PERFORMANCE OF BROILER CHICKENS FED ON DIETS SUPPLEMENTED WITH YELLOW MEAL WORM LARVAE (*Tenebrio molitor*)

By

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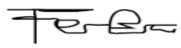
TECHNOLOGY

NOVEMBER 2023

DECLARATION AND APPROVAL

Declaration

This research thesis is my original work and has not been presented for an award of degree or diploma in any other university or institution.

Signature………  **Date…14/11/2023**

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DEDICATION

To my parents: Mr and Mrs Terera.

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ABSTRACT

Insects are a promising feed resource which can contribute to scarce protein rich feedstuffs in developing countries**.** A study was conducted to investigate the performance of broiler chickens fed on diets supplemented with yellow meal worm larvae (*Tenebrio molitor*. The larvae was processed and included in broiler chicken diets at different levels 0%YMWL (control), 2.5%YMWL, 5%YMWL and 7.5%YMWL. The diets were formulated to be iso-nitrogenous and iso-caloric in mash form for the starter and finisher phases. 160 cobb-500 day old broiler chicks obtained from a hatchery were randomly allocated to the four diets and replicated four times with ten birds each per replicate in a completely randomized design. Feed intake, body weight gain, feed conversion ratio, performance efficiency factor, carcass characteristics and meat sensory attributes were evaluated. Supplementation with YMWL increased ($p<0.05$) the average daily weight gain at 5%YMWL (54.5g) inclusion followed by 2.5%YMWL (48.8g), 0%YMWL (47.1g) and 7.5%YMWL (42.5g) being the lowest for the entire feeding period of 42 days. The average daily feed intake was similar across all the treatments ($p>0.05$). The feed conversion ratio (FCR) improved at 5%YMWL (1.69) inclusion compared with control 0%YMWL (1.9), 2.5%YMWL (1.9) and 7.5%YMWL (2.1) during the entire feeding phase ($p<0.05$). The performance efficiency factor was highest in 5% YMWL (323.9) followed by 2.5%YMWL (258.2), 0%YMWL (248.6) and lowest in 7.5%YMWL (204) at ($p<0.05$). Dietary supplementation with 5% YMWL significantly increased the absolute weights of carcass and carcass parts (wing, thigh, breast, back and drumstick) compared to other treatments ($p<0.05$). The viscera weight (heart, liver, spleen, gizzard) were similar across the treatment ($p>0.05$). There was a significant difference ($p<0.05$) in abdominal fat weight across all the treatments with 7.5%YMWL recording the highest weight compared to other treatments. Meat sensory attributes were not affected by dietary inclusion of YMWL. In conclusion, the study demonstrated that YMWL meal can be included up to 5% in broiler rations without any adverse effects on their growth performance and meat sensory attributes.

TABLE OF CONTENTS

Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND ACRONYMS

FCR – Feed Conversion Ratio

CF- Crude Fibre

CP- Crude Protein

EE- Ether Extract

FCR- Feed Conversion Ratio

FI- Feed intake

BWG- Body weight Gain

LW- Live weight

PEF-Performance Efficiency Factor

YMWL-Yellow Meal Worm Larvae

TML-*Tenebrio molitor* Larvae

GDP-Gross Domestic Product

SSA-Sub Saharan Africa

SBM- Soya bean meal

CHAPTER 1
INTRODUCTION

1.0 Background

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

Currently, soya bean meal and fishmeal are the most important protein ingredient in poultry feeds because of their balanced essential amino acid composition, easy digestibility, palatability and crucial attributes that enhance nutrient digestion and absorption (Van Huis et al., 2014). Protein sources are the most important component of poultry feed. It contributes for more than 70% of overall animal production costs, and a shortage of such feed resource base continues to hinder effective poultry production (Omojola et al, 2015). Soya bean meal and fish meal are the primary protein sources in chicken diets in intensive poultry production systems. However, in developing nations such as Kenya, the rising cost of these feed additives is impeding chicken production advancement (Driemeyer, 2016). This had been hampered by inefficiencies in production caused by climate change, lack of soybean bulking systems, poor agricultural practices, shortage of inputs, and high reliance on imports (Jonas and Justina, 2008). Furthermore, the supply of these feed ingredients has been constrained because they are also used for human consumption and biofuel production, resulting in an imbalance between supply and demand (Nasonga, 2022). This has resulted in increased demand and scarcity of these feed ingredients, resulting in high meat product prices. This was revealed by the decline in consumption of poultry meat from 2.4 kg per capita consumption against the recommended 12 kg as per WHO recommendation (Kenya Market Trust, 2021). Therefore, to meet the nutritive requirements, demand for poultry and poultry products there is need to identify low cost, locally available and sustainable alternative protein sources for animal feeds.

In searching for a sustainable solution that can ensure increased production and sustainability of the industry, a priority is to identify alternative sources of protein, which is the most expensive element in poultry production. Insect protein is one option since insects are consumed naturally by many animals, including fish, wild birds, zoo animals, pets and free-range poultry(Khan et al., 2018). It can be assumed that these animals are evolutionarily adapted to eating them as a part of their regular diet. Therefore, it is very likely that chickens would do well with insect meal as part of their dietary rations in the coming years. Edible insects have been recognized as a highly nutritious and healthy food with high protein content (40-65%), fats (15-43%), vitamin, fiber, and minerals (Marono et al., 2015; Van Huis et al., 2014). Rearing these insects can provide future protein and income generation to farmers and producers (Hanboonsong et al., 2013). Insect species that are normally used in animal feeds include, *Hermetia illucens L*. (black soldier fly), *Musca domestica L*. (common house fly), *Tenebrio molitor* L. (yellow meal worm), *Bombyx mori* L. (silkworm), termites, crickets and grasshoppers (Biasato et al., 2017). Supplementation with these alternative protein sources allows poultry producers to adopt the feeding strategy that reduces their feed expenses and increasing profitability (FAO, 2013).

Yellow mealworm larvae (*Tenebrio molitor*) has the potential for use as a protein source to supplement soybean meal and fishmeal in poultry diets (Selaledi et al., 2019). YMWL is rich in protein, fat, energy, and fatty acids; thus, it can be successfully used as feedstuff in poultry diets (Elahi et al., 2020). Research has been done on effect of dietary inclusion with YMWL on poultry (Biasato et al., 2016; Biasato et al. 2018; Ramos-Elorduy et al., 2002 ; Elahi et al., 2020; Khan et al., 2018), Alectoris Barbara birds (Loponte et al., 2017), Japanese quails (Zadeh et al., 2019), pigs (Duhra, 2020; Meyer et al., 2020) and aquaculture performance (Ido et al., 2019; Jintasataporn, 2019), positive results on productivity were obtained. Despite these successful results (Elahi et al., 2020) recorded poor body weight gain of broilers at 8% YMWL inclusion level and (Ballitoc and Sun., 2013) reported poor FCR of broilers at 10% YMWL meal inclusion. However, there is paucity of information on the usage of YMWL as a feed ingredient in poultry diets in Kenya. Therefore, the effects of YMWL as a non-traditional feedstuff and the appropriate inclusion levels in poultry diets on growth performance parameters, carcass characteristics and sensory attributes need to be documented.

This study was undertaken to evaluate the performance of broiler chickens fed on diets supplemented with yellow meal worm larvae (*Tenebrio molitor*) on feed intake, feed conversion efficiency, performance efficiency factor, body weight gain, carcass characteristics and meat sensory attributes.

1.1 Statement of the problem

The International Feed Industry Federation (IFIF) states that, the world population is expected to increase to more than 10 billion people by 2050 (FAO 2013). Moreover, it is expected that consumption of animal protein will be doubled for the mentioned population (FAO 2013). Poultry, being among most consumed meat is expected to play a major role in meeting this demand. However, this production may not be achieved due to high cost of conventional feedstuff (soya bean meal, sunflower cake, fish meal) accounting to 70% of total production cost (Omojola et al, 2015). This has become a critical aspect for the economic sustainability of the poultry meat industry, particularly in some developing countries (Belforti et al., 2015). Hence it has prompted the search for sustainable alternatives sources for poultry feeds that are cost effective.

Reliability of rainfall for production of conventional plant protein sources results in availability being seasonal. Therefore, there is a need to enlarge the feed resource base and ensure there is an efficient use of available ones to meet the demand for animal feed. Novel feed sources, especially those that are not competing with human food are key to the development of the livestock sector. Adoption of insects could be of greater potential since they can be produced all year round without being affected much by seasonality and shift in climate thus sustaining famers productivity and profitability (PROteINSECT, 2016).

For these reasons this study will be of public benefit providing empirical evidence of potential use of YMWL as a component of animal diets currently and in future. The study was therefore conceived on the background of the following objectives:

`1.3 Objectives

1.3.1 Main objective

To contribute to the utilization of Yellow Meal Worm larvae as protein source in broiler chicken diets

1.3.2 Specific objectives

1. To determine effect of supplementing broiler diets with different levels of YMWL on growth performance parameters.
2. To determine effect of supplementing broiler diets with different levels of YMWL on carcass characteristics.
3. To determine effect of supplementing broiler diets with different levels of YMWL on meat sensory attributes.

1.4 Hypotheses

The null hypotheses tested were:

1. **H_{01}**: Supplementation of broiler diets with YMWL has no significant effect on growth performance parameters
1. **H_{02}**: Supplementation of broiler diets with YMWL has no significant effect on carcass characteristics.
2. **H_{03}**: Supplementation of broiler diets with YMWL has no significant effect on meat sensory attributes.

1.5 Justification of the Study

The increasing scarcity of local animal feed ingredients, mainly soya bean, fish meal and sunflower cake has led to increased costs of up to 80% in poultry production (Ncube et al., 2017). Consequently, alternative protein sources for livestock are required. The alternate sources need to be cheaper, climate smart and not competing with human food. Insects as alternative source of protein in animal feeds are becoming an area of interest due to their potential of replacing convectional protein source in poultry diets (Van Huis et al. 2013).

Compounded feed made from insects can help to alleviate feed inadequacy in most underdeveloped nations. Simultaneously, it will aid in the mitigation of environmental issues caused by soya bean production as it is one of the main causes of deforestation and requires very high water input and insecticide products .Therefore, to exploit the full potential of insects in animal production, devising research and commercial initiatives are required.

According to (Abro et al., 2020), in Kenya insect farming is still in its infancy in feed industry. Therefore, this study will also benefit the feed industry to diversify into other protein sources apart from the conventional ones and leverage their prices to compete favorably with the imported feeds or feed raw materials.

This study intended to contribute to knowledge on the use of YMWL as an alternative protein source to lower the cost of broiler production. The reduced cost of production will help in increasing meat production at a lower cost thus increased consumption and improvement in the standards of living of the people.

1.6 Scope of the study

The expansion of the poultry industry is dependent on the affordability and availability of poultry feeds. Soya bean meal and fish meal are two prominent ingredients in the chicken industry; however they are not sustainable because of the shortages of resources and rising costs. Exploring alternatives ingredients is an option among nutritionist to produce high quality feeds at feasible cost. In order to supplement the traditional protein sources, yellow meal worm larvae might be introduced to the feed sector. Thus, the purpose of this study is to determine the effect of YMW larvae on the growth performance, feed intake, carcass characteristics and meat eating qualities of broilers fed insect-based diets. The study was conducted at Jaramogi Oginga Odinga University of Science and Technology located in Bondo, Kenya for a period of 6 months.

1.7 Delimitations

Due to the limited number of farmers in Kenya who are into yellow meal worm larvae production, searching for this feed resource was a challenge. Lack of laboratories with the necessary tools for sample analysis was another drawback.

1.8 Definition of terms

Broiler starter- high protein feed given to broiler chicks from day old to 3 weeks of age

Broiler finisher- high energy feed given to the broilers from 3 to 6 weeks of age prior slaughtering

Cobb 500- Broiler breed

Error bars-shows the variability of data in scientific plots

Feed formulation- the process of quantifying the amount of feed ingredients that need to be combined to form a single uniform mixture that supplies all of the nutrient requirements by an animal

Iso-nitrogenous diets –diets with similar amount of dietary nitrogen or protein

Iso-energetic diets- diets with similar caloric values or energy

Null hypothesis-a claim that there is no relationship exists between two sets of data or variables being analyzed

CHAPTER 2
LITERATURE REVIEW

2.0 Introduction

Poultry is one of the fastest growing industries within the agriculture sector (Gororo & Kashangura, 2016). There is a huge interest in research and development focused on improving its health, disease resistance and productivity (Hruby & Pierson, 2002). As a result of continuous research and development, today's commercial broilers are four times larger at the same age and require less feed to achieve market weight compared to the broilers of 60 years ago (Chang, 2007). Currently, the high cost feeds is considered to be the main limitation to sustainable growth of the poultry industry in the developing countries where feed accounts for 60-70% of production cost (Bagopi et al., 2014).

