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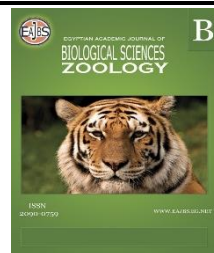


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Effects of Insect Formulated Feeds on Performance and Nutrient Retention Characteristics of Caged Cobb Broilers

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ABSTRACT

Objective: The objective was to evaluate the effects of varying grades of insect-formulated feeds (IFF) on finishing-phase performance and nutrient retention of caged Cobb broilers. **Materials and Methods:** Cobb broilers (n=1050) were randomly assigned 50 per treatment in triplicates to African palm weevil (APW), housefly maggot (HFL) and Cockroach (CKR) formulated meals for six weeks respectively. Meals were formulated with larval stages of APW, HFL and adult CKR in single and combined forms, and commercial hybrid feed served as control. Birds were raised in an experimental animal house dimensioned 21.34-meter length by 3.05-meter breadth and divided into seven squared compartments. These seven compartments were further partitioned into three compartments each using wood, ply boards and net gauze which served as the triplicates for the experiment. Meals and water were served *ad libitum* and feeding was done twice daily. Weekly readings of body length, weight, breast width, feed efficiency and nutrient retention analysis were done using fecal samples. **Results and Discussion:** Growth performance increased weekly and was highest in broilers fed African palm weevil meals ($p < 0.05$). Nutrient retention equally increased ($p < 0.05$). The retention of dry matter, crude protein and calcium, ether extract, crude ash and phosphorus increased in housefly and African palm weevil and commercial hybrid feed respectively. **Implications and Applications:** Using these insects can result in improved performance and greater nutrient retention; however, an increased number of weeks is required to assess more growth performance. A formulated feed meal of African palm weevils could be adopted as a viable alternative meals for commercial production of broiler meat.

INTRODUCTION

A substantial proportion of the world's population relies on protein for daily nutrient requirements which comes either in the form of plant or animal sources (FAO, 2015). Most indigenous people take advantage of the available insects in their locality, which they perceive are well-known nutritious substances containing diverse macro- and micronutrients (Kouřimsk and Adámková, 2016; Meyer-Rochow *et al.*, 2021). Tropical insects are highly abundant and distributed, and some studies have pointed to them as

prospecting ingredients for human diets and animal feed (Ijaiya and Eko, 2009). This is equally due to their economic and environmental values which outnumber other animal proteins (Huis, 2013). From the economic perspective, insect-formulated diets would potentially reduce the cost of purchasing commercial feed, the stress of overusing other protein sources, alleviate poverty, reduced infections to birds, and in turn increase growth performances, digestibility, and quantity of feed supply for domesticated animals (Hwangbo *et al.*, 2009; Chia *et al.*, 2019). From the environmental point of view, insects are already known as delicacies for their numerous nutritional qualities which by far exceed other protein sources, but their mass production guarantees faster reproduction rates in a short time, low emission of pollution to the environment, less required space for breeding and feed requirements as most can be reared on waste organic materials (Rumpold and Schluter 2013; Abro *et al.*, 2020). Insect protein (hereinafter IPs) range between 10 and 96%, carbohydrate content between 293 and 762 kcal per 100g of dry matter, fat and oil between 10 and 60%; higher and balanced in larvae compared to adults, fibre content between 2.7 and 137.2mg per kg for fresh and dry weight, iron content ranging from 31 to 77 mg per 100 g of dry matter, and invariable content of minerals (Xiaoming *et al.*, 2010; Atteh and Ologbenla, 2015).

Globally, the rise in the human population projected to reach 15 billion in the coming decades have mandated the search for innovative approaches to boost food production (FAO, 2015). Huis, (2013) supported the use of insects as inexpensive and proportionally nutrient-rich alternatives for partial or complete substitution of livestock feeds in order to significantly reduce the impacts on the environment. Before now, studies have highlighted the importance of insects, nutritional contents and rearing in facilities (Mustapha and Kolawole, 2019; Akande *et al.*, 2020; Boate and Suotonye, 2020; Ojianwuna *et al.*, 2021). They prospectively showed that their nutritional component varied between species, stage of the insect life cycle, size, sex, age and sometimes food source (Meyer-Rochow *et al.*, 2021). Addeo *et al.* (2022) reported that sex, age and size of black soldier fly did not significantly influence the choice of thermal requirements. Before the innovation of insects as feed resources was birthed, some edible species such as larvae of African palm weevil (hereinafter APW), and crickets (*Acheta domesticus*) amongst others were traditional edibles and eaten whole (Ebenebe and Okpoko, 2015). Though, with some sense of disgust in the westernized world (Shouteten *et al.*, 2016; Menozzi *et al.*, 2017). However, a few studies have shown the benefits and effects of incorporating fractions of IPs in complete substitution or enhancing the protein of commercial feeds. Agunbiade *et al.* (2007) administered 5% of maggot meal and observed no adverse effect in laying birds, but the complete substitution was deleterious to egg and shell production. Further to this, Awoniyi, (2007) set the optimal inclusion rate of maggot at 10%, since higher rates resulted in the darkening of bird feed thus making them less appealing and causing lower intake. Similarly, Ramos-Elorduy *et al.* (2002) observed that feed inclusion of dry mealworms up to 10% did not show negative effects on performance and feed efficiency. More so, higher inclusion rates of black soldier flies up to 25% were a suitable alternative (Schiafone *et al.*, 2018).

The African region has suffered notable setbacks in the area of developing industrially-made insect feed diets reported with huge successes. Some studies showed the potential of rearing insects on organic waste in mini-facilities (Fowles and Nansen, 2020). This ruling out the cost of procuring fish meal and soya beans for the production of commercial diet which is perceived as high in developing countries (Meyimdjui and Combes, 2021). Even with these potentials and innovations, many countries of Africa still rely on commercial diets for the production of animals, especially poultry birds. Continued reliance on commercial feed may mean deregulation of efforts in achieving the production

of alternative feeds from locally available and less expensive resources (Premalatha, 2011). AIFP (2004), reported that the complete substitution of animal feed with IPs in desired proportion would complement the stress in livestock production and output. Parallel to this, several successes have been reported with IPs in single and their combinations with other feed resources. For instance, in Nigeria, feed meal comprising of cassava peel and 29% maggot inclusion replaced 50% maize in meal formulations, with no resulting effects (Adesina *et al.*, 2011). The same trial involving the inclusion of 1.7% desert locust meal (*S. gregaria*) in a diet of 1-28 days old broilers resulted in high body weight gain, feed intake and feed conversion ratio while substituting 50% fishmeal protein (Adeyemo *et al.*, 2008). In China, grasshopper meal (*Acrida cinerea*) replaced 20- 40% fish meal in broiler diets with a similar growth rate and feed consumption (Liu and Lian, 2003). Some insects include grasshoppers (*Zenoceros variegatus*) (Hassan *et al.*, 2009), adult houseflies (*Musca domestica*) (Hwangbo *et al.*, 2009), mealworms (RamosElorduy *et al.*, 2002), black fly larvae (*Hermetia illucens*) (Schiavone *et al.*, 2018), mealworm (*Tenebrio molitor*) (Gasco *et al.*, 2014) have been explored as key species for animal feed inclusion in single forms. However, information on their effect in combined form is lacking as well as on nutrient retention. This study, therefore, tends to evaluate the effect of insect feed formulations in single and combinations on the growth performance in broilers and their digestibility. This study would close the existing gap in the discovery and the discrepancies with insect-formulated feeds, especially in a developing nation like Nigeria.

