DIETARY SUPPLEMENTATION WITH SILKWORM PUPAE ON GROWTH AND MEAT QUALITY OF KUROILER BIRDS

BY

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DECLARATION AND APPROVAL

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

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To my beloved parents, my late father Dickson Nyanchoka Mogire and my mother Ann Nyanchoka. My uncle Kefa Ombuhi Mogire, and my awesome and gorgeous wife Valentine.

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ABSTRACT

Utilization of silkworm pupae meal for feed will partially meet the protein feed deficiency, competition and high cost. Silkworm pupae, a protein rich by-product from silk reeling has the potential to spur poultry production. In this study, silkworm pupae were used to substitute fish meal in poultry feeds to determine the growth performance, carcass characteristics and sensory evaluation after feeding day old Kuroiler chicks for 8 weeks. The silkworm pupae were substituted with fish meal at percentages of 25%SWP (T1), 50% SWP(T2), 100% SWP(T3) with a conventional commercial diet used as a control with 0%SWP(T0). The feeds were formulated using a least cost feed formulation software. 72 one day old chicks, female sexed were procured from a reputable hatchery and housed in wooden cages. The four diets were assigned to each cage and replicated three times in a complete randomized design. Feed intake, weight gain and feed conversion were measured. At 8 weeks of age, three birds were slaughtered and carcasses obtained to assess the weight of heart, liver, kidney, gizzard, thigh, wings, back, breast and viscera. A sensory evaluation was thereafter conducted using a 9-point hedonic scale on colour, taste, odor and texture. Diet had a significant effect on growth performance. Live weight gain was highest in T3 (1014 ± 51.6^{a}), T0 (995 ± 50.8^{a}), T2 (912 ± 24.7^{b}) respectively and low in T1 (780 ± 11.1^{c}). Dressed weight was affected by the replacement of fish meal with silkworm pupae ($p<0.05$) and the percentage yield was as follows T3 (88.18%), T2 (88.08%) T0 (86.84%) and T1 (85.55%). The dressed chicken components were not significantly different ($p>0.05$). The sensory evaluation conducted noted no significant difference ($p>0.05$) across treatments. This study found out that supplementation of SWP pupae-based feeds on Kuroiler diets in 100% supplementation level will result to optimal performance with a significantly positive effect on growth indices and good carcass yield without affecting carcass sensory parameters.

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B. mori- *Bombyx mori L*

FCR- Feed conversion ratio

SWP- Silkworm pupae.

KALRO- Kenya Agricultural and Livestock Research Organization.

FAO- Food and Agriculture Organization

NRC- National Research Council

FM- Fishmeal

NSRC- National Sericulture Research Center

HRI- Horticultural Research Institute

CHAPTER ONE: INTRODUCTION

1.1 Background Information

Poultry makes a major contribution to sustainable food security through provision of eggs, meat and manure, and it is the most rapidly growing agribusiness in Kenya (Okello et al., 2021; Ssepuuya et al., 2017). Poultry keeping in Kenya is popular as an enterprise because it requires small space and low capital requirements. It is estimated that poultry subsector contributes 55% of the livestock GDP and 30% agricultural GDP and in totality 7.8% of Kenya's GDP (National Livestock Policy, 2019). Kenya is estimated to have a poultry population of 43.8 million chicken of which 75% are indigenous and 22% comprising of broilers and layers and 2% other poultry like ducks, turkey, pigeons, ostrich, guinea fowls and quails (GoK, 2019; Vernooij et al., 2018). The main production system is the extensive or free range which permits the chicken to scavenge throughout the whole day and get locked up at night consisting of the indigenous chicken (Nyaga, 2007). Most indigenous chicken are found in rural set ups while broilers and layers are most reared in peri-urban and urban areas (Wambua et. al., 2022).

According to Kleyn & Ciacciariello (2021), various factors determine optimum poultry production and key among them is feed. In Kenya, there are different feed categories used including chick mash, growers' mash, layers' mash, broilers' mash and Kienyeji mash. These are made from resources such as cereal grains and its by-products, soybean meal, animal by-products meals, fats, minerals and vitamin premixes. Fishmeal and soybean meal are the major protein ingredients (Chia et al., 2020). Nutrition plays a critical role in the performance and productivity, therefore there is need to formulate diets that will satisfy growth requirements (Khobondo et al., 2014). Poultry require highly digestible feed sources with an adequate supply of energy, protein, essential amino acids, minerals, vitamins and most importantly water for optimal performance. Nutrient requirement by poultry tend to vary according to species, age and production objective: either for meat or egg (Ravindran, 2013). Dietary protein is critical as it supplies amino acids for muscle growth and synthesis of egg protein (Oladokun & Johnson, 2012). Some of the protein sources for poultry diets include cottonseed meal, rapeseed meals, soybean meal which are obtained from plant sources (Chinrasri et al., 2009).

With a rapidly growing population as well as constraints in resource availability, eggs and poultry meat have been utilized significantly in providing protein sufficiency in Kenya (Magothe et. al., 2012). Poultry is estimated to contribute 37% of the animal protein supply in Kenya with the industry having vast opportunities for expansion and growth (Kleyn & Ciacciariello, 2021). Poultry meat is greatly cherished by consumers because of its health properties and outstanding features like flavor, tenderness, leanness and color and perception as a healthy substitute to red meats (Bett et al., 2012). The demand for poultry meat and eggs especially in Kenya continues to rise due to the rapid population growth, rise in incomes and urbanization necessitating the need to enhance adequate production to meet nutritional requirements (Nkukwana, 2018; Mottet & Tempio, 2017).

