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Growth characteristics and meat quality of broiler chickens fed earthworm meal from *Eudrilus eugeniae* as a protein source

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HIGHLIGHTS

- Protein is a limiting factor for broiler chickens production.
- A feeding experiment was conducted to evaluate the effect of earthworm meal from *Eudrilus eugeniae* on broiler chickens.
- The results showed that earthworm meal supplementation did not affect the growth performance and meat quality.
- Earthworm meal can replace fish meal as source of protein for broiler chicken.
- More replications of experiments, but also ecologic, economic and environmental evaluations are required.

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ABSTRACT

The demand and cost of animal-based protein sources for broiler chickens production like fish meal has increased in many countries. An alternative protein source can be earthworm meal (EWM). A study was conducted to evaluate the effects of supplementing broiler chickens diets with EWM derived from dried *Eudrilus eugeniae* on growth performance, carcass attributes, and the meat quality of broiler chickens. The starter and finisher basal diets were formulated to contain 10% fish meal and it was replaced with 0, 1, 3, 5, and 7% EWM. For the experiment, 150 one-day-old broiler chickens were randomly assigned to the 5 diets with 3 pens per diet and 10 broiler chickens per pen. Based on the data recorded in the experiment, the body weight gain (BWG), and the feed intake (FI) were computed. At 6 wk of age, 3 broiler chickens were randomly selected from each pen to assess their organ weights and sensory characteristics. Overall, there was a quadratic and cubic effect on BWG when EWM supplementation was increased ($P < 0.05$). There was no difference in the overall FI of broiler chickens with increase in the supplementation of EWM. As the dietary supplementation of EWM increased, the juiciness in breast meat of the broiler chickens increased quadratically ($P < 0.05$) while the flavor increased linearly ($P < 0.05$). However, there were no differences in broiler chickens meat aroma, first bite, chewiness, and the amount of residues as dietary EWM increased. Supplementation of EWM did not affect broiler chickens meat quality in terms of pH and drip loss. The EWM may be a suitable source of protein for broiler chickens production and a particularly useful substitute for fish meal. More research is required to determine the optimal inclusion rate for the most affordable, and nutritious broiler chickens diet, and to sufficiently understand the wider implications of alternative feed sources on the ecologic, economic, and environmental impact of broiler chickens production.

1. Introduction

Broiler chickens meat is an important source of animal-based protein (Chia et al., 2019). Thus, in many countries, it has become a major consumer product (Elahi et al., 2020). This trend is projected to increase (Enahoro et al., 2018; Janković et al., 2020; Kasule et al., 2014; Van Harn et al., 2019), due to a number of factors including innovations in dietary ingredients for broiler chickens production (Beski et al., 2015;

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Janković et al., 2020).

The common feed for broiler chickens are cereals to supply carbohydrates, and fish, soybean and meat meal to supply protein (Khan et al., 2016; Selaledi et al., 2020; Toomer et al., 2020). However, the high costs of protein present a challenge to farmers (Admasu et al., 2019). Currently, protein contributes to 60% of the costs associated with broiler chickens production in many countries (Ssepuuya et al., 2017; World Bank, 2020), with adverse effects on both the profits of producers' and the food supply for the population (Abro et al., 2020). Associated with these feeds is the competition between consumption for humans and that of other animals (Gunya et al., 2019a; Parolini et al., 2020). These aspects of broiler chickens production have led to the search for alternative and suitable feeds (Chia et al., 2019; Ravindran, 2013; Gunya et al., 2016; Khan, 2018; Komakech, 2014; Parolini et al., 2020; Pieterse et al., 2014).

One such feed can be earthworm meal (EWM) from dried earthworms supplied by the vermicomposting process (Bahadori et al., 2017; Jjagwe et al., 2019). Having lower environmental impacts than other sources (Tedesco et al., 2019) and higher concentrations of essential amino acids (Parolini et al., 2020), earthworms are a natural protein source for chickens with currently no competition for other uses (Admasu et al., 2019; Gunya et al., 2019a). Thus, EWM hypothetically has a high potential to be an important protein source for broiler chickens feeds (Prayogi, 2011; Zang et al., 2018).

