CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

The widening gap between animal protein supply and increasing human population in developing countries is of global concern. FAO (1995) recommended 34g of animal protein consumption per person per day for normal growth and development but in Nigeria, animal protein consumption level is 7 – 10g per person per day (Ebenebe, 2005) corroborating the claims of Mmadubuike (2000) about failure of conventional meat protein to meet the animal protein needs of the teeming population. In Nigeria, animal production is faced with numerous challenges; though there is large population of all livestock species, the meat supply is still generally low (Bamaiyi, 2012). Apparently, efforts to increase animal protein supply through various meat proteins have failed to meet the animal protein requirement of the populace (Ebenebe, 2005). Therefore, a search for cheaper, environmentally friendly animal protein is essential; insect based protein could be of great interest as a possible solution to animal protein deficiency in the country, due to their capability to provide cheap protein of high amino acid profile with little or no harm to the environment.

1.2 Animal Protein Situation in Nigeria

The shortage of animal protein in the diet of many Nigerians has long been recognized. The demand for protein of animal origin in Nigeria is greater than its supply (Akinmutimi and Onukwe, 2002). The supply of animal products has been declining over the past two decades, while demand has been increasing, as a result of population growth and urbanization. A review of the data of food supplies according to Food and Agricultural Organization available for consumption in different countries, shows that the per caput protein intake in developing countries, Nigeria inclusive is comparatively low. Not only is the

total protein supply deficient, but the quality of dietary protein available is inferior to that consumed in developed countries (FAO, 1995). Most of the foods consumed in Nigeria are carbohydrates mainly in the form of starch. A major possible reason for this is that the distribution of energy and protein to individuals within a population differs substantially with protein, especially animal protein much more unequally distributed than energy (Jamison *et al.*, 2003).

The consequence of this poor nutritional status is sub-clinical diseases which will eventually result in weakness, lethargy, poor productivity and stress. Observed consumption patterns show that most citizens consume more of beef, followed by fish and then egg, while other animal protein sources followed in smaller quantities (Muhammed and Balogun, 2007). The food and Agricultural Organization of the United Nations stated that Nigeria is a protein deficient country (FAO, 2011). The protein deficiency in the diets can be primarily remedied through the consumption of protein- rich plants, animal foodstuff or insects.

1.2.1 Problems of inadequate supply of conventional animal protein

The poor performance of the Nigerian Livestock industry in terms of meat and milk production has been documented by many authors (Niang and Jubrin, 2001; Taiwo *et al.*, 2012), inspite of an estimated livestock population of about 600million. With reference to the 34g of animal protein per person per day recommended by FAO, the shortfall in minimum protein requirement is about 89% (Mafimisebi *et al.*, 2008). In fact, by the year 2020 when the Nigerian population is expected to be about 230million, a quantum leap in livestock production is required if the seemingly formidable problem of protein malnutrition is to be surmounted (Taiwo *et al.*, 2012). The possibility of such a quantum leap remains unforeseeable as the livestock industry is still facing a number of problems outlined as follows:

i. Decline in Pastureland

Human population in Nigeria is still growing at 1.2 percent per year (FAO, 2010). The rapid population growth has relatively resulted in rapid rate of urbanization, as people will be clearing the forests and converting pasture lands for residential purposes to meet the need of accommodation (Abdullah *et al.*, 2011; Steinfeld *et al.*, 2006; Kearney, 2010; FAO, 2011).

For ruminant animals, inadequate nutrition due to degraded pasture lands, shortage of feed and all year round quality forage is the major constraint (Areegbe *et al.*, 2012). According to the authors, forage shortage is more severe in the dry season when ruminants subsist on very poor quality crop residues and which results in corresponding low level production performance of livestock. This has also led to Southward movement of herders which have resulted to the increasing recurrent farmers – herder's conflict. Besides, pasture land has been on the decline as a result of the need to provide adequate food for the burgeoning human population and also urbanization needs for infrastructural development (Abdullah *et al.*, 2011).

ii. High cost of feed ingredients

Feed is the most important input for livestock production and the availability of low – priced, high quality feeds is critical for the expansion of poultry industry (FAO, 2011, 2003; Ismoyowatiand Sumarmono, 2011;Ayele and Rich, 2010; Thornton, 2010; Adebayo and Adeola, 2005). Massive production of livestock has also been limited by problems associated with high cost of feed ingredients. This stems from direct competition between man and livestock animals for available feed ingredients (Bamgbose, 1999). Recently, the performance of the livestock industry in Nigeria has fallen below expectation due to high feed cost arising from: fluctuations in feed supplies, rising prices of ingredients, poor feed quality (adulterated feed) and inefficiency in production (Olatunji and Ifeanyi –Obi, 2011). According to Obasi (2007), these farmers experience high risk and uncertainty during periods of inflation due to price variability. Nweze

et al. (2011) and Ravindra and Blair (1992) stated that the survival of the livestock industry in most developing countries in future will undoubtedly depend on the ability of livestock industry to compete with humans for the available food supply. John and Njenga (1992) also reported that alternative feed resources must be initiated to encourage production of livestock feed ingredients.

iii. Diseases

Livestock diseases remain a veritable threat to the animal production industry. Animal products are constantly under threat by diseases that affect livestock and hence reduce productivity (MacRae *et al.*, 2005). Endemic animal diseases such as Helminthosis, Contagious Bovine Pleuropneumonia (CBPP), Brucellosis, Mastitis, Peste des Petits Ruminants (PPR) and many others have devastating impacts upon the animal industry leading to losses in hundreds of millions of dollars every year in developing economies like Nigeria (Bamaiyi, 2012). Brucellosis alone in sheep and goats of Borno and Yobe states of Nigeria is estimated to cost the economy USD 3.2 million annually (Brisibe *et al.*, 1996). The poultry industry is even more devastated by viral infections such as Newcastle disease and Infectious bursal disease (Gumboru) in spite of several attempts at vaccinations. Some of the reasons for these may be vaccine failure and the involvement of quacks in fighting these endemic animal diseases in the country (Babalobi, 2005; Olugasa *et al.*, 2013).

1.3 Alternative Feed Ingredients and Reduction in Cost of Feed Production

Feed is the single most expensive factor in animal production, and the protein component constitutes the highest cost (Alphonsus *et al.*, 2009). It is imperative that livestock farmers and feed manufacturers be conversant with the techniques of ensuring adequate levels of proteins in formula feeds (Alphonsus *et al.*, 2009). Global consumption of poultry products, especially poultry meat as consistently increased over the years and this trend is expected to continue. It is also becoming clear that the requirements for the

four traditional feed ingredients- maize, soybean meal, fish meal and meat meal cannot be met, even according to optimistic forecasts. The gap between local supply and demand for these traditional ingredients is expected to widen over the coming decades, providing a compelling reason for exploring the usefulness of locally available, alternative feed stuff in feed formulations (Ravindran, 1992). He also stated that it has been proven that feed constitutes the most expensive component of the industry, approximately 50 to 60 percent of operational costs. Therefore, it is always critical to produce the best diet at a minimum cost, in order to trim down the operational cost and gain more profits. According to Suarez *et al.* (2009), one solution considered in reducing production costs and increase producer's profitability is the use of feeds with low levels of fishmeal and high levels of less expensive, high quality plant protein sources. Ravindran (1992) noted that alternative feed stuffs (referred to as non-traditional feed stuffs), are now being used increasingly in commercial diets. Feeding costs is therefore a major determinant of profitability in livestock production enterprise (Westhuizen *et al.*, 2004). Fernando *et al.* (2008) reported that the search for alternative ingredients such as barley, oats, wheat, among others have increased in recent years. Most of these alternative feed stuffs have obvious potential, but their use has been negligible owing to constraints imposed by nutritional, technical and socioeconomic factors. These include variability of nutrients, seasonal and unreliable supply, need for processing, limited research and development facilities for determining nutrient composition, competition with use as human food, poor prices relative to other arable crops, limiting amino acids, relative to traditional feedstuffs and cost of processing (Ravindran, 1992; Fasakin *et al.,* 2003; Alphonsus *et al.,* 2009; Suarez *et al.,* 2009). According to Ravindran and Blair (1992) alternative novel protein sources of animal origin include insects: fly larvae, earthworms, termites, caterpillars, moth, bugs etc. while those of plant origin include leaf meals and aquatic plant meals.

1.4 Insect Protein as a more Promising Animal Protein Source

Insect meals have been described as a cheap animal protein which could serve as an alternative to soya beans or fish meal (Atteh and Ologbenla, 1993; Okubanjo *et al.,* 2014; Hwangbo *et al.,* 2009; Teguia *et al.,* 2002; Adeyemo and Longe, 2008; Ijaiya and Eko, 2009). The biological digestion of animal wastes by the larval stage of flies (especially house and solider flies), and the harvest and use of larvae and pupae of insects is a cheap way of supplying high protein materials. Interestingly, study of the use of insect meals as a substitute for fish meal have increased in recent times (Adesulu and Mustapha, 2000; Fasakin *et al.,* 2003; Ajani *et al.,* 2004; Awoniyi *et al.,* 2000, 2003; Okah and Onwujiariri, 2012; Dube and Tariro, 2014; Jumaa *et al.,* 2014; Okubanjo *et al.,* 2014; Chisowa *et al.,* 2015; Hassan, 2009). Maggot meal has been reported to be a possible alternative (Sheppard, 2002; Teguia *et al.,* 2002; Ogunji *et al.,* 2006; Awoniyi *et al.,* 2003; Awoniyi and Aletor, 1999; Okah and Onwujiariri, 2012). It has good nutritional value, cheaper and less tedious to produce than other animal protein sources. It is also produced from wastes, which otherwise would constitute environmental nuisance. Other insect meals such as watermelon bug meal, termite meal, silkworm caterpillar meal, locust meal, grasshopper meal have been proven to be significantly better in performance (weight gain, feed conversion ratio, protein efficiency ratio, linear body measurements, carcass and organ weight measurements and haematological indices) and insect meals are not nutritionally inferior to fish meal (Jumaa *et al.,* 2014; Dube and Tariro, 2014; Solomon and Yusuf, 2005; Ijaiya and Eko, 2009; Adeyemo and Longe, 2008; Gabriel and Idris, 1997; Chisowa *et al.,* 2015).

1.4.1 Nutritional values of insect

Insects are a highly nutritious and healthy food source with high fat, protein, vitamin, fibre and mineral content (FAO/WUR, 2013; Kelemu *et al.*, 2015; Van Huis, 2003; Van Huis *et al.*, 2013). In their joint report, they stated that the nutritional value of edible insects is highly variable because of the wide range of edible insect species. They noted that the nutritional value may differ even

within the same group of species, depending on the metamorphic stage of the insect, the habitat in which it lives and its diet. For example, the composition of unsaturated omega – 3 and 6 fatty acids in mealworms are comparable with that in fish (and higher than in cattle and pigs), and the protein, vitamin and mineral content of mealworm is similar to that in fish and meat (FAO/WUR, 2013).

Protein

Insects have been reported to be rich in high quality protein (Edjiala *et al.*, 2009; Braide *et al.*, 2010; Nzikou *et al.*, 2010; Ayieko and Oriaro, 2008; Rumpold and Schluter, 2013; Xiaoming *et al.,* 2010; Banjo *et al.,* 2006; Alamu *et al.,* 2013; Ekpo and Onigbinde, 2005; Womeni *et al.,* 2009; Wang *et al.,* 2004; Headings and Rahnema, 2002; Ramos-Elorduy *et al.,* 1997; Ademolu *et al.,* 2010; Bukkens, 1997; Ebenebe *et al.*, 2007; 2017). Such good quality crude protein source is required to meet the human population growth. It is on this basis of realities that FAO is promoting entomophagy (FAO/WUR, 2013). Insects are very high in crude protein, many species ranging above 60%. Banjo *et al.* (2006) analysis of nutritional value of insects showed that crude protein content of the termite ranges from 20.4% for *Macrotermes bellicosus* to 35.88% for *Macrotermes nigeriensis*. That of the silkworm larvae, *Anaphevenata* ranges from 25.7% (Banjo *et al.*, 2006) to 60% (Ashiru, 1988) while that of the Giant silkworm larvae, *Cirina forda* is 20.2% according to Banjo *et al.* (2006). For the variegated grasshopper, *Zonocerus variegatus*, the crude protein ranges from 26.8% (Banjo *et al.*, 2006) to 38.72% (Mba and Elekima, 2007).

Amino acids

Cereal proteins that are key staples in diets around the world are often low in lysine and, in some cases, lack the amino acids tryptophan (e.g. maize) and threonine. In some insect species, these amino acids are very well represented (Igwe *et al.*, 2011; Bukkens, 2005; Alamu *et al.,* 2013; Ekpo and Onigbinde, 2005; Womeni *et al.,* 2009). For example, several caterpillars of the Saturniidae

family, palm weevil larvae and aquatic insects have amino acid scores for lysine higher than 100mg amino acid per 100g crude protein. In countries in Africa where maize is a staple food – such as Angola, Kenya, Nigeria and Zimbabwe – there are occasionally widespread tryptophan and lysine deficiencies; supplementing diets with termite species like *Macrotermesbellicosus*should be a relatively easy step, as they already form accepted parts of traditional diets (Sogbesan and Ugwumba, 2008).

Fat

Edible insects are a considerable source of fat (Womeni *et al.,* 2009; Igwe *et al.*, 2011; Alamu *et al.,* 2013; Rumpold and Schluter, 2013; Xiaoming *et al.,* 2010; Bukkens, 1997, 2005; Ebenebe *et al.,* 2017; FAO/WUR, 2013). Their oils are rich in polyunsaturated fatty acids and frequently contain the essential linoleic and α-linolenic acids (Michaelsen *et al.*, 2009). Greater attention has been paid to the potential deficient intake of these omega-3 and omega-6 fatty acids in recent times, and insects could play an important role, in particular in landlocked developing countries with lower access to fish food sources, by supplying these essential fatty acids to local diets (FAO/WUR, 2013; Womeni *et al.,* 2009; Alamu *et al.,* 2013). The fatty acid composition of insects appears to be influenced by the plants on which they feed (Bukkens, 2005). The presence of unsaturated fatty acids will also give rise to rapid oxidation of insect food products during processing, causing them to go rancid quickly.

Vitamins and Minerals

Insects have also been reported to be rich in minerals and vitamins (Bukkens, 2005; Womeni *et al.,* 2009; Igwe *et al.*, 2011; Alamu *et al.,* 2013; Wang *et al.,* 2004; Headings and Rahnema, 2002; Ramos -Elorduy *et al.,* 1997). Winged adults of the termite, *Macrotermesbellicosus*, are high in magnesium and copper, and the palm weevil larva, *Rhynchophorusphoenicis* in zinc, thiamin and riboflavin (Bukkens, 2005). In each case, 1,009 of these insects provided more than the minimum daily requirement. In Nigeria, studies conducted by

Banjo *et al.* (2006) on fourteen species of edible insects in southwestern Nigeria also showed that insects are a good source of minerals and vitamins. Edible insects are undeniably rich sources of iron and their inclusion in the daily diet could improve iron status and help prevent anaemia in developing countries (FAO, 1995; Bukkens, 2005; Banjo *et al.,* 2006; Womeni *et al.,* 2009). Bukkens (2005) showed for a whole range of insects that thiamine (also known as vitamin B1an essential vitamin that acts principally as a co- enzyme to metabolize carbohydrate into energy) ranged from 0.1mg to 4mg per 100g of dry matter. Riboflavin (vitamin B2) ranged from 0.11 to 8.9mg per 100g dry matter. Vitamin B12 is well represented in mealworm larvae, *Tenebrio molitor* (0.47µg per 100g) and house cricket, *Acheta domesticus* (5.4 µg per 100g in adults and 8.7 µg per 100g in nymphs) (Finke, 2002).

Fibre

The fibre content of insects is largely associated with presence of chitin, an insoluble fibre derived from the exoskeleton (FAO/WUR, 2013). Finke (2007) estimated the chitin content of insect species raised commercially as food for insectivores, and found it to range from 2.7mg to 49.8mg per kg (fresh) and from 11.6mg to 137.2mg per kg (dry matter). Some argue that chitin acts like a dietetic fibre (Muzzarelli *et al.*, 2001) and this could imply a high –fibre content in edible insects, especially species with hard exoskeletons (Bukkens, 2005).

1.5 Statement of Problem

Nigerian population grows at 3-3.5% annually while livestock production is at 2% annually, hence resulting in animal protein deficiency in the country at consumption level of 7-10g/person/day against FAO recommendation of 34g/person/day (Ebenebe, 2005). Thus, conventional animal protein has apparently failed to meet needs of the country due to high cost of animal protein ingredients especially fish meal. Besides, there are serious environmental problems leading to high volume of greenhouse gases in the atmosphere and the consequential global warming effects. Feed millers have

resorted to the use of plant proteins (soyabean, lima beans, cotton seeds, moringa leaves, etc) which has been limited by presence of anti-nutritional factors and low amino acid profile. The use of insect meal appears to be a cheaper and environmentally friendly animal resource that could replace fish meal in fish and livestock feeds.

This study therefore attempts to evaluate the performance of broiler chicks on African palm weevil larva and winged termite meals especially when considering the increased cost of animal protein for poultry feeds and the demand for animal protein being witnessed by the poultry industry in Nigeria.

1.6 Significance of the study

This study is significant in the light of the need to improve animal protein supply at affordable costs to all consumers by use of low cost feed ingredients through alternative animal protein sources in feed formulation. Besides, in this era of environmental degradation and global warming issues, best practices of livestock production will involve use of environmental friendly inputs. Insects appears as one major environmentally friendly input that could replace fish meal in livestock and fish feed formulation.

1.7 Aim and Objectives

The aim of this research was to determine the effect of African palm weevil larva and winged termite meals on performance of broiler chicks.

The specific objectives of the study were to:

1. determine the growth performance and linear body measurement of the broilers fed with diet based on insect meal.
2. investigate the carcass quality of the broilers fed with insect based diet.
3. evaluate the blood chemistry of broiler chicks fed with insect based diet.
4. investigate mineral concentration of broiler meat from each treatment.
5. assess the economic value/ cost effectiveness of the insect based diet

CHAPTER TWO

LITERATURE REVIEW

2.1 Origin of Domestic Fowl

Fowl originated as jungle fowl in Asia and were domesticated over 3000 years ago, and are known now as chicken; *Gallus gallus domestics* (Dickson, 2002; Johnson *et al.*, 1999). There has been a debate on whether the domestic fowl is monophyletic or polyphyletic origin (Dickson, 2002). It was indicated by many research studies that the red jungle fowl is the direct ancestor of the domestic chicken (*Gallus gallus domesticus*) used in commercial production for meat and eggs (Dickson, 2002; Johnson *et al.*, 1999). Johnson *et al.* (1999) reported that *Gallus gallus* of the red jungle fowl is the origin of all domestic breeds. Dickson (1996) reported that the red jungle fowl is the principal and perhaps the sole ancestor of the domestic fowl.

Moreover, the use of molecular genetics and micro-satellite techniques provided evidence that the origin of domestic fowl is monophyletic. Johnson *et al.* (1999) evaluated the gene pool of 52 chicken populations from a wide range of origins using the micro-satellite markers technique. They found out that the red jungle fowl is the main progenitor of the domestic chickens. Al-Naseer *et al.* (2007) investigated the similarity and evolutionary relationships between *Gallus gallus* and different chicken breeds. The authors conducted four experiments on genetic relationships using different estimation criteria including morphological discrete characters, body measurements, biochemical markers, and the activity of serum esterase-1. They found that the greatest similarity was found between *Gallus gallus* and egg type breeds of Mediterranean roots. In addition, Dickson (2002) reported that Leghorn breed is very similar to the red jungle fowl.

2.2 Domestication of Chicken

Domestication is a process where a wild organism is habituated to survive in the company of human beings. It involves adaptation of animals to environmental conditions, therefore, some changes in behavior and physiology of the animal would be expected (Garrigus, 2007). As reported, these behavioral and physiological changes associated with domestication is a must, however, these changes vary according to type of domestication whether it is toward meat or egg production. Archaeological discoveries in China indicate that chickens had been domesticated by 5400 BC (Garrigus, 2007) but it is not known whether these birds made much contribution to the modern domestic fowl. Chickens from Harappan culture of the Indus Valley (2500-2100 BC) may have been the main source for diffusion through the world (Dickson, 2002). Birds were first domesticated for cultural and entertainment purposes, until much later birds were utilized as a source for human food (Dickson, 2002). It is therefore expected that the physiological and behavioral changes occurred for adaptation to entertaining purposes are different from adaptation for human food. Domestication process resulted in some differences and similarities between domestic chicken and its ancestor the red jungle fowl (Dickson, 2002; Johnson *et al.*, 1999). This partially could be due to differences in their genetic makeup. These commercial egg and meat stocks are believed to exhibit heterosis and are available throughout the world (Oluyemi and Roberts, 2000). However, the potential loss of genetic diversity is of great concern for most scientists and to the poultry industry due to the concentration of breeding programmes under the control of few large poultry organizations. Several studies were conducted to investigate the genetic diversity of the poultry stocks available in the world. Al- Naseer *et al. (*2007) estimated the genetic distances among the breeding stocks to evaluate the genetic diversity. They reported that there is still a considerable amount of genetic diversity among chicken populations overall, but specialized types of fowl such as meat type and egg type have suffered of reduced diversity and increased similarity. These results

indicate that concerns about reduced genetic diversity in highly selected populations may be well founded and attention must be given to prevent further losses in genetic diversity. On the other hand, Katule, (1989) used DNA fingerprinting technique to evaluate genetic diversity in elite pure lines of commercial broilers and layers. They found that the broiler sire, broiler dam, and parental lines that compose the majority of commercial breeder populations available in the USA contain a considerable reservoir of genetic diversity. Again, the concern over loses in genetic diversity still remains.

2.3 Taxonomy of the Domestic Fowl

Chickens being the most populous domesticated poultry worldwide are classified based on morphological and behavioral characteristics (Al- Naseer *et al.*, 2007). A detailed classification of chicken is given below:

Kingdom: Animalia

Phylum: Chordata

Sub-phylum: Vertebrata

Class: Aves

Order: Galliformes

Family: Phasianidae

Genus: *Gallus*

Species: *Gallus gallus*

(Al-Naseer *et al.*, 2007)

2.4 Description and Morphology of the Domestic Fowl

Chickens like all poultry birds have two legs and two wings which enables them for light flight. Their bony structures are light and their digestive system short (Oluyemi and Roberts, 2000), with eyes placed laterally in a way that limits vision. But a significant number of cervical vertebrae (14 in chicken)

compensates for the position of the eye. Among the senses, the vision is the best developed (Freeman, 2000).

Poultry birds lack teeth and the jaws are covered by a horny beak. The lower part of the beak is hinged at the jaw and is movable while the upper part is fused to the skull. The comb is small, red skin clearly placed on the top of the head. It is larger for the cock which may serrate at the top edge. Under the effect of stimulation, it straightens up and becomes sharp red sometimes certain hens carry a beautiful cap called hoope, imposed like a fan on top their head (Dickson, 2002).

Feathers are highly anatomical feature of birds and are modified scales which are important in several ways. Soft down feathers trap still air close to the surface of the body for thermal insulation of the bird. Contour feathers on the body establish the smooth streamlined contour of the bird's body and the enlarged flight feathers from the aerodynamics surface of the wings and tail (Olowofeso, 2005). Feathers are important in bird's behavior, the brightly colored feathers of the male species such as finch is used as signal during courtship and mating (Freeman, 2000). Birds feathers used in mate attraction may form huge crests, ruffs or tassels. Only the male has saddle feathers.

Birds lack bladder and they excrete uric acid in form of solid white crystals rather than urea in a water solution. The epidermis is keratinized and lipogenic and the skin as a whole acts as a sebaceous secretory organ. Heavily confined epidermis covers their back, spurs and the scales on the legs and feet. Avian claws are like those of the reptiles with heavily covered integument over the base of a terminal phalanx. All birds have toes claws which are composed of a dorsal plate that curves downward on the tip and sides (Olowofeso, 2005). The eyeball is covered by the eye ring which when open appears as a circle of skin.