Due to the low production potential for local chicken, there have been efforts to upscale egg and meat production through exotic breeds for commercial purposes but the efforts have not satisfied the demand due to their high input intensive requirement and susceptibility to disease and poor adaptability to harsh environmental conditions (Biazen et. al., 2021). This has prompted to the rise of tropically adapted dual purpose chicken breeds ideal for both meat and egg and reared under free range conditions giving rise to the Kuroiler breed (Sharma et. al., 2015). Kuroiler originates from India through crossing some genetic lines of chicken including White leghorn, Rhode Island Red, colored broiler and local desi chicken selected for optimal performance and capacity to thrive in the rural under scavenging or semi-scavenging system (Guni et. al., 2021). Kuroiler chicken breed was therefore used in this study as experimental subjects.

Traditional sources of protein in poultry feeds are declining in supply mainly because of the high competition between poultry, human and other animals leading to increases in price (Ijaiya&Eko, 2009). Animal protein sources include meat meals, blood meal, feather meal and fishmeal which is the highly ranked quality protein for monogastric livestock (Anjum et. al., 2014). Fish meal is most preferred as it gives balanced quantities of all essential nutrients comprising amino acids, phospholipids, fatty acids and minerals for optimum development, growth and reproduction (Barlow, 2002). Soybean meal is also greatly used source of protein (Agazzi et al., 2016). Despite the continous use of fish meal in poultry diets, overfishing has drastically limited the supply leading to high market prices. Therefore, there is a need to explore alternative protein sources of comparable nutritive value to drive the poultry industry (Józefiak & Engberg, 2015).

Insects have been recommended as a nutrient rich sustainable alternative protein source that can effectively promote feed security by inclusion in feeds (Rumpold & Schluter, 2013). According to Van Huis (2013) insects can effectively replace fish meal and even fish oil to reduce the stress that has been channelled to marine overexploitation, high demand for soybean fuelled by the growing global population. In view of the poultry production constraints that are prevalent in the feed industry, one of the animal protein ingredients that can sufficiently substitute the declining volumes and adulterated fish meal is silkworm pupae meal.

A cocoon where the pupae is housed is often oval to football shaped according to Takeda (2009) and only made by fully grown mature silkworm larva through spinning of the silk proteins. The top producers of cocoon in the world are China, India, Uzbekistan, Brazil and Thailand with small volumes of fresh cocoon produced by Japan, Turkey and Indonesia. China is the biggest producer of cocoons representing 77.38% of world production in 2008 and 2009 (Wei et al., 2009). According to International Sericulture Commission Statistics, the global production of cocoons by 2007 was 806,396.5, in 2008 was 883,035.6, in 2009 was 741,831.9 tons and in 2010 was 789,341.7 tons while Kenya produces less than 2 tons annually. The statistics show the potential this industry has in terms of not only producing cocoons but pupae which is the by-product of silk-reeling with a potential for use in feeds.

The mass rearing of the silkworms commonly known as sericulture is a low-cost investment industry with village made appliances for rearing and reeling (Tuigong et al., 2015). Kenya offers favorable climatic conditions for mulberry cultivation which is planted under rain fed conditions with four locally adapted varieties. It does well in aerated rich soils with good water holding capacity that is deep and friable (Gitonga et al., 2016). This therefore outlines the potential sericulture has even in semi-arid areas for production of cocoons and ultimately silkworm pupae.

Sericulture was introduced in Kenya in 1972 as a collaboration between the Kenya government through the ministry of agriculture and Japanese government through Japan International Cooperation Agency (JICA) (Tuigong et al., 2015). The suitability of Sericulture in Kenya was supported by factors such as an ideal climatic condition for silkworm rearing and mulberry cultivation, availability of labor, good cocoon quality and absence of major cocoon pest (Nyamu et al., 2018). Despite the long history of silkworm production in Kenya, there is limited knowledge on the potential source of supplement in Kuroiler feed.

1.2 Statement of the Problem

The demand for poultry meat and eggs in Kenya continues to spiral significantly since they are nutritious and relatively cheap. With the increasing demand for such products from the steadily growing population coupled with the decline of agricultural areas for feed production due to human settlement, a challenge is presented in sustaining poultry production to meet population needs. Fishmeal is the most commonly preferred and available animal protein used in formulating various livestock feeds but however, due to multiple competing needs from other livestock sectors for feeds, pollution in water bodies, unsustainable harvesting of fish and the increased invasive alien species in water bodies, fishmeal supply currently is declining, adulterated and unable to sufficiently satisfy the increasing demand (FAO, 2018). This has resulted to substandard and low quality of poultry feeds, crippling the poultry sector. It is vital to find an alternative protein source that faces less competition with humans and other livestock by introducing silkworm pupae in poultry feed to substitute or replace fishmeal. This study therefore aims to supplement the protein supply sources in feed formulation by using silkworm pupae. This may increase poultry production as silkworm pupae is a major by-product of silk reeling that is usually discarded (Van Huis et al., 2013). Silkworm pupae contains a high protein content of 58% competing with fish meal at 60% (Rahmasari et. al., 2014) which makes it ideal for supplementation.

1.3 Objectives of the study

1.3.1 General objective

To evaluate the effect of dietary supplementation with silkworm pupae on growth and meat quality performance of Kuroiler broilers for enhanced household food security.

1.3.2 Specific objectives

1. To evaluate the potential of SWP as a protein supplement on growth performance in Kuroiler diet.
2. To analyze the carcass yield of Kuroiler chicken fed on a diet supplemented with silkworm pupae protein.