However, there is little information on the nutrient content of EWM from earthworms like the African night crawler (*Eudrilus eugeniae*), as well as the effects of using EWM from this species on food intake, conversion ratio, meat and carcass characteristics, quantity, and flavor of broiler chickens and their meat. This study aims to close these research gaps by evaluating the potential of using dried EWM from *Eudrilus eugeniae* as an alternative protein source to conventional ones, i.e. fish meal from silver cyprinid (*Rastrineobola argentea)*, for broiler chickens.

2. Materials and methods

2.1. Determination of the nutritional composition of the earthworms

Eudrilus eugeniae, the species of earthworms used in this study, were obtained from vermicomposting units that were set up and maintained at Makerere University Agricultural Research Institute Kabanyolo (MUARIK) (Kampala, Uganda), as described by Jjagwe et al. (2019). The earthworms were harvested from the units by hand, thoroughly cleaned and euthanized using warm water (45 °C). They were then dried in a natural convection solar dryer at temperatures between 61 to 63 °C for 2 d. The dried earthworms were then ground to produce EWM using a mortar and pestle. Five samples of the EWM were randomly picked, and mixed to form a composite sample of about 15 g. This was taken to the animal sciences laboratory, school of agricultural sciences, Makerere university (Kampala, Uganda) to determine its nutritional composition. The composition of Ca and P was determined using the atomic absorption spectrophotometer (Model 4110ZL; PerkinElmer, London, UK) by following the procedures specified by Okalebo et al. (2002). The Kjedahl method was used to determine the crude protein content of the EWM using the automated protein analyzer (Foss 2200; Kjeltec Auto Distillation unit, Foss evaporators, Goole, UK). Ether extract (crude fat) was also determined using a fat extraction unit (Soxtec Avanti 2050; Foss Analytical AB, Hoganas, Sweden).

2.2. Experimental design: broiler chickens, diet composition, and growth performance

A total number of 150 one-day-old broiler chickens (Cobb 500; Oyayansa Heights Ltd., Kampala, Uganda) were randomly assigned to 5 treatments with 3 pens (1.0 × 0.8 m) per treatment and 10 broiler chickens per pen in a completely randomized design. The dietary treatments were initially 0% EWM, which was the control, with a gradual increase in the percentages of EWM in the diets to 1, 3, 5, and 7% EWM. As EWM was intended to substitute fish meal, in the present case derived from silver cyprinids (*Rastrineobola argentea*) from Lake Victoria, the percentage of the fish meal in the dietary treatment was gradually reduced from 10% fish meal in the treatment with 0% EWM to 3% fish meal in the treatment with 7% EWM. After 3 wk of brooding, the broiler chickens were transferred to finishing pens where they spent the next 3 wk. The feeding program of the broiler chickens consisted of the starter diets (wk 0 to 3) and the finisher diets (wk 3 to 6). The composition of the dietary meals for both experimental phases, and the quantities fed to the broiler chickens are shown in Tables 1 and 2, respectively. Feed intake (FI) was recorded daily while body weight gain (BWG) of the broiler chickens was recorded weekly using a digital weighing scale (Zollyss ZLSK-272; T.C. Patel & Co., Surat-Gujarat, India), and the feed conversion ratio (FCR) was calculated by dividing the FI by the BWG.

2.3. Slaughter procedure and determination of the dressing percentage

At wk 6, 45 broiler chickens were randomly selected, with 9 broiler chickens per treatment. These were deprived of food for 18 h (Magala et al., 2012). The broiler chickens were then weighed to determine their final body weight (BW), after which they were stunned by cervical dislocation, slaughtered, and allowed to bleed for 5 min. They were then placed in hot water (65 °C), and manually de-feathered. After 60 min, the weight of the hot carcass was determined, as described by Magala et al. (2012), before subsequently determining the weight of the following body organs individually: liver, lungs, *proventiculus*, heart, gizzard, caeca, and crop. Based on the final BW and the carcass weight, the dressing percentage was calculated. Then, the carcasses were packed into sterilized polythene bags and placed into cooler boxes filled with ice, and transported to the food technology and business incubation center of Makerere University (Kampala, Uganda) for physical and chemical analysis.

