), stearic acid (C18:0), oleic acid (C18:1), linoleic acid (C18:2) and alpha-linoleic acid (C18:3). The analysis of femoral bone strength was carried out in the framework of the Erasmus+ mobility in collaboration with the Hungarian University of Agriculture and Social Sciences at the Institute of Animal Physiology and Nutrition, mechanical quality of bones with apparatus Zwick/Roell (Z005). Weight was measured on laboratory digital calibrated scales with 0.1 g of accuracy (Kern PCB 10000, Germany). The following techniques and analyses were used for individual qualitative analyses: dry matter (drying to the constant weight, freeze-drying of samples), crude protein (Kjeldahl method, Kjeltec, FOSS), crude fat (Soxhlet method, Soxtec FOSS), crude ash (burning in a Mufl furnance), nitrogen free extract (calculation), fatty acids (GC Agilent 7890 A analyzer), and bone strength (Zwick/Roell instrument - Z005). For statistical evaluation and processing of the results, SPSS 26.0 (IBM) programs were used to evaluate the basic variability and statistical parameters (arithmetic mean, standard deviation and coefficient of variation). ANOVA-Tukey's HSD test was used to determine the statistical significance of differences between the variants. A significance level of 5% was determined for all significance levels.

RESULTS AND DISCUSSION

Thigh weight

One of the basic carcass traits of fattening broilers is the proportion and weight of thigh muscle. In Table 3, the demonstrated differences in mean weights (g) for the thigh are shown. Across all observed parameters for non-boned and boned and boned thighs, demonstrably ($P<0.05$), the highest mean values in the group with the highest replacement of soy protein by IM from BSF larvae were found. In the 100% replacement group, the mean weight of uncleaned thighs was 279.23 g. The mean clean muscle weight ranged from 169.74 g to 216.52 g in the 100% experimental group. Lalev et al. (2022) reported the same increase in thigh muscle weight in the experimental groups with 10% inclusion of IM from BSF (*Hermetia illucens*) and silkworm (*Bombix mori*) as alternative protein sources in broiler diets. The highest mean weight (759.33 g) was recorded in the experimental group with the addition of *Bombix mori*. The opposite findings were reported by Murawska et al. (2021).

Table 3. Thigh weight (g)

Parameter	Group (n = 10)	Mean	S.D.	*P* - level
Thighs together - uncleaned (g)	0%	239.25[b]	21.04	0.003
	50%	239.02[b]	36.34	
	100%	279.23[a]	21.65	
Thigh with bone (g)	0%	211.58[b]	16.83	0.001
	50%	209.50[b]	23.99	
	100%	240.99[a]	15.13	
Thigh without bone (g)	0%	164.05[b]	3.94	0.004
	50%	163.99[b]	11.44	
	100%	191.32[a]	7.91	
Tibia (g)	0%	28.82	4.32	0.831
	50%	29.18	6.30	
	100%	30.10	3.36	

n – number of observations, g – gram, % – per cent, *P* – significance, [a, b] – values are statistically significant between groups ($P<0.05$)

With the addition of IM from BSF larvae, they observed a statistically significant decrease in thigh muscle weight when feeding diets containing 100% (385.68 g) and 75% (460.41 g) IM.

Content of basic nutrients analyzed in the thigh muscle sample

Basic nutrient analysis of thigh muscle showed statistically significant differences only for dry matter of the original mass and nitrogen-free extract. The results of the basic analysis are presented in Table 4. Except for these parameters ($P<0.05$), only insignificant differences were found ($P>0.05$). The highest mean statistically significant differences ($P<0.05$) for the parameter dry matter of the original mass were recorded in the experimental group without IM content of BSF larvae in the feed mixture (260.68 g). In the case of nitrogen-free extract, the highest mean values were measured in the group with 100% replacement of BSF larvae with IM (7.15 g). The highest mean protein abundance was seen without statistical significance ($P>0.05$) in the experimental group with 100% BSF larvae IM. A tendency ($P>0.05$) of the highest crude fat content in average (25.94%) in the control group of chickens was detected. However, the lowest crude fat content was found in the group with the highest IM supplementation ($P>0.05$). The same results with insignificant changes in the nutrient content of the thigh muscle were also reported by Cullere et al. (2019). The author and his experimental co-investigators similarly substituted soy protein with IM from BSF larvae with an experimental duration of 48 days. The average contents they recorded in the experiment were 75.7% for protein and 18.8% for fat in the thigh muscle. A decrease in the fat content of thigh muscle as a function of increasing IM concentration in the feed mixtures was also reported by Sun et al. (2013).

