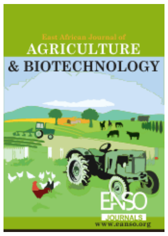

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Original Article

Effects of Dietary Supplementation with Yellow Meal Worm Larvae (Tenebrio molitor) on Performance of Broiler Chicken

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Yellow Meal Worm Larvae, Broilers, Growth Performance, Tenebrio Molitor.

ABSTRACT

A 6-week feeding trial was conducted to investigate the effects of dietary supplementation with Yellow Meal Worm larvae (YMWL) on growth performance and carcass characteristics of broiler chicken. The larvae was processed and included in diets at different levels 0%YMWL (control), 2.5%YMWL, 5%YMWL and 7.5%YMWL. The diets were formulated to be iso-nitrogenous and iso-caloric in mash form for the starter and finisher phases. 160-day-old cobb-500 broiler chicks were randomly allocated to the four diets and replicated four times with ten birds each per replicate in a completely randomized design. The average daily feed intake was similar across all the treatments ($p>0.05$). Birds fed on 5%YMWL had a significantly higher body weight gain than other treatment diets for the entire feeding phase of 42 days. The feed conversion ratio (FCR) improved at 5%YMWL inclusion compared with the control (0%YMWL) diet for the entire feeding phase ($p<0.05$). The performance efficiency factor was lowest at 7.5% YMWL and the control diet ($p<0.05$). Dietary supplementation with 5% YMWL significantly increased the absolute weights of carcass and carcass parts (wing, thigh, breast, back and drumstick) ($p<0.05$). The dressing percentage of the carcass were not affected by the treatments ($p>0.05$). It was concluded that YMWL meal can be included up to 5% in broiler rations without affecting the growth performance and carcass attributes.

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INTRODUCTION

The world population is expected to rise to about 10 billion by 2050 (Bruno, 2020) resulting in approximately 72% increase in global meat consumption (PROteINSECT, 2016). Poultry, being among most consumed meat, is expected to play a major role in meeting this demand (Roberto, 2021). However, the constraint to the achievement of sustainable increase in poultry meat production is nutrition. Therefore, sustainable supply of affordable and quality feed resources is fundamental to the growth of this industry (Sedgh et al., 2021).

In intensive poultry production, feed accounts for 60-80% of the overall cost of production (Omojola et al., 2015). Meeting the need for animal protein, especially in emerging countries, has been greatly impeded by the rising cost of feed supplies for livestock production (Abu et al., 2015). This challenge has prompted researchers to focus on reducing the cost of feeds without affecting the performance of the chickens through cheap alternative energy and protein sources (Onyimonyi & Okeke, 2007).

Broilers can grow fast and reach market weight faster than ruminants (Cudjoe & Brew, 2010). This ability has piqued the interest of many farmers because it contributes greatly to revenue creation as well as providing an animal protein source in human diets by supplying critical amino acids required for growth, development, and repair of worn-out tissues (Omojola et al, 2015). Maize and soya bean meal, which together account for 80-85% of the chicken feed production cost, are the main sources of energy in diets for monogastric animals (Ncube et al., 2017).

In addition, maize and soya bean meal are also used for human consumption and biofuel production (Driemeyer, 2016). However, there is also reduced productivity of these traditional crops due to unpredictable weather patterns resulting into competition by the three industries: human, livestock and fuel, for the same crop commodities (Nasonga, 2022). This competition and inadequate supply have invariably led to constant increases in market prices of both crops, thus resulting in the high cost of poultry production (Hassan et al., 2012). It is, therefore, necessary to prospect alternative energy and protein feed resources for broiler production that are climate change independent, readily available and not in competition with humans nor the biofuel industry, particularly in Sub-Saharan Africa (Food and Agricultural Organization [FAO], 2015).

Edible insects have been recognized as a highly nutritious and healthy food with high protein content (40-65%), fats (15-43%), vitamin, fibre, and minerals (Marono et al., 2015; Van Huis et al.,

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2014). Rearing these insects can provide future protein and income generation to farmers and producers (Hanboonsong et al., 2013). Insect species that are normally used in animal feeds include, *Hermetia illucens L*. (black soldier fly), *Musca domestica L*. (common house fly), *Tenebrio molitor* L. (yellow meal worm), *Bombyx mori* L. (silkworm), termites, crickets and grasshoppers (Biasato et al., 2017). Supplementation with these alternative protein sources allows poultry producers to adopt the feeding strategy that reduces their feed expenses and increasing profitability (FAO, 2013).

Recently, edible insects have received more attention across the globe due to their multiple functions in livestock production. Several studies have been conducted on effect of dietary inclusion with black soldier fly, housefly maggots, crickets and mealworms on poultry (Biasato et al., 2016), pigs (Duhra, 2020) and aquaculture (Ido et al. 2019). However, there is paucity of information on the usage of YMWL as a feed ingredient in poultry diets in Sub-Saharan Africa. Therefore, the effects of YMWL as a non-traditional feedstuff and the appropriate inclusion levels in poultry diets on growth parameters and organoleptic properties need to be investigated and documented. This study was therefore, undertaken to evaluate the effects of supplementation of broiler diets with yellow meal worm larvae on feed intake, body weight gain, feed conversion efficiency, performance efficiency factor and carcass characteristics.

MATERIALS AND METHODS

The study was carried out at Jaramogi Oginga Odinga University of Science and Technology (JOOUST) farm.

Preparation of Yellow Meal Worm Larvae

The YMWL was procured from a producer in Nairobi and upon receipt; it was washed with clean running water and sundried. It was then milled using a hammer mill with 2 mm screen size then stored in sacks. Samples were taken for laboratory nutrient analysis.