MATERIALS AND METHODS

Feed Preparation, Design, and Animals:

Insects for this experiment were locally sourced. Palm weevils were purchased from a trusted dealer in Mosogar, Delta State, Nigeria while cockroaches were collected in large numbers beside septic tanks in Delta State University, Abraka at night using the food bait method (Hu *et al.*, 2020). Housefly larvae (*Musca domestica*) were produced using a mixture of wheat bran, poultry droppings and pig faeces (Hussein *et al.*, 2017). The mixture was kept in an open space for oviposition of houseflies and then transferred to the Hatchery Unit of the Animal Husbandry Unit, Delta State University, Abraka. The hatchery unit was set at $30\pm 2^{\circ}\text{C}$ and relative humidity of $75\pm 5\%$. The fourth instar housefly larvae were harvested, killed by freezing at -10°C for 10 minutes and oven dried at 60°C for another 10 minutes. Mash diets were formulated using insect protein added in single and mixed forms in equal proportion (50:50). Insects were milled using an electrified blender. Ground insects were used to formulate feed in quantity stated in Tables 1 and 2 for single and mixed diets. All the insects were identified by an entomologist as African Palm weevil, *Rhynchophorus phoenicis* F. (Diptera: Curculionidae), Housefly, *Musca domestica* L. (Diptera: Muscidae) and Cockroach, *Periplaneta americana* L. (Blattodea: Blattidae).

Feeding experiments were conducted to evaluate the efficiency of using IPs as formulated feeds. To achieve this, the experimental animal house made up of concrete and wire gauze was first measured at 21.34-meter length by a 3.05-meter breadth and divided into seven squared compartments which gave rise to 3.05 by 3.05 meters. The seven divisions represent the six treatment groups and a control group; the commercial diet. The seven divisions were labelled APW for African palm weevil (*R. phoenicis*), CK for cockroach (*P. americana*) and HFL for housefly larvae (*M. domestica*) in single forms and in mixed forms were labelled APW+CK (African palm weevil + cockroach), APW+HFL (African palm weevil+ housefly larvae), and CK+HFL (cockroach + housefly larvae).

These seven divisions were further partitioned into three compartments each using wood, ply boards and net gauze which measured 1.02 by 1.22 meter in cages. These three compartments served as the triplicates for the experiment. The floor of compartments was equally made of concrete to enable easy assessment of birds for measurements as they grew bigger.

Table 1. Formulated diets of insect in single forms and their chemical composition

	Finisher diet	APW diet	CKR diet	HFL diet
<i>Ingredients</i>	<i>Analysis (g/kg)</i>	<i>Analysis (g/kg)</i>	<i>Analysis (g/kg)</i>	<i>Analysis (g/kg)</i>
Maize	590.0	590.0	590.0	590.0
Animal fat/oil	80.0	80.0	80.0	80.0
Wheat bran	82.0	82.0	82.0	82.0
Salt	3.0	3.0	3.0	3.0
Crude fibre	50.0	50.0	50.0	50.0
Insect proteins ^a	0.0	195.0	195.0	195.0
Soybeans meal	195.0	0	0	0
Total	1000.0	1000.0	1000.0	1000.0
<i>Chemical composition</i>	<i>(g/kg)^b</i>	<i>(g/kg)^c</i>	<i>(g/kg)^d</i>	<i>(g/kg)^e</i>
M. Energy (Kcal/kg)	2950	733.1	4180	2890
Crude proteins	22.0	31.2	8.7	47.1
Crude fat	4.5	45.2	17.6	25.3
Crude fibre	3.5	2.1	12.2*	7.5
Calcium	1.8	0.3*	0.2*	1.7*
Moisture	-	8.2	12.4	-
Lysine	1.33	4.2**	5.7**	6.1**
Available phosphorus	0.5	4.9*	0.5*	0.6*
Methionine	0.5	2.1**	2.4**	2.2**
Ash	-	4.7	4.9*	6.3

Note: CKR= cockroach, HFL= housefly, APW= African palm weevil. ^a Made up of cockroach, African palm weevil and housefly larvae and added per kg diet. **Sources:** ^b Premium Quality Ultima Poultry Feed, Olam Animal Feed Mill, Nigeria; ^c Ojianwuna *et al.*, 2021, ^{**}Elemo *et al.*, 2011, ^{*}Omotosho and Adedire, 2007, ^d ^{*}Boateng *et al.*, 2018; Ukoroije and Bawo, 2020, ^e Aniebo *et al.*, 2008, ^{**}Makkar *et al.*, 2014, ^{*}Hamani *et al.*, (2022), ^{**}Sule *et al.*, 2020.

Table 2. Formulated diets of insects in combined forms and their chemical composition

	APW + CKR diet	APW + HFL diet	HFL + CKR diet
<i>Ingredients</i>	<i>Analysis (g/kg)</i>	<i>Analysis (g/kg)</i>	<i>Analysis (g/kg)</i>
Maize	590.0	590.0	590.0
Animal fat/oil	80.0	80.0	80.0
Wheat bran	82.0	82.0	82.0
Salt	3.0	3.0	3.0
Crude fibre	50.0	50.0	50.0
Insect proteins ^a	195.0	195.0	195.0
Soybeans meal	0	0	0
Total	1000.0	1000.0	1000.0
<i>Chemical composition</i>	<i>(g/kg)</i>	<i>(g/kg)</i>	<i>(g/kg)</i>
M. Energy (Kcal/kg)	1700.3	2770.2	4164.4
Crude proteins	37.5	23.9	22.6
Calcium	0.51	0.47	0.49
Moisture	26.6	30.6	16.4
Lysine	6.16	6.29	5.93
Available phosphorus	2.40	2.56	2.21
Methionine	3.27	3.12	2.33
Ash	4.36	10.71	9.91

Note: CKR= cockroach, HFL= housefly, APW= African palm weevil. ^a Made up of cockroach, African palm weevil and housefly larvae and added per kg diet.

