Assessment of the chemical characteristics and nutritional quality of meat from broiler chicken fed black soldier fly (*Hermetia illucens*) larvae meal

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**A R T I C L E   I N F O**

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- Chicken meat
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- Proteins
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**A B S T R A C T**

In this study, we aim to evaluate the chemical characteristics, and nutritional quality of raw meat from broiler chicken fed a black soldier fly larvae meal. Three hundred twenty female broiler chicks were divided into four dietary treatments (8 replicates/treatments). Birds were fed maggot meal at 0%, 4%, 8%, and 12% at 42 days of age, 16 birds/treatment were randomly selected and slaughtered. The chemical characteristics and nutritional quality of the meat were assessed. Abdominal fat, intramuscular lipid levels, and cholesterol levels increased ($p < 0.05$) in chicken-fed larve meal. The latter had a higher level of mono-unsaturated and polyunsaturated fatty acids but a lower level of omega 3 (ω3) compared to the control. The atherogenicity index (AI) and the thrombogenicity index (TI) decreased with maggot meal incorporation. The unsaturation index was better at 4% and 8% maggot meal. Chickens fed with 8% maggot meal would present less risk for cardiovascular health.

**1. Introduction**

Worldwide, poultry meat consumption is growing in developed and developing countries (OECD/FAO, 2020). Fresh chicken meat and products are universally appreciated. The interest in poultry products is explained on the one hand by the fact that it is not subject to any cultural or religious restrictions. On the other hand, they allow an interesting protein intake for a low-fat content. However, depending on the strain or muscle considered, these proportions of the different macronutrients differ, as for other micronutrients such as vitamins, fatty acids, or mineral elements, which can also vary. Certain factors, including age, sex, farming method, and diet, are likely to cause the proportions of these different constituent elements to vary. The poultry sector grows technically with food in many parts of the world. Demographic growth and the increase in purchasing power, as well as urbanization, are powerfully driving the development of this sector. In Sub-Saharan Africa, poultry consumption has expanded faster than other meat (Mottet and Tempio, 2017).

Poultry meat consumption is projected to increase globally to 152 Mt over the projection period, accounting for 52% of the other meat consumed (OECD & FAO, 2021). This increase is reflected both in traditional culinary treatments and in the techniques for the preparation of processed and or elaborated products. Based on the 2014's report by the Food and Agriculture Organization of the United Nations (FAO), world chicken production was 110.5 million tons; FAO's agricultural outlook shows that poultry production can be expected to increase by 1.8% per year from 2015 to 2024 (OECD & FAO, 2014). The progress has made it possible to obtain chickens that meet the needs and requirements of the consumer. Nowadays, farmers are subject to severe constraints in terms of the supply of protein source ingredients that necessarily influence the cost price and especially the quality of the final product. Indeed, the primary raw materials used in farm animal feed are fish and soybean meal. About 27% (20 million tons) of sea fishery products are processed into fish meal or fish oil (Cashion et al., 2017). Many endangered fish species are caught and processed into meals to meet the protein and fat needs of the animal production sector (Amar, 2010). Soybean, the primary source of vegetable protein, has seen its global production increase from 30 million tons in 1960 to more than 350 million tons (USDA, 2017). This negatively impacts the terrestrial ecosystem's various components through the massive use of agricultural inputs. Several studies have been undertaken to address these bioclimatic constraints of breeding and improve the ratio between the quality and price of chicken carcasses. Thus, numerous studies have shown the alternative role that insects could play in animal feed (Kelemu et al., 2015a; Van Huis and Oominxc, 2017; Ahmad et al., 2022). Indeed, the lipid profile of insects also offers good prospects for incorporation as a dietary supplement in...
poultry feed (Makkar et al., 2014; Devic et al., 2018). With their powerful enzymatic system, better bioconversion, and rapid prolificacy, black soldier flies (Hermetia illucens) are a potential source of animal protein in poultry (Newton et al., 2005). Indeed, several researchers have investigated the partial or total substitution of fish or soy meal in poultry feed (Schiavone et al., 2017; Auza et al., 2021). Thus, Auza et al., (2021), showed that 75% of fishmeal could be replaced by black soldier fly maggot meal in Native Chicken’s diets to improve the relative length of the digestive tract organs, a histomorphological feature of the small intestine villi, and the percentage of carcass parts. Akpodiete et al. (1998) and Ruhnke et al. (2018) also concluded that maggot meal could be used in laying hens without affecting chicken performance. Attivi et al. (2020) also concluded that maggot meal could substitute fishmeal with improved chicken live weights.

Although most studies on the use of maggots in poultry feed have found noticeable results on poultry performance, few studies have been conducted on the impact of this ingredient on the chemical and nutritional profile of broiler chicken meats. This study assessed “The Impact of Meal Soldier Fly larvae (Hermetia illucens) on chemical characteristics and nutritional quality of broiler chicken meats.” We aim to evaluate the effect of using insects as a source of protein in poultry feed on meat quality.

2. Materials and methods

2.1. Ethics statements

We carried out this study in strict compliance with the recommendations of The Care and Use of Experimental Animals guideline of the University of Lomé, Togo (ref: 008/2021/BC-BPA/FDS-UL). The Animal Experimentation Ethics Committee of the same University approved the protocols. All efforts were made to minimize bird discomfort.