Content of selected fatty acids analyzed in the thigh muscle sample

The average abundance of selected fatty acids of particular interest from a consumer point of view is presented in Table 5. Lauric acid (C12:0) is characterized by its positive properties from a consumer and human nutrition point of view.

Table 4. Content of basic nutrients in the thigh muscle (g, %)

Parameter	Group (n = 10)	Mean	S.D.	*P* - level
Dry matter of the original mass (g)	0%	260.68[a]	11.98	0.044
	50%	253.43[b]	11.92	
	100%	246.58[b]	11.84	
Crude Protein (%)	0%	67.08	4.37	0.143
	50%	69.01	3.36	
	100%	70.71	4.11	
Crude Fat (%)	0%	25.94	4.02	0.755
	50%	23.89	3.63	
	100%	22.14	4.06	
Crude Ash (g)	0%	4.69	0.80	0.144
	50%	5.04	0.61	
	100%	5.34	0.75	
Nitrogen free extract (%)	0%	2.45[b]	1.71	0.001
	50%	4.59[b]	2.71	
	100%	7.15[a]	1.02	

n – number of observations, g – gram, % – per cent, *P* – significance, [a, b] – values are statistically significant between groups (P<0.05)

In metabolism, it serves as a rapid source of energy, as it is not stored in adipose tissue but directly in the liver. Among the saturated fatty acids (SFA), lauric acid contributes the least to fat accumulation. It also shows antimicrobial activity against Gram-positive bacteria, fungi and viruses (Dayrit, 2015). Statistically, the highest mean showed recorded values of this acid C12:0 (P<0.05), were seen in the experimental group 100% (6.45) and 50% (4.61), while we did not observe its values in the 0% group. The same increases in C12:0 were also reported by Cullere et al. (2019). Ulbricht and Southgate (1991) report possible health risks with hypercholesterolemic properties; however, the author Dayrit (2015) reports inconsistent results of different trials due to different effects of C12:0 on serum cholesterol. Palmitic (C16:0) and stearic acids (C18:0), as well as C12:0, are among the SFAs. For both fatty acids, we observed the highest statistically significant mean results (P<0.05) in the experimental groups with the highest IM replacement from BSF larvae (100% C16:0- 23.97, 100% and 50% C18:0- 4.95) in the experimental groups with the highest IM replacement from BSF larvae (100% C16:0- 23.97, 100% and 50% C18:0- 4.95, respectively). Thijssen and Mensink (2005) reported the possibility of a potential risk of cardiovascular disease associated with the consumption of these fats, but in the case of C18:0, the authors report the results of a study where no effect on total cholesterol concentrations was observed by consuming this fatty acid. Pravst (2014) reports the value of intake of SFA´s according to the WHO at 10%. Cullere et al. (2019) saw the same increase in C16:0 content along with an increase in IM content from BSF larvae in feed mixtures. Oleic acid (C18:0 1cis n9) belongs to the monounsaturated fatty acids (MUFA). For this fatty acid, we saw statistical evidence of differences between experimental groups (P<0.05) associated with the increase in the content of

Table 5. Content of selected fatty acids analyzed in the thigh muscle sample (% fatty acids in fat)

Trivial name	Formula	Group (n = 10)	Mean	S.D.	*P* - level
Lauric acid	C12:0	0%	0[c]	0	0.001
		50%	4.61[b]	0.38	
		100%	6.45[a]	0.52	
Palmitic acid	C16:0	0%	18.14[c]	1.01	0.001
		50%	23.53[b]	1.08	
		100%	23.97[a]	0.77	
Stearic acid	C18:0	0%	4.49[b]	0.38	0.020
		50%	4.96[a]	0.52	
		100%	4.96[a]	0.27	
Oleic acid	C18:1cis n9	0%	48.34[a]	1.02	0.001
		50%	38.27[b]	1.39	
		100%	37.48[b]	1.12	
Linoleic acid	C18:2cis n6	0%	17.73[a]	0.65	0.001
		50%	14.05[b]	0.82	
		100%	12.09[c]	0.89	
α-linolenic acid	C18:3 n3	0%	2.35[a]	0.19	0.001
		50%	0.85[b]	0.06	
		100%	0.73[b]	0.08	
Polyunsaturated fatty acids	PUFA	0%	20.37[a]	0.81	0.001
		50%	15.19[b]	0.96	
		100%	12.90[c]	0.90	
Monounsaturated fatty acids	MUFA	0%	53.39[a]	0.90	0.001
		50%	46.60[b]	1.59	
		100%	45.86[b]	1.20	
Saturated fatty acids	SFA	0%	23.02[c]	1.40	0.001
		50%	35.50[b]	1.63	
		100%	38.44[a]	0.37	

n – number of observations, % – per cent, *P* – significant; [a,b,c] – a,b,c values are statistically significant between groups ($P<0.05$)