Feed Formulation and Mixing

Four iso-nitrogenous and iso-energetic diets were formulated, each consisting of the following inclusion levels: YMWL meal 0% (control), 2.5%, 5% and 7.5%. The diets were formulated according to Kenya Bureau of Standards (KEBS) requirements. In this respect, the starter diets were targeted at 21-22% Crude Protein (CP) level and metabolizable energy (ME) of 3000 Kcal/kg. The finisher diets were targeted at 18-19% CP level of and metabolizable energy of 3000Kcal/kg.

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Table 1: Ingredient composition (as fed) and calculated nutrient content of the experimental diets

(%)	Starter				Finisher			
	0% YMWL	2.5% YMWL	5% YMWL	7.5% YMWL	0% YMWL	2.5% YMWL	5% YMWL	7.5% YMWL
Maize grain	51	51	50	50	56	56	56	56
Pollard	15	15	15	15	15	15	15	15
*YMWL	0	2.5	5	7.5	0	2.5	5	7.5
Soya bean meal	29.5	27	24	22	23.5	21	18.6	16
L-Lysine	0.2	0.28	0.43	0.43	0.22	0.3	0.37	0.5
DL-Methionine	0.36	0.37	0.4	0.43	0.2	0.23	0.25	0.3
DCP	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Limestone	2.2	2.2	2.3	2.2	2.3	2.3	2.3	2.3
Salt	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Vit/mineral Premix**	0.25	0.25	0.25	0.25	0.2	0.25	0.25	0.25
Toxin Binder	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Coccidiostat	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Enzymes (phytase)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Calculated nutrient content								
Dry matter	88.87	88.9	89	89.1	88.6	88.7	88.7	88.8
Crude protein (CP)	21.84	21.7	21.6	21.58	19.34	19.2	19.1	18.9
Ether extract (EE)	3.9	4.3	4.8	5.3	3.9	4.4	4.8	5.3
Crude fibre (CF)	5.34	5.5	5.6	5.8	4.9	5.1	5.2	5.4
Lysin	1.4	1.39	1.38	1.38	1.32	1.29	1.28	1.28
Methionine	0.48	0.42	0.41	0.41	0.4	0.38	0.38	0.37
Phosphorus	0.71	0.68	0.65	0.64	0.69	0.6	0.61	0.6
Calcium	1.22	1.18	1.18	1.17	1.08	1.04	1.04	1.03
ME Kca/Kg	3001	3052	3071	3080	3044	3058	3060	3091

**Four dietaries' treatments: YMWL0%: control, YMWL2.5%, YMWL5%, YMWL7.5% inclusion*

***1Vit/mineral premix gave the following per kg of diet: vitamin A, 11500IU;cholecalciferol,2100IU;vitaminE(fromdltocopherylacetate),22IU;vitamin B12, 0.60 mg; riboflavin, 4.2 mg; nicotinamide, 40 mg; calcium pantothenate, 35 mg; menadione (from menadione dimethyl-pyrimidinol), 1.50 mg; folic acid, 0.8 mg; thiamine, 3 mg; pyridoxine, 10 mg; biotin, 1 mg; choline chloride, 560 mg; ethoxyquin, 125 mg; Mn (from MnSO4·H2O), 65 mg; Zn (from ZnO), 55 mg; Fe (from FeSO4·7H2O),50 mg; Cu(fromCuSO4·5H2O),8 mg; (from Ca(IO3)2·H2O),1.8 mg; Se,0.3 mg; Co(from Co_2O_3),0.2 mg; Mo,0.16 mg*

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Experimental Design

160 Cobb 500-day old broiler chicks were used as experimental material in a completely randomized design. The chicks were randomly assigned to the 4 treatments (2.5%, 5%, 7.5%YMWL and control (0%). Each treatment comprised of 40 chicks in 4 replicates of 10 chicks per replicate, which were housed in 1.5 square meters pens.

Birds and Diets

160 Cobb 500 broilers were randomly allocated into 16 ply wood pens, each measuring 1 m width x 1.5 m length x 0.9 m height and reared on the floor with wood shavings as a bedding material. Each pen held ten chicks, giving a stocking density 0.15 m^2 per chick. The pens were each provided with individual feeder and drinker. Vaccination against Infectious Bursal Disease (Gumboro) was done on the 7th day, while that of New Castle Disease at 14th day. Daily mortality was determined by counting the number of birds that succumbed during the trial period. Other management practices were carried out in compliance with the International Standards of Animal welfare, Animal Handling and Care Standards of 2018. Infrared lights were used to provide warmth during the brooding period. Temperatures were maintained at 30- 32 °C in the first week, and reduced gradually, by 2 °C every week to 26 °C by the end of the third week depending on chick behaviour. The bedding was turned frequently using a fork, depending on the level of compaction. Wet beddings on areas around water troughs was removed and replaced with fresh ones. The experimental birds were fed starter diet from day 1 up to day 21, and the finisher diet from day 22 to day 42 when the trial was terminated. Clean water was supplied ad *libitum.* The height of drinkers and feeders were adjusted as the birds grew, and were made to be slightly above the level of chicken backs to minimize spillage and spoilage. In order to observe biosecurity, visitors were to sanitize their hands before handling chickens. Foot bath with disinfectant was provided at the entrance.

Data Collection

Data on broiler performance parameters was collected over the 42 days of the feeding trial. The variables monitored included: feed intake, body weight, feed conversion efficiency, performance efficiency factor and carcass characteristics. All the feed and animal weight measurements were taken using digital scale.

Feed Intake (FI)

Feed intake was calculated as the difference between feed offered at the beginning of the day (9am) minus any left over the following morning (9am). The mean per treatment was calculated as the mean of four replicates.