1.4 Research hypotheses

H_0: Silkworm pupae supplementation in Kuroiler diet has no significant effect on growth performance.

H_A: Silkworm pupae supplementation in Kuroiler diet has no significant effect on carcass yield.

1.5 Significance of the study

Formulating a feed based on silkworm pupae to supply animal protein in chicken feeds will reduce competition for the declining fish meal currently facing competing uses so as to make quality livestock feeds and provide an alternative protein ingredient in poultry feeds. The findings of this research will contribute to the development of a nutrient rich poultry feed by using silkworm as a substitute for fishmeal while promoting growth performance parameters, carcass yield and sensory qualities. The study outcomes will be vital for feed manufacturers, poultry farmers, Ministry of Agriculture, National Sericulture Research Center, chicken brooders, chicken vendors and feed research organizations.

1.6 Justification of the study

Protein sources for feed formulation have declined and are no longer sustainable due to the increasing demand from various users and the dwindling levels of fish due to climate change, pollution and invasive alien species in the blue economy. This study introduces a new feed alternative for animal protein and foster sustainable harvesting and exploitation of fish resources while diversifying the increasing demand for fish meal with the availability of the alternative silkworm pupae (Gahukar, 2011).

According to Mburu et. al., (2013) Sericulture in Kenya has been having low adoption levels since its introduction in 1972 despite the lucrative benefits that can be derived. Therefore, by farmers becoming aware of the utilization of the discarded silkworm pupae by product, most farmers will be involved in this venture to supplement poultry due to its availability as an affordable source of protein for the chicken. 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. Silkworm pupae utilization for feed will also ensure affordable cost of poultry products especially eggs and meat. With the improved kienyeji breed in this study, farmers are assured of attaining faster maturity for the market while consumers are also attracted by the weight gained (Hiroyuki Tomotake, 2010).

CHAPTER TWO: LITERATURE REVIEW

2.1 Overview of poultry production and Kuroiler chicken breed in Kenya

Poultry production gives the rural households opportunities to increase incomes, diversify their small holder enterprises, creation of employment opportunities and enhancement of soil nutrient status through manure usage (Kamau et al., 2018). Kenyan poultry industry is comprised of dualism with both small holder and large-scale poultry producers consisting of both the commercial hybrid poultry system and indigenous poultry production system (Okello et al., 2010). Indigenous poultry is mainly done in the rural areas involving 75% of rural households involving unconfined birds scavenging around the homestead for their feed (Kwesisi et al., 2015). White meat which is derived from poultry accounts for 19% of the meat consumed locally and in totality the indigenous chicken contributes 71% of the total egg and meat produced therefore showing how poultry plays a significant role in meeting the protein requirements (Kingori et al., 2010).

2.2 Kuroiler chicken

Kuroiler, a dual-purpose hybrid chicken from India with increased genetic potential than the indigenous chicken has aided in boosting the availability of meat and eggs (Dessie & Getachew, 2016). Kuroiler breed resulted from crossing colored broiler males with Rhode Island Red females or white leghorn males crossed with female Rhode Island Reds (Sharma et al., 2015). Kuroiler can live on kitchen diet and agricultural waste giving around 150 eggs per year compared with the indigenous laying 40 eggs in a year (Sharma et al., 2015). According to Mwesigwa et al., (2015) weight yield in Kuroilers is also greater in males weighing approximately 3.5kg and females weighing 2.5kg while indigenous males weigh 1 kg and females 0.8kg. In addition, Vernooij et. al. (2018) found out that Kuroilers are highly favored by small scale farmers due to their taste, faster growth rate and its purchase is increasing in East Africa with many hatching companies focusing on Kuroiler like Nature kuku and kuku Chic. This therefore makes this study ideal in order to optimize Kuroiler production.

2.3 Poultry feed ingredients

The major ingredients used in formulating poultry feeds consist of high energy and protein concentrates which account for 80% of the production cost (Chia et al., 2019). Despite the fact that most energy concentrates are sourced locally, protein rich ingredients are imported by majority of developing countries, Kenya included (Ravindran, 2013).

Due to the ongoing climate change effects experienced globally and especially in Kenya, the demand for animal feed continues to spiral as the food demand particularly animal protein gets constrained in supply (Van Huis & Oonincx, 2017). The conventional sources that are used in producing poultry feed are unable to sustain the increasing demand for poultry products as a result of population growth, urbanization and increased incomes (Doberman et al., 2017; FAO, 2018). This has resulted to a food-feed competition and a great imbalance between demand and supply of poultry feeds and their products. Insect usage in animal feed ingredients is a prospective solution to resolve the stalemate currently constraining the poultry production sector (Makkar et al., 2014).

2.4 Protein feed sources

Protein sources are the second largest constituents of poultry diets. Sufficient supply of the required protein levels coupled with a balanced amino acid profile are vital for poultry species to enhance rapid growth performance (Sharma et al., 2015). Soybean and fish meal are usually the main ingredients used in Kenya (Agazzi et al., 2016). Fishmeal is the sole source of animal protein feed ingredients in majority of the developing countries which is either imported or produced locally. It is therefore a high-grade feed ingredient for pigs, poultry and aquaculture (FAO, 2016). Soya bean meal is a critical protein source in poultry feed preferred due to its high protein content ranging between 40-48% crude protein, good balance of essential amino acids and better digestibility. Other protein sources include rape seed meal, canola seed, sunflower seed meal, groundnut meal, cotton seed meal, meat and bone meal, blood meal and poultry slaughter house waste meal (Ravindran, 2013; Iji et al., 2017).

