South African Journal of Animal Science 2024, VOL 54

Broiler performance on maize (*Zea mays*)–cowpea (*Vigna unguiculata)* diets fortified with black soldier fly *(Hermetia illucens*) larvae meal

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(Submitted 12 July 2023; Accepted 4 September 2024; Published 31 October 2024)

Abstract

Effects of incorporating full-fat Black Soldier fly (*Hermetia illucens*) larvae meal (BSFLM) in 4-d sprouted cowpea-based grower and finisher broiler diets were evaluated in broilers. Chicks were raised in an open deep litter facility; 360 Ross 308 chicks started (0–21 days) on a commercial starter diet. In week two, the chicks were divided by sex into 30 steel-framed pens (2.16 m^2) and randomly assigned to five grower (22–35 d) and finisher (36–42 days) maize-based groups: commercial; soyabean, sprouted cowpeas with no BSFLM; sprouted cowpeas, low fat, with 5% BSFLM; sprouted cowpeas, high fat, with 5% BSFLM; and sprouted cowpeas with 10% BSFLM. Weekly pen feed intake, live weight gain, and feed conversion ratio were evaluated, with carcass measurements at 42 d. During the grower phase, broilers on commercial feed outperformed those on cowpea diets in growth and feed conversion. In the finisher phase, broilers on commercial feed had higher feed intake than those on sprouted cowpeas with 10% BSFLM. Broilers on commercial feed had higher feed intake, weight gain, and slaughter weights, and better feed conversion. Male broilers had higher feed intake during the grower phase and gained more weight during finishing. The 10% BSFLM reduced meat drip loss. BSFLM increased liver size and abdominal fat, especially in females, with an inverse effect on breast meat yield. BSFLM improved the efficacy of the sprouted-cowpea diets. Broiler performance followed the order commercial feed > sprouted cowpeas, 10% BSFLM > sprouted cowpeas, high-fat, 5% BSFLM > sprouted cowpeas, low-fat, 5% BSFLM > non-supplemented sprouted cowpea diet.

Keywords: insect feed, native legumes, novel feedstuffs, poultry
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Introduction

Modern broiler nutrition has achieved remarkable productivity and nutrient efficiency, with a minimal environmental footprint, in large part through the application of high-precision feeding strategies. High-precision feeding requires a nutritionally well-defined basket of quality feed ingredients. This feed matrix is currently exclusive to what are considered “conventional” feedstuffs, which are largely the most commercialized, edible legumes (pulses) and cereals, and their industrial processing byproducts. These are feedstuffs which have been nutritionally characterized extensively, using the most advanced nutrient evaluation systems. They constitute the primary and default matrix on which iterative, computer-assisted, least-cost procedures are used to draw ingredients in formulating commercial diets that are nutritionally balanced to meet highly specification nutrient standards for broilers. Conventionally, such high-precision poultry diets use soyabean oil cake as the primary protein source in maize-based diets. Depending on the quality of these basal ingredients, the diets typically include supplementary animal protein, or, if still deficient, synthetic essential amino acids, to ensure a balance of essential amino acids.

URL: http://www.sasas.co.za
ISSN 0375-1589 (print), ISSN 2221-4062 (online)
Publisher: South African Society for Animal Science http://dx.doi.org/10.4314/sajas.v54i4.05

In addition to the growing demand for food, sustained global growth in commercial animal production is projected into the mid-21st century (Alexandratos & Bruinsma, 2012). This is already exerting immense pressure on the conventional stock-feed markets (Belghit *et al*., 2018). This trend is exacerbated by the intensifying, adverse impacts of climate change (Belghit *et al*., 2018). In response to the complex interplay of climate change and competing demand for food, poultry producers should consider shifting to alternative feedstuffs, for which there are some emerging options, including the two that are the subject of this study.

The cowpea (*Vigna unguiculata L.* Walp) is an herbaceous annual legume that is native to the arid and semi-arid sub-Saharan Africa (Abebe & Alemayehu, 2022; Affrifah *et al*., 2022). It is considered an important and potential alternative dietary protein source for livestock in the arid tropics of the tropical, developing world (Kirse & Karklina, 2015;). With ~24% crude protein, and up to 65% starch (Affrifah *et al*., 2022), the cowpea stands out as the most nutritious, and the most agronomically versatile among the grain legumes that are native to this ecosystem (Defang *et al*., 2008; Kirse & Karklina, 2015; Ehirim *et al*., 2018); Abebe & Alemayehu, 2022; Affrifah *et al*., 2022). Typical of the legumes, the cowpea is a rich source of essential amino acids, particularly lysine, leucine, and arginine (Abebe & Alemayehu, 2022), though deficient in cysteine and methionine (Affrifah *et al*., 2022).

Shifting to the native legumes for livestock feeding without rigorous dietary evaluation can be retrogressive to the current, high production standards. It could also lead to increased demand for costly supplementary animal protein, a role currently played by fishmeal, complemented by limited supplies of other animal products. Unfortunately, climate change also increasingly poses a threat to the fishmeal industry, particularly considering growing concerns about overfishing (Ehirim *et al*., 2018). Insect feed is fast emerging as a viable option to fishmeal (van Huis & Oonincx, 2017; Makkar, 2018; Patterson *et al*., 2021). Several insect species are considered candidates, with the most promising being the Black Soldier fly (*Hermetia illucens*), the yellow mealworm (*Tenebrio molitor*), and the common house fly (*Musca domestica*) (Khan *et al.*, 2016; Laconisi *et al*., 2017; Schiavone *et al*., 2017b; Khan *et al.*, 2018 Secci *et al*., 2018). Of these species, the Black Soldier fly stands out due to its high (40–44%) protein content (Lee *et al*., 2018), and considering its capacity for efficient, industrial, or mass production in environmentally-friendly organic waste removal systems (Patterson *et al.*, 2021). Black Soldier fly larvae meal (BSFLM) is high in both energy (in the form of fat) and essential amino acids, such as lysine, methionine, cysteine, arginine, and tryptophan (Patterson *et al*., 2021). If produced at low cost, incorporating the larvae meal into sprouted cowpea–maize based broiler diets should cost-effectively boost the dietary energy and improve the dietary protein quantity and quality, while contributing to a better planet through alternative blue economy-driven waste management.

