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Research Article
The Effects of Feeding Black Soldier Fly (*Hermetia illucens*) Maggot Meal as a Substitute for Fish Meal on Broiler Meat Quality

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Abstract

Background and Objective: There has been a search for non-conventional feedstuffs such as maggot meal as a result of scarcity and high cost of fishmeal. The objective of this study was to evaluate the effect of the black soldier fly maggot meal as a protein source on meat quality of broiler chickens. **Materials and Methods:** A total of 22_5 broiler chicks (Ross 308) were assigned to five treatment groups of varying dietary inclusion levels of fish and maggot meal; 100% fishmeal and 0% maggot meal (control group) (A_0), 75% fishmeal: 25% maggot meal (A_{25}), 50% fishmeal: 50% maggot meal (A_{50}), 25% fishmeal: 75% maggot meal A($_{75}$) and 100% maggot meal and 0% fishmeal (A_{100}). At the 57th day, 6 chickens per replicate were randomly selected and slaughtered to evaluate the carcass yield and meat quality. **Results:** Results showed that there was a reduction of breast water loss in group A_{100} compared to the other batches ($p<0.05$). The maggot meal increased the yield and ultimate pH (pHu) of the breast of A_{100} group ($p<0.05$). In addition, meat protein levels were also higher in the treated groups than that of the control group ($p<0.001$). In contrast, thigh yield, abdominal fat and mineral contents were not affected by the dietary inclusion of maggot meal. **Conclusion:** Broilers fed 100% maggot meal obtained the best meat characteristics. This could be attributed to the high-quality protein contained in the Black Soldier fly (*Hermetia illucens*) maggot meal. It can be concluded that maggot meal is a non-conventional protein source which can be used as fish meal replacer in broiler diet.

Key words: Broiler, maggot meal, meat nutritional component, meat yield, poultry feed, meat quality

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

According to the FAO[1], poultry meat ranked second to pork (over 110 million tons) in the meat consumed in the world with 101 million tons in 2011. A wide variety of feed ingredients are available for poultry feed formulation and usually poultry farmers supply animal based protein by using meat meal, blood meal and fishmeal. In recent times, Fishmeal which is the conventional animal protein source is becoming increasingly scarce and expensive due to its competition for use between animals and humans. This is a major challenge and several studies are being undertaken to find sustainable protein substitute which are less consumed by man. Insect based protein source is a viable alternative which has been identified by various researchers.

Unconventional protein sources such as insects are naturally consumed by birds. The inclusion of insect meal in poultry diets is in line with the recommendations of several international organizations[2]. Studies in Nigeria and Benin Republic by Awoniyi *et al*.[3], in Cameroun by Téguia *et al*.[4] and in Togo by Ekoué and Hadzi[5]have shown that maggots obtained from houseflies (*Musca domestica*) contain high level of proteins and are used by farmers to meet the protein requirements of the birds.

The protein content of house fly maggot meal was estimated at 64% by Hwangbo *et al*.[6] According to Pieterse *et al*.[7] and Teotia *et al*.[8], house fly larvae contains 28.22% of non-essential amino acids and 29.46% of essential amino acids with high proportions of lysine, methionine, arginine, phenylalanine, tryptophan and valine. In addition, Pieterse *et al*.[6] showed a better apparent digestibility of house fly maggot proteins (98.50%) and essential amino acids (94.80%) and they suggest high availability of protein nutrients for absorption. Unfortunately, Newton *et al*.[9] pointed out that houseflies are pathogenic vectors and the dietary inclusion of housefly maggot is a potential source of contamination. Therefore, recent research works have focused on Soldier Fly maggot which has been successfully used in the recycling of organic waste into high protein, without spreading pathogens and without producing high-fat biomass products unlike maggot meals[10,11]. Although, progress has been made in incorporating of fly-maggot meal into poultry feed[12,13], its effect on poultry meat quality has not been fully researched. Therefore, this study was undertaken to evaluate the meat quality of birds fed with varying dietary inclusion level of Black Soldier fly (*Hermetia illucens*) maggots.