2.4.1 Fish meal

The major contribution of commercial fishmeal is derived from small and oily fish, dried and milled carcasses of fish, small wild caught marine fish that possesses a higher proportion of bones and oil which are usually not used in human consumption (Nalwanga et al.,2009). Fishmeal, is a protein rich, energy and minerals feed ingredient that is well balanced and also loaded with vitamins such as choline, biotin and vitamin B12, A, D and E with trace elements such as selenium and iodine (Cho & Kim, 2011). Good quality fishmeal contains a crude protein of between 60-72% and an appealing amino acid profile making it a preferred protein ingredient in livestock feeds which lacks in cereal grains and plant concentrates especially lysine and methionine (Opiyo et al., 2014; Cho & Kim, 2011). The constitution of nutrients in fishmeal makes it distinct from other similar alternatives due to its richness in essential amino acids and long chain polyunsaturated omega-3 fatty acids. The amino acids constitution integrates well with other animal and vegetable proteins to spur faster growth and lower feeding costs (FAO, 2018).

2.5 Insect Utilization in livestock feed

Numerous studies continue to point out that insects can be a suitable substitute for fishmeal, soybean meal and other conventional protein meals. Insects have drawn a lot of attention as a potential protein source to sustain the resource constrained feed industry due to their rich nutritional value, biological efficiency, minimal space occupation and the ability to recycle organic wastes for their production (Rumpold & Schluter, 2013; Sanchez- Muros et al., 2014). The potential for insects for feed has been highly promoted due to its sustainability since they are poikilothermic with a high feed conversion efficiency. Moreover, they also need low amounts of water and land for farming and many can subsist on organic side streams thus converting low value organic by-products into high value protein ((Van Huis et al., 2013; Khan, 2018).

Insects possess various features that make them a suitable substitute in feeds (Khusro et al., 2012). Some crucial characteristics making them ideal for feed include high species richness, biodiversity and short life cycle and their physical and bio-chemical composition making a wide range of insects available for feed utilization (Khusro et. al., 2012).

Protein composition in insects has been found to be quite high but disparities have been noted across various species (Belluco et al., 2013; van Huis et al., 2013). An analysis of different insect species demonstrate that the protein content was ranging between 13-81% of dry matter. Major causes for such disparities include the type of feed consumed by the insect and the stage of metamorphosis which have a great determinant on the protein content. Belluco et al. (2013) also points out that the protein content is usually greater in adults than instars. Processing and preservation techniques have been noted to have an effect on the protein content and the digestibility (Kinyuru et al., 2018). Therefore, insects have shown to possess a high protein content with better quality and digestibility properties when utilized as an alternative source of animal protein.

Table 2.1 below shows various insects that have been used in feed and the protein content alongside other mineral composition. Comparing the protein levels of the various insects in comparison to fish meal, it is evident that there is a little disparity with most insects. Silkworm pupae and house cricket demonstrate a high crude protein and all insects contain a high lipid composition than fishmeal. This explains why insects hold a huge potential in supplementing the protein feed sources considering their comparable nutritional content.

Table 2. 1: Nutritional composition of major insect species ideal for feed

Constituents % In DM	**Black Soldier Fly larvae**	**Housefly Maggot meal**	**Mealworm**	**Locust meal**	**Mormon cricket**	**Silkworm pupae**	**House cricket**	**Fish meal**
Crude protein	42.1	50.4	52.8	57.3	59.8	60.7	63.3	70.6
Lipid	26.0	18.9	36.1	8.5	13.3	25.7	17.3	9.9
Calcium	7.56	0.47	0.27	0.13	0.20	0.38	1.01	4.34

Phosphorus	0.90	1.60	0.78	0.11	1.04	0.60	0.79	2.79

Source: (Makkar et al., 2014).

2.5.1 Poultry feed substitution using Insects

Global demand for poultry meat and eggs is projected to rise due to the increasing middle class, population surge and high nutritive value of such products. The global per capita consumption of poultry meat has increased from 2.88kg to 14.13kg (FAOSTAT, 2016). This demand will be higher in developing countries than in developed countries as a result of rapid population growth (Mottet and Tempio, 2017; Van Huis and Oonincx, 2017). There has been an increase in poor quality poultry feed due to the expensive and declining protein ingredients that are used in formulation of poultry rations like fish meal, sunflower seed, rape seed, meat and bone meal, soybean meal, groundnut cake. These ingredients are facing competing uses and becoming costly in developing countries (Józefiak and Engberg, 2015; Opiyo et al., 2014). Easily available raw materials can impact hugely in reducing the stress on fish meal and making poultry meat and eggs in supply at a lower cost (Józefiak and Engberg, 2015; Khatoon et al., 2006). Major ingredients that are used in poultry feeds are projected to decline in supply within the next ten years due to the rise in human population and changing climatic conditions (Veldkamp and Bosch, 2015). There is need to make poultry production a sustainable enterprise by venturing into alternative protein sources where fish meal has become very limited for either total or partial replacement to meet the dietary requirements while optimizing the growth performance of poultry (Egonyu et. al.,2021; Khusro et. al., 2012).

