Metabolizable Energy Value of Fat and Meals Obtained from Black Soldier Fly Larvae (Hermetia illucens) for Broiler Chickens

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Article

Metabolizable Energy Value of Fat and Meals Obtained from Black Soldier Fly Larvae (*Hermetia illucens*) for Broiler Chickens

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Abstract: An experiment was conducted to determine the apparent metabolizable energy (AME) and nitrogen-corrected AME (AMEn) of defatted black soldier fly larvae meal (BSM), full-fat dry larvae meal (BSL), and larvae fat (LF) for broiler chickens. The BSM, BSL, and LF contained on a g/kg basis, respectively, crude protein, 459, 399, 0; crude fat, 171, 240, 923; dry matter, 963, 940, 997; neutral detergent fiber, 210, 333, 0; acid detergent fibers, 95, 93, 0; and gross energy (MJ/kg), 22.04, 22.78, 38.16. An AME bioassay was performed wherein broilers were fed four experimental diets (a maize–wheat–soy basal diet and three test diets containing 100 g/kg BSM, BSL, or LF, respectively). The AME of BSM, BSL, and LF was calculated based on the differences between the AME values of basal and test diets (substitution method). The AME and AMEn for BSM, BSL, and LF were determined to be 18.20 and 17.40; 17.60 and 16.50; and 36.50 and 35.60 MJ/kg DM, respectively. There were no significant differences ($p > 0.05$) between nutrient retention coefficients of dry matter, N, and fat. The results showed that the examined products from black soldier fly larvae are a good source of available energy and crude protein (BSL and BSM) and can be incorporated in broiler diets as alternative protein and energy sources.

Keywords: insect meal; insect fat; broilers; metabolizable energy

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1. Introduction

Poultry meat is an important food and a major source of protein in the diet of many people [1], contributing essential nutrients that are difficult to obtain from plant sources [2,3]. Notwithstanding variations between and within countries, in general, there is a tendency to decrease red meat consumption and increase poultry consumption [4–6]. This increasing demand for poultry meat will inevitably require an increase in poultry meat production, followed by increased demand for ingredients to formulate diets for poultry. Depending on the stage of production, diets for meat-producing birds, e.g., broilers, require between 20 and 23% of high-quality protein and between 12.6 and 13.5 MJ/kg metabolizable energy (ME; Aviagen Ltd., Edinburgh, UK). Worldwide, soybean meal (SBM) is the main protein source incorporated in poultry diet formulations. Soybean oil (SBO) is also used to increase the ME level in poultry diets. However, due to an increase in global demand, SBM is one of the most expensive components in poultry diets [7]. Soybean production is often associated with changes in land use (e.g., deforestation) associated with a negative impact on the environment [8–10]. The resulting climate change has a significant impact on arable and livestock production, requiring producers to adapt and be resilient and efficient to ensure global food security [1,11,12]. Insect products, including larvae meals and fats, are often considered competitive alternatives to soybean products, and are important for developing more sustainable poultry meat production systems [13–16]. Insects can also be part of a circular economy whereby they do not compete with humans for resources, utilizing organic waste to grow [17–19]. Recent research [14,20] found that the ME of oil from black soldier fly (BSF; *Hermetia illucens*) larvae is similar to that of SBO and may be directly substituted in poultry diet formulations. Mahmoud et al. [16] reported that the nutritional profile of a larvae meal from BSF, especially the contents and digestibility of amino acids, closely resembles that of SBM and can be used as a potential SBM alternative in broiler diets. In addition, the higher ME content, compared to SBM, makes the larvae meal attractive both as a protein and energy source [16], thus suggesting that insect-based feed materials may be essential to decreasing the dependency of the poultry industry on SBM [21–24]. However, variations in the chemical composition of insect meal samples (batches) are well documented and mostly depend on larvae age, drying and defatting techniques, and rearing substrate [25,26]. Given the increasing interest in using insect-based products in poultry diet formulations, information on their nutritional value, including ME, is needed. However, published data on ME of insect-based products for poultry are limited. Thus, the aim of the study was to determine the apparent ME (AME), nitrogen-corrected AME (AMEn), and total tract retention coefficients of dry matter (DMR), nitrogen (NR), fat (FR), and gross energy (GER) of defatted larvae meal (BSM), non-defatted dry larvae meal (BSL), and fat (LF) samples obtained from larvae of the BSF. Bird weight (BW), daily feed intake (FI), daily weight gain (WG), and feed conversion ratio (FCR) were determined as baseline bird performance metrics.