2.2. Production of Hermetia illucens maggot meal

The meal of black soldier fly larva used in this study was produced at the Regional Centre of Excellence in Avian Sciences (CERSA), University of Lomé, Togo. H. illucens larvae were produced by a modified method based on Sheppard et al. (2002). Freshly laid eggs on stacked wooden sticks were transferred to plastic dishes for incubation, where the larvae hatched within three and four days. The larvae were initially fed a diet of local brewers’ grains. After a maximum development time of 6 days, the larvae were transferred to growth units on substrates composed of 1/3 brewers’ grains and 2/3 palm kernel cakes. The larvae were fed these vegetarian by-products until day 14. The larvae were harvested before they reached the pre-pupal stage to have a low degree of cuticle sclerotization and higher digestibility (Bosch et al., 2014). They were washed followed by killing, and dried at 70 °C for 48–72 h depending on the water content. Once dried, the maggot larvae were mechanically ground into a fine powder. The resulting product was a Hermetia larvae meal with 25% fat, 9.57% ash, and 41.1% crude protein (Table 1).

2.3. Experimental treatments, layout, and housing system

We obtained three hundred and twenty (320) female Cobb 500 chicks from a reputable hatchery. The eggs obtained were from the same parental group. The chicks were randomly selected and weighed in groups of ten and then randomly allocated to the treatment cages and immediately fed the respective treatment diets.

The experiment consisted of four dietary treatments: diet with 0% (T0), 4% (T4), 8% (T8), and 12% (T12) powder of black soldier fly (H. illucens) larva replacing fish meal in the diet (Table 1). The diets were prepared by the blender using corn and soybean meal to meet the nutrient requirements of the broiler chicken (NRC, 1994). Except for the larva meal (Table 2), all the components used have undergone an authorization analysis by the Togolese Institute for Agronomic Research (ITRA), a CERSA partner laboratory.

The four treatments consisted of eight replicates of 10 birds, each equivalent to 32 experimental units (cages). CERSA organic feed manufacturers produce the diets, and we provide the birds with feed and water ad libitum. At 42 days of age, two broiler chickens from each replicate (n = 16 birds per group) were selected and slaughtered based on the average live weight. After stunning and bleeding, the carcasses were plucked, eviscerated, and their feet removed. Abdominal fat was removed. The carcasses were then kept at 4 °C for 24 h. In addition, the breast of each carcass was separated, the skin was removed, and the skinned samples were immediately stored at –80 °C for analysis in the Laboratory.

2.4. Data collection

2.4.1. Measurement of dry meat matter and water content

Each meat sample’s dry matter (DM) content was determined by drying 5 g of the sample in an oven for 72 h at 70 °C. The results are expressed using Eqs. (1) and (2) in g/100 g of fresh matter.

\[
DM = \frac{M2}{M1} \times 100 \quad (1)
\]

\[
Te = \frac{M1 - M2}{M1} \times 100 \quad (2)
\]

M2 weight of sampling after drying M1: weight of the sample before drying Te: moisture content.

2.4.2. Measurement of meat ash content

The dried sample was weighed and incinerated at a high temperature (550 °C) for 6 h in a muffle furnace, and then the residue (ash of grey, light, or whitish color) was collected. We calculate via Eq. (3) the percentage of total ash on a dry basis for more reproducibility in the results.

\[
% \text{ Total ash} = \frac{M2 - M0}{M1 - M2} \times 100 \quad (3)
\]

M0: mass in grams of the empty crucible M1: total mass in grams of the crucible containing the test portion M2: total mass in grams of the crucible and the crude ash.

2.4.3. Meat’s protein content determination

The protein content was determined by measuring the total nitrogen of 1 g of the sample according to the kjeldahl method. The principle consists of mineralizing 1 g of the sample by heating in the presence of

| Chemical, nutritional characteristics (analysis) | Black soldier fly larvae (Hermetia illucens), dehydrated | Commercial fishmeal 40% |
|-------------------------------------------------|------------------------------------------------------|-------------------------|
| Dry matter (%)                                  | 91.3                                                 | 90.4                    |
| Crude protein (%)                               | 41.1                                                 | 40                      |
| Crude fat (%)                                   | 25                                                   | 10                      |
| Cholesterol (% Ether extract)                   | 79.42                                                | 22.10                   |
| Ash %                                           | 9.57                                                 | 18.2                    |
| Crude fibre (%)                                 | 7                                                    | 1.5                     |
| Lysine (%)                                      | 4.90                                                 | 1.91                    |
| Methionine (%)                                  | 1.84                                                 | 1.54                    |
| Methionine + Cystine (%)                        | 1.42                                                 | 2                       |
| Tryptophan (%)                                  | 0.47                                                 | 0.04                    |
| Threonine (%)                                   | 1.20                                                 | 1.53                    |
| Calcium (%)                                     | 6.50                                                 | 4                       |
| Total Phosphor (%)                              | 1.05                                                 | 2.5                     |
| Metabolism Energy, Mj/kg                        | 13.02                                                | 10.92                   |

Table 1. Chemical-nutritional characteristics of the Hermetia illucens larvae and fish meals.
Table 2. Calculated composition of experimental diet fed during starter (1–10 days), grower (10–32 days), and finisher (32–42 days) phases.