2.4. Evaluation of meat quality parameters

The broiler chickens meat quality parameters were assessed using the breast muscle in terms of the initial pH, ultimate pH, and drip loss. The initial pH was taken 1 h after slaughter and the ultimate pH was taken after chilling the breast muscle meat for 24 h in temperatures between 1 to 4 °C. In both cases, the pH was determined by inserting a digital pH meter (Kelway meter, Model B003DWAM9Q, Pacific Star Co., Huston, TX, US) into the breast muscle at a depth of 3 cm. Thirty grams of the breast meat was cut from each sample, tied with a string, and hung in the refrigerator for 48 h at temperatures between 1 to 4 °C, as recommended by Hopkins et al. (2014). The samples were weighted to determine the drip loss (%).

2.5. Sensory evaluation

Breast meat from the various samples was cut into strips of 12 mm thickness, vacuum packed, and cooked for 50 min at 94 °C in a water bath. No additives or spices were added to the meat as these would alter the results. The sensory evaluation was conducted from the sensory evaluation laboratory at the school of food technology, nutrition and bio-engineering of Makerere university (Kampala, Uganda). The laboratory was set up in such a way that the panelists could not interact with each other during the evaluation, thus reducing bias. A total of 10 trained panelists (5 females and 5 males) were used, and each panelist evaluated the sample 3 times. The panelists were trained in order to familiarize themselves with the sensory attributes before the final evaluation. The panelists had no idea which treatments they were given as these were coded with different numbers for each serving session. The serving of each sample was administered 3 times to the panelists on clean white disposable plates and water was provided for rinsing the

Table 1
Feed compositions of starter and finisher diets for broiler chickens fed with different concentrations of earthworm meal.

Item	Earthworm meal (%)									
	Starter					Finisher				
	0	1	3	5	7	0	1	3	5	7
Ingredient (% as-fed)										
Maize	10.5	10.5	10.5	10.5	10.5	17.5	17.5	17.5	17.5	17.5
Maize bran	60.0	60.0	60.0	60.0	60.0	50.0	50.0	50.0	50.0	50.0
Cotton seed cake	4.0	4.0	4.0	4.0	4.0	7.0	7.0	7.0	7.0	7.0
Soybean meal	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
Fish meal	10.0	9.0	7.0	5.0	3.0	10.0	9.0	7.0	5.0	3.0
Earthworm meal[a]	0.0	1.0	3.0	5.0	7.0	0.0	1.0	3.0	5.0	7.0
Eggshells	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Salt	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Premix[b]	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Calculated composition (as-fed)										
Crude protein (%)	21.7	21.7	21.8	21.8	21.8	21.7	19.7	19.3	19.5	19.3
Ca. (g/kg)	9.1	7.3	8.1	6.9	6.0	9.1	8.7	7.8	8.3	6.1
Metabolizable energy (kcal/kg)	2,967	2,931	2,931	2,932	2,926	2,967	3,023	3,025	2,926	3,038

[a] Earthworm meal was obtained from *Eudrilus eugeniae* and contained: ash −143.2 g/kg, crude protein −60.54%, crude fiber −2.35%, crude fat −0.90%, total phosphorus −14.6 g/kg, Ca. −60.3 g/kg, all on dry basis.

[b] Provided per kilogram of feed: 21,000 IU of vitamin A, 2100 IU of vitamin D_3, 42 mg of vitamin E, 1.2 mg of vitamin K, 0.6 mg of vitamin B_1, 0.6 mg of vitamin B_2, 0.6 mg of vitamin B_{12}, 0.006 mg of folic acid, 300 mg of Cu, 3.6 mg of Mn, 75 mg of Zn, 75 mg of I, 0.6 mg of Mg, 0.12 mg of Se, 15 mg of antioxidant.

Table 2
Total quantity of feeds in kg/d (as-fed) provided per replicate across all treatments throughout the experiment.