Generally, members of one breed are alike in shape with the varieties of the breed differing in minor characteristics such as the shape of the comb and in

color and markings. A group of breeds developed in a single country or geographical area is often grouped as a class (Dickson, 2002).

2.4.1 Description of the broiler

Broilers are chickens (*Gallus gallus domesticus*) bred and raised specifically for meat production. Chickens are one of the most common and widespread domestic animals, and although the global population has decreased from more than 24 billion in 2003 to 19billion in 2011, there are more chickens in the world than any other species of bird. Typical broilers have white feathers and yellowish skin. Most commercial broilers bred for meat reach slaughter weight between 5 to 7 weeks of age, although slower growing strains reach slaughter weight at approximately 14 weeks of age (Kruchten, 2002). Because of this young age, most of their behavior and physiology is that of an immature bird. Broilers and egg laying hen are the same species and share many characteristics, however due to the rapid growth and selection for enlarged breast muscles, broilers are susceptible to different welfare concerns, particularly skeletal. Broilers are usually grown as mixed sex flocks in large sheds under intensive conditions, but some strains can be grown as free range flocks (Kruchten, 2002).

2.5 Poultry Production in Nigeria

The poultry sub- sector is the most commercialized (capitalized) of all the sub-sectors of Nigeria's agriculture (Adene, 2006). There is however no comprehensive data on the sub- sector, thus making proactive intervention and planning in the sub- sector due to lack of accurate information or current data. With the global spread of Highly Pathogenic Avian Influenza (HPAI) across countries since 2003 and especially, the confirmation of the epidemic in Nigeria in February 2006, there is a new attention focused on the sub- sector by the Government of Nigeria (GON) and the International community (Adene, 2004). The types of poultry that are commonly reared in Nigeria are chickens, ducks, guinea fowls and turkeys, amongst which the chickens predominate (Adene,

2000). The growth in poultry production in Nigeria is as a result of the opportunities for high economic returns in the poultry industry (Ufele *et al.*, 2015). The poultry industry is currently a private sector led and has the highest potential not only for achieving the reduction of hunger but also of poverty (Adene, 2004). The data below shows the projected population of poultry in Nigeria as presented by the Federal Department of Livestock and Pest Control Services (dated 2013). The data puts the estimated population of poultry in Nigeria in the year 2013 as 165 million producing 650,000 metric tonnes of eggs and 290,000 metric tonnes of poultry meat.

2.6 Types of Poultry Production in Nigeria

There are two distinct poultry production systems in Nigeria, as in most developing countries of Africa and Asia (Adene and Oguntade, 2006). Each of these two systems is associated with features of scale, stock, husbandry and productivity that therefore define the two distinct production systems. The two systems are conventionally referred to as the Commercial Poultry and the Rural Poultry. The Commercial production system is industrial in its prototype and therefore based on large, dense and uniform stocks of modern poultry hybrids. It is capital-and labour-intensive; as well as inputs and technology-demanding. On the other hand, the rural poultry is by convention a subsistence system which comprises stocks of non-standard breeds or mixed strain, types and ages. It is generally of small scale, associated with household or grass root tenure and little or no veterinary inputs. The rural poultry sector is therefore in its original sense, a village–based, household or individual holding and occupation which as however been extended to non–village settings in peri-urban localities, mainly by the middle class dwellers (Adene, 2006). He further stated that the common features to all these intermediate grades are in their subsistence scale generally, with minimal or no inputs and labour overheads. However, between these two rater distinct prototypes, intermediate grades have evolved over time, in response to the National agro–economy and consumer demands. According to him, available information shows that the scale of

operation can range from stocks of a few units or a few dozens of a variety of poultry birds in the household to tens or hundreds of thousands of chickens in the grades of commercial poultry. These two distinct production systems as well as the range of the intermediate types have been grouped into four operational sectors viz;

Sector 1: Industrial Integrated System with high bio–security systems

Sector 2: Commercial Poultry Production System with moderate to high bio–security systems

Sector 3: Commercial Poultry Production System with low to minimal bio–security systems

Sector 4: Village or backyard production with minimal bio–security systems

It is implied therefore that Sectors 1 to 3 cover grades of intensive and or commercial poultry production systems, while Sector 4 embraces types and scales of village or family subsistence but mostly extensive poultry production (Adene, 2006).

2.6.1 Housing and husbandry practices

The housing and husbandry practices in Nigeria follows the convention in tropical intensive open–sided deep litter housing and poultry management. The specifications for housing include concrete core flooring; 2 to 3 feet dwarf perimeter walls with chicken wire mesh sides and roofs of corrugated asbestos or galvanized sheets. Although this is a design which is relatively cheaper than the closed and environmentally controlled design in temperature countries, it exposes poultry stock to the impacts of direct vagaries of climate and weather with negative consequences on the productivity and health of stock (Adene, 2004). The daily variations in temperature and relative humidity in parts of

Nigeria can reach 120^{0}C or more and 25% respectively. These unfavorable circumstances have therefore, in some instances compelled the incorporation of environmental amelioration systems like industrial or tunnel ventilator fans, foggers and cooling pads along with shade trees (Udeh, 2003). In recent times, one of the major (integrated) operators in this sector, which is located in the South –West Nigeria, introduced custom built closed environmental housing, thus blazing the trail in this innovation. The watering and feeding systems for poultry in this sector are either the manual trough or bucket types. However, in the more advanced integrated holdings, automated chain feeding and watering systems are involved. Egg collection is mainly based on manually operated nest boxes with straw or wood shaving floors (Adene, 2006).

2.6.2 Feed

There are three types of feed millers namely; custom, toll and integrated farms. The custom millers mill and market their feeds under registered trade names. The dominant trade names in the market include Amo Sanders, Vital Feed, Guinea Feed, Top Feed and Livestock Feed, among others. Some of these custom millers have adopted franchising as an operational method for achieving a wider reach across the country. The toll millers are spread across major locations with significant concentrations in small to medium scale poultry farms. They will mill feed to the specification of customers and charge a fee (toll) per quantity milled. The customers either bring their feed ingredients or purchase them from the millers, if the millers have them in stock. The third category of feed millers is the integrated poultry farms, which own feed mills and produce feed for own use. The feed millers acquire their grains from grains merchants/buying agents who source their grains mostly from the northern parts of the country. These merchants have established networks for aggregating grains from smallholder farmers and have mastered the logistics of grain transportation across the country (Adene, 2006).

2.6.3 Drugs, supplements and vaccines

There are major importers of poultry drugs, supplements and vaccines. The National Veterinary Research Institute (NVRI) also produces some quantities of vaccines locally. The large–scale poultry farms obtain their supplies either directly or through suppliers from these importers. The small to medium scale poultry farms obtain their supplies from the poultry shops, private sector poultry extension agents and at times from veterinary doctors (Adene, 2004).

2.7 Nutrient Requirements for Poultry Birds

Nutrient can be defined as chemical substances found in feed ingredients which when made available to the animal are used for maintenance, production and health of the animals (Smith, 2001). It can also be described as a specific chemical element or compound supplied by or derived from the diet and absorbed into the body tissues to support physiological processes. These nutrients are essential to be in appropriate amounts and proportions in the diets of intensively housed birds, because they have no access to other sources of nutrients.

The essential nutrients required by the poultry birds are carbohydrates, fat and oil (mostly served as energy givers); protein (amino acid), minerals (micro and macro), vitamins and water (Olomu, 1995; Smith, 2001). The dietary requirement of nutrients varies with age, bodyweight and rate of growth of the birds. Thus, the requirement for any nutrient may be defined as the amount of that nutrient which must be supplied in the diet to meet the needs of the normal healthy animal given on otherwise completely adequate diet in an environment compatible with good health (Olomu, 1995). Such level of nutrient must meet the requirement for maintenance, growth, productive and reproductive potential of the animal.

2.7.1 Energy requirements

Poultry, like other farm animal, consume feed primarily to satisfy their energy requirement. According to Adene (2006) the energy required by the bird to perform its maintenance and productive functions is usually given to the animal through carbohydrate and fats. Protein can also be broken down to supply energy, though this only occurs where the lipid and carbohydrate sources of energy are inadequate. Cereal grains, cereal by-products, fats and oils from animal and vegetable supply most of the energy in poultry diets. Poultry have limited ability to utilize high fibrous feeds such as roughages. Olomu (1995) reported that most chickens have the ability to adjust feed intake in-order to obtain the necessary energy required for optimum performance. When fed ad-libitum, chickens on low energy diets consumed more feed than those fed high energy diets. Therefore, the amount of nutrients required in the poultry rations must be adjusted in relation to the energy levels of the rations. Fats can be used to increase the energy level of low-energy rations. Fats inclusion should be limited to not more than five to ten percent of the diets. Fats supply of 9cal/g as much energy as that which an equal weight of carbohydrate supplies (Freeman, 2000). It increases the utilization of feed and performs important functions in the cells. In hot climate areas, feed containing added fats might become rancid quickly, unless it has been properly stabilized. In poultry, energy of the rations is usually expressed in unit of metabolizable energy per unit weight; joules per kg, or calories per kg, where one calorie is equivalent to 4.16 joules.

According to FAO (2013) the energy requirements of tropical countries are lower than those of temperate regions. The recommended energy requirements for chickens, pullets and layers under tropical environments have been estimated at 3200, 2900 and 2900kcal/kg respectively. Olomu (1995) fed birds' dietary energy levels of 2500, 3000 and 3200kcal metabolizable energy (ME) per kg. He observed that, the best performance of chicks was realized with the ration containing 3000KcalME per kg. For tropical environment, Freeman

(2000) recommended an energy level of 2850Kcal ME per kg for broiler starter diet and 2900Kcal ME per kg for broiler finisher diet. It must be noted that increasing the dietary energy resulted in an increase in the cost of diet.

2.7.2 Protein and amino acid requirements

Amino acids are the basic fundamental structural units of protein, which are required by the birds for growth and for repairing worn out tissues (Smith, 2001). Chickens and pigs can produce in their bodies some but not all the amino acids. Those amino acids that must be supplied in the feed are known as the essential amino acids. Thus Smith (2001) reported that the protein requirement of a bird can be defined as the birds' requirement for the supply of each essential amino acid together with sufficient supply of suitable nitrogenous compounds from which the non-essential amino acids can be synthesized.

According to Olomu (1995) under normal circumstance birds eat more as they grow older. Therefore, the total protein consumed increases as the birds gets older and presumably increase in weight. However, the protein consumed per unit weight either reduces or remains constant. Thus, if dietary protein level remains constant throughout the life of the birds, more protein than necessary may eventually be consumed.

Since protein is not stored in the body to any appreciable extent, any protein consumed above the birds' requirement is oxidized for energy (Olomu, 1995). All essential amino acids are required by poultry and the most commonly deficient amino acids in the chicken diets are arginine, lysine, methionine, tryptophan and non-essential glycine. Environmental temperature affects protein requirements of chicks in the tropics. The high ambient temperature in the tropics has been found to adversely affect the feed intake as well as the protein intake of chicks.

2.7.3 Water requirements

Water is one of the most important nutrients needed by chicken. Water constitutes more than half of the weight of poultry meat and about two-third of the weight of egg (Olowofeso, 2005). The newborn animal contains 750 to 800g of water per kg weight, though this falls to about 500g/kg in the matured fat animal. Oluyemi and Roberts (2007) reported that for every kg of feed, 2-3 liters of water is consumed. Smith (2001) also reported that drinking water for poultry should be free from salt and toxic substances. He also reported that the ratio of dry matter to water intake by poultry in a temperate environment is normally 1:2, but does depend to some extent on the diet. Thus, increase in protein level also increases the water consumption of the birds. Water is available in the feed (metabolisable water) but the bulk of water must be provided separately in drinking cans or troughs. The water must be provided ad-libitum, clean and free from excessive salts, which might have a laxative effect and must be cool. Olomu (1995) suggested that 2 to 2.5 liters of water in the first two weeks is adequate for 100 chicks, this is doubled after another 2 weeks. On very hot days, the water consumption may be increased as much as three times of the water intake on cooler days.

2.7.4 Mineral requirements

Minerals are mainly inorganic components of feed. The body of animals contains large number of mineral elements, which occur in combination with the organic constituents. Chicken body contains about four per cent mineral matter. Phosphorus and calcium are the two most abundant mineral elements in the bone and other skeletal components of the birds. Olomu (1995) classified mineral elements as macro and micro depending on the quantitative requirement for each. Macro elements include: calcium, phosphorus, sodium, chlorine, sulphur, magnesium and potassium while some of the micro-elements are iodine, zinc, cobalt, iron, copper and molybdenum. Excess or

deficiency of these mineral elements is detrimental to the health and development of the birds. Minerals function in many ways such as in body structural components and acid-base balance. Calcium and phosphorus have been found to have closely related metabolic functions. The requirement of these minerals appears to be higher for warm climates than for cold climates (Olomu, 1995). It is therefore recommended that the level of calcium be increased from 1 – 1.2% to 4 – 4.5% and the level of total phosphorous from 0.7 – 0.8% to 1 – 1.1% during periods of hot weather.

Smith (2001) stated that mineral deficiency and over supply have serious adverse effects and could lead to death of chicks. Thus, in practice 0.30 – 0.35% common salt or sodium chloride would take care of the requirements for sodium and chlorine which must be supplied from sources other than the normal ingredients used in formulating poultry feeds.

2.7.5 Vitamin requirements

Vitamins are organic compounds that cannot be synthesized in the poultry body and they are required in extremely small quantities but absolutely essential for normal growth and health. Oluyemi and Robert (2007) listed the vitamins required in poultry diets as follows: the fat soluble-vitamins A, D, E and K and the water-soluble vitamins thiamine (B1), niacin, riboflavin (B2), pyridoxine (B6), biotin, pantothenic acid, folic acid, choline, and vitamin B12. Vitamin C can be synthesized in the body of birds but they are required as anti–stress in hot environment. The deficiency of these vitamins in the feed consumed by birds or non-availability of these vitamins to the birds usually result in disease symptoms, such as rickets which is caused by vitamin D deficiency associated with low or imbalance of calcium and or phosphorous level in the diet; curled toe paralysis (Vitamin B12) and perosis associated with deficiency of choline and biotin (Olomu, 1995). Deficiency of folic acid causes poor feathering, poor feather pigmentation and anemia (Dickson, 2002).

2.8 Limitations of Poultry Production in Nigeria

Limitations of poultry production in Nigeria include: farm size, labor, feed intake, cost on drugs and medication, farming experience, gender, education (Ashagidigbi *et al.*, 2011). Others according to Smith and Coste (2001) include.

- The competition for consumption with man leading to high cost of feed ingredients.
- Housing, disease and parasitic problems
- The nutrient composition of available feed ingredient not well understood
- The nutrient requirement of birds for maintenance and production, not well known
- Unavailability of adaptable egg laying and broiler birds.

Farm size: The output of a poultry farm is partly dependent on the number of birds in the farm (Yusuf and Malomo, 2007).

Labour: Family and hire labour plays an important role in agricultural production especially in developing economies where capital is less (Yusuf and Malomo, 2007). Hence, the prior expectation is that yield should increase with optimum labour used.

Feed intake: The relative importance of feed in poultry production cannot be over emphasized. Increase in poultry production can be more experienced by increasing the feed (quality and quantity) than by increase in any other factors that influence poultry. Thus, the coefficient of feed intake should be positive and significant.

Education: Studies have shown that farmers with formal education have greater ability to adopt new technology and innovation. This is expected to have a positive influence on their level of efficiency.

Extension contact: This is expected to have a positive and significant impact on efficiency.

Access to credit: This is expected to have a positive and significant impact on efficiency.

2.8.1 Low productivity of indigenous species

Pym *et al.* (2006) stated that despite the lower productivity of indigenous poultry genotypes compared with that of commercial strains, indigenous genotypes still comprise a large proportion of the overall poultry population in many developing countries, frequently in excess of 80 percent. In rural villages in most countries, the majority of families have small flocks of poultry mainly chickens but sometimes other species including ducks, turkeys and guinea fowls, which provide family needs for poultry meat and egg. According to him, these birds are invariably indigenous genotypes, or cross breeds with a significant indigenous genotype component. In most countries, flocks of indigenous breed birds are not found in significant numbers in urban or peri-urban areas, owing to the lack of scavenging opportunities. In some countries, there are restrictions on small scale scavenging flocks in urban areas because of the risk of disease transmission to the human population and to commercial poultry flocks. The poor productivity of indigenous birds means that their total contribution to poultry meat and egg production and consumption is considerably lower than their numerical contribution to the overall poultry production.

2.8.2 Climate and low productivity

According to Anderson (1998), the climatic factors affecting poultry productivity are;

High temperature: This is a situation whereby the degree of hotness is higher than the normal temperature.

High rainfall: This is the situation whereby there is increase in the percentage of rainfall that is normally experienced in a place.

High relative humidity: This is the level of moisture content in the environment.

Depressive environmental heat: This is the heat that is caused by factors such as human activities, heat from sunshine due to the depletion of the ozone layer.

Poultry production is highly affected by high temperature. It reduces the ability of poultry birds to feed properly which lead to loss of body weight.

2.8.3 Diseases

According to Sainsbury (1992), diseases of poultry can be broadly classified into:

Pathogenic diseases: These are diseases brought about by the presence of one or more pathogenic or causative organisms.

Management diseases: Bad management can be caused by pathogenic invasion and can also cause diseases directly e.g overcrowding can lead to rapid transfer of disease from sick animals to healthy ones. It can also cause inadequate access to feed and water. Other examples of poor or bad management that can lead directly to diseases are:

- Failure to vaccinate at the right time
- Failure to remove dead birds promptly
- Poor or old litter
- Over crowding
- Poor ventilation

- Failure to remove droppings regularly
- Poor incubation hygiene

Deficiency diseases: These are diseases caused by lack of one or more essential nutrients needed for growth and development of the body.

Metabolic diseases: These are group of diseases which are caused by a faulty metabolic process in the body. This is caused by the absence in the body of certain fat carrying substances resulting in the accumulation of fat in the liver, intestines, gizzard, kidneys and heart.

2.9 Economic Importance of Poultry Farming

The challenges of food insecurity and hunger in developing African countries like Nigeria have caught the attention of experts and governments worldwide (Joseph and Ajayi, 2002; FAO, 2013). Population growth, urbanization, and income improvements are the main drivers of increased demand for foods of animal origin in developing countries (Muhammed *et al.,* 2000). The sufficient supply of animal protein is most critical in the global food basket crisis (FAO, 1995). As a result, growing demand has led to a rise in the production of foods of animal origin all around the globe, especially from poultry and pigs (FAO, 2011).

Poultry production plays an important role in rural incomes in sub-Saharan Africa; especially in Nigeria (Muhammed *et al.,* 2000). A country's economic development is normally accompanied by improvement in its food supply and the gradual elimination of dietary deficiencies (FAO, 2011). This raises global demand for animal products, thus offering potential opportunities for animal producers worldwide (Jain, 1993). The enforced demand for foods of animal origin could be satisfied especially by the production of poultry, as these products have seen the greatest increase in production in recent years (FAO, 2011).

For farmers in sub-Saharan Africa, poultry production plays an exceptionally important role; approximately 80% of rural households are engaged in smallholder poultry production (FAO, 2012). But, although chicken production is likely to become the fastest growing agro business sector in sub-Saharan Africa, it still faces problems of feed-food competition and dependency on the import of improved breeds (Muhammed *et al.,* 2000).

In Nigeria, where the production of animal protein falls far short of meeting the demands of a rapidly growing population (Dickson, 2002), poultry is the most common livestock kept (Muhammed *et al.,* 2000). The poultry industry has emerged as the most dynamic and fastest growing segment in the animal husbandry subsector. It represents an important source of high-quality proteins, minerals, and vitamins to balance the human diet.

2.10 Haematological Parameters as an Index of the Value of Feed Ingredient

The use of blood examination as a way of assessing the value of feed ingredients and the health status of animals has been documented by many authors (Muhammed *et al.,* 2000). This is because it plays a vital role in physiological, nutritional and pathological status of organisms (Muhammed *et al.,* 2000). They range from giving the level of the blood to detecting ailments or disorders through them. Blood examination has its tangible values in poultry rearing business, e.g. it provides information on the assessment of poultry health such as the items on traumatic injury, parasitism, organic disease, bacteria septicaemia, nutritional deficiency and also physiological changes in growth with time of broilers (Jain, 1993).

Hematological profiles both in humans and in animal sciences is an important index of the physiological state of the individual. The ability to interpret the state of blood profile in normal and in diseased condition is among its primary tasks. It has been seen by many researches that there is a definite change in

the profile of the blood cells throughout the life (Khan *et al.*, 1987). Not only the blood picture changes with the advancement of the age but it also varies with certain conditions as stress, bacterial infection, viral infection and intoxication. The blood of the domestic fowl contains erythrocytes, thrombocytes, non-granular leukocytes and granular leukocytes, suspended in plasma. Most researchers have studied the avian blood and found a great degree of variation for red blood cell and considered it to be normal. It was concluded after an extensive study that red blood cell and other parameters as haemoglobin and estrogen of a bird vary among species, other factors, which affect the counts, include breed, sex and the nutrition supplied to the bird (Sturkie, 1999).

Haematology: Haematology also spelled hematology (from Greek word "haima" meaning blood), is the study of blood, the blood-forming organs and blood disease. Haematology includes the study of etiology, diagnosis, treatment, prognosis and prevention of diseases of the blood and bone marrow as well as of the immunologic, haemostatic (blood clotting) and vascular systems. Because of the nature of blood, the science of haematology profoundly affects the understanding of many diseases (Muhammed *et al.,* 2000).

Avian blood differs in cells' characteristics from their mammalian counterparts. Ali *et al.* (1996) stated that several factors including physiological and environmental conditions, diets content and, water and feed restriction, fasting, age, administration of drugs, anti-aflatoxin premixes and continous supplementation of vitamin E (Odunsi *et al.*, 2007) affects the blood profiles of healthy birds.

Although mammalian and avian haematology is similar in many ways, there are differences that must be considered.
The important differences are;

1. Birds have nucleated mature erythrocytes
2. Birds have nucleated thrombocytes instead of platelets

3. Birds have heterophils instead of Neutrophils
4. Birds do not have a storage spleen so that splenic contraction does not cause an increase in erythrocyte parameters.
5. The initial pathways for blood coagulation in birds are different from those of mammals. The avian system relies primarily on the extrinsic pathways
6. Avian blood has a lower concentration of plasma albumin than mammalian blood.

2.10.1 Significance of haematological parameters

Haematological parameters are those parameters that are related to the blood and blood-forming organs. Haematological parameters are blood characteristics, which affect both the health and nutritional state of an animal. The nutritional value of a feed stuff could therefore be reflected through parameters such as: white blood cell (WBC), red blood cell (RBC), packed cell volume (PCV), haemoglobin (Hb), mean corpuscular haemoglobin (MCH), lymphocytes, and neutrophilis.

The full blood count (FBC), sometimes referred to as a full blood examination or complete blood count, is one of the most commonly performed blood tests, as it can tell us so much about the status of our health. It is important for diagnosing conditions in which the number of blood cells is abnormally high or abnormally low, or the cells themselves are abnormal. A full blood count measures the status of a number of different features of the blood, including:

- The amount of haemoglobin in the blood;
- The number of red blood cells (red cell count);
- The percentage of blood cells as a proportion of the total blood volume (haematocrit or packed cell volume);
- The volume of red blood cells (mean cell volume);
- The average amount of haemoglobin in the red blood cells (known as mean cell haemoglobin);
- The number of white blood cells (white cell count);

- ❖ The percentages of the different types of white blood cells (leucocyte differential count); and
- ❖ The number of platelets. (Ali *et al.*, 1996)

2.10.1.1 Red blood cell

Red blood cell is erythrocyte which specializes in transportation of oxygen to the presence of haemoglobin within the erythrocytes which also contributes to red colouration of the blood. The red blood cell is produced in the bone marrow. Red cell count is an estimation of the number of red blood cells per litre of blood. Abnormally low numbers of red blood cells may indicate anaemia as a result of blood loss, bone marrow failure, and malnutrition such as iron deficiency, over-hydration, or mechanical damage to red blood cells. Abnormally high numbers of red blood cells may indicate congenital heart disease, some lung diseases, dehydration, kidney disease or polycythaemiavera. The function of red blood cell is to carry oxygen to the tissues at pressures sufficient to permit rapid diffusion of oxygen. This is done by a carrier molecule, haemoglobin; a vehicle (red blood cell) capable of bringing the intact haemoglobin to the cellular level; and a metabolism geared to protect both the red blood cell and the haemoglobin from damage, Interference with synthesis or release of haemoglobin, production or survival of red blood cell, or metabolism causes disease (Aiello, 1998).