Utilization of insects as poultry feed is a reliable solution to ensure sustainability and continuity of poultry production due to the high protein content and amino acid balance (Van Huis, 2013). It is more sustainable, nutritive and healthy with reduced microbial contamination despite having some allergens and off-flavors (Agazzi et al., 2016). Digestibility of nutrients has shown to be effective by the incorporation of insects in poultry feeds in contrast to fish meal when wholly replaced with insect meal (Doberman et al., 2017). The potential of insect protein as a raw material in poultry diets has attracted attention since outdoor indigenous chicken have been feeding on them in various life stages (Iji et al., 2017). In addition, no study has found negative effects on the performance of insect enriched feeds on livestock but most indicate similar or better growth results compared to soybean meal and fishmeal. Similar or better nutrient digestibility has been obtained using insect meal in poultry feeds due to the rich amino acid profile hence being an effective replacer of fishmeal in their diet (Agazzi et al., 2016). Insect inclusion in poultry feeds as novel feed additives has also been found to promote gut health since they contain bioactive components like lauric acid, antimicrobial peptides and chitin which comprises of immune-boosting properties making chicken perform optimally and healthy (Gasco et. al., 2018).

Many insect species are also found in mass in various geographical settings and do not require complex structures or requirements for breeding and reproduction leading to high multiplication (Makkar et al., 2014). They also possess high levels of protein compared to plant sources and high feed conversion efficiency and minimal production costs (Rumpold and Schulter, 2013). The insect species replacing the usual protein ingredients should be simple in rearing, can be mass reared intensively with the viability to provide high amounts of protein and amino acids for sustainable supply with no negative effects on human health and environment (Kenis et. al., 2014). Insects can also subsist on various by-products like vegetable waste which translates to both economic and environmental preservation by degradation (Agazzi et al., 2016).

2.6 Silkworm

Silkworm, *Bombyx mori* Linnis a type of a commercial insect belonging to the family Bombyciidae and order Lepidoptera domesticated due to its production of silk fiber towards the completion of its larval stage (Abdelli, 2018). They usually feed heavily on mulberry leaves with their growth spurt being rapid. Female silkworm moths give about 500 eggs with an egg similar to a pin head (Tuigong et al., 2015).

Silkworms are reared in many countries for commercial purposes and some of the commercial species of silkworm include *Bombyx mori* (Linnaeus), Antheraea pernyi (Guerin-Meneville), Antherayamamai, Philosamia Cynthia ricini (Boisduval), Antheraeamylitta (Drury) (Samami et. al., 2019). Bombyx mori is the most intensively studied and used and whose rearing practices are greatly improved. Various segments within Sericulture include mulberry culture, silkworm egg production, silkworm rearing, cocoon production and silk reeling (Samami et. al., 2019).

2.6.1 Life cycle of Silkworm

Silkworm is a holometabolous insect that undergoes a complete metamorphosis from the egg to larva (caterpillar), pupa (cocoon) and then the adult stage. As shown in the figure 2.1 below, an egg ready to hatch starts by the larva biting the shell then squeezing itself out containing a tiny larva which is a caterpillar. The larva is the growth stage where ingestion and nutrient accumulation occurs which is the first instar. At the fifth larval instar, the larvae begin to spin cocoon and when the process is over the larvae can undergo moulting inside the cocoon transforming itself into pupae. A cocoon is spanned by the silkworm larva and usually the spinning is done on tree branches (Takeda, 2009). At the pupa stage of the silkworm there is no feeding and most larval organs are dissolved. The pupa has a soft pale-yellow color that eventually becomes darker (Chauhan & Tayal, 2017; Sadat et. al., 2022). The moth usually emerges out of a hole created by enzymes produced from the pupa. For silk production the pupae are killed by boiling, drying and soaking in NaOH before production of the enzymes (Sadat et. al., 2022).

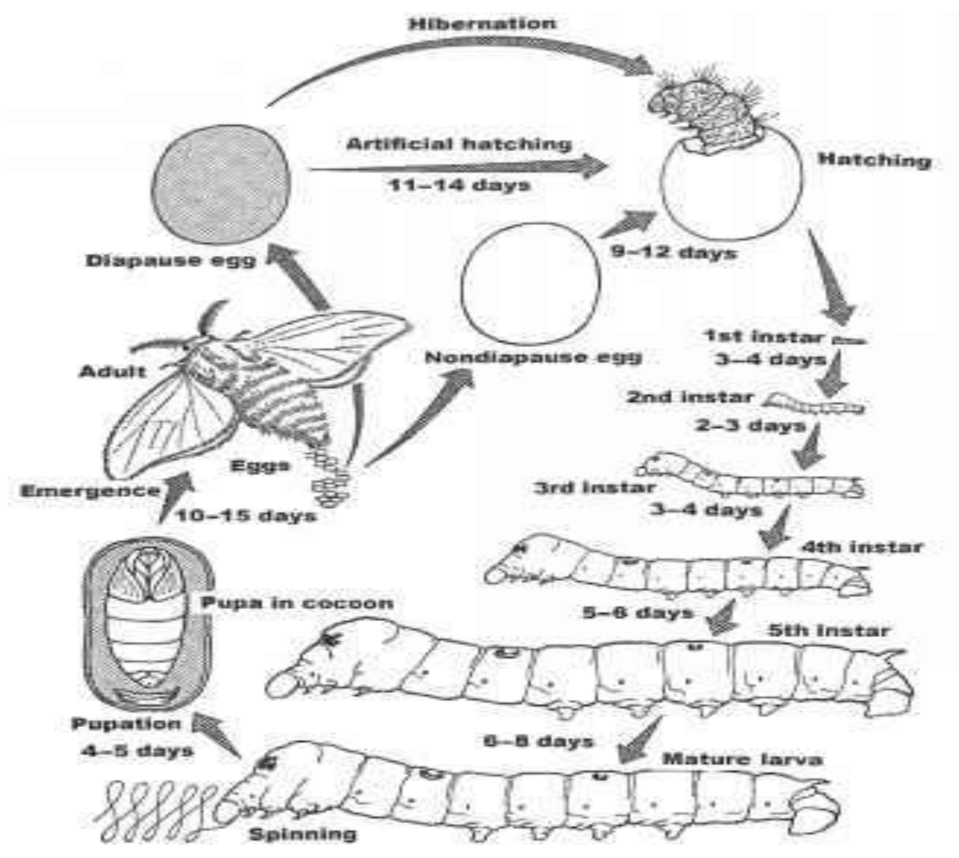

Figure 2. 1: Life cycle of silkworm moth (Source: Takeda, 2009).