The study evaluated broiler growth, slaughter performance, and meat quality on sprouted cowpea–maize (SCPM) grower and finisher diets containing 0%, 5%, or 10% BSFLM, to determine the insect feed supplement required to match the efficacy of conventional, soyabean oil cake–maize diets.

Methods and Materials

The experimental procedures were approved by the ethics committee of the University of Venda (SARDF/18/ANS/02/1206).

The study was conducted in March 2022, at the University of Venda experimental farm (Thohoyandou, Limpopo Province, South Africa, which is located at 22°58′32″ S, 30°26′45″ E, 596 m above sea level). The mean daily temperature is in the range 25–40°C in summer, and 12–26°C in winter. The annual average rainfall is 800 mm, which is highly temporally variable, with 95% occurring between October and March (Mzezewa & Gwata, 2012).

Typical of the legumes, cowpeas contain antinutrients, such as protease inhibitors and lectins, which limit protein digestibility (Boukar *et al*., 2015). Sprouting is considered a cost-effective and practical method for processing legumes for safe feeding to monogastric livestock (Lubisi *et al.*, 2023). In this study, cowpeas were sourced from a local retailer and manually cleaned to remove dirt and damaged grains. The cleaned cowpeas were then sterilized in batches by soaking them for 30 min in a 2.5% sodium hypochlorite solution (bleach). After sterilization, the grains were thoroughly rinsed in clean tap water to remove any residual surface bleach. Subsequently, the cleaned cowpeas were soaked in tap water overnight for approximately 12 h to initiate germination. The germinating cowpeas were spread on steel screens to sprout at ambient temperature for 4 d under intermittent sprinkle irrigation. The sprouting was terminated through enhanced sun-drying by thinly spreading the grain on black plastic sheeting laid on a hot concrete floor during the hot (10:00–16:00) hours of the day.

Dried Black Soldier fly larvae were sourced from AEGIS Environmental (Pty) Ltd, Gauteng, South Africa, who produced the larvae through controlled conditions for optimal breeding of the parent flies, hatching the eggs into larvae at 32 °C and 80% relative humidity, rearing the larvae on vegetable waste for 13 d, and drying them to a constant weight in a ventilated oven at 65 °C for 24 h.

Prime Broiler Starter (Product V17767, Meadow Feeds (Pty) Ltd, Delmas, South Africa) containing 200 g crude protein, 25 g crude fat, 12 g total lysine, and a maximum of 50 g crude fibre. kg^{-1} was used to feed 360 experimental birds during the starter period (1–21 d). Experimental diets were then prepared for evaluation during the growing (22–35 d) and finishing (36–42 d) phases. The test diets contained maize meal as the energy source, and sprouted cowpea meal as the primary protein source instead of the soybean oil cake in the conventional diet, with 0%, 5% or 10% BSFLM as a supplementary protein source to fortify the potentially-inferior dietary cowpea protein.

The grower and finisher diets were formulated by calculating the nutrient content to match the respective positive controls (PC). The respective PC diets were the Meadow Feed Budget Broiler Grower (product V17768, containing 180 g crude protein, 25 g crude fat, 10.0 g total lysine, and 50.0 g crude fibre per kilogram), and Budget Broiler Finisher (product: V17810, containing 160 g crude protein, 25 g crude fat, 9.0 g total lysine, and 60–70 g crude fibre per kilogram). To evaluate the nutritional implications of the sharply-contrasting dietary fat content between the 0% and 10% BSFLM diets, two diets were formulated at the mid (5%) BSLFM dietary inclusion, which were low fat (LF) and high fat (HF), with the HF diets enriched in fat using soyabean cooking oil. All test diets were fortified with micronutrient additives to meet the minimum feeding standards for grower and finisher broiler diets (National Research Council (NRC), 1998). To avoid clogging the hammer mill sieve, the dried larvae were first mixed into the total diet and other feed ingredients before milling through a 3-mm sieve. The chemical composition of dietary ingredients, and the ingredient and resultant dietary chemical composition are presented in Tables 1 and 2, respectively.

The batch of 360-day-old Ross 308 broilers was received and reared in an open, deep litter house (17.0 m long × 9.0 m wide), in a section partitioned by wire mesh into 30 experimental pens measuring 150 cm in length and 144 cm in width. Brooding, lighting, vaccination, hygiene, and biosecurity mimicked the management common with the local small-scale broiler producers, as previously described by Benyi *et al*. (2015). The chicks received a uniform starter feed (1–21 d), with supplementary stress vitamins (Virbac© Samrand Business Park, Centurion, Pretoria, South Africa) from 1–6 d. Chicks were sexed during the second week and uniformly divided by sex into pens (stocking density of 12 birds per pen), which were randomly assigned to diets in a 5 (diets) × 2 (sex) factorial experiment with three replications. Each experimental pen was equipped with a height-adjustable, 390 -mm diameter tube feeder, and a 360-mm diameter bell drinker. A coccidiostat (Esb3, Reg. No. G1305) was added to all drinking water from 22–42 d at a subtherapeutic concentration of 14 g per 14 L.

Feed intake, live body weight (random four birds per pen), and feed conversion ratio were assessed weekly. On the day 41, the birds were subjected to a 12-h feed withdrawal period while maintaining access to water. On day 42, the chickens were humanely slaughtered, and three random chickens from each replication were selected for carcass measurements. The slaughter, dressing, and dissection of carcass components followed the procedures described by Benyi *et al*. (2015). Measurements included the weights of warm, dressed carcasses, thighs, breast, wings, visceral organs, and abdominal fat. Carcass components and viscera weights were scaled to percentages of the warm carcass and live weight, respectively.