The broiler chicks used for this experiment were reared using day-old chicks that were fed a commercial starter diet (Premium quality Ultima Poultry Feed) in a temperature-regulated room ($33.5 \pm 1^\circ\text{C}$). The starter feed was made up of 72.0% 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 diseases until 28 days of age following management practices as described by Cobb International breed (Cobb, 2021). In a six-week feeding trial, a total of 1050 broiler chicks (Cobb, 4 weeks old, average $369.70 \pm 54.07\text{g}$ body weight) were randomly assigned (50 broiler chicks per replicated cages) to the commercial hybrid feed, APW, CK, HFL, APW+CK, APW+HFL, and CK+HFL cages. The Premium Quality Hybrid finisher diet, manufactured in Nigeria was used as a reference point for the formulation of diets. The ingredient of the hybrid feed includes maize, soya beans meal, animal protein sources, wheat bran, oil seed cake, vegetable oil, limestone, bone meal, salt, vitamin-mineral premix, amino acids, mycotoxin binder enzyme and additive. The nutritional composition of the hybrid feed was shown to contain 19.5% of crude protein, 6.5% of fat, 3.0% crude fibre, 1.2% calcium, 0.44% available phosphorus, 0.50% methionine, 1.2% lysine and 3100Kcal/kg of metabolizable energy. Broilers in the treatment groups were fed insect-formulated feed which completely replaced the crude protein of plant and animal sources (19.5%) in the hybrid feed. Furthermore, broilers in the control group were fed a diet containing soya beans meal and animal protein sources. For every 1kg of feed, insects in single form measured 195g while in the combined forms, insects were measured in equal proportion (50:50). The insect formulated feed contained 19.5% insect protein, 5% crude fiber, 59% maize, 8% fat and oil, 0.3% salt and 8.2% wheat bran as described in the company's composition (Hybrid Feeds) (Tables 1 and 2). The 4-week-old chicks were fed the respective insect-formulated feeds *ad libitum* and even water. Nutrient retention studies were conducted using broilers fed with insect-formulated and finisher diets containing 0.25% chromic oxide as an indigestible marker at ten-week of age as described by Chae *et al.* (2005) with modifications. On weekly basis from week 5 to 10, faecal samples were collected from each compartment to determine the nutrient retention of broilers. Faeces were air dried in an oven at 65°C for 3 days and stored.

Sample Analyses:

Growth parameters including body weight gain (BWG), body length gain (BLG), breast width gain (BWG) and feed efficiency (FE) were recorded weekly during the experiment. Broilers were first weighed before taking growth performance. The weight of broilers was measured using a weighing scale and length using measuring tape from week 5 to week 10. Feed efficiency was calculated as the inverse of feed conversion ratio (FCR). All analyses were done at the Department of Animal and Environmental Biology Laboratory, Delta State University, Abraka. Following the procedures described by AOAC (2002), the 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 in the oven and the proximate analysis was done according to colorimetric determination as described in AOAC (2002). The EDTA titration method and Bray number 1 method were used to determine calcium and phosphorus content respectively.

Statistical Analysis:

Data collected were subjected to statistical analysis using XL Stat Software (2020 Version) in a Microsoft Excel spreadsheet and, reported as mean \pm SD and percentages. Feed efficiency, feed conversion ratio, growth rates and nutrient retention were calculated using the following formulas:

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

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

$$\text{Growth rates} = \frac{\text{Log}_{10} \text{ final weight} - \text{Log}_{10} \text{ initial weight}}{\text{Time in days}} \times 100$$

$$\text{Nutrient retention} = \frac{\text{nutrient intake} - \text{nutrient in excreta}}{\text{Nutrient intake}} \times 100$$

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 a 5% probability level. Other body measurements described in the study of Amobi and Ebenebe (2018) were adopted.

RESULTS AND DISCUSSION

Effect on Growth Performance:

In this current study, the complete substitution of protein from animal sources and soya beans meal with insect proteins in the diet did not negatively affect growth performance, feed efficiency, or nutrient utilization of broilers in Southern Nigeria. Broilers fed various insect formulated feed showed an increasing mean body weight, body length and breast width as presented in Figures 1-3. The growth parameters (mean body weight, length and width) increased as the week progressed. Mean body weight, length, and breast width were between 0.56 and 3.93kg, 0.223 and 0.425 m, and 0.075 and 0.175 m respectively. At the end of the experiment, broilers administered formulated feed of APWs alone had the highest mean body weight (3.93kg), body length (0.425 m) and breast width (0.180 m). The lowest mean body weight, breast width and body length were recorded in broilers fed commercial hybrid feed respectively and cockroach formulated feed at week 5 (0.56kg, 0.075 m and 0.223 m respectively). The growth parameters were equally high in broilers fed formulated feeds of APW + CK, APW + HF and CK + HF. The difference was significant ($p < 0.05$). These results are in agreement with previous studies on the inclusion of IPs as ingredients in various animals. The inclusion of insects at various grades in poultry diets caused no differences in the growth parameters (Adesina *et al.*, 2011; Bovera *et al.*, 2015). Partial substitution of commercial hybrid feed with housefly maggot (*M. domestica*) meal (between 5 and 75% inclusion) did not result in negative effects on the growth of poultry birds (Awoniyi, 2007; Agunbiade *et al.*, 2007). The inclusion of insects above 10% was found to reduce the attractiveness of feed and, be deleterious to egg and shell production (Awoniyi, 2007, Agunbiade *et al.*, 2007). Across the weeks in this present study, observable performances were recorded with the various insect-formulated feeds in individual and mixed forms. The mean body length and body weight of broilers do not differ significantly ($p > 0.05$) (Figs. 1, 2 and 3).

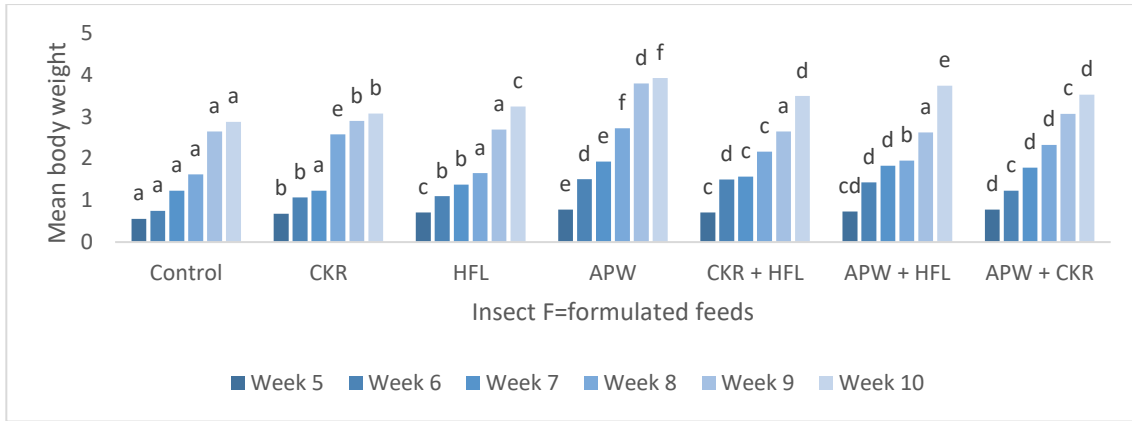


Fig. 1. Weekly variations of mean body weight in broilers fed insect formulated meals. **Note:** CKR= cockroach, HFL= housefly, APW= African palm weevil. Means of the same superscript letter do not differ significantly within weekly variations of treatments ($p < 0.05$) using Tukey’s test.