Body Weight Gain (BWG)

Mean body weight per replicate was recorded weekly between week 1 and week 6. The birds from each pen were weighed simultaneously by placing all the 10 birds from each replicate into a tarred plastic bucket. Body weight gain was calculated as the difference in body weights per replicate for consecutive weeks. Mean weight gain per treatment was obtained as a mean of the four replicates.

Feed Conversion Ratio (FCR)

The feed conversion ratio was calculated weekly as the ratio of feed consumed to body weight gain per replicate per treatment as follows;

$$\text{FCR} = \frac{\text{Total feed (kg)consumed}}{\text{Total live weight gain (kg)}}$$

Performance Efficiency Factor (PEF)

The PEF for each treatment was calculated at the end of the trial to compare live-bird performance for each treatment. The PEF value incorporated live weight, age at depletion, liveability and FCR. The PEF was calculated according to Marcu et al., (2013) as follows:

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$$PEF = \frac{\text{Liveweight (g) X Livability(\%)}}{\text{Age at depletion (days) X Feed conversion ratio}} x100$$

Where: Live weight = Live weight at slaughter (42 days); Liveability (%) = number of live birds over the growing cycle/total number of birds at the beginning of the experiment; Age at depletion = terminal age (42 days); FCR = cumulative feed intake (g)/total weight gain (g)

Carcass Characteristics

At the end of the trial after 42 days, 8 birds per treatment were starved for 12 hours and slaughtered for carcass evaluation. Dressed weights and organ parts (wings, drumstick, breast, back and neck) were weighed and recorded.

Laboratory Analysis

Chemical analysis was done in the Nutrition Laboratory, Department of Animal Production, in University of Nairobi. Samples were analysed for dry matter (DM), crude protein (CP), ether extract (EE), crude fibre (CF), ash, minerals (phosphorus and calcium) according to procedures of the Association of Official Analytical Chemists (AOAC, 1989) for proximate analysis. Dry matter was obtained by heating all samples at 105 ^{0}c for 12 hours. Ash was obtained by igniting the sample in the muffle furnace at 600 °C for four hours to burn off organic material. Crude protein was obtained by the Kjeldahl method. The nitrogen content obtained was multiplied by the standard factor of 6.25 to give an estimate of the crude protein. Crude fibre was determined by digesting the feed sample in 2.04N H_2SO_4 acid followed by digestion in 1.78N KOH alkali. The ether extract was determined by dissolving the sample in diethyl ether which dissolved fats, oils, pigments and other fat-soluble substances. The nitrogen-free extract (NFE) was determined by subtracting the percentages of moisture, ash, lipid and fibre from 100%.

Statistical Analysis

The data for feed intake, growth performance and carcass characteristics on broilers supplemented with YMWL were tested for normality (normal distribution) using Mintab version 17 and one-way Analysis of Variance (ANOVA) was performed. Significant treatment means were separated using Tukey Pairwise and the level of significance set at $P \leq 0.05$.

RESULTS

Chemical Composition of Sundried Yellow Meal Worm Larvae and Soya Bean Meal

The nutrient composition of dried yellow meal worm larvae and soya bean meal used in this study are shown in *Table 2*.

Table 2: Nutrient composition (% DM) of sundried YMWL and SBM

	YMWL	SBM
Dry Matter (DM)	93.3±0.14	91.17±0.7
Crude Protein (CP)	45.3±1.4	50±2.83
Crude Fibre (CF)	14.9±0.2	9.4±0.6
Ether Extract (EE)	23.9±0.45	6.81±0.9
Ash	8.6±0.42	6.81
Nitrogen free extracts (NFE)	0.9±0.16	21.8±0.8

Nutrient Composition of the Experimental Diets

The nutrient compositions of the diets are shown in *Table 3*. The diets were formulated to meet the KEBS standards for broiler diets. From the analysed values, all the diets met the standards.

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Table 3: Nutrient composition of experimental diets

	Broiler Starter Mash				Broiler Finisher Mash			
	0 YMWL	2.5 YMWL	5 YMWL	7.5 YMWL	0 YMWL	2.5 YMWL	5 YMWL	7.5 YMWL
Dry matter	91.7	91.9	92.4	91.7	91.9	91.7	92.0	92.2
Crude protein	22.4	22.4	22.4	22.4	19.1	19.2	19.3	19.4
Ether extract	3.40	3.69	4.60	4.67	3.89	3.98	4.52	4.62
Ash	6.33	6.59	7.44	7.89	7.80	8.40	8.61	8.09
Crude fibre	5.78	5.82	6.57	6.47	5.64	5.83	8.09	9.91
Nitrogen Free Extracts	52.69	52.07	52.51	51.54	55.43	54.24	52.69	53.12

YMWL0: control, YMWL 2.5: 2.5% inclusion, YMWL5: 5% inclusion, YMWL7.5: 7.5% inclusion

Growth Performance

The average daily feed intake (ADFI), body weight gain (BWG), feed conversion ratio (FCR) and performance efficiency factor (PEF) are summarized in *Table 4* for the starter, finisher phases as well as the entire feeding period.

During the starter phase ADFI was lower for the control diet (p> 0.043) compared to other experimental diets. The BWG was significantly (p<0.05) different between the diets with the highest gain recorded for 5%YMWL. The FCR varied significantly between treatments (p<0.05), with broilers fed on 5%YMWL having the lowest compared to other experimental diets.

During the finisher phase, the ADFI was similar (p>0.05) for all treatments. Both BWG and FCR were significantly (p<0.001) affected by the inclusion of different levels of YMWL in the diets with 5%YMWL having lower FCR followed by 2.5%YMWL, 0%YMWL and 7.5%YMWL.

During the entire feeding period, the ADFI was similar (p=0.187) for all the treatments. The daily weight gain was highest for 5%YMWL diet (54.5 g/d) and lowest for 7.5%YMWL (42.47 g/d) (p=0.001). The FCR was significantly different between all treatments, with 7.5% YMWL having the highest FCR (2.1) and 5%YMWL the lowest compared to other experimental diets. There was a significant difference in PEF (P<0.05) for all the treatments with 5%YMWL having the highest PEF compared to other treatments.