Item	wk 1	wk 2	wk 3	wk 4	wk 5	wk 6
d 1	0.20	0.50	0.70	0.80	0.90	1.00
d 2	0.20	0.50	0.70	0.80	0.90	1.00
d 3	0.30	0.50	0.70	0.80	0.90	1.00
d 4	0.30	0.60	0.75	0.85	0.95	1.00
d 5	0.45	0.60	0.75	0.85	0.95	1.00
d 6	0.45	0.65	0.75	0.85	0.95	1.00
d 7	0.45	0.65	0.75	0.85	0.95	1.00
Total	2.35	4.00	5.10	5.80	6.50	7.00

mouth before tasting each sample. The evaluated sensory attributes included: broiler chickens meat flavor, ease of chewing, first bite, broiler chickens aroma, juiciness, and residue after chewing (Gunya et al., 2018). These were assessed based on a 5-point scale, with 1 being extremely bland, extremely hard, extremely tough, extremely good, extremely dry, abundant, respectively, and 5 being extremely intense, very chewable, very tender, extremely bad, extremely juicy, and none, respectively.

2.6. Statistical analysis

The effect of different EWM inclusion levels on broiler chickens growth performances, sensory evaluation attributes, and breast muscle meat quality were subjected to statistical analysis of variance using the General Linear Model procedure at a significance level of 5%. Orthogonal polynomials (linear, quadratic and cubic) were used to examine the dose responses due to increasing amounts of EWM in the diet. All statistical analyses were performed using GenStat software (GenStat for Windows; version 14, VSN Inc., Hemel-Hempstead, UK).

3. Results and discussion

3.1. Nutritional composition of the earthworm meal and feeds formulated

The crude protein content of 60.5% of EWM obtained in this study (Table 1) is similar to the 58.4% obtained by Reinecke et al. (1991) for the same earthworm species (*Eudrilus eugeniae*), but higher than that found by other studies, such as the 51.6–57.5% for *Eisenia feotida* (Gunya et al., 2018; Musyoka et al., 2020) and the 41.4% for *Lumbricus rubellus* (Janković et al. (2020). The variation in crude protein content could be attributable to the differences in the earthworm species and management practices, particularly the substrate in which the earthworms were raised (Ncobela and Chimonyo, 2015). The protein content of the EWM for this study is also similar to the 55–60% found for various fish meals (Istiqomah et al., 2009) but greater than the 49.0% (Wanapat et al., 2013) and the 41.3% (Yu et al., 2020) for cotton seed meal, the 47.0% (Diers et al., 1992) and the 42.4% (Yu et al., 2020) for soybean seeds, the 12.3% for wheat bran (Donkoh and Attoh to Kotoku, 2009), the 32.5% for rapeseed cake (Drażbo et al., 2019), the 23.6% for sunflower and the 10.9% for maize bran (Mlay et al., 2005). Hence, the EWM with its high protein content can be a good substitute for fish meal. In addition, EWM similar to the ones investigated in this study are also reported to be superior in essential amino acids and fatty acids if compared to fish meal (Bahadori et al., 2017).

3.2. Body weight gain

The effect of different EWM contents in the feed in this study on BWG of the broiler chickens is shown in Table 3. Initial body weight (0.039 ± 0.001 kg/broiler chicken) did not differ between groups prior to the assignment of experimental diets. Overall, there were quadratic ($P = 0.003$) and cubic ($P < 0.001$) effects on broiler chickens BWG with increase in EWM supplementation. Broiler chickens BWG showed a cubic effect ($P = 0.005$) in wk 1, quadratic effect ($P < 0.001$) in wk 2, linear effect ($P < 0.001$) in wk 4, and both linear ($P = 0.003$) and quadratic ($P = 0.005$) effects in wk 6. However, inclusion rate of EWM substitution did not show differences on BWG at wk 3 and wk 5. Broiler chickens fed diet containing 3% EWM showed the greatest overall increase in BWG (1.176 kg/broiler chicken) while those with 7% EWM the lowest (0.996 kg/broiler chicken). The difference in BWG could be attributed to the higher protein content in the diets with 3% EWM. According to Safa and Tazi (2014), increased metabolism of protein leads to increased weight gain. The results of this study, however, differed from those obtained by Gunya et al. (2019b), which indicated that the greatest BWG was obtained after feeding broiler chickens a diet of 5% EWM. In their study, the BWG of the broiler chickens decreased when the EWM content surpassed 5%. The difference in the results may well be due to the difference in the earthworm species used (*Eisenia fetida* vs *Eudrilus eugeniae*) or the length of the experiments (6 wk vs 5 wk). Rezaeipour et al. (2014), on the other hand, reported that broiler chickens obtained the greatest body weight when the EWM of *Lumbricus rubellus* was 10% of the diet. Jankovic et al. (2015) and Jankovic et al. (2020), however, found that BWG of the broiler chickens decreased with increased inclusion of earthworms (*Lumbricus rubellus*) in their diets. The difference between