2.10.1.2 Haemoglobin

Haemoglobin is the important respiratory pigment in the blood that carries oxygen and consists of 4-haem units and 4-polypeptide genes. Its concentration in an animal system is in proportion of the animal to sustained muscular activities or ability to meet demand for sudden burst of speed (Aiello, 1998). Haemoglobin molecule consist photoporphynin, native globulin and ferrous iron. The iron content is 3.35mg/g of haemoglobin. This implies that haemoglobin is an iron containing compound found in the red blood cells, and physiologically, it is indispensable for tissue oxygenation because of its

unusual affinity for molecular oxygen which it aid to transport from the lungs to the tissues and carbon(iv)oxide from the tissues to the lungs. Measuring the concentration of haemoglobin in the blood can help diagnose anaemia, a condition caused by a deficiency of haemoglobin. Anaemia can arise due to:

- Inadequate production of red blood cells in the bone marrow;
- Inadequate iron intake;
- Inadequate foliate or vitamin B_{12} intake;
- Microscopic bleeding or other blood loss;
- Blood cell destruction;
- A chronic illness; or
- A defect in the haemoglobin molecule itself. (Aiello, 1998).

Haemoglobin is red in colour and the intensity of colouration it impacts to the blood is proportional to the concentration of iron (iii) ions. Haemoglobin concentration is expressed as gram per deci litter (g/dl) of the blood (Ganomg, 1991). The most accurate method of haemoglobin determination is the chemical determination of its iron content or oxygen carrying capacity. However, this is involved for practical clinical haemoglobinometer and thus the following methods are used:

a. Direct matching of the red colour with artificial standards using dare haemoglobinometer.
b. Conversion of the haemoglobin to acid haematin and matching the brown colour with glass standard.
c. Measurement to oxy/haemoglobin by the light absorption in the green portion of the spectrum using a suitable green filter and matching it through an eye piece with coloured glass.

Haemoglobin concentration less than normal indicates anaemia while high concentration above normal indicates polycythaemia. This may occur in higher animals with chronic lung disease, as an adaptation to high altitudes, or

because of an abnormal increase in red cell production by the bone marrow (polycythaemiavera).

2.10.1.3 White blood cell

White blood cell is an intrinsic body defense system. They are also produced in the bone marrow and carried in the blood stream. A low level of white blood cell in the blood could be as a result of no disease condition or low production from bone marrow (Ganomg, 1991). There are 5 types of white blood cells found in birds. Heterophils, Eosinophils and Basophils are known as granulocytes because they all contain coloured granules (tiny spindle shaped bodies) in their cytoplasm. These cells are all produced in the bone marrow, lymphocytes and monocytes are known as mononuclear WBC's. These two types of cells have a single nucleus and no granules in their cytoplasm. They originate in the spleen and tiny collection of lymphoid tissue found throughout the body as opposed to the bone marrow by looking at the smear under microscope (Ali *et al.*, 1996).

The total white blood cell count can be estimated by determining the number and relative proportions (percentage) of the five different types of WBC's. In addition, the WBC's can be examined, for abnormal characteristics. All these findings are significant in determining whether a bird is fighting some type of disease and how serious it is (Ali *et al.*, 1996). An increase in the WBC count is called Leukocytosis. A common cause of leukocytosis is the actual transporting and handling of a bird at the clinic. This is a physiological change due to stress. Disease causes includes bacteria and fungi infection. A decrease in the WBC count is called Leukopenia. The most common causes of this include acute viral infections and the end stages of overwhelming Septicaemia (blood poisoning) in which the body literally runs out of WBC's with which it fights with (Ali *et al.*, 1996). The percentage of the different types of WBC's is called the Differential. As stated before alterations of the differential from the normal change in cell characteristics are significant for various disease conditions

2.10.1.4 Packed cell volume

Packed Cell Volume is derived from the red blood cell (Frandson and Elmer, 2001). Anaemia is reflected when the mean ratio of red cell in fluid is below normal in the blood or when there is a fall in packed cell volume below the minimum range of the wide species study. Haemo-concentration is the opposite of anaemia which results when packed cell volume exceeds the maximum of the normal range, although decrease of fluid could arise as a result of lowered intake of water or excess loss of water, thereby increasing red blood concentration (Edosein and Switzer, 2002). Packed cell volume (PCV) is an important hematologic assay because it provides an easy and objective way of estimating the number of erythrocytes in the sample.

The haematocrit means to separate blood into its component units. It is the measure of the red blood cell mass determined by spinning blood on a centrifuge and then measuring the percentage (by height of the test tube) of the blood that consists of packed red blood cell versus the liquid plasma. The blood separates into 3 distinct parts including the mass of erythrocytes at the bottom, white or gray layer of leucocytes and a thrombocytes immediately above the RBC mass known as the bluffy coat and above the bluffy coat comes the plasma (Ihedioha, 2004). It is measured in mm^3 and expressed as a percentage of the total volume.

Error factors in PCV measurement includes:

1. Prolonged occulation of the vein which can cause venous statis and increase in PCV by 50%,
2. Epinephrine level: In hyper excited animals, the release of epinephrine and subsequent spleenic contraction can increase in PCV up to 10%, and
3. Excessive use of anti-coagulant (EDTA) can reduce PCV as much as 3% (Ihedioha, 2004). PCV increases (erthrocytosis) with stress factors such as excitation, dehydration, high

altitude and decrease with anaemia, chronic infections and blood loss due to bleeding. Variation in PCV is given due to the diverse pathological state of the animal.

2.10.1.5 Lymphocytes

Lymphocytes are of large and small morphology, which are two types the B and T-forms. The B is derived from the bone marrow and T from the thymus. The B-form produces antibodies which combine with foreign materials or antigens, while the T is responsible for the regulation of the antigen and the cell medicated response of the animal. Aggregates of lymphocytes are found within the bone marrow of the birds, although major sites of lymphopoiesis in adult birds are located in the spleen, liver, intestines, and caecal tonsils. An increase in the cell count of lymphocytes is an indication of viral infection.

2.10.1.6Leucocyte (White Cell) Differential Count

According to Mitruka and Rawnsley (1977), leucocyte differential count provides an estimate of the numbers of the 5 main types of white blood cells. These are: neutrophilis; monocytes; lymphocytes; eosinophils; and basophils. Each of the 5 types has a specific role in the body. Neutrophils and monocytes protect the body against bacteria and eat up small particles of foreign matter.

Lymphocytes: Lymphocytes and heterophils are the most numerous white blood cells seen in psittacine birds and are involved in the immune process, producing antibodies against foreign organisms, protecting against viruses and fighting cancer. They decrease in numbers is acute viral infection. The normal proportion of lymphocytes is 20-50% but it varies between species. Such species such as cockatiels and Amazon panels are naturally lymphocytic which means more lymphs than heterophils are seen.

Eosinophils: Eosinophils are responsible for the body's defence against parasitic infection and are involved in allergic responses. High numbers of Eosinophils may be associated with worm infections or exposure to substances

that cause allergic reactions but decreases with anything that suppresses WBC. It ranges in value 1-4% of the TWBC.

Basophils: Basophils also take part in allergic responses and increased basophil production may be associated with bone marrow disorders or viral infection. This is phagocytic in action, engulfing pathogenic microbes. It increases with infection and decreases with stress. It ranges in value from 0.5-1% of TWBC.

Monocytes: Monocytes are the largest WBC's found in the avian blood and they are very similar in appearance to lymphocytes.

They occur in small numbers with a normal range of 0.3% an increase (up to 10%) is seen with certain chronic diseases such as psittacosis, systemic fungal infection, Avian TB.

2.11 Review on the Effect of Insect based meal on Performance of Chickens

According to Ravinder *et al.* (1996), insect-based meal such as silkworm pupae meal though only available in small quantities have served to bridge the gap in supply of animal protein sources as well as lower feed cost. Jumaa *et al.* (2014) compared the performance of including different levels of watermelon bug meal on broiler diets and found out that the broilers fed on different inclusion level of watermelon bug meal performed better significantly ($P<0.05$) in terms of weight gain, feed conversion ratio and feed intake as compared with conventional feed. Dube and Tariro (2014) in their experiment of including some insects as feed supplement on broilers found out that feed fortified with *Econsternum delegorguei* and *Macrotermes falciger* performed significantly ($P<0.05$) better in terms of weight gain than commercial feeds. They also reported the same better performance of linear body measurements, feed conversion ratio, protein efficiency ratio and specific growth rate of the broilers implying that such insects- based meal can be substituted with commercial feed without adverse effect or loss of potential to grow to desired levels with

added advantage that insects are cheaper. Solomon and Yusuf (2005) found out in the experiment they conducted on the amino acid profile, proximate and mineral composition of silkworm caterpillar meal as possible alternative to fishmeal in the diets of cultured fish species discovered a much better performance on growth, protein efficiency ratio and specific growth rate than the conventional feed. Also, Ijaiya and Eko (2009) found out in the experiment they conducted with replacing fishmeal with silkworm caterpillar meal that the broiler birds were significantly ($P<0.05$) better in terms of weight gain, feed conversion ratio, protein efficiency ratio and haematological indices. The authors attributed the improved performance of broilers fed with silkworm caterpillar meal to the pleasant aroma, palatability and nutrient availability in insect- meal for adequate growth and development. The authors also reported that the broiler birds recorded higher ($P<0.05$) carcass and organ weight measurements than the commercial diets (control) and also stated that the weight of the carcass and cut- up parts increased almost linearly on increased dietary levels of silkworm meal. Adeniji (2007) who worked on replacement of groundnut cake with maggot meal in broiler diets reported that there was no significant difference ($P>0.05$) in the weight gain, feed intake, feed conversion ratio with increasing levels of maggot meal in the diets of the broilers. The author also noted that from the result of the experiment, maggot meal has high potential in poultry nutrition, particularly being an animal protein source in broiler feed. In terms of the insignificant weight gain, feed intake and feed conversion ratio, broilers can tolerate the 100% maggot meal replacement for groundnut cake in their diet. Nzamujo (1999) also reported that mass production of maggot and other insect species has solution to the high cost of livestock production. Adeyemo and Longe (2008) in their experiment of feeding desert locust meal (*Schistocerca gregaria*) on performance and haematology of broilers found out that there is a significant ($P<0.05$) performance on growth rate, proximate and haematological indices of the broilers. Their result therefore indicated that desert locus has great potential as a protein source in broiler diets without causing any physiological disorder as reflected in the

haematological analysis. Okubanjo *et al.* (2014) in their experiment of carcass and organoleptic qualities of broiler chickens fed maggot meal in replacement for dietary fish meal reported significant differences ($P<0.05$) in carcass composition were observed in the breast, fore back and neck cuts as well as liver. All the other cut –up parts and organ weights were not affected by the inclusion of maggot meal in replacement for fish meal in the diet. Hwangbo *et al.* (2009) who worked on the utilization of maggots, a feed supplement in the production of broiler chickens reported that weight gain was significantly ($P<0.05$) higher in the chicks receiving diets 10% or 15% maggot supplementation than in the control group. However, feed intake and feed conversion ratio were not significantly ($P>0.05$) different among the treatment groups. There was also a significant ($P<0.05$) differences in the carcass weight evaluation of the chicken among the treatment groups. They concluded that the maggots can effectively be used as a diet of low cost for production of high quality carcass and promotion of growth performance in broiler chickens, and also reduction of environmental pollution due to manure. Okah and Onwujiariri (2012) in their experiment of performance of finisher broiler chickens fed maggot meal as a replacement for fish meal reported that feed intake significantly ($P<0.05$) reduced with increase in the level of maggot meal in the diets which also agrees with the findings of Atteh and Ologbenla (1993). Their observed superior growth performance by birds fed maggot meal diets over the control group agreed with the reports of Awoniyi and Aletor (1999) and Awoniyi *et al.* (2000) that maggot meal was not nutritionally inferior to fish meal. They also reported that feed conversion ratio, protein efficiency ratio and specific growth rate of birds fed maggot meal diets were better ($P<0.05$) than those fed the control diet. It therefore follows that the inclusion of maggot meal in the diets of broilers enhanced nutrient utilization than the fish meal-based diet. They also reported a higher significant ($P<0.05$) performance in carcass and organ weight measurement of the broilers fed with maggot meal diet than those fed with fish meal diets. Awoniyi *et al.* (2003) replaced fishmeal with

maggot meal at levels of 25, 50, 75 and 100% respectively with no significant effect on feed intake (P>0.05). The effect of maggot meal supplementation is more visible after three weeks of age and this may be due to the difference in which adults and young broiler chickens utilize the maggot meal protein (Awoniyi *et al.*, 2003). Furthermore, Teguia *et al.* (2002) studied the effect of maggot meal supplementation in broiler nutrition and its effect on performance and carcass characteristics. Results showed that there was no significant effect (P>0.05) regarding weight gain when 10% of the fish meal was replaced with maggot meal as compared with the control group. This may be attributed to the lower crude protein concentration of the control diets as compared with the formulated diets. The authors concluded that weight gain, feed intake, feed conversion ratio, carcass and organ weight measurements were significantly better (P<0.05) when 100% of the fish meal was replaced with maggot meal when compared to the control diet. Gabriel and Idris (1997) studied the utilization of locust meal in poultry diets. Their observed result the chicks fed locus meal diet did not increase in weight than those fed conventional diet of sorghum grains. Hassan (2009) studied the effect of replacing graded levels of fishmeal with grasshopper meal in broiler starter and reported a higher weight gain and significantly (P<0.05) better feed intake, feed conversion ratio, linear body measurements and carcass quality than those on control diet. Wang (2007) who studied the nutritional value of grasshopper for broilers reported that the birds performed significantly (P<0.05) better on grasshopper meal diet than the control diet. The author also stated that insect meal could replace legume grains without adversely affecting all the growth indices in broiler chickens. Chisowa *et al.* (2015) who worked on evaluation of winged termites as sole sources of protein in growing Japanese quails reported no significant (P>0.05) effect on the performance of the birds in terms of weight gain, feed intake, feed conversion ratio of the quails fed with winged termites. They also stated that based on the nutritional value of the insect meal diet, it can effectively serve as a cheaper source of protein in poultry feed formulation.

2.12 Description of Termites

Scientific classification:

Kingdom: Animalia

Phylum: Arthropoda

Class: Insecta

Subclass: Pterygota

Infraclass: Neoptera

Superorder: Dictyoptera

Order: Blattodea

Infraorder: Isoptera

Family: Mastotermitidae

Genus: *Macrotermes*

Species: *bellicosus*

Termites are usually small, measuring between 4 to 15 millimeters (0.16 to 0.59 in) in length (Mbata, 1995). The largest of all extant termites are the queens of the *Macrotermes bellicosus*, measuring up to over 10 centimeters (4 in) in length (McGrew and Collins, 1985).Like other insects, termites have a small tongue-shaped labrum and a clypeus; the clypeus is divided into a postclypeus and anteclypeus. Termite antennae have a number of functions such as the sensing of touch, taste, odours (including pheromones), heat and vibration. The three basic segments of a termite antenna include a scape, a pedicel (typically shorter than the scape), and the flagellum (all segments beyond the scape and pedicel) (De-Foliart, 1999). The mouth parts contain maxillae, a labium, and a set of mandibles. The maxillae and labium have palps that help termite sense food and handling (De-Foliart, 1999).Termites have a ten-segmented abdomen with two plates, the tergites and the sternites (Blum, 1994). The tenth abdominal segment has a pair of short cerci (Fasoranti and Ajiboye, 1993). There are ten tergites, of which nine are wide and one is elongated (Kinyuru *et al.*, 2012). The reproductive organs are similar to those in cockroaches but are more simplified.

2.12.1 Distribution of termites

Termites are found on all continents except Antarctica. The diversity of termite species is low in North America and Europe (10 species known in Europe and 50 in North America), but is high in South America, where over 400 species are known (Mbata, 1995). Of the 3,000 termite species currently classified, 1,000 are found in Africa, where mounds are extremely abundant in certain regions. Approximately 1.1 million active termite mounds can be found in the Northern Kruge National Park alone (Kinyuru *et al.*, 2012). In Asia, there are 435 species of termites, which are mainly distributed in China. Within China, termite species are restricted to mild tropical and subtropical habitats south of the Yangtze River (Kinyuru *et al.*, 2012). In Australia, all ecological groups of termites (damp wood, dry wood, subterranean) are endemic to the country, with over 360 classified species (Kinyuru *et al.*, 2012).

Due to their soft cuticles, termites do not inhabit cool or cold habitats (Mbata, 1995). There are three ecological groups of termites: damp wood, dry wood and subterranean. Damp wood termites are found only in coniferous forests, and dry wood termites are found in hardwood forests; subterranean termites live in widely diverse areas (Mbata, 1995).

2.12.2 Nutritional value of termites

The negative view that most people have of termites prevails in many places, and it often masks the ecological role of these insects as mediators of the process of decomposition of plant organic matter and as agents with influence on the formation of soils and energy and nutrient flows, especially in tropical forests (Vasconcellous and Moura, 2010). It should be emphasized that, from a utilitarian perspective, termites are commonly used insects in traditional popular medicine (Solavan *et al.*, 2006; Alves and Alves, 2011). They are used in the treatment of various diseases that affect humans, such as influenza, asthma, bronchitis, whooping cough, sinusitis, tonsillitis and hoarseness (Alves, 2009). Additionally, these animals have historically been an important

source of food that may contribute to improving human diet, particularly for people who suffer from malnutrition due to a deficit of protein, as they are considered a non-conventional food with great economic and social importance. They have been consumed for generations in many regions of the world, a practice that has increased in popularity in recent years (Shockley and Dossey, 2014).

2.13 Description of African Palm Weevil

Kingdom: Animalia

Phylum: Arthropoda

Sub phylum: Hexapoda

Class: Insecta

Sub class: Pterygota

Order: Coleoptera

Family: Curculionidae

Genus: *Rhynchophorus*

Species: *phoenicis*

Rhynchophorus phoenicis (plates 1) can reach a body length of about 25mm. These large beetles are considered a serious pest in palm plantations particularly damaging young palms mainly Raphia species.

The life cycle of African palm weevil is similar to that of other *Rhynchophorus* species. The adults lay eggs in wounds in the stems of dying or damaged parts of palms. After hatching, the weevil larvae excavate tunnels in the trunk and feed on the shoot and young leaves, frequently leading to the death of the host plants.

Plate 1: *R. phoenicis* showing the presence of acutely tapered scutellum

2.13.1 Distribution of African palm weevil

The genus *Rhynchophorus* is worldwide in distribution. The geographical range extends throughout the Oriental region, Africa and the New World. These species extend eastward from India, through East Pakistan, Burma, Southern Mainland China, Southern Japan, Taiwan, North Vietnam, South Vietnam, Laos, Cambodia, Thailand, Malasia, Indonesia (Sumatra, Java, Borneo and neighbouring islands), Territory of New Guinea and Papua, New Caledonia, other islands in the East Indies and Southern Australia. In Africa, there are two species recorded: *phoenicis* and *quadrangulus*. The geographical range of these species extends from Guinea, across the continent eastward to Uganda and southward to South Africa. In the New World, there are three species recorded: *cruentatus*, *palmarum*, and *ritcheri*. These species range from the United States of America and Cuba southward into Mexico, Central America, South America and the West Indies. Most species of *Rhychophorus* are restricted to their ranges of distribution: *bilineatus* in the oceanic islands in the East Indies; *cruentatus* in the Southern parts of the United States; *distinctus* in Borneo; *ferrugineus* and *vulneratus* throughout the Oriental region and Southern Australia; *lobatus* in Sumatra; *palmarum* from Southern California of the United States of America to South America; *phoenicis* and *quadrangulus* in Africa; *ritcheri* in Peru and Brazil.

2.13.2 Nutritional value of African palm weevil

The larva of the beetle *Rhynchophorus phoenicis* popularly known as "Edible worm" is a delicacy in many parts of Nigeria and other countries in Africa where it is found. The larva is known by various names by the different ethnic groups in Nigeria who strongly believe it to have high nutritive as well as certain pharmaceutical potentials. The mode of preparing it for eating differs from one geographical locality to another. In some places, it is boiled (Ilesha) while others smoke, fry or simply eat it raw (Ibibio's in Akwa Ibom State, and Igbos in Anambra state). It may be consumed as part of meal or as a complete

meal with Tapioca or bread (Urhobo's in Delta State). Some tribes (Urhobo's and Isoko's, both in Delta State) strongly recommend it to their pregnant women, probably as a source of essential nutrients (Ekpo, 2003). The use of the larva of *Rhynchophorus phoenicis* is believed to extend beyond the nutritional value. Traditionally, many claim that the larva has medicinal properties. For example, the Itsekiri's in Delta state believe that the live larva could cure a certain ailment in infants which presents such symptoms as the twitching of the hands and feet, restlessness and other such movements. To affect cure for these conditions, the larvae are left in water which is then used to bathe the child for several days at the end of which the larvae are crushed together with alligator pepper and administered orally to the child. The biochemical basis for this treatment is not known.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area

The study was carried out in a mini – poultry research station at Iyi – Enu, Ogidi in Idemili North Local Government Area, Anambra State of Nigeria. Ogidi is a town located between latitude 6^0N and 7^0N and longitude 7^0N and 8^0N. It is located along the Enugu – Onitsha Old Road. Ecologically, it lies in the tropical region experiencing an annual rainfall of 1500mm – 2000mm with two seasons – the dry and rainy season and average annual temperature of 26.8^0C (Okafor, 2011).

The station has an area of $100m^2$ (50m x 50m) and poultry houses were pitched in an East- west orientation to protect it from direct rain and sunlight. Each enclosure was roofed with aluminum roofing sheets and sealed with ceiling boards. There were plantain trees, coconut trees and rich vegetation around the farm to minimize wind effect.

3.2 Production and Processing of African Palm Weevil Larvae (APWL)

Raffia palm trees used for the project were obtained from Ebenebe town in Awka South Local Government Area of Anambra State. The raffia palms (Plate 5) were cut into 2m length logs, 40 in number and transported to the study area. The individual logs were placed under a shade and adult APW (Plate 3) were introduced into the enclosure where the logs were kept and covered with flaps of palm bark thereby providing a protected space for the adult weevils. The logs were moistened with two liters of water per log once every two days to avoid drying up. After approximately 3 months, cracking and wiggling sounds were heard among the logs; showing presence of larvae in the logs (Plate 7). Each log produced approximately an average of 3kg larvae. The harvested larvae were oven dried at a temperature of 50^0C until they were dried and crispy. The larvae were then milled using a mechanized milling machine (Model A 02).

3.3 Identification of African Palm Weevil Larvae (APWL)

African palm weevil (*Rhynchophorus phoenicis*) is the species of *Rhynchophorus* in Africa. However, weevils were identified by the presence of acutely tapered scutellum (Giblin – Davis *et al.*, 2013). They were sexed based on the presence of a tuft of fine bristles on the dorsal end of the rostrum in males and which were absent in females according to Giblin – Davis *et al.* (2013) and El-Shafie *et al.* (2013). African palm weevil larvae are yellowish- white, legless and oval, with a reddish – brown head capsule; at maturity they are about 5 – 6cm long and the abdomen is about 1.5 – 2cm (Giblin – Davis *et al.*, 2013).