Table 4: Effect of dietary supplementation with YMWL meal on performance of broilers during different phases

	Treatment				p-value
	0%YMWL	2.5%YMWL	5%YMWL	7.5%YMWL	
Starter phase (d1-d21)					
Initial weight (g) d1	40.1±1.4[a]	39.55a±1.2[a]	41.48±0.44[a]	42.10±0.6[a]	0.503
Weight (g) at d21	828.5±10[b]	860.6±11.1[b]	919.7±13.1[a]	666.1±11.8[c]	0.012
BWG[1] g/day	37.54±0.43[b]	39.1±0.56[b]	41.85±0.63[a]	29.75±0.58[c]	0.001
ADFI[1] (g/day)	55.4±0.53[b]	60.63±0.8[a]	58.34±1.52[ab]	59.88±1.59[ab]	0.043
FCR[1]	1.41±0.02[b]	1.48±0.035[b]	1.33±0.043[b]	1.87±0.061[a]	0.010

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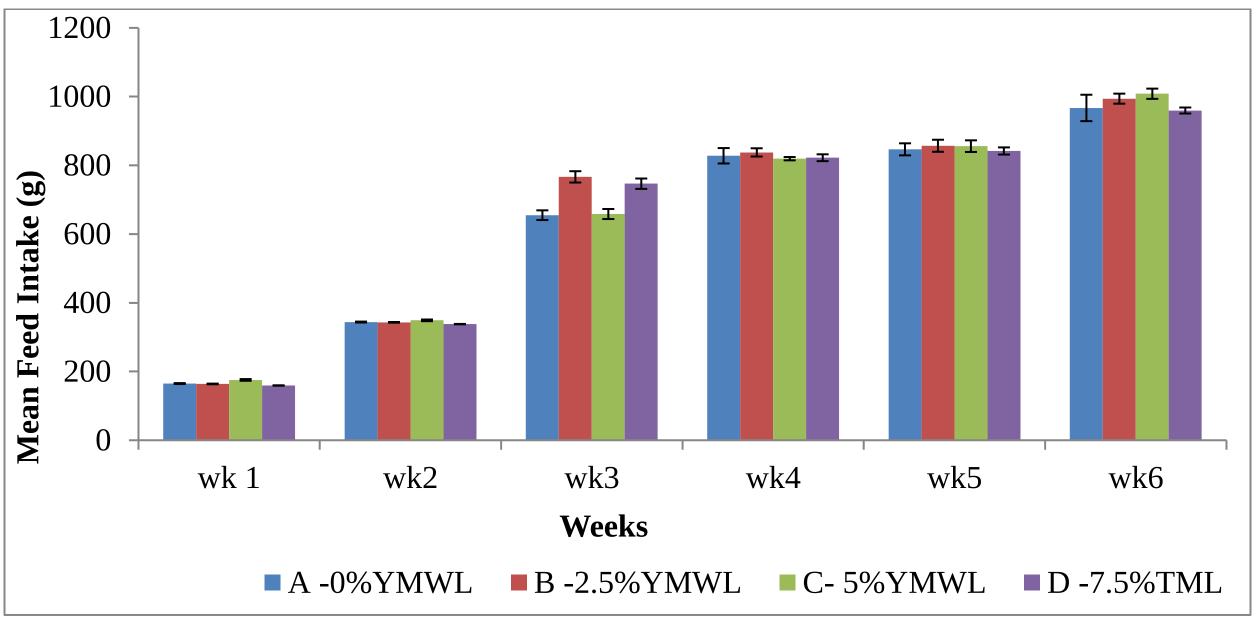
	Treatment				p-value
	0%YMWL	**2.5%YMWL**	**5%YMWL**	**7.5%YMWL**	
Finisher phase (d22-d42)					
Initial weight (g) d22	828.5±10[b]	860.6±11.1[b]	919.7±13.1[a]	666.1±11.8[c]	0.012
Final weight (g) d42	2016.8±19.7[b]	2088.9±36.7[b]	2329±22.4[a]	1825.7±21.3[c]	0.001
BWG[1] g/day	56.6±0.96[b]	58.49±1.79[b]	67.11±1.28[a]	55.22±1.01[b]	0.001
ADFI[1] (g/day)	128.15±3.64[a]	130.88±1.8[a]	131.59±1.62[a]	126.83±0.39[a]	0.407
FCR[1]	1.72±0.637[ab]	1.63b±0.02[b]	1.5±0.026[c]	1.86±0.048[a]	0.001
Entire Feeding period					
Initial weight d1 (g)	40.1±1.4[a]	39.55±1.2[a]	41.48±0.44[a]	42.10±0.6[a]	0.503
Final weight d42 (g)	2016.8±19.7[b]	2088.9±36.7[b]	2329±22.4[a]	1825.7±21.3[c]	0.001
BWG[1] g/day	47.1±0.48[b]	48.8±0.88[b]	54.5±0.53[a]	42.47±0.52[c]	0.001
ADFI[1] (g/day)	91.8±1.8[a]	92.9±0.78[a]	94.9±1.49[a]	90.7±0.91[a]	0.187
FCR[1]	1.91±0.042[b]	1.93±0.023[b]	1.69±0.02[c]	2.12±0.034[a]	0.001
PEF[1]	248.6±0.01[a]	258.2±0.01[b]	323.9±0.05[c]	204.0±0.75[d]	0.001

[a,b,c]Least square means with different superscript letters in a column differ ($p<0.05$)
[1]BWG – Body Weight Gain, ADFI – Average Daily Feed Intake, FCR – Feed Conversion Ratio, PEF-Performance Efficiency Factor, d1= day 1; d21 = day 21; d22= day 22 and d42= day 42
YMWL0: control, YMWL2.5: 2.5% inclusion, YMWL5: 5% inclusion, YMWL7.5: 7.5% inclusion
YMWL: Yellow meal worm larvae

Weekly Feed intake

The effects of supplementation with YMWL on feed intake of broilers for week 1 to 6 are shown in *Figure 1*. There was significantly lower feed intake in week 3 for 0%YMWL and 5%YMWL compared to other treatments.