2. Materials and Methods

2.1. Insect Larvae Meals, Insect Oil, and Experimental Diets

The insect meal samples used in this experiment were from two different batches of BSF larvae (no older than 17 days), reared on dried wheat distiller's grains with soluble (DDGS) substrate, and were purchased from Hexafly (Navan, Co., Meath, Ireland). The production process followed EC regulations EU 142/2011, as previously described [27].

A basal feed (BF; Table 1) containing maize, wheat, and SBM was formulated in mash form to meet bird nutrient recommendations (Aviagen Ltd., Edinburgh, UK). There were no coccidiostats, enzymes, or other feed additives in BF. The BF was then split into four batches, with one batch used as the BF control diet, a second diet comprising 900 g/kg BF + 100 g/kg BSM (BSMd), a third diet comprising 900 g/kg BF + 100 g/kg BSL (BSLd), and the fourth diet comprising 900 g/kg BF + 100 g/kg LF (LFd), giving a total of four experimental diets. Both insect meals were milled prior to incorporation in BF.

Table 1. Basal feed composition and nutritive value (g/kg, as-fed).

Ingredients (g/kg)	Basal Feed
Maize	322.00
Wheat	280.00
Sunflower meal (36% CP)	80.00
Soybean meal (46% CP)	230.00
Lysine	2.90
Methionine	1.40
Threonine	0.85
NaCL	2.50
Sodium bicarbonate	2.00
Vitamin and mineral premix [1]	2.00
Choline chloride	1.85
Monocalcium phosphate	5.50
Calcium carbonate	15.00
Vegetable oil	54.00
	1000
Calculated analysis (as fed):	
Crude protein (g/kg)	195
Metabolisable energy (MJ/kg)	12.91

Table 1. *Cont.*

Ingredients (g/kg)	Basal Feed
Crude fat (g/kg)	75.7
Ca (g/kg)	8.5
Available P (g/kg)	5.5
Lysine (g/kg)	11.5
Methionine (g/kg)	4.6
Analyzed composition (as fed):	
Gross energy (MJ/kg)	17.06
Dry matter (g/kg)	920
Crude protein (g/kg)	181
Crude fat (g/kg)	66

[1] The vitamin and mineral premix contained vitamins and trace elements to meet the requirements specified by Aviagen Ltd., Edinburgh, UK. The premix provided (units/kg diet): retinol 3600 µg, cholecalciferol 125 µg, α-tocopherol 34 mg, menadione 3 mg, thiamine 2 mg, riboflavin 7 mg, pyridoxine 5 mg, cobalamin 15 µg, nicotinic acid 50 mg, pantothenic acid 15 mg, folic acid 1 mg, biotin 200 µg, iron 80 mg, copper 10 mg, manganese 100 mg, cobalt 0.5 mg, zinc 80 mg, iodine 1 mg, selenium 0.2 mg, and molybdenum 0.5 mg.

2.2. Birds, Management, and Sample Collection

The experiment was performed at Trakia University (Stara Zagora 6000, Bulgaria) and approved by the University Research Ethics Committee. Initially, 55-day-old female Ross 308 broiler chicks were purchased from a local hatchery (Nik 58 Ltd., Stara Zagora, Bulgaria) and reared in a single floor pen until 24 d of age with a commercial broiler starter diet (230 g/kg crude protein (CP) and 12.56 MJ/kg AME). At 24 d age, 48 broilers, selected randomly, were allocated to 24 pens with a wire-mesh floor, each holding 2 birds. Chickens were reared following breeders' recommendations (Aviagen Ltd., Edinburgh, UK).

Each diet was fed to 6 pens following randomization in a completely randomized experimental design. Birds and feed were weighed at the start (at 24 d old) and at the end of the study (at 31 d old), whereupon FI, WG, and FCR were determined. During the last four days, from 27 to 31 d age, FI was also monitored. Excreta were totally collected daily for the last four days, oven dried at 60 °C, milled to pass through a 0.75 mm sieve, and used for determination of total tract DMR, NR, FR, GER, AME, and AMEn of diets and insect products.

2.3. Laboratory Analysis

Dry matter (DM), nitrogen (N), and oil (as ether extract; EE) in samples were determined as previously described [28]. Crude protein in BF and excreta was calculated as 6.25 × N, and in BSM and BSL was calculated as 5.60 × N [29,30]. An isoperibol bomb calorimeter was used to determine the gross energy (GE) values of feed and excreta samples [31]. Acid detergent fiber (ADF) and neutral detergent fiber (NDF) in BSM and BSL were determined following standard procedure [32].