MATERIALS AND METHODS

Experimental design: The experiment was carried out at the Experimental Unit of the Centre d'Excellence Regional sur les Sciences Aviaires (CERSA) of the University of Lomé, Togo. A total of two hundred and twenty-five, 14 day-old Ross 308 broilers chickens were allotted to 5 treatment groups: A_0, A_{25}, A_{50}, A_{75} and A_{100} having 3 replicates of 15 birds each. The birds in each experimental treatment were fed with varying dietary inclusion level of fish and maggot meal; 100% fishmeal and 0% maggot meal (control group) (A_0), 75% fishmeal: 25% maggot meal (A_{25}), 50% fishmeal: 50% maggot meal (A_{50}), 25% fishmeal: 75% maggot meal A($_{75}$) and 100% maggot meal and 0% fishmeal (A_{100}). Gross composition of the experimental diets fed during grower phase is presented in Table 1. The experimental diets containing similar levels of energy, protein and fibre are shown in Table 2. The same poultry house was used for the birds and each group was assigned to a space of 1.20 m wide $\times$3.00 m long. During the 42-day experiment, birds were supplied both water and feed *ad libitum*.

Table 1: Gross composition of the experimental diets fed during grower phase (%)

	Treatments				
Ingredients	A_0	A_{25}	A_{50}	A_{75}	A_{100}
White maize	65.00	65.50	65.50	65.00	64.60
Roasted soya bean meal	18.00	16.50	15.50	15.00	14.40
Wheat bran	3.00	3.00	4.00	5.00	6.00
Fish meal 40%	8.00	6.00	4.00	2.00	0.00
Oyster shell	1.00	1.00	1.00	1.00	1.00
Maggot meal	0.00	2.00	4.00	6.00	8.00
Lysine	0.50	0.60	0.60	0.60	0.70
Methionine	0.50	0.40	0.40	0.40	0.30
Concentrate	4.00	5.00	5.00	5.00	5.00
Calculated values					
Metabolizable energy (kcal)	3105.00	3111.60	311.93	3112.44	3112.28
Crude protein (%)	19.62	19.66	19.51	19.54	19.57
Crude fiber (%)	4.61	4.6	4.57	4.52	4.43
Fat (%)	7.26	7.32	7.56	7.80	8.70
Dry matter	91.23	91.17	91.34	91.37	90.97
Ash	9.57	8.63	8.04	5.45	5.40

Table 2: Gross composition of the experimental diets fed during finisher phase (%)

	Treatments				
Ingredients	A_0	A_{25}	A_{50}	A_{75}	A_{100}
White maize	72.00	71.00	71.00	71.00	71.00
Roasted soya bean meal	16.00	16.00	15.00	14.00	13.40
Wheat bran	2.00	3.00	3.20	4.20	4.80
Fish meal	8.00	6.00	4.00	2.00	0.00
Oyster shell	1.00	1.00	10.00	1.00	1.00
Lysine	0.50	0.50	0.50	0.50	0.50
Maggot meal	0.00	2.00	4.00	6.00	8.00
Methionine	0.50	0.50	0.30	0.30	0.30
Concentrate	0.00	0.00	1.00	1.00	1.00
Dry matter (%)	91.98	91.84	91.37	91.74	90.94
Calculated values					
Metabolizable energy (kcal)	3159.63	3160.31	3161.96	3162.29	3169.35
Crude protein (%)	17.53	17.63	17.69	17.54	17.51
Crude fibre (%)	4.65	4.62	4.58	4.54	4.49
Fat (%)	6.94	7.10	7.50	7.70	8.90
Ash (%)	9.68	8.71	8.32	5.59	5.56

Slaughtering method and meat sample preparation: At 57 days of age, 6 broiler birds were randomly selected, balanced for weight and slaughtered. The broilers were rendered unconscious by electrical stunning (50-70 volts; 3-5 sec), the unilateral cut of the neck was manually performed immediately and the birds were bled for 120 sec. The broilers were scalded at 53.3°C for 191 sec, plucked manually and then eviscerated. After 2 h postmortem, breast (boneless) and the whole thigh were removed from the carcass and placed in a labelled bag and stored in refrigerator at 4°C. At 24 h postmortem, the right and left parts of breast were separated. The right portions of the breast were used for ultimate pH and the determination of nutritional value, while the left parts and the left thighs were used for the determination of water loss.