IM from BSF larvae in the experimental feed mixtures. The highest mean measured content was seen in the 0% experimental group (48.34), while the highest was seen in the 100% experimental group (37.48). Cullere et al. (2019) did not see any statistically significant differences (*P*>0.05) for this MUFA. Pravst (2014) reported positive effects of C18:0 intake on lowering blood cholesterol. Polyunsaturated fatty acids (PUFA) reported in Table 4 are represented by linoleic acid (C18:2cis n6) and α-linolenic acid (C18:3 n3). For both PUFA´s, we saw statistically significant results (*P*>0.05) with the highest values mainly in the groups without IM from BSF larvae in the feed mixtures (0%). The C18:2cis n6 and C18:3cis n3 contents were 17.73 and 2.35, respectively. Both acids are essential fatty acids for humans (Pravst, 2014). Cullere et al. (2019) reported the same decrease in C18:2cis n6 in thigh muscle with increasing IM content in the feed mixture. High concentrations of C12:0 can block the synthesis of C18:0 1cis n9 in fat metabolism (Smink et al., 2010). The content of total fatty acids, specifically SFA, MUFA and PUFA, rejects the representation of the unit fatty acids reported. The highest statistically significant mean SFA content was recorded in the highest IM group at 100% (38.44). On the contrary, in the case of MUFA and PUFA, the highest measured mean values (*P*<0.05) were recorded in the experimental groups without IM content of BSF larvae in the 0% feed mixture (MUFA - 53.39 and PUFA - 20.37). The same findings are also reported by Cullere et al. (2019).

Strength of bones – Tibia

Bone strength is a principal factor indicating the quality of broiler rearing. We saw statistically significant differences (*P*<0.05) for the bone length parameter in Table 6. We saw statistically significant differences (*P*<0.05) for the bone length parameter as a function of increasing replacement of the allergenic IM protein from BSF larvae. The longest mean bone length - Tibia was seen in the group with 100% IM replacement (91 mm), while a similar mean bone length was also observed in the group with 50% replacement (88.9 mm). For the mean shear force values found, we did not see statistically significant differences between the groups (*P*>0.05). The lowest mean shear force was seen in the 100% group (5.86 N/mm^2), and the lowest shear force may be related to the greatest mean bone length seen in the same experimental group. Moyo et al. (2021) report related results with average bone length. They recorded the longest mean length in the group with the highest insect addition from the larvae of the Gonibrasia belina butterfly (*Imbrasia belina*), but did not observe any demonstrable results related to bone strength. In contrast, Loponte et al. (2017) reported different results, with the longest femur length recorded in the group without IM from *Tenebrio mollitor* or *Hermetia illucens* larvae in the feeding mixture.

Table 6. Strength of bones - *Tibia*

Parameter	Group (n = 10)	Mean	S.D.	*P* - level
Length of cleaned bone (mm)	0%	83.3^a	3.89	0.001
	50%	88.9^b	5.50	
	100%	91.0^b	3.02	
Shear force (N/mm^2)	0%	6.53	3.03	0.050
	50%	7.31	3.17	
	100%	5.86	1.83	

n – number of observations, g – gram, % – per cent, *P* – significance, $^{a, b}$ – values are statistically significant between groups (*P*<0.05)

CONCLUSIONS

The results allow for an analysis of the positive and potentially negative characteristics of the IM feeding of BSF larvae to fattening poultry. A study showed that IM feeding supplementation can reduce the mortality of broilers during the fattening period. However, after the feeding adaptation, there aren´t problem with IM intake. Supplementation with IM can improve the performance, thigh muscle yield and partially improve the production health of chickens. Feeding of IM of BSF larvae didn´t affect the quality of chicken meat. Further studies and monitoring of the effects of IM from BSF larvae on fattening and quality parameters are necessary, as the increased SFA content may potentially be suboptimal.

ACKNOWLEDGEMENT

This study was supported by the project of the Science Grant Agency of the Slovak Ministry of Education, Research, Development and Youth and the Slovak Academy of Sciences (project n. 1/0384/24).