2.4. Calculations

Total tract nutrient retention coefficients, AME, and AMEn values of the experimental diets were determined following standard techniques [33,34].

$$AME = \frac{GE\ int - GE\ out}{Feed\ intake}$$

$$AMEn = \frac{GE\ int - GE\ out - 34.39 \times N\ retained}{Feed\ intake}$$

where *AME* (MJ/kg) = apparent metabolizable energy content of the diet; *AMEn* (MJ/kg) = N-corrected AME content of the diet; *GE* = gross energy of the diet and excreta, respectively;

GE int = *GE* of diet multiplied by feed intake; *GE out* = *GE* of excreta multiplied by excreta voided; and 34.39 (MJ/kg) = energy value of uric acid. The *retained N* was calculated as:

$$N\ retained = N\ int - N\ out$$

where *N int* = *N* in diet multiplied by feed intake; *N out* = *N* in excreta multiplied by excreta voided.

The *AME* and *AMEn* in insect products (*IP*) were determined as follows:

$$AME(n)\ (IP) = \frac{AME(n)\ of\ IP\ diet - AME(n)\ of\ BF * 0.900}{0.100} \quad (1)$$

where *BF* = basal feed; 0.900 is the proportion of *BF* in *IP* diet; and 0.100 is the proportion of *IP* in the *IP diet*, respectively.

2.5. Statistical Analysis

Performance data were analyzed by one-way ANOVA using Genstat (22nd edition) statistical software (IACR Rothamsted, Hertfordshire, UK). Comparisons among the studied variables were performed by Duncan's multiple range test. Data were checked for homogeneity and normality prior to ANOVA. Results were considered significant at $p < 0.05$. Data are expressed as means and their pooled standard errors of means (SEM).

3. Results

The content of CP, EE, GE, and DM in BF were 181 g/kg, 66 g/kg, 17.06 MJ/kg, and 920 g/kg, respectively (Table 1).

The analyzed chemical composition (g/kg DM) of the BSM, BSL, and LF samples is presented in Table 2. The BSM had more CP, 459 g/kg, compared to 399 g/kg in BSL. The LF contained 923 g/kg EE, followed by 240 g/kg in the BSL and 171 g/kg EE in BSM, respectively. The LF sample had 38.16 MJ/kg GE, followed by 22.78 MJ/kg GE in the BSL and 22.04 MJ/kg GE in BSM. Dry matter content was led by LF with 997 g/kg, followed by 963 g/kg in BSM and 940 g/kg in BSL samples. The BSM sample contained 210 g/kg NDF and 95 g/kg ADF and the BSL contained 333 g/kg NDF and 93 g/kg ADF, respectively.

Table 2. Proximate composition (air dried basis) of defatted meal (BSM), dried larvae meal (BSL), and larvae fat (LF) used in the study [1].

Item	Crude Protein (g/kg)	Ether Extract (g/kg)	Gross Energy (MJ/kg)	Dry Matter (g/kg)	NDF (g/kg)	ADF (g/kg)
BSM	459	171	22.04	963	210	95
BSL	399	240	22.78	940	333	93
LF	-	923	38.16	997	-	-

[1] Analyzed in technical duplicates.

Table 3 contains information on growth performance variables of the chickens. There were no statistically significant differences ($p > 0.05$) in initial and final body weight and growth performance of the birds, while birds fed BSMd and BSLd tended ($p = 0.092$) to have lower FCR. The performance data are shown as baseline performance metrics, although the diets became unbalanced with the inclusion of the larvae products.

Total tract nutrient retention coefficients and ME values of diets are shown on Table 4. Compared to the others, the BF had lower FR ($p = 0.008$).

The AME and AMEn of BSM and BSL did not differ statistically ($p > 0.05$), although the values for LF were higher ($p < 0.001$) (Table 5). The value of DMR tended ($p = 0.09$) to be higher for LF.

Table 3. Effect of dietary insect product inclusion on growth performance of broiler chickens, nutrient retention coefficients, and dietary energy metabolism.