2.6.2 Silkworm pupae use in feed formulation

Some other common names used to refer to silkworm pupae (SWP) include silkworm meal, spent silkworm pupae, defatted silkworm pupae meal, deoiled silkworm pupae meal, non-defatted silkworm pupae meal, non-deoiled silkworm pupae meal. SWP is available after obtaining silk through spinning and reeling making the pupae available as waste in huge quantities (Sheikh et al., 2018; Khan, 2018). Feed formulation entails the correlation of nutrient requirements of the birds with the levels of nutrients available in the feed ingredient to be used in constituting a feed (Ravindran, 2013; Thirumalaisamy et. al., 2016). The presence of anti-nutritional factors and toxins may hinder the digestion of various nutrients making them scarce to the birds. Toxic substances may also harm the animal when given in excess and thus caution should be undertaken when mixing such ingredients (Samuel et. al., 2015). Borah and Praban (2020) report that pupa is the stage in the life cycle of silkworm where optimum storage of nutrients is available. More often this nutrient rich product of sericulture is disposed as garbage and even composted in some places. Karthick et. al. (2019) found out that SWP contains a pleasant aroma, more digestible and preferred by both broilers and layer birds.

2.6.3 Nutritional composition of silkworm pupae

Silkworm pupae is a protein rich byproduct obtained from the silk thread after being successfully reeled hence serving as a feedstuff (Rahmasari et al., 2014). Silkworm pupae for feed substitution can spur optimum growth performance and productivity since it possesses high quality protein (49.4-60%), lipids (14.5-30.3% crude fat) with an amino acid profile similar to fish meal (Rahmasari et al., 2014). The lipid composition by dry weight is 32.2% entailing palmitic, oleic, palmitoleic, linoleic, stearic (24.6% of lipid), myristic, linoleic 36.3%, 27.7% monounsaturated fatty acids and 43.6% polyunsaturated fatty acids (Wu et. al., 2021; Paul & Dey, 2014).

High levels of essential amino acids such as valine, methionine and phenylalanine have also been recorded (Tomotake & Yamato, 2010). This contains most nutrients which are necessary to effectively replace fish meal without any effect in terms of nutritional deficiencies or stunted growth due to poor feed quality (Sadat et. al., 2022).

Undefatted pupae meal is rich in fat ranging from 20-40% on dry matter basis. Silkworm pupae meal is relatively deficient in minerals ranging from 3-10% dry matter compared to other animal by-products (Rumpold & Schulter, 2013; Asimi et al., 2017). Rumpold and Schluter (2013) observed that silkworm pupae had a CP of 48.7% dry basis with a high fat content of 30.1% dry basis with high levels of essential amino acids like phenylalanine, methionine and valine.

The major drawback to SWP is the availability of chitin and insoluble protein which explains the presence of fiber and thus levels of 6-12% of dry matter have been reported making it difficult to digest nutrients by the birds (Kenis, 2014). However, oven drying at 80^0c is effective in the removal of the chitin layer before grinding it for feed. Other studies found chitin to be a pre-biotic that serves to elevate the immune capacity of the birds (Miah et. al., 2020).

Table 2.2 below shows various studies that have been undertaken in determining the nutritional composition of the silkworm pupae. It can be concluded that the studies found the silkworm pupae to have a crude protein of above 50% which makes it ideal for use in the feed industry as a source of animal protein. The differences and variations in nutritional composition can be attributed to the influence of geographical location, seasonality and diet alongside other internal factors (Wu et. al., 2021).

Table 2. 2: Chemical composition and energy content of silkworm pupae larvae on dry matter basis

	% Content	**Reference**
Crude protein	65-75% 50-80% 51.1% 54% 55.6% 71.9% 50.31%	Khatun et.al., (2005) Asimi et.al., (2017) Perreira et al., (2002) Wu et al., (2021) Tomotake & Yamato (2010) Japan Zhou&Han (2006) Jintasatapomr (2012)
Lipid	4.8-9.0% 34.4%	Tomotake& Yamato (2010) Japan Zhou & Han, (2006) Perreira et al., (2002),
Crude fiber (%)	5.8	(Solomon & Yusuf, 2005)

	5.01	Jintasatapomr (2012)
Ash	7.4 4.0 3.67	(Rumpold & Schulter, 2013) Zhou&Han (2006) Jintasatapomr (2012)
Lysine Methionine	7.52% 3.88%	(Ullah, 2017) (Kenis, 2014)
Metabolizable energy(Kcal/kg	2950	Jintasatapomr (2012)

2.6.4 Growth performance with Silkworm pupae

Different studies have been conducted to evaluate the growth performance of various poultry breeds ranging from broilers, Rhode Island Red layer chicks, white leghorn layers on varying supplementation levels of silkworm pupae. Some of the indices that have been under study include: feed intake, body weight gain, feed conversion efficiency, carcass weight and sensory evaluation.