Meat colour was evaluated from 30-mm thick × 20-mm wide × 10-mm long samples dissected from fresh breast fillets. The Lab Scan-XE spectrophotometer (Hunter Associates Laboratory Inc., USA) was used to measure meat lightness (L*), redness (a*), and yellowness (b*), following the methodology described by Mohamed *et al*. (2008). Drip loss was estimated using the bag-loss procedure previously described by Bowker & Zhuang (2015). Samples measuring 20-mm thick × 30-mm wide × 50-mm long were dissected from the central region of fresh breast fillets, and were placed in biodegradable zip-seal plastic bags and stored at 4 °C. After 72 h, the samples were re-weighed. The pH of the breast meat was measured using a basic 20 pH meter (Crimson Instruments, SA EU) after homogenizing 10 g tissue slurries in 90 ml distilled water, following the methodology described by Zhang *et al*. (2012).

Table 1 Analysed chemical composition (dry matter basis) of maize, raw cowpea, sprouted cowpea, and Black Soldier fly larvae meal

Chemical components	Maize	Raw Cowpeas	[1]Sprouted Cowpeas	[2]Black Soldier Fly Larvae Meal
Dry matter (g kg $^{-1}$)	863.0	926.0	876.0	927.0
Ash (g kg $^{-1}$)	32.4	42.0	73.7	85.2
Crude protein (g kg $^{-1}$)	94.3	258.6	297.4	375.1
Fat (g kg $^{-1}$)	60.2	15.7	12.7	422.8
Neutral detergent fibre (g kg $^{-1}$)	210.9	372.8	357.8	325.0
Acid detergent fibre (g kg $^{-1}$)	42.1	124.9	155.5	86.9
Ca (g kg $^{-1}$)	0.1	0.7	1.3	11.7
P (g kg $^{-1}$)	3.6	4.0	5.2	6.4
Essential amino acids (g/100g)				
Arginine	0.05	0.15	0.20	0.22
Alanine	0.06	0.07	0.12	0.27
Asparagine	0.05	0.14	0.35	0.32
Glutamine	0.15	0.27	0.43	0.42
Glycine	0.04	0.07	0.13	0.24
Histidine	0.04	0.07	0.11	0.13
Isoleucine	0.03	0.08	0.12	0.18
Leucine	0.10	0.18	0.23	0.30
Lysine	0.03	0.15	0.12	0.18
Methionine	0.01	0.02	0.05	0.11
Phenylalanine	0.04	0.10	0.20	0.23
Proline	0.07	0.07	0.13	0.23
Serine	0.04	0.09	0.14	0.17
Threonine	0.03	0.06	0.11	0.15
Tyrosine	0.03	0.03	0.12	0.42
Valine	0.04	0.09	0.14	0.24

[1]Soaked for 12 h, 4-d open-air sprouting, rapidly sun-dried
[2]Full-fat, supplied by AEGIS Environmental (Pty) Ltd, Gauteng, South Africa – eggs hatched into larvae at 32 °C and 80% relative humidity, larvae transferred to rearing unit after 4 d, reared for 13 d on mixed vegetable waste, dried to constant weight (24 h) in a ventilated oven at 65 °C

Feed and dietary chemical components were analysed using official AOAC (2000) methods for dry matter (method 934.01), crude protein (method 954.01), crude fibre (method 978.10), crude fat (method 920.39), and ash (method 942.05). Acid detergent fibre (ADF) and neutral detergent fibre (NDF) were determined according to the methods of Goering & van Soest (1970).

The General Linear Model (GLM) procedure of SAS (SAS, 2017) was used to analyse the data. All slaughter parameters were analysed using Model I, and model II was used for feed intake, weight gain, feed conversion, and mortality.

$$Yijk = \mu + Di + Si + (DS)ij + \epsilon ijk \quad \textbf{\textit{Model I}}$$

$$Yijk = \mu + Di + Sj + Wk + (DS)ij + \in ijk \quad \textbf{\textit{Model II}}$$

where Y_{ijk} is the l^{th} observed parameter value; μ the overall mean; D_i the effect of the i^{th} diet, i = 1,2,3,4,5; Sj the effect of the j^{th} sex, j = 1,2; W_k the effect of k^{th} week as a fixed effect, k = 1,2,3; $(DS)_{ij}$ the sex × diet interaction; and ϵ_{ijk} the residual error.

Tukey's test was used for post-hoc separation of statistically significant (P <0.05) main effect means.

Table 2 Ingredient, calculated, and analysed chemical composition of maize-sprouted cowpea diets

Composition	Grower (22 to 35 days)					Finisher (36 to 42 days)				
	[1]Positive Control	% Black Soldier Fly Larvae Meal[2]				[2]Positive Control	% Black Soldier Fly Larvae Meal[2]			
		0	5 (LF[3])	5 (HF[4])	10%		0%	5 (LF[3])	5 (HF[4])	10
Ingredients (% as is)										
[5]Sprouted cowpeas		50.3	41.7	43.0	33.5		40.4	32.5	32.5	24.0
Maize		41.0	45.5	41.5	48.0		52.4	54.0	53.4	57.5
Vegetable oil		0.7	0.0	1.7	0.0		0.4	0.0	1.8	0.0
[6]Grower macro pack		3.0	3.0	3.0	3.0		3.0	3.0	30	3.0
Sand		0.8	0.9	1.9	2.5		0.3	2.0	0.8	1.9
BSFM		0.0	5.0	5.0	10.0		0.0	5.0	5.0	10.0
Lysine		0.0	0.0	0.0	0.2		0.0	0.1	0.1	0.2
Methionine		0.6	0.6	0.6	0.0		0.4	0.4	0.4	0.4
Dicalcium Phos		1.5	1.5	1.5	1.3		1.5	1.5	1.5	1.7
Limestone		1.1	0.8	0.8	0.5		0.6	0.5	0.5	0.3
Salt		1.0	1.0	1.0	1.0		1.0	1.0	1.0	1.0
Total		100.0	100.0	100.0	100.0		100.0	100.0	100.0	100.0
Analysed chemical composition (g kg $^{-1}$ dry matter)										
Ash	107.4	169.0	159.7	130.0	125.0	94.2	148.6	142.3	163.8	141.3
Crude protein	178.9	183.0	214.7	195.8	184.5	166.5	171.4	173.2	154.4	171.5
Crude fat	45.1	40.5	29.3	42.9	54.0	45.8	39.7	42.4	55.3	64.3
Starch	431.2	410.4	392.0	323.4	355.1	460.2	365.8	404.7	380.1	281.9
Neutral detergent fibre	172.3	258.2	289.0	278.9	300.3	193.7	385.8	236.5	184.0	195.7
Acid detergent fibre	61.4	77.2	79.2	88.9	76.8	70.3	50.0	110.0	61.9	70.8
Ca	9.9	14.0	12.7	14.5	12.1	7.6	8.7	7.2	13.0	7.8
P	6.0	10.2	12.0	8.7	9.1	6.3	9.2	4.9	13.6	7.4