Item	BW Start (g)	BW End (g)	FI (g/day)	WG (g/day)	FCR (g:g)
BF	1166	1699	149.9	76.1	1.985
BSMd	1184	1722	136.3	76.8	1.783
BSLd	1190	1678	131.1	69.6	1.888
LFd	1184	1658	132.9	67.7	1.980
SEM	26.5	42.3	5.75	4.08	0.0606
p-value	0.926	0.742	0.122	0.312	0.092

BW: body weight; FI: daily feed intake; WG: daily weight gain; FCR: feed conversion ratio corrected for mortality; BF: basal feed; BSMd: diet containing 10% defatted black soldier fly larvae meal; BSLd: diet containing 10% black soldier fly dry larvae meal; LFd: diet containing 10% black soldier fly larvae fat; SEM: pooled standard error of the mean; *p*: probability of differences.

Table 4. Effect of dietary insect product inclusion on nutrient retention coefficients and dietary energy metabolism when fed to broiler chickens.

Item	DMR	NR	FR	GER	AME (MJ/kg DM)	AMEn (MJ/kg DM)
BF	0.782	0.721	0.826 [a]	0.786	13.30 [a]	12.49 [a]
BSMd	0.770	0.718	0.912 [b]	0.791	13.79 [a]	12.97 [a]
BSLd	0.758	0.710	0.918 [b]	0.785	13.74 [a]	12.89 [a]
LFd	0.797	0.747	0.900 [b]	0.820	15.63 [b]	14.79 [b]
SEM	0.0118	0.0218	0.0186	0.0122	0.213	0.207
p-value	0.156	0.657	0.008	0.163	<0.001	<0.001

DMR: dry matter retention; NR: nitrogen retention; FR: fat retention: GER: gross energy retention; AME: apparent metabolizable energy; AMEn: dietary N-corrected apparent metabolizable energy; BF: basal feed; BSMd: diet containing 10% defatted black soldier fly larvae meal; BSLd: diet containing 10% black soldier fly dry larvae meal; LFd: diet containing 10% black soldier fly larvae fat; SEM: pooled standard error of the mean; *p*: probability of differences. Values with different superscript letters differ significantly ($p < 0.05$).

Table 5. Gross energy, nutrient retention coefficients, and metabolizable energy of insect products for broiler chickens.

Item	GER	DMR	NR	AME (MJ/kg DM)	AMEn (MJ/kg DM)
BSM	0.824	0.663	0.690	18.20 [a]	17.40 [a]
BSL	0.774	0.542	0.610	17.60 [a]	16.50 [a]
LF	0.957	0.927	-	36.50 [b]	35.60 [b]
SEM	0.0851	0.1167	0.2030	2.030	1.990
p-value	0.321	0.090	0.415	<0.001	<0.001

GER: gross energy retention; DMR: dry matter retention; NR: nitrogen retention; AME: apparent metabolizable energy; AMEn: dietary N-corrected apparent metabolizable energy; BSM: defatted black soldier fly larvae meal; BSL: black soldier fly dry larvae meal; LF: black soldier fly larvae fat; SEM: pooled standard error of the mean; *p*: probability of differences. Values with different superscript letters differ significantly ($p < 0.05$).

4. Discussion

The aim of the study was to determine the ME and nutrient retention coefficients in two types of insect meal and insect fat when fed to broiler chickens. Insect-based feed materials are increasing in availability for animal diets due to legislative changes and advances in production methods; thus, they may be used as an alternative to SBM in poultry feed. The growth performance results were used to assess the comparability of the study, i.e., FI and growth of birds, as differences in performance were not expected for a feeding period of seven days. There were no mortalities and birds were in good health. The higher AME and AMEn values of LFd were also expected since they were formulated to contain more available energy.

The chemical composition of the two insect meals was within the expected range [16,21,23,35]. However, variations in fats, protein, and chitin content of insect meal samples are recognized and mostly depend on larvae age, drying and defatting techniques, and rearing substrate [17,25]. The CP values (N × 5.6) of the reported BSM and BSL were 399 and 459 g/kg, respectively, and were greater than those in plant protein sources, like rapeseed meal, DDGS, sunflower meal, or field beans, often considered as SBM alternatives in poultry diets [36–40]. The NR coefficients for BSM and BSL were within range with other insect meal studies [16,21,23]. Mahmoud et al. [16] also found that the amino acid content of insect meal and their ileal digestibility compare closely to those reported for SBM [41], thus further highlighting the importance of research on insect meals as an alternative to SBM protein source for poultry.