2.1 Global Poultry Production

According to the Food and Agriculture Organization (FAO), the current global chicken population is over 23 billion, which translates to approximately three birds per capita (FAOSTAT, 2016). Although the production systems vary widely, the main products are fairly the same: meat, eggs, and manure for the purpose of fertilizing crops (Velmurugu Ravindran, 2013). According to Alexander et al., (2016), poultry meat and eggs are most popular protein sources and are largely consumed across a wide range of cultures, traditions, cuisines and religions, and, consequently contributing greatly to household food security and nutrition. Within the livestock industry, poultry appears as the most efficient sub-sector to meet an ever-increasing global protein source due to their ability to mature fast and reach market weight faster than ruminants (Cudjoe and Brew., 2010).

Alexandratos and Bruinsma (2012) observed that, between 2005 and 2050, demand for animal based food is expected to increase by 70%. During that period, beef and pig demand is expected to increase by 66% and 43%, respectively, while at the same time, the demand for poultry meat and egg will increase by 121% and 65% respectively. Mottet and Tempio (2017) noted that although chicken meat is the fastest growing subsector, output is expected to grow at a slower rate than in previous decades. They further reported that globally, the sector will grow at a rate of

1.8 percent by 2050, and at 2.4 percent in the developing countries; and that this expansion will be fueled by significant geographical disparities.

2.2 Livestock Industry of Kenya

The livestock sub-sector of Kenya accounts for about 10-12% of the entire GDP and about 42% of the agricultural GDP (Livestock Industry Kenya, 2021). Furthermore, it provides the domestic requirements of meat, milk and dairy products, and other livestock products while accounting for about 30% of the total marketed agricultural products (Kimta, 2021). The dairy industry contributes to about 3.5% of the GDP, beef industry contributing about 70% of total beef consumed in the country (Ammanulah, 2020). The sheep and goat industry accounts about 30% of the total red meat consumed in the country and poultry production constitutes 23.8% with broilers representing 6.2% and layers 7.8% (Omiti and Okuthe, 2009; Köln and Humpreys, 2012). About 2.2% of the overall chicken population raised by commercial production methods constitutes other poultry species like ducks, guinea hens, and turkeys (MOLFD, 2012).

2.2.1 The poultry industry of Kenya

The poultry population is estimated 31 million birds with 75% consist of indigenous chicken, 22% of broilers and layers and 1% of breeding stock (MOLFD, 2012). This sector is estimated to contribute approximately 30% to agriculture's Gross Domestic Product (GDP) and about 7.8 percent of the total GDP in Kenya, with the agriculture sector contributing 25% of the GDP (FAO, 2008; Omiti and Okuthe, 2008; Zootecnica international, 2016). According to Köln, (2012) the Kenyan poultry industry is composed of two main genetic groups: the indigenous and imported breeds. According to Omiti and Okuthe, (2009), indigenous breeds are the native chickens that are often raised in rural and peri-urban settings, whereas imported varieties are commercial breeds of chickens that have been produced in recent decades to meet rising worldwide demand for animal-source foods.

Okello et al., (2010) reported that the poultry production system of Kenya is characterized by dualism comprising of both indigenous and the commercial sector. The indigenous poultry sector is characterized by low input and low output (Omiti and Okuthe, 2009). It is estimated that indigenous poultry provides around 71% of Kenya's eggs and chicken meat, with each household keeping an average of 13 birds (Republic of Kenya, 2008). The indigenous system is defined by low productivity of 30-80 small eggs per hen per year, high chick mortality rates and low body weight compared to commercial strains (MoLD, 2012). In contrast, the commercial sector is characterized by high input and high output whose objective is profit making (Okello et al., 2010). Commercial poultry production is estimated to constitute 22-23.8% of the total poultry population consisting of both broilers and layers (Poultry Sector, 2016).

2.3 Demand for poultry products

According to the UN-Habitat, (2010), the overall human population of SSA grew at an average rate of 2.7% over the past 20 years. At the same time, urbanization grew at about 4.2%, suggesting that that about 45% (490 million) of Africa‘s population will live in urban areas by 2030. In the case of Kenya, the population grew by about 9 million, from 38.6 million in 2009 to 56.5 million in 2022 (Worldometer, 2022). This population growth was associated with rapid urbanization, leading to increased demand for food of animal origin largely because the urban population is characterized by higher incomes relative to the rural population (Stroebel et al., 2010).

Robinson and Pozzi, (2011) reported that consumption of poultry meat in Kenya is predicted to increase from 54.8 thousand metric tons in 2000 to 164.6 in 2030, due to urbanization, population growth, economic growth making people wealthier, and the continuing viability of current broiler chicken systems. To address this expected demand growth, poultry production in Kenya is expected to increase from 56.9 to 1,666 metric tons by 2030 (FAO, 2011). Subsequently, livestock, and in particular the poultry sector, will play significant role in sustainable food security in Kenya.

2.4 Challenges faced by poultry farmers

According to The Poultry Site (2020), the primary barrier to the growth of the poultry business is the high cost of commercial feeds, which frequently include pre-mixes and soya bean meal that are imported. The primary base ingredient in broiler feed is maize, a staple diet for Kenyans, which can lead to some food-feed competition

Lack of traditional technologies like feed supplementation, vaccination, brooding and housing is another challenge to poultry productivity (Métayer at el., 2009). Lack of awareness among chicken farmers such as poultry diseases, potential zoonotic diseases and other emerging diseases like Highly Pathogenic Avian Influenza also causes loses to farmers (Murangiri et al., 2016). Besides, poor or non-existent extension service, lack of credit services, marketing support service, poor marketing infrastructure and lack of market information affects poultry production as reported by (Goitom et al., 2017).

2.5 Global supply and demand of feeds

According to FAO et al., (2014), domestic animals were making significant contributions to the global food supply and, as a result, animal feeds were becoming an increasingly critical component of the integrated food chain. The report further observed that the demands for livestock products were also increasing greatly due to population growth. Given this scenario, there would be need for a commensurate increase in feed supply to cope with increasing safety and welfare concerns. By 2050, the world's population is estimated to reach 9.1 billion, 34% higher than current. The FAO (2014) estimated that, the total global consumption and demand for poultry meat will increase by 85%, while egg production will increase by about 30% by 2050**.** This increasing demand for animal proteins will result in the compound feed sector to increase production since the feed industry is the most crucial component for sustainable growth in livestock. According to the International Feed Industry Federation,(2021), global compound feed production hiked to over one billion tons per year in 2020 and global animal feed market is expected to grow at a Compounded annual growth rate (CAGR) of 4.6% in 2021 to 2028 whilst the Africa compound feed market has projected CAGR of 3.6% during the forecast period (2021-2026) (Alltech Global Feed Survey 2021) to meet the requirements. However, the high prices of raw materials are expected to hinder the growth of the animal feed market during the forecast period. The growing shift toward climate change and the adoption of a vegan-based diet impeded the growth of the animal feed market in the forecast period and the upcoming years(Food and Agriculture Organization of the United Nations, 2020). To meet feed needs, it is necessary to identify other sources of animal protein (FAO, 2015).

2.6 Livestock feed constrains

The increasing cost of feed resources used in livestock production has been identified as a major constraint to sustainable increases in poultry production to partly meet the demand for animal protein, particularly in developing countries (Abu and Omojola, 2015). In order to address this problem, several studies are currently focusing on reducing the cost of feeding without compromising the performance of the birds. The studies involve compounding of feed in which all the required nutrients should be derived from cheap alternative energy and protein sources (Ballitoc, 2013).

According to Acamovic (2001), feed contributes the highest cost of livestock production thus there is need to use low-cost feed ingredients to reduce the cost of production. This is the focus of livestock feed and production research, man and his livestock compete for basic ingredients that are not usually produced in sufficient quantities locally. Livestock depends mainly on maize and soya bean meal as major feedstuff (Woyengo et al., 2014). However, the rising price of these feedstuffs and reduced productivity of these convectional ingredients (Okpanachi et al., 2013) due to adverse climatic conditions and scarcity of land has led to advanced feed and food production, and compounded will be further worsened by the food, feed and fuel competition (Prudêncio et al., 2010 and Stastnik et al., 2021). With the above problems there is therefore need to seek alternative feed sources that will use limited arable land, cheaper, readily available, climate smart and utilized by livestock for productive purposes(Ballitoc, 2013). The use of non-conventional feed material such as insects' meals is one of the ways to address this problem (Henry et al., 2015).

2.7 Role of Insects in Poultry Production

Veldkamp et al. (2012) states that insects have been proposed as high quality, efficient and sustainable protein source for livestock. Furthermore, they are regarded as attractive and important natural food source, for various kinds of animals, such as birds, lizards, snakes, amphibians, fish, insectivore, and other mammals hence making them acceptable in chicken production (Ravzanaadii et al., 2012). Studies has shown that using insects as a protein source can contribute to global food security via feed to supplement poultry production (Gasco et al., 2018).

Black soldier fly (*Hermetia illucens*), common housefly (*Musca domestica*), and yellow meal worm larvae (*Tenebrio molitor*) are identified as most promising alternative protein source for poultry production (Van Huis, 2013 and Veldkamp & Bosch, 2015). These three species have received attention due to their potential to valorize organic waste into high protein of required amino acid composition by poultry (Feng, 2018).

Ramos-Elorduy J. et al, (2002) reported that partial replacement of soybean meal with dried yellow meal worm larvae did not affect performance of broiler thus indicating that the yellow meal larvae can be used as protein source for raising broilers. Hwangbo et al., (2009) also performed a feeding trial with maggot meal and diets containing 10 to 15% maggots improved carcass quality and growth performance of broiler chickens. It was concluded that the use of insects as a sustainable protein-rich ingredient in pig and poultry feed is technically feasible.

Uushona, (2015) evaluated the effect of black soldier fly larvae (*Hermetia illucens*) (BSF) as a protein source in broiler diets on chicken production parameters. Four treatment diets were utilized to partially substitute soya-bean meal (0%, 5%, 10%, and 15%). The study concluded that BSFL can be utilized as a protein source in broiler diets up to 15% with no influence on broiler growth performance. However, Dahiru et al., (2016) reported that black soldier fly larvae meal can be included at 5% in both spring and broiler chicken without any negative effects on growth performance.

According to Sedgh-Gooya et al., (2021), the prebiotic component found insect skeletons (chitin) plays an important role on poultry health by lowering harmful microbes in chicken production. On the other hand (Van Huis., 2013) reported that feeding insects to chickens reduced antibiotic use due the presence of chitin. Thus insect meals as feed ingredient sources are beneficial to poultry production (Dalton, 2019).

2.7.1 Yellow Meal worm *(Tenebrio molitor)*

Yellow meal worms (*Tenebrio molitor*) belongs to Tenebriondidae family, of the order Coleoptera, also called the darkling beetle family, which also includes Zophobasmorio (superworm) and *Alphitobius diaperinus* (lesser mealworm) (Veldkamp & Bosch, 2015). Currently, 468 Coleoptera species have been described as edible, largely as larvae(Moore, 2018). *Tenebrio molitor* was first given its scientific name by the taxon author Linnaeus in 1758, and it is commonly known as the yellow mealworm, grain/flour beetles, or ténébrionmeunier (in French). It favors dark, moist and undisturbed areas like warehouses where cereal crops are kept.It is approximately 10-32mm in length and weighs of approximately 0.2g (Selaledi et al., 2019). They are currently grown and consumed in Africa, Asia and Australia (Agrarie et al., 2019). Larvae and pupa stages of yellow meal worm are rich in protein, their breeding and feeding is not complex. They feed on organic waste and are food to broilers (Hussain et al., 2017).