[1,2]Meadow Feed (Pty) Ltd, Delmas, South Africa - Budget Broiler Grower (Product V17768) - Budget Broiler Finisher (Product: V17810). [3]Supplied by AEGIS Environmental (Pty) Ltd, Gauteng, South Africa – eggs hatched into larvae at 32 °C and 80% relative humidity, larvae transferred to rearing unit after 4 d, cultured on mixed vegetable waste, harvested after 13 d growth, dried to constant weight in a ventilated oven for 24 h at 65 °C.[34] Diets formulated for high (HF), low (LF) fat content; [5]Soaked for 12 h, 4 d open-air sprouting, rapidly sun-dried. [3] Trouw Nutrition South Africa (Pty) Ltd: Broiler Grower Macro pack: Vitamin A, 294117.700 IU; Vitamin D3, 58823.530 IU; Vitamin E, 882.353 IU; Vitamin K, 58.824 mg; Vitamin B1, 58.824 mg; Vitamin B2, 161.765 mg; Vitamin B6, 117.647 mg; Niacin, 1029.412 mg; Calcium Pantothenate, 323.529 mg; Biotin, 2941.177 mcg; Folic acid, 23.529 mg; Vitamin B12, 588.235 mcg; Choline Chloride, 7639.412 mg; 6-Phytase, 29411.770 FTU; Lasalocid, 2647.059 mg; Zinc bacitracin, 661.765 mg; Limestone (as carrier), 485.294 g; Salt, 117.647 g; Dicalcium phosphate, 294.118g; Cobalt from cobalt sulphate, 14.706 mg; Copper from Copper sulphate, 220.588 mg; Iron from Ferrous sulphate, 588.235 mg; Iodine from Potassium iodide, 29.412 mg; Manganese from Manganese sulphate, 2352.941 mg; Zinc from Zinc sulphate, 1470.588 mg; Selenium from Sodium selenite, 8.824 mg; Lysine 5.882 g; Methionine, 38.235; Enzyme Natuphos E 10000 G, 2.941 g

[6]Trouw Nutrition South Africa (Pty) Ltd: Broiler finisher Macro pack: Vitamin A, 303030.300 IU; Vitamin D3, 60606.060 IU; Vitamin E, 757.576 IU; Vitamin E Equivalent, 151.515 IU; Vitamin K, 60.606 mg; Vitamin B1, 60.606 mg; Vitamin B2, 166.667 mg; Vitamin B6, 121.212 mg; Niacin, 1060.606 mg; Calcium Pantothenate, 333.333 mg; Biotin, 3030.303 mcg; Folic acid, 24.242 mg; Vitamin B12, 606.061 mcg; Choline Chloride, 7870.909 mcg; 6 Phytase (FTU), 30303.030 FTU; Lasalocid, 2727.273 mg; Zinc bacitracin, 681.818 mg; Limestone (as carrier), 544.182 g; Salt, 121.212 g; Dicalcium phosphate, 272.727 g; Cobalt from cobalt sulphate, 15.152 mg; Copper from Copper sulphate, 227.273 mg; Iron from Ferrous sulphate, 606.061 mg; Iodine from Potassium iodide, 30.303 mg; Manganese from Manganese sulphate, 2424.242 mg; Zinc from Zinc sulphate, 1515.151 mg; Selenium from Sodium selenite, 9.091 mg; Methionine, 3.030 g; Enzyme Natuphos E 10000 G, 3.030g

Results

Table 4 presents the growth performance data of broilers fed different diets. The initial live weight of broilers was similar across all dietary treatments (*P* >0.05). During the grower phase, broilers on the PC diet consumed more feed and had higher weight gain (*P* <0.05) than those on the 0% BSFLM and LF 5% BSFLM diets and showed lower FCR (*P* <0.05) compared to broilers on the 0% BSFLM and HF 5% BSFLM diets. During the finisher phase, broilers on the PC diet consumed more feed than those on the 10% BSFLM diet (*P* <0.05). Cumulatively, broilers on the PC diet had a higher feed intake and weight gain (*P* <0.05) than those on the 0% BSFLM and HF 5% BSFLM diets and achieved higher final live weights with lower FCR (*P* <0.05) than broilers on the 0% BSFLM diet. Male broilers consumed more feed during the grower phase and by slaughter, had higher weight gain during finishing, resulting in heavier live weight at slaughter (*P* <0.05). However, there was no sex × diet interaction on parameters measuring the growth performance (*P* >0.05).

Table 5 shows the dietary effects on scaled weights of carcass components, visceral organs, and abdominal fat. Broilers on the PC diet had heavier breasts than those on the 0% BSFLM and 10% BSFLM diets (*P* <0.05), with heavier thighs than those on all other treatments (*P* <0.05). Broilers on the PC diet also had heavier spleens compared to birds on the 0% BSFLM and the 5% BSFLM diets (*P* <0.05). Females had lighter thighs and livers compared to males (*P* <0.05).

Tables 6 and 7 present the treatment effects on breast meat keeping quality and colour, respectively. The 0% BSFLM diet had higher drip loss compared to the 10% BSFLM diet (*P* <0.05).