Since dietary ME comprises about half of the total cost of broiler production and is essential for dietary formulation, precise information on the AME of feedstuffs is vital for sustainable poultry production. In the current experiment, the AME and AMEn of BSM were 18.20 and 17.40 MJ/kg DM and for the BSL were 17.60 and 16.50 MJ/kg DM, respectively. Mahmoud et al. [16] obtained values of 19.10 and 18.00 MJ/kg DM, for AME and AMEn, respectively, for insect meal containing 320 g/kg crude oil vs. 171 g/kg in the current BSM. De Marco et al. [21] reported 17.38 and 16.60 MJ/kg DM for AME and AMEn, respectively, for *Hermetia illucens* larvae meal containing 121 g/kg crude fat. The values are closer to those of BSL and lower than those of BSM. Schiavone et al. [23] reported AME and AMEn of 16.25 and 14.87 MJ/kg DM and AME and AMEn values of 11.55 and 9.87 MJ/kg DM, in *Hermetia illucens* larvae meals containing 180 and 46 g/kg crude fat, respectively. Although most of the published work suggests a positive correlation between fat content and ME, the lack of statistically significant difference between the values of BSL and BSM in the present study suggests that other factors than fat may also influence the content of bioavailable energy in insect meal. In addition, there were no differences between the GER, DMR, and NR of the two meals. Dietary fiber influences AME in poultry diets, as high fiber content is generally a reason for lower AME [42,43]. Fiber is also a rough estimate of chitin in insects, an N-containing carbohydrate, nutritionally unavailable to birds [44], which may vary with the age of larvae and feed substrate. Compared to BSM, in the reported study, BSL contained 37% more NDF, which may be the reason for the lower AME and AMEn values in BSL. Other reports suggested that chitin itself may also contribute to the low poultry performance and AME [30,45]. Although chitin was not determined in this study, it should be considered when assessing the feeding value of insect meal for poultry. In addition, values of AME reported for SBM, rapeseed, beans and pulses [46–49] are lower compared to BSM and BSL assessed in this study.

The AMEn value of LF was 35.60 MJ/kg, which is about 2.5% lower than its AME value of 36.50 MJ/kg. Huyghebaert et al. [46] found that the difference between AMEn and AME values of 23 different fats vary from −1.41% to +3.40%, respectively. Assessing the caloric value of insect fat, Kieronczyk et al. [20] found a difference of about 0.5% between AME and AMEn. However, fat does not contain any N; thus, the observed differences between AME and AMEn regarding fats may be due to the techniques (substitution or regression) which use dietary AMEn values. It seems that for fats, AME aligns more closely with the actual energy levels that are available to growing birds, compared to AMEn.

Insect fat is high in AME [20] and may replace SBO in poultry diet formulations, thus improving the sustainability of poultry production. The AME of the LF in our study was 36.50 MJ/kg, which is slightly lower compared to the previous estimated value of 37.72 MJ/kg [20]. Dietary fat digestibility and absorption depend on gastrointestinal tract development and are lower in younger birds [47,50]. Compared to Kieronczyk et al. [20], the AME in the reported study was determined with younger birds (17–21 d), thus suggesting that age may be the reason for the observed difference in AME. In addition, the two studies employed different calculation techniques, linear regression vs. ingredient substitution, which may further contribute to the difference. The evaluated AME of LF was similar to vegetable oils, including soybean, rapeseed, corn, and palm oils [47–49]. It should be noted, however, that the insect-rearing medium may have an impact on the fatty acid composition of BSF [17], which warrants further consideration.

5. Conclusions

The present study demonstrated that the examined products from black soldier fly larvae are a good source of available energy and crude protein (BSL and BSM) and can be incorporated in broiler diets as alternative protein and energy sources. The meals from *H. illucens* larvae, with different degrees of defatting, contain CP comparable to an AME greater than those commonly reported in SBM. The fat from *H. illucens* larvae had an AME similar to values reported for SBO. Thus, making insect products attractive components for sustainable poultry diet formulations.

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Institutional Review Board Statement: The study was conducted at the poultry research facility of Trakia University (Stara Zagora 6000, Bulgaria) and approved by the University Research Ethics Committee on 17/11/2022. The study was designed in compliance with the guidelines of the European and Bulgarian legislation regarding the protection of animals used for experimental and other scientific purposes put into law in Bulgaria with Regulation 20/2012. The manuscript has been prepared to comply with the ARRIVE 2.0 guidelines [51].

Informed Consent Statement: Not applicable.

Data Availability Statement: The data that support the findings of this study are available on reasonable request from the corresponding author.

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