2.7.2 Climatic Conditions that favor YMW production

Yellow meal worms are poikilothermic, and they rely on environmental conditions for heat. They survive at optimum temperature of 25-28ºC (Kim et al., 2015). Ribeiro et al., (2018) reported that temperatures below 17ºC and above 30ºC inhibit embryonic development and poor survival rates. Punzo (2010) further observed that they require an optimal humidity of approximately 75%. The author also noted faster growth rates in larvae at humidity levels of 90-100%, but however this high humidity encouraged the growth of pollutants such as fungi. When there is low relative humidity of 10%, larvae may stop feeding and become inactive until the humidity rises (Ribeiro et al., 2018). Yellow meal worms utilize small amounts of water contained in dry feeds, however the productivity of water-deprived mealworms is low (one generation per year). Thus it is preferable to provide them with a source of water for better productivity (up to 6 generations per year) and in order to prevent cannibalism (Ribeiro et al., 2018).

2.7.3 Geographical Distribution of Yellow meal worm

The yellow meal worms (*Tenebrio molitor*) are thought to be native to tropics, sub tropics and warm temperatures (Da Morais et al., 2016). It is believed that this insect is most widely bred and traded in Europe (Bordiean et al., 2020). In East Africa, yellow meal worm farming is still in its infancy, though it is becoming a fast-growing and expanding agribusiness by farmers (Abro et al., 2020). However, there is limited research attention to the rapidly growing industry of yellow meal worm (Tanga et al., 2021).

2.7.4 Life cycle of Yellow Meal Worm

The life cycle of Yellow Meal Worm which undergoes through four distinct stages of complete metamorphosis: egg, larva, pupa and adult is shown in Figure 1. The average life-cycle of a yellow meal worm beetle is around 3 months, and starts at around 4 to 17 days after copulation, where a female beetle can lay an average of 500 eggs (Alves et al., 2016). The embryonic development lasts from 4 to 6days, which can be accelerated with a slight increase in temperature (25 to 27°C). Under optimum temperature and moisture conditions, the larval period lasts 3-4 months (Dalton, 2019). As yellow meal worm larvae develop, they grow out of their old skin and shed their exoskeleton 9-17 times (Ribeiro et al., 2018). After 3-4 months of development, the yellow meal worms are ready to be harvested, processed and consumed (Agrarie et al., 2019). The larvae that are not harvested after this phase will turn into a pupa, a stage that lasts 5 to 6days and culminates in an adult individual (Feng, 2018). Overall, on the YMW life cycle the larvae is reported to be a good source of protein for chickens and other captive animals due to its nutritional composition (Biasato et al., 2016).

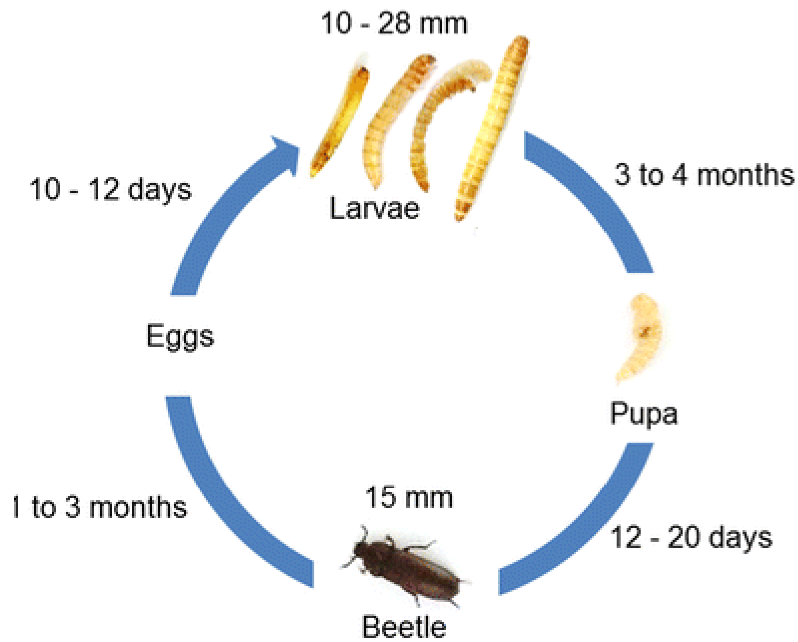


Figure 1: Life cycle of Yellow meal worm (Bennett, 2003)

2.7.5 Nutritional composition of Yellow meal worm larvae meal

Yellow meal worm larvae contains a high amount of crude protein ranging from 44% - 69% and crude fat that is between 23% - 47% (Józefiak et al.,2015 and Veldkamp et al., 2012), thus can be included in the poultry rations (Aguilar-Miranda et al., 2002). The crude fiber (CF) content of YMWL reported was between 23.0-36.0% on DM basis (Ghaly & Alkoaik, 2009; Ravzanaadii et al., 2012; Sanabria et al., 2019) and from 4.19% to 22.35% (Hong et al., 2020). In contrary to this Sedgh-Gooya et al., (2021) recorded 7.53% crude fiber. The reported ash content was 5.0–8.8% (Ramos-Elorduy et al., 2002; Ravzanaadii et al., 2012). Bovera et al., (2016) also compared YMW larvae chemical composition and amino acid profile with SBM and further stated that CP, EE, and fiber of YMW larvae was higher (51.93, 21.57, and 7.20%) than that of SBM (44.51, 1.84, and 4.79%). The gross energy (GE) content ranged between 4150 kcal/kg and 6,366 kcal/kg (Nascimento et al., 2021 and Biasato et al., 2016) while the apparent metabolizable energy ranges from 2010kca/kg to 3332kca/kg (De Marco et al., 2015). However, these values are depended on the production or processing of the larvae (Makkar et al., 2014 and Elahi et al., 2020).

DeFoliart, (1992) stated that YMW larvae contains a high amount of lysine and threonine which are deficient in most commonly used cereals (wheat, rice, cassava and maize) but low amount of amino acids, methionine and cysteine. YMWL is deficient in calcium, but rich in phosphorus (Ravzanaadii et al., 2012). Therefore, it is recommended that calcium is supplemented when yellow meal worm larvae are used in poultry diets (Selaledi et al., 2020). According to Dreyer & Wehmeyer (1982), yellow meal worm larvae contain chitin which reduces the protein digestibility in chickens. Insect chitin has the potential to improve poultry health by reducing intestinal Escherichia coli and Salmonella spp and could also increase intestinal Lactobacillus spp (Khempaka et al., 2011). Yellow meal worm larvae is reported to be one of the best insect based meals as they improve broiler performance and meat quality (Khan et al., 2017).

2.7.6 Use of Yellow meal worm larvae in Poultry production

According to reports, adding YMWL to broiler feeds enhances the meat quality and broiler development performance (Ramos-Elorduy et al., 2002). In an experiment by Hussain *et al*., (2017), in determining the dietary inclusion of YMWL in broilers performance at 0%, 50, 100, 150g respectively. The study reported that supplementation of YMWL improved both the growth performance of broilers and meat quality.

In another study with YMW larvae, Elahi et al., (2020) assessed the growth performance, hematological characteristics, carcass, and meat quality of broiler chicks. Broiler chicks were assigned to five dietary YMWL treatments containing 0%, 2%, 4%, and 8% dried YMWL and 10.48% fresh YMWL (corresponding to 4% dried YMWL). The results showed that supplementation with YMWL significantly increased body weight and average daily gain and feed conversion ration efficiency at 4% inclusion level.

Ballitoc and Sun (2013) reported that YMWL up to 10% in a broiler diet had no affect palatability and birds' performance. Ramos-Elorduy et al., (2002) reported that YMWL can be included in broiler starter diets without detrimental impacts on growth rate or showing signs of feed rejection because of palatability difiiculties. Likewise, Schiavone et al,(2012) noticed improved BWG at maximum level of 25% YMWL. However, (Khan et al., 2018) reported reduced FI in broiler chicken fed with high levels of YMWL in their diets. The same author reported that the high lipid and protein percentage reduces feed intake.

Bovera et al., (2015) partially replaced SBM with YMW larvae in broiler's diet. The study reported that use of YMWL as the main protein source in the broiler diet had no significant effect on most growth performance, carcass traits, chemical and physical properties of meat. The same author also reported an increase in performance efficiency factor on broilers fed on the YMW larvae diet (156.2) than isoproteic and isoenergetic SBM diet (132.6).

Furthermore, a study carried out by Biasato et al.,(2017) reported that increasing levels of dietary YMWL meal inclusion in male broiler chickens did not affect haematochemical parameters and carcass traits. Another study by Sogari et al., (2019) and Biasato et al. (2019) discovered that including YMWL at 10% or above reduced *Firmicutes spp*. which have an impact on bird health and feed digestion, as well as proliferation in bacteria recognized to improve bird health, such as *Clostridium*, *Sutterela*, and *Alistipes.* Thus the potential use of YMWL is very important in health and physiological status of poultry as well as reducing feed and vaccination expenses to farmers (Ballitoc, 2013).

However, YMWL has proven to be the most promising diet for a variety of species, including aquatic species like catfish, gilthead sea bream, rainbow trout, and white shrimp as well as chickens as reported by (Belforti et al. 2015).

2.7.7 Limitations of YMWL in poultry production

Yellow meal worm larvae are considered to be potential alternative of protein supplement in poultry diets for replacing soya meal or fishmeal (Belforti et al., 2015). Its protein quality is similar to that of soya meal, but the methionine, calcium, cystine and arginine content are limited (Selaledi et al., 2019; Makkar et al., 2014; Veldkamp et al., 2012). Supplementation with these nutrients is recommended when feeding YMWL. De Marco et al., (2015) and Kurdu et al., (2017) reported that YMWL has chitin contained in the exoskeleton that can negatively influence the apparent digestibility and utilization of nutrients by domestic poultry As a result, partial chitin removal via high pressure processing or the use of enzymes to remove chitin-bound proteins is recommended (Rumpold & Schlüter, 2013).

Furthermore, Biasato et al., (2017) reported that increasing levels of dietary YMWL meal inclusion in male broiler chickens may improve body weight and feed intake, but negatively influence feed efficiency and intestinal morphology, thus suggesting that low levels of YWML in broilers diets may be beneficial (Sun et al., 2013).

2.8 Performance Efficiency Factor

PEF, according to Astra (2006) is a measure of how successfully broilers convert the feed they eat into meat. It also measures how well a ration matches a broiler's precise nutrient requirements as well as the relative demands of other nutrients. The same author reported that, feed efficiency, along with growth rate, days to market, and mortality, has been identified as a significant criterion in measuring the viability of PEF in relation to bird feeding strategy.

Despite the complexity of assessing broiler performance, various formulae have been devised to provide a solid understanding of the effectiveness of the relevant manufacturing system (Kelebemang, 2005). The benefit of adopting PEF is to measure technical efficiency of broiler performance through bird weight, age at slaughter, mortality, and FCR (Astra, 2006).

2.9 Carcass characteristic determination

Animals of all species vary greatly in composition depending on their stage of development, dietary history, and genetic background (Kauffman, 1988) . This is a concern for those who raise animals, the meat industry, and consumers because the economic worth of an animal raised for meat is significantly influenced by its composition.

Bernau et al., (2015) reported that, in the broiler production chain carcass and parts yields provide useful information to guide farmers on strain, sex and slaughter age options that would meet consumers' demands. Consumers prefer chickens with high yield of noble parts, such as breast, drumsticks, and thighs (Fanático et al., 2005). Furthermore, Webb, (2015) reported that, carcass and parts yield of broiler strains used in semi-extensive systems, fast-growing birds usually present higher breast yield as compared to slow-growing birds, which present higher drumstick and thighs yield. Differences are also observed between sexes, with males having higher thighs yield, and females, higher breast yield (Fanático et al., 2005). In addition, identifying the carcass characteristics of broilers allows producers to improve management and genetic changes if necessary to fit their goals and production objectives (Walker, 2016). Hence carrying out evaluation of the carcass properties helps in determining the quality and worth of the animal at slaughter.

