NUTRIENT RETENTION AND PERFORMANCE OF BROILER CHICKS FED FINISHER DIETS FORTIFIED WITH INSECTS MEALS

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ABSTRACT

This study was designed to evaluate the effect of finisher diets fortified with African palm weevil larvae meal (APWLM), housefly maggot meal (HMM) and cockroach protein meal (CPM) on the performance and nutrient retention of caged broilers (Cobbs). One thousand four hundred (1400) broiler chicks were assigned in four groups to livestock feed (LF) fortified with APWLM, HMM and CPM for single form diets, and to LF fortified with APWLM and HMM, APWLM and CPM, and HMM and CPM for the combined forms. Insect inclusion rate was 19.5 and 9.75 % respectively as LF alone served as control. Growth performance parameters and nutrient retention were measured. Body weight (0.56 – 3.57 kg), body length (23.75 – 43.00 cm) and breast width (7.50 – 18.50 cm) ranges increased with increasing weeks. Growth performance was highest at week 10 in chicks fed LF fortified with APWLM and maggot (3.57 ± 0.03 kg), APWLM (43.0 ± 0.02 cm), and APWLM and CPM (18.50 ± 0.02 cm) respectively. Feed efficiency and body weight versus body length were highest in chicks fed LF fortified with APWLM and maggot. Dry matter, crude protein and ether extract were highest in broilers fed fortified diet in combined forms, while crude ash, calcium and phosphorus were highest in broilers fed fortified diet in single forms. Finisher diets fortified with insects in this study especially in the combined form advantageously increased growth rate of broilers and its adoption to brace commercial broilers diets is advised.

Keywords: Broilers, Entomophagy, Fortified feed, Growth performance, Insects

INTRODUCTION

The use of insect as feed has been an ongoing innovation supported by Huis *et al.* (2013), since human's ability to consume insects have a long tradition in many parts of Asia, Latin America and Africa. Currently, securing quality feed is one prevailing challenge generally affecting sustainable production of poultry birds. It is a serious huddle in terms of finance to acquire quality feed necessary to compensate the required quantities in the present era for many developing countries especially in Nigeria. Studies on alternative innovations are increasing lately on the use of insects (Sidali *et al.,* 2019). The world is growing in terms of population and as such concerns such as inflation, urban development, environment and nutrition related concerns, and other anthropogenic activities are expected to impact on the global food system and thus causing a remarkable shift (Myers *et al.,* 2017). With this remarkable shift, interests in research have been to change the formulation of diets from standard animal and plant feed ingredients to commonly available feed resource in the environment. This shift is most likely to sustain the population in coming decades. Farming poultry birds with insects is profitable to meet the deficiency in feed formulation due to their rich protein content and short life cycle (McGuire *et al*., 2015). The cost of acquiring poultry feeds makeup approximately 60 to 80 % of the total cost of poultry farming, which is one of the major setbacks of profitable animal production, thus mandating more consideration for alternative protein supplements in poultry feeds (Thirumalaisamy *et al.,* 2019).

Insects have been extensively studied in terms of their nutritional contents, sensory requirements, lifecycle requirements, ethical issues as well as successful innovations (Makkar *et al.,* 2014; Kim *et al.,* 2017; Ojianwuna *et al*., 2021). However, some studies have highlighted the importance of adopting black soldier fly larvae, housefly maggots, yellow mealworm, locusts–grasshoppers–crickets, and silkworm meal as well as their incorporation in diets for supplementation of commercial feedstuffs such as soybean meal, fish meal and other commercialized feedstuffs. Makkar *et al*. (2014) confirmed that the proteins, amino acids, mineral contents, palatability and digestibility of insects are high compared to feed materials of plant origins.