Experimental studies conducted in Thailand, Pakistan, India, Bangladesh and Nigeria on broilers when fed on a silkworm pupae supplemented diet at various supplementation levels, found out that there was no significant difference across the treatment levels with a better FCR noted. The FCR was not significant and the lowest FCR was noted in 0%SWP and highest was in 100%SWP supplementation. Significantly higher dressing percentage was obtained in 100% fishmeal. There were no significant effects of feed treatments diets on the appearance, color, odor, taste, texture and overall acceptability (Ijaiya and Eko, 2009; Banday et al.,2023; Dutta et al., 2012). However different results were noted upon substituting soybean with SWP on broiler chicks at finisher phase. Both feed intake and live body weight were significantly different due to the substitution and the FCR was not significant and the lowest FCR was noted in 0%SWP and highest was in 100%SWP substitution (Ullah et al., 2017).

On the layers chicks' studies conducted in Bangladesh, Pakistan and Thailand, upon feeding them with Silkworm pupae meal, SWP inclusion had a significant increase in weight gain. Egg production also increased significantly and feed intake per bird was significantly higher in SWP diets. Feed efficiency showed no significant effect through pupae supplementation. The FCR was not significant and the lowest FCR was noted in 0%SWP and highest was in 100%SWP supplementation. SWP in layers had no significant influence on layer performance. Feed consumption, body weight, hen day production and FCR did not differ significantly. Body weight, daily feed intake (g/day/bird), hen production, average egg weight and FCR did not differ significantly based on varying supplementation levels (Ullah et al., 2017b; Jintasatapomr 2012; Khan et. al., 2020).

However, most of the studies do not document the source of their silkworm pupae and have no proximate analysis on the same to show the variations and what could have caused the differences. Moreover, some studies did not have a silkworm pupae diet as the initial starting feed in the starting phase of the experiments in order to give a solid conclusion on the efficacy of the pupae diet. Also, a lot of studies have centered around the exotic breed without having any focusing on any indigenous breed which are more common, hardy and easy to rear unlike the exotic breeds. This study therefore seeks to bridge those gaps to a point of conducting a sensory evaluation to ascertain consumer preference on the effectiveness of silkworm pupae feed.

2.7 Feed Conversion Ratio (FCR)

This is the measure of an animal's ability and efficiency to convert feed mass into increased body mass (Karthick et. al., 2019). A feed that has a low FCR refers that less of that feed is needed to produce a kilogram of chicken meat. High quality feeds possess a low FCR. An increase in the amount of protein in a feed lowers the FCR. Therefore, less feed will be required to produce a kilogram of chicken meat. This will be very vital in this era of increased poultry meat demand leading to efficient utilization of grain and protein feeds (Sánchez-Muros et al., 2014; Van Huis, 2013).

There is a variation in the FCRs due to the class of the animal and feeding practices used in producing the meat. From the US statistics, the FCRs for chicken was found to be at 2.5, 5 for pork and 10 for beef (Van Huis, 2012). Ravindran (2013) notes that FCR can differ based on numerous factors which entail the nutritional and physical quality of the feed, environmental deviations such as temperature, production intensity and even genetics.

Khan et al. (2018) conducted a study to determine the effect of maggot meal, silkworm meal and mealworm on production performance and some features in broiler meat quality. Feed conversion ratio was calculated on a weekly basis. The study found out that rations that had the protein constituted of maggot meal and silkworms had attained a greater body weight as compared to soya bean meal. Birds fed with insect meal recorded a higher FCR starting from mealworm, silkworm pupae, maggot meal and lastly soybean meal. The FCR in broiler in regards to silkworm pupae was high due to efficient utilization of protein and quality amino acids (Khan et al., 2018).

2.8 Carcass characteristics of poultry meat

Poultry meat is highly preferred since its relatively cheap, lacks religious restrictions and compared to red meat; it is low in fat, cholesterol and contains high amounts of iron (Dyubele et. al., 2010). The diet of the birds significantly impinges upon meat quality and consumer preference (Mir et. al., 2017). Meat qualities such as water holding capacity, shear force, drip loss, cook loss, collagen content, protein solubility, cohesiveness, fat binding capacity are parameters considered in meat evaluation. Various factors have an effect in regards to chicken meat quality which include slaughtering age, density, environment, rearing system, sex, genetic breeds (fast and slow growing, physical activity and feed (Davoodi & Ehsani, 2020; Da silva et. al., 2017).

Meat quality characteristics that appeal to consumers include appearance, texture, juiciness, flavour and functionality (Tougan et. al., 2013). Colour, appearance and texture are crucial factors that consumers look at before they contemplate to buy poultry (Liu et. al., 2004). Appearance is important in marketing poultry products since pink or red appearance is linked with undercooking. Colour is a vital parameter that is of interest to consumers when purchasing entire poultry carcasses or carcass parts (Ruiz-Capillas et. al., 2021). The skin colour is genetically controlled by the capacity of the bird to produce melanin pigment in its dermis and epidermis and absorption and deposition of carotenoids, feed sources, feed additives, xanthophyll concentrates and exotic sources, management and processing (Qudsieh, 2014).

In an experiment undertaken to find the effect of replacing fish meal with silkworm pupae meal on growth performance and carcass characteristics on finishing broiler chicken by Ijaiya &Eko, (2009); Ullah et al., (2017); Banday et. al., (2023) under various substitution percentages. The dressed carcass components including the viscera, head, wings, Breast, back, Gizzard, lungs, heart, liver, and kidney weights were not significantly different across treatments. The results of the studies indicated no significant differences in terms of carcass yield within the treatment levels. The replacement of soya bean meal with silkworm pupae also did not significantly affect carcass quality. The weights increased linearly upon an increment of substitution levels of silkworm with a negligible effect on the meat yield characteristics.