3.4 Collection and Processing of Winged Termite (WT)

The nights after the rains have fallen; basins of water were placed under hung lamps (Plate 6) in various locations and also basins of water were placed half way into a shallow pit in the soil with lamps hung overhead while some were placed under electric bulbs on the outside of residential buildings. As the termites are attracted to light, many of them fell into the basin of water. The harvested termites were oven dried at a temperature of 50^0C until they were dried and crispy. The larvae were then milled using milling machine (Model A 02).

3.5 Preparation of Brooder House

The brooder house was demarcated with ply woods into nine pens of 1.5sqmeters floor space allowance for each pen. Heat for brooding was supplied using kerosene stove under a metal brooder supplemented with 200watts of electric bulb. Also, tarpaulin was used to cover the wire-netted parts of the building to prevent cold during brooding. Wood shaving was provided as the litter cover for each pen to the depth of 7.5cm level. One feeder and drinker per pen was also provided. The brooder house was properly cleaned and disinfected two weeks to the arrival of the chicks to kill disease microbes.

3.6 Procurement of Study Animals

One hundred and thirty-five (135) day old *Arbor acre* broiler chicks in number were procured from CHI farms Ltd located in Ibadan, Oyo State. The birds were transported using a motor vehicle in the early hours of the morning to minimize transit stress in a ventilated box. Upon arrival, the birds were provided with 4 liters of glucose water to cushion out the effect of stress on them.

3.7 Formulation of Experimental Diets

The ingredients for the broilers starter and finisher were purchased from Ose main market, Onitsha. Two diets were formulated as experimental diet while a standard diet of the brand vital feed purchased from the open market was used as control. The feed was formulated with an assistance of nutritionists.

Diet A (which is the control diet was a commercial broiler starter and finisher feeds of the brand name "Vital" procured from open market).

Diet B (consisted of formulated broiler starter and finisher mash with African Palm Weevil Larvae meal).

Diet C (consisted of formulated broiler starter and finisher mash with winged termite meal) as shown in Table 1 below.

Diets A, B and C were used in Treatments I, II and III respectively.

Table 1: Gross composition of the formulated feeds (%)

	Broiler starter		Broiler finisher	
Ingredients	**APWLM**	**WTM**	**APWLM**	**WTM**
Maize	45.0	45.0	40.60	40.60
Wheat offal	7.72	7.72	15.0	15.0
P.K.C	28.06	28.06	26.0	26.0
Insect meal**	15.0	15.0	12.0	12.0
Bone meal	3.0	3.0	5.0	5.0
Premix	0.25	0.25	0.2	0.2
Methionine	0.25	0.25	0.3	0.3
Lysine	0.2	0.2	0.2	0.2
Salt	0.3	0.3	0.3	0.3
Enzyme	0.2	0.2	0.2	0.2
Toxynil	0.02	0.02	0.2	0.2
Total	100	100	100	100

APWLM: African palm weevil larvae based meal; WTM: Winged termite based meal

3.8 Experimental Design

The birds were weighed and randomly assigned to three dietary treatments, TI, comprised birds on Diet A without inclusion of any insect meal, TII consisted of birds on Diet B with African palm weevil larvae meal and TIII comprised of birds on Diet C with winged termite meal. Each treatment comprised 15 birds, with each treatment replicated three times in a Completely Randomized Design (CRD) experiment.

3.9 Brooding Management

Six hours prior to the arrival of the chicks to the experimental farm, the electric bulbs were switched on to preheat the brooder house. The one hundred and thirty-five (135) day old *Arbor acre* broiler chicks were then randomly assigned to each of the nine (9) pens; three pens represented the three replicates of each dietary treatment. Within this period of brooding, the birds were allowed to acclimatize in the environment for one week. Brooding was carried out for four weeks. One conical feeder size of 34.25cm and conical drinker of 3litre capacity water fountain each were provided for each pen. Equal amount of starter feed was provided for the chicks with respect to the different dietary treatments daily and one 3liter capacity water fountain of drinking water was also provided for the first four weeks of life. Every morning, leftover feed was properly weighed and recorded accordingly; the feeders and drinkers were properly cleaned daily before provision of fresh water and feed. Wet litters were packed out and replaced with dry litters. Lasota vaccine for prevention of Newcastle disease was administered at the 7th day of the bird's arrival and repeated on the 21st day. Gumboro vaccine for prevention of Infectious Bursal Disease (Gumboro) was administered at the 14th day and repeated at the 28th day of the bird's arrival.

3.10 Management of Brooded chicks

After four weeks of brooding, the hover and tarpaulin were removed. Two conical feeders of size 56cm and one 3litre capacity drinker each were provided for each pen. Exact quantities of finisher feed were provided for the chicks with respect to the different dietary treatments daily and 8 liters of drinking water were also provided. Every morning, leftover feed was properly weighed and recorded accordingly; the feeders and drinkers were properly cleaned. Wet litters were packed out and replaced with dry fresh litter.

3.11 Data Collection

a) Growth performance records

The data collected include:

i) Feed intake: This was determined using the formular:

Weight of feed given – weight of feed leftover at the end of each day

The feed given and left over were weighed using a sensitive weighing balance (Model EK 5055) to the nearest 0.1g.

ii) Weight gain: Weights of the broiler birds (Plate 11) were taken weekly for 8 weeks to the nearest 0.1g with the aid of a sensitive electronic balance (Model EK 5055).

$$\textbf{Weekly Weight gain (WG)} = \frac{W_2 - W_1}{T_2 - T_1}$$

Where W_1 = mean Initial weight

W_2 = mean Final weight

t_1 = Initial time

t_2 = Final time

iii) Feed Conversion Ratio$= \frac{Feed\ consumed}{Weight\ gain}$

iv) Feed Efficiency Ratio$= \frac{Weight\ gain}{Feed\ consumed}$

v)Specific Growth Rate$= \frac{Log_{10} final\ weight - Log_{10}\ initial\ weight}{time(days)} \times 100$

b) Linear body measurements

Linear body measurements were taken as additional growth index. Measurements taken included

i) Body length was taken as the length from the tip of the beak to the uropigeal gland.

ii) Body width was taken as the circumference of the body at the tip of the pectus.

iii) Thigh length was taken as the length between the mid region of the coxa (hip bone) and that of genu (knee) on the right limb.

iv) Shank length was taken as the length from the hock joint to the base of the three toes (i.e. length between the genu and the Regiotarslis on the right limb).

v) Wing length was taken as length from the shoulder to the tip of the longest primary feathers.

vi) Neck length measurement covers the entire length of straight axial skeleton (i.e. the first neck bone of the skull and the last cervical vertebrae at the shoulder point).

All measurements were taken to the nearest 0.1cm.

c) Carcass characteristics and organ weight measurements

After the eight weeks of the experiment, one bird from each replicate was randomly selected for carcass and organ weight evaluation after starving them

overnight though water was made available for them. The birds were weighed, slaughtered by severing the jugular vein and allowed to bleed thoroughly according to the methods recommended by Odunsi *et al.* (2007). The birds were scalded at 75^0C in water bath for about thirty seconds before defeathering and then the birds were reweighed to know the defeathered weight by difference (Plate 11). The dressed chickens were later eviscerated (Plate 13); the wings were removed by cutting anteriorly severing at the humeo-scapular joint. The cuts were made through the rib head to the shoulder girdle; the back was removed intact by pulling anteriorly. The wings, thigh, breast and organs were dissected from each carcass and weighed separately with a sensitive weighing balance (Model EK 5055). The carcass and body organs weight were taken on a fresh basis (Plates 14 and 15).

d) Haematology

Blood samples were collected from the wing vein of experimental birds by bleeding (Plate 16) from three randomly selected birds per replicate for haematological studies. The blood samples were taken twice for this study (at the end of the starter phase, and at the end of the finisher phase). At the end of each phase, 2ml of blood was collected. Bleeding was done by pricking the vein under the wing. The blood collected in syringe was put inside clean bottles. One needle per syringe per bird was used for bleeding. The samples were cooled at 4^0C using ice packs and transferred to Soniraph laboratory, Onitsha for analysis within 12hrs of collection. The following haematological parameters were analyzed from the collected blood samples

1. Haemoglobin concentration (Hb)
2. Red blood cells count (RBC)
3. White blood cells count (WBC)
4. Packed cell volume (PCV)

1. **Packed Cell Volume**

   This was done using the microhaematocrit method (Coles, 1986). The heparinized capillary tubes were used to collect blood from the sample

bottle after gentle mixing of the blood up to three quarter full. One end of the blood-filled capillary tube was sealed with plastacine and then centrifuged in microhaematocrit centrifuge (model SH 120-1) for 5 minutes at 10,000 rpm. The PCV was read as a percentage using the microheamatocrit reader.

2. **Haemoglobin concentration**

   This was determined as described by Schalm *et al.* (1975) using the Cyanomet haemogloblin method. Five (5mls) of drabkins solution was added to test-tubes containing 20µl of blood sample and mixed properly. The absorbance of the samples was read against the sample blank using a spectrophotometer at wavelength of 540nm. The absorbance obtained were multiplied by a constant to give the Hb concentration in g/dl.

3. **White Blood Cell (Total Leucocyte Count**

   The WBC was counted using the modified Naubauer chamber (Coles, 1986). White blood cell diluting fluid (380µl) was added to test-tube containing 20µl of blood sample and mixed properly. The counting chamber was charged with the diluted cells and mounted on a microscope. This was allowed to settle for a while, viewed using the ×10 objective lens and counted with a hand held tally counter. The WBCs were counted using the 4 corner squares and the number obtained multiplied by 50 and recorded as thousand cells per cubic millimeter ($\times 10^3 cells/mm^3$).

4. **Red Blood Cell (Total Erythrocyte Count)**

   This was determined using the haemocytometer method as described by Schalm *et al.* (1975). Blood samples (0.02ml) were pipetted and added to 4ml of RBC diluting fluid in a clean test tube to make a 1:20 dilution of the blood sample. The diluted blood samples were loaded into a Neubauer counting chamber and all red blood cells in the five groups of 16small squares in the central area of the Neubauer chamber were counted using a light microscope at x10 eyepiece and x40 objective lens.

The number of cells enumerated for each sample were multiplied by 10^6 to obtain the red blood cell count per microliter of blood.

e) Nutrient composition of chicken meat from each dietary treatment

The meat samples of the broiler chicken, African Palm Weevil larvae and winged termites were randomly collected from each of the experimental diets and sent to Springboard Laboratories, Awka. The meats collected were analyzed in laboratory with the assistance of the laboratory scientists for proximate composition according to AOAC (2005) and mineral concentration.

Dry matter: A petri – dish was washed and dried in the oven

i. Exactly 2g of the sample was weighed into petri dish
ii. The weight of the petri dish and sample was noted before drying
iii. The petri dish and sample were put in the oven for another 30minutes and the weight was noted
iv. The drying procedure was continued until a constant weight was obtained

%dry matter = W1 – W2/

Weight of sample × 100

Where W1 = weight of petri dish and sample before drying

W2 = weight of petri dish and sample after drying

Ash: Ash is the inorganic residue remaining after the organic matter has been burnt away.

i. Empty platinum crucible was washed, dried and the weight was noted.
ii. Exactly 5g of wet sample was weighed into the platinum crucible and placed in a muffle furnace at 600^0c for 3 hours
iii. The sample was cooled in a dessicator after burning and weighed
    a. %ash = W2 – W1/W3 – W1 × 100

Where,

W1 = weight of empty platinum crucible

W2 = weight of platinum crucible and sample before burning

W3 = weight of platinum crucible and sample after burning

Crude protein: The method used was the digestion of sample with hot concentrated sulphuric acid in the presence of a metallic catalyst. Organic nitrogen in the sample is reduced to ammonia. This is retained in the solution as ammonium sulphate. The solution is made alkaline, and then distilled to release the ammonia. The ammonia is trapped in dilute acid and then titrated.

i. Exactly 1g of sample was weighed into 30ml of Kjedahl flask (gently to prevent the sample from touching the walls of each side and then the flasks were stoppered and shaken. Then 1g of the Kjedahl catalyst mixture was added. The mixture was heated cautiously in a digestion rack under fire until a clear solution appeared
ii. The clear solution was then allowed to stand for 30minutes and cool. After cooling, about 100ml of distilled water was added to avoid caking and then 50ml was transferred to the kjedahl distillation apparatus (Plate 4.14).
iii. A 100ml receiver flask containing 5ml of 2% boric acid and indicator mixture containing 5 drops of Bromocresol blue and 1 drop of methylene blue was placed under a condenser of the distillation apparatus so that the tap was about 20cm inside the solution. The 5ml of 40% sodium hydroxide was added to the digested sample in the apparatus and distillation commenced immediately until 50 drops gets into the receiver flask, after which it was titrated to pink colour using 0.01N hydrochloric acid.

    %Nitrogen = Titre value × 0.01 × 14 × 4

    %Protein = %Nitrogen × 6.25

Crude fibre:

i. 2g of the material was defatted with petroleum ether; it was then boiled under reflux for 30minutes with 200ml of a solution containing 1.25g of H_2SO_4 per 100ml of solution.
ii. The solution was filtered through linen on a fluted funnel, the residue was then washed with boiling water and transferred to a beaker and boiled for 30minutes with 200ml of a solution containing 1.25g of carbonate free NaOH per 100ml.
iii. The final residue was filtered through a thin but close pad of washed and ignited asbestos in a Gooch crucible. It was dried in an electric oven and weighed; incinerated, cooled and weighed again. The loss in weight after incineration × 100 is the percentage of crude fibre.

$$\% \text{ Crude fibre} = \frac{\text{Weight of fibre}}{\text{Weight of sample}} \text{x } 100$$

Crude fat: The method used was that involving continuous extraction of food with non- polar organic solvent such as petroleum ether for 1hour. Dried 250ml clean boiling flasks was placed in oven at 105-110^{0}C for about 30mintues.

i. It was then transferred into a dessicator and allowed to cool. The boiling flask was filled with 300ml of petroleum ether.
ii. The extraction thimble was lightly plugged with cotton wool. The Soxhlet apparatus was assembled and allowed to reflux for 6hours. The thimble was removed with care and petroleum ether was collected in the top container of the set – up and drained into a container for re – use.
iii. When the flask was almost free of petroleum ether, it was removed and dried at 105 -110^{0}C for 1hour. It was transferred from the oven into a dessicator and allowed to cool; then weighed.

Carbohydrate Determination: Differential method

100 – (%protein + %Moisture + %Ash + %Fat + % Fibre)

Minerals were determined by Atomic Absorption Spectrophotometry (AAS) (Plate 19) according to the method of APHA, 1995. The sample was thoroughly mixed by shaking, and 100ml of it was transferred into a glass beaker of 250ml volume, to which 5ml of conc. Nitric acid was added and heated to boil till the volume was reduced to about 15 – 20ml, by adding Concentrated Nitric acid in increments of 5ml till all the residues were completely dissolved. The mixture was cooled, transferred and made up to 100ml using metal free distilled water. The sample was aspirated into the oxidizing air – acetylene flame. When the aqueous sample was aspirated, the sensitivity for 1% absorption was observed using Buck 200 (Buck scientific, UK). Calcium was by flame photometry using Jenway digital flame photometer (Babalola and Akinsoyinu, 2011).

3.12 Assessment of Economic Benefit of the Insect based diets

The economic benefit of the insect based diets was assessed using the production and cost of culture medium, the collection of the winged termites and cost of experimental diet ingredients given the current market price.

3.13 Statistical Analysis

The data collected on each of the parameters studied – weight gain, feed intake, feed conversion ratio, feed efficiency ratio, specific growth rate, linear body measurement, carcass and organ weight, haematological analysis and nutrient composition for each of the dietary treatments were separately subjected to analysis of variance (ANOVA) in a completely randomized design (CRD). Difference among the treatment means were separated using the least significant difference (LSD) at 95% confidence limit.

CHAPTER FOUR

RESULTS

4.1 Proximate Analysis of Experimental Diets

The proximate analyses of the experimental diets; Diet 1(Commercial Vital feeds Control), Diet 2 containing African palm weevil larvae meal (APWLM) and Diet 3 containing winged termite meal (WTM) starter and finisher feeds and the edible insects are presented in the tables below:

Table 2: Proximate composition (%) of experimental diets (Starter feeds) I, II and III

Parameters	Treatment I (Control)	Treatment II (APWLM)	Treatment III (WTM)
Crude protein	20.02	20.15	20.36
Moisture	7.60	8.30	8.15
Crude fibre	3.10	3.80	3.65
Crude fat	7.00	6.25	6.35
Ash	6.22	6.60	6.68
Carbohydrate	56.06	54.90	54.81
Energy	3000.00	3110.10	3115.10

****APWLM= African palm weevil larvae meal, WTM= winged termite meal, control= commercial feed of brand name 'vital feed'**

Table 3: Proximate composition (%) of experimental diets (Finisher feeds) I, II and III

Parameters	Treatment I (Control)	Treatment II (APWLM)	Treatment III (WTM)
Crude protein	17.26	17.48	17.60
Moisture	7.65	8.10	8.05
Crude fibre	4.00	4.25	4.20
Crude fat	7.82	6.80	6.85
Ash	7.00	7.56	7.40
Carbohydrate	56.27	55.81	55.90
Energy	2960.10	2990.15	2995.10

****APWLM= African palm weevil larvae meal, WTM= winged termite meal, control= commercial feed of brand name 'vital feed'**

The table shows equiprotein and equicaloric composition of the broiler finisher feed.

Table 4: Proximate composition (%) of the Insects used in feed formulation

Parameters	APL	WT
Moisture	1.82	10.78
Dry matter	96.25	74.60
Ash	4.54	7.60
Crude protein	50.35	30.94
Crude fat	18.20	10.71

****APL= African palm larvae; WT= winged termite**

Table 4 shows that African palm weevil larvae have more crude protein and crude fat than the winged termite.

4.2 Weekly Mean Weight of Broiler Chicken

The weekly mean weight of the broiler chicken subjected to the dietary treatments I, II and III for 8 weeks is presented in Tables 5a and 5b below:

Table 5a: Weekly mean weight records (g) of broiler chickens subjected to three dietary treatments for 8weeks

Treatments	Wk0	Wk1	Wk2	Wk3	Wk4	Wk5	Wk6	Wk7	Wk8
I	47.10±0.22	120.08±1.20	279.42±2.82	540.86±4.02	827.92±4.70	1099.89±59.80	1216.82±56.64	1428.67±42.89	1605.07±26.36
II	46.98±0.28	125.14±1.25	289.06±2.86	611.85±6.01	958.39±4.13	1292.71±14.15	1628.16±41.60	2056.71±24.84	2200.85±47.57
III	50.00±0.12	123.31±1.78	284.88±1.85	587.91±10.58	915.95±17.05	1240.54±10.88	1480.85±20.88	1843.83±30.28	2046.23±5.18

Table 5b: Summary of Mean weight gain (g) of broiler chickens subjected to three dietary treatments for 8weeks

Parameters	I	II	III
Initial mean weight	47.10±0.22	46.98±0.28	50.00±0.12
Final mean weight	1605.07±26.36	2200.85±47.57	2046.23±5.18
Mean weight gain	1557.98±10.24	2153.87±8.60	1996.23±15.32

Data presented in Table 5a were summarized in Table 5b. The highest mean weight gain was recorded in chickens subjected to treatment II (2153.87±8.60g) followed by treatment III (1996.23±15.32g) while the least weight gain was recorded for treatment I (1557.98±10.24g).

4.3 Weekly mean feed intake of broiler chicken

The weekly mean feed intake of the broiler chickens subjected to the dietary treatments I, II and III for 8 weeks is presented in Table 6 below:

Table 6: Weekly mean feed intake (g) of broiler chickens subjected to three dietary treatments for 8weeks

Treatments	Wk1	Wk2	Wk3	Wk4	Wk5	Wk6	Wk7	Wk8
I	852.26± 158.47	1227.33±43.39	1521.48±76.90	2104.30±169.63	2601.22±220.06	3804.74±67.24	4611.72±109.39	5827.52± 206.42
II	821.71±121.85	1216.07±43.28	1506.11±74.84	2064.60±132.46	2404.55±193.62	3777.18±72.96	4291.99±108.25	5616.38± 206.50
III	842.91±146.62	1223.49±42.25	1515.44±78.58	2093.21±143.92	2473.33±167.46	3790.95±70.70	4404.23±109.38	5621.74± 207.88

Table 6 highlights the mean feed intake of broiler chicken subjected to the dietary treatments for 8 weeks. The highest mean feed intake was recorded in chickens subjected to treatment I followed by treatment III while the least feed intake was recorded for treatment II.

4.4 Feed conversion ratio of broiler chickens

The feed conversion ratio of the broiler chickens subjected to the dietary treatments I, II and III is presented in Table 7 below:

Table 7: Feed conversion ratio (FCR) of the broiler chicken

Treatments	Feed fed (g)	Feed leftover (g)	Feed consumed (g)	Weight gain (g)	FCR
I	3500.00	681.68	2818.82	1557.98	1.809
II	3500.00	787.68	2712.32	2153.87	1.259
III	3500.00	754.34	2745.66	1996.23	1.375

Table 7 highlights the feed conversion ratio of broiler chickens subjected to the dietary treatments. The highest feed conversion ratio was recorded in chickens subjected to treatment I followed by treatment III while the least feed conversion ratio was recorded for treatment II. Treatment II showed best feed conversion potential as evident in better weight gain recorded.

4.5 Specific growth rate of broiler chicken

The specific growth rate of the broiler chickens subjected to the dietary treatments I, II and III is presented in Table 8 below:

Table 8: Specific growth rate (SGR) of the broiler chicken

Treatments	Initial weight	Final weight	SGR
I	47.09	1605.07	0.2175
II	46.98	2200.85	0.0357
III	46.99	2046.23	0.0325

Table 8 highlights the specific growth rate of broiler chickens subjected to the dietary treatments. The best specific growth rate was recorded in chickens subjected to treatment III followed by treatment II while the least specific growth rate was recorded for treatment I.

4.6 Feed efficiency ratio of broiler chicken

The feed efficiency ratio of the broiler chickens subjected to the dietary treatments I, II and III is presented in Table 9 below:

Table 9: Feed efficiency ratio (FER) of the broiler chickens

Treatments	Feed fed (g)	Feed leftover (g)	Feed consumed (g)	Weight gain (g)	FER
I	3500.00	681.68	2818.82	1557.98	0.552
II	3500.00	787.68	2712.32	2153.87	0.794
III	3500.00	754.34	2745.66	1996.23	0.727

Table 9 highlights the feed efficiency ratio of broiler chickens subjected to the dietary treatments. The highest feed efficiency ratio was recorded in chickens subjected to treatment II followed by treatment III while the least feed efficiency ratio was recorded for treatment I.

4.7 Effect of insect meal on growth performance indices of broiler chicks

The effects of the insect meal on growth performance of the broiler chicks are shown on Table below:

Table 10: Effect of Insect Meal on Growth Performance Indices of Broiler Chicks

Parameters	Treatment I (Control)	Treatment II (APWLM)	Treatment III (WTM)
Initial weight (g)	47.10±0.22	46.98±0.28	50.00±0.12
Final weight (g)	1605.07±26.36	2200.85±47.57	2046.23±5.18
Weight gain (g)	1557.98±10.24^{c}	2153.87±8.60^{a}	1996.23±15.32^{b}
Total feed intake(g)	2818.82±196.42^{a}	2712.32±134.21^{c}	2745.66±140.10^{b}
Average daily feed intake (g/day)	93.96^{a}	90.41^{c}	91.52^{b}
Feed conversion ratio	1.809^{a}	1.259^{c}	1.375^{b}
Specific growth rate	0.217^{a}	0.035^{b}	0.032^{c}
Feed efficiency ratio	0.552^{c}	0.794^{a}	0.727^{b}

****APWLM= African palm weevil larvae meal, WTM= winged termite meal, control= commercial feed of brand name 'vital feed'; a,b,c means with different superscript in a row are significantly different (P<0.05)**

From Table 10 above, the mean weight gains of broiler chickens subjected to different dietary treatments showed high significant difference ($P<0.05$) across each dietary treatments. There was a significant difference ($P<0.05$) in the feed intake, feed conversion ratio, specific growth rate and feed efficiency ratio of the broiler chickens among each dietary treatments.