In Nigeria, African palm weevil larvae (*Rhynchophorus pheonicis* Fabricius, 1801, Coleoptera: Curculionidae) is indigenously consumed and at larger focus in sub-Sahara Africa. Similarly, cockroaches (*Periplaneta americana* Linnaeus, 1758, Blattodea: Blattidae), and housefly larvae (*Musca domestica* Linnaeus, 1758, Diptera: Muscidae) are indigenous insects though not consumable but with high nutritional values (Ekpo and Onigbinde, 2005; Banjo *et al*., 2006). The most important aspect of these insects is that they can be reared from larvae to adult on common, available and affordable substrates and even waste products before they are incorporated into poultry diets (Kim *et al*., 2017). These insects have great potentials of being mass bred due to their short life cycles, generational cycle and reproductive rates (Huis *et al*., 2013). Considering their great nutritional potentials, adoption of feed ingredients of insects origin would help reduce the stress in acquiring standard dietary ingredients. It is based on this requisite that these insects were adopted for this study in fortification of commercial feed to assess their growth rates and progress in nutrient retention.

Poultry birds like other monogastric animals require energy in calories, protein and fat for their daily maintenance, growth and survival. These nutrients should be in high quantities, sufficient enough to compensate deficiencies. Nutritional contents of animals are dependent mostly on what they fed on. In bird production, protein sources of feedstuff have a direct link to their protein content, digestibility, palatability and flesh index (Beski *et al*., 2015). This study in a bid to redeem the anticipated search for advantageous insects adopted African palm weevil larvae meal (APWLM), cockroaches and housefly larvae in which their nutritional properties have been evaluated (Banjo *et al.,* 2006; Kim *et al.,* 2017; Ojianwuna *et al*., 2021). Studies on poultry diets fortified with proteins from palm weevils, housefly maggot and cockroaches in single and combined forms are lacking. This study was then designed to evaluate the effect of livestock fed finisher diets fortified with insects' proteins on nutrient retention and growth performance of cage broilers. This study is expected to contribute to the existing knowledge on the formulation of diets using insects as dietary ingredients or feed addictive.

MATERIALS AND METHODS

Design, Animals and Feed Fortification: The experiment was carried out with a complete randomized design (CRD) of seven treatments replicated four times with each replicate having 50 day old broiler chick. The experimental cage for this study was dimensioned 21.34 meter length by 3.05 meter breadth. The length was further divided into seven compartments with a constant breadth. This gave rise to a perfect square compartment of 3.05 by 3.05 meter. Six of which were labelled and assigned to birds fed diets fortified with insects, while one group fed livestock diet alone served as control for the feed trial. Each treatment compartment was divided into four which served as replicates for the experiment. This further division gave rise to 1.02 by 1.22 meter cage for each replicate. The poultry house was built with concrete walls and floors. The experimental house was partitioned using plywood, wood and net wires. This was done to ease the taking of readings.

The insects for the study were sourced locally. African palm weevil larvae were gotten from Eku and Sapele, Delta State Nigeria. Cockroaches were trapped *en masse* by using the food baiting method as described by Hu *et al*. (2020). Housefly larvae were reared by using a mix of poultry dropping and pig dung with wheat brans (Hussain *et al.*, 2017). The mixture was left in open spaces for adult housefly to oviposit. The baited culture was then transferred to the Entomology Laboratory of the Department of Animal and Environmental Biology, Delta State University, Abraka, Nigeria, kept at room temperature for larvae to emerge and grow to maturity. The resulting larvae were killed by freezing at - 10^{o}C for 10 minutes, washed, oven dried at 60^{o}C for 10 minutes after defrosting. All insects were separately oven dried (60^{0}C) and grounded for the fortification of feed. The insect meals have been checked for their proximate composition (Table 1).