2.10 Sensory evaluation properties of poultry meat

The evaluation usually involves different parameters based on our senses of taste (salty, sweet, sour, and bitter), smell (odors), touch (texture), sight (color, shape) and sound (for example crunchy) (Choi, 2022). The field of sensory analysis has matured over the years to become a recognized discipline in food science. From the industry perspective, sensory evaluation is particularly applicable to meat consumers since organoleptic properties play a major role in the purchasing decision and final acceptability of meat and meat products in the market (Ventanas et al., 2020).

Stone and Sidel (2004) observed that overall sensory analysis comprises a set of techniques that measure human responses to a particular food or a consumer product measuring, analyzing and interpreting responses to products, as perceived through the senses of taste, touch and smell. The sensory profiles differed between conventional standard broilers and organic niche broilers, and between breeds. In a recent study, Choi (2022) reported that aroma and taste attributes were more important to consider since the gives the overall acceptability of broiler meat.

According to Madzimure et al.(2015), flavor is one of the most important aspect of meat palatability that is regulated by the senses of smell and taste. In addition, it plays a decisive role in consumers' acceptance and consumption of meat. The sensory properties of meat are affected by cooking techniques such as heating duration, heating temperature, and heating technique (Shi et al., 2020). Furthermore, Adi et al., (2020) reported that high cooking temperatures and cooking techniques lower meat juiciness hence affecting the sensory attributes of meat. Apart from parameters mentioned above Jacques et al.,(2017) reported that, breed, age, sex, and genetics, diet, environment and slaughtering procedures can also affect sensory attributes of meat. However, it is important to consider all these factors as they all contribute to the overall sensory properties of meat (Sepúlveda et al., 2010; Díaz et al., 2002; Hoffman et al., 2020).

CHAPTER 3
MATERIALS AND METHODS

3.1 Study area

The study was carried out at Jaramogi Oginga Odinga University of Science and Technology (JOOUST) farm, located within the main campus. The university is located in the western part of Kenya, approximately 62 km (39 miles), west of Kisumu City (Fig 1). The geographical coordinates of the university's main campus are: 0°05'38.0"S, 34°15'31.0"E (Latitude: -0.093889, Longitude: 34.258611).

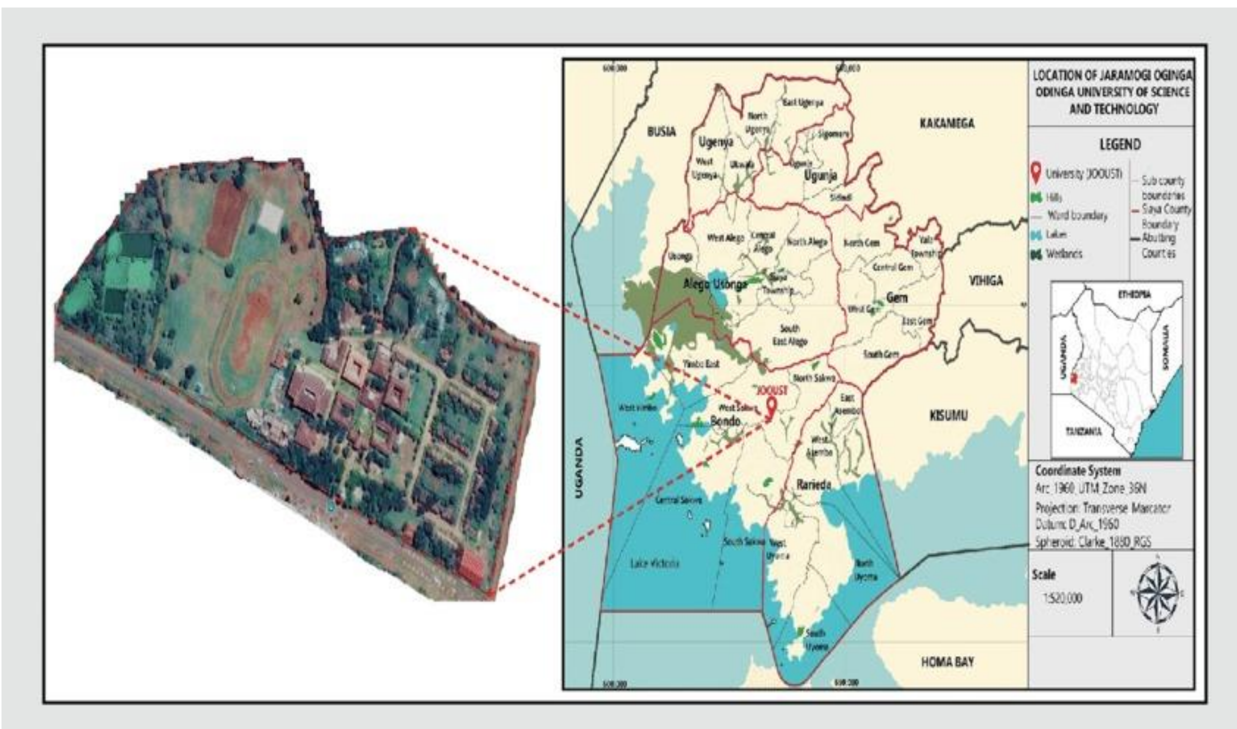


Figure 2: Location of study area

3.2 Preparation of Yellow Meal Worm Larvae

The YMWL was obtained from a producer in the capital city of Nairobi. Upon receipt, the YMWL was washed with clean running water to remove some debris and sundried for 4 days. It was then milled using 2mm screen size then stored in sacks. Samples were taken for laboratory nutrient analysis.

3.2.1 Experimental diets

Four iso-nitrogenous and iso-energetic diets containing the following inclusion levels of YMWL were formulated: YMWL meal 0% (control), 2.5%, 5% and 7.5% were formulated. The diets were compounded to meet the specifications set forth by the Kenya Bureau of Standards (KeBS) for broiler starter and finisher. In this respect, the starter diets were targeted at 21-22% CP level and metabolizable energy (ME) of 3000 Kcal/kg. The finisher diets were targeted at 18-19% CP level of and metabolizable energy of 3000 Kcal/kg. The ingredients of the 4 experimental diets are reported in ***Table 1*** below.

Table 1: Ingredient Composition of the experimental diets

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

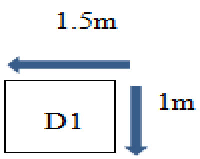
**Four dietary treatment: YMW0%: control, YMWL2.5%, YMWL5%, YMWL7.5% inclusion*
***1Vit/mineral premix gave the following per kg of diet: vitamin A, 11500IU;cholecalciferol,2100IU;vitaminE(fromdltocopherylacetate),22IU;vitamin B12, 0.60mg; riboflavin, 4.2mg; nicotinamide, 40mg; calcium pantothenate, 35mg; menadione (from menadione dimethyl-pyrimidinol), 1.50mg; folic acid, 0.8mg; thiamine, 3mg; pyridoxine, 10mg; biotin, 1mg; choline chloride, 560mg; ethoxyquin, 125mg; Mn (from MnSO4·H2O), 65mg; Zn (from ZnO), 55mg; Fe (from FeSO4·7H2O), 50mg;Cu (from CuSO4·5H2O),8mg; (from Ca(IO3)2·H2O),1.8mg;Se,0.3mg;Co(from Co_2O_3),0.2mg;Mo,0.16mg*

3.2.2 Experimental birds and design

160 Cobb 500 broiler chicks were used in a completely randomized design. The day old chicks were randomly assigned to the 4 treatments (2.5%, 5%, 7.5%YMWL and control (0%) on arrival. Each treatment comprised of 40 birds in 4 replicates of 10 chicks each, and housed in 1.5 square meters floor space pens as shown in ***Fig 3*** below.

A3	C1	D4	B2	D1	C2	A1	B3
PASSAGE							
B1	D3	C4	A2	C3	D2	B4	A4

KEY



Treatment A-0% YMWL +100% SBM

Treatment B-2.5% YMWL+ 97.5% SBM

Treatment C-5% YMWL+ 95% SBM

Treatment D-7.5% YMWL+ 92.5% SBM

Figure 3: Layout of the experimental design

3.3 Housing and placement of chickens

The chicken house and equipment were cleansed and disinfected two weeks before chick arrival, starting from roofs, walls and floors.Wood shavings were used as bedding at a thickness of 7-10cm from the floor. Pre-heating was done a day before chicks arrival using infrared bulbs. The house was well-lit and well-ventilated. Upon arrival the chicks were weighed and randomly allocated into 16 ply wood walled pens measuring (1m width x1.5 m length x 0.9m height). Each pen held holding ten chicks as shown in ***(Fig. 4 A&B).*** The stocking density was 0.15m^2 per chick. The chicks were given treatment diets from day one and administered with stress mix (multi-vitamin) via drinking water for the first five days after arrival.

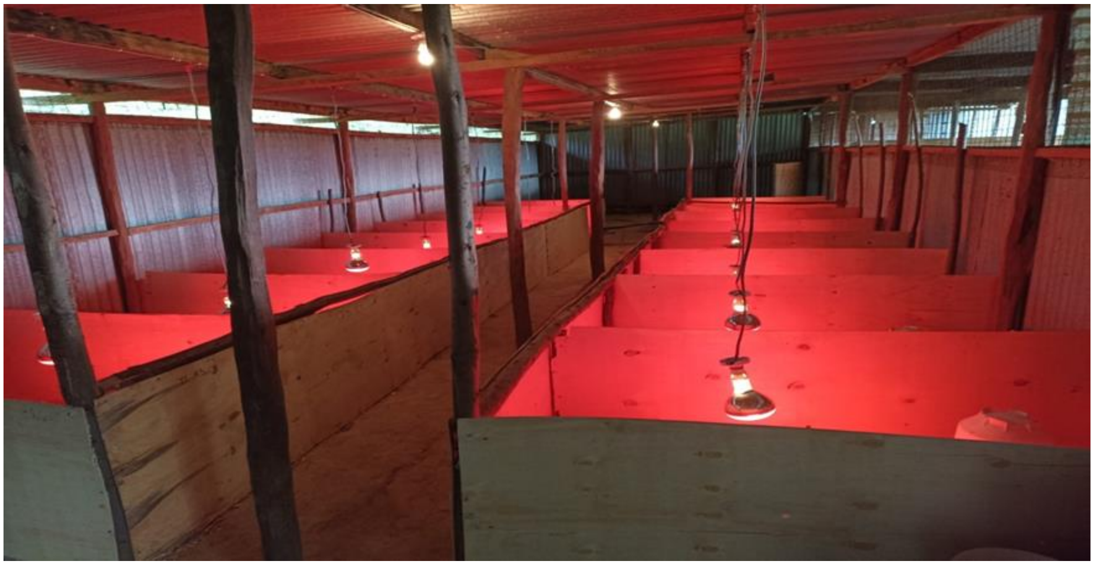


Figure 4: Experimental pen A

Figure 5: Experimental pen B

3.3.1 Management of experimental birds

On the 7^{th} day, the birds were vaccinated against Infectious Bursal Disease (Gumboro), while the New Castle Disease vaccine was administered on day 14 via drinking water. Daily mortality was determined by counting the number of birds that succumbed during the trial.

Infrared bulbs were used to provide warmth during the brooding period. Temperatures were maintained at 30- 32°C in the first week, and reduced gradually, by 2°C every week to 26°C by the end of the third week. Brooder ventilation was also monitored regularly to check on changes in temperatures through chick behaviour. The bedding was turned frequently using a fork, depending on the level of compaction. Wet bedding on areas around water troughs was removed and replaced with fresh material. Clean water was supplied *ad libitum* through drinkers. The experimental birds were fed the various starter diets up to day 21 and experimental finisher diets from day 22 to day 42 when the trial was terminated. The height of drinkers and feeders were adjusted as the birds' grew, and were made to be slightly above the level of chicken backs to minimize spillage and spoilage. In order to observe biosecurity, visitors were to sanitize their hands before handling chickens. Foot bath with disinfectant was provided at fowl run entrance.

3.4 Data and data collection

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

3.4.1 Feed intake (FI)

Daily feed intake was calculated as the difference between feed offered at the beginning of the day minus any left over the following morning. Prior to weighing the left over feed, it was sieved to remove any contaminants like droppings and wood shavings. The remaining sieved feed was put back, mixed with the fresh feed and weighed. The mean feed intake in grams per bird per day was derived by dividing the total intake per replicate (pen) with the total number of birds per replicate for the day. The mean per treatment was calculated as the mean of 4 replicates.