Table 3
Effect of dietary earthworm meal inclusion on growth performance of broiler chickens.

Item [a]	Earthworm meal (%)					SEM [b]	*P*-value [c]		
	0	1	3	5	7		Linear	Quadratic	Cubic
BWG									
wk 1	0.062	0.051	0.081	0.042	0.068	0.004	0.904	0.816	0.005
wk 2	0.120	0.092	0.098	0.092	0.106	0.007	0.115	< 0.001	0.402
wk 3	0.174	0.156	0.167	0.142	0.150	0.014	0.048	0.648	0.854
wk 4	0.327	0.299	0.292	0.273	0.225	0.024	< 0.001	0.417	0.341
wk 5	0.150	0.116	0.144	0.171	0.142	0.035	0.615	0.926	0.127
wk 6	0.193	0.250	0.373	0.338	0.301	0.046	0.003	0.005	0.515
Overall	1.026	0.992	1.176	1.058	0.966	0.038	0.762	0.003	0.011
FI									
wk 1	0.017	0.015	0.014	0.014	0.013	0.002	0.049	0.611	0.938
wk 2	0.043	0.043	0.039	0.039	0.038	0.002	< 0.001	0.565	0.546
wk 3	0.053	0.053	0.054	0.053	0.053	0.001	0.380	0.422	0.913
wk 4	0.066	0.067	0.072	0.70	0.068	0.002	0.030	0.004	0.124
wk 5	0.061	0.059	0.063	0.063	0.062	0.001	0.125	0.318	0.007
wk 6	0.056	0.057	0.059	0.059	0.056	0.001	0.260	< 0.001	< 0.001
Overall	0.301	0.298	0.297	0.294	0.289	0.005	0.234	0.073	0.120
FCR									
wk 1	1.967	1.945	1.293	1.667	1.381	0.002	< 0.001	< 0.001	0.003
wk 2	2.121	1.905	1.576	1.703	1.675	0.019	< 0.001	< 0.001	0.248
wk 3	1.841	1.719	1.480	1.488	1.382	0.012	< 0.001	< 0.001	< 0.001
wk 4	1.519	1.663	1.570	1.716	1.969	0.014	< 0.001	< 0.001	< 0.001
wk 5	1.630	1.856	1.998	1.823	1.616	0.037	< 0.001	0.705	< 0.001
wk 6	1.103	1.352	1.975	1.790	1.416	0.015	< 0.001	< 0.001	< 0.001
Overall	2.521	1.264	0.957	0.853	1.121	0.013	< 0.001	< 0.001	< 0.001

[a] BWG: body weight gain (kg/d); FI: feed intake (kg/d); FCR: feed conversation ratio.
[b] SEM: standard error of the mean ($n = 3$).
[c] Data were assessed for linear, quadratic, and cubic effects by orthogonal polynomial contrasts. *P*-values of less than 0.05 were considered statistically significant.

their results and this study could be due to the different states of the earthworms fed to the broiler chickens. In their study, the broiler chickens were fed with fresh earthworms, unlike in this study where EWM from dried earthworms was used. Usually, fresh earthworms are less accepted by poultry because the live worms tend to crawl away from the feed, in addition to rotting shortly after death, hence becoming less palatable to broiler chickens (Janković et al., 2020).