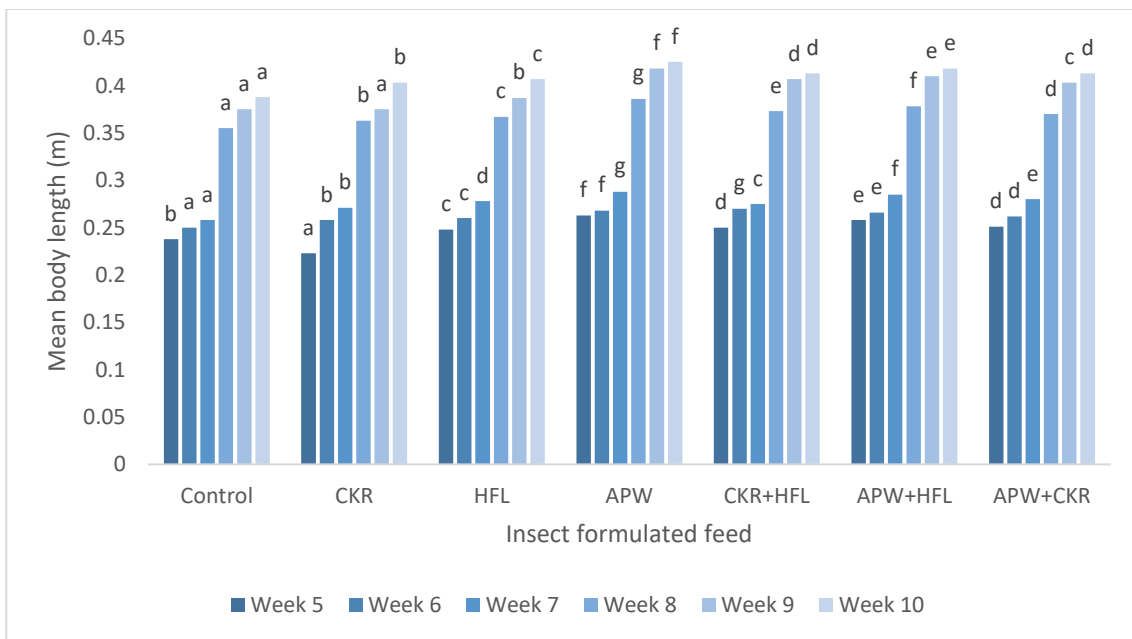


Fig. 2. Weekly variations of mean body length in broilers fed insect formulated meals. **Note:** CKR= cockroach, HFL= housefly, APW= African palm weevil. Means of the same superscript letter do not differ significantly within weekly variations of treatments ($p < 0.05$) using Tukey’s test.

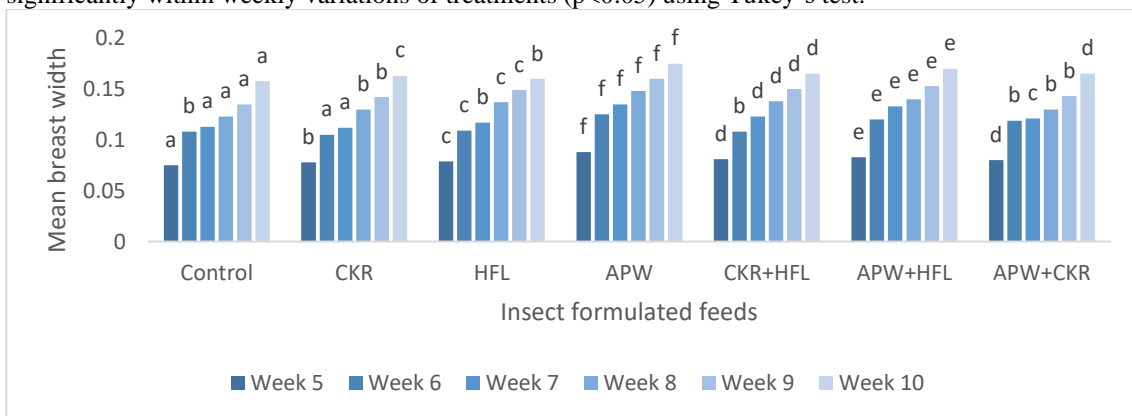


Fig. 3. Weekly variations of mean breast width in broilers fed insect formulated meals. **Note:** CKR= cockroach, HFL= housefly, APW= African palm weevil. Means of the same superscript letter do not differ significantly within weekly variations of treatments ($p < 0.05$) using Tukey’s test.

Partial or total substitution of some fish feed with housefly maggot meal did not lead to adverse effects (Lin and Mui, 2017). Interestingly, a total substitution of the commercial diet with the cricket, *Gryllus bimaculatus*, meal at an inclusion rate of 350g/kg caused an increase growth performance of the African catfish (Taufek *et al.*, 2016). However, a negative impact of insect-formulated feed has been reported in some juvenile fishes (Kroeckel *et al.*, 2012). This present study used insect-formulated diets made from APW purchased from the region, housefly larvae, and cockroaches. These insects are highly abundant in Southern Nigeria, probably due to the favourable environmental factors that supported their abundance and this informed their utilization in feed meals. APWs are locally consumed in the region while houseflies and cockroaches are abundant as nuisance pests (Ojianwuna, 2014; Ebenebe and Okpoko, 2015; Geden *et al.*, 2021). Overall, these varied results in growth performances and nutrient retention between different feed trials might be due to differences in the life stages of insect ingredients used. The studies of Xiaoming *et al.* (2010) and Atteh and Ologbenla, (2015) confirmed that larvae had higher nutritional content compared to other stages of insect development. This might have been the reason why growth performance was low in the cockroach because the adult stage was used. A previous study by Kroeckel *et al.* (2012) reported that the presence of chitin in insects can affect nutrient utilization, and palatability of feed and cause low feed intake. This may be the case for cockroach meals in this study as growth performance was lower compared to other insects incorporated into diets.

This study has shown that these insects used are good sources of protein for reared broilers following the rates of growth parameters reported in the insect-formulated meals. This predicts that formulated feeds in this study have great potential. APW meals in single and mixed were observed to have higher nutritional composition compared to other feeds. The study of Makkar *et al.* (2014) supported the nutritional components of this study that several insects are vital delicacies and have almost all the nutrients embedded in plant and other animal proteins. In this present study, cockroach + housefly incorporated meal had lower nutrient content. The differences observed in the nutritional composition of insects in this study can be linked to the different developmental stages, individual species, as well as the breeding process as reported by Adesina *et al.* (2011), and Jintataporn (2012). Adesina *et al.* (2011) found out that the chemical composition of housefly maggot feed had 50% crude protein, 6% crude fibre, 19% ether extract, 10% crude ash, and 23% gross energy. When compared to those recorded in this present study, slight variation was observed. Akande *et al.* (2020), Ojianwuna *et al.* (2021), Boate and Suotonye, (2020), and Mustapha and Kolawole, (2019) reported that the nutritional composition of these insects is higher when combined than in single forms. Comparing the nutrient retention to the chemical composition of the housefly maggot diet, a slight nutrient composition was observed. Similar deviations were observed with other insect feed in this study. All the feed showed a lowered crude protein in nutrient retention against the chemical composition except the APW. The dry matter of protein in broilers fed the insect-formulated feed corroborated the study of Veldkamp *et al.* (2012).