This study used broiler chicks reared from day old and fed commercial super starter diet (Premium Quality Ultima Poultry Feed, Olam Animal Feed Mill, Nigeria) for four weeks in a temperature-regulated room (33.5 ± 1^{o}C). The starter diet used constituted 22.0% crude protein, 4.5% crude fat, 3.5% crude fibre, 1.8% calcium, 0.5% phosphorus, 1.33% lysine, 0.5% methionine and 2950 Kcal/kg metabolisable energy. These chicks were vaccinated against Newcastle diseases and associated infectious disease until 28 days of age following management practices as described by Cobb International breed (Cobb, 2021). The resulting chicks (1400 broilers) after four weeks of breeding were weighed (425.70 ± 36.20) and reassigned randomly at 50 broiler chicks per replicate, and fed commercial finisher diet (Premium Quality Ultima Poultry Feed, Olam Animal Feed Mill, Nigeria) (crude protein 19.5 %, fat 6.5 %, crude fibre 3 %, calcium 1.2 %, phosphorus 0.44 %, methionine 0.5 %, lysine 1.2 % and metabolizable energy 3100 kcal/kg) fortified with APWLM, cockroach protein meal (CPM) and housefly maggot meal (HMM) in single forms, and in combined forms in a six weeks feeding trial. Insects were used to fortify the livestock feed (finisher diet) at an inclusion rate of 19.50 % in single forms and 9.75 % in combined forms as shown in Table 2. Proximate compositions of the resulting diets were assay according to the methods in AOAC (2002) (Table 3).

Sample Analyses: Weekly readings of body weight gain (BWG), body length gain (BLG), breast width gain BWG) and feed efficiency (FE) were taken. Broiler chicks were first weighed before readings of other growth parameters were taken. These readings were taken from week 5 to week 10. Weights of birds were taken using weighing balance and length was measured using meter rule. Feed efficiency, feed conversion ratio, growth rates and nutrient retention were calculated using the following formulas:

$$\text{Feed efficiency} = \frac{feed\ consumed\ (g)}{weigh\quad gain\ (g)}$$

$$\text{Feed Conversion Ratio} = \frac{weig\quad gain\ (g)}{Feed\ consumed\ (g)}$$

$$\text{Growth rates} = \frac{Log10\ final\ weight - Log10\ initial\ weigh}{Time\ in\ days}\ x\ 100$$

$$\text{Nutrient retention} = \frac{nutrient\ intake - nutri\quad in\ excreta}{Nutrient\ intake}\ x\ 100$$

Other body measurements described in the study of Amobi and Ebenebe (2018) were adopted. All analyses were done at the Entomology Laboratory, Department of Animal and Environmental Biology, Delta State University, Abraka, Nigeria. Following the procedures described by AOAC (2002), chemical composition of samples was done for dry matter, crude protein, ash, calcium, available phosphorus, and ether extract. Fecal samples were collected, weighed and dried with the oven and the proximate analysis was done according to colorimetric determination as described in AOAC (2002).

Table 1: Proximate composition of insect meals

Proximate composition	African palm weevil larvae meal (%)[a]	House fly maggot meal (%)[b]	Cockroach protein meal (%)[c]
Ash	4.7	6.3	4.9*
Carbohydrate	11.7	24.3	87.6
Fat	45.2	25.3	17.6
Fibre	2.1	7.5	12.2*
Moisture	8.2	ND	12.4
Protein	31.2	47.1	8.7
Ether extract	ND	27.3*	26.9*
Metabolizable energy (Kcal/kg)	733.1	2890*	4180*
Nitrogen-free extract	ND	ND	0.4*
Calcium	0.3*	1.7*	0.2*
Phosphorus	4.9*	0.6*	0.5*

*[a](Ojianwuna et al., 2021; *Omotosho and Adedire, 2007), [b](Aniebo et al., 2008; *Hamani et al., 2022) and [c](*Boateng et al., 2018; Ukoroije and Bawo, 2020), ND means not determined*

Table 2: Formulation of fortified feeds of insects

Feed composition	(%) Insect composition	Formulation (g)
LF only (control)	0	1000
LF and APWLM	19.5	800 + 200
LF and HMM	19.5	800 + 200
LF and CPM	19.5	800 + 200
LF, APWLM and HMM	9.75 each	800 + 100 + 100
LF, APWLM and CPM	9.75 each	800 + 100 + 100
LF, CPM and HMM	9.75 each	800 + 100 + 100

***Key:** LF is livestock feed, HMM is housefly maggot meal, APWLM is African palm weevil larvae meal, and CPM is cockroach protein meal*