3.4.2 Body weight gain (BWG)

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

3.4.3 Feed conversion Ratio (FCR)

The feed conversion ratio was calculated as the ratio of feed consumed to body weight gain per replicate per treatment. The formula below was used;

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

3.4.4 Performance efficiency factor (PEF)

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

$$\textbf{PEF} = \frac{\textbf{Liveweight (g) X Livability (\%)}}{\textbf{Age at depletion (days) X Feed conversion ratio}} \textbf{ X 100}$$

Where:

Live weight= Live weight at slaughter (42 days)

Livability= survival rate over the growing cycle/ total number of birds at the beginning of the experiment

Age at depletion=terminal age (42 days)

FCR= cumulative feed intake (g)/total weight gain (g)

3.5 Carcass characteristics

At the termination of the feeding trial after 42 days, 8 birds per treatment were starved for 12 hours and slaughtered for carcass and meat sensory evaluation. The birds were stunned and beheaded using a single cut and left in a killing cone to allow blood to drip out before the birds were scalded in hot water. The birds were thereafter completely de-feathered, eviscerated, dissected and all internal organs and external offals (head, shank, feets and neck) were carefully removed. Live weight, dressed weight, breast, drumstick, thigh, wing, neck , back, gizzard with fat, liver, spleen, heart and abdominal fat) were taken using electronic weighing balance and expressed as percentage of live weight of the birds by dividing the weight of the carcass with the weight of the live bird before slaughter and expressed in percentage. Thereafter, the carcasses were kept in the refrigerator at -4ºC for one week awaiting sensory evaluation.

3.6 Sensory evaluation

The meat sensory evaluation was done by 40 randomly selected semi-trained panelists consisting of 23 females and 17 males aged between 23 and 55. The panelists consisted of students and lecturers at JOOUST University. The panelists were first trained on how to evaluate the chicken samples and to complete the sensory evaluation forms. Eight dressed carcasses per treatment were used. The part/portion evaluated was the breast muscle. Skin was removed and breast muscle was cut into cubes of 40 pieces of approximately 2cmx 1cm in length. Forty (40) chicken cubes per treatment were cooked using shallow fat frying method (Angad et al., 2015). The meat was cooked till it turned golden brown at 140 ^{0}C (Chatli et al., 2015). Meat for each treatment was presented to the tasting panellists for evaluation. Meat sensory evaluation forms were used to evaluate the meat quality attributes. Eight point descriptive scales were used to evaluate aroma intensity (1 =extremely bland to 8 = extremely intense), initial impression of juiciness (1 = extremely dry to 8 = extremely juicy), first bite (1 = extremely tough to 8 = extremely tender), sustained impression of juiciness (1 = extremely dry to 8 = extremely juicy), muscle fibre and overall tenderness (1 = extremely tough, to 8 = extremely tender), amount of connective tissue (1= extremely abundant to 8 = none), overall flavour intensity (1= extremely bland to 8 = extremely intense) and a-typical flavour intensity (1= none to 8 = extremely intense) (Madzimure et al., 2015). The waiting period between meat samples tasting of different treatments was estimated at 10 minutes. To minimize crossover effects, the panellists were instructed to rinse their mouths out with water after each sample consumed.

3.6.1 Ethical Considerations

All the panelists who participated in the sensory evaluation were informed about the product and disclosure on carrying out meat eating qualities on broiler chickens fed on yellow meal worm larvae based diets was made. Participation was made voluntary.

This research was approved for study by the Jaramogi Oginga Odinga Ethics Review Committee on 16th May 2022 with approval number ERC 30/5/22-06.

3.7 Laboratory analysis

Chemical analysis was done in the Nutrition Laboratory, Department of Animal Production, in University of Nairobi. Ingredients and composite feed samples were analysed for dry matter (DM), crude protein (CP), ether extract (EE), crude fibre (CF) and ash, according to procedures of the Association of Official Analytical Chemists (AOAC, 1989) for proximate analysis.

Dry matter was obtained by heating the sample in an oven to remove moisture at 105 ^{0}C for 12hours. Ash was obtained by igniting the sample in the muffle furnace at 600°C to burn off organic material for 4 hours.

The Kjeldahl method was used to determine the nitrogen content of the sample. Crude protein was obtained by digesting organic materials in sulphuric acid in the presence of a catalyst (selenium) to release ammonia which was then distilled and titrated to determine the nitrogen content. The nitrogen content obtained from the titration was multiplied by the standard factor of 6.25 to give an estimate of the crude protein.

Crude fiber was determined by digesting the feed sample in 2.04N H_2SO_4 acid followed by digestion in 1.78N KOH alkali. The residue was subsequently weighed and ashed. The loss of weight after ashing was considered as crude fiber content of the feed.

The ether extract was determined by refluxing the sample with diethyl ether which dissolved fats, oils, pigments and other fat soluble substances. The ether was then evaporated from the fat/ether mixture and the resulting residue was then weighed to give an estimate of the ether extract or crude fat content.

The nitrogen-free extract (NFE) was determined by subtracting the percentages of moisture, ash, lipid and fiber from 100%.

3.8 Data Analysis

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

The following model was used for data analysis;

$$\mathbf{Y_{ij} = \mu + T_i + e_{ij}}$$

Where Y_{ij}= Response variable being BWG, FI, FCR, PEF, carcass characteristics and sensory attributes

μ = Overall constant mean, common to all observations

T_i= effect due to the i^{th} level of YMWL meal (i = 0% YMWL meal 2.5% YMWL meal, 5% YMWL meal and 7.5% YMWL meal)

e_{ij}= Random residual error associated with the response from an experimental unit

CHAPTER 4

RESULTS

4.1.1 Chemical composition of sundried Yellow Meal Worm Larvae and Soya Bean Meal

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

Table 2: Nutrient composition (% DM) of sundried yellow meal worm larvae (YMWL) and soya bean meal (SBM)

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

4.1.2 Nutrient composition (%DM) of the experimental diets

In diet formulation, the aim was to have all diets for each feeding phase to be iso-nitrogenous and iso-energetic in which the target for the crude protein content was 21 to 22% and 18-19% in the starter and finisher diets, respectively. The starter meal in the four treatments had a crude protein range of 22.38 to 22.4%, whereas the finisher diet had a range of 19.1 to 19.4%. The diet with the highest amount of YMWL inclusion had greater percentage of crude fiber of 6.6% for the starter diet and 9.91% for the finisher diet and high fat content on both starter and finisher diet as shown in ***Table 3*** below.

Table 3: Nutrient composition of experimental diets

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

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

4.2 Growth performance

The feed intake, body weight gain, feed conversion ratio and performance efficiency factor (PEF) are shown in ***Table 3*** below for the starter phase, finisher phase, and the entire feeding period.

During the starter phase ADFI was lower for the control diet (0%YMWL) (p= 0.043) compared to other experimental diets 5%YMWL, 7.5%TML with 2.5%TML being the highest. The BWG was significantly (p<0.05) different between the diets with the highest gain recorded for 5%YMWL, followed by 2.5%YMWL and 0%YMWL (control), and lowest in 7.5%TML. The FCR varied significantly between treatments (p<0.05), with broilers fed on 5%YMWL having better FCR compared to other experimental diets.

During the finisher phase, the ADFI was similar (p>0.05) for all treatments. The BWG was significantly (p=0.001) affected by the inclusion of different levels of YMWL in the diets. The highest body weight gain was recorded in 5%YMWL (67.11g/d), followed by 2.5%TML and 0%YMWL (control), and lowest in 7.5%YMWL with the latter 3 being similar. The FCR was significantly different (p=0.001) across all the treatments with 5%YMWL having better FCR (1.5) followed by 2.5%YMWL, 0%YMWL and 7.5%YMWL being the poorest.

During the entire feeding period, the ADFI was similar (p=0.187) for all the treatments. The daily weight gain was highest for 5%YMWL diet (54.5g/d), similar for 2.5%YMWL and 0%YMWL (48.8g/d and 47.1g/d), and lowest for 7.5%YMWL (42.47g/d) respectively

($p=0.001$). The FCR was significantly different for all treatments with 7.5% TML ($p<0.05$) having the poorest FCR (2.1) compared to other experimental diets. There was a significant difference in PEF ($P<0.05$) for all the treatments. Birds fed on 5%YMWL had the highest PEF compared to other treatments with 7.5%YMWL being the lowest.

Table 4: Effect of different inclusion levels with YMWL meal on performance of broilers during different phases

	Treatment				p-value
	0%YMWL	2.5%YMWL	5%YMWL	7.5%YMWL	
Starter phase (d1-d21)					
Initial weight (g) d1	40.1±1.4[a]	39.55a±1.2[a]	41.48±0.44[a]	42.10±0.6[a]	0.503
Weight (g) at d21	828.5±10[b]	860.6±11.1[b]	919.7±13.1[a]	666.1±11.8[c]	0.012
BWG[1] g/day	37.54±0.43[b]	39.1±0.56[b]	41.85±0.63[a]	29.75±0.58[c]	0.001
ADFI[1] (g/day)	55.4±0.53[b]	60.63±0.8[a]	58.34±1.52[ab]	59.88±1.59[ab]	0.043
FCR[1]	1.41±0.02[b]	1.48±0.035[b]	1.33±0.043[b]	1.87±0.061[a]	0.010
Finisher phase (d22-d42)					
Initial weight (g) d22	828.5±10[b]	860.6±11.1[b]	919.7±13.1[a]	666.1±11.8[c]	0.012
Final weight (g) d42	2016.8±19.7[b]	2088.9±36.7[b]	2329±22.4[a]	1825.7±21.3[c]	0.001
BWG[1] g/day	56.6±0.96[b]	58.49±1.79[b]	67.11±1.28[a]	55.22±1.01[b]	0.001
ADFI[1] (g/day)	128.15±3.64[a]	130.88±1.8[a]	131.59±1.62[a]	126.83±0.39[a]	0.407
FCR[1]	1.72±0.637[ab]	1.63b±0.02[b]	1.5±0.026[c]	1.86±0.048[a]	0.001
Entire Feeding period					
Initial weight d1 (g)	40.1±1.4[a]	39.55±1.2[a]	41.48±0.44[a]	42.10±0.6[a]	0.503
Final weight d42 (g)	2016.8±19.7[b]	2088.9±36.7[b]	2329±22.4[a]	1825.7±21.3[c]	0.001
BWG[1] g/day	47.1±0.48[b]	48.8±0.88[b]	54.5±0.53[a]	42.47±0.52[c]	0.001
ADFI[1] (g/day)	91.8±1.8[a]	92.9±0.78[a]	94.9±1.49[a]	90.7±0.91[a]	0.187
FCR[1]	1.91±0.042[b]	1.93±0.023[b]	1.69±0.02[c]	2.12±0.034[a]	0.001
PEF[1]	248.6±0.01[a]	258.2±0.01[b]	323.9±0.05[c]	204.0±0.75[d]	0.001

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

4.2.1 Weekly Feed intake

The effects of supplementation with YMWL on feed intake of broilers for week 1 to 6 are shown in ***Fig 6***. There were no significant differences across all the treatments at week1 and week2 of study. There was significantly lower feed intake on week 3 for 0%YMWL and 5%YMWL as compared to other treatments. The results show that there was no significant difference in feed intake (FI) from week 4 to week 5 across all the treatments. During the last week there was an insignificant higher intake for birds supplemented with 5%YMWL followed by birds supplemented with 2.5%YMWL, 0%YMWL and 7.5%YMWL respectively.