| Composition (%) | starter phase | grower phase | finisher phase |
|-----------------|--------------|--------------|---------------|
|                 | T0  | T4  | T8  | T12 | T0  | T4  | T8  | T12 | T0  | T4  | T8  | T12 |
| White maize     | 55.5 | 55  | 54  | 54  | 62  | 62.4 | 61.7 | 60.9 | 68.5 | 68.5 | 68.6 | 68.4 |
| Wheat bran      | 2    | 3.2 | 4   | 3.7 | 1.5 | 1.5   | 2    | 2    | 0.5  | 0.8  | 0.4  | 0.4  |
| Larvae meal     | 8    | 0   | 0   | 0   | 0   | 0     | 0    | 0    | 0    | 0    | 0    | 0    |
| Roasted soybeans| 21.5 | 22.5| 20.5| 17  | 20  | 20.4  | 17.5 | 15   | 17.9 | 18.2 | 14.4 | 11.2 |
| Soybean meal    | 0    | 2.3 | 0.5 | 0.3 | 0   | 4     | 2.7  | 1.4  | 0    | 3.4  | 3.5  | 2.9  |
| Drench          | 2    | 2   | 2   | 2   | 2   | 2.5   | 2.5  | 2.5  | 2.5  | 2.5  | 2.5  | 2.5  |
| Oyster shell    | 2    | 2   | 2   | 2   | 2   | 2.5   | 2.5  | 2.5  | 2.5  | 2.5  | 2.5  | 2.5  |
| Broiler concentrate | 8  | 8   | 8   | 8   | 3.5 | 3.5   | 3.5  | 3.5  | 1.5  | 1.5  | 1.5  | 1.5  |
| Lysolecithin    | 0.5  | 0.5 | 0.5 | 0.5 | 0.3 | 0.3   | 0.3  | 0.3  | 0.3  | 0.3  | 0.3  | 0.3  |
| Methionine      | 0.5  | 0.5 | 0.5 | 0.5 | 0.3 | 0.3   | 0.3  | 0.3  | 0.3  | 0.3  | 0.3  | 0.3  |
| Nutrient concentrations (g/100 g dry matter) |
| Crude protein (% DM) | 21.3 | 21.3 | 21.3 | 21.3 | 19.5 | 19.5 | 19.5 | 19.6 | 18  | 18  | 18  | 18  |
| Lysine (% DM)    | 1.4  | 1.4 | 1.5 | 1.5 | 1.1 | 1.2   | 1.3  | 1.4  | 1.2  | 1.2  | 1.2  | 1.3  |
| Methionine (% DM) | 1    | 1   | 1   | 1   | 0.7 | 0.7   | 0.8  | 0.8  | 0.7  | 0.7  | 0.8  | 0.8  |
| Tryptophan (% DM) | 0.1  | 0.1 | 0.1 | 0.1 | 0.1 | 0.1   | 0.1  | 0.1  | 0.1  | 0.1  | 0.1  | 0.1  |
| Threonine (% DM) | 0.3  | 0.4 | 0.3 | 0.3 | 0.3 | 0.4   | 0.3  | 0.3  | 0.3  | 0.3  | 0.3  | 0.3  |
| Crude fat (% DM) | 7.5  | 8   | 8.6 | 8.8 | 7.6 | 7.7   | 8.2  | 8.2  | 7.2  | 7.2  | 7.2  | 7.3  |
| Crude fiber (% DM) | 4.3  | 4.2 | 4.3 | 4.4 | 4.4 | 4.5   | 4.4  | 4.3  | 4.3  | 4.2  | 4.2  | 4.1  |
| Calcium (% DM)   | 1.8  | 1.9 | 1.9 | 1.9 | 1.6 | 1.5   | 1.8  | 2.22 | 1.4  | 1.3  | 1.5  | 1.5  |
| Phosphorus (% DM) | 0.5  | 0.4 | 0.4 | 0.4 | 0.61| 0.55  | 1.8  | 1.9  | 0.5  | 0.4  | 0.4  | 0.4  |
| Metabolizable Energy (MJ/Kg) | 12.6 | 12.6| 12.6| 12.6| 12.8| 12.8 | 12.8| 12.8 | 13  | 13  | 13  | 13  |

T0: control group; T4, T8, and T12: diets containing respectively 4, 8, and 12% maggot meal, DM: dry matter.

Concentrated sulfuric acid and a catalyst. After the alkalinization of the reaction products, the ammonia released is distilled and trapped in a boric acid solution. It is then titrated with a sulfuric acid solution. After calculating the total nitrogen content, the protein content is calculated according to the following Eq. (4):

\[
\text{% protein} = \frac{\text{% nitrogen} \times 6.25}{\text{g fresh tissue}}
\]

(4)

2.4.4. Meat's total lipid content determination

The apparatus used for fat extraction was Soxhlet and proofer, and the reagent used for this analysis was hexane. The sample's test portion (M1) was 0.5g ±1mg, and the analysis time was one hour.

The samples were weighed and placed in cellulose cartridges. These cartridges of mass M2 were inserted into the crucibles containing 30 ml of hexane placed previously empty in the oven for 10 min and cooled in a desiccator. The crucibles containing the hexane and the samples' cartridges were placed in the Soxhlet. The fat extraction takes place in three stages for one hour: boiling, rinsing, and recovery of the hexane. The crucibles were then recovered, placed in the oven for 15 min, cooled in a desiccator, and weighed (M3). We use Eq. (5) to obtain the fat content:

\[
\text{Fatty matter} = \frac{M3 - M2}{M1} \times 100
\]

(5)

2.4.5. Meat's fatty acid profile

The test sample of about 5g to the nearest 1mg was weighed and placed in a Soxhlet device. The sample was refluxed for 4–6 h with 150 ml of petroleum ether at 40–60 °C. After extraction, the cartridge was removed, and the solvent was recovered using a rotary evaporator. The lipid extract was used to determine the fatty acid and cholesterol profile.