PH measurement of meat: Fifteen minutes after slaughter, pH_{15} was measured on each bird by inserting pH-meter probe into the right portion of the breast at about 2.5 cm depth after incision of the thickest part near the furcula according to the method described by Corzo *et al.*[14]. At 24 h post mortem, the ultimate pH (pHu) was determined by inserting the pH-meter probe at the same location. Between the two pH measurements, the probe was rinsed with distilled water and introduced into a 3M KCl electrolytic solution for a period of time. The drop in the pH value was determined by the difference between pH_{15} and pHu.

Measurement of breast and thigh yield and abdominal fat weight: After cutting the carcass, the whole breast (boneless) and the thigh were isolated for yield evaluation. Percentage of yield was calculated according to the equation:

$$\text{Percentage of yield}(\%) = \frac{100 \times \text{carcass portion weight}}{\text{Body weight}}$$

The adipose tissue of the abdominal cavity was meticulously isolated and weighed to determine the relative weight of abdominal fat using the equation:

$$\text{Percentage of abdominal fat }(\%) = \frac{\text{Abdominal fat} \times 100}{\text{Body weight}}$$

Water loss measurement: The water loss was evaluated using the method of Berri *et al.*[15]. The left breast and the left thigh were weighed and kept in a closed plastic bag. The bag was suspended by a hook and placed in the refrigerator for four days at 4°C. At the end of this period, the breast and thigh were again weighed to calculate the loss of water.

$$\text{Percentage of water loss}(\%) = \frac{(\text{Initial weight} - \text{final weight}) \times 100}{\text{Initial weight}}$$

Assessment of the nutritional value of meat: At 24h post mortem, the left pectoral muscle and the left thigh muscle were collected. Samples of 1g and 5 g of each part of the carcass were collected for the determination of crude protein (by Kjeldahl method) minerals composition such as Fe, Ca, K and Zn contents (by spectrophotometry), respectively.

Statistical analysis: All values were expressed as mean±SEM. Significant differences between groups were determined with one-way analysis of variance (ANOVA) using Graph Pad

Prism 5 (Software, Inc., a privately held California, USA). Pairwise comparisons were done using the Tukey's test at $p<0.05$. In addition, the principal component analysis was carried out with the software TANAGRA 1.4.

RESULTS

Effect of black soldier fly maggot meal on breast and thigh meat yield and abdominal fat: The yields of breast and thigh and the weight of abdominal fat are summarised in Table 3. There was a significant difference ($p<0.05$) in the breast yield of broiler birds. However, there were no significant difference ($p>0.05$) in the thigh yield and abdominal fat of the birds across the treatments. The breast yield of birds in A_{100} was significantly higher ($p<0.05$) than those fed with control diet.

Effect of black soldier fly maggot on pH and water loss of meat: Table 4 shows the effect of soldier fly maggot meal on pHu, breast and thigh water loss of chickens. There was a significant difference ($p<0.05$) in the pHu and exudate values, however no significant difference ($p>0.05$) was observed in pH_{15} value. The meat pHu of birds fed in A_{100} was significantly higher ($p<0.05$) than those of the other treatment groups, while the birds inA_{25}, A_{50} and A_{75}were similar but higher than that of the control group. In contrast, after fifteen minutes, A_{100} had numerically lowest pH drop (0.40) compared to those of the chickens in groups A_0, A_{25}, A_{50} and A_{75}, whose pH drops were 0.95, 0.45, 0.75 and 0.5, respectively. With regard to meat water loss in general, water loss from the breast or thigh meats decreased as the level of maggot meal increased in the diet. The breast meat water loss of the birds in A_{100} was the lowest while the thigh water loss of birds in A_{25}, A_{50} and A_{75} were not different from the control. The water loss of the breast was generally higher ($p<0.05$) than that of the thigh.