4.8 Weekly mean body length of broiler chicken

The weekly mean body length of the broiler chickens subjected to the dietary treatments I, II and III for 8 weeks is presented in Tables 11a and 11b-below

Table 11a: Weekly mean body length records (cm) of broiler chicken subjected to three dietary treatments for 8weeks

Treatments	Wk0	Wk1	Wk2	Wk3	Wk4	Wk5	Wk6	Wk7	Wk8
I	13.60±0.60	15.10±0.10	21.03±0.59	23.30±1.05	25.83±0.59	31.07±2.20	32.60±2.55	35.97±4.72	39.47±3.00
II	13.57±0.67	15.60±0.20	23.97±0.47	27.90±0.61	30.37±0.71	38.77±1.99	40.70±1.81	41.90±1.15	43.43±1.56
III	13.63±0.40	15.40±0.10	22.93±0.61	27.13±0.55	28.87±1.55	35.93±1.92	38.23±1.85	39.80±1.18	42.57±0.81

Table 11b: Summary of mean body length increase (cm) of broiler chicken subjected to three dietary treatments for 8weeks

Parameters	I	II	III
Initial mean body length	13.60±0.60	13.57±0.67	13.63±0.40
Final mean body length	39.47±3.00	43.43±1.56	42.57±0.81
Mean body length increase	25.87±2.10	29.86±4.00	28.94±3.12

Data presented in Table 11a were summarized in Table 11b. Table 11b highlights the mean body length increase of broiler chickens subjected to the dietary treatments for 8 weeks. The highest mean body length increase was recorded in chickens subjected to treatment II (29.86±4.00) followed by treatment III (28.94±3.12) while the least body length increase was recorded for treatment I (25.87±2.10).

4.9 Weekly mean body width of broiler chicken

The weekly mean body width of the broiler chickens subjected to the dietary treatments I, II and III for 8 weeks is presented in Tables 12a and 12b below:

Table 12a: Weekly mean body width records (cm) of broiler chicken subjected to three dietary treatments for 8weeks

Treatments	Wk0	Wk1	Wk2	Wk3	Wk4	Wk5	Wk6	Wk7	Wk8
I	12.70±0.98	13.73±0.21	17.97±0.57	22.10±0.46	24.93±0.42	28.50±1.45	30.53±1.40	33.50±1.50	36.50±1.47
II	13.07±1.00	14.20±0.30	23.23±0.38	26.23±0.72	29.26±0.70	36.20±0.80	38.57±0.40	40.97±0.68	43.27±0.8
III	12.67±0.85	13.97±0.15	21.50±0.95	24.33±0.67	27.03±0.47	33.30±0.82	35.60±1.31	38.93±1.02	41.37±1.11

Table 12b: Summary of mean body width increase (cm) of broiler chicken subjected to three dietary treatments for 8weeks

Parameters	I	II	III
Initial mean body width	12.70±0.98	13.07±1.00	12.67±0.85
Final mean body width	36.50±1.47	43.27±0.8	41.37±1.11
Mean body width increase	23.80±2.10	30.20±3.15	28.70±4.30

Data presented in Table 12a were summarized in Table 12b. Table 12b highlights the mean body width increase of broiler chickens subjected to the dietary treatments for 8 weeks. The highest mean body width increase was recorded in chickens subjected to treatment II (30.20±3.15) followed by treatment III (28.70±4.30) while the least body width increase was recorded for treatment I (23.80±2.10).

4.10 Weekly mean thigh length of broiler chicken

The weekly mean thigh length of the broiler chickens subjected to the dietary treatments I, II and III for 8 weeks is presented in Tables 13a and 13b below:

Table 13a: Weekly mean thigh length records (cm) of broiler chicken subjected to three dietary treatments for 8weeks

Treatments	Wk0	Wk1	Wk2	Wk3	Wk4	Wk5	Wk6	Wk7	Wk8
I	3.77±0.49	4.23±0.21	6.03±0.15	6.87±0.31	8.13±0.35	9.77±0.25	10.17±0.21	12.13±0.55	13.03±0.21
II	3.83±0.21	4.60±0.26	7.60±0.56	8.23±0.35	9.53±0.95	11.97±0.15	12.23±0.25	14.27±0.25	15.70±0.70
III	3.60±0.10	4.53±0.06	6.90±0.10	7.53±0.31	9.00±0.72	10.80±0.53	11.30±0.44	12.80±0.61	14.13±0.35

Table 13b: Summary of mean thigh length increase (cm) of broiler chickens subjected to three dietary treatments for 8weeks

Parameters	I	II	III
Initial mean thigh length	3.77±0.49	3.83±0.21	3.60±0.10
Final mean thigh length	13.03±0.21	15.70±0.70	14.13±0.35
Mean thigh length increase	9.26±2.10	11.87±1.50	10.53±2.10

Data presented in Table 13a were summarized in Table 13b. Table 13b highlights the mean thigh length increase of broiler chickens subjected to the dietary treatments for 8 weeks. The highest mean thigh length increase was recorded in chickens subjected to treatment II (11.87±1.50) followed by those in treatment III (10.53±2.10) while the least mean thigh length increase was recorded for treatment I (9.26±2.10).

4.11 Weekly mean shank length of broiler chicken

The weekly mean shank length of the broiler chickens subjected to the dietary treatments I, II and III for 8 weeks is presented in Tables 14a and 14b below:

Table 14a: Weekly mean shank length records (cm) of broiler chicken subjected to three dietary treatments for 8week

Treatments	Wk0	Wk1	Wk2	Wk3	Wk4	Wk5	Wk6	Wk7	Wk8
I	2.57±0.35	3.33±0.31	4.37±0.32	4.97±0.15	5.77±0.55	7.67±0.31	8.10±0.36	8.53±0.42	9.10±0.36
II	2.70±0.30	3.83±0.15	5.13±0.42	5.80±0.20	6.97±0.15	8.67±0.31	9.00±0.20	9.30±0.26	9.83±0.25
III	2.47±0.06	3.77±0.25	4.87±0.21	5.33±0.15	6.40±0.53	8.03±0.45	8.40±0.53	8.90±0.46	9.37±0.55

Table 14b: Summary of mean shank length increase (cm) of broiler chicken subjected to three dietary treatments for 8weeks

Parameters	I	II	III
Initial mean shank length	2.57±0.35	2.70±0.30	2.47±0.06
Final mean shank length	9.10±0.36	9.83±0.25	9.37±0.55
Mean shank length increase	6.53±0.45	7.13±0.60	6.90±0.54

Data presented in Table 14a were summarized in Table 14b. Table 14b highlights the mean shank length increase of broiler chickens subjected to the dietary treatments for 8 weeks. The highest mean shank length increase was recorded in chickens subjected to treatment II (7.13±0.60) followed by treatment III (6.90±0.54) while the least mean thigh length increase was recorded for treatment I (6.53±0.45).

4.12 Weekly mean wing length of broiler chicken

The weekly mean wing length of the broiler chicken subjected to the dietary treatments I, II and III for 8 weeks is presented in Tables 15a and 15b below:

Table 15a: Weekly mean wing length records (cm) of broiler chicken subjected to three dietary treatments for 8 weeks

Treatments	Wk0	Wk1	Wk2	Wk3	Wk4	Wk5	Wk6	Wk7	Wk8
I	4.63±0.21	6.00±0.20	8.00±0.60	10.57±0.55	14.27±0.50	14.93±0.31	15.97±0.15	17.90±0.36	18.77±0.38
II	4.40±0.40	6.90±0.10	12.30±0.10	12.67±0.31	16.23±0.38	17.30±0.26	18.00±0.20	20.83±0.76	22.83±0.35
III	4.47±0.15	6.70±0.10	11.23±0.83	11.73±0.83	15.13±0.50	16.93±0.12	17.23±0.25	19.00±0.50	20.50±0.89

Table 15b: Summary of mean wing length increase (cm) of broiler chicken subjected to three dietary treatments for 8weeks

Parameters	I	II	III
Initial mean wing length	4.63±0.21	4.40±0.40	4.47±0.15
Final mean wing length	18.77±0.38	22.83±0.35	20.50±0.89
Mean wing length increase	14.14±2.12	18.43±2.40	16.03±3.10

Data presented in Table 15a were summarized in Table 15b. Table 15b highlights the mean wing length increase of broiler chickens subjected to the dietary treatments for 8 weeks. The highest mean wing length increase was recorded in chickens subjected to treatment II (18.43±2.40) followed by treatment III (16.03±3.10) while the least mean thigh length increase was recorded for treatment I (14.14±2.12).

4.13 Weekly mean neck length of broiler chicken

The weekly mean neck length of the broiler chicken subjected to the dietary treatments I, II and III for 8 weeks is presented in Tables 16a and 16b below:

Table 16a: Weekly mean neck length records (cm) of broiler chicken subjected to three dietary treatments for 8weeks

Treatments	Wk0	Wk1	Wk2	Wk3	Wk4	Wk5	Wk6	Wk7	Wk8
I	4.80±0.20	5.37±0.25	6.00±0.20	6.80±0.20	7.43±0.21	9.37±0.71	10.06±0.50	10.77±0.25	11.27±0.50
II	4.70±0.56	6.53±0.31	7.23±0.15	7.63±0.15	9.10±0.56	10.63±0.32	11.27±0.64	11.80±0.61	13.00±0.50
III	4.80±0.20	5.90±0.26	6.73±0.31	7.20±0.26	8.17±0.49	10.67±0.42	11.03±0.45	11.77±0.25	12.10±0.36

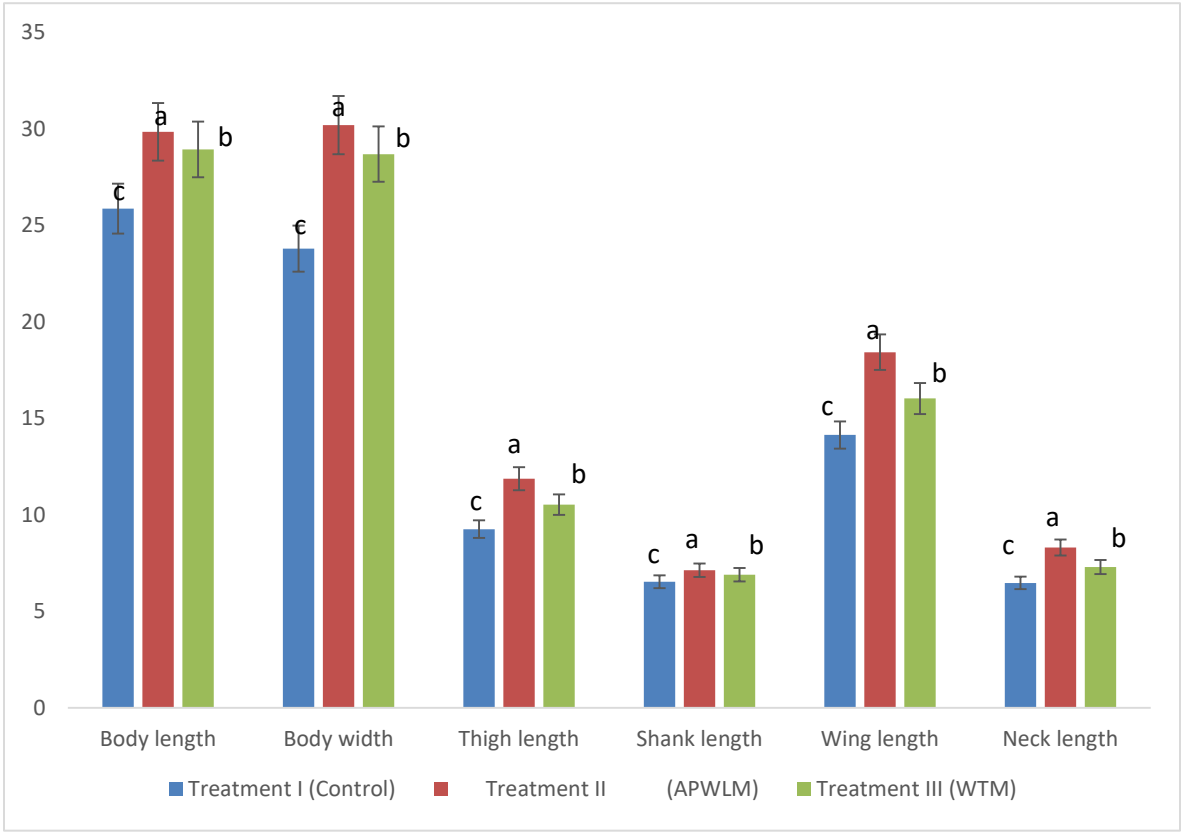
Table 16b: Summary of mean neck length increase (cm) of broiler chicken subjected to three dietary treatments for 8 weeks

Parameters	I	II	III
Initial mean neck length	4.80±0.20	4.70±0.56	4.80±0.20
Final mean neck length	11.27±0.50	13.00±0.50	12.10±0.36
Mean neck length increase	6.47±0.35	8.30±0.10	7.30±0.45

Data presented in Table 16a were summarized in Table 16b. Table 16b highlights the mean neck length increase of broiler chicken subjected to the dietary treatments for 8 weeks. The highest mean neck length increase was recorded in chicken subjected to treatment II (8.30±0.10) followed by treatment III (7.30±0.45) while the least mean neck length increase was recorded for treatment I (6.47±0.35).

4.14 Effect of Insect Meal on Linear Body Measurements of Broiler Chicks

The effects of the insect meal on linear body measurements of the broiler chicks are shown in Figure below:



****APWLM= African palm weevil larvae meal, WTM= winged termite meal, control= commercial feed of brand name 'vital feed'; a,b,c means with different superscript in a bar are significantly different (P<0.05)**

Fig 1: Effect of Insect Meal on Linear Body Measurements of Broiler Chicks

Figure 1 shows the summary of mean computations in all the indices used to determine linear body measurement in the three dietary treatments. The mean increases of all the linear body parameters measured appear to be higher significantly ($P<0.05$) for chicks subjected to treatment II.

4.15 Carcass measurement

4.15.1 Defeathered weight of the broiler chicken

The mean defeathered weights of the broiler chicken subjected to the dietary treatments I, II and III after 8 weeks of experiment is presented in Table 17:

Table 17: Defeathered weights (g) of broiler chicken subjected to three dietary treatments

Treatments	Mean defeathered weight
I	1526.47±40.23
II	2187.74±62.72
III	2015.83±74.62

The highest mean defeathered weight was observed in chicken subjected to treatment II (2187.74±62.72g) followed by treatment III (2015.83±74.62g) while the least defeathered weight was recorded in treatment I (1526.47±40.23g).

4.15.2 Eviscerated weight of the broiler chicken

The mean eviscerated weights of the broiler chickens subjected to the dietary treatments I, II and III after 8 weeks of experiment is presented in Table 18:

Table 18: Eviscerated weights (g) of broiler chicken subjected to three dietary treatments

Treatments	Mean eviscerated weight
I	1240.30±64.53
II	1788.93±70.70
III	1466.97±100.05

The highest mean eviscerated weight was observed in chickens subjected to treatment II (1788.93±70.70g) followed by treatment III (1466.97±100.05g) while the least eviscerated weight was recorded in treatment I (1240.30±64.53g).

4.16 Cut up parts measurement

4.16.1 Head weight of the broiler chicken

The mean head weights of the broiler chicken subjected to the dietary treatments I, II and III after 8 weeks of experiment is presented in Table 19:

Table 19: Head weights (g) of broiler chickens subjected to three dietary treatments

Treatments	Mean head weight
I	41.60±4.06
II	63.70±0.46
III	57.20±2.55

The highest mean head weight was observed in chickens subjected to treatment II (63.70±0.46g) followed by treatment III (57.20±2.55g) while the least head weight was recorded in treatment I (41.60±4.06g).

4.16.2 Shank weight of the broiler chicken

The mean shank weights of the broiler chicken subjected to the dietary treatments I, II and III after 8 weeks of experiment is presented in Table 20:

Table 20: Shank weights (g) of broiler chicken subjected to three dietary treatments

Treatments	Mean shank weight
I	56.93±3.88
II	102.37±1.19
III	98.80±1.25

The highest mean shank weight was observed in chickens subjected to treatment II (102.37±1.19g) followed by treatment III (98.80±1.25g) while the least shank weight was recorded in treatment I (56.93±3.88g).

4.16.3 Drumstick weight of the broiler chicken

The mean drumstick weights of the broiler chicken subjected to the dietary treatments I, II and III after 8 weeks of experiment is presented in Table 21:

Table 21: Drumstick weights (g) of broiler chicken subjected to three dietary treatments

Treatments	Mean drumstick weight
I	146.50±4.00
II	251.87±5.59
III	226.33±5.50

The highest mean drumstick weight was observed in chickens subjected to treatment II (251.87±5.59g) followed by treatment III (226.33±5.50g) while the least drumstick weight was recorded in treatment I (146.50±4.00g).

4.16.4 Neck weight of the broiler chicken

The mean neck weights of the broiler chicken subjected to the dietary treatments I, II and III after 8 weeks of experiment is presented in Table 22:

Table 22: Neck weights (g) of broiler chicken subjected to three dietary treatments

Treatments	Mean neck weight
I	51.63±3.23
II	99.53±0.91
III	78.30±1.85

The highest mean neck weight was observed in chickens subjected to treatment II (99.53±0.91g) followed by treatment III (78.30±1.85g) while the least neck weight was recorded in treatment I (51.63±3.23g).

4.16.5 Wing weight of the broiler chicken

The mean wing weights of the broiler chicken subjected to the dietary treatments I, II and III after 8 weeks of experiment is presented in Table 23:

Table 23: Wing weights (g) of broiler chicken subjected to three dietary treatments

Treatments	Mean wing weight
I	128.47±8.05
II	194.73±5.31
III	181.80±4.18

The highest mean wing weight was observed in chicken subjected to treatment II (194.73±5.31g) followed by treatment III (181.80±4.18g) while the least wing weight was recorded in treatment I (128.47±8.05g).

4.16.6 Breast weight of the broiler chicken

The mean breast weights of the broiler chicken subjected to the dietary treatments I, II and III after 8 weeks of experiment is presented in Table 24:

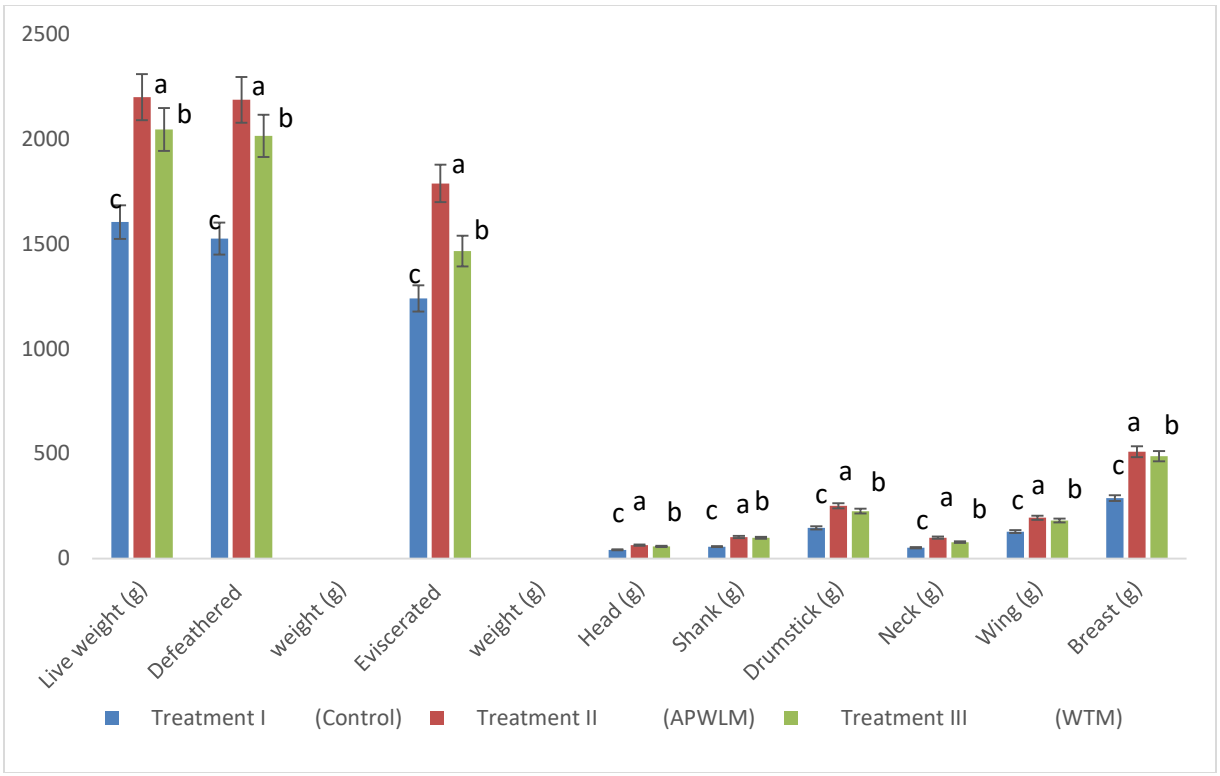
Table 24: Breast weights (g) of broiler chicken subjected to three dietary treatments

Treatments	Mean breast weight
I	288.27±12.44
II	509.47±1.07
III	487.50±8.03

The highest mean breast weight was observed in chicken subjected to treatment II (509.47±1.07g) followed by treatment III (487.50±8.03g) while the least breast weight was recorded in treatment I (288.27±12.44g).

4.17 Effect of Insect Meal on Carcass Weight Measurements of Broiler Chicks

The effects of the insect meal on carcass weight measurements of the broiler chicks are shown in Figure below:



****APWLM= African palm weevil larvae meal, WTM= winged termite meal, control= commercial feed of brand name 'vital feed'**

Fig 2: Effect of Insect Meal on Carcass Weight Measurements of Broiler Chicks

Figure 2 shows the summary of mean computations in all the indices used to measure carcass weight in the three dietary treatments. The mean increases of all the carcass weight parameters measured appear to be higher significantly ($P<0.05$) for chicks subjected to treatment II.

4.18 Organ weight measurement

4.18.1 Gizzard weight of the broiler chicken

The mean gizzard weights of the broiler chicken subjected to the dietary treatments I, II and III after 8 weeks of experiment is presented in Table 25:

Table 25: Gizzard weights (g) of broiler chicken subjected to three dietary treatments

Treatments	Mean gizzard weight
I	59.67±3.16
II	79.37±1.02
III	76.13±0.70

The highest mean gizzard weight was observed in chicken subjected to treatment II (79.37±1.02g) followed by treatment III (76.13±0.70g) while the least gizzard weight was recorded in treatment I (59.67±3.16g).

4.18.2 Pancreas weight of the broiler chicken

The mean pancreas weights of the broiler chicken subjected to the dietary treatments I, II and III after 8 weeks of experiment is presented in Table 26:

Table 26: Pancreas weights (g) of broiler chicken subjected to three dietary treatments

Treatments	Mean pancreas weight
I	1.47±0.50
II	1.27±0.25
III	1.33±0.15

The highest mean pancreas weight was observed in chicken subjected to treatment I (1.47±0.50g) followed by treatment III (1.33±0.15g) while the least pancreas weight was recorded in treatment II (1.27±0.25g).

4.18.3 Lungs weight of the broiler chicken

The mean lungs weight of the broiler chicken subjected to the dietary treatments I, II and III after 8 weeks of experiment is presented in Table 27:

Table 27: Lungs weight (g) of broiler chicken subjected to three dietary treatments

Treatments	Mean lungs weight
I	13.53±0.42
II	16.10±0.26
III	15.80±0.40

The highest mean lungs weight was observed in chicken subjected to treatment II (16.10±0.26g) followed by treatment III (15.80±0.40g) while the least lungs weight was recorded in treatment I (13.53±0.42g).