The lipid extracts were first saponified with potassium hydroxide, then methylated using the boron methanol-trifluoride method BF3 (Morisson and Smith, 1964), and the methyl esters were separated and quantified by gas chromatography (PerkinElmer® Clarus® SQ 8 GC/MS Perkin-Elmer auto system XL). The column was made of molten silica 30 m long with an internal diameter of 0.25 mm. The stationary phase comprised 80% bicyanopropyl and 20% cyanopropylphenyl; the mobile phase was helium. The oven was programmed for an initial temperature of 80 °C. It was then ramped 15 °C/min up to 150 °C and held for a few seconds, and ramped up 3 °C/min to 250 °C hold 6 min. We set the temperatures of the injector and detector to 220 °C and 280 °C, respectively. Fatty acids were expressed as a percentage using an internal standard (C17:0). We expressed the results as a percentage (%) of total fatty acids of fat from breast meat.

2.4.6. Calculation of lipid health indices

The fatty acid profile was used to determine several nutritional parameters of lipids in chicken breast muscles. Indices were calculated using Eqs. (6), (7), (8), (9), and (10) as:

\[
\text{AI} = \frac{(\text{C12:0 + 4 \times C14:0 + C16:0})}{(\text{MUFA + } \sum (n-6) + \sum (n-3))}
\]

(6)

\[
\text{TLI} = \frac{(\text{C14:0 + C16:0 + C18:0})}{0.5 \times \text{MUFA + } 0.5 \times (n-6) + 3 \times (n-3) + 3 \times (n-3) + (n-6)}
\]

(7)

The h/H ratio was calculated, as suggested by Mierliště et al., 2018:

\[
\text{h/H} = \frac{(\text{C18:1 + C18:2n-6 + C20:4n-6 + C18:3n-3 + C20:5n-3 + C22:5n3 + C22:6n3})}{(\text{C12:0 + C14:0 + C16:0})}
\]

(8)

\[
\text{Ul} = (1 \times (\text{monoenoics}) + 2 \times (\text{dieneoics}) + 3 \times (\text{trieneoics}) + 4 \times (\text{tetraenoics}) + 5 \times (\text{pentaenoics}) + 6 \times (\text{hexaenoics})}
\]

(9)
NVI = \( \frac{(C_{18} : 0 + C_{18} : 1)}{C_{16} : 0} \) (Chen et al., 2016)

PI was calculated as:
\[
\text{PI} = \frac{ \text{monoenoic acid} \times 0 + \text{dienoic acid} \times 1 }{ \text{monoenoic acid} \times 0 + \text{trienoic acid} \times 2 + \text{tetraenoic acid} \times 4 + \text{pentaenoic acid} \times 6 + \text{hexaenoic acid} \times 8 } \quad (\text{Erickson, 1992})
\]

\[
\text{IA} = \frac{\text{Unsaturation index}}{\text{Ratio between hypocholesterolemic/ hypercholesterolemic fatty acid}} \quad (\text{IU} = \text{Unsaturation index}; \text{NVI} = \text{Nutritive Value Index}; \text{PI} = \text{peroxidability index})
\]

2.4.7. Meat total cholesterol determination

Total cholesterol was determined using the cholesterol test kit (Fortress Diagnostics, UK). The kit contained the standards, assay reagent, and color development reagent. 80 μl of the sample/standard and 1000 μl of cholesterol reagent were added. The solution was vortexed and incubated for 5 min at 37 °C. The absorbance of the color developed by the sample or standard was measured against the reagent blank at 505 nm (eq. (11)).

\[
\text{Conc of cholesterol} = \frac{\Delta \text{abs of sample}}{\Delta \text{abs of standard}} \times \text{conc. of standard} \quad (11)
\]

2.5. Statistical analysis

The collected data and calculations were analyzed using Graph Pad Prism 8.0.2. We use one-way variance analysis (ANOVA) to process results. The significant mean differences were separated by the TUKEY test at a significance level of \( p < 0.05 \). The principal component analysis (PCA) was applied to correlate chemical and nutritional parameters variables that differed between dietary treatments using XISAT software (2021). Results are presented as the mean plus or minus the standard error of the mean (M ± SEM).

3. Results

3.1. Dry matter, water content, and mineral matter

Table 3 shows the effect of maggot meal on the variations of dry matter, water content, total ash, and protein content of meat samples on a dry matter basis. There was no significant variation between the values of these parameters.

3.2. Variation in abdominal fat in chickens

Figure 1 shows the abdominal fat level of chickens as a function of the rate of incorporation of maggot meal in the diet of broiler chickens. This figure shows a significant increase in the abdominal fat of chickens as a function of the incorporation rate. Chickens fed 8% and 12% had higher abdominal fat levels than control birds and birds receiving 4% maggot meal.

3.3. Protein content

Figure 2 shows the variation in the protein content of raw chicken breast as a function of the rate of incorporation of black soldier fly maggot meal. There was no significant variation in protein levels between the meat of birds fed with maggot meal and chickens receiving fishmeal as a source of animal protein in their ration.

3.4. Intramuscular lipid content

The birds receiving an 8% maggot meal diet had higher (\( P < 0.05 \)) lipid content compared to birds receiving a control diet or 4% maggot meal. The birds receiving a 12% maggot meal diet had higher lipid content than birds fed an 8% maggot meal diet. Intramuscular lipid levels increased significantly with the rate of incorporation of soldier fly maggot meal into the chicken feed (Figure 3).