Table 4 Effects of maize–sprouted cowpea diets fortified with Black Soldier Fly larvae meal on production performance of Ross 308 broiler chickens

Treatments		Initial Live Weight (g/bird)	Growth Parameters												
			Grower (22 to 35 days)				Finisher (36 to 42 days)				Slaughter				
			Daily weight gain (g/bird/day)	Feed Intake (g/day)	FCR	Mortality (%)	Daily weight gain (g/bird/day)	Feed intake (g/bird/day)	FCR	Mortality (%)	Final live Weight (g/day)	Weight gain (g/bird/day)	Feed intake (g/day)	FCR	Mortality (%)
[1]Diets															
	Positive Control	962.3	57.70^{a}	114.98^{a}	2.01^{b}	0.69	69.09	155.57^{a}	2.31	0.00	1988.7^{a}	61.50^{a}	128.51^{a}	2.11^{b}	0.00
	0% BSFLM	1009.2	37.85^{b}	103.41^{b}	2.80^{a}	0.69	64.86	127.81^{ab}	2.00	1.39	1703.8^{b}	46.86^{b}	111.55^{b}	2.53^{a}	0.92
	5% LF BSFLM	940.0	44.65^{b}	101.44^{b}	2.37^{ab}	0.00	60.62	129.38^{ab}	2.27	8.33	1722.9^{ab}	49.98^{b}	112.45^{b}	2.34^{ab}	2.77
	5% HF BSFLM	924.6	46.03^{ab}	114.65^{a}	2.55^{a}	0.00	78.68	136.44^{ab}	1.76	6.94	1841.3^{ab}	56.91^{ab}	121.91^{ab}	2.28^{ab}	2.31
	10% BSFLM	933.5	46.86^{ab}	108.69^{ab}	2.46^{ab}	0.00	69.44	126.38^{b}	1.82	5.56	1785.8^{ab}	54.38^{ab}	114.59^{b}	2.25^{ab}	2.31
	SEM	23.000	3.030	2.430	0.130	0.444	5.580	6.870	0.160	2.560	63.80	2.550	2.700	0.100	0.910
Sex															
	Female	913.80^{b}	46.52	103.70^{b}	2.35	0.27	62.30^{b}	130.86	2.16	2.78	1735.8^{b}	51.78	113.43^{b}	2.28	1.11
	Male	994.00^{a}	46.71	113.57^{a}	2.53	0.27	74.77^{a}	139.37	1.90	6.11	1881.2^{a}	56.07	122.17^{a}	2.32	2.22
	SEM	14.600	1.920	1.540	0.080	0.280	3.530	4.340	0.100	1.620	40.40	1.610	1.700	0.060	0.580
Sex	Diets														
Female	Positive control	947.1	59.12	110	1.89	0.00	63.88	151.89	2.41	2.78	1921.7	60.71	123.96	2.06	0.00
	0% BSFLM	951.2	37.65	100.39	2.76	0.00	58.47	123.63	2.1	0.00	1654.2	44.59	108.14	2.54	0.93
	5% LF BSFLM	932.9	42.36	98.75	2.4	0.00	55.41	129.39	2.52	2.78	1659.2	46.71	112.35	2.44	0.93
	5% HF SFLM	870	45.91	109.04	2.5	0.00	68.88	125.11	1.83	5.56	1732.5	53.57	114.4	2.27	1.85
	10% BSFLM	867.9	47.58	100.3	2.22	1.39	64.86	124.3	1.91	2.78	1711.7	53.34	108.3	2.11	1.85
Male	Positive control	1071.3	56.28	119.97	2.14	0.00	74.3	159.25	2.19	0.00	2055.8	62.29	133.07	2.15	0.00
	0% BSFLM	973.3	38.06	106.43	2.85	1.39	71.25	131.99	1.9	0.00	1753.3	49.12	114.95	2.53	0.93
	5% LF BSFLM	947.1	46.94	104.13	2.35	0.00	65.83	129.37	2.01	13.89	1786.7	53.24	112.54	2.23	4.63
	5% HF BSFLM	979.2	46.14	120.26	2.61	0.00	88.47	147.76	1.68	8.33	1950.0	60.25	129.43	2.3	2.78
	10% BSFLM	999.2	46.13	117.08	2.71	0.00	74.02	128.47	1.73	8.33	1860.0	55.43	120.88	2.38	1.85
	SEM	32.60	4.290	3.440	0.180	0.630	7.890	9.710	0.230	3.620	90.300	3.600	3.810	0.140	1.300
P Values															
Diet		0.834	0.001	0.000	0.002	0.138	0.256	0.039	0.083	0.332	0.000	0.004	0.000	0.121	0.241
Sex		0.117	0.945	0.000	0.128	0.161	0.021	0.182	0.093	0.252	0.000	0.093	0.000	0.727	0.171
Diet × Sex		0.903	0.930	0.476	0.637	0.389	0.965	0.815	0.932	0.736	0.316	0.948	0.610	0.673	0.314

For each factor or combination of factors, means in the same column not sharing a common superscript are significantly different (P <0.05) [1]Diets; Negative control = Sprouted cowpea-based diet; Positive control = Meadow Feeds' Budget Broiler Grower (Product V17768) and Budget Broiler Finisher (Product: V17810) commercial diets. AEGIS Environmental (Pty) Ltd, Gauteng, South Africa – eggs hatched into larvae at 32 °C and 80% relative humidity, larvae transferred to rearing unit after 4 d, cultured on mixed vegetable waste, harvested after 13 d growth, dried to constant weight in a ventilated oven for 24 h at 65 °C; 5% LF BSFLM = 5% Black Soldier Fly larvae meal, low fat diet; 5% HF BSFLM = 5% Black Soldier Fly larvae meal, high fat diet; 10% BSFLM = 10% Black Soldier Fly larvae diet

Table 5 Effect of maize–sprouted cowpea diets fortified with Black Soldier Fly larvae on weight (g) of carcass components, visceral organs, and abdominal fat of Ross 308 broiler chickens