Table 3: Proximate compositions of the resulting diets

Proximate composition	LF only (control)	LF and APWLM	LF and HMM	LF and CPM	LF, APWLM and HMM	LF, APWLM and CPM	LF, CPM and HMM
Fat	6.5	51.7	31.8	24.1	41.8	37.9	28.0
Fibre	3.0	5.1	10.5	15.2	7.8	10.2	12.9
Protein	19.5	50.7	66.6	28.2	58.7	39.5	47.4
Calcium	1.2	1.5	2.0	1.4	2.2	1.5	2.2
Phosphorus	0.4	5.3	1.0	0.9	3.2	5.6	1.0
Metabolizable energy (Kcal/kg)	3100	1941.6	2995	3640	3361.6	4066.6	5085.0

The EDTA titration method and Bray number 1 method was used to determine calcium and phosphorus content respectively.

Data Analysis: Readings of the study were collected and entered in Microsoft Excel Spreadsheet and subjected to statistical analysis using XL Stat Software 2020 Version. Growth performance data including mean body weight, mean body length, breast width, body weight over length, feed efficiency and conversion ratios were subjected to Analysis of Variance (ANOVA) and mean growth performances were separated using Tukey's test at 5 % probability level. Descriptive statistics including mean, standard deviation and percentages were used in result presentation.

RESULTS

Growth Performance of Broilers: Mean body weight, body length, and breast width in this study ranged between 0.56 and 3.57 kg, 23.75 and 43.00 cm, 7.50 and 18.50 cm respectively. Body weight, length and breast width increased with increasing weeks feed trial (Table 4). The highest growth parameters were recorded in week 10. Mean body weight was higher in broiler chicks fed livestock feed fortified with APWLM and HMM (3.57 ± 0.03 kg) compared to the other feed trials. The mean body length was highest in chicks were fed livestock feed fortified with APWLM (43.0 ± 0.02 cm). Breast width was higher in chicks fed livestock feed fortified with APWLM and HMM. Livestock feed fortified with APWLM also caused high growth performance APWLM and CPM respectively (18.50 ± 0.02 cm) compared to other feed trials. The differences between body weight, length and breast width in broilers fed insect fortified feeds and livestock feed were significant (Table 4). Broilers fed livestock diet had the lowest growth performances. In addition, feed efficiency and body weight versus body length increased in broiler chicks fed the fortified diets (Table 5). Feed efficiency was higher in chicks fed livestock feed fortified with APWLM and HMM than in other diets. Similarly, body weight versus body length was higher in chicks fed livestock feed fortified with APWLM and HMM compared to other diets. The differences were significant (Table 5). The lowest feed efficiency and body weight versus body length was recorded in broilers fed livestock feed.

Nutrient Retention: In this study, insect fortified feed showed various degrees of nutrient retention (%) in caged broilers (Table 6). Broilers fed the fortified feed combinations of HMM and CPM recorded the highest dry matter. The crude protein and ether extract of broilers were higher in those fed APWLM and HMM fortified diet than in others. Crude ash was higher in broilers fed CPM fortified feed than in other feed diets. Calcium and phosphorus were higher in broilers fed APWLM fortified feed than in other feed diets. Dry matter and crude ash, crude protein and ether extract, and calcium and phosphorus were lowest in broilers fed conventional diet, CPM and HMM fortified feed respectively (Table 6). The differences between the nutrient retention in broilers fed fortified feeds were significant ($p<0.05$).

DISCUSSION

The world population has been modelled to grow beyond the expected carrying capacity and this has mandated the prompt search for innovative approaches involving the formulation or fortification of feed adopting the available and affordable feedstuffs to replace the current pricy ones. It is quite tasking to guarantee quantity supply of feed resources for animal production which could in turn benefit human food production. Every developed, developing and underdeveloped countries of the world have raw feedstuffs that are localized for possible incorporations into diets. Some studies have pointed out the benefits of adopting proteins of plant origin, blood meals from animals, and additives including antibodies and probiotics in broiler chicks' production (Beski *et al.,* 2015; Krysiak *et al.*, 2021). The utilization of African palm weevils as feedstuffs is competitive since they are equally potential food stuffs for human consumption and could be difficult to apply in feedstuffs if not endemic in the location. Though, HMM and CPM are not human food stuffs but require attention in their breeding. Insect have a widespread distribution and nutritional potential, and are underutilized in different regions of the world. However, a few studies in some parts of the world shown that they are utilized as food and in others areas as feed; including maggot, yellow meal worm, silkworm and so many others (Awoniyi *et al.*, 2003; Ijaiya and Eko, 2009; Ballitoc and Sun, 2013; Moula *et al.,* 2018).