REFERENCES

Barbut, S., Leishman, E. M. (2022) Quality and processability of modern poultry meat. Animals, 12 (20), 2766. DOI: https://doi.org/10.3390/ani12202766

Belhadj Slimen, I., Yerou, H., Ben Larbi, M., M'Hamdi, N., Najar, T. (2023) Insects as an alternative protein source for poultry nutrition: a review. Frontiers in Veterinary Science, 10, 1200031. DOI: https://doi.org/10.3389/fvets.2023.1200031

Bingqian, N., Ali Shah, A., Matra, M., Wanapat, M., Ullah Khan, R., Ahmad, S., Ullah S., Shuaib Khan M., Kamal Shah, M. (2023) Insect bioactive compounds and their potential use in animal diets and medicine. Entomological Research, 53(11), 429-443. DOI: https://doi.org/10.1111/1748-5967.12682

Bordoni, A., Danesi, F. (2017) Poultry meat's nutritive value and human health. In: Poultry quality evaluation. Woodhead Publishing, pp. 279-290. DOI: https://doi.org/10.1016/B978-0-08-100763-1.00011-8

Bosch, G., Van Zanten, H. H. E., Zamprogna, A., Veenenbos, M., Meijer, N. P., Van der Fels-Klerx, H. J., Van Loon, J. J. A. (2019) Conversion of organic resources by black soldier fly larvae: Legislation, efficiency and environmental impact. Journal of Cleaner Production, 222, 355-363. DOI: https://doi.org/10.1016/j.jclepro.2019.02.270

Chodová, D., Tůmová, E., Ketta, M. (2021) The response of fast-, medium-and slow-growing chickens to a low protein diet. Czech Journal of Animal Science, 66 (3), 97-105. DOI: https://doi.org/10.17221/260/2020-CJAS

Choi, J., Kong, B., Bowker, B. C., Zhuang, H., & Kim, W. K. (2023) Nutritional strategies to improve meat quality and composition in the challenging conditions of broiler production: a review. Animals, 13 (8), 1386. DOI: https://doi.org/10.3390/ani13081386

Cullere, M., Schiavone, A., Dabbou, S., Gasco, L., Dalle Zotte, A. (2019) Meat quality and sensory traits of finisher broiler chickens fed with black soldier fly (*Hermetia illucens* L.) larvae fat as alternative fat source. Animals, 9 (4), 140. DOI: https://doi.org/10.3390/ani9040140

Dayrit, F. M. (2015) The properties of lauric acid and their significance in coconut oil. Journal of the American Oil Chemists' Society, 92, 1-15. DOI: https://doi.org/10.1007/s11746-014-2562-7

de Jong, B., Nikolik, G. (2021) No longer crawling: insect protein to come of age in the 2020s. RaboResearch, Rabobank, Utrecht, the Netherlands.

Dowarah, R. (2013) The role of poultry meat and eggs in human nutrition. Poultry Line, June, 31-33. UP-243122

Doyeni, M. O., Barcauskaite, K., Buneviciene, K., Venslauskas, K., Navickas, K., Rubezius, M., Tilvikiene, V. (2023) Nitrogen flow in livestock waste system towards an efficient circular economy in agriculture. Waste Management & Research, 41 (3), 701-712. DOI: https://doi.org/10.1177/0734242X221123484

Gasco, L., Renna, M., Bellezza Oddon, S., Rezaei Far, A., Naser El Deen, S., Veldkamp, T. (2023). Insect meals in a circular economy and applications in monogastric diets. Animal Frontiers, 13 (4), 81-90. DOI: https://doi.org/10.1093/af/vfad016

Kapoor, B., Kapoor, D., Gautam, S., Singh, R., Bhardwaj, S. (2021). Dietary polyunsaturated fatty acids (PUFAs): Uses and potential health benefits. Current nutrition reports, 10, 232-242. DOI: https://doi.org/10.1007/s13668-021-00363-3

Kralik, G., Kralik, Z., Grčević, M., Hanžek, D. (2018) Quality of chicken meat. Animal husbandry and nutrition, 63. DOI: https://dx.doi.org/10.5772/intechopen.72865

Lalev, M., Hristakieva, P., Mincheva, N., Oblakova, M., Ivanova, I. (2022) Insect meal as alternative protein ingredient in broiler feed. Bulgarian Journal of Agricultural Science, 28 (4), 743-751.