4.18.4 Spleen weight of the broiler chicken

The mean spleen weight of the broiler chicken subjected to the dietary treatments I, II and III after 8 weeks of experiment is presented in Table 28:

Table 28: Spleen weight (g) of broiler chicken subjected to three dietary treatments

Treatments	Mean spleen weight
I	1.43±0.21
II	2.00±0.20
III	1.77±0.35

The highest mean spleen weight was observed in chicken subjected to treatment II (2.00±0.20g) followed by treatment III (1.77±0.35g) while the least spleen weight was recorded in treatment I (1.43±0.21g).

4.18.5 Liver weight of the broiler chicken

The mean liver weight of the broiler chicken subjected to the dietary treatments I, II and III after 8 weeks of experiment is presented in Table 29:

Table 29: Liver weight (g) of broiler chicken subjected to three dietary treatments

Treatments	Mean liver weight
I	31.83±3.56
II	46.47±1.56
III	43.93±1.26

The highest mean liver weight was observed in chicken subjected to treatment II (46.47±1.56g) followed by treatment III (43.93±1.26g) while the least liver weight was recorded in treatment I (31.83±3.56g).

4.18.6 Heart weight of the broiler chicken

The mean heart weight of the broiler chicken subjected to the dietary treatments I, II and III after 8 weeks of experiment is presented in Table 30:

Table 30: Heart weight (g) of broiler chicken subjected to three dietary treatments

Treatments	Mean heart weight
I	10.70±0.72
II	13.73±0.25
III	12.77±0.25

The highest mean heart weight was observed in chicken subjected to treatment II (13.73±0.25g) followed by treatment III (12.77±0.25g) while the least heart weight was recorded in treatment I (10.70±0.72g).

4.18.7 Kidney weight of the broiler chicken

The mean kidney weight of the broiler chicken subjected to the dietary treatments I, II and III after 8 weeks of experiment is presented in Table 31:

Table 31: Kidney weight (g) of broiler chicken subjected to three dietary treatments

Treatments	Mean kidney weight
I	0.60±0.46
II	0.83±0.35
III	1.07±0.45

The highest mean kidney weight was observed in chicken subjected to treatment III (1.07±0.45g) followed by treatment II (0.83±0.35g) while the least kidney weight was recorded in treatment I (0.60±0.46g).

4.18.8 Intestine weight of the broiler chicken

The mean intestine weight of the broiler chicken subjected to the dietary treatments I, II and III after 8 weeks of experiment is presented in Table 32:

Table 32: Intestine weight (g) of broiler chicken subjected to three dietary treatments

Treatments	Mean intestine weight
I	127.40±2.88
II	166.63±2.20
III	151.70±6.06

The highest mean intestine weight was observed in chicken subjected to treatment II (166.63±2.20g) followed by treatment III (151.70±6.06g) while the least intestine weight was recorded in treatment I (127.40±2.88g).

4.18.9 Crop weight of the broiler chicken

The mean crop weight of the broiler chicken subjected to the dietary treatments I, II and III after 8 weeks of experiment is presented in Table 33:

Table 33: Crop weight (g) of broiler chicken subjected to three dietary treatments

Treatments	Mean crop weight
I	42.17±2.10
II	70.67±0.31
III	68.23±1.80

The highest mean crop weight was observed in chicken subjected to treatment II (70.67±0.31g) followed by treatment III (68.23±1.80g) while the least crop weight was recorded in treatment I (42.17±2.10g).

4.18.10 Oesophagus weight of the broiler chicken

The mean oesophagus weight of the broiler chicken subjected to the dietary treatments I, II and III after 8 weeks of experiment is presented in Table 34:

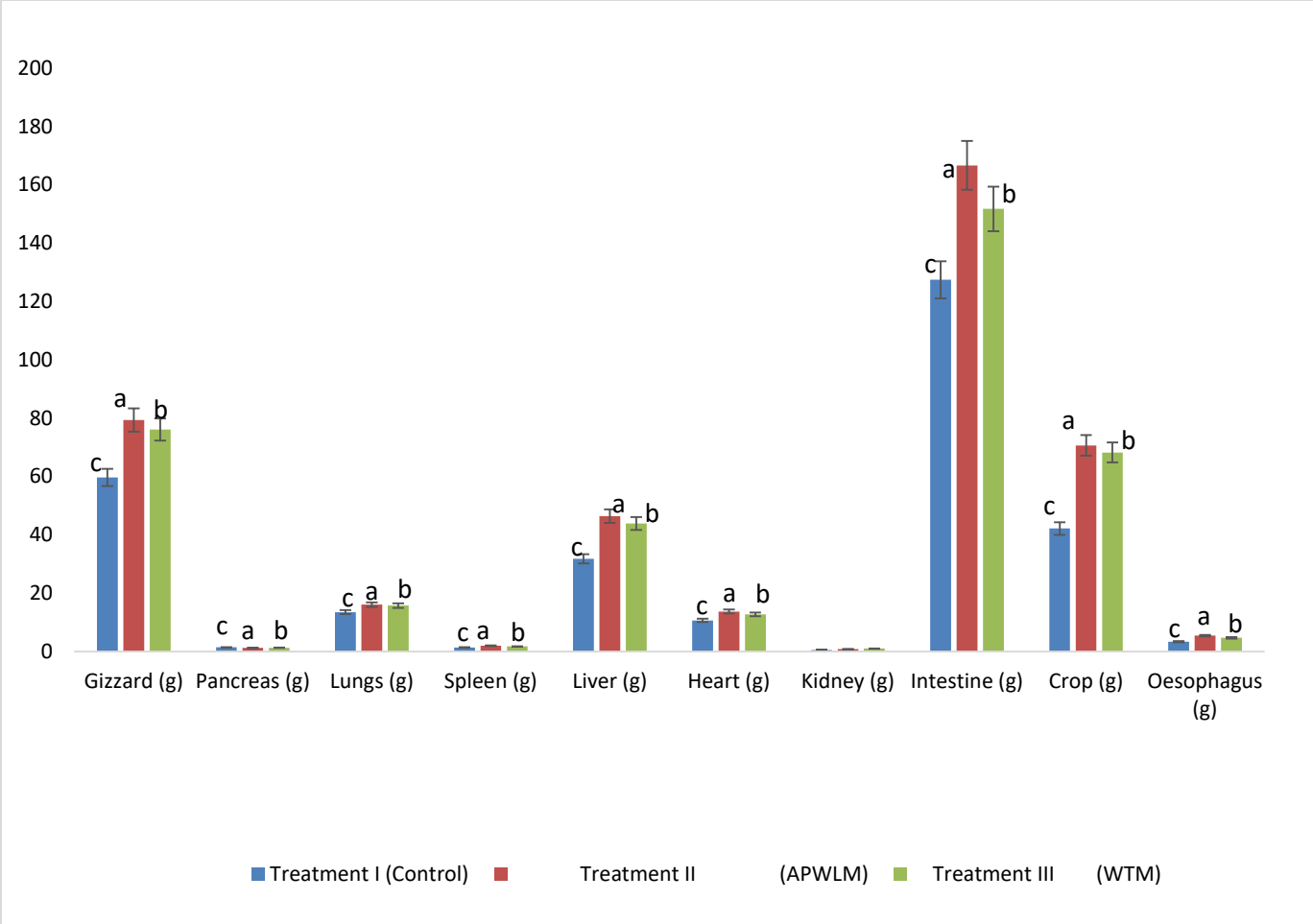
Table 34: Oesophagus weight (g) of broiler chicken subjected to three dietary treatments

Treatments	Mean oesophagus weight
I	3.40±0.53
II	5.47± 0.57
III	4.73± 0.31

The highest mean oesophagus weight was observed in chicken subjected to treatment II (5.47±0.57g) followed by treatment III (4.73±0.31g) while the least oesophagus weight was recorded in treatment I (3.40±0.53g).

4.19 Effect of Insect Meal on Organ Weight Measurements of Broiler Chicks

The effects of the insect meal on organ weight measurements of the broiler chicks are shown in Figure below:



****APWLM= African palm weevil larvae meal, WTM= winged termite meal, control= commercial feed of brand name 'vital feed'**

Fig 3: Effect of Insect Meal on Organ Weight Measurements of Broiler Chicks

From the above Figure, gizzard, lungs, liver, heart, intestine, crop and oesophagus weight increased significantly ($P<0.05$) in treatment II than other treatments while pancreas, spleen and kidney weight showed no significant difference ($P>0.05$) among the dietary treatments.

4.20 Haematological Performance of the broilers at starter phase (4th week)

The effects of insect meal on haematological performance of the broilers at starter phase are presented in Figure below:

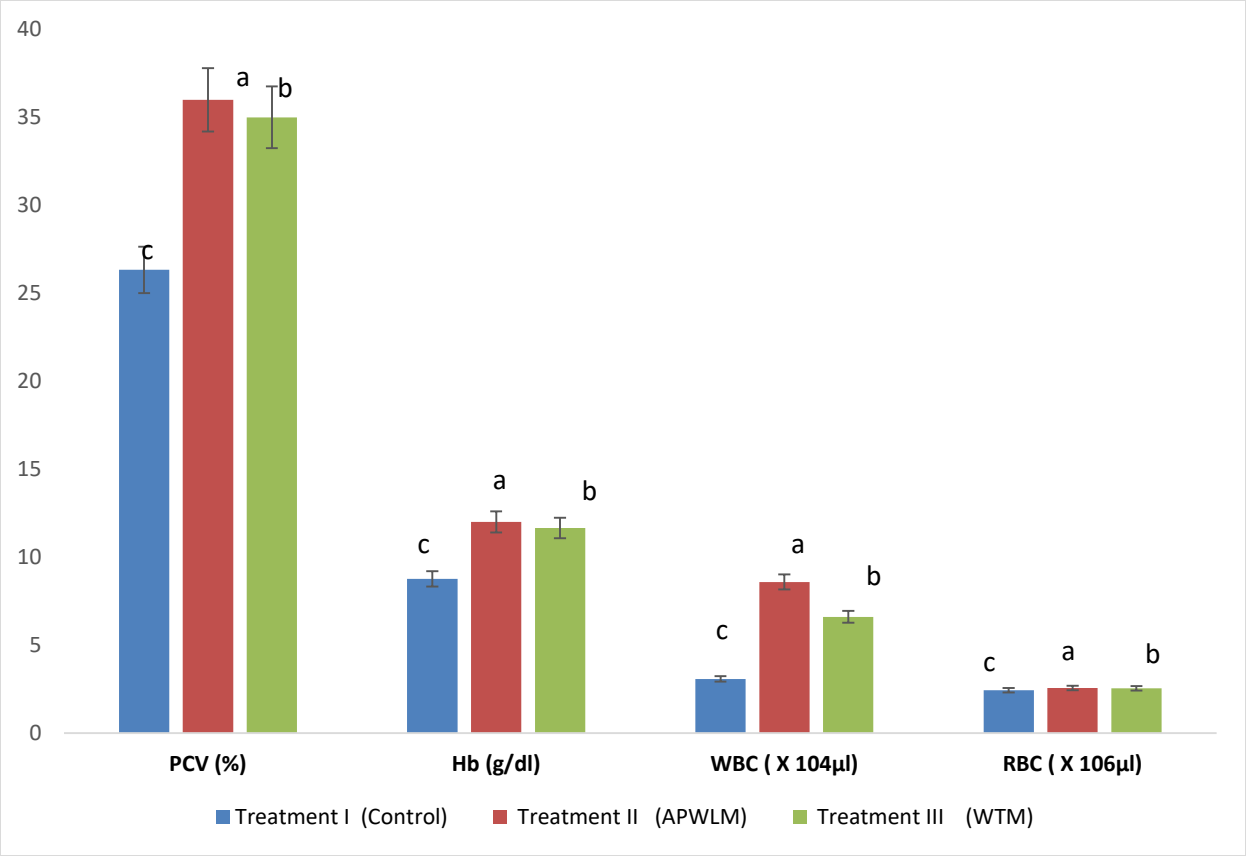


Fig 4: Effect of Insect meal on Haematological Performance of Broiler chicks at starter phase (4th week)

The result of the haematological analysis of the blood of broiler chicken subjected to the three dietary treatments at starter phase showed that treatment II gave a higher value in terms of PCV, Hb, WBC and RBC followed by treatment III while treatment I produced least values.

4.21Haematological Performance of the broilers at finisher phase (8th week)

The haematological performance of the broiler chicken subjected to the dietary treatments at the finisher phase is presented in Figure 5.

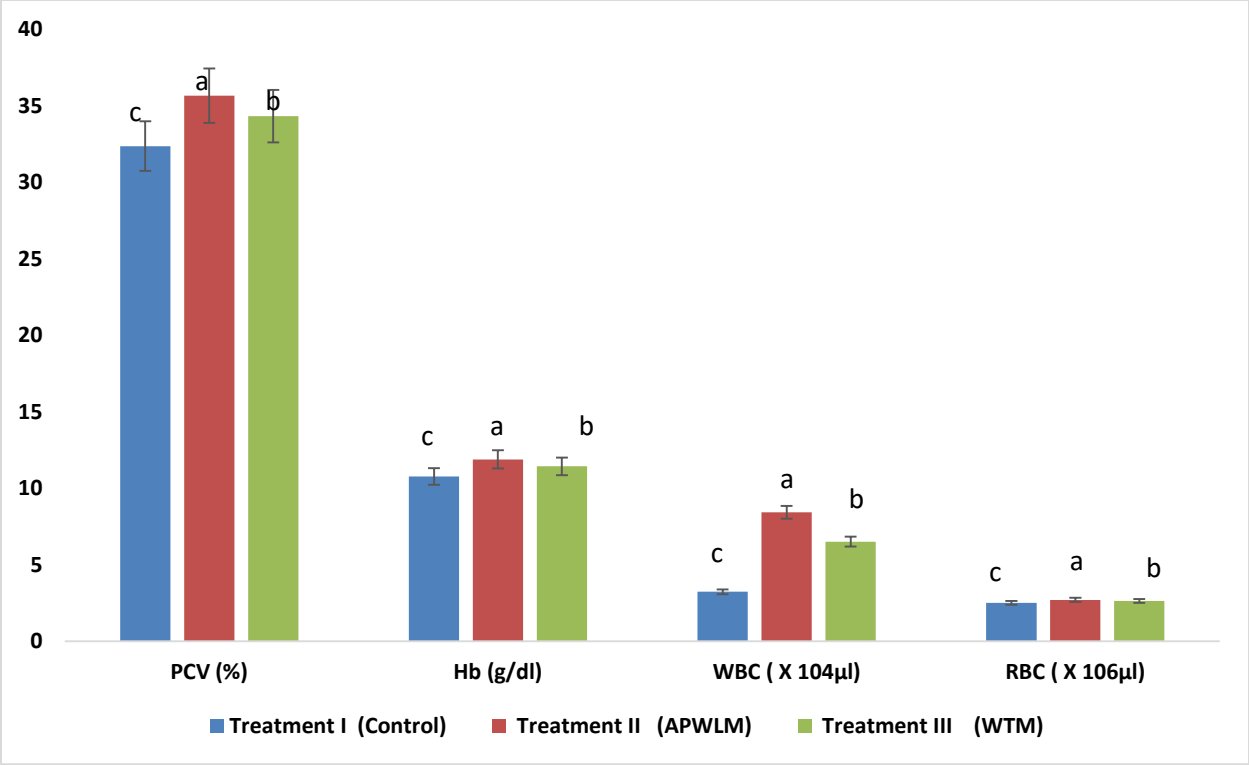
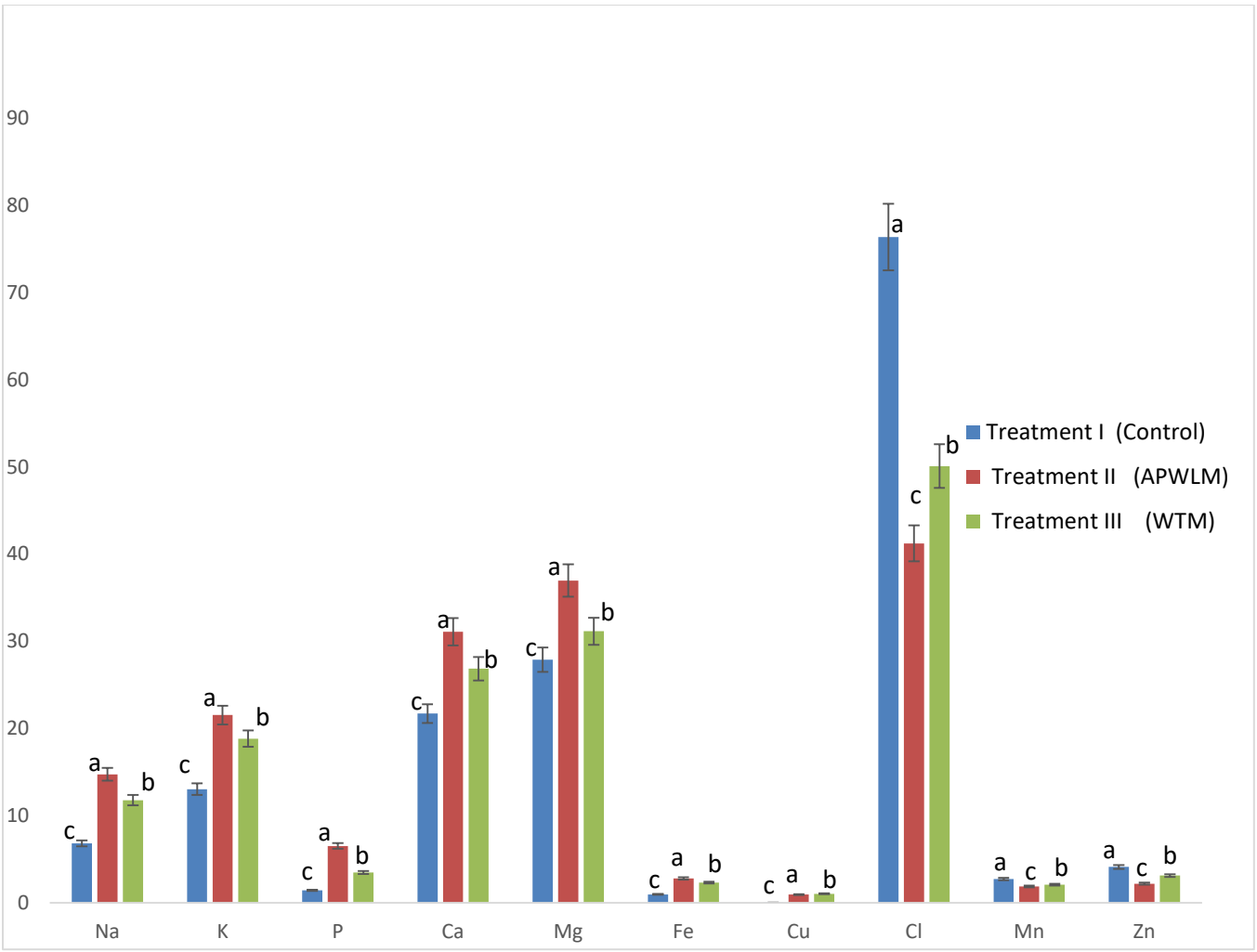


Fig 5: Effect of Insect meal on Haematological Performance of Broiler chicks at finisher phase (8th week)

The result of the haematological analysis of the blood of broiler chickens subjected to the three dietary treatments at finisher phase showed that treatment II gave a higher value in terms of PCV, Hb, WBC and RBC followed by treatments III and I respectively. There was a significant difference ($P<0.05$) in the haematological parameters in terms of WBC and RBC of the broiler chickens among each dietary treatment while there was no significant difference ($P>0.05$) in the haematological parameters in terms of PCV and Hb of the broiler chickens among each dietary treatments.

4.22 Mineral concentration of broiler meat

The mineral profile (sodium, potassium, phosphorus, calcium, magnesium, iron, copper, chlorine, manganese and zinc) of broiler meat from each of the dietary treatment is presented in Figure 6.



**APWLM= African palm weevil larvae meal, WTM= winged termite meal, control= commercial feed of brand name 'vital feed'

Fig 6: Effect of Insect meal on mineral concentration (ppm) of broiler meat from the experimental chickens

The result of the mineral analysis for broiler meat from chicken for Sodium (Na), Potassium (K), Phosphorus (P), Calcium (Ca), Magnesium (Mg), Iron (Fe), Copper (Cu), Chlorine (Cl), Manganese (Mn) and Zinc (Zn) subjected to the dietary treatments are represented in Figure 6. There was significant ($P<0.05$) increase in all the minerals analyzed for all the treatment groups for broiler meat. Chicken subjected to treatment II recorded significantly ($P<0.05$) highest in all the minerals (macro) and iron compared with values obtained for treatment III and treatment I respectively. Chickens subjected to treatment I recorded significantly ($P<0.05$) highest in chlorine, manganese and zinc concentrations with values obtained for treatment III and treatment II respectively (Figure 6).

4.23 Assessment of Economic Benefit of African palm weevil larvae production and formulated broiler feeds

Feasibility study was conducted on the mass production of African palm weevil larvae and the data generated was used to establish the price of a kg of the larvae and a 25kg bag of the formulated feeds.

Table 35: Cost analysis of African palm weevil larvae production

Months	**1**	**2**	**3**	
Operational cost:				
Landing cost of 40 logs	N 40,000	----	----	
Miscellaneous	N 5,000	N 5,000	N 5,000	
Total				₦ 55,000

Total number of raffia palm logs used: 40

3kg of larvae were harvested per log/ month

i.e 3kg of 40logs/month = 120kg/month

Then, for 3 months = 360kg of larvae

Therefore, the price/kg of larvae = N 152.77

The table above shows the production of 360kg of African palm weevil larvae for three months from 40 pieces of raffia palm logs. The data generated was used to calculate the cost of a kg of the larvae which stood at the cost of ₦152.77/kg.

Table 36: Cost analysis of the formulated broiler starter feeds

Ingredients	APWLM			WTM		
	Qty (kg)	N price/kg	Total (₦)	Qty (kg)	₦ price/kg	Total (₦)
Maize	45.0	140	6,300	45.0	140	6,300
Wheat offal	7.72	65	501.8	7.72	65	501.8
PKC	28.06	37	1,038.22	28.06	37	1,038.22
Insect meal	15.0	152.77	2,291.55	15.0	200	3000
Bone meal	3.0	48	144	3.0	48	144
Premix	0.25	100	25	0.25	100	25
Methonine	0.25	180	45	0.25	180	45
Lysine	0.2	80	16	0.2	80	16
Salt	0.3	60	18	0.3	60	18
Enzyme	0.2	450	90	0.2	450	90
Toxynil	0.02	480	9.60	0.02	480	9.60
			10,479.17 ie **₦2,619.79/bag**			11,187.62 ie **₦ 2,796.90/bag**

**** APWLM: African palm weevil larvae based meal; WTM: Winged termite based meal

The table shows the analysis of production of the formulated broiler starter feeds. The data generated was used to calculate the cost of 25kgbag of the insect based formulated starter feeds at the cost of ₦2,619.79 (Two thousand, six hundred and nineteen naira seventy-nine kobo) for a bag of African palm weevil larvae based starter feed and ₦2,796.90 (Two thousand seven hundred and ninety-six naira, ninety kobo) for a bag of winged termite based starter feed compared to the fixed price of25kg bag of vital starter feed (control diet) at the rate of ₦3,350 (Three thousand, three hundred and fifty naira) in open market.