3.3. Feed intake

The FI by the broiler chickens for each of the treatments is shown in Table 3. Overall, the increase in EWM supplementation did not affect the FI of broiler chickens. However, FI showed a linear effect ($P < 0.001$) in wk 2, linear ($P = 0.030$) and quadratic ($P = 0.004$) effects in wk 4, cubic effect ($P = 0.007$) in wk 5, and both quadratic ($P < 0.001$) and cubic effects ($P < 0.001$) in wk 6. The increase in EWM supplementation did not affect FI of broiler chickens in wk 1 and wk 3. Increasing the EWM content in the diet led to a reduction in the FI by the broiler chickens. The broiler chickens with 0% EWM ate the largest amount of feed while those with 7% EWM consumed the least amount of feed. This finding is similar to the results of Dairo et al. (2010) and Gunya et al. (2019b), who reported decreasing feed consumption with increasing inclusion levels of EWM. This may be attributed to the presence of coelomic fluid in the EWM, which is reportedly unpalatable to the broiler chickens (Ngoc et al., 2016). Increasing the EWM quantity in a feed also leads to increasing levels of certain amino acids such as arginine and cysteine, which are known to reduce the broiler chickens' appetite, hence lowering feed consumption (Prayogi, 2011). Moreover, the dark coloration, as a result of drying the earthworms, could have affected the broiler chickens' affinity for the feed as color has been shown to have an effect on the broiler chickens' attraction to food (Khan et al., 2016). Because broiler chickens are color sensitive, the dull colored particles make the feed less attractive, thus reducing the total quantities consumed by the broiler chickens (Elahi et al., 2020). It should be noted that one of the objectives of rearing broiler chickens, especially in the brooding phase, is to increase the broiler chickens' appetites so as to maximize feed consumption for better growth performance.

3.4. Feed conversion ratio

The effect of FCR of broiler chickens by increase in EWM supplementation is shown in Table 3. The overall FCR showed linear, cubic and quadratic effects ($P < 0.001$) with increase in EWM supplementation. The 0% EWM yielded the greatest overall FCR while the least overall FCR resulted from 3% EWM. A high FCR indicates low feed consumption with a high body weight gain. This implies that a broiler chickens farmer spends less on feeds when the FCR is high. Generally, a broiler chickens producer would aim at producing feeds with a low intake, high FCR resulting in high BWG (Gunya et al., 2019b). As shown in Table 3, 3% EWM would be the most desirable due to relatively low FI with high FCR, and BWG.

3.5. Meat quality characteristics

The effect of different treatments on drip loss, pH, and ultimate pH of breast muscle meat of broiler chickens are shown in Table 4. Increase in EWM supplementation showed linear ($P < 0.001$), and quadratic effects ($P = 0.002$) on the ultimate pH while it did not affect the initial pH and drip loss of the breast meat of the broiler chickens. During aging, pH plays an important role in the conversion of muscle into meat. pH also has an effect on other attributes of meat such as color (Drażbo et al., 2019), texture (Toomer et al., 2019), shelf life, and loss during thermal processing (Janković et al., 2020). Our results are corroborated by Janković et al. (2020), who reported no differences in the initial pH values of breast meat for broiler chickens fed diets with different contents of another earthworm species (*Lumbricus rubellus*). According to Van Laack et al. (2000), normal broiler meat fit for human consumption should have pH values in the range 5.76–6.50. The pH of all poultry meat in the study was within this range. After chilling the meat, the ultimate pH values were still within the recommended range. These results are all in agreement with those obtained by Gunya et al. (2019a). No variation in the drip loss was observed for increase in EWM supplementation, showing that inclusion of EWM in the diet of the broiler chickens has no effect on the drip loss. The no differences in drip loss between the control of 0% EWM and other treatments indicated that

Table 4
Effect of dietary earthworm meal inclusion on chemical carcass characteristics of broiler chickens.

Meat quality characteristics	Earthworm meal (%)					SEM[a]	*P*-value[b]		
	0	1	3	5	7		Linear	Quadratic	Cubic
Drip loss (%)	2.19	2.30	2.17	2.10	2.16	0.023	0.103	0.542	0.071
Initial pH	5.89	5.87	5.53	5.88	5.80	0.067	0.317	0.185	0.295
Ultimate pH	5.86	5.89	5.97	5.98	5.89	0.076	<0.001	0.002	0.192

[a] SEM: standard error of the mean ($n = 3$).
[b] Data were assessed for linear, quadratic, and cubic effects by orthogonal polynomial contrasts. *P*-values of less than 0.05 were considered statistically significant.

including EWM in the diet had no effect on broiler meat quality (Drażbo et al., 2019; Yu et al., 2019).