Effect of black soldier fly maggot meal on protein and minerals contents of meat: Table 5 shows the protein and the mineral contents of chicken meat as affected by maggot meal. In general, the protein content of meat increased with the rate of inclusion of the maggot meal in the diet. The protein value

Table 3: Effect of soldier fly maggot meal on breast and yield, thigh meat yield and abdominal fat weight of broiler chickens

	Treatments					
Part of the carcass	A_0	A_{25}	A_{50}	A_{75}	A_{100}	p-value
Breast yield (%)	10.96±0.32 [b]	13.20±0.44 [ab]	13.80±1.37 [ab]	14.02±1.15[ab]	15.09±0.73 [a]	0.0206
Thigh yield (%)	20.79±0.67	22.23±0.51	21.98±2.66	22.03±2.20	22.50±0.54	0.9540
Abdominal fat (%)	1.58±0.23	1.23±0.23	1.33±0.29	1.22±0.17	1.47±0.28	0.8142

[a,b,c]Within row data sharing no common letter are significantly different ($p<0.05$). A_0: Control diet 100% fish meal, A_{25}: 25% maggot meal, 75% fish meal, A_{50}: 50% maggot meal, 50% fish meal, A_{75}: 75% maggot meal, 25% fish meal and A_{100}: 100% maggot meal

Table 4: Effect of soldier fly maggot meal on pHu, breast and thigh water loss of chickens

	Treatments					
Parameters	A_0	A_{25}	A_{50}	A_{75}	A_{100}	p-value
pHu	5.61±0.01[c]	5.71±0.05[b]	5.68±0.03[b]	5.73±0.06[b]	5.90±0.05[a]	0.0035
Breast water loss(%)	7.02±0.65[a]	5.30±0.36[b]	5.96±0.45[b]	5.76±0.28[b]	3.44±0.37[c]	0.0001
Thigh water loss(%)	2.97±1.00	2.59±0.94	2.63±0.66	2.60±0.25	1.64±0.44	0.7514
pH_{15}	6.50±0.28	6.15±0.12	6.45±0.28	6.35±0.23	6.25±0.34	0.1383

[a,b,c]Within row data sharing no common letter are significantly different ($p<0.05$) A_0: Control diet with 100% of fish meal A_{25}: 25% maggot meal, 75% fish meal, A_{50}: 50% maggot meal, 50% fish meal, A_{75}: 75% maggot meal,25% fish meal and A_{100}: 100% maggot meal

Table 5: Effect of soldier fly maggot meal on the protein and mineral contents of chicken meat

	Treatments					
Parameters	A_0	A_{25}	A_{50}	A_{75}	A_{100}	p-value
Protein content (mg g^{-1})	19.74±0.02 [c]	25.21±0.03 [b]	24.69±0.07 [b]	25.05±0.02 [b]	27.75±0.06 [a]	p<0.0001
Mineral content (mg 100 g^{-1})						
Iron (Fe)	31.21±1.2	30.83±0.12	32.11±0.04	30.88±0,57	32.39±0.66	0.4254
Zinc (Zn)	11.60±0.86	11.20±1.07	12.98±1.03	11.82±0.10	11.62±1.31	0.7502
Calcium (Ca)	285.30±2.11	288.70±3.08	281.70±6.44	294.90±4.18	287.80±1.37	0.3083
Potassium (K)	30.57±0.02	31.34±0.55	31.82±0.07	31.89±0	31.86±0.03	0.0506

[a,b,c]Within row data sharing no common letter are significantly different ($p<0.05$) A_0: Control diet with 100% fish meal, A_{25}: 25% maggot meal, 75% fish meal, A_{50}: 50% maggot meal, 50% fish meal, A_{75}: 75% maggot meal, 25% fish meal and A_{100}: 100% maggot meal