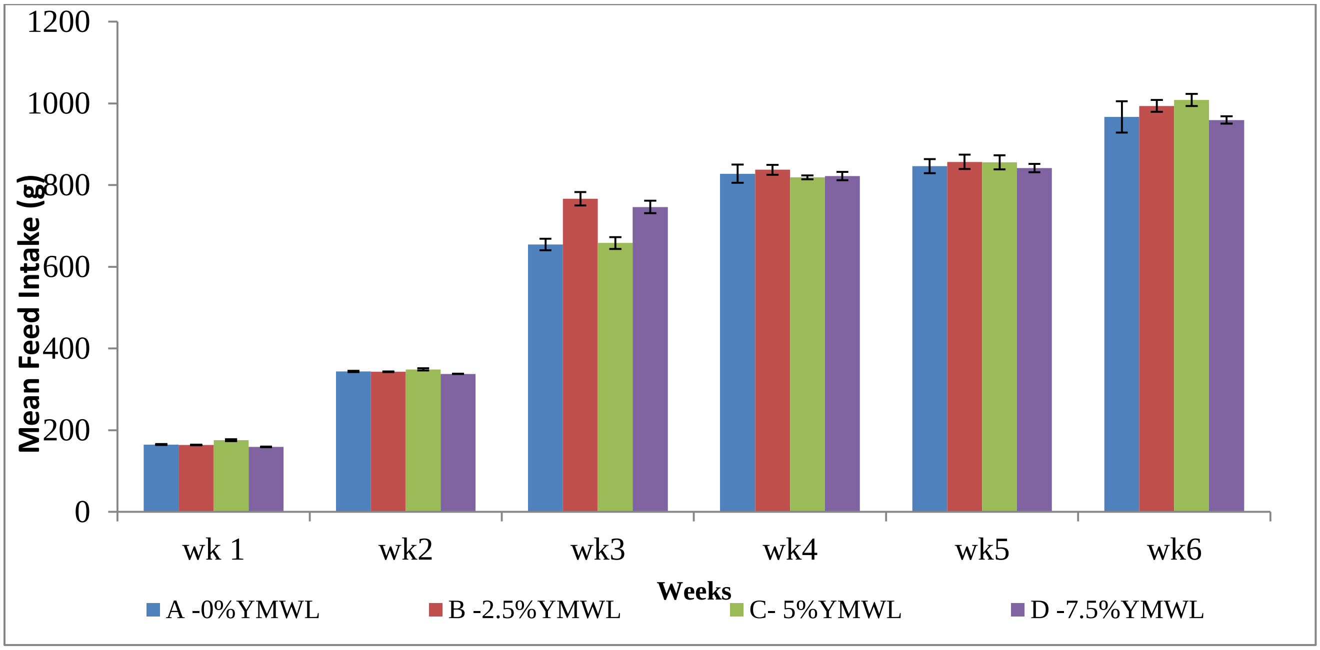


Figure 6: Trends for mean weekly feed intake of broiler chicken fed on diets with different inclusion levels of YMW larvae. The bars represent standard error of the mean

4.2.2 Average weekly live weight

The effects of inclusion of YMWL in broiler diets on weekly live weight (WLW) for week 1-6 are shown in ***Fig 7*** below. There was no significant difference on weekly live weight (WLW) during the first 2 weeks across all the treatments. However, from week 3 to week 6 live weights were highest for birds supplemented 5%YMWL followed by 2.5%YMWL then 0%YMWL and 7.5%YMWL having the least.

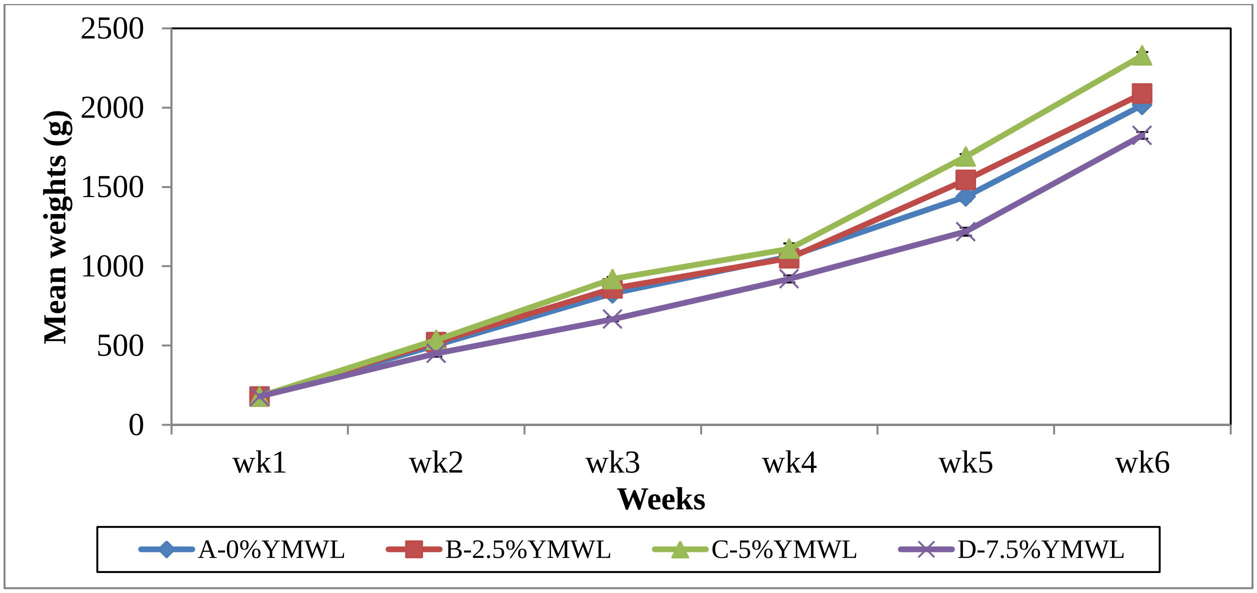


Figure 7: Trends in weekly live weights of birds fed on broiler diets with different inclusion levels of YMWL larvae. The bars represent standard error of the mean

4.2.3 Average Body Weight Gain

The effects of YMW larvae on average body weight gain (ABWG) of broilers for week 1 to 6 are shown in ***Fig 8.*** There were no significant differences on ABWG during the first week across all the treatments. However, at week 2 and 3, chicks on diets supplemented with 5%YMWL had the highest ABWG compared to others. At week 4, all the treatments had a decrease in ADG. At week 5 and 6 the average daily gain increased with 5%YMWL recording the highest whilst 7.5%YMWL had the least.

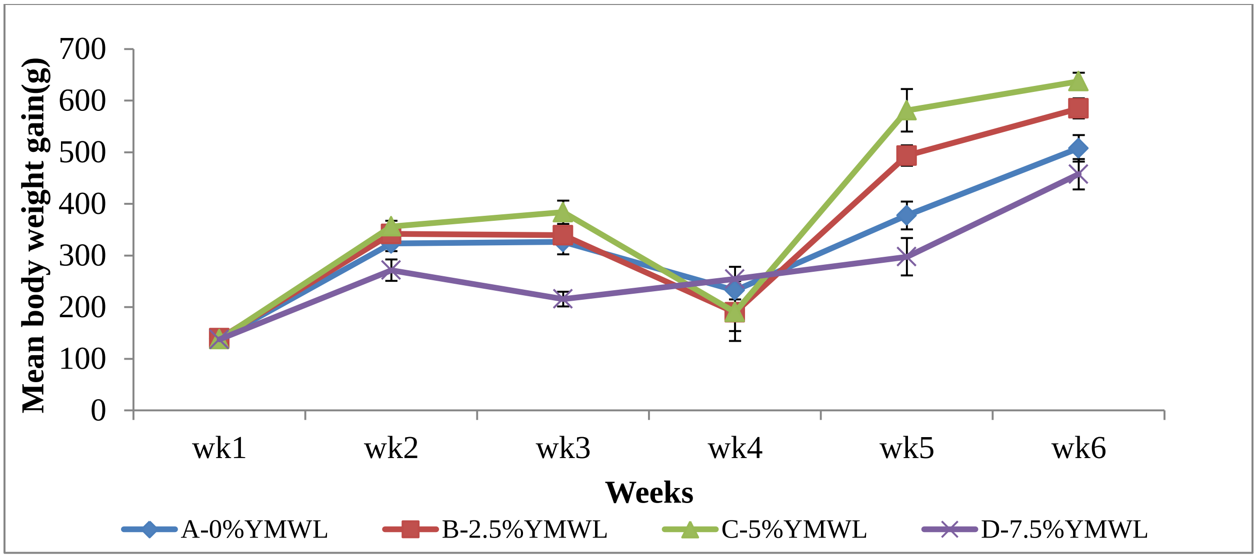


Figure 8: Trends in weekly weight gain of birds fed on broiler diets with different inclusion levels of YMW larvae. The bars represent standard error of the mean.

4.2.4 Feed Conversion Ratio

The feed conversion ratios (FCR) of broilers for week 1 to 6 are shown on ***Fig 9***. The FCR for week 1 and 2 were similar for all treatments. There were significant differences in FCR from week 3 to 6 with YMWL 7.5% having the highest. Birds fed diets supplemented with 5%YMWL had the lowest feed conversion ratio, followed by 2.5%YMWL and 0%YMWL (control).

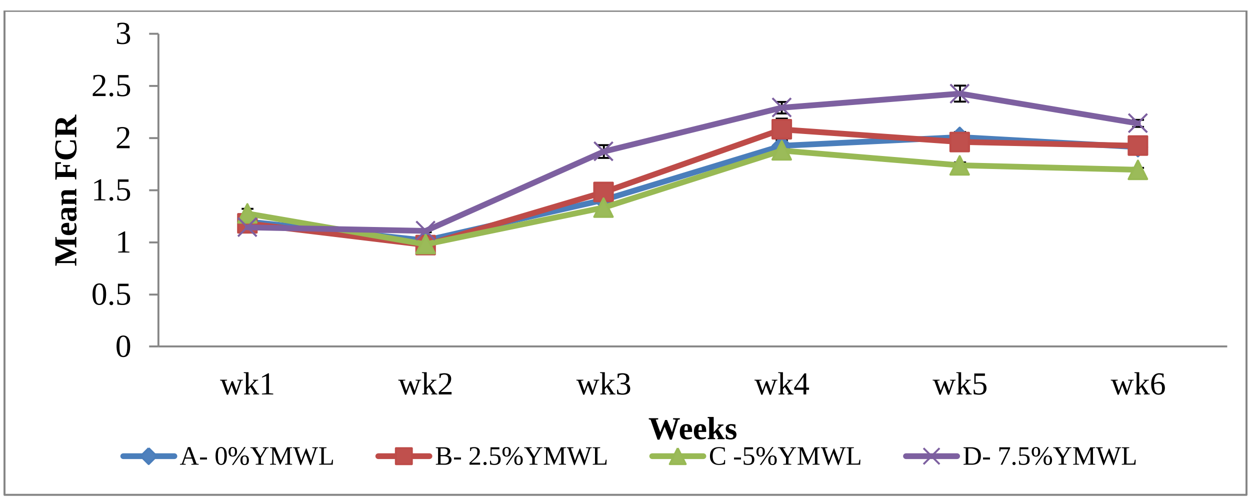


Figure 9: The trend in weekly feed conversion ratio of birds fed on broiler diets with different inclusion levels of YMWL. The bars represent standard error

4.4 Carcass characteristics

The carcass characteristics and proportion of carcass parts are shown in ***Table 5***. The carcass weight (both whole and eviscerated) was highest in 5%YMWL diet and lowest for7.5% diet *(P>0.05)*. Organ weights (breast weight, back weight, wing weight, thigh and drumstick weight) showed significant differences among the treatments (p<0.05) with 5%YMWL having the highest scores and 7.5%YMWL the lowest scores. The neck weights were similar across all the treatments (p>0.05). Overall, the dressing percentage of the organs as a percentage of the carcass were similar across the treatments (p>0.05).