Treatments		Carcass components (% Dressed weight)			Viscera (% Live weight)				
		Breast	**Thigh**	**Wing**	**Heart**	**Spleen**	**Gizzard**	**Liver**	**Abdominal fat**
[1]Diet									
	0% BSFLM	27.86^{b}	11.46	5.35	0.63	0.15	3.19^{ab}	2.68^{a}	1.98^{ab}
	Positive control	31.11^{a}	11.44	4.94	0.63	0.18	2.97^{b}	2.18^{b}	1.43^{b}
	5% LF BSFLM	29.14^{b}	11.07	5.37	0.62	0.15	3.65^{a}	2.77^{a}	2.13^{a}
	5% HFBSFLM	29.73^{ab}	10.99	5.02	0.65	0.15	3.33^{ab}	2.66^{a}	2.16^{a}
	10% BSFLM	29.01^{b}	11.26	5.14	0.62	0.18	3.45^{a}	2.54^{a}	2.21^{a}
	SEM	0.443	0.166	0.154	0.025	0.012	0.108	0.062	0.135
Sex									
	Female	29.84^{a}	11.00^{b}	5.19	0.63	0.16	3.34	2.57	2.12^{a}
	Male	28.77^{b}	11.48^{a}	5.14	0.64	0.16	3.29	2.57	1.85^{b}
	SEM	0.280	0.105	0.098	0.016	0.007	0.686	0.039	0.086
Interactions									
Sex	Diets								
Females	Positive control	31.38	11.33	4.97	0.65	0.18	3.08	2.23	1.60^{ab}
	0% BSFLM	27.44	11.25	5.63	0.62	0.15	3.14	2.78	1.93^{ab}
	5% LF BSFLM	29.89	10.83	5.49	0.61	0.15	3.65	2.69	2.31^{a}
	5% HFBSFLM	31.27	10.55	4.87	0.65	0.15	3.44	2.62	2.38^{a}
	10% BSFLM	29.26	11.05	4.99	0.63	0.18	3.4	2.53	2.38^{a}
Males	Positive control	30.85	11.56	4.91	0.62	0.18	2.87	2.14	1.27^{b}
	0% BSFLM	28.279	11.66	5.08	0.65	0.14	3.25	2.58	2.03^{ab}
	5% LF BSFLM	28.39	11.31	5.25	0.63	0.15	3.64	2.85	1.96^{ab}
	5% HFBSFLM	28.24	11.43	5.18	0.66	0.14	3.21	2.70	1.94^{ab}
	10% BSFLM	28.77	11.47	5.29	0.63	0.17	3.49	2.54	2.05^{ab}
	SEM	0.626	0.235	0.218	0.036	0.176	0.153	0.087	0.192
P Values									
Diet		0.000	0.003	0.092	0.051	0.003	0.043	0.024	0.046
Sex		0.336	0.005	0.052	0.138	0.783	0.087	0.034	0.002
Diet × Sex		0.808	0.985	0.560	0.892	0.983	0.382	0.601	0.034

For each factor or combination of factors, means in the same column not sharing a common superscript are significantly different ($P < 0.05$) [1]Diets; Negative control = Sprouted cowpea-based diet; Positive control = Meadow Feeds' Budget Broiler Grower (Product V17768) and Budget Broiler Finisher (Product: V17810) commercial diets. AEGIS Environmental (Pty) Ltd, Gauteng, South Africa – eggs hatched into larvae at 32 °C and 80% relative humidity, larvae transferred to rearing unit after 4 d, cultured on mixed vegetable waste, harvested after 13 d growth, dried to constant weight in a ventilated oven for 24 h at 65 °C; 5% LF BSFLM = 5% Black Soldier Fly larvae meal, low fat diet; 5% HF BSFLM = 5% Black Soldier Fly larvae meal, high fat diet; 10% BSFLM = 10% Black Soldier Fly larvae diet

Table 6 Effect of maize–sprouted cowpea diets fortified with Black Soldier Fly larvae meal on meat quality (meat pH and drip loss) of Ross 308 broiler chickens

	Treatments	Meat quality parameter	
		pH	**Drip Loss**
[1]Diet			
	Positive control	5.94	2.48[ab]
	0% BSFLM	5.95	2.84[a]
	LF 5% BSFLM	5.96	2.62[ab]
	HF 5% BSFLM	5.98	2.26[ab]
	10% BSFLM	6.02	1.87[b]
	SEM	0.041	0.193
Sex			
	Female	5.98	2.37
	Male	5.96	2.36
	SEM	0.026	0.122
Interaction			
Sex	Diet		
Female	Positive Control	5.91	2.38
	0% BSFLM	5.95	2.91
	LF 5% BSFLM	5.98	2.60
	HF 5% BSFLM	5.97	2.32
	10% BSFLM	6.08	1.63
Male	Positive Control	5.97	2.59
	0% BSFLM	5.94	2.76
	LF 5% BSFLM	5.95	2.64
	HF 5% BSFLM	5.98	1.69
	10% BSFLM	5.97	2.11
	SEM	0.059	0.272
P Values			
Diet		0.633	0.028
Sex		0.679	0.960
Diet × Sex		0.701	0.506

For each factor or combination of factors, means in the same column not sharing a common superscript are significantly different ($P < 0.05$)
[1]Diets; Negative control = Sprouted cowpea-based diet; Positive control = Meadow Feeds' Budget Broiler Grower (Product V17768) and Budget Broiler Finisher (Product: V17810) commercial diets. AEGIS Environmental (Pty) Ltd, Gauteng, South Africa – eggs hatched into larvae at 32 °C and 80% relative humidity, larvae transferred to rearing unit after 4 d, cultured on mixed vegetable waste, harvested after 13 d growth, dried to constant weight in a ventilated oven for 24 h at 65 °C; 5% LF BSFLM = 5% Black Soldier Fly larvae meal, low fat diet; 5% HF BSFLM = 5% Black Soldier Fly larvae meal, high fat diet; 10% BSFLM = 10% Black Soldier Fly larvae diet