The Feed efficiency, feed conversion ratio and body weight over the length of bred broilers fed with the various insect-formulated feed increased as the week progressed as shown in Table 3. Feed efficiency ranged between 0.077 and 0.546, feed conversion ratio between 1.83 and 12.93, and body weight over length ranged between 0.023 and 0.092 kg/m. The highest feed efficiency and body weight over length was recorded in APW respectively. Across the weeks, various insect-formulated meals were efficient and did not differ significantly ($p < 0.05$) (Table 3). The growth performance of broilers fed insect-formulated feed in single and combined forms was higher compared to those fed with a conventional livestock diet. APW meal was significantly higher ($p < 0.05$) in body

weight, length, breast width, feed efficiency as well as body weight over the length. This suggests that formulating feed with insects especially that of APW is a better option for bird nutrition than commercially hybrid feeds. No negative effect on feed intake was observed in this study. A similar trend of increase in the body weight, length, breast width as well as other measurements was observed in the studies of Hassan (2009) and Chisowa *et al.* (2015), and this corresponds to this study. An increase in feed efficiency predicts that feed conversion to the flesh was efficient. Insect formulated feeds in this study were highly efficient and corresponded to the reports of Jumaa *et al.* (2014), and Okah and Onwujiariri (2012) and Dube and Tariro (2014). The insects in this study have the potential of being reared on cheap and available resources. Dipteran larvae including the housefly maggot and black soldier fly have been adopted in bio-waste recycling to reduce bio-accumulation of organic waste by half, reduction in the growth of bacteria in manure as well as conversion to utilizable proteins (Čičkova *et al.*, 2015, Diener *et al.*, 2011). Khusro *et al.* (2012) and Saxe *et al.* (2013) have reiterated the importance of insect inclusion as animal feed to reduce global issues of climate.

Table 3. Variations in feed efficiency and body weight over body length in broilers chicken fed insect formulated feeds.

Parameters	Treatment	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10
Feed Efficiency	Control	0.077±0.001 ^a	0.104±0.004 ^a	0.171±0.003 ^a	0.225±0.004 ^a	0.368±0.003 ^a	0.400±0.004 ^a
	CKR	0.095±0.001 ^b	0.149±0.004 ^b	0.171±0.003 ^a	0.358±0.004 ^e	0.403±0.003 ^b	0.428±0.004 ^b
	HFL	0.099±0.001 ^c	0.153±0.004 ^b	0.192±0.003 ^b	0.229±0.004 ^a	0.375±0.003 ^a	0.451±0.004 ^c
	APW	0.109±0.001 ^e	0.209±0.004 ^d	0.268±0.003 ^e	0.379±0.004 ^f	0.528±0.003 ^d	0.546±0.004 ^f
	CKR + HFL	0.099±0.001 ^c	0.208±0.004 ^d	0.218±0.003 ^c	0.301±0.004 ^c	0.368±0.003 ^a	0.486±0.004 ^d
	APW + HFL	0.102±0.001 ^{cd}	0.199±0.004 ^d	0.254±0.003 ^d	0.271±0.004 ^b	0.365±0.003 ^a	0.521±0.004 ^e
	APW + CKR	0.103±0.001 ^d	0.171±0.004 ^c	0.247±0.003 ^d	0.324±0.004 ^d	0.426±0.003 ^d	0.490±0.004 ^d
BW/BL	Control	0.023±0.00 ^a	0.030±0.001 ^a	0.048±0.001 ^{ab}	0.046±0.001 ^a	0.071±0.001 ^b	0.074±0.001 ^a
	CKR	0.031±0.00 ^d	0.042±0.001 ^b	0.045±0.001 ^a	0.071±0.001 ^e	0.077±0.001 ^c	0.077±0.001 ^a
	HFL	0.029±0.00 ^b	0.042±0.001 ^b	0.050±0.001 ^b	0.045±0.001 ^b	0.070±0.001 ^b	0.080±0.001 ^b
	APW	0.030±0.00 ^c	0.056±0.001 ^d	0.067±0.001 ^e	0.071±0.001 ^e	0.091±0.001 ^d	0.092±0.001 ^b
	CKR + HFL	0.029±0.00 ^b	0.056±0.001 ^d	0.057±0.001 ^c	0.058±0.001 ^c	0.065±0.001 ^a	0.085±0.001 ^c
	APW + HFL	0.028±0.00 ^b	0.054±0.001 ^d	0.064±0.001 ^d	0.052±0.001 ^b	0.064±0.001 ^a	0.090±0.001 ^d
	APW + CKR	0.030±0.00 ^c	0.047±0.001 ^c	0.064±0.001 ^d	0.063±0.001 ^d	0.076±0.001 ^c	0.086±0.001 ^c
Feed Conversion Ratio	Control	12.93±0.01 ^d	9.60±0.04 ^d	5.85±0.03 ^e	4.45±0.04 ^e	2.72±0.03 ^d	2.50±0.04 ^f
	CKR	10.55±0.01 ^c	6.76±0.04 ^c	5.87±0.03 ^e	2.79±0.04 ^a	2.48±0.03 ^c	2.34±0.04 ^e
	HFL	10.11±0.01 ^b	6.57±0.04 ^b	5.23±0.03 ^d	4.37±0.04 ^e	2.67±0.03 ^d	2.22±0.04 ^d
	APW	9.20±0.01 ^a	4.78±0.04 ^a	3.74±0.03 ^a	2.64±0.04 ^a	1.90±0.03 ^a	1.83±0.04 ^a
	CKR + HFL	10.12±0.01 ^b	4.85±0.04 ^a	4.59±0.03 ^c	3.33±0.04 ^c	2.72±0.03 ^d	2.06±0.04 ^c
	APW + HFL	9.83±0.01 ^b	5.05±0.04 ^a	3.94±0.03 ^{ab}	3.70±0.04 ^d	2.74±0.03 ^d	1.92±0.04 ^b
	APW + CKR	9.73±0.01 ^b	5.85±0.04 ^b	4.05±0.03 ^b	3.09±0.04 ^b	2.35±0.03 ^d	2.04±0.04 ^c

Note: CKR= cockroach, HFL= housefly, APW= African palm weevil. BW/BL= body weight/body length (kg/m). Means of the same superscript letter do not differ significantly within weekly variations of treatments (p<0.05) using Tukey’s test.

Effect on Nutrient Retention:

In this present study, except for dry matter, the retention of all the nutrients was significantly different in the insect-formulated feed (Table 4). The retention of dry matter was higher in housefly maggot meals (83%) than in other insect-formulated and conventional diets (64%). More so, the nutrient retention of crude protein (64.3%), and calcium (19.2%) were higher in APW. Ether extract (65.0%), crude ash (18.1%), and phosphorus (19.4%) were equally higher in commercial hybrid diets compared to the insect feed formulations. The mass production of insects which remains the major challenge affecting insect adoption on a large scale and integration into commercial feeds would help avert the high cost of acquiring poultry feed (Kouřimská and Adámková, 2016). It could equally help to meet the increasing demand for meat for an increasing population which has been suggested to exceed 15 billion in coming decades (Thornton, 2010; Kim *et al.*, 2019). An insect-formulated feed could argument poultry production and

in turn complement the overall food production required to increase by 70% (Lensvelt and Steenbeekers, 2014). Various degrees of nutrient retention were observed in this study. Ether extracts, crude ash and phosphorus recorded in the insect-formulated feed were lower than the conventional diet. Dry matter was higher than the conventional feed group except for the African palm weevil. Calcium and crude protein were higher in the palm weevil group compared to broilers fed other feed formulations.