3.6. Effect on the body organs

The effect of EWM supplementation on the weights of body organs is shown in Table 5. Increase in EWM supplementation showed a cubic effect on the weight of the gizzard and both linear, and quadratic effects ($P < 0.05$) on the weight of liver for broiler chickens. However, the weights of caeca, heart, pancreas, crop, proventriculus, and lungs were not affected by increase in EWM supplementation. The greatest liver weight was obtained from 0% EWM and the lowest from 5% EWM. The greatest gizzard weight was obtained from 1% EWM and the lowest from 5% EWM. This was similar to the findings of Gunya et al. (2019a). According to Swatson et al. (2002), an increase in protein content in broiler chickens diets could result in a reduction in the size of the gizzard and liver.

3.7. Sensory evaluation attributes

The sensory evaluation scores for the different attributes are shown in Table 6. The increase in EWM supplementation showed linear increases in both juiciness and flavor ($P < 0.05$) while no differences were observed in aroma, chewiness, first bite and residues ($P > 0.05$). These findings were similar to those reported by Gunya et al. (2018). The meat tenderness (ease of chewiness) is mainly influenced by changes in the structure of the connective tissue soluble during heating. The denaturing of the protein content in the meat causes meat toughness (Barbanti and Pasquini, 2005).

There was an increase in broiler chickens aroma and flavor with an increase in EWM supplementation in the diet (Table 6). These findings are in line with Gunya et al. (2018), who reported increased aroma and flavor with increased inclusion of *Eisenia fetida* in the poultry diet. This finding could be attributed to increased fatty acid composition such as Omega 3 and Vaccenic acid, which are found in earthworms which directly influence meat aroma (Ramarathnam et al., 1993).

Results, as shown in Table 6, also indicate a linear ($P = 0.013$) increase in the juiciness with increased inclusion of EWM. This was similar to the results obtained by Gunya et al. (2018). The results of this study, however, contrast with the findings of Alonso et al. (2010), who reported that decreasing protein in the poultry diet led to an improvement in the juiciness. The variation in the results could be due to the difference in the earthworm species used. According to Muchenje et al. (2009), meat quality and fat composition affect the juiciness of the meat. The juiciness of meat is defined by two main critera: (1) the first impression of wetness during chewing due to the rapid release of fluids, and (2) the salivation resulting from the fat content (Trembecká et al., 2017). The 7% EWM had the greatest score for juiciness. This could be due to the high fat accumulation in the breast muscle of the chickens as influenced by a high fatty acid composition of *Eudrilus eugeniae*. The 7% EWM had the least residues whereas 0% EWM had the greatest number of residues. Residue levels decreased with increased inclusion of EWM in the diet of the broiler chickens (Table 6). The sensory evaluation of a number of attributes as compared to a single characteristic is key in indicating the overall acceptability and quality of broiler meat (Janković et al., 2020).

3.8. The potential of earthworm meal to increase sustainability and food security

The results of the study show the suitability of EWM as a protein source in feeds for broiler chicken. Yet, the question remains as to what this means for the overall food security and sustainable development in broiler chickens production. EWM can substitute protein-containing components of poultry feeds with similar nutritional values like, as in the present case, silver cyprinids. This substitution may reduce the pressure on the fish populations in water bodies and thus improve the quality of these ecosystems (Nyamweya et al., 2017; Nyamweya et al., 2020; Yongo et al., 2018). Furthermore, EWM can be produced decentral through vermicomposting, allowing shorter transport distances than for fish meal and thus reducing environmental impacts and costs associated to transportation (Rutaisire, 2007). The degree to which these positive impacts on the ecology, environment, and local economy can be realized in the future is not yet entirely clear and likewise have to be investigated.