Figure 1: Mean weekly feed intake of broiler chicken fed on diets with different inclusion levels with YMWL.



The bars represent standard error of the mean; A-0%YMWL; B-2.5%YMWL; C- 5%YMWL; D-7.5%YMWL

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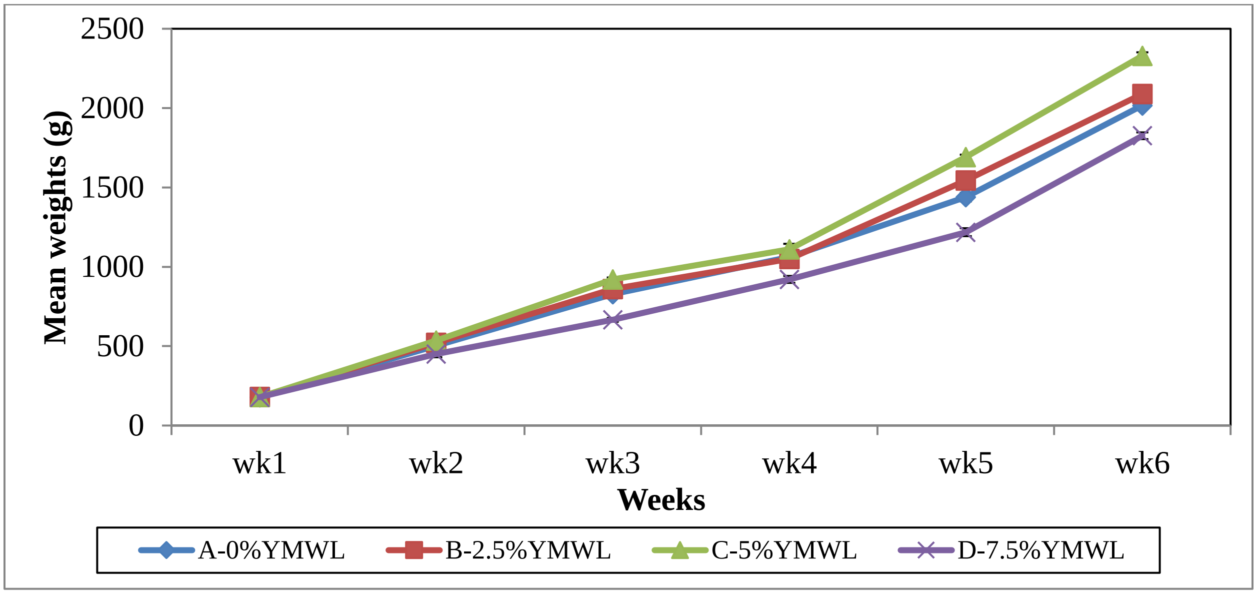
Average Weekly Live Weight

The effects of dietary supplementation with YMWL on weekly live weight (WLW) for week 1-6 are shown in *Figure 2*. There was a significant difference on WLW from week 3 to week 6. The heaviest and lowest WLW occurred at the 5%YMWL and 7.5%YMWL supplementation levels respectively.

Figure 2: Weekly live weight changes of broiler chickens fed on different dietary inclusion levels with TML.



The bars represent standard error of the mean. A-0%YMWL; B-2.5%YMWL; C- 5%YMWL; D-7.5%YMWL

Average Weekly Body Weight Gain

The effects of dietary supplementation with YMWL on average weekly body weight gain (AWBWG) of broilers for weeks 1 to 6 are shown in *Figure 3***.** There were significant differences on AWBWG at week 2 and 3; chicks on diets supplemented with 5%YMWL had the highest AWBWG compared to other treatments. At week 4, there was a decrease in AWBWG for all the treatments, while at week 5 and 6 the average daily gain increased for 5%YMWL.

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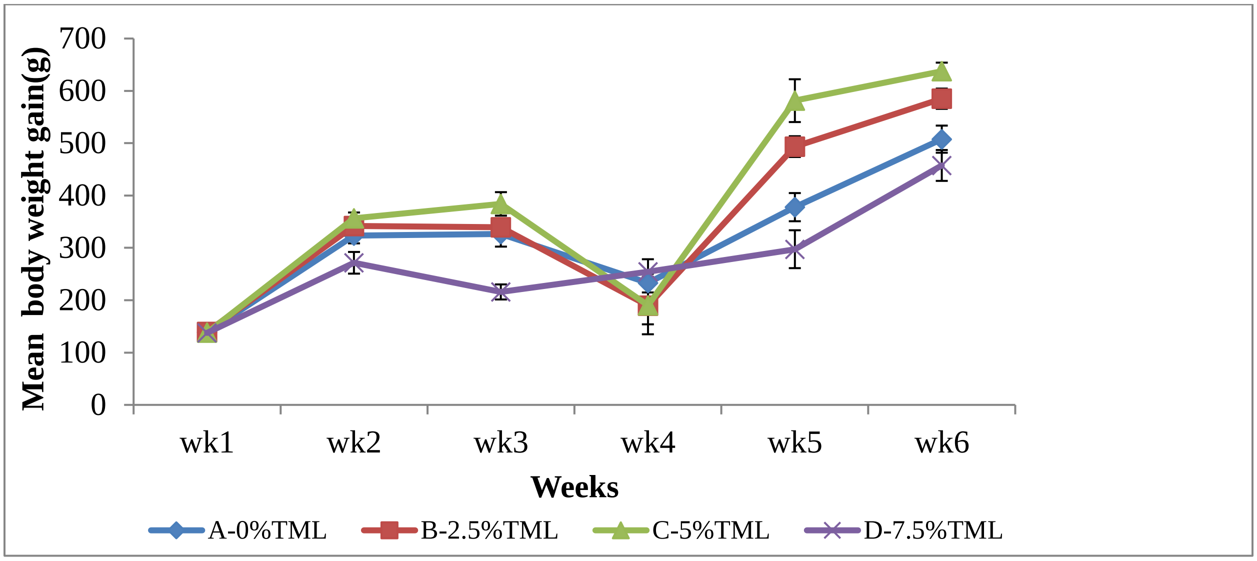
Figure 3: Trends in weekly weight gain of broilers fed on diets with different supplementation