Table 4. The effect of insect formulated feed on nutrient retention (%) in broilers at 10 weeks.

Treatments	CTRL	HFL + CKR	CKR	APW + HFL	APW + CKR	HFL	APW
Dry matter	63.96 ^b	83.21 ^d	82.98 ^d	71.22 ^c	70.99 ^c	83.44 ^d	59.01 ^a
Crude protein	62.54 ^f	45.13 ^b	35.50 ^a	59.54 ^e	49.91 ^c	54.77 ^d	64.32 ^g
Ether extract	65.04 ^g	53.08 ^b	51.18 ^a	58.80 ^e	56.90 ^d	54.98 ^c	62.61 ^f
Crude ash	18.12 ^g	16.32 ^c	15.62 ^a	16.84 ^e	16.14 ^b	17.02 ^f	16.66 ^d
Calcium	17.80 ^f	14.84 ^b	16.09 ^c	16.37 ^d	17.62 ^e	13.58 ^a	19.15 ^g
Phosphorus	19.38 ^g	10.56 ^b	11.76 ^c	13.86 ^d	15.06 ^e	9.36 ^a	18.35 ^f

Note: CKR= cockroach, HFL= housefly, APW= African palm weevil. Means of the same superscript letter do not differ significantly within treatments ($p < 0.05$) using Tukey's test.

Applications: From the results obtained in this work, it can be concluded that African palm weevils in single and to a lesser extent other edible insects in single and combined forms improved growth performance. Nutrient retention and feed efficiency ratios were equally high in the insect-formulated feeds. There is a need to mass produce these insects and incorporate them into large-scale production, especially in palm weevil formulated diet. Using these insects can result in improved performance and greater nutrient retention; however, an increased number of weeks is required. A formulated feed meal of African palm weevils could be adopted as a viable alternative meal for commercial production of broiler meat.

Abbreviations: CK: cockroach, HFL: housefly, APW: African palm weevil.

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REFERENCES

- Abro, Z.; Kassie, M.; Tanga, C.; Beesigamukama, D. and Diiro G. (2020). Socio-economic and environmental implications of replacing conventional poultry feed with insect-based feed in Kenya. *Journal of Cleaner Production*, 265: 121871.
- Addeo, N.F.; Li, C.; Rusch, T.W.; Dickerson, A.J.; Tarone, A.M.; Bovera, F.; and Tomberlin, J.K. (2022). Impact of age, size, and sex on adult black soldier fly [*Hermetia illucens* L. (Diptera: Stratiomyidae)] thermal preference. *Journal of Insects as Food and Feed*, 8: 2. <https://doi.org/10.3920/JIFF2021.0076>
- Adesina, M.A.; Adejinmi, O.O., Omole, A.J., Fayenuwo, J.A., and Osunkeye, O. (2011).

- Performance of broilers' finishers fed graded levels of cassava peel-maggot meal-based diet mixtures. *Journal of Agriculture, Forestry and the Social Sciences*, 9: 226–231.
- Adeyemo, G.O.; Longe, O.G. and Lawal, H.A., (2008). Effects of feeding desert locust meal (*Schistocerca gregaria*) on performance and haematology of broilers. Tropentag; October 7-9; Hohenheim, Germany.
- Agunbiade, J.A.; Adeyemi, O.A., Ashiru, O.M., Awojobi, H.A., Taiwo, A.A., Oke, D.B., Adekunmis, A.A., (2007). Replacement of fish meal with maggot meal in cassava-based layers' diet. *Journal of Poultry Science*, 44: 278-282. <http://doi.org/10.2141/jpsa.44.278>.
- AIFP. (2004). Inventory of feed producers in Nigeria. Aquaculture and Inland Fisheries Project. 37p.
- Akande, OA., Falade, OO., Badejo, AA., and Adekoya, I. (2020). Assessment of Mulberry silkworm pupae and African palm weevil larvae as alternative protein sources in snack fillings. *Heliyon*, 6: e03754
- Amobi, M.I. and Ebenebe, C.I., (2018). Performance of broiler chicks fed on two insect based-diets in South East Nigeria. *Journal of Insects as Food and Feed*, 4(4): 263-268. <https://doi.org/10.3920/JIFF2017.0078>
- Aniebo, A.O., Erundu, E.S. and Owen, O.J. (2008). Proximate composition of housefly larvae (*Musca domestica*) meal generated from the mixture of cattle blood and wheat bran. *Livestock Research for Rural Development*, 20(12): 2008
- AOAC., (2002) Official Method of Analysis. 16th Edition, Association of Official Analytical, Washington DC.
- Atteh, J. and Ologbenla, F., (2015). Replacement of fish meal with maggots in broiler diets: effects on performance and nutrient retention. *Nigerian Journal of Animal Production*, 20: 44-49.
- Awoniyi, T. A. M., (2007). Health, nutritional and consumers' acceptability assurance of maggot meal inclusion in livestock diet: a review. *International Journal of Tropical Medicine*, 2 (2): 52-56
- Boate UR and Suotonye BD. (2020). Cockroach (*Periplaneta americana*): Nutritional value as food and feed for man and livestock. *Asian Food Science Journal*, 15(2): 37-46.
- Boateng, M., Okai, D.B., Frimpong, Y.O., Ntim, A. and Acheampong, Y.S. (2018). Entomophagous response of albino rats to cockroach (*Periplaneta Americana*) meal. *Open Agriculture*, 3: 220-225.
- Bovera F, Loponte R, Marono S, Piccolo G, Parisi G, Iaconisi V, Gasco L, Nizza A. (2015). Use of *Tenebrio molitor* larvae meal as protein source in broiler diet: effect on growth performance, nutrient digestibility, and carcass and meat traits. *Journal of Animal Science*, 94:639–647. doi: 10.2527/jas.2015-9201
- Chia, S.Y., Tanga, C.M., Loon, J.J., and Dicke, M. (2019). Insects for sustainable animal feed: inclusive business models involving smallholder farmers. *Current Opinion in Environmental Sustainability*, 41:23-30.
- Chisowa, D.M., Mupeyo, B. and Kasamba, R.T., (2015). Evaluation of winged termites on sole sources of protein in growing Japanese quails. *European Academic Research*, 2: 15214-15227.
- Čičkova H., Newton G.L., Lacy R.C. and Kozanek M., (2015). The use of fly larvae for organic waste treatment. *Waste Management*, 35: 68–80. <http://doi.org/10.1016/j.wasman.2014.09.026>
- Cobb, S.F. (2021). Parent rearing management record (Cited 2021 January 12). Available