Table 37: Cost analysis of the formulated broiler finisher feed

Ingredients	APWLM			WTM		
	Qty (kg)	**₦ price/kg**	**Total (₦)**	**Qty (kg)**	**₦ price/kg**	**Total (₦)**
Maize	40.60	140	5,684	40.60	140	5,684
Wheat offal	15.0	65	975	15.0	65	975
PKC	26.0	37	962	26.0	37	962
Insect meal	12.0	152.77	1,833.24	12.0	200	2,400
Bone meal	5.0	48	240	5.0	48	240
Premix	0.2	100	20	0.2	100	20
Methonine	0.3	180	54	0.3	180	54
Lysine	0.2	80	16	0.2	80	16
Salt	0.3	60	18	0.3	60	18
Enzyme	0.2	450	90	0.2	450	90
Toxynil	0.2	480	96	0.2	480	96
			9,988.24 i.e.			10,555 i.e.
			₦ 2,497.06/bag			**₦ 2,638.75/bag**

**** APWLM: African palm weevil larvae based meal; WTM: Winged termite based meal

The table shows the analysis of production of the formulated broiler finisher feeds. The data generated was used to calculate the cost of 25kg bag of the insect based formulated finisher feed at the cost of ₦2,497.06 (Two thousand, four hundred and ninety-seven naira, six kobo) for a bag of African palm weevil larvae based finisher feed and ₦2,638.75 (Two thousand six hundred and thirty-eight naira, seventy-five kobo) for a bag of winged termite based finisher feed compared to the fixed price of 25kg bag of vital finisher feed (control diet) at the rate of ₦3,400 (Three thousand, four hundred naira) in open market.

Plate 2: Winged termites

Plate 3: African palm weevil larvae

Plate 4: African palm weevil

Plate 5: Raffia palm logs

Plate 6: Light trapping of termites

Plate 7: Harvesting of palm larvae

Plate 8: Birds at a day old stage

Plate 9: Birds at 2-weeks old stage

Plate 10: Birds at 4-weeks old stage

Plate 11: Weighing of broiler chicks

Plate 12: Defeathered weight measurement

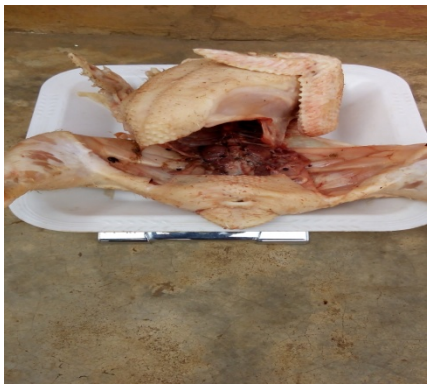


Plate 13: Eviscerated weight measurement

Plate 14: Cut- up parts measurement

Plate 15: Organ weight measurement

Plate 16: Extraction of blood with syringe

Plate 17: Haematocrit centrifuge

Plate 18: Microscope

Plate 19: Atomic Absorption spectrophotometer

CHAPTER FIVE

DISCUSSION

5.1 Weekly weight gain of broiler chicken

The initial weight of the broiler chickens was between (46.98±0.28g – 50.00±0.12g). The highest mean final weekly gain of 2153.87±8.60g was recorded for chickens subjected to dietary treatment II (African palm weevil larvae-based meal) followed by treatment III (Winged termite-based meal) (1996.23±15.32g) while the least mean final weekly weight gain of 1557.98±10.24g was observed in treatment I (Control feed) (Tables 5a and 5b). There was a significant difference ($P<0.05$) in the means of the weight gain of the broiler chickens subjected to the three dietary treatments (Table 10). Better performance of broiler chicks fed on insect meal has been reported by several authors. Jumaa *et al*. (2014) worked on watermelon bug meal on broiler production and reported that the chickens fared better in terms of weight gain as compared with conventional feed; Hassan (2009) reported that grasshopper protein-based diet resulted in higher weight gain of broilers. Wang (2007) posited that field crickets could replace legume grains without adversely affecting weight gain of broiler chickens. Other authors: Awoniyi and Aletor (1999); Okah and Onwujiariri (2012) and Awoniyi *et al*. (2003) also reported significant increase in weight gain of broiler chickens fed maggot meal and therefore stated that maggot meal diets were not nutritionally inferior to other plant protein diet. Ijaiya and Eko (2009) worked on replacing fishmeal with silkworm caterpillar meal in the diet of broiler birds and reported a significant ($P<0.05$) better performance, they attributed the improved performance of broilers fed with silkworm caterpillar meal to the pleasant aroma, palatability and nutrient availability in insect-meal for adequate growth and development. Similarly, Adeyemo and Longe (2008) reported that feeding desert locust meal (*Schistocerca gregaria*) to broilers resulted in a significantly ($P<0.05$) better performance on growth rate. Hwangbo *et al*. (2009) also supporting the use of insect protein reported that birds fed on maggot meal performed significantly

higher (P<0.05) than conventional diets, they concluded that the maggots can effectively be used as a diet of low cost for production of broiler birds. Teguia *et al*. (2002) replaced completely fishmeal with maggot meal in diets of broilers and reported that the weight gain of the birds on maggot meal diet was significantly better (P<0.05). Dube and Tariro (2014) stated that feed fortified with insect protein: *Econsternum delegorguei* and *Macrotermes falciger* were significantly better than conventional feeds in terms of weight gain. On the other hand, the result obtained disagreed with the findings of Gabriel and Idris (1997) who reported that chicks fed locust meal did not significantly increase in weight when compared to those fed conventional diet of sorghum grains. Adeniji (2007) reported that there was no significant increase in weight gain of broiler chickens subjected to maggot meal diet. Chisowa *et al*. (2015) also reported that there was no significant effect on performance in terms of weight gain of quails fed with winged termites. The result of this study suggests that improving weight gain in broilers through insect-based meal prove to be profitable and can be used broadly as a source of animal protein in feed formulation of broiler birds.

5.2 Weekly feed intake of broiler chickens

The highest mean feed intake of 2818.82±196.42g was recorded for chickens subjected to dietary treatment I (Conventional feed) followed by treatment III (Winged termite-based meal) (2745.66±140.10g) while the least mean feed intake of 2712.87±134.21g was observed in treatment II (African palm weevil larvae-based meal) (Table 6). This could be as a result of higher crude fiber content of the insect-based diets (treatments II and III) (Table 10). This disagreed with the findings of Jumaa *et al*. (2014); Hassan (2009) and Ranjhan (2001) who reported that birds on high fibre diet tend to consume more of the feed to meet their requirement for growth and development. However, the findings agreed with Nielse (2011) who stated that high fibre diet reduces hunger, thereby reducing feed intake.

5.3 Feed conversion ratio of broiler chickens

The highest feed conversion ratio of 1.809 was recorded in chickens subjected to treatment I, followed by treatment III (1.375) while the least feed conversion ratio of 1.259 was observed in treatment II. There was significant difference ($P<0.05$) in the feed conversion ratio of the broiler chickens subjected to each of the dietary treatments (Table 10) which was in line with the observations of Ijaiya and Eko (2009); Jumaa *et al.* (2014); Wang (2007); Okah and Onwujiariri (2012) and Dube and Tariro (2014) who stated that the lower the food conversion ratio, the better the food conversion efficiency of each experimental diet. Feed conversion ratio is a direct indication of how best the feed given to birds was turned to meat and the result of this experiment shows that insect meal-based diet has better food conversion efficiency than fishmeal-based diet as evident in higher weight gain recorded in insect meal diets compared to the control diet.

5.4 Specific growth rate of broiler chickens

The best specific growth rate of 0.0325 and 0.0357 was recorded in chickens subjected to treatments III and II respectively while the least specific growth rate of 0.2175 was observed in treatment I which was evident in the higher weight gain observed in insect–based diets than the control diet. There was significant difference ($P<0.05$) in the specific growth rate of the broiler chickens subjected to each of the dietary treatments (Table 8) which was in line with the observations of Jumaa *et al.* (2014); Okah and Onwujiariri (2012); Dube and Tariro (2014) and Awoniyi *et al.* (2003).

5.5 Feed efficiency ratio of broiler chickens

The highest feed efficiency ratio was recorded in chickens subjected to treatment II; 0.794 while the least was observed in treatment I; 0.552 (Table 9). The higher feed efficiency ratio as recorded in treatments II and III shows that they have high/better efficiency potential to convert feed to appreciable body mass as evident in better performance of the broiler chickens subjected to

insect-based diet in terms of weight gain to those subjected to control diet. There was significant difference (P<0.05) in the feed efficiency ratio of the broiler chickens subjected to each of the dietary treatments (Table 10) which was in line with the observations of Ijaiya and Eko (2009); Jumaa *et al.* (2014); Teguia *et al. (*2002) and Nielse (2011).

5.6 Weekly body length increase of broiler chickens

The initial body length of the broiler chickens was between (13.57±0.67cm - 13.63±0.40cm). The highest weekly body length increase in broiler chickens was observed in treatment II; 29.86±4.00cm while the least was observed in treatment I; 25.87±2.10cm (Figure 1). There was a significant difference (P<0.05) in the means of the broiler chickens which is in line with the observations of Hassan (2009); Awoniyi and Aletor (1999) and Awoniyi *et al.* (2003).

5.7 Weekly body width increase of broiler chickens

The initial body width of the broiler chickens was between (12.67±0.85cm - 13.07±1.00cm). The highest weekly body width increase in broiler chickens was observed in treatment II; 30.20±3.15cm while the least was observed in treatment I; 23.80±2.10cm (Figure 1). There was a significant difference (P<0.05) in the means of the body width increase of the broiler chickens which is in line with the observations of Hassan (2009); Awoniyi *et al.* (2003).

5.8 Weekly thigh length increase of broiler chickens

The initial thigh length of the broiler chickens was between (3.60±0.10cm - 3.83±0.21cm). The highest weekly thigh length increase in broiler chickens was observed in treatment II; 11.87±1.50cm while the least was observed in treatment I; 9.26±2.10cm (Tables 13a and 13b). The result showed a significant increase (P<0.05) in the means of the thigh length of the broiler chickens which is in line with the observations of Awoniyi and Aletor (1999) and Awoniyi *et al.* (2003).

5.9 Weekly shank length increase of broiler chickens

The initial shank length of the broiler chickens was between (2.47±0.06cm - 2.70±0.30cm). The highest weekly shank length increase was observed in treatment II; 7.13±0.60cm followed by treatment III; 6.90±0.54cm while the least was observed in treatment I; 6.53±0.45cm (Tables 14a and 14b). The result showed a significant increase ($P<0.05$) which is in line with the observations of Gabriel and Idris (1997) and Chisowa *et al*. (2015).

5.10 Weekly wing length increase of broiler chickens

The initial wing length of the broiler chickens was between (4.40±0.40cm - 4.63±0.21cm). The highest weekly wing length increase was observed in treatment II; 18.43±2.40cm followed by treatment III; 16.03±3.10cm while the least was observed in treatment I; 14.14±2.12cm (Tables 15a and 15b). The result showed a significant increase ($P<0.05$) which is in contrast with the observations of Chisowa *et al*. (2015).

5.11 Weekly neck length increase of broiler chickens

The initial neck length of the broiler chickens was between (4.70±0.56cm - 4.80±0.20cm). The highest mean weekly neck length increase of 8.30±0.10cm was recorded in chickens subjected to treatment II while the least (6.47±0.35cm) was recorded in chickens subjected to treatment I (Table 16b). There was a significant difference ($P<0.05$) in the means of the neck length increase of the broiler chickens.

The observed increase in body length, body width, thigh length, shank length, wing length and neck length of the broiler chickens is not out of place. As the body weight increased, there seemed to be a corresponding increase in the linear body measurement of the broiler chickens. This is in line with the observations of Hassan (2009); Gabriel and Idris (1997) and Chisowa *et al*. (2015).

5.12 Carcass weight measurement

The highest mean defeathered weight was observed in broiler chickens subjected to treatment II; 2187.74±62.72g followed by treatment III; (2015.83±74.62g) while the least (1526.47±40.23g) was observed in treatment I. There was a significant difference ($P<0.05$) in the means of the defeathered weight of the broiler chickens. The result is in contrast with the observations of Chisowa *et al.* (2015).

The highest mean eviscerated weight was observed in broiler chickens subjected to treatment II; 1788.93±70.70g followed by treatment III; 1466.97±100.05g while the least (1240.30±64.53g) was observed in treatment I. The mean increase was significant ($P<0.05$) which is in line with the observations of Teguia *et al. (*2002); Dube and Tariro (2014); Ijaiya and Eko (2009) who reported that the weight of the carcass in broilers increased linearly on increased dietary levels of silkworm pupae meal.

5.13 Cut up parts measurement

The results obtained for head weights among the dietary treatments were 41.60±4.06g, 63.70±0.46g and 57.20±2.55g for treatments I, II and III respectively. The result showed a significant difference ($P<0.05$) among the feeding treatments which is in line with the observations of Ijaiya and Eko (2009) and Awoniyi *et al.* (2003).

Shank weights among the dietary treatments were 56.93±3.88g, 102.37±1.19g and 98.80±1.25g for treatments I, II and III respectively. The result obtained showed a significant difference ($P<0.05$) among the dietary treatments which is in line with the observations of Awoniyi *et al.* (2003).

Drumstick weight values among the dietary treatments; 146.50±4.00g, 251.87±5.59g and 226.33±5.50g for treatments I, II and III respectively were significantly different ($P<0.05$). This agrees with the findings of Ijaiya and Eko (2009).

Neck weight values among the dietary treatments; 51.63±3.23g, 99.53±0.91g and 78.30±1.85g for treatments I, II and III respectively were significantly different (P<0.05). This agrees with the findings of Ijaiya and Eko (2009).

Wing weights among the dietary treatments were 128.47±8.05g, 194.73±5.31g and 181.80±4.18g for treatments I, II and III respectively. The result obtained showed a significant difference (P<0.05) among the dietary treatments which is in line with the findings of Teguia *et al. (*2002); Ijaiya and Eko (2009).

Breast weight values among the dietary treatments; 288.27±12.44g, 509.47±1.07g and 487.50±8.03g for treatments I, II and III respectively were significantly different (P<0.05). This agrees with the findings of Teguia *et al. (*2002); Awoniyi *et al.* (2003); Ijaiya and Eko (2009) who reported that the weight of the cut-up parts of broilers increased almost linearly on increased dietary levels of silkworm pupae meal.

5.14 Organ weight measurement

The weights of gizzard, Lungs, Liver, Heart, Intestine, Crop and Oesophagus among the three dietary treatments were significantly different (P<0.05) while the weights of Pancrease, Spleen and Kidney among the dietary treatments were not significantly different (P>0.05). Treatment II had a significantly higher (P<0.05) weights of gizzard, lungs, liver, heart, intestine, crop and oesophagus (Figure 3). This is consistent with the findings of Dube and Tariro (2014); Awoniyi and Aletor (1999) and Awoniyi *et al.* (2003). Treatments III and I had a higher weight of kidney and pancrease respectively that were not significant (P>0.05). This result agrees with the findings of Okah and Onwujiariri (2012) and Chisowa *et al.* (2015).

5.15 Haematological performance

The packed cell volumes (PCV) for treatments I, II and III at the starter phase (4th week) were 26.33±1.53%, 36.00±1.00% and 35.00±1.00% respectively. The result obtained showed a significant difference (P<0.05) among the dietary

treatments (Figure 4). The PCV value obtained from treatment I is lower than 35% which suggests that the birds are susceptible to anaemia as reported by Thrall (2006); Ali *et al.* (1996) and Ihedioha (2004). At the finisher phase (8th week), the PCV values for treatments I, II and III were 32.37±2.52%, 35.66±0.58% and 34.33±0.59% respectively. The result obtained showed no significant difference (P>0.05) among the dietary treatments (Figure 5). The PCV values obtained from treatments I and III are lower than 35% which suggests that the birds are susceptible to anaemia as reported by Thrall (2006); Ali *et al.* (1996) and Ihedioa (2004).

The haemoglobin (Hb) concentrations for treatments I, II and III at the starter phase (4th week) were 8.77±0.51g/dl, 12.00±0.33g/dl and 11.66±0.34g/dl respectively. There was a significant difference (P<0.05) in the means of the Hb concentrations of the broilers' blood at starter phase and all of the measured values were within the range identified as normal range of 7.0 – 13.0g/dl by Ali *et al.* (1996) for *Arbor acre* chickens. Also, the Hb concentrations for treatments I, II and III at the finisher phase (8th week) were 10.78±0.84g/dl, 11.89±0.19g/dl and 11.44±0.20g/dl respectively. There was no significant difference (P>0.05) in the means of the Hb concentrations of the broilers' blood at finisher phase and all the measured values were within the normal range for *Arbor acre* as reported by Ali *et al.* (1996); showing that the birds were in normal physiological and nutritional state.

The white blood cell counts (WBC) for treatments I, II and III at the starter phase (4th week) were 3.08±0.02 X 10^4µl, 8.59±0.03 X 10^4µl and 6.61±0.02 X 10^4µl respectively. The result obtained showed a significant difference (P<0.05) among the dietary treatments. At the finisher phase (8th week), the WBC values for treatments I, II and III were 3.24±0.05 X 10^4µl, 8.44±0.05 X 10^4µl and 6.52±0.06 X 10^4µl respectively. The result also showed significant difference (P<0.05). The WBC values obtained from treatments II and III were within the normal range while treatment I had value below the normal range of 4.0 – 10.0 X 10^4µl (Ali *et al.*, 1996; Mitruka and Rawnsley, 1977). This shows that the

birds on treatments II and III were physiologically, pathologically and nutritionally healthy.

The red blood cell counts (RBC) for treatments I, II and III at the starter phase (4th week) were 2.44±0.03 X 10^6µl, 2.56±0.01 X 10^6µl and 2.54±0.01 X 10^6µl respectively. The result showed a significant difference ($P<0.05$) among the dietary treatments. At the finisher phase (8th week), the RBC values from treatments I, II and III were 2.52±0.02 X 10^6µl, 2.71±0.05 X 10^6µl and 2.64±0.05 X 10^6µl respectively. The result also showed significant difference ($P<0.05$). All the values obtained were within the normal range of 2.5 -3.5 X 10^6µl (Ali *et al.*, 1996 and Ihedioha, 2004) except for values from treatment I at starter phase.

5.16 Mineral profile composition of broiler meat

The minerals (Sodium [Na], Potassium [K], Phosphorus [P], Calcium [Ca], Magnesium [Mg] and Iron [Fe] concentrations are significantly highest when the chickens were subjected to treatment II followed by treatments III and I; Copper [Cu] concentration were highest in chickens subjected to treatment III followed by treatments II and I while Chlorine [Cl], Manganese [Mn] and Zinc [Zn]) concentrations are significantly highest when the chickens were fed with treatment I followed by treatment III and lastly treatment II (Table 38). This also agrees with the observations of Aletor and Egberongbe (1992) and Amobi *et al.* (2014) that the mineral composition indices are the reflections of the effect of dietary treatment on the animals in terms of the type and amount of feed ingested.

5.17 Assessment of Economic Benefit of the Insect based diets

Market survey revealed that 25kg bag of a vital broiler starter and finisher feeds (control diet) sells for an average of N3,350 (Three thousand, three hundred and fifty naira) and N3,400 (Three thousand, four hundred naira)

respectively in the local market while 25kg bag of African Palm Weevil Larvae based starter and finisher formulated feeds were produced at a cost of N2,619.79 (Two thousand, six hundred and nineteen naira seventy-nine kobo) and N2,497.06 (Two thousand, four hundred and ninety-seven naira, six kobo) respectively and winged termite based starter and finisher formulated feeds at a cost of N2,796.90 (Two thousand, seven hundred and ninety-six naira, ninety kobo) and N2,638.75 (Two thousand, six hundred and thirty-eight naira, seventy-five kobo) respectively showing that the insect – based feeds are much cheaper and profitable to poultry farmers in farming of broiler chickens.

CONCLUSION

As the need to improve animal protein supply at affordable costs through the use of low–cost feed ingredients increase globally, the use of African palm weevil larvae and winged termite–based feeds proved to be profitable in performance of broiler chickens and can conveniently be used as a major source of animal protein in feed formulation for poultry industry. Therefore, if much effortsare put into farming, harvesting and processing of insects into meal, high opportunities lies ahead in its use as a major source of protein in poultry feed to reduce cost of production. This equally agrees with the findings of Nzamujo (1999) who reported that mass production of maggots and other insects has solution to the high cost of livestock production.

RECOMMENDATIONS

From the study carried out to determine the effects of insect meals on performance of broiler chickens (*Arbor acre*), the following recommendations were made:

1. The use of African palm weevil larvae and winged termite – based meals as a major source of animal protein in feed formulation for poultry industry.
2. The establishment of insect farms to produce the quantity that will meet the demands of livestock feed industries.
3. Further research work to investigate the keeping quality of insect–based feed; improvement of the feed and use of insects that are of no value to man to avoid competition.

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APPENDICES

Raw data

Weekly Mean Weight gain (g) of Broiler Chicks

Replicates	Initial mean wt	WK 1	WK 2	WK 3	WK 4	WK 5	WK 6	WK 7	WK 8	Gain
I1	47.32	118.75	278.20	540.90	824.28	1091.52	1153.24	1384.17	1582.59	1535.27
I2	47.08	121.08	282.64	536.82	833.22	1163.43	1235.37	1432.09	1598.54	1551.46
I3	46.89	120.40	277.41	544.86	826.26	1044.72	1261.86	1469.74	1634.09	1587.20
Total	141.29	360.23	838.25	1622.58	2483.76	3299.67	3650.47	4286.00	4815.22	
II1	47.01	124.32	286.84	613.86	957.62	1276.44	1580.16	2029.37	2146.01	2099.00
II2	47.25	126.58	292.29	616.6	962.86	1299.57	1650.41	2077.88	2231.04	2183.79
II3	46.69	124.53	288.06	605.1	954.7	1302.12	1653.9	2062.88	2225.51	2178.82
Total	140.95	375.43	867.19	1835.56	2875.18	3878.13	4884.47	6170.13		
III1	46.89	122.5	284.64	575.98	913.26	1227.98	1504.86	1811.2	2047.49	2000.60
III2	46.98	125.35	286.84	591.6	934.18	1246.7	1466.96	1849.29	2040.53	1993.55
III3	47.12	122.08	283.16	596.15	900.4	1246.95	1470.72	1871.01	2050.66	2003.54
Total	140.99	369.93	854.64	1763.73	2747.84	3721.63	4442.54	5531.5		

Weekly Mean LinearBody Measurements

Body length

Replicates	Initial	WK 1	WK 2	WK 3	WK 4	WK 5	WK 6	WK 7	WK 8	Length increase
I1	14.2	15.1	20.6	24.4	26.5	30	32.5	36.5	40.1	25.9
I2	13.6	15.2	21.7	23.2	25.4	29.6	30.1	31	36.2	22.6
I3	13	15	20.8	22.3	25.6	33.6	35.2	40.4	42.1	29.1
Total	40.8	45.3	63.1	69.9	77.5	93.2	97.8	107.9	118.4	
Pooled mean										
II1	12.8	15.4	24.5	28.6	31	40.5	42.6	43.2	45.1	32.3
II2	13.9	15.6	23.6	27.5	29.6	36.6	39	41.5	42	28.1
II3	14	15.8	23.8	27.6	30.5	39.2	40.5	41	43.2	29.2
Total	40.7	46.8	71.9	83.7	91.1	116.3	122.1	125.7	130.3	
Pooled mean										
III1	14	15.4	22.4	27.5	30.6	38	40.1	40.8	42.1	28.1
III2	13.7	15.3	22.8	27.4	28.4	35.6	38.2	40.1	43.5	29.8
III3	13.2	15.5	23.6	26.5	27.6	34.2	36.4	38.5	42.1	28.9
Total	40.9	46.2	68.8	81.4	86.6	107.8	114.7	119.4	127.7	

Body width

Replicates	Initial	WK 1	WK 2	WK 3	WK 4	WK 5	WK 6	WK 7	WK 8	increase
I1	13.8	13.5	17.5	22.5	25.4	30	32.1	35	38.1	24.3
I2	12.4	13.8	18.6	21.6	24.6	28.4	30.1	33.5	35.2	22.8
I3	11.9	13.9	17.8	22.2	24.8	27.1	29.4	32	36.2	24.3
Total	38.1	41.2	53.9	66.3	74.8	85.5	91.6	100.5	109.5	
II1	14.1	14.5	23.4	26.7	30	37	39	41.5	43.2	29.1
II2	13	14.2	23.5	25.4	29.2	36.2	38.5	40.2	42.5	29.5