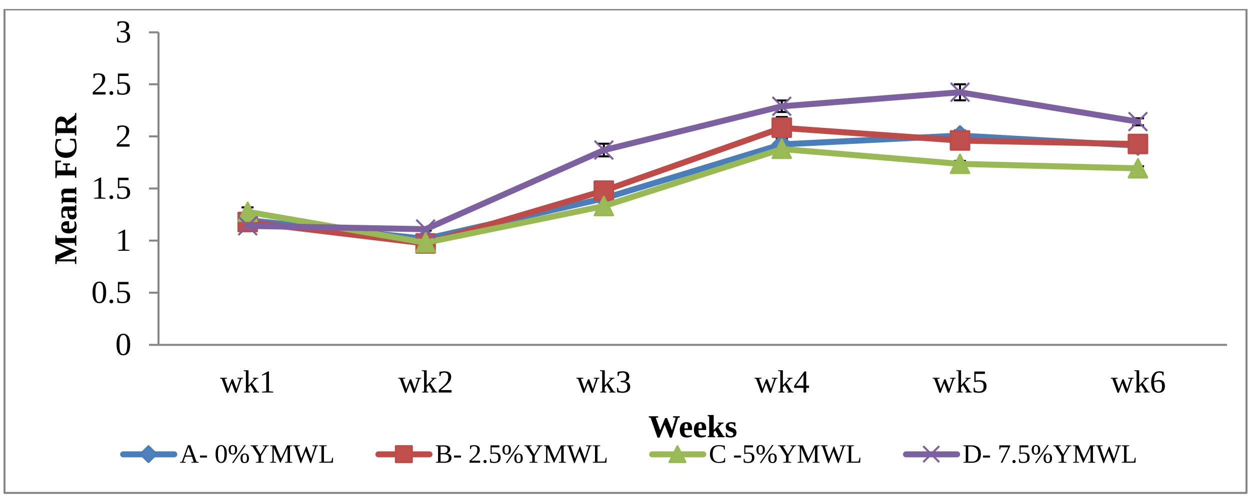


The bars represent standard error of the mean. A-0%YMWL; B-2.5%YMWL; C- 5%YMWL; D-7.5%YMWL

Feed Conversion Ratio

The feed conversion ratios (FCR) of broilers during weeks 1 to 6 are shown on *Figure 4*. There were significant differences in FCR from week 3 to 6 with YMWL 7.5% having the highest FCR. Birds fed diets supplemented with 5%YMWL had the lowest feed conversion ratio, followed by 2.5%YMWL and 0%YMWL.

Figure 4: The trends in weekly feed conversion ratio of birds fed on broiler diets supplemented with YMWL



The bars represent standard error of the mean.

Carcass Characteristics

The carcass characteristics and weight of carcass portions are presented in **Table 5**. The carcass weight (both whole and eviscerated) was highest in 5%YMWL diet and lowest for 7.5% diet (P>0.05). Organ weights were significantly different among the treatments ($p<0.05$), with 5%YMWL having the highest scores and 7.5%YMWL the lowest. The neck weights were similar across all the treatments ($p>0.05$). Overall, the dressing percentage of the

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organs as a percentage of the carcass were similar across the treatments (p>0.05).

Table 5: Least square means ±SE of carcass, organ weights (g) and dressing percentage for broilers fed diet with different inclusion levels of YMWL