4. Conclusion

The EWM from *Eudrilus eugeniae,* as investigated in this study, has a high protein content similar to that of fish meal, but is also rich in

Table 5
Effect of dietary earthworm meal inclusion on weight of body organs of broiler chickens.

Organ [a]	Earthworm meal (%)					SEM [b]	*P*-value [c]		
	0	1	3	5	7		Linear	Quadratic	Cubic
Gizzard	31.22	38.11	33.56	26.44	30.33	2.158	0.801	0.524	0.005
Caeca	8.00	9.11	8.44	7.56	7.56	0.787	0.173	0.247	0.138
Liver	22.67	18.67	19.89	16.89	18.67	1.295	0.009	0.011	0.879
Heart	6.11	5.22	5.44	6.11	5.78	0.793	0.901	0.463	0.241
Pancreas	2.22	2.00	1.33	1.06	1.44	0.444	0.016	0.178	0.270
Crop	7.78	9.56	6.67	7.33	9.11	1.496	0.895	0.374	0.092
Proventriculus	44.33	44.11	48.89	44.56	45.33	4.800	0.821	0.579	0.992
Lungs	4.33	4.67	4.67	5.33	4.33	0.641	0.644	0.245	0.358

[a] Weight of different organs (g/broiler chicken).
[b] SEM: standard error of the mean ($n = 3$).
[c] Data were assessed for linear, quadratic, and cubic effects by orthogonal polynomial contrasts. *P*-values of less than 0.05 were considered statistically significant.

Table 6
Effect of dietary earthworm meal inclusion on sensory evaluation of broiler chickens.

Item [a]	Earthworm meal (%)					SEM [b]	P-value [c]		
	0	1	3	5	7		Linear	Quadratic	Cubic
Aroma	2.87	2.83	3.16	3.17	3.40	0.253	0.012	0.519	0.518
Chewiness	3.80	3.62	3.29	3.73	3.70	0.246	0.716	0.083	0.623
Juiciness	3.30	3.17	3.38	3.43	3.80	0.214	0.013	0.102	0.405
First bite	3.57	3.28	3.55	3.43	3.50	0.194	0.818	0.560	0.491
Residues	3.37	3.41	3.52	3.63	4.00	0.260	0.036	0.267	0.529
Flavor	2.80	2.86	3.13	3.30	3.53	0.232	< 0.001	0.828	0.798

[a] Sensory attributes examined on a scale of 1–5.
[b] SEM: standard error of the mean ($n = 3$).
[c] Data were assessed for linear, quadratic, and cubic effects by orthogonal polynomial contrasts. *P*-values of less than 0.05 were considered statistically significant.

essential amino acids such as lysine. These are very critical to the growth of broiler chickens. In this study, EWM in the broiler chickens' diets led to a reduction in feed consumption, while not taking away from the BWG during development, implying that less could be spent on buying extra feed for the broiler chickens. Therefore, EWM is a good substitute for fish meal in the diet of the broiler chickens, especially, as shown by this study, at a 3% EWM. The research further reveals the effectiveness of *Eudrilus eugeniae* on the carcass characteristics of the broiler chickens, their digestive organs, and the overall meat quality. The EWM can be regarded as an alternative source of protein in the broiler diet for excellent meat quality. According to the results obtained, increased inclusion of EWM in the feed improved meat and sensory scores. Therefore, it is recommended to increase the amount of EWM in the diet of broiler chickens or to use it as a substitute for fish meal. Even though these findings are important for contributing to food security, further research should be done, not only to verify the results by conducting a larger number of experimental trials, but also to determine the economic viability, the ecological impacts and impact reductions, as well as the environmental sustainability of using EWM as an addition to or substitute for fish meal in the diet of broiler chickens.

CRediT authorship contribution statement

A. Nalunga: Writing - original draft, Formal analysis, Validation. **A. J. Komakech:** Conceptualization, Writing - review & editing, Supervision. **J. Jjagwe:** Data curation, Writing - review & editing. **H. Magala:** Conceptualization, Writing - review & editing, Supervision. **J. Lederer:** Project administration, Writing - review & editing, Funding acquisition.

Declaration of Competing Interest

All authors declare that they have no competing interests.

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