- from: [http://www.cobb-vantress.com/docs/default-source/cobb-500-guides/cobb-500sf-parent-rearing-laying-record---english-\(grams\)25BF39AB3EABF46297DB2B50.pdf](http://www.cobb-vantress.com/docs/default-source/cobb-500-guides/cobb-500sf-parent-rearing-laying-record---english-(grams)25BF39AB3EABF46297DB2B50.pdf).
- Diener S., Zurbrügg C., Gutiérrez F.R., Nguyen D.H., Morel A., Koottatep T. and Tockner K., (2011). Black soldier fly larvae for organic waste treatment –prospects and constraints. Proc. Waste Safe – 2nd International Conference on Solid Waste Management in the Developing Countries, Khulna, Bangladesh.
- Dube, S. and Tariro, M., (2014). Effect of including some insects as feed supplementation broilers reared in Zimbabwe. *International Journal of Poultry Science*, 13: 42-46. <http://doi.org/10.3923/ijps.2014.42.46>
- Ebenebe, I. and Okpoko, C., (2015). Microbiological quality of raw and roasted African palm Weevil (*Rhynchophorus phoenicis*) consumed in the South Eastern Nigeria. *Animal Research International*, 12 (2): 2159 – 2165.
- Elemo, B.O., Elemo, G.N., Makinde, M.A., and Erukainure, O.L. 2011. Chemical evaluation of African palm weevil, *Rhynchophorus phoenicis*, larvae as a food source. *Journal of Insect Science*, 11: 146
- FAO, (2015). The State of Food and Agriculture 2015 - Social protection and agriculture: breaking the cycle of rural poverty. Reduce Rural Poverty Paper; FAO: Rome. <http://www.fao.org/3/a-i4910e.pdf>
- Finke, M.D., (2007). Estimate of chitin in raw whole insects. *Zoo Biology*, 26: 105-115. <https://doi.org/10.1002/zoo.20123>
- Fowles, T.M. and Nansen, C. (2020). Insect-based bioconversion: value from food waste. In: Narvanen, E., Mesiranta, N., Mattila, M, and Heikkinen, A. (Eds) Food waste management. Palgrave Macmillan, Cham. http://doi.org/10.1007/978-3-030-20561-4_12.
- Gasco, L., Gai, F., Piccolo, G., Rotolo, L., Lussiana, C., Molla, P. and Chatzifotis, S., (2014). Substitution of fish meal by Tenebriomolitor meal in the diet of *Dicentrarchus labrax* juveniles Abstract book Conference “Insects to Feed The World”, The Netherlands 14-17 May 2014, 80 pp.
- Geden, C.J., Nayduch, D., Scott, J.G., Burgess, E.R., Gerry, A.C., Kaufman, P.E., Thomson, J., Pickens, V., and Mächtinger, E.T. (2021). Housefly (Diptera: Muscidae): Biology, Pest Status, Current Management Prospects, and Research Needs. *Journal of Integrated Pest Management*, 12(1): 39.
- Hamani, B., Moula, N., Taffa, A.G., Leyo, I.H., Mahamadou, C., Dettileux, J. and Van, Q.C.D. 2022. Effect of housefly (*Musca domestica*) larvae on the growth performance and carcass characteristics of local chicken in Niger. *Veterinary World*, 15(7): 1738-1748.
- Hassan, A.A., (2009). The effect of replacing graded levels of fish meal with grasshopper meal in broiler starter diet. Publication of Faculty of Agriculture, Nasarawa State University, Keffi, Pat 5: 30-38.
- Hu, I.H., Chen, S.M., Lee, C.Y., Neoh, K.B. (2020). Insecticide Resistance, and Its Effects on Bait Performance in Field-Collected German Cockroaches (Blattodea: Ectobiidae) From Taiwan. *Journal of Economic Entomology*, 2020:1-10. DOI: 10.1093/jee/toaa053
- Huis, A. V., Itterbeeck, J. V., Klunder, H., Mertens, E., Halloran, A., Muir, G. and Vantomme, P. (2013). *Edible Insects: Future Prospects for Food and Feed Security*. FAO Forestry Paper 171, Food and Agriculture Organization of the United Nations, Rome, Italy. <https://www.fao.org/3/i3253e/i3253e.pdf>
- Hussein M, Pillai VV, Goddard JM, Park HG, Kothapalli KS, Ross DA, Ketterings, Q.M.,

- Brenna, J.T., Milstein, M.B., Marquis, H., Johnson, P.A., Nyrop, J.P., Selvaraj, V. (2017). Sustainable production of housefly (*Musca domestica*) larvae as a protein-rich feed ingredient by utilizing cattle manure. *PLoS ONE*, 12(2): e0171708. <https://doi.org/10.1371/journal.pone.0171708>
- Hwangbo, J., Hong, E.C., Jang, A., Kang, H.K., Oh, J.S., Kim, B.W. and Park, B.S., (2009). Utilization of housefly maggot, a feed supplement in the production of broiler chicken. *Journal of Environmental Biology*, 30: 609-614.
- Ijaiya, A.T and Eko, E.O., (2009). Effect of replacing dietary fish meal with silkworm (*Anaphe infracta*) caterpillar meal on growth, digestibility and economics of production of starter broiler chicks. *Pakistan Journal of Nutrition*, 8(6): 845-849. <https://doi.org/10.3923/pjn.2009.845.849>
- Jintasataporn, O., (2012). Production performance of broiler chickens fed with silkworm pupa (*Bombyx mori*). *Journal of Agricultural Science and Technology*, 2 (4): 505-510.
- Jumaa, B.J., Dafalla, M.M., Bushara, I. and Amin, M.H.H., (2014). Effects of inclusion of different levels of watermelon bug meal in broiler diets on feed intake, body weight changes and feed conversion ratio. *Global Journal of Animal Scientific Research*, 2: 76-85.
- Khusro, M., Andrew, N. R. and Nicholas, A., (2012). Insects as poultry feed: a scoping study for poultry production systems in Australia. *World Poultry Science Journal*, 68: 435-446. <https://doi.org/10.1017/S0043933912000554>
- Kim, T.K., Yong, H.I., Kim, Y.B., Kim, H.W. and Choi, Y.S., (2019). Edible Insects as a Protein Source: A Review of Public Perception, Processing Technology, and Research Trends. *Food Science of Animal Resources*, 39(4):521-540. <https://doi.org/10.5851/kosfa.2019.e53>
- Kouřimská, L. and Adámková, A., (2016). Nutritional and sensory quality of edible insects. *NFS Journal*, 4: 22-26. <https://doi.org/10.1016/j.nfs.2016.07.001>
- Kroeckel, S., Harjes, A.G.E., Roth, I., Katz, H., Wuertz, S., Susenbetg, A., Schutz, C. 2012. When a Turbot catches a fly: Evaluation of a pre-pupae meal of the Black soldier fly (*Hermetia illucens*) as fish meal-substitute-Growth performance and chitin degradation in juvenile Turbot (*Psetta maxima*). *Aquaculture*, 364-365: 345-352.
- Lensvelt, E. and SteenBekkers, L., 2014. Exploring Consumer Acceptance of Entomophagy: A Survey and Experiment in Australia and the Netherlands. *Ecology of Food and Nutrition*, 53: 543-561. <https://doi.org/10.1080/03670244.2013.879865>
- Lin, Y.H. and Miu, J.J. 2017. Evaluation of dietary inclusion of housefly maggot (*Musca domestica*) meal on growth, fillet composition and physiological responses for barramundi Lates calcarifer. *Aquaculture Research*, 48: 2478-2485.
- Liu, C.M. and Lian, Z.M., 2003. Influence of *Acridia cinerea* replacing Peru fish meal on growth performance of broiler chickens. *Journal of Economic Animals*. 7: 48-51.
- Makkar, H.P.S., Tran, G., Heuzé, V., Ankers, P., 2014. State-of-the-art on use of insects as animal feed, *Animal Feed Science and Technology*, 197: 1-33. <https://doi.org/10.1016/j.anifeedsci.2014.07.008>
- Menozi, D., Sogari, G., Veneziani, M., Simoni, E., Mora, C. 2017. Eating novel foods: An application of the theory of planned behaviour to predict the consumption of an insect-based product. *Food Quality and Preference*, 59: 27-34
- Meyer-Rochow, V.B., Gahukar, R.T., Ghosh, S. and Jung, C. 2021. Chemical Composition, Nutrient Quality and Acceptability of Edible Insects Are Affected by Species, Developmental Stage, Gender, Diet, and Processing Method. *Foods*,