3.5. Total cholesterol

The total cholesterol of meat samples increased with the rate of incorporation of maggot meal in chicken feed (Figure 4). All groups fed maggot meal had significantly higher cholesterol levels than the control birds. The cholesterol level was significantly higher in birds fed 8% or 12% maggot meal compared to birds fed 4% maggot meal. However, birds fed 4% maggot meal had higher cholesterol levels than control birds.

3.6. Fatty acid profile

The fatty acid composition of broiler chicken breast meat is presented in Table 4. The use of maggot meal has influenced the different types of fatty acids in meat.

3.6.1. Variation in atherogenic fatty acid levels

We observed a decrease in saturated fatty acids C14:0; C16:0 and an increase in C12:0 fatty acids depending on the rate of maggot meal incorporation in chicken feed (\( p < 0.05 \)). The meat from groups that received maggot meal had lower levels of atherogenic fatty acids.

3.6.2. Change in oleic acid levels

The level of oleic acid was very high in all the meat samples analyzed (>40%). This level was higher (\( p < 0.05 \)) in the chickens that received maggot meals in their diet compared to the control birds. The chicken of group T12 had higher oleic acid levels than T4 and T8 groups which had similar levels.

Table 3. Effect of maggot meal on the variation of dry matter, moisture content, mineral matter and protein content on a dry matter basis.

| Parameters                  | Treatments | p-value   |
|-----------------------------|------------|-----------|
|                            | T0         | T4        | T8        | T12       |
| Moisture content            | 72.67 ± 0.1| 72.33 ± 0.37| 73.42 ± 0.40| 73.42 ± 0.18| 0.0790 |
| Dry matter (%)              | 27.33 ± 0.41| 27.67 ± 0.37| 26.58 ± 0.40| 26.58 ± 0.18| 0.0790 |
| The protein of (% DM)       | 84.94 ± 0.33| 83.65 ± 0.94| 83.36 ± 0.99| 83.59 ± 0.69| 0.4833 |
| Ash content (% DM)          | 7.74 ± 0.12| 7.36 ± 0.15| 7.564 ± 0.11| 7.65 ± 0.073| 0.1440 |

a,b,c The mean values within the same row with different superscripts differ significantly: p < 0.05. T0: control diet with 0% of maggot meal and 8% of fish meal T4: 4% of maggot meal; T8: 8% of maggot meal; T12: 12% of maggot meal. % DM: percentage of dry matter.
3.6.3. Variation in arachidonic acid, linolenic and linoleic acid

C20:4n-6 was higher in T8 birds, and the T4 and T12 birds had lower levels than the control. On the other hand, the linoleic acid C18:2 n-6 was lower (p < 0.05) in the meat of the T12 birds compared to the birds of T4, T8, and T0. The T4 and T8 had intermediate values and were statistically comparable.

3.6.4. Change in DHA and EPA

The docosahexaenoic acid content of raw meat (Table 4) increased with the level of incorporation of maggot meal into the chicken feed. The best DHA levels were obtained with the meats of T0 and T12 birds, and T4 and T8 meats gave a low level of DHA (p < 0.05).

Other fatty acids such as C20:3n-6 (DGLA) and C22:5n-3 increased with the rate of incorporation of maggot meal into the chicken diet.

However, all birds fed maggot meal had a significantly lower level of n-3 fatty acid than control birds receiving fishmeal. C18:0 also increased significantly in birds fed maggot meal, and dietary treatments did not influence C20:5n-3. C12:0 and C20: 1n-9 were missing in the control birds who received fishmeal.

3.7. Variation of different types of intramuscular fatty acids

We observed that saturated fatty acid levels in the meat of birds fed maggot meal were lower than those of control birds. Also, the level of polyunsaturated fatty acids was significantly lower in T12 compared to T0 and T4. The n-6 fatty acids of T8 and T4 were respectively higher (p < 0.05) than T0 and T12. We also noted that n-3 fatty acids increased as a function of the rate of maggot incorporation into chicken feed (Figure 5). However, T0 meats had a better n-3 rate (p < 0.05).

3.8. Variation in the different nutritional indices of intramuscular fat

The PUFA/SFA, n-6/n-3, and h/H ratio of T4 and T8 meats were significantly higher than those of T0 and T12 meat. The atherogenicity index (AI) and thrombogenicity index (TI) decreased with the rate of incorporation of maggot meal into chicken feed (Table 5). There is no significant variation between the meat from treated birds for the atherogenicity index, but this index was higher for the T0 meats (p < 0.05). The n-6/n-3 ratio was significantly low in T0. However, the meats of the T8 subjects had a higher level of unsaturation (p < 0.05) compared to T0, T4, and T12.

3.9. Principal component analysis (PCA)

3.9.1. Correlation circle

Figure 6 shows the degree of relationship between the variables. The h/H ratio and the meat nutritional value index were positively correlated. We also observed a positive correlation between the level of polyunsaturated fatty acids, the peroxidability index, and the index of unsaturation on the one hand; similarly, between the level of total lipids, the level of mono-unsaturated fatty acids, and the peroxidability index and the unsaturation index, the level of the atherogenicity index and saturated fatty acids on the other hand. However, there was a negative correlation between h/H and AI, total cholesterol, and TI.
3.9.2. Combination of correlation circle and treatment map

The combination of the correlation circle and treatment map showed that T8 and T4 had similar characteristics in terms of total cholesterol, h/H ratio, PUFA/SFA, unsaturation index, and peroxidation index (Figure 8).