Table 7 Effect of maize–sprouted cowpea diets fortified with Black Soldier Fly larvae meal on meat colour parameters of Ross 308 broiler chickens

Treatments		Breast Meat Colour Parameters					
		a*	b*	L*	Chroma	Hue	Colour difference
Diets							
	Positive control	8.77	17.66	32.09	19.80	62.50	22.95
	0% BSFLM	9.33	19.97	36.10	20.17	65.10	19.85
	5% LF BSFLM	9.24	20.28	35.84	22.38	65.83	21.79
	5% HF BSFLM	9.48	19.71	33.67	21.95	64.54	23.91
	10% BSFLM	8.98	19.97	36.48	21.99	65.89	21.15
	SEM	0.750	0.751	1.350	1.250	1.720	1.280
Sex							
	Female	9.35	20.14	35.55	21.53	65.31	22.24
	Male	8.97	18.89	34.12	20.98	64.24	21.63
	SEM	0.474	0.475	0.851	0.790	1.090	0.808
Interaction							
Sex	Diets						
Female	Positive control	8.94	18.89	34.99	20.96	64.99	20.89
	0% BSFLM	9.13	20.50	36.16	18.61	65.91	20.17
	5% LF BSFLM	10.43	19.47	36.66	23.65	64.13	21.43
	5% HF BSFLM	10.07	19.92	33.07	22.41	63.53	27.35
	10% BSFLM	8.21	20.36	36.89	22.01	68.03	21.34
Male	Positive control	8.61	16.47	29.27	18.64	60.03	25.02
	0% BSFLM	9.53	19.45	36.04	21.96	64.31	19.53
	5% LF BSFLM	8.06	19.47	35.02	21.11	67.54	22.15
	5% HF BSFLM	8.90	19.50	34.26	21.48	65.56	20.47
	10% BSFLM	9.75	19.58	36.08	21.96	63.76	20.97
	SEM	1.060	1.060	1.900	1.770	2.430	1.810
P Values							
Diet		0.936	0.134	0.140	0.486	0.632	0.234
Sex		0.577	0.077	0.247	0.628	0.490	0.601
Diets × Sex		0.438	0.899	0.448	0.517	0.352	0.081

For each factor or combination of factors, means in the same column not sharing a common superscript are significantly different (*P* <0.05) [1]Diets; Negative control = Sprouted cowpea-based diet; Positive control = Meadow Feeds' Budget Broiler Grower (Product V17768) and Budget Broiler Finisher (Product: V17810) commercial diets. AEGIS Environmental (Pty) Ltd, Gauteng, South Africa – eggs hatched into larvae at 32 °C and 80% relative humidity, larvae transferred to rearing unit after 4 d, cultured on mixed vegetable waste, harvested after 13 d growth, dried to constant weight in a ventilated oven for 24 h at 65 °C; 5% LF BSFLM = 5% Black Soldier Fly larvae meal, low fat diet; 5% HF BSFLM = 5% Black Soldier Fly larvae meal, high fat diet; 10% BSFLM = 10% Black Soldier Fly larvae diet

Discussion

The present study evaluated the efficacy of SCPM grower/finisher broiler diets and tested the benefit of 5% versus 10% dietary inclusions of BSFLM. Raw cowpeas contain characteristic legume antinutrients (Abebe & Alemayehu, 2022), a range of compounds that can adversely affect nutrient extraction in the poultry gut (Ehirim *et al*., 2018). Therefore, for efficient utilization when feeding to the monogastric animal, the common practice is to process the cowpeas before feeding (Abebe & Alemayehu, 2022). In broilers, Akanji *et al*. (2016) reported reduced feed intake and growth in broilers fed unprocessed cowpeas. However, a study by Georgeta *et al*. (2022) suggested some tolerance by broilers to raw cowpeas with inclusion levels of up to 20% raw cowpeas not affecting feed utilization. The disparity among different studies suggests cowpea genotypic variations, which may be further influenced by the growing conditions. In the current study, the cowpeas were processed by sprouting. Although there are other, mostly thermal processing methods, in resource-limited settings, processing legumes by germination and sprouting is arguably more practical and advantageous, given that the process is thermoneutral, therefore chemically mild and a low-cost, and improves nutrient metabolism (Ethirim *et al*., 2018; Sugiharto, 2021; Affrifah *et al*., 2022). Thermal processing is more widely investigated than sprouting.

Assuming similar product quality regardless of the processing method, the findings from thermally-processed cowpeas provide useful insight into the potential for using differently processed cowpeas in maize-based broiler diets. At 20% dietary inclusion, roasted cowpeas did not affect broiler intake (Anjos *et al*., 2012), Previously, at the same dietary level, cooked cowpeas did not affect growth and slaughter performance (Kur *et al*., 2013). In a study by Adino *et al.* (2018), as much as 75% substitution of soaked cowpea for soaked soyabean meal did not affect dietary efficacy. However, low protein intake and weight gain were recorded at 100% substitution. In the present study, despite improved performance, 5% and 10% BSFLM inclusion in SCPM grower and finisher diets could not match performance on the conventional diets. The design of the test dietary treatments considered potential nutritional and dietetic effects of high dietary fat on the broiler response. Accordingly, two 5% BSFLM dietary treatments were formulated with contrasting fat content. This was achieved by adding soyabean oil to the HF mixes, with some limited, relative displacement of dietary starch by BSFLM fat. The HF 5% BSFLM diet resulted in better broiler performance than the LF 5% BSFLM diet. Given similar dietary nutrient profiles, and similar intake, the inferior broiler response to the LF, compared to the HF 5% BSFLM diet, suggests inefficient, likely poor (resistant) starch energy utilisation, and implied energy deficiency in the LF 5% BSFLM diet, likely more so in the 0% BSFLM. In a previous study (Schiavone *et al.*, 2017b), 25% dietary inclusion in a conventional diet of partially de-fatted, compared to fully-defatted, BSFLM resulted in higher apparently metabolizable energy, both without (AME), and with nitrogen (AME_n) (16.25 vs 14.87 MJ/kg DM, respectively). This similarly suggests more efficient utilisation of BSFLM (fat) energy compared to the basal energy.