- 10: 1036.
- Meyimdjuji, C., and Combes, J. (2021). Food price shocks and household consumption in developing countries: the role of fiscal policy. *IMF Working Paper*, 2021(12): 25. <http://doi.org/10.5089/9781513566887.001>
- Mustapha AK and Kolawole, AA 2019. Potentials of fresh housefly maggot in the diet of *Oreochromis niloticus* fingerlings. *Journal of Applied Science, Environment and Management*, 23(4): 681-687.
- Ojianwuna, C.C. 2014. Potentials of cockroach vectors in transmitting parasites of medical importance in Abraka, Delta State, Nigeria. *International Journal of Applied Biological Research*, 6(2): 9-20.
- Ojianwuna, C.C., Enwemiwe, V.N., and Odibo, E.O. 2021. Nutritional composition of some insects consumed in Delta State, Nigeria. *FUW Trends in Science & Technology Journal*, 6(1): 141-145.
- Okah, U. and Onwujiariri, E.B., 2012. Performance of finisher broiler chickens fed maggot meal as a replacement for fish meal. *Journal of Agricultural Technology*, 8: 471-477.
- Omotosho, O.T. and Adedire, C.O. 2007. Nutrient composition, mineral content and the solubility of the proteins of palm weevil, *Rhynchophorus phoenicis* f. (Coleoptera: Curculionidae). *Journal of Zhejiang University Science B*, 8(5): 318-322.
- Premalatha, M., Abbasi, T., and Abbasi, S.A., 2011. Energy-efficient food production to reduce global warming and eco degradation: the use of edible insects. *Renewable Sustainable Energy Reviews*, 15: 4357-4360. <https://doi.org/10.1016/j.rser.2011.07.115>
- Ramos-Elorduy, J., Avila Gonzalez, E., Rocha Hernandez, A. and Pino, J.M., 2002. Use of *Tenebrio molitor* (Coleoptera: Tenebrionidae) to recycle organic wastes and as feed for broiler chickens. *Journal of Economic Entomology*, 95(1): 214-220. <https://doi.org/10.1603/0022-0493-95.1.214>
- Ramos-Elorduy, J., Pino, M.J.M., Prado, E.E., Perez, M.A., Otero, J.L., De Guevara, O.L., 1997. Nutritional value of edible insects from the State of Oaxaca, Mexico. *Journal of Food Composition and Analysis*, 10: 142-157. <https://doi.org/10.1006/jfca.1997.0530>
- Rumpold, B.A. and Schlüter, O.K., 2013. Potential and challenges of insects as an innovative source for food and feed. *Innovative Food Science and Emerging Technologies*, 17: 1-11. <https://doi.org/10.1016/j.ifset.2012.11.005>
- Saima, M.A., Khan, M.Z.U., Anjum, M.I., Ahmed, S., Rizwan, M. and Ijaz, M., 2008. Investigation on the availability of amino acids from different animal protein sources in golden cockerels. *Journal of Animal and Plant Science*, 18(2-3): 53-56.
- Saxe, H., Larsen, T.M. and Mogensen, L., 2013. The global warming potential of two healthy Nordic diets compared with the average Danish diet. *Climatic Change*, 116: 249-262. <https://doi.org/10.1007/s10584-012-0495-4>
- Schiavone, A., Dabbou, S., DeMarco, M., Cullere, M., Biasato, I., Biasibetti, E., Capuccchio, MT., Bergagna, S., Dezzutto, D., Meneguz, M., Gai, F., Dalle Z. A. and Gasco, L., 2018. Black soldier fly (*Hermetia illucens* L.) larva fat inclusion in finisher broiler chicken diet as an alternative fat source. *Animal: An International Journal of Animal Bioscience*, 12, 2032-2039. <https://doi.org/10.1017/S1751731117003743>
- Shouteten, J.J., De Steur, H., De Pelsmaeker, S., Lagast, S., Juvinal, J.G., De Bourdeaudhuij, L., Verbeke, W., Gellynck, X. 2016. Functional and sensory

- profiling of insect-, plant- and meat-based burgers under blind, expected and informed conditions. *Food Quality and Preference* 52: 27–31
- Sogbesan, A. and Ugwumba, A., 2008. Nutritional evaluation of termite (*Macrotermes subhyalinus*) meal as animal protein supplements in the diets of *Heterobranchus longifilis*, *Turkish Journal of Fisheries and Aquaculture Science*, 8: 149–157.
- Sule, S.O., Ojetayo, T.A. and Sotolu, A.O. (2020). Cockroach (*Periplaneta Americana*) meal nutritive composition. *FUW Trends in Science and Technology Journal*. 5(1): 238-240.
- Taufek, N.M., Aspani, F., Muin, H., Raji, A.A., Razak, S.A., Alias, Z. 2016. The effect of dietary cricket meal (*Gryllus bimaculatus*) on growth performance, antioxidant enzyme activities and haematological responses of African Catfish (*Clarias gariepinus*). *Fish Physiology and Biochemistry*, 42: 1143-1155.
- Thornton, P.K., 2010. Livestock production: recent trends, future prospects. *Philosophical Transactions of the Royal Society B-Biological Sciences*, 365(1554): 2853-2867. <https://doi.org/10.1098/rstb.2010.0134>
- Ukoroiye, R.B. and Bawo, D.S. (2020). Cockroach (*Periplaneta americana*): Nutritional value as food and feed for man and livestock. *Asian Food Science Journal* 15(2): 37-46.
- Veldkamp, T. G., van Duinkerken, A., van Huis, C.M.M., Lakemond, E., Ottevanger, E. and van Boekel, M.A.J.S., 2012. Insects as a sustainable feed ingredient in pig and poultry diets. A feasibility study. *Wageningen UR Livestock Research, Report*, 638.
- Xiaoming, C., Ying, F. and Hong, Z., 2010. Review of the nutritive value of edible insects. Edible insects and other invertebrates in Australia: future prospects, Proceedings of a Workshop on Asia-Pacific Resources and their Potential for Development, 19–21 February, Bangkok, 85–92 pp.