T12 and T0 have opposite characteristics (Figure 7). Control chickens receiving fishmeal were characterized by a high content of saturated fatty acids and n-3 fatty acids and higher TI and AI values. T4 and T8 had similar characteristics, but T0 meat characteristics appeared opposite to T12 (Figure 8).

4. Discussion

Water content is one of the most important and widely used indices in food processing and control (Mathlouthi, 2001). It has an essential effect on the chemical stability of food during storage and distribution. The soldier flies maggot meal which did not influence the moisture content of the meat compared to the control, would not alter the chemical properties of the meat. Indeed, the variation in meat's water content impacts microbial development. The dry matter content of a food is inversely proportional to its water content. Thus, the dry matter of chicken meats fed maggot meal was comparable to that of control birds.

Contrary to the results of Schiavone et al. (2019), the study showed no significant effect on protein content in response to the incorporation of an increasing rate of soldier fly maggot meal. Indeed, chitin in feeds containing soldier fly larvae meal stimulates chitinase production at the proventriculus. The chitinase reduces protein digestibility (De Marco et al., 2015; Bovera et al., 2018) and subsequently induces low protein retention in the meat of birds fed larvae meal. However, the observed
results suggest that the composition of the chicken breast meat (in terms of ash and protein level) would not affect the stability and quality of chicken meat for the processors and consumers (Verbeke & Viaene, 2000; Mathlouthi, 2001). The chemical composition of broiler chicken meat was not affected by the incorporation of maggot meal into chicken feed. These results constitute a significant positive factor in consumers' evaluation of this new alternative ingredient in poultry nutrition. The results of this study correlate with those reported by Bovera et al. (2016) and Cullere et al. (2019b).

The fatty acid profile is of great importance for the health value of food, and animal feed is one of the factors that most influence the fatty acid composition of meat (Mir et al., 2021). In this study, the fatty acid profile of breast meat showed an appreciable increase in C12:0 levels, which the high content of lauric acid could explain in the meal of soldier fly larvae. Lauric acid is a medium-chain fatty acid with important metabolic characteristics, especially in cellular metabolism. Their lower energy metabolism compared to long-chain fatty acids make them an alternative solution for preventing and treating lipid-related problems such as cardiovascular diseases and obesity (Hainer et al., 1994; ST-Onge & Jones, 2003). Furthermore, increasing its level in chicken meat in the present study would have a more significant proportional effect on high-density lipoprotein (HDL) levels than on low-density lipoprotein (LDL) levels (Li et al., 2016). The increase in the proportion of C12:0 was

### Table 4. Effect of maggot meal on intramuscular fatty acids (percentage (%) of total fatty acids of fat from breast meat).

| Fatty acid | Treatments | P-value |
|------------|------------|---------|
|            | T0         | T4      | T8      | T12     |
| C12:0      | -          | 1.07 ± 0.02b | 1.45 ± 0.05b | 2.75 ± 0.01b | 0.01477 |
| C14:0      | 0.96 ± 0.00b | 0.94 ± 0.01b | 0.81 ± 0.01b | 0.84 ± 0.01b | 0.00732 |
| C16:0      | 18.39 ± 0.05a | 12.52 ± 0.16b | 12.26 ± 0.02b | 10.94 ± 0.01c | 0.01348 |
| C18:0      | 8.23 ± 0.02c | 9.52 ± 0.08b | 10.49 ± 0.22b | 10.11 ± 0.00b | <0.00014 |
| C20:4n-6   | -          | 0.04 ± 0.00c | 0.02 ± 0.00c | 0.01 ± 0.00c | 0.00504 |
| C22:5n-3   | 3.57 ± 0.02a | 0.86 ± 0.01f | 0.87 ± 0.02f | 0.98 ± 0.00b | 0.00584 |
| C16:1n-7   | 0.27 ± 0.01 | 0.21 ± 0.01i | 0.21 ± 0.00 | 0.19 ± 0.00 | 0.00595 |
| C18:1n-9   | 44.11 ± 0.10f | 51.97 ± 0.11b | 51.44 ± 0.08b | 55.75 ± 0.00b | <0.00016 |
| C20:1n-9   | -          | 0.55 ± 0.00c | 0.48 ± 0.00c | 0.27 ± 0.01b | 0.01498 |
| C18:3n-3   | 1.99 ± 0.01a | 0.12 ± 0.00d | 0.44 ± 0.04c | 0.45 ± 0.02c | 0.01598 |
| C18:2n-6   | 17.4 ± 0.05b | 20.29 ± 0.05g | 20.29 ± 0.08g | 14.45 ± 0.00e | <0.00017 |
| C20:3n-6   | 0.16 ± 0.01b | 0.2 ± 0.02b | 0.17 ± 0.01b | 0.51 ± 0.00a | 0.04058 |
| C20:4n-6   | 1.88 ± 0.00c | 1.07 ± 0.01c | 2.05 ± 0.02c | 0.21 ± 0.01d | 0.00978 |
| C20:5n-3   | 0.04 ± 0.01 | 0.07 ± 0.01 | 0.07 ± 0.01 | 0.03 ± 0.01 | 0.17648 |
| C22:5n-3   | 0.23 ± 0.04d | 0.20 ± 0.05c | 0.31 ± 0.02c | 0.33 ± 0.01c | 0.02628 |
| C22:6n-3   | 1.26 ± 0.01c | 0.75 ± 0.06b | 0.81 ± 0.00b | 1.22 ± 0.1a | 0.06538 |

abc Within row data sharing, no common letters are significantly different (p < 0.05). T0: control diet with 0% of maggot meal and 8% of fish meal; T4: 4% of maggot meal; T8: 8% of maggot meal; T12: 12% of maggot meal.