II3	12.1	13.9	22.8	26.6	28.6	35.4	38.2	41.2	44.1	32
Total	39.2	42.6	69.7	78.7	87.8	108.6	115.7	122.9	129.8	
III1	13.5	14	22.4	24.9	27.4	34	36.2	38.5	40.2	26.7
III2	11.8	13.8	20.5	23.6	26.5	32.4	34.1	38.2	41.5	29.7
III3	12.7	14.1	21.6	24.5	27.2	33.5	36.5	40.1	42.4	29.7
Total	38	41.9	64.5	73	81.1	99.9	106.8	116.8	124.1	

Thigh length

Replicates	**Initial**	**WK 1**	**WK 2**	**WK 3**	**WK 4**	**WK 5**	**WK 6**	**WK 7**	**WK 8**	**Increase**
I1	4	4.3	6	6.8	7.8	9.5	10	12.4	13.1	9.1
I2	4.1	4	6.2	7.2	8.5	10	10.4	11.5	12.8	8.7
I3	3.2	4.4	5.9	6.6	8.1	9.8	10.1	12.5	13.2	10
Total	11.3	12.7	18.1	20.6	24.4	29.3	30.5	36.4	39.1	
II1	3.6	4.3	7.1	7.9	8.6	12	12.5	14.5	16.5	12.9
II2	3.9	4.8	8.2	8.6	10.5	11.8	12	14	15.2	11.3
II3	4	4.7	7.5	8.2	9.5	12.1	12.2	14.3	15.4	11.4
Total	11.5	13.8	22.8	24.7	28.6	35.9	36.7	42.8	47.1	
III1	3.5	4.5	7	7.6	9.6	11	11.5	13.1	14.1	10.6
III2	3.7	4.6	6.9	7.2	8.2	10.2	10.8	12.1	13.8	10.1
III3	3.6	4.5	6.8	7.8	9.2	11.2	11.6	13.2	14.5	10.9
Total	10.8	13.6	20.7	22.6	27	32.4	33.9	38.4	42.4	

Shank length

Replicates	Initial	WK 1	WK 2	WK 3	WK 4	WK 5	WK 6	WK 7	WK 8	increase
I1	2.2	3	4.6	5	6.3	8	8.5	9	9.5	7.3
I2	2.6	3.4	4.5	5.1	5.8	7.4	8	8.4	9	6.4
I3	2.9	3.6	4	4.8	5.2	7.6	7.8	8.2	8.8	5.9
Total	7.7	10	13.1	14.9	17.3	23	24.3	25.6	27.3	
II1	2.7	3.8	5	5.8	7.1	9	9.2	9.5	9.8	7.1
II2	3	4	4.8	5.6	6.8	8.4	8.8	9	9.6	6.6
II3	2.4	3.7	5.6	6	7	8.6	9	9.4	10.1	7.7
Total	8.1	11.5	15.4	17.4	20.9	26	27	27.9	29.5	
III1	2.5	3.5	4.7	5.2	6	7.6	8	8.8	9	6.5
III2	2.4	3.8	4.8	5.3	6.2	8	8.2	8.5	9.1	6.7
III3	2.5	4	5.1	5.5	7	8.5	9	9.4	10	7.5
Total	7.4	11.3	14.6	16	19.2	24.1	25.2	26.7	28.1	

Wing length

Replicates	Initial	WK 1	WK 2	WK 3	WK 4	WK 5	WK 6	WK 7	WK 8	increase
I1	4.4	6	7.4	10.2	14.2	15	16	17.5	18.5	14.1
I2	4.8	6.2	8.6	11.2	14.8	15.2	15.8	18	18.6	13.8
I3	4.7	5.8	8	10.3	13.8	14.6	16.1	18.2	19.2	14.5
Total	13.9	18	24	31.7	42.8	44.8	47.9	53.7	56.3	
II1	4.4	7	12.2	12.4	16.4	17.5	18	21	22.5	18.1
II2	4.8	6.9	12.4	13	16.5	17.4	18.2	21.5	23.2	18.4
II3	4	6.8	12.3	12.6	15.8	17	17.8	20	22.8	18.8
Total	13.2	20.7	36.9	38	48.7	51.9	54	62.5	68.5	
III1	4.3	6.6	12.2	12.4	15.6	17	17.5	18.5	19.5	15.2
III2	4.6	6.8	10.3	10.8	14.6	16.8	17	19	21.2	16.6

III3	4.5	6.7	11.2	12	15.2	17	17.2	19.5	20.8	16.3
Total	13.4	20.1	33.7	35.2	45.4	50.8	51.7	57	61.5	

Neck length

Replicates	**Initial**	**WK 1**	**WK 2**	**WK 3**	**WK 4**	**WK 5**	**WK 6**	**WK 7**	**WK 8**	**increase**
I1	4.6	5.6	6.2	6.8	7.5	9.5	10	10.8	11.2	6.6
I2	5	5.1	5.8	6.6	7.2	8.6	9.6	10.5	10.8	5.8
I3	4.8	5.4	6	7	7.6	10	10.6	11	11.8	7
Total	14.4	16.1	18	20.4	22.3	28.1	30.2	32.3	33.8	
II1	4.2	6.2	7.4	7.6	8.6	10.4	11	11.5	13	8.8
II2	4.6	6.8	7.2	7.8	9.5	11	12	12.5	13.5	8.9
II3	5.3	6.6	7.1	7.5	9.2	10.5	10.8	11.4	12.5	7.2
Total	14.1	19.6	21.7	22.9	27.3	31.9	33.8	35.4	39	
III1	5	5.6	7	7.4	8.5	10.8	11	11.5	11.8	6.8
III2	4.8	6	6.8	7.3	8.4	11	11.5	12	12.5	7.7
III3	4.6	6.1	6.4	6.9	7.6	10.2	10.6	11.8	12	7.4
Total	14.4	17.7	20.2	21.6	24.5	32	33.1	35.3	36.3	

Mean Defeathered Weight (g) Measurement

	Treatments		
Replicates	**I**	**II**	**III**
R1	1572.6	2184.6	2024.1
R2	1498.2	2190.4	2000.9
R3	1508.6	2188.2	2022.5
Total			

Mean Eviscerated Weight (g) Measurement

	Treatments		
Replicates	**I**	**II**	**III**
R1	1193.4	1707.3	1361.4
R2	1313.9	1830.4	1479.1
R3	1213.6	1829.1	1560.4
Total			

Mean Organ Weight (g) Measurement

Gizzard

	Treatments		
Replicates	**I**	**II**	**III**
R1	56.1	79.8	76.2
R2	60.8	78.2	75.4
R3	62.1	80.1	76.8
Total			

Pancrease

Replicates	**I**	**II**	**III**
R1	2	1	1.2
R2	1.4	1.5	1.5
R3	1	1.3	1.3
Total			

Lungs

Replicates	**I**	**II**	**III**
R1	13.2	16	15.8
R2	14	16.4	16.2
R3	13.4	15.9	15.4
Total			

Spleen			
Replicates	**I**	**II**	**III**
R1	1.5	2	1.4
R2	1.2	2.2	2.1
R3	1.6	1.8	1.8
Total			

Liver			
Replicates	**I**	**II**	**III**
R1	32.2	45	44.1
R2	28.1	48.1	42.6
R3	35.2	46.3	45.1
Total			

Heart			
Replicates	**I**	**II**	**III**
R1	10.1	14	12.8
R2	11.5	13.7	13
R3	10.5	13.5	12.5
Total			

Kidney			
Replicates	**I**	**II**	**III**
R1	0.2	0.8	1.5
R2	0.5	0.5	0.6
R3	1.1	1.2	1.1
Total			

Intestine			
Replicates	**I**	**II**	**III**
R1	126.1	168	146.2
R2	130.7	167.8	150.7
R3	125.4	164.1	158.2
Total			

Crop			
Replicates	**I**	**II**	**III**
R1	42.1	71	68.1
R2	44.3	70.4	66.5

R3	40.1	70.6	70.1
Total			
Pooled mean			

Oesophagus			
Replicates	**I**	**II**	**III**
R1	2.8	5.0	4.8
R2	3.6	6.1	5.0
R3	3.8	5.3	4.4
Total			

Mean Cut up parts Weight (g) Measurement

Head

	Treatments		
Replicates	**I**	**II**	**III**
R1	46.1	63.2	56.2
R2	38.2	64.1	60.1
R3	40.5	63.8	55.3
Total			

Shank

Replicates	**I**	**II**	**III**
R1	60.1	101.4	98.4
R2	52.6	102	100.2
R3	58.1	103.7	97.8
Total			

Drumstick

Replicates	**I**	**II**	**III**
R1	142.5	247.3	220.1
R2	146.5	250.2	228.4
R3	150.5	258.1	230.5
Total			

Neck

Replicates	**I**	**II**	**III**
R1	55.2	100.2	80.1
R2	48.9	99.9	78.4
R3	50.8	98.5	76.4
Total			

Wing

Replicates	**I**	**II**	**III**
R1	120.4	194.4	180.4
R2	136.5	200.2	178.5
R3	128.5	189.6	186.5
Total			

Breast			
Replicates	**I**	**II**	**III**
R1	289.4	509.7	480.2
R2	300.1	508.3	496.1
R3	275.3	510.4	486.2
Total			

Appendix 1

Effect of Insect meal on Linear Body Measurements of broiler chicks

Parameters (cm)	**Treatment I (Control)**	**Treatment II (APWLM)**	**Treatment III (WTM)**
Body length	25.87±2.10^{c}	29.86±4.00^{a}	28.94±3.12^{b}
Body width	23.80±2.10^{c}	30.20±3.15^{a}	28.70±4.30^{b}
Thigh length	9.26±2.10^{c}	11.87±1.50^{a}	10.53±2.10^{b}
Shank length	6.53±0.45^{c}	7.13±0.60^{a}	6.90±0.54^{b}
Wing length	14.14±2.12^{c}	18.43±2.40^{a}	16.03±3.10^{b}
Neck length	6.47±0.35^{c}	8.30±0.10^{a}	7.30±0.45^{b}

****APWLM= African palm weevil larvae meal, WTM= winged termite meal, control= commercial feed of brand name 'vital feed'; a,b,c means with different superscript in a row are significantly different (P<0.05)**

Appendix 2

Effect of Insect meal on Carcass Weight Measurements of broiler chicks

Parameters	**TreatmentI (Control)**	**Treatment II (APWLM)**	**Treatment III (WTM)**
Live weight (g)	605.07±28.30^{c}	2200.85±64.23^{a}	2046±58.40^{b}
Defeathered weight (g)	526.47±40.23^{c}	2187.74±62.72^{a}	2015.83±74.62^{b}
Eviscerated weight (g)	240.30±64.53^{c}	1788.93±70.70^{a}	466.97±100.05^{b}
Head (g)	41.60±4.06^{c}	63.70±0.46^{a}	57.20±2.55^{b}
Shank (g)	56.93±3.88^{c}	102.37±1.19^{a}	98.80±1.25^{b}
Drumstick (g)	146.50±4.00^{c}	251.87±5.59^{a}	226.33±5.50^{b}
Neck (g)	51.63±3.23^{c}	99.53±0.91^{a}	78.30±1.85^{b}
Wing (g)	128.47±8.05^{c}	194.73±5.31^{a}	181.80±4.18^{b}
Breast (g)	288.27±12.44^{c}	509.47±1.07^{a}	487.50±8.03^{b}

****APWLM= African palm weevil larvae meal, WTM= winged termite meal, control= commercial feed of brand name 'vital feed'; a,b,c means with different superscript in a row are significantly different (P<0.05)**

Appendix 3

Effect of Insect meal on Organ Weight Measurements of broiler chicks

Parameters	Treatment I (Control)	Treatment II (APWLM)	Treatment III (WTM)
Gizzard (g)	9.67±3.16^{c}	79.37±1.02^{a}	76.13±0.70^{b}
Pancreas (g)	1.47±0.50^{a}	1.27±0.25^{a}	1.33±0.15^{a}
Lungs (g)	3.53±0.42^{c}	16.10±0.26^{a}	15.80±0.40^{b}
Spleen (g)	1.43±0.21^{a}	2.00±0.20^{a}	1.77±0.35^{a}
Liver (g)	1.83±3.56^{c}	46.47±1.56^{a}	43.93±1.26^{b}
Heart (g)	0.70±0.72^{c}	13.73±0.25^{a}	12.77±0.25^{b}
Kidney (g)	0.60±0.46^{a}	0.83±0.35^{a}	1.07±0.45^{a}
Intestine (g)	27.40±2.88^{c}	166.63±2.20^{a}	151.70±6.06^{b}
Crop (g)	2.17±2.10^{c}	70.67±0.31^{a}	68.23±1.80^{b}
Oesophagus (g)	3.40±0.53^{c}	5.47±0.57^{a}	4.73±0.31^{b}

****APWLM= African palm weevil larvae meal, WTM= winged termite meal, control= commercial feed of brand name 'vital feed'; a,b,c means with different superscript in a row are significantly different (P<0.05) while means with same superscript in a row are not significantly different (P>0.05)**

Appendix 4

Effect of Insect meal on Haematological Performance of Broiler chicks at starter phase (4th week)

Parameters	Treatment I (Control)	Treatment II (APWLM)	Treatment III (WTM)
PCV (%)	26.33±1.53^{c}	36.00±1.00^{a}	35.00±1.00^{b}
Hb (g/dl)	8.77±0.51^{c}	12.00±0.33^{a}	11.66±0.34^{b}
WBC (X 10^{4}µl)	3.08±0.02^{c}	8.59±0.03^{a}	6.61±0.02^{b}
RBC (X 10^{6}µl)	2.44±0.03^{c}	2.56±0.01^{a}	2.54±0.01^{b}

****APWLM= African palm weevil larvae meal, WTM= winged termite meal, control= commercial feed of brand name 'vital feed'; a,b,c means with different superscript in a row are significantly different (P<0.05) while means with same superscript in a row are not significantly different (P>0.05)**

Appendix 5

Effect of Insect meal on Haematological Performance of Broiler chicks at finisher phase (8th week)

Parameters	Treatment I (Control)	Treatment II (APWLM)	Treatment III (WTM)
PCV (%)	32.37±2.52[a]	35.66±0.58[a]	34.33±0.59[a]
Hb (g/dl)	10.78±0.84[a]	11.89±0.19[a]	11.44±0.20[a]
WBC (X 10^4µl)	3.24±0.05[c]	8.44±0.05[a]	6.52±0.06[b]
RBC (X 10^6µl)	2.52±0.02[c]	2.71±0.05[a]	2.64±0.05[b]

****APWLM= African palm weevil larvae meal, WTM= winged termite meal, control= commercial feed of brand name 'vital feed'; a,b,c means with different superscript in a row are significantly different (P<0.05) while means with same superscript in a row are not significantly different (P>0.05)**

Appendix 6

Effect of Insect meal on proximate composition of broiler meat from the experimental chickens

Parameters (%)	Treatment I (Control)	Treatment II (APWLM)	Treatment III (WTM)
Crude protein	11.20±2.22[c]	34.15±4.12[a]	30.96±3.25[b]
Crude fat	6.10±1.00[a]	3.20±0.12[c]	3.60±0.14[b]
Ash	2.90±0.02[a]	2.40±0.24[c]	2.50±0.35[b]
Fibre content	0.50±0.10[a]	0.28±0.12[c]	0.30±0.04[b]
Moisture content	30.00±1.52[b]	28.06±2.25[c]	30.05±3.20[a]
Carbohydrate	49.30±2.15[a]	31.91±1.01[c]	32.59±2.01[b]

****APWLM= African palm weevil larvae meal, WTM= winged termite meal, control= commercial feed of brand name 'vital feed'; a,b,c means with different superscript in a row are significantly different (P<0.05)**

Appendix 7

Effect of Insect meal on mineral concentration of broiler meat from the experimental chickens

Parameters (ppm)	Treatment I (Control)	Treatment II (APWLM)	Treatment III (WTM)
Na	6.80±0.54^{c}	14.73±0.58^{a}	11.77±1.08^{b}
K	13.03±1.12^{c}	21.53±1.06^{a}	18.82±1.11^{b}
P	1.42±0.51^{c}	6.52±0.54^{a}	3.48±1.01^{b}
Ca	21.70±0.62^{c}	31.09±0.99^{a}	26.85±1.49^{b}
Mg	27.89±0.31^{c}	36.97±0.98^{a}	31.14±1.19^{b}
Fe	0.95±0.17^{c}	2.80±0.04^{a}	2.31±0.13^{b}
Cu	0.03±0.01^{c}	0.94±0.08^{b}	1.03±0.07^{a}
Cl	76.38±1.51^{a}	41.23±3.51^{c}	50.09±2.01^{b}
Mn	2.71±0.52^{a}	1.86±0.13^{c}	2.07±0.10^{b}
Zn	4.10±0.59^{a}	2.19±0.23^{c}	3.12±0.44^{b}

****APWLM= African palm weevil larvae meal, WTM= winged termite meal, control= commercial feed of brand name 'vital feed'; a,b,c means with different superscript in a row are significantly different (P<0.05)**

Appendix 8

Analysis of variance of mean weight gain (g) of broiler chickens as influenced by feed treatments

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	38171285.241[a]	26	1468126.355	2454.970	.000
Intercept	69145784.767	1	69145784.767	115624.111	.000
Treatment	728889.913	2	364444.956	609.417	.000
weeks	36630818.897	8	4578852.362	7656.660	.000
Treatment * weeks	811576.431	16	50723.527	84.819	.000
Error	32293.198	54	598.022		
Total	107349363.206	81			
Corrected Total	38203578.440	80			

Analysis of feed conversion ratio of the broiler chickens as influenced by feed treatments

	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
FCR	9.019	2	.012	.713000	.37286	1.05314

Analysis of specific growth rate of the broiler chickens as influenced by feed treatments

	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
SGR	1.558	2	.020	.09523	-.1678	.3583

Analysis of variance of mean body length increase (cm) of broiler chickens as influenced by feed treatments

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	7978.700[a]	26	306.873	118.659	.000
Intercept	67369.086	1	67369.086	26049.723	.000
Treatment	255.855	2	127.928	49.466	.000
week	7621.751	8	952.719	368.390	.000
Treatment * week	101.094	16	6.318	2.443	.007
Error	139.653	54	2.586		
Total	75487.440	81			
Corrected Total	8118.354	80			

Analysis of variance of mean body width increase (cm) of broiler chickens as influenced by feed treatments

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	7703.231[a]	26	296.278	374.743	.000
Intercept	59888.966	1	59888.966	75749.629	.000
Treatment	338.448	2	169.224	214.040	.000
weeks	7253.288	8	906.661	1146.776	.000
Treatment * weeks	111.495	16	6.968	8.814	.000
Error	42.693	54	.791		
Total	67634.890	81			
Corrected Total	7745.924	80			

Analysis of variance of mean thigh length increase (cm) of broiler chickens as influenced by feed treatments

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1014.020[a]	26	39.001	225.486	.000
Intercept	6544.810	1	6544.810	37839.373	.000
Treatment	31.939	2	15.969	92.328	.000
weeks	972.593	8	121.574	702.891	.000
Treatment * weeks	9.488	16	.593	3.429	.000
Error	9.340	54	.173		
Total	7568.170	81			
Corrected Total	1023.360	80			

Analysis of variance of mean shank length increase (cm) of broiler chickens as influenced by feed treatment

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	447.875[a]	26	17.226	145.344	.000
Intercept	3331.855	1	3331.855	28112.526	.000
Treatment	7.800	2	3.900	32.907	.000
weeks	438.728	8	54.841	462.721	.000
Treatment * weeks	1.346	16	.084	.710	.772
Error	6.400	54	.119		
Total	3786.130	81			
Corrected Total	454.275	80			

Analysis of variance of mean wing length increase (cm) of broiler chickens as influenced by feed treatments

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	2354.437[a]	26	90.555	434.794	.000
Intercept	14837.947	1	14837.947	71243.254	.000
Treatment	70.217	2	35.108	168.570	.000
weeks	2256.232	8	282.029	1354.140	.000
Treatment * weeks	27.988	16	1.749	8.399	.000
Error	11.247	54	.208		
Total	17203.630	81			
Corrected Total	2365.683	80			

Analysis of variance of mean neck length increase (cm) of broiler chickens as influenced by feed treatments

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	522.033[a]	26	20.078	129.588	.000
Intercept	5987.320	1	5987.320	38643.264	.000
Treatment	17.267	2	8.633	55.722	.000
weeks	500.126	8	62.516	403.488	.000
Treatment * weeks	4.640	16	.290	1.872	.045
Error	8.367	54	.155		
Total	6517.720	81			
Corrected Total	530.400	80			

Analysis of variance of defeathered weights (g) of broiler chickens subjected to three feeding treatments

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	825082.176	2	412541.088	111.287	.000
Within Groups	22241.953	6	3706.992		
Total	847324.129	8			

Analysis of variance of eviscerated weights (g) of broiler chickens subjected to three feeding treatments

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	456038.847	2	228019.423	35.677	.000
Within Groups	38347.633	6	6391.272		
Total	494386.480	8			

Analysis of variance of proximate composition (%) of broiler meat from chickens fed the experimental diets

Parameters	**Trt. I**	**Trt. II**	**Trt. III**	**F.Pr**	**$LSD_{0.05}$**
Crude protein	11.20±2.22	34.15±4.12	30.96±3.25	0.006	0.001
Crude fat	6.10±1.00	3.20±0.12	3.60±0.14	0.004	0.003
Ash	2.90±0.02	2.40±0.24	2.50±0.35	<0.001	0.001
Fibre content	0.50±0.10	0.28±0.12	0.30±0.04	<0.001	0.003
Moisture content	30.00±1.52	28.06±2.25	30.05±3.20	0.008	0.010
Carbohydrate	49.30±2.15	31.91±1.01	32.59±2.01	5.100	0.022

STARTER

ANOVA

PCV%

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	169.556	2	84.778	58.692	.000
Within Groups	8.667	6	1.444		
Total	178.222	8			

ANOVA

RBC ×106µl

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.027	2	.014	29.927	.001
Within Groups	.003	6	.000		
Total	.030	8			

ANOVA

WBC ×104µl

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.452	2	.226	383.830	.000
Within Groups	.004	6	.001		
Total	.456	8			

FINISHER

ANOVA

PCV%

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	16.889	2	8.444	3.619	.093
Within Groups	14.000	6	2.333		
Total	30.889	8			

ANOVA

HB (g/dl)

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	1.872	2	.936	3.594	.094
Within Groups	1.562	6	.260		
Total	3.434	8			

ANOVA

RBC ×106µl

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	.058	2	.029	15.878	.004
Within Groups	.011	6	.002		
Total	.069	8			

ANOVA

WBC ×104µl

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	1.165	2	.582	189.913	.000
Within Groups	.018	6	.003		
Total	1.183	8			

ANOVA

SODIUM

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	96.258	2	48.129	80.633	.000
Within Groups	3.581	6	.597		
Total	99.839	8			

ANOVA

POTASSIUM

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	112.909	2	56.454	47.088	.000
Within Groups	7.193	6	1.199		
Total	120.102	8			

ANOVA

PHOSPHORUS

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	39.493	2	19.746	37.594	.000
Within Groups	3.152	6	.525		
Total	42.644	8			

ANOVA

CALCIUM

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	132.871	2	66.435	55.690	.000
Within Groups	7.158	6	1.193		
Total	140.029	8			

ANOVA

MAGNESSIUM

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	126.852	2	63.426	76.483	.000
Within Groups	4.976	6	.829		
Total	131.828	8			

ANOVA

MANGANESE

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.178	2	.589	5.847	.039
Within Groups	.604	6	.101		
Total	1.782	8			

ANOVA

IRON

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	5.460	2	2.730	171.347	.000
Within Groups	.096	6	.016		
Total	5.556	8			

ANOVA

COPPER

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.829	2	.915	252.079	.000
Within Groups	.022	6	.004		
Total	1.851	8			

ANOVA

CHLORINE

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2005.562	2	1002.781	161.267	.000
Within Groups	37.309	6	6.218		
Total	2042.870	8			

ANOVA

ZINC

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	5.487	2	2.743	13.793	.006
Within Groups	1.193	6	.199		
Total	6.680	8			