In this present study, the effect of insect fortified feed on the growth performance of broilers was evaluated. APWLM, HMM and CPM in single and combined administrations were tried against the commercialized feed. Body weight, length and breast width increased with increasing weeks of feeding.

Table 4: Weekly variations of body weight, body length and breast width in caged broilers fed insect fortified meals

Parameters	Treatment	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10
Mean body weight (Kg)	LF (Control)	0.56 ± 0.01^{a}	0.76 ± 0.03^{a}	1.22 ± 0.02^{a}	1.62 ± 0.03^{a}	2.65 ± 0.03^{a}	2.87 ± 0.03^{a}
	LF + CPM	0.66 ± 0.01^{b}	1.40 ± 0.03^{d}	1.52 ± 0.02^{cd}	2.17 ± 0.03^{b}	3.02 ± 0.03^{bc}	3.45 ± 0.03^{c}
	LF + HMM	0.60 ± 0.01^{a}	1.10 ± 0.03^{c}	1.45 ± 0.02^{bc}	2.57 ± 0.03^{d}	2.70 ± 0.03^{a}	2.92 ± 0.03^{a}
	LF + APWLM	0.73 ± 0.01^{c}	0.98 ± 0.03^{b}	1.57 ± 0.02^{de}	2.62 ± 0.03^{d}	2.97 ± 0.03^{bc}	3.17 ± 0.03^{b}
	LF, CPM + HMM	0.71 ± 0.01^{c}	1.50 ± 0.03^{d}	1.57 ± 0.02^{de}	2.17 ± 0.03^{b}	2.65 ± 0.03^{a}	3.50 ± 0.03^{cd}
	LF, APWLM + HMM	0.75 ± 0.01^{c}	1.05 ± 0.03^{bc}	1.37 ± 0.02^{b}	2.40 ± 0.03^{c}	3.07 ± 0.03^{c}	3.57 ± 0.03^{d}
	LF, APWLM + CPM	0.60 ± 0.01^{a}	1.02 ± 0.03^{bc}	1.65 ± 0.02^{e}	2.40 ± 0.03^{c}	2.95 ± 0.03^{b}	3.42 ± 0.03^{c}
Mean body length (cm)	LF (Control)	23.75 ± 0.03^{a}	26.00 ± 0.02^{a}	27.00 ± 0.02^{a}	35.00 ± 0.03^{a}	37.50 ± 0.02^{a}	38.75 ± 0.02^{a}
	LF + CPM	25.50 ± 0.03^{d}	27.01 ± 0.02^{c}	28.25 ± 0.02^{d}	36.50 ± 0.03^{d}	39.25 ± 0.02^{b}	40.25 ± 0.02^{c}
	LF + HMM	25.25 ± 0.03^{c}	27.25 ± 0.02^{d}	28.75 ± 0.02^{e}	36.00 ± 0.03^{c}	39.25 ± 0.03^{b}	40.70 ± 0.02^{d}
	LFR + APWLM	25.50 ± 0.03^{d}	26.75 ± 0.02^{b}	27.75 ± 0.02^{c}	37.00 ± 0.03^{e}	42.00 ± 0.03^{e}	43.00 ± 0.02^{g}
	LF, CPM + HMM	25.00 ± 0.03^{b}	27.00 ± 0.02^{c}	27.50 ± 0.02^{b}	37.25 ± 0.03^{f}	40.71 ± 0.02^{d}	42.25 ± 0.02^{f}
	LF, APWLM + HMM	25.75 ± 0.03^{e}	27.00 ± 0.02^{c}	27.75 ± 0.02^{c}	36.50 ± 0.03^{d}	39.50 ± 0.02^{c}	40.00 ± 0.02^{b}
	LF, APWLM + CPM	26.00 ± 0.03^{f}	28.01 ± 0.02^{e}	28.25 ± 0.02^{d}	31.50 ± 0.03^{a}	40.75 ± 0.02^{d}	41.25 ± 0.02^{e}
Breast Width (cm)	LF (Control)	7.50 ± 0.02^{a}	10.75 ± 0.02^{b}	11.25 ± 0.02^{b}	12.25 ± 0.02^{a}	15.50 ± 0.02^{c}	15.75 ± 0.02^{a}
	LF + CPM	8.83 ± 0.02^{b}	9.37 ± 0.02^{a}	11.00 ± 0.02^{a}	12.50 ± 0.02^{b}	14.12 ± 0.02^{a}	16.00 ± 0.02^{b}
	LF + HMM	8.66 ± 0.02^{c}	11.00 ± 0.02^{c}	12.00 ± 0.02^{c}	13.00 ± 0.02^{c}	15.00 ± 0.02^{b}	16.00 ± 0.02^{b}
	LFR + APWLM	9.38 ± 0.02^{e}	12.50 ± 0.02^{d}	13.00 ± 0.02^{f}	14.87 ± 0.02^{f}	16.75 ± 0.02^{e}	17.87 ± 0.02^{d}
	LF, CPM + HMM	8.87 ± 0.02^{d}	10.75 ± 0.02^{b}	12.25 ± 0.02^{d}	13.75 ± 0.02^{d}	16.00 ± 0.02^{d}	17.50 ± 0.02^{c}
	LF, APWLM + HMM	8.86 ± 0.02^{c}	11.00 ± 0.02^{c}	12.25 ± 0.02^{d}	13.66 ± 0.02^{d}	16.75 ± 0.02^{e}	18.50 ± 0.02^{e}
	LF, APWLM + CPM	8.87 ± 0.02^{d}	11.00 ± 0.02^{c}	12.50 ± 0.02^{e}	14.12 ± 0.02^{e}	16.75 ± 0.02^{e}	18.50 ± 0.02^{e}