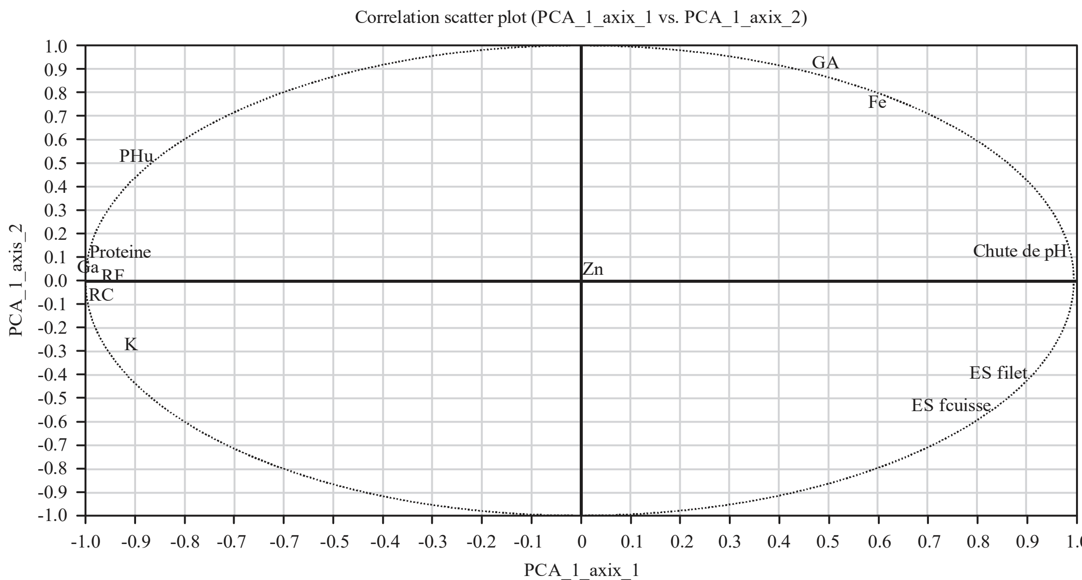

Fig. 1: Correlation circle of the principal component analysis of nutritional quality variables (protein, fillet (RF) and thigh (RC), Ca, K, Zn, Fe) and meat quality [pHu, drop pH, breast water loss (ES filet) and thigh water loss (ES thigh), abdominal fat (GA)] according to the incorporation levels of maggot meal into the diet of broilers

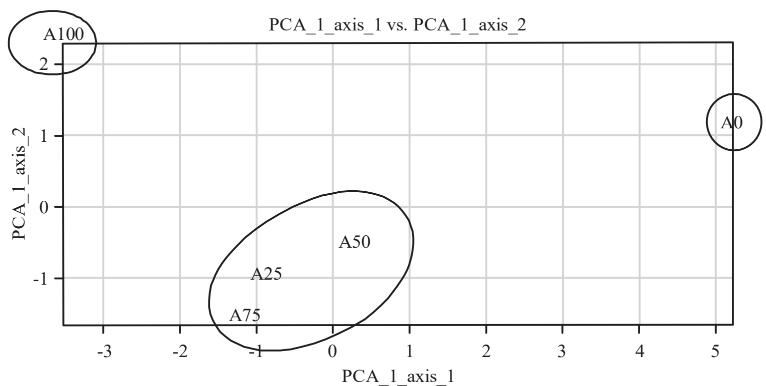

Fig. 2: Principal components analysis of variables showing the factorial pan of individuals

was higher ($p<0.05$) in the meat of the birds in A_{100} than those of A_0, A_{25}, A_{50} and A_{75} groups. Also, the protein of A_{25}, A_{50} and A_{75}, was similar and higher ($p<0.05$) than that of A_0. Mineral content (iron, zinc, calcium, phosphorus and potassium) of the meat was not influenced by the dietary inclusion of maggot meal.

Effect of black soldier fly maggot meal on the analysis of the principal components of meat quality parameters: The principal component analysis of broiler meat quality parameters are presented in Fig. 1. Protein content, breast yield, thigh yield, pHu, Ca and K were strongly and positively correlated. In contrast, these parameters were negatively correlated with meat pH drop and water loss of the breast and thigh. In addition, pHu was positively correlated with meat protein ($r = 0.8932$) and negatively correlated with breast water loss ($r = 0.9938$).

Effect of black soldier fly maggot meal on the analysis of the main components in relation to the treatments: Figure 2 shows the results of the analysis of the principal component in relation to treatments. In the factorial plan, the groups were distributed differently. Three groups comprising A_{25} A_{50} and A_{75}treatments in the first group, A_{100} treatment in the second group and A_0 in the third group were observed. In the first group, the treatments had similar characteristics while the other two treatments A_{100} and A_0 were opposite.