2.9 Sensory evaluation and consumer acceptance of SWP fed chicken.

Sensory evaluation involves the examination of a product characteristic as judged by human senses of smell, taste, touch, sight and tenderness. Volunteers/ consumers are used to verify the product properties and offer feedback based on perception (Sharif et. al. 2017). A sensory evaluation can either be Laboratory/analytical involving a small number of panelists to ascertain differences in samples or consumer affective methods involving large number of panelists (Lyon & Lyon, 2000).

Most consumers tend to prefer to make purchases of chickens raised outdoors in a free-range system because their carcasses possess better sensory qualities in terms of taste and flavor (Li et al., 2017). Meat birds attain an acceptable market weight by five weeks and possess high breast meat yield due to their genetic potential. Quality especially for broilers also takes into consideration the chemical composition contained, breast proportion and decreased abdominal fat (Dabbou et. al., 2020). Previous studies note that free-ranged chicken demonstrated good meat quality and chemical composition with the obtained meat having healthy characteristics. Chemical composition in free ranged birds proved excellent than the confined or caged birds therefore scoring higher in terms of meat sensory scores, overall acceptability and offering healthy diet (Davoodi and Ehsani, 2020).

Several considerations affect acceptance of meat or food products which include sensory characteristics, nutritional value and effect on health. Sensory assessments are biased on a number of factors including availability and familiarity of the food product, ease of obtaining it, frequency of buying the product and cultural restrictions (Dyubele et al., 2010). Damaziak et al., (2019) also noted that meat colour, processing technique, chemical exposure, storage method and way of cooking affect sensory judgement.

Jintasataporn (2012) conducted a sensory evaluation using the breast muscle of the chicken fed on silkworm pupae obtained from spun silk industry (SSP) and silk yarn reeling industry (RSP) substituted at different levels, panelists could not tell the difference between treatments therefore noting no significant variation in terms of appearance, color, odor, taste, texture and overall acceptability. This points out that utilizing silkworm pupae for feed is possible without altering the key sensory parameters that consumers use in judging suitability of a food product. The study however used three-week-old male commercial broilers in the experiment which could have compromised the sensory flavors from the previous diet but this study sought to establish substantively the effect by using day old female chicks of the Kuroiler breed fed on silkworm pupae. Sun et al. (2013) discovered better scores for chewiness, flavor, aroma and overall acceptability for the breast and thigh section of the male broilers that were raised on grassland that had a large population of grasshoppers in it compared with a control sample that was fed on maize and soybean diet. No significant differences were noted in regards to colour and juiciness in the two set ups.

Consumers continue to display acceptance for insect-fed foodstuffs and specifically insect-fed fish and chicken and other value-added insect products (Kinyuru et. al., 2015). Rumpold and Oliver (2013) observed that consumers are ready to purchase insect-based feed or food should they possess unique attributes like distinct flavor, leanness, tenderness and colour which are satisfactory. Harriet et al., (2019) in a study to ascertain the consumer willingness to pay for meat obtained from chicken fed on insect-based feed noted that consumers were persuaded to buy the chicken and this was influenced by factors such as income, awareness of the insect types, purchase store and preference for the chicken meat and this will culminate to the availability of affordable chicken to suit the increased consumer demand.

Following the trend of the various researches done in regards to the sensory evaluation and acceptability levels of chicken raised from insects, most articles tend to agree that replacement of soybean meal and fish meal with insects did not pose any negative effects on flavor, juiciness or texture of the samples under testing. However, most studies do not disclose how the meat was prepared, procedure of cooking whether fried or boiled, taste panel, unavailability of information as to whether the panel was trained or untrained, formulation of the acceptability questions, if it was a blinded test thus affecting the accuracy of the sensory findings.

2.10 Research gap

From the review of the literature, better results have been concluded with the utilization of SWP on various chicken breeds especially the broilers and Rhode Island layers and conclusions have been a significant increase in growth performance indicators like weight, feed conversion ratio and carcass yield. Kamau *et. al*. (2018) in a study to find out the impact of improved indigenous chicken breeds on productivity in Makueni and Kakamega, on the two counties of Kenya, it was found out that average egg production/hen/year greatly improved among the adopters of the improved indigenous chicken. However, despite the results that have been obtained, the improved indigenous chicken hasn't received research attention on the feeds and the impact on its growth performance to reduce the production cost of a farmer. Most of the research has been tilted towards genetic improvement with little attention directed towards feeds and the effect on growth performance. These breeds have a history of subsisting on insects in their various cycles as they scavenge which has led to their optimum growth, disease resistance and even yielding tastiest meat. Apart from their genetic potential which contributes to their hardiness, good growth performance and suitable carcass characteristics that is preferred by many, feeds also contribute significantly to these results. Insects have been used for food and feed but the utilization in Kenya has not been robust especially on our local poultry breeds that are easy to produce. This study seeks to fill the gap in the insect usage for feed by employing the silkworm pupae whose production volumes in Kenya are rising following the concerted efforts by JICA, KALRO (NSRC) and other partners.

2.11 Conceptual framework

A conceptual framework is a hypothesized model that tends to look into identification of the concepts under investigation and the interrelationship. It brings out the relationship between independent and dependent variable respectively (Mahmmod et. al., 2021). Thus, the concept in this study is that chicken growth performance and carcass characteristics can be influenced by the feed components especially the protein sources. The dependent variables in this study entails the bird weight gain and feed conversion ratio while the independent variable here according to treatments were the conventional feed, percentages of substitution. Intervening variable including favorable weather condition.