Note: *LF= livestock feed, CPM = cockroach protein meal, HMM= housefly maggot meal, APWLM = African palm weevil larvae meal. Means of the same superscript letter do not differ significantly within weekly variations of treatments (p<0.05) using Tukey's test*

Table 5: Weekly variations in feed efficiency and body weight over body length in broilers chicken fed insect fortified feeds

Parameters	Treatment	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10
Feed Efficiency	LF (control)	0.087 ± 0.001^{a}	0.117 ± 0.004^{a}	0.190 ± 0.003^{a}	0.252 ± 0.004^{a}	0.412 ± 0.003^{a}	0.447 ± 0.004^{a}
	LF + CPM	0.102 ± 0.001^{b}	0.217 ± 0.004^{d}	0.236 ± 0.003^{cd}	0.338 ± 0.004^{b}	0.470 ± 0.003^{bc}	0.537 ± 0.004^{c}
	LF + HMM	0.093 ± 0.001^{a}	0.171 ± 0.004^{c}	0.226 ± 0.003^{bc}	0.400 ± 0.004^{d}	0.420 ± 0.003^{a}	0.454 ± 0.004^{a}
	LF + APWLM	0.113 ± 0.001^{e}	0.152 ± 0.004^{b}	0.244 ± 0.003^{de}	0.408 ± 0.004^{d}	0.462 ± 0.003^{bc}	0.493 ± 0.004^{b}
	LF, CPM + HMM	0.111 ± 0.001^{c}	0.233 ± 0.004^{d}	0.244 ± 0.003^{de}	0.338 ± 0.004^{b}	0.412 ± 0.003^{a}	0.545 ± 0.004^{cd}
	LF, APWLM + HMM	0.116 ± 0.001^{c}	0.163 ± 0.004^{bc}	0.213 ± 0.003^{b}	0.373 ± 0.004^{c}	0.478 ± 0.003^{c}	0.555 ± 0.004^{d}
	LF, APWLM + CPM	0.093 ± 0.001^{a}	0.159 ± 0.004^{bc}	0.257 ± 0.003^{e}	0.373 ± 0.004^{c}	0.459 ± 0.003^{b}	0.532 ± 0.004^{c}
BW/BL	LF (control)	0.023 ± 0.00^{a}	0.029 ± 0.001^{a}	0.045 ± 0.001^{a}	0.068 ± 0.001^{a}	0.071 ± 0.001^{a}	0.074 ± 0.001^{a}
	LF + CPM	0.026 ± 0.00^{b}	0.052 ± 0.001^{c}	0.054 ± 0.001^{c}	0.085 ± 0.001^{b}	0.077 ± 0.001^{d}	0.086 ± 0.001^{c}
	LF + HMM	0.024 ± 0.00^{a}	0.040 ± 0.001^{b}	0.050 ± 0.001^{b}	0.102 ± 0.001^{d}	0.069 ± 0.001^{b}	0.072 ± 0.001^{a}
	LF + APWLM	0.028 ± 0.00^{c}	0.036 ± 0.001^{b}	0.057 ± 0.001^{cd}	0.103 ± 0.001^{d}	0.071 ± 0.001^{bc}	0.074 ± 0.001^{a}
	LF, CPM + HMM	0.029 ± 0.00^{c}	0.056 ± 0.001^{c}	0.057 ± 0.001^{cd}	0.087 ± 0.001^{b}	0.065 ± 0.001^{a}	0.083 ± 0.001^{b}
	LF, APWLM + HMM	0.029 ± 0.00^{c}	0.039 ± 0.001^{b}	0.049 ± 0.001^{b}	0.093 ± 0.001^{c}	0.078 ± 0.001^{d}	0.089 ± 0.001^{d}
	LF, APWLM + CPM	0.023 ± 0.00^{a}	0.036 ± 0.001^{b}	0.058 ± 0.001^{d}	0.092 ± 0.001^{c}	0.072 ± 0.001^{c}	0.083 ± 0.001^{b}