Liu, C., Wang, C., Yao, H. (2019) Comprehensive resource utilization of waste using the black soldier fly (*Hermetia illucens* (L.)) (Diptera: Stratiomyidae). Animals, 9 (6), 349. DOI: https://doi.org/10.3390/ani9060349

Lopes, I. G., Yong, J. W., Lalander, C. (2022) Frass derived from black soldier fly larvae treatment of biodegradable wastes. A critical review and future perspectives. Waste Management, 142, 65-76. DOI: https://doi.org/10.1016/j.wasman.2022.02.007

Loponte, R., Nizza, S., Bovera, F., De Riu, N., Fliegerova, K., Lombardi, P., Vassalotti, G., Mastellone V., Nizza A., Moniello, G. (2017) Growth performance, blood profiles and carcass traits of Barbary partridge (*Alectoris barbara*) fed two different insect larvae meals (*Tenebrio molitor* and *Hermetia illucens*). Research in Veterinary Science, 115, 183-188. DOI: https://doi.org/10.1016/j.rvsc.2017.04.017

Moyo, S., Jaja, I. F., Mopipi, K., Masika, P., Muchenje, V. (2021) Effect of graded levels of *Imbrasia belina* meal on blood lipid profile, bone morphometric and mineral content of broiler chickens. Animal Feed Science and Technology, 271, 114736. DOI: https://doi.org/10.1016/j.anifeedsci.2020.114736

Murawska, D., Daszkiewicz, T., Sobotka, W., Gesek, M., Witkowska, D., Matusevičius, P., Bakuła, T. (2021) Partial and total replacement of soybean meal with full-fat black soldier fly (*Hermetia illucens* L.) larvae meal in broiler chicken diets: impact on growth performance, carcass quality and meat quality. Animals, 11 (9), 2715. DOI: https://doi.org/10.3390/ani11092715

Petracci, M., Mudalal, S., Soglia, F., Cavani, C. (2015) Meat quality in fast-growing broiler chickens. World's Poultry Science Journal, 71 (2), 363-374. DOI: https://doi.org/10.1017/S0043933915000367

Pravst, I. (2014) Oleic acid and its potential health effects. In: Whelan, L. ed. Oleic acid: Production, Uses and Potential Health Efffects. New York: Nova Science Pub, 35-54.

Ramirez, J., McCabe, B., Jensen, P. D., Speight, R., Harrison, M., Van Den Berg, L., O'Hara, I. (2021) Wastes to profit: a circular economy approach to value-addition in livestock industries. Animal Production Science, 61 (6), 541-550. DOI: https://doi.org/10.1071/AN20400

Smink, W., Gerrits, W. J. J., Hovenier, R., Geelen, M. J. H., Verstegen, M. W. A., Beynen, A. C. (2010) Effect of dietary fat sources on fatty acid deposition and lipid metabolism in broiler chickens. Poultry Science, 89 (11), 2432-2440. DOI: https://doi.org/10.3382/ps.2010-00665

Spatola, G., Giusti, A., Mancini, S., Tinacci, L., Nuvoloni, R., Fratini, F., Di Iacovo F., Armani, A. (2024) Assessment of the information to consumers on insects-based products (Novel Food) sold by e-commerce in the light of the EU legislation: when labelling compliance becomes a matter of accuracy. Food Control, 162, 110440. DOI: https://doi.org/10.1016/j.foodcont.2024.110440-

Sun, T., -Long, R. J., Liu, Z. Y. (2013) The effect of a diet containing grasshoppers and access to free-range on carcase and meat physicochemical and sensory characteristics in broilers. British poultry science, 54 (1), 130-137. DOI: https://doi.org/10.1080/00071668.2012.756575

Thijssen, M. A., Mensink, R. P. (2005) Small differences in the effects of stearic acid, oleic acid, and linoleic acid on the serum lipoprotein profile of humans. The American journal of clinical nutrition, 82 (3), 510-516. DOI: https://doi.org/10.1093/ajcn.82.3.510

Thornton, P. K. (2010) Livestock production: recent trends, future prospects. Philosophical Transactions of the Royal Society B: Biological Sciences, 365 (1554), 2853-2867. DOI: https://doi.org/10.1098/rstb.2010.0134

Ulbricht, T. L. V., Southgate, D. A. T. (1991) Coronary heart disease: seven dietary factors. The lancet, 338 (8773), 985-992. DOI: https://doi.org/10.1016/0140-6736(91)91846-M

Valenta, J., Chodová, D., Tůmová, E., Ketta, M. (2022) Carcass characteristics and breast meat quality in fast-, medium-and slow-growing chickens. Czech Journal of Animal Science, 67 (7). DOI: https://doi.org/10.17221/91/2022-CJAS

van Huis, A. (2022) Edible insects: Challenges and prospects. Entomological Research, 52 (4), 161-177. DOI: https://doi.org/10.1111/1748-5967.12582