### Table 5. Effect of maggot meal on the nutritional indices of intramuscular fat in broiler chicken breast meat.

| Parameters | Treatments | P-value |
|------------|------------|---------|
|            | T0         | T4      | T8      | T12     |
| PUFA/SFA   | 0.84 ± 0.00c | 0.96 ± 0.01b | 0.93 ± 0.01c | 0.71 ± 0.01d | <0.0001 |
| PUFA/FSA   | 5.55 ± 0.01b | 18.66 ± 0.14b | 13.74 ± 0.01d | 7.48 ± 0.02c | <0.0001 |
| AI         | 0.31 ± 0.00c | 0.24 ± 0.00b | 0.22 ± 0.01b | 0.23 ± 0.01b | 0.0013 |
| TI         | 0.62 ± 0.00c | 0.58 ± 0.01b | 0.58 ± 0.01b | 0.55 ± 0.00c | 0.0008 |
| UI         | 105.0 ± 0.01b | 103.1 ± 0.03c | 107.0 ± 0.01d | 96.70 ± 0.01c | 0.0023 |
| h/H        | 3.44 ± 0.01c | 4.96 ± 0.02c | 4.97 ± 0.01c | 4.85 ± 0.00b | <0.0001 |
| PI         | 31.9 ± 0.00c | 30.04 ± 0.07c | 33.53 ± 0.01c | 24.99 ± 0.02c | <0.0001 |
| NVI        | 10.65 ± 0.01c | 13.70 ± 0.03c | 14.70 ± 0.01c | 15.23 ± 0.01c | <0.0001 |

abc Within row data sharing, no common letters are significantly different (p < 0.05). T0: control diet with 0% of maggot meal and 8% of fish meal T4: 4% of maggot meal; T8: 8% of maggot meal; T12: 12% of maggot meal.

 IA = atherogenicity index; TI = thrombogenicity index, h/H = Ratio between hypocholesterolemic/hypercholesterolemic fatty acid.
 UI = Unsaturation index; NVI = Nutrition Facts Index; PI = peroxidability index; PUFA/SFA = \( \frac{\text{PUFA}}{\text{SFA}} \).

**Figure 5.** Effect of maggot meal on the variation of different types of intramuscular fatty acids. a,b,c The bars with different superscript differ significantly: p < 0.05.
Figure 6. Correlation circle showing the correlations between the measured parameters.

Figure 7. Map of the groups or treatments showing the differences and similarities between treatments. T0: control diet with 8% of fish meal; T4: 4% of larva meal; T8: 8% of larva meal; T12: 12% of larva meal.
accompanied by an increase in the level of C14:0 according to the level of incorporation. However, the C14:0 values of the groups that received maggot meal remained significantly lower than the increase of the control group. Similarly, the level of C18:1 n-9 increased significantly. The results correlated with those found by Schiavone et al. (2017), Cullere et al. (2019a), Schiavone et al. (2019), who observed a linear increase in lauric and myristic acid contents in broiler chicken meat with partial or total substitution of soybean oil with fat derived from fly larvae or increasing amounts of defatted soldier fly meal.

The control feed would have a higher SFA level than the soldier flies maggot meal, known for its high level of PUFA. Indeed, a surplus of dietary SFA inhibits the biosynthesis of C18:1n-9 by suppressing the activity of elongase (Poureslami et al., 2010; Mir et al., 2021).

There was an increase in C18:2n-6 in broiler chicken meat, incorporating soldier fly meal into the diet. The content of n-3 PUFA tended to increase in the breast of the T4, T8, and T12 groups. Still, it remained significantly lower than the T0 value, which confirms the results of Secci et al. (2018) and Schiavone et al. (2019), who reported a significant decrease in long-chain n-3 PUFA content.

The increase in C18:2 n-6 increased the n-6/n-3 ratio, which remained very high in all groups fed larvae meal compared to the recommended values (<4) (Department of Health, 1994; Enser et al., 2001; Mir et al., 2021).

It is, therefore, necessary to make additional changes to the formula of broiler chicken feed so that they meet the health criteria for a balanced fatty acid profile. On the other hand, the PUFA/SFA ratio was higher than the minimum of 0.45 recommended in the human diet to prevent the development of cardiovascular diseases and certain chronic diseases such as cancer (Mapiye et al., 2011). The significant decrease in SFA and, in particular, C14:0 and C16:0 was associated with a decrease in AI, TI, and an increase in h/H. AI and TI were negatively correlated with total cholesterol ($r = -0.984$) and MUFA ($r = -0.951$) respectively. The atherogenic and thrombogenic indices are indicators of the quality of lipids that depend on the variations of the different types of fatty acids. They indicate the potential effects of lipids on the development of cardiovascular diseases. Both AI and TI decreased in breast meat of broiler chicken fed maggot meal. The maximum values were observed in the control group T0. This corresponds to the significantly higher SFA content of this group that did not receive a maggot meal. Therefore, a positive and significant relationship is observed between SFA and AI and TI ($r = 0.79$ and $r = 0.762$, respectively) in broiler chicken meat (Attia et al., 2017). This study's results differ from those of Schiavone et al. (2019). They observed AI values between 0.29 and 0.34 of breast meats in broiler chicken receiving rations containing 50–150 g kg$^{-1}$ of partially defatted soldier fly maggot meal.