Note: *LF= livestock feed, CPM= cockroach protein meal, HMM = housefly maggot meal, APWLM= African palm weevil larvae meal. BW/BL= body weight/body length. Means of the same superscript letter do not differ significantly within weekly variations of treatments (p<0.05) using Tukey's test*

Table 6: The effect of insect fortified feed on percentage nutrient retention of caged broilers

Treatments	CTRL	HMM + CPM	CPM	APWLM + HMM	APWLM + CPM	HMM	APWLM
Dry matter	64.08^{a}	81.11^{d}	77.86^{c}	69.17^{b}	68.92^{b}	78.36^{c}	64.97^{a}
Crude protein	62.14^{d}	54.83^{b}	40.13^{a}	69.38^{e}	59.68^{c}	59.52^{c}	69.24^{e}
Ether extract	65.04^{c}	68.08^{d}	58.18^{a}	73.80^{g}	71.90^{f}	61.98^{b}	69.61^{e}
Crude ash	18.12^{a}	18.20^{a}	19.42^{e}	18.64^{c}	18.94^{d}	18.82^{d}	18.46^{b}
Calcium	17.80^{c}	16.84^{b}	18.09^{d}	18.37^{e}	19.62^{f}	15.58^{a}	21.15^{g}
Phosphorus	19.38^{f}	12.56^{b}	13.76^{c}	15.88^{d}	17.06^{e}	11.36^{a}	20.35^{g}

Note: *CPM= cockroach protein meal, HMM = housefly maggot meal, APWLM = African palm weevil larvae meal. Means of the same superscript letter do not differ significantly within treatments (p<0.05) using Tukey's test*

This can be ascribed to the nutritional content of the insects tried. It was observed that as mean weight of broiler chicks increased the length equally increased. This probably may favour the femoral part and shank of the chicks with the bid to hold the chicks' weight. These observations were in agreement with the reports of Hassan *et al.* (2009) and Chisowa *et al.* (2015). Let this follow. A similar study by Ojianwuna and Enwemiwe (2022) confirmed that formulated feed of these insects especially African palm weevil meal caused high growth performance in broiler chicks. Nutritional composition of insects due to breeding substrate, conditions of the environment and other related factors, and their incorporation in feed could have influenced growth performance in broiler chicks as observed by Ojianwuna and Enwemiwe (2022) and other authors (Ojianwuna *et al.*, 2021; Rodriguez-Ortega *et al.*, 2022; Hamani *et al.*, 2022).