Table 5: Effects of YMWL supplementation on carcass characteristics of experimental broiler chickens

	Treatment				
	0%YMWL	**2.5%YMWL**	**5%YMWL**	**7.5%YMWL**	**p-Value**
Weight of live bird	2016.8 ± 20^{b}	2088.9 ± 37^{b}	2329 ± 22.4^{a}	1825.7 ± 21^{c}	0.001
Carcass weight	1831.8 ± 24^{b}	1974 ± 23^{a}	2100.8 ± 22^{a}	1672 ± 49.7^{c}	0.001
Eviscerated carcass with (no head & feet)	1507.7 ± 7.6^{b}	1556.8 ± 35.5^{b}	1791.9 ± 12^{a}	1403.5 ± 8.3^{c}	0.001
Breast	635.8 ± 25.7^{b}	697.5 ± 22.7^{ab}	779.75 ± 7.2^{a}	623 ± 48.4^{b}	0.011
Thigh	143.2 ± 3.26^{ab}	146.8 ± 3.33^{a}	151.5 ± 2.6^{a}	132.8 ± 2.06^{b}	0.001
Drumstick	106.5 ± 3.3^{b}	110.5 ± 2.78^{a}	119.3 ± 0.43^{a}	104.3 ± 0.63^{b}	0.002
Wings	82.45 ± 2.93^{b}	88.78 ± 2.01^{a}	94.8 ± 1.31^{a}	81.7 ± 2.35^{b}	0.004
Neck	68.22 ± 2.61^{a}	70.47 ± 1.78^{a}	74.83 ± 1.63^{a}	67.4 ± 4.21^{a}	0.275
Back	290.25 ± 6.9^{b}	291 ± 13.7^{b}	322.8 ± 13^{a}	274 ± 10.2^{b}	0.003
		Dressing %			
Carcass	74.8 ± 0.61^{a}	74.6 ± 1.75^{a}	76.9 ± 0.77^{a}	76.9 ± 1.33^{a}	0.359
Breast	31.6 ± 1.47^{a}	33.45 ± 1.5^{a}	33.5 ± 0.42^{a}	34.1 ± 2.57^{a}	0.728
Thigh	7.1 ± 0.12^{a}	7 ± 0.25^{a}	6.6 ± 0.12^{a}	7.3 ± 0.13^{a}	0.113
Drumstick	5.3 ± 0.2^{a}	5.3 ± 0.19^{a}	5.1 ± 0.06^{a}	5.7 ± 0.09^{a}	0.088
Wings	4.1 ± 0.13^{a}	4.3 ± 0.17^{a}	4.1 ± 0.09^{a}	4.5 ± 0.15^{a}	0.185
Neck	3.4 ± 0.11^{a}	3.3 ± 0.03^{a}	3.2 ± 0.08^{a}	3.7 ± 0.19^{a}	0.081
Back	14.4 ± 0.37^{a}	13.9 ± 0.87^{a}	14.7 ± 0.55^{a}	15 ± 0.16^{a}	0.578

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

4.5 Visceral characteristics and dressed weight (%)

The weight of visceral and their percentage dressed weight are shown in ***Table 6***. The viscera weights (g) were similar (p>0.05*)* for all treatment diets. The abdominal fat weight was higher in 7.5% YMWL and lowest for the control diet of 0%YMWL. The birds under 7.5%YMWL diets recorded the highest percentage dressed weight of abdominal fat, liver, and gizzard (without content) compared to other treatments. The dressing percentage of the heart and the spleen were similar across all treatments (p>0.05).

Table 6: Weight (g) and dressed % of internal viscera for broilers fed on YMWL based diets

	Treatment				
	0%YMWL	**2.5%YMWL**	**5%YMWL**	**7.5%YMWL**	**P-value**
Weight of live bird	2016.8 ± 19.7^{b}	2088.9 ± 36.7^{b}	2329 ± 22.4^{a}	1825.7 ± 21.3^{c}	0.001
Abdominal fat	35.8 ± 2.14^{b}	38.47 ± 0.46^{ab}	40.17 ± 0.71^{ab}	42.01 ± 0.94^{a}	0.023
Heart	6.43 ± 0.41^{a}	7.03 ± 0.53^{a}	6.96 ± 0.5^{a}	6.52 ± 0.63^{a}	0.801
Liver	45.53 ± 1.13^{a}	47.3 ± 1.16^{a}	48.64 ± 1.13^{a}	45.95 ± 1.4^{a}	0.303
Spleen	1.86 ± 0.11^{a}	1.85 ± 0.07^{a}	1.91 ± 0.12^{a}	1.71 ± 0.07^{a}	0.47
Gizzard without content	44.6 ± 3.21^{a}	40.32 ± 1.82^{a}	42.3 ± 1.42^{a}	40.1 ± 1.63^{a}	0.453
	Dressed %				
Abdominal fat	1.8 ± 0.09^{b}	1.8 ± 0.04^{b}	1.7 ± 0.01^{b}	2.3 ± 0.08^{a}	0.001
Heart	0.91 ± 0.57^{a}	0.34 ± 0.03^{a}	0.3 ± 0.02^{a}	0.36 ± 0.035^{a}	0.418
Liver	2.3 ± 0.06^{ab}	2.3 ± 0.03^{ab}	2.1 ± 0.06^{a}	2.5 ± 0.09^{a}	0.006
Spleen	0.092 ± 0.005^{a}	0.09 ± 0.002^{a}	0.08 ± 0.006^{a}	0.09 ± 0.004^{a}	0.31
Gizzard without content	2.2 ± 0.14^{a}	1.9 ± 0.07^{ab}	1.8 ± 0.06^{b}	2.2 ± 0.07^{a}	0.019

^{abc} Least square means with different superscript letters in a column differ(P< 0.05)

4.6 Sensory Evaluation

The results of sensory evaluation on the broiler carcass are shown in ***Table 7***. There were no differences in aroma intensity, amount of connective tissue, muscle fiber and overall tenderness, first bite, overall flavor intensity and a-typical flavor intensity among treatment(p>0.05). Broilers in the 7.5%YMWL diet had the highest initial impression of juiciness scores while 0% YMWL had the lowest (p<0.05). For sustainable impression of juiciness and Initial impression of juiciness, broilers in the 0%YMWL and 2.5%YMWL had the lowest score, while those in the

7.5%YMWL had the highest scores ($p<0.05$). The 2.5% and 5% groups were not different from each other on initial and sustainable impression of juiciness.

Table 7 : Sensory ratings for broilers fed on different inclusion levels of YMWL

	Treatments				
	0% YMWL	**2.5%YMWL**	**5%YMWL**	**7.5%YMWL**	**P-Value**
Aroma Intensity	5.3 ± 0.211^{a}	5.1 ± 0.26^{a}	5.6 ± 0.279^{a}	5.4 ± 0.286^{a}	0.583
Initial impression of juiciness	4.6 ± 0.261^{b}	5 ± 0.253^{ab}	5.4 ± 0.264^{ab}	5.7 ± 0.241^{a}	0.007
First bite	5.3 ± 0.25^{a}	5.5 ± 0.237^{a}	5.5 ± 0.221^{a}	5.6 ± 0.248^{a}	0.803
Sustainable impression of juiciness	$4.9\pm0.233b^{c}$	4.8 ± 0.226^{c}	5.8 ± 0.227^{ab}	5.83 ± 0.234^{a}	0.002
Muscle fiber and overall tenderness	5.6 ± 0.273^{a}	5.5 ± 0.198^{a}	5.1 ± 0.205^{a}	5 ± 0.235^{a}	0.191
Amount of connective tissue	5.1 ± 0.196^{a}	5.3 ± 0.224^{a}	5.1 ± 0.221^{a}	5.1 ± 0.214^{a}	0.856
Overall flavor intensity	5.3 ± 0.221^{a}	5.3 ± 0.199^{a}	5.6 ± 0.221^{a}	5.2 ± 0.251^{a}	0.71
A-typical flavor intensity	5.2 ± 0.246^{a}	4.9 ± 0.223^{a}	5.1 ± 0.215^{a}	5.2 ± 0.263^{a}	0.707

^{a,b} *Within a row, means with different superscripts differ ($P< 0.05$)*

CHAPTER 5
DISCUSSION

5.1 Nutritional composition of Yellow meal worm larvae

The Yellow meal worm larvae (YMWL) used in study had a crude protein content of 45%. The results concurs with the range of 45-60% recorded by Ghaly & Alkoaik, (2009) and 44-69% by Józefiak et al.,(2015) and Veldkamp et al., (2012). Furthermore, Nery et al., (2018) reported 45% CP. In contrast, Elahi et al., (2020) and Sedgh-Gooya et al., (2021) reported a higher CP ranging from 50% and 53%. The difference in the CP content could be attributed to raising medium and raw material processing. The fat content recorded in this study was 23.9% .The results are in agreement with Biasato et al., (2018) who reported a fat content ranging from 16.6–43.1%. Józefiak et al., (2015 and Veldkamp et al., (2012) recorded 23% crude fat. However, crude fat reported in this study was lower than 30% recorded by Elahi et al., (2020) and 28% by (Sedgh-Gooya et al., 2021). The crude fiber (CF) content of YMWL reported by other studies (25.0-36.0%) were higher than the current study (Ghaly & Alkoaik, 2009; Ravzanaadii et al., 2012; Sanabria et al., 2019). Sedgh-Gooya et al., (2021) and (Bovera et al., 2016) recorded 7.53% crude fiber which was lower than the present study. However, Hong et al., (2020) stated that the crude fiber of YMWL ranges from 4.19% to 22.35% which are range with the current study. The difference in the CF content could be the chitin found in the exoskeleton of the larvae. The reported ash content was 8.6 and is within range of 5.0–8.8% reported by several authors (Ramos-Elorduy et al., 2002; Ravzanaadii et al., 2012). The nutritional profile discrepancy of YMWL in the current study with that of other studies could have been due to the raising medium and processing involved in the production of insects (Elahi et al., 2020).

5.2 Growth performance parameters

5.2.1 Feed intake

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

5.2.2 Body weight gain

Supplementation with YMWL meal increased the BWG and LW at 5% inclusion level compared to other groups on both finisher and entire feeding phase. The results are in consistence with that of (Biasato et al., 2017) and (Bovera et al., (2016) who reported increase in BWG and live weight on broiler chicks and free-range chicks fed on 50 to 100g/kg YMWL meal inclusion level. Other studies also reported that Alectoris Barbara birds (Loponte et al., 2017), and Japanese quails (Zadeh et al., 2019) fed a YMWL diet grew considerably faster compared to the control at 250 to 500 g/kg YMWL and 30g/Kg YMWL meal inclusion level. (Elahi et al., 2020) also reported an increase in body weight and average daily gain of broilers fed 4% of YMWL inclusion level with broiler chicks were assigned 0%, 2%, 4%, and 8% dried YMWL and 10.48% fresh YMWL respectively. According to (Sedgh-Gooya et al., 2021), there was an increase BWG and live weight of birds supplemented with 2.5% YMWL meal. According to Benzertiha and Kiero, (2019), reported increase in BWG on broilers fed with low levels of YMWL and Zophobas morio full-fat meals (0.2% and 0.3% respectively). Hussain et al., (2017) also reported improved BWG with increase in amount of YMWL meal in their diet (1,322.0, 1,346.3, and 1,423.3 g for 0.1%, 0.2%, and 0.3% YMWL meal, respectively). In contrast, Biasato et al., (2016) and Bovera et al., (2015) reported no differences in BWG in chickens fed on the YMWL meal and the control diet. Thus the use of YMWL based diets at lower inclusion level can improve digestibility and utilization of nutrients hence resulting in rapid growth and development.

Additionally, in this current study 7.5% YMWL inclusion level significantly reduced both LW and BWG compared to other treatments diets. Similar finding were reported for broiler chickens by (Elahi et al., 2020) who recorded poor BWG and LW at the level of 8% YMWL. The results also contradict those of Schiavone et al, (2012) who observed improved BWG at maximum level of 25% YMWL. The reduced live weights and BWG recorded at 7.5% YMWL inclusion level in this current study might be due to the high fibre in the diet since insects contain exoskeleton composed of chitin which makes it difficult to be digested by chickens causing nutrients in the feed to be less accessible. De Marco et al., (2015) also speculated that chitin present in the exoskeleton of YMWL meal have a negative impact on the apparent digestibility coefficient of nutrients. Furthermore, (Ravindran & Blair, 1993) also pointed out that insect chitin makes it difficult for domestic fowl to digest. Sánchez-Muros et al., (2014) mentioned that YMWL contains chitin, a polymer found in the exoskeleton of arthropods that is indigestible to monogastric animals. Khempaka et al., (2011) reported that chitin reduces protein digestibility in broilers but on the other hand it have a positive effect on poultry health as stated by (Van Huis., 2013) who observed that feeding black soldier fly larvae, yellow meal worm larvae or field crickets to chickens reduced antibiotic use because diets containing around 3% chitin increased populations of intestinal Lactobacillus spp. and decreased populations of intestinal Escherichia coli and Salmonella spp.