	Treatment				
	0%YMWL	**2.5%YMWL**	**5%YMWL**	**7.5%YMWL**	**p-Value**
Weight of live bird	2016.8 ± 19.7^{b}	2088.9 ± 37^{b}	2329 ± 22.4^{a}	1825.7 ± 21^{c}	0.001
Carcass weight	1831.8 ± 24^{b}	1974 ± 23.3^{a}	2100.8 ± 22.4^{a}	1672 ± 49.7^{c}	0.001
Eviscerated carcass with (no head & feet)	1507.7 ± 7.6^{b}	1556.8 ± 35.5^{b}	1791.9 ± 12.2^{a}	1403.5 ± 8.3^{c}	0.001
Breast	635.8 ± 25.7^{b}	697.5 ± 22.7^{ab}	779.75 ± 7.2^{a}	623 ± 48.4^{b}	0.011
Thigh	143.2 ± 3.26^{ab}	146.8 ± 3.33^{a}	151.5 ± 2.6^{a}	132.8 ± 2.06^{b}	0.001
Drumstick	106.5 ± 3.3^{b}	110.5 ± 2.78^{a}	119.3 ± 0.433^{a}	104.3 ± 0.63^{b}	0.002
Wings	82.45 ± 2.93^{b}	88.78 ± 2.01^{a}	94.8 ± 1.31^{a}	81.7 ± 2.35^{b}	0.004
Neck	68.22 ± 2.61^{a}	70.47 ± 1.78^{a}	74.83 ± 1.63^{a}	67.4 ± 4.21^{a}	0.275
Back	290.25 ± 6.9^{b}	291 ± 13.7^{b}	322.8 ± 13^{a}	274 ± 10.2^{b}	0.003
		Dressing %			
Carcass	74.8 ± 0.61^{a}	74.6 ± 1.75^{a}	76.9 ± 0.77^{a}	76.9 ± 1.33^{a}	0.359
Breast	31.6 ± 1.47^{a}	33.45 ± 1.5^{a}	33.5 ± 0.42^{a}	34.1 ± 2.57^{a}	0.728
Thigh	7.1 ± 0.12^{a}	7 ± 0.25^{a}	6.6 ± 0.12^{a}	7.3 ± 0.13^{a}	0.113
Drumstick	5.3 ± 0.2^{a}	5.3 ± 0.19^{a}	5.1 ± 0.06^{a}	5.7 ± 0.09^{a}	0.088
Wings	4.1 ± 0.13^{a}	4.3 ± 0.17^{a}	4.1 ± 0.09^{a}	4.5 ± 0.15^{a}	0.185
Neck	3.4 ± 0.11^{a}	3.3 ± 0.03^{a}	3.2 ± 0.08^{a}	3.7 ± 0.19^{a}	0.081
Back	14.4 ± 0.37^{a}	13.9 ± 0.87^{a}	14.7 ± 0.55^{a}	15 ± 0.16^{a}	0.578

[a,b,c] Least square means with different superscript letters in a column differ (P< 0.05) YMWL0: control, YMWL2.5: 2.5% inclusion, YMWL5: 5% inclusion, YMWL7.5: 7.5% inclusion

DISCUSSION

Nutritional Composition of Yellow Meal Worm Larvae

The Yellow meal worm larvae (YMWL) used in study had a crude protein content of 45%. The results concur with the range of 45-60% recorded by Ghaly and Alkoaik (2009) and 44-69% by Józefiak et al. (2015) and Veldkamp et al. (2012). Furthermore, Nery et al. (2018) reported 45% CP. In contrast, Elahi et al. (2020) and Sedgh-Gooya et al. (2021) reported a higher CP ranging from 50% and 53%. The difference in the CP content could be attributed to larvae rearing media and subsequent processing. The fat content recorded in this study was 23.9% which is within the range reported by Biasato et al. (2018), Józefiak et al. (2015) and Veldkamp et al. (2012). However, crude fat reported in this study was lower than 30% recorded by Elahi et al. (2020) and 28% by Sedgh-Gooya et al. (2021). The crude fibre (CF) content (25.0-36.0%) of YMWL reported by other studies (Ghaly & Alkoaik, 2009; Ravzanaadii et al., 2012; Sanabria et al., 2019) were higher than the current study. Sedgh-Gooya et al. (2021) and Bovera et al. 2016 recorded 7.53% crude fibre which was lower than the present study. However, Hong et al. (2020) stated that the crude fibre of YMWL ranges from 4.19% to 22.35% which was within range with the current study. The difference in the CF content could be the chitin found in the exoskeleton of the larvae. The ash content was 8.6 and is within range of 5.0–8.8%

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reported by several authors (Ramos-Elorduy et al., 2002; Ravzanaadii et al., 2012). The nutritional profile discrepancy of YMWL in different studies has been attributed to the raising media and processing involved in the production of larvae (Elahi et al., 2020).

Growth Parameters

Feed Intake

During the finisher and entire feeding phase the ADFI was similar across all the treatments. The findings are consistent with those by Elahi et al. (2020) who recorded no discernible influence on Feed Intake (FI) at 8% inclusion level of YMWL. Additionally, Biasato et al. (2017) reported that the broilers birds supplemented with 75 g/kg YMWL meal to replace gluten meal had no effect on the FI. According to Hussain et al. (2017), FI was not significantly impacted by the varying amounts of YMWL meal (0, 1, 2, 3 g/kg) fed to broiler chicken. In another study, Ballitoc (2013) recorded higher feed intake at 1% YMWL meal inclusion, while the lowest FI was associated with the treatment containing 10% YMWL meal. In contrast with the current study, Khan et al. (2017) reported that completely substituting YMWL meal for soybean meal drastically decreased FI in broiler hens. The findings from this study indicate that YMWL meal was palatable to broiler chickens. As such, YMWL meal can be included in broiler chicken diets taking into account that insects are naturally eaten by wild birds and free-range chicken (Zuidhof et al., 2003).

Body Weight Gain

Supplementation with YMWL meal increased the BWG and Live weight (LW) at 5% inclusion level compared to other treatments during both finisher and entire feeding phase. The results are consistent with those of Biasato et al. (2017) and Bovera et al. (2016) who reported increase in BWG and live weight on broiler chicks and free-range chicks fed on 50 to 100 g/kg YMWL meal inclusion level. Other studies also reported that Alectoris Barbara birds (Loponte et al., 2017), and Japanese quails (Zadeh et al., 2019) fed a YMWL diet grew considerably faster compared to the control at 250 to 500 g/kg YMWL and 30 g/Kg YMWL meal inclusion level. Elahi et al. (2020) also reported an increase in body weight and average daily gain of broilers fed 4% of YMWL inclusion level. According to Sedgh-Gooya et al. (2021), there was an increase BWG and live weight of birds supplemented with 2.5% YMWL meal. Benzertiha and Kiero (2019) reported increase in BWG on broilers fed with low levels of YMWL and Zophobasmorio full-fat meals (0.2% and 0.3% respectively). Hussain et al. (2017) also reported improved BWG with increase in amount of YMWL meal in their diet (1,322.0, 1,346.3, and 1,423.3 g for 0.1%, 0.2%, and 0.3% YMWL meal respectively). In contrast, Biasato et al. (2016) and Bovera et al. (2015) reported no differences in BWG in chickens fed on the YMWL meal and the control diet. Thus the use of YMWL based diets at lower inclusion level can improve digestibility and utilization of nutrients and sufficient supply of essential amino acids profile of the larvae (Sedgh-Gooya et al. 2021) hence resulting in better growth.