Growth performance in this study occurred at the tenth week of exposure. Mean body weight was highest most especially for the insects in combination probably because the synergist effect of the fortified feeds. Hence, livestock feed fortified with APWLM and HMM favoured mean weight gain, and APWLM favoured mean body length of broiler chicks. More so, livestock feed fortified with APWLM and HMM, and APWLM and CPM respectively favoured breast width, where the bulk of flesh in broiler chicks is localized. This observation was in agreement with the study of Shadreck and Mukwanise (2014) that reported body weight gain of chicks fed locust and termite fortified diets. A similar finding to this study was reported by Okah and Onwujiariri (2012) in the use of maggot fortified diets. Contrary findings to the findings of the present study have been reported by Adeniyi (2007) using maggot meal fortified diets. The growth performance in this study could be ascribed to the nutritional content of APWLM which boosted the performance in combinations. Significant growth was observed in the parameters assessed including body weight, length and breast width in broilers fed insect fortified feeds. Considering the results of this study the insect proteins boosted the nutrient retention likewise growth performance.

Broiler chicks of six to eight weeks of breeding are considered matured and ready for consumption in Nigeria and most African Countries. According to Poultry World (2016), protein requirements of broiler chicks have been predicted to be between 18 and 22 %. This may be the reason why the protein combinations did better in terms of increased growth performance in the present study. The practice of farming animals using insects have changed the world’s perspective of feed for breeding animals in captive especially birds. Most especially in the face of utilizing the available. Feed efficiency is important in monitoring the utilization of feed by experimental animals. This study observed that feed efficiency and body weight versus body length increased in broiler chicks fed the fortified diets. Feed efficiency and body weight versus body length was higher when chicks were fed livestock feed fortified with APWLM and HMM compared to other diets. Significant increases were observed in the different feed stuffs. This corresponded to observation made by Okah and Onwujiariri (2012) and Shadreck and Mukwanise (2014).

Nutrient retention measures the amount of feed utilized in caged broilers. Broilers fed the fortified feed combinations of HMM and CPM recorded the highest dry matter. The crude protein and ether extract of broilers was higher in those fed APWLM and HMM fortified diet than in others. Crude ash was higher in broilers fed CPM fortified feed than in others. Calcium and phosphorus was higher in broilers fed APWLM fortified feed than in others. Dry matter and crude ash, crude protein and ether extract, and calcium and phosphorus was lowest in broilers fed conventional diet, CPM and HMM fortified feed respectively. Significant variations in nutrient retention were observed in caged broilers. The findings of this present study corroborated the study of Ojianwuna and Enwemiwe (2022) where similar insects reported in formulated feed caused high nutrient retention. More so, high nutrient retention observed in the study of Đorđević *et al.* (2008) and Bovera *et al.* (2016) is in line with this present study where meal worm diet recorded higher nutrient retention.

Conclusion: This study has demonstrated that fortified finisher diets of insects in combinations especially APWLM and HMM had synergistic effect in growth performance in broiler chicks. Fortified feeds of these insects in combination favoured nutrient retention in caged broilers. Livestock feed fortified with APWLM and HMM and to some extent HMM and CPM showed higher nutrient retention. Fortified feeds of CPM, and APWLM in their single forms equally showed high nutrient retention. These findings have positive impact for global food security and emphasize their importance in large scale trials to conquer the threat of pricy feed stuffs discouraging small scale famers while encouraging large scale farming in poultry birds. Large production technologies of these insects are required to encourage cultivation process and utilization. Bagging of these feeds and sensitization programmes of insect feed is equally required.

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