DISCUSSION

In the current study, the results showed that the dietary inclusion of black soldier fly maggot meal in broiler diet favoured breast meat yield than the use of fish meal. Thigh meat yield were not different when both protein sources were compared. A comparison of the quality of the meat yield showed a better quality in terms of ultimate pH, water loss and protein content for both breast and thigh meats of broilers reared on maggot meal.

Breast meat is an economically valuable part of broiler chickens. Despite feeding the broilers isoenergetic and isoproteinic diets in the present study, the rate of protein utilization of maggot meal for pectoral muscle increased with level of substitution and peaked at 100% substitution with a significant difference between A_0 and A_{100}. Maggot meals have been reported to be high and better in amino acid profile than fish meal[7,8]. Leclercq[16] reported that some amino acids e.g. lysine have specific effects on carcass composition and muscle growth. Tesseraud *et al.*[17] also reported that some amino acids act as a "signal nutrient" by modulating the activity of intracellular protein kinases involved in the regulation of proteins synthesis and energy metabolism. The enhanced pectoral muscle weight recorded in the birds fed maggot meal in the present study is in agreement with the observations of Hwangbo *et al.*[6] and Pieterse *et al.*[7]. Both authors attributed the enhancement to the role of methionine in biological methylation reactions from house fly maggot meal.

The similarity in the weights of thigh muscle in this study suggests that amino acids effects depend on the muscle type indicating differential metabolic processes. Similar observation was reported by Teguia *et al.*[4] and Debut *et al.*[13], who also used Black Soldier fly maggot meal. In congruence with the amount of meat yield, protein content of the breast muscle was significantly higher in the meat of broilers fed maggot meal feed. This again, may be related to the quality of the protein in the diet and amino acid digestibility as discussed earlier.

Our results also revealed that birds fed diets containing maggot meal had higher pHu especially in the A_{100} group. This corroborates the results of Debut *et al.*[18] who correlated the high value of the pHu with the quality of the meat. Since the ultimate pH of the meat is essentially determined by the glycogen content in the muscle at the time of slaughter[19], the higher pHu of the birds in $A_{75\%}$ and $A_{100\%}$ groups may be due to a low glycogen reserve in the breast muscles that would slow down their acidification[20]. According to Bendall[21], the acidification of muscles is the result of an important post-mortem anaerobic glycolysis. Indeed, before bleeding, the rate of ATP remains approximately constant, as long as the concentration of phosphocreatine is relatively high. During the post mortem period, glycogen, glucose and glucose-6-phosphate are converted to lactic acid by anaerobic glycolysis. The accumulation of lactic acid and H^+ protons (by the hydrolysis of ATP) induces muscle acidification and the pH decreases to final values (final pH or ultimate pH). Berri *et al.*[15] obtained a similar result and estimated that essential amino acids, as metabolism modulators, would stimulate protein synthesis at the expense of glycogen synthesis pathways. In addition, the difference between pHu and pH_{15} decreased with increasing maggot meal inclusion rate indicating that a rapid drop in the post-mortem pH can lead to protein degradation resulting in low water-holding capacity. This low water holding capacity observed in our study is in line with the report of Boakye *et al.*[22]. Principal components analysis clearly showed this positive correlation between protein content, breast and thigh meat yields and pHu on the one hand and their negative correlation with pH drop and breast and thigh water loss on the other hand. The different data on meat water loss between thigh and breast may be due to the metabolic and contractile types of these muscles as pointed out by Northcutt *et al.*[23]. These authors reported that the water loss was higher in the pectoral muscles than in the thigh muscles which were deeper red in colour.

With regard to abdominal fat and the mineral components analysed (K, Ca, Zn and Fe) the meat contents were unaffected by the maggot meal, confirming the results of Teguia *et al.*[4], Hwangbo *et al.*[6] and Uushona[24].

CONCLUSION

Based on the results of this study, it can be concluded that the substitution of 100% fish meal with maggot meal will provide consumers with a high quality broiler meat. The higher quality of meat of broiler in the A_{100} group was illustrated by the factorial plan of the individual diet groups showing the net opposition between A_{100} and the control group (A_0).

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