Therefore, subject to the relative feed costs, these findings support high levels of dietary inclusion of full-fat BSFLM to replace as much as possible of both dietary maize and the legume protein source, particularly concerning the experimental, low energy SCPM diet. There are very few reports on the effects of graded to higher levels of BSFLM in SCPM diets to afford a deeper mechanistic insight into the beneficial effects of BSFLM in SCPM. De Marco *et al.*, (2015) reported high energy (17.38 MJ/kg DM AME; 16.60 MJ/Kg DM AME_n) in BSFLM. However, they also reported comparatively low (0.86 vs 0.68) apparent ileal digestibility of 17 essential amino acids compared to *Tenebrio molitor* larvae meal, the result of poor relative digestibility of isoleucine, lysine, methionine, phenylalanine, valine, alanine, aspartic acid, glycine, glutamic acid, and tyrosine. Limited comparatively mechanistic research is available to explain the influences of BSFLM inclusion in SCPM diets. However, there has been research on BSFLM as a dietary replacement for soyabean cake and fishmeal in conventional maize–soyabean broiler diets. In a study by Schiavone *et al.* (2017b), replacement of soyabean oil in a conventional diet with 50% or 100% Black Soldier fly oil did not affect the broiler growth and slaughter performance, feed-choice test, or blood parameters. Supplementary BSFLM up to 15% did not improve broiler growth but dietary inclusion of 20% BSFLM reduced the 42-d broiler FCR and improved the immune response (de Souza Vilela *et al.,* 2021). Previously, the replacement of soyabean cake oil cake at 50% and 100% maintained broiler performance (Schiavone *et al*., 2017a). In contrast, Schiavone *et al.,* (2017b) reported a linear decrease in weight gain with 0–15% BSFLM supplementation during the finisher period. Low (4%) BSFLM dietary inclusion did not improve weight gain during the grower and finisher phase (Mohammed *et al*., 2017).

In the present study, cowpea-based diets reduced the breast and thigh yields relative to the control. BSFLM inclusion did not affect these parameters or the sizes of the visceral organs. However, the standard, maize–soyabean commercial diet increased the spleen size compared to the 0% BSFLM diet. Increasing the BSFLM inclusion to 10% also resulted in an intermediate improvement in spleen size. Previously, breast and thigh yield and the size of the heart, liver, and gizzard were not affected by partial or total replacement of soyabean oil cake with BSFLM (Nayohan *et al*., 2022). The organ size reflects metabolic activity in response to toxic anti-nutritive compounds (Teguia & Beynen, 2005). Defang *et al*. (2008) reported higher heart, liver, and gizzard sizes in birds fed 14% boiled (as opposed to sprouted) cowpeas, suggesting that sprouting was more effective in reducing toxic anti-nutritional compounds.

Consumer preferences and meat-keeping quality are primary considerations in investigating diets which optimise meat quality. In the present study, birds on the 10% BSFLM had lower drip loss than the other diets. The 0% BSFLM diet recorded the highest drip loss, suggesting inferior meat-keeping quality. An important objective is to produce meat which best preserves desirable meat colour attributes while on the shelf. In previous studies, Laudadio & Tufarelli (2010) and Biesek *et al*. (2020) reported influences of dietary protein source on meat colour. Contrary to their observation, in this study, none of the cowpea-BSFLM dietary treatments affected the breast meat colour. Similarly, dietary BSFLM did not affect meat colour in a study by Moula *et al*. (2018). In contrast, the breast meat of broilers fed a 15% BSFLM diet showed a higher meat redness (a*) index compared to birds on 5% and 10% BSFLM, with the least redness observed on the standard diet (Abd El-Hack *et al*., 2020). Abd El-Hack *et al*. (2020) reported a linear decrease in the yellowness value (b*) colour index with increasing dietary BSFLM. Schiavone *et al*. (2019) observed a linear increase in meat redness to a maximum of 15% defatted BSFLM inclusion. There is limited information on the lipid effects of BSFLM feeding on broiler meat. On conventional diets, Schiavone *et al*. (2017a), reported that short chain fatty acids, mostly lauric and myristic acids, increased with 50–100% Black Soldier fly oil inclusion at the expense of the polyunsaturated fatty acids, without any change in monounsaturated fatty acids. This change in the meat lipid profile is considered detrimental to human health and should guide decisions on the extent of defatting BSFLM in relation to the dietary inclusion level. Currently, there are no comparative studies of such effects in SCPM diets.

Conclusion

Full fat BSFLM at 5% and at 10% dietary inclusion improved broiler growth and slaughter performance on the sprouted-cowpea grower–finisher dietary regimen to match performance on the standard diet, with the overall broiler performance in the order commercial feed > sprouted cowpeas with 10% BSFLM > sprouted cowpeas, high-fat, with 5% BSFLM > sprouted cowpeas, low-fat, with 5% BSFLM > non-supplemented sprouted cowpeas feed. The better broiler response to the HF, compared to the LF (5%) BSFLM diet was attributed to either energy deficiency or its inefficiency in the LF 5% BSFLM diet, which would at least in part explain the low broiler response to the 0% BSFLM diet. Therefore, the dietary inclusion of full-fat BSFLM in grower–finisher broiler diets should be guided by the cost-benefit analysis and by implications on abdominal fat, meat drip loss, and the energy supply and efficiency of utilisation.

Acknowledgments

The authors would like to gratefully acknowledge the National Research Foundation for a Post Graduate Scholarship (grant number MND210525603890) and the further funding for running costs through the Research and Technology Fund (grant number RTF181119393189).

Author Contributions

TTM, FF, and EB collaboratively planned and designed the experiment. The experiment was conducted by TTM, and the data analysed and interpreted with assistance from EB and FF. All the authors contributed to writing the manuscript.

Conflict of interest declaration

Authors declare no conflict of interest, and that all authors read and approved this article, and that we all agreed to its submission for publication.

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