5.2.3 Feed conversion Ratio

The results of this study show that FCR was better in 5% YMWL compared to other diets on both finisher and entire feeding period. This is in agreement with (Ijaiya & Eko, 2009) who recorded improved FCR in broilers in response to insect meals (silkworm). Benzertiha and Kiero, (2019), reported improved FCR in broiler chickens that were fed with low levels (0.2% and 0.3%) of YMWL. In addition Hwangbo et al., (2009) also reported better FCR in response to YMWL meal. These results contradicts those of Ballitoc and Sun., (2013) who reported a poor FCR of broilers from 0% to 10% YMWL meal inclusion. The discrepancies between the current and other studies may be partly due to level of YMWL meal which was used in different studies. Additionally, in this study replacing soya bean meal with 7.5% YMWL meal in broiler diets strongly worsen FCR.These findings are similar to the trends observed by Józefiak et al., (2016) who reported reduced FCR with increase of YMWL meals in chicken. (Bovera et al.,

2016) also reported the reduced FCR ranging for 1.9 – 2.6 with increase in YMWL meal. Furthermore, Khan et al.,(2017) recorded the worst FCR for broilers fed with YMWL meal diet as a total replacement by soybean meal. These detrimental effects could have been attributed to high fibre content in YMWL, which might have affected the utilisation of the feed by the birds. Ravindran and Blair, (1993) stated that the chitin content of YMWL diets negatively influence the nutrient digestibility of crude protein hence impairing FCR in broilers. Hence Rumpold and Schlüter, (2013) recommended partial chitin removal through high pressure processing or use of enzymes to break chitin-bound proteins to improve FCR in insects meals as feeding ingredient.

5.2.4 Performance Efficiency Factor

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

5.3 Carcass yield and organ weight

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

5.4 Viscera weight

In the current study, dietary supplementation with YMWL meal had no discernible effect on the relative weights of the liver, heart, gizzard and spleen. This is in agreement with the results of Ballitoc,(2013) who reported no differences on viscera weights on broiler chickens supplemented with YMWL, though there is lack of information on effects of YMWL meal on internal organs of broiler chickens.

5.5 Abdominal fat

The lower abdominal fat weight observed in diets containing 2.5%YMWL and 5%YMWL compared to 7.5% in the present study strongly agree with Marono et al.,(2017) who reported lower abdominal fat and triglyceride levels from birds fed on black soldier fly-based diets compared to birds fed on soya bean meal based diets. Biasato et al., (2017) observed lower abdominal fat on free-range and male broiler chicken fed on 75 g/kg YMWL inclusion level. However, chitin that is present in insects' exhibits hypolipidaemic and hypocholesterolaemic effects on broiler chickens, which might cause the development of leaner meat and reduction in body fat. (Hossain & Blair, 2007), also reported that chitin have the ability to bind bile acids and free fatty acids. Similar outcomes were observed in laying hens fed 1.02g of dietary inclusion of black soldier fly larval meal per day (Marono et al., 2017). The same authors found that birds fed on black soldier fly-based diets had lower abdominal fat and triglyceride levels than birds fed diets based on soybean meal. However, (Biasato et al., 2017) recorded high abdominal fat weight on broiler chickens fed on diet containing 15% full fat YMWL meal as a replacement of soybean meal, corn gluten meal. In addition (Biasato et al., 2017) also recorded increased abdominal fat weight on diet containing 10% YMWL meal, these results are almost similar with the one recorded in 7.5% YMWL in this present study. This implies that, increasing YMWL inclusion levels in the diet of broiler chickens may increase abdominal fat mass.

5.6 Sensory characteristics

There were no differences in aroma intensity, amount of connective tissue, muscle fiber and overall tenderness, first bite, overall flavor intensity and a-typical flavor intensity among treatments. These results are in agreement with those of Hussein et al., (2017) who reported that supplementing broiler diets with YMWL based protein had no effect on meat eating qualities, including taste, tenderness, juiciness and flavor. Similarly, Hwangbo et al., (2009) also observed that adding insect meal to broiler diets had no effect on the organoleptic qualities of meat. (Elahi et al., 2020) fed 4% YMWL meal in broiler diet and discovered no significant difference between treatment and control group in terms of texture, flavor, taste, or juiciness. Similar study was also conducted by Khan et al., (2018) to assess the organoleptic properties of meat of broiler chicken fed with several types of insect meal (maggot meal, silkworm meal, and mealworm) and reported no differences in the sensory profile. However in the current trial 5% and 7.5% YMWL recorded higher scores of initial impression of juiciness and sustainable impression of juiciness amongst other treatments. The results are in agreement with the study of Khan et al., (2018) who recorded an increase in meat tenderness and juiciness on broiler chickens supplemented with 8% YMWL meal. This juiciness maybe correlated with intramuscular fat concentration in meat which plays a major role in meat juiciness.

CHAPTER 6

6.1 CONCLUSIONS

According to the results of this study, it can be concluded that:

1. YMWL based diets has a positive significant effect on growth performance parameters (feed intake, weight, daily feed intake and PEF). Therefore, YMWL can be used effectively to replace soya bean meal without influencing growth parameters of broilers hence the null hypothesis was rejected at 5% inclusion level.

2. Supplementation with YMWL on broiler chickens diets increased the weight of the eviscerated carcass and carcass parts (breast, drumstick, wing, thigh and back); hence the null hypothesis was rejected was rejected at 5% inclusion level.

3. The meat sensory attributes showed no effects on aroma intensity, amount of connective tissue, muscle fiber and overall tenderness, first bite, overall flavor intensity and a-typical flavor intensity of broilers supplemented with YMWL based diets; hence the null hypothesis was accepted.

6.2 RECOMMENDATIONS

From the findings of this study, farmers can partially substitute *T. molitor* larvae as a protein supplement in broiler diet to improve digestibility and absorption of nutrients by the chickens.

6.3 FURTHER RESEARCH

Further studies on how to partially remove chitin through high pressure processing methods (pelleting) to improve the use of insects as feeding ingredient are recommended.

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APPENDICES

Appendix 1: Organoleptic test questionnaire

Meat eating qualities of broilers fed on Yellow meal worm based diets.

Age: ≤ 20——. 21-25——. 26-30——., ≥ 30——.

Gender: Male———, Female———.

Signature.......................... **Date..................**

Please evaluate the following samples of broilers for the designated characteristics and give your opinion on a scale of 1to 8

	Characteristics	Rating scale	Trt1	Trt2	Trt3	Trt4
1	**Aroma intensity** Take a few short sniffs as soon as you remove the foil. Typical broiler meat aroma	1= Extremely bland 2= Very bland 3= Fairly bland 4= Slightly bland 5=Slightly intense 6= Fairly intense 7= Very intense 8=Extremely intense				
2	**Initial impression of juiciness** The amount of fluid exuded on the cut surface when pressed between the thumb and forefinger	1= Extremely dry 2= Very dry 3= Fairly dry 4= Slightly dry 5=Slightly juicy 6= Fairly juicy 7= Very juicy 8=Extremely juicy				
3	**First bite** The impression that you form on the first bite	1= Extremely tough 2= Very tough 3= Fairly tough 4= Slightly tough 5=Slightly tender 6= Fairly tender 7= Very tender 8=Extremely tender				
4	**Sustained impression of juiciness** The impression of juiciness that you form as you start chewing	1= Extremely dry 2= Very dry 3= Fairly dry 4= Slightly dry 5=Slightly juicy 6= Fairly juicy 7= Very juicy 8=Extremely juicy				
5	**Muscle fibre & overall**	1= Extremely tough 2= Very tough				

	tenderness Chew sample with a light chewing action	3= Fairly tough 4= Slightly tough 5=Slightly tender 6= Fairly tender 7= Very tender 8=Extremely tender				
6	**Amount of connective tissue (Residue)** The chewiness of the meat	1=Extremely abundant 2= Very abundant 3=Excessive amount 4= Moderate 5= Slight 6= Traces 7= Practically none 8= None				
7	**Overall flavour intensity** This is the combination of taste while chewing and swallowing referring to the typical broiler flavour	1= Extremely bland 2= Very bland 3= Fairly bland 4= Slightly bland 5=Slightly intense 6= Fairly intense 7= Very intense 8=Extremely intense				
8	**A-Typical flavour intensity**	1= None 2= Practically none 3= Traces 4= Moderate 5= Slightly intense 6= Fairly intense 7= Very intense 8=Extremely intense				

Appendix 2: Ethical Review approval letter

JARAMOGI OGINGA ODINGA
UNIVERSITY OF SCIENCE AND TECHNOLOGY

DIVISION OF RESEARCH, INNOVATION AND OUTREACH
JOOUST-ETHICS REVIEW OFFICE

Tel. 057-2501804
Email: erc@jooust.ac.ke
Website: www.jooust.ac.ke

P.O. BOX 210 - 40601
BONDO

OUR REF: JOOUST/DVC-RIO/ERC/E3

16th May, 2022

Adeline Tariro Terera
A451/4224/2020
JOOUST

Dear Ms. Terera,

RE: APPROVAL TO CONDUCT RESEARCH TITLED "PERFORMANCE OF BROILERS FED ON DIETS SUPPLEMENTED WITH YELLOW MEAL WORM LARVAE *(TENEBRIO MOLITOR)*"

This is to inform you that JOOUST ERC has reviewed and approved your above research proposal. Your application approval number is **ERC 30/5/22-06.** The approval period is from 16th May, 2022–15th May, 2023.

This approval is subject to compliance with the following requirements:

i. Only approved documents including (informed consents, study instruments, MTA) will be used.
ii. All changes including (amendments, deviations and violations) are submitted for review and approval by JOOUST IERC.
iii. Death and life threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to NACOSTI IERC within 72 hours of notification.
iv. Any changes, anticipated or otherwise that may increase the risks of affected safety or welfare of study participants and others or affect the integrity of the research must be reported to NACOSTI IERC within 72 hours.
v. Clearance for export of biological specimens must be obtained from relevant institutions.
vi. Submission of a request for renewal of approval at least 60 days prior to expiry of the approval period. Attach a comprehensive progress report to support the renewal.
vii. Submission of an executive summary report within 90 days upon completion of the study to JOOUST IERC.

Prior to commencing your study, you will be expected to obtain a research permit from National Commission for Science, Technology and Innovation (NACOSTI) https:oris.nacosti.go.ke and also obtain other clearances needed.

Yours sincerely,

For
Prof. Francis Anga'wa
Chairman, JOOUST ERC

Copy to: Deputy Vice-Chancellor, RIO   Director, BPS   DEAN, SAFS

Abe

Appendix 3: Board of Postgraduate Studies research approval letter

JARAMOGI OGINGA ODINGA UNIVERSITY OF SCIENCE & TECHNOLOGY

BOARD OF POSTGRADUATE STUDIES

Office of the Director

Tel. 057-2501804
Email: bps@jooust.ac.ke

P.O. BOX 210 - 40601
BONDO

Our Ref: A451/4224/2020

Date: 23^{rd} February 2022

TO WHOM IT MAY CONCERN

RE: ADELINE TARIRO TERERA - A451/4224/2020

The above person is a bonafide postgraduate student of Jaramogi Oginga Odinga University of Science and Technology in the School of Agricultural and Food Sciences pursuing Master of Science in Food Security and Sustainable Agriculture. She has been authorized by the University to undertake research on the topic: **"Performance of Broilers Fed on Diets Supplemented with Yellow Meal Worm Larvae *(Tenebrio molitor)*".**

Any assistance accorded her shall be appreciated.

Thank you.

JARAMOGI OGINGA ODINGA
DIRECTOR BOARD OF
POST GRADUATE STUDIES

Prof. Dennis Ochuodho
DIRECTOR, BOARD OF POSTGRADUATE STUDIES

Appendix 4: NACOSTI Research License

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY & INNOVATION

Ref No: 614709

Date of Issue: 05/October/2022

RESEARCH LICENSE

This is to Certify that Miss.. TARIRO ADELINE TERERA of Jaramogi Oginga Odinga University of Science and Technology, has been licensed to conduct research in Siaya on the topic: PERFORMANCE OF BROILERS FED ON DIETS SUPPLEMENTED WITH YELLOW MEAL WORM LARVAE (Tenebrio molitor) for the period ending : 05/October/2023.

License No: NACOSTI/P/22/20643

614709

Applicant Identification Number

Director General

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY & INNOVATION

Verification QR Code

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