Similarly, Cullere et al. (2019a) reported a significant increase in AI and TI in broiler chicken with 50% and 100% substituting soybean oil with soldier fly maggot oil. These differences are due to these authors' direct use of maggot oil. Maggot farming substrates or the nature of the ingredients used in chicken feed would also influence the effect of larvae on the lipid quality of the meat produced. The AI and TI values determined in this study could be considered low compared to other studies (Attia et al., 2017; Del Puerto, Cabrera & Saadoun, 2017; Cullere et al., 2019a), indicating no negative effect of black soldier fly meal on the lipid quality of the chicken meat produced.

Like lipids, the variability in cholesterol content reflects differences in the type of diet used. It is accepted that fats rich in medium-chain fatty acids compared to long-chain fats decrease total cholesterol in chickens (Wang et al., 2015; Khatibjoo et al., 2018). The result of the present study showed a positive correlation between these two parameters ($r = 0.736$).

A ratio between the long-chain saturated fatty acids and the medium-chain fatty acids of the food would be necessary for the effectiveness of the hypocholesterolemic effect of the latter (Kumar et al., 2021). In addition, maggots contain a higher cholesterol level than fishmeal, and

![Figure 8. Combination of correlation circle and treatment map. T0: control diet with 8% of fish meal, T4: 4% of larva meal; T8: 8% of larva meal; T12: 12% of larva meal.](image-url)
dietary cholesterol levels would also influence the cholesterol concentration of meat from chickens fed maggot meal. Thus, a high level of cholesterol in poultry meat was observed in this study.

The observed differences in abdominal fat percentage show that using maggot meal increased fat mass in broiler chicken. These results are consistent with the work of Ballitoc and Sun (2013). Maggot meal contains medium-chain fatty acids, including lauric acid. These fatty acids are known for their modulating effect on lipid metabolism (Taulesco et al., 2010; Khatun et al., 2018) in chickens (Schiavone et al., 2018). It is therefore not surprising that chickens fed maggot meal had a higher level of abdominal fat than the chicken in the control group. It is well accepted that dietary fats influence the fatty acid composition of broiler chicken's meat and adipose tissues (Crespo and Esteve-Garcia, 2001; Skrivan et al., 2018; Kumar et al., 2021). Therefore, by incorporating the soldier fly maggot meal, abdominal fat levels increased, and intramuscular fatty acid profiles improved. Medium-chain fatty acids (lauric acid and myristic acid) increased with maggot meal incorporation. Similarly, unsaturated fatty acids (oleic acid, linoleic acid) significantly improved compared to the control. In general, maggot meal improves the level of unsaturation (UI) of intramuscular fatty acids in chicken meat and decreases the atherogenic saturated fatty acids compared to the control. This decrease led to a decrease in the atherogenicity index (AI). A higher value of NVI was observed, negatively correlated with AI (r = -0.971), and characterizes meat from chickens fed maggot meal. This characteristic is due to the higher proportion of C18:0, C18:1n-9, with a low percentage of C16:0 in the muscles of these meats. C18:0 fatty acids are known for their effects on the induction of cardiovascular disease and are particularly interesting to consumers. The peroxidability index represents the relationship between the fatty acid composition of a tissue and its sensitivity to oxidation and indicates the technological quality of the meat. The PI index is used to assess the stability of PUFAs in food products and to protect them from possible oxidation processes. The higher the value of the PI index, the more the food has protective potential against coronary heart disease. Excessive consumption of PUFAs has adverse effects such as oxidative stress due to high susceptibility to lipid peroxidation. Oxidative stress, associated with forming lipid peroxides, has been identified as a risk factor and contributor to the pathological processes of aging and many diseases such as atherosclerosis (Kang et al., 2005; Sinanoglu et al., 2013; Skalecki et al., 2016). In the present study, breast meats from chickens fed 12% maggot meal showed a significantly lower value of PI (24.99%) compared to T8, T0, and T4 meats, which had 33.53, 31.9, and 30.04%, respectively. The low PI value in T12 indicates a lower level of auto-oxidation in meat and, therefore, a possibility of longer preservation. Generally, the values of the PI index obtained in the meat of chickens fed with larvae meal were lower than those found in native Turkish or polish geese (Oz and Celik, 2015; Wołoszyn et al., 2020). However, the PI index of this study was similar to that of Mapiye et al. (2011) found in beef. Although n-3 fatty acids increased with the maggot meal incorporation, the value of these fatty acids remained lower than that found in the control group. This result would be due to the low percentage of linoleic acid in maggot meal compared to fish meal.

5. Conclusion

The present study has shown that using Hermetia illucens larvae in broiler chicken feed is technically feasible, up to an 8% inclusion level. The overall quality of the chicken meat was nutritionally satisfactory. The results showed that Hermetia illucens larval meal could be considered a valuable ingredient and included in commercial broiler chicken feed. The fatty acid profile of derived meat was improved from the point of view of the different nutritional indices evaluated in this study. However, increased cholesterol levels were the only drawback of using this alternative ingredient in chicken feed. Meat from chickens fed maggot meal would offer less risk to cardiovascular health because it has the best index of atherogenicity, thrombogenicity, nutrition facts index, and higher amounts of unsaturated fatty acids, which are very beneficial for human health.

Declarations

Author contribution statement

K. G. Mlaga: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

K. Agboka, K. Tona: Contributed reagents, materials, analysis tools or data.

K. Attivi: Conceived and designed the experiments; Performed the experiments.

E. Osseyi: Analyzed and interpreted the data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interest's statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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