Additionally, in this study 7.5% YMWL inclusion level significantly reduced both LW and BWG compared to other treatments diets. Similar findings were reported for broiler chickens by Elahi et al. (2020) who recorded poor BWG and LW at the level of 8% YMWL. The results also contradict those of Schiavone et al. (2012) who observed improved BWG at maximum level of 25% YMWL. The reduced live weights and BWG recorded at 7.5% YMWL inclusion level in this current study might be due to the high fibre in the diet since insects contain exoskeleton composed of chitin which makes it difficult to be digested by chickens causing nutrients in the feed to be less accessible. De Marco et al. (2015) also speculated that chitin present in the exoskeleton of YMWL meal have a negative impact on the apparent digestibility coefficient of nutrients. Furthermore, Ravindran and Blair (1993) also

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pointed out that insect chitin makes it difficult for domestic fowl to digest. Sánchez-Muros et al. (2014) noted that YMWL contains chitin, a polymer found in the exoskeleton of arthropods that is indigestible to monogastric animals. Khempaka et al. (2011) reported that chitin reduces protein digestibility in broilers but on the other hand it has a positive effect on poultry health as stated by (Van Huis, 2013) who observed that feeding black soldier fly larvae, YMWL or field crickets to chickens reduced antibiotic use because diets containing around 3% chitin increased populations of intestinal Lactobacillus spp. and decreased populations of intestinal Escherichia coli and Salmonella spp.

Feed Conversion Ratio

The results of this study show that FCR was better at 5% YMWL inclusion compared to other diets for both finisher phase and entire feeding period. This is in agreement with Ijaiya and Eko (2009) who recorded improved FCR in broilers in response to insect meals (silkworm). Benzertiha and Kiero (2019) reported improved FCR in broiler chickens that were fed with low levels (0.2% and 0.3%) of YMWL. In addition, Hwangbo (2009) also reported better FCR in response to YMWL meal. These results contradicts those of Ballitoc and Sun (2013) who reported a poor FCR of broilers from 0% to 10% YMWL meal inclusion. The discrepancies between the current and other studies may be partly due to level of YMWL meal which was used in different studies. Additionally, in this study replacing soya bean meal with 7.5% YMWL meal in broiler diets strongly reduced FCR. These findings are similar to the trends observed by Józefiak et al. (2016) who reported reduced FCR with increase of YMWL meals in chicken. Bovera et al. (2016) also reported the reduced FCR ranging for 1.9–2.6 with increase in YMWL meal. Furthermore, Khan et al. (2017) recorded the lowest FCR for broilers fed with YMWL meal diet as a total replacement by soybean meal. These detrimental effects could have been attributed to high fibre content in YMWL, which might have affected the utilisation of the feed by the birds. Ravindran and Blair (1993) stated that the chitin content of YMWL diets negatively influence the nutrient digestibility of crude protein hence impairing FCR in broilers. Hence, Rumpold and Schlüter (2013) recommended partial chitin removal through high pressure processing or use of enzymes to break chitin-bound proteins to improve FCR in insects meals as feeding ingredient.

Performance Efficiency Factor

High performance efficiency factor (PEF) was observed for birds fed diet supplemented with 5%YMWL compared to other treatments. These results are similar to the findings of Bovera et al. (2015) who partially replaced SBM with YMW larvae in broiler diets. They reported an increase in performance efficiency factor for broilers fed on the YMW larvae diet (156.2) compared to isonitrogeneous and isoenergetic SBM diet (132.6). The same author also reported that higher PEF value from 200 to 225 units indicates a flock with acceptable growth and liveability parameters. Marcu et al. (2013) reported that PEF of broilers can be above 260.49 to 376.18 depending on the breed, good management procedures and feed type. However, since the factors used in PEF calculation are related to growth performance (liveability, live weight, day of age and FCR which includes FI and BWG), it is possible to affirm that feeding YMWL meal had a positive effect on broiler growth performance when compared to the SBM (Astral, 2006).

Carcass Yield and Organ Weight

In the current study supplementation of broilers diets with 5% YMWL meal increased the weight of the eviscerated carcass and carcass parts (breast, drumstick, wing, thigh and back). This is in agreement with the performance parameters (BWG and FCR) discussed earlier where birds on 5% inclusion had a better performance. Ballitoc (2013) reported an increase in absolute weights of carcass

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and carcass parts of broiler chickens fed YMWL diets. Hwangbo (2009) and Ballitoc and Sun (2013) reported similar findings regarding improved eviscerated carcass weights with different insect meals inclusion levels (at 5% and 10% maggot meal) and (1% and 2% YMWL meal). Khatun et al. (2003) also noted improved carcass yield, breast muscle and thigh muscle weights for broilers fed diets supplemented with silkworm pupae at 4% and 6% inclusion levels. Cullere et al. (2016) also reported that, quails that were fed on BSF larvae meal diets improved carcass yield and breast muscle weight. The difference between 5%YMWL and other groups might depend on utilization of YMWL by the birds.

CONCLUSIONS

According to the results of this study, it can be concluded that, yellow mealworm larvae could be used as an alternative protein supplement in broiler diets. Dietary inclusion of yellow mealworm larvae meal at 5% demonstrated the potential to improve growth performance, feed conversion ratio, and feed intake and performance efficiency factor without altering carcass characteristics.

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Conflict of Interest

The authors declares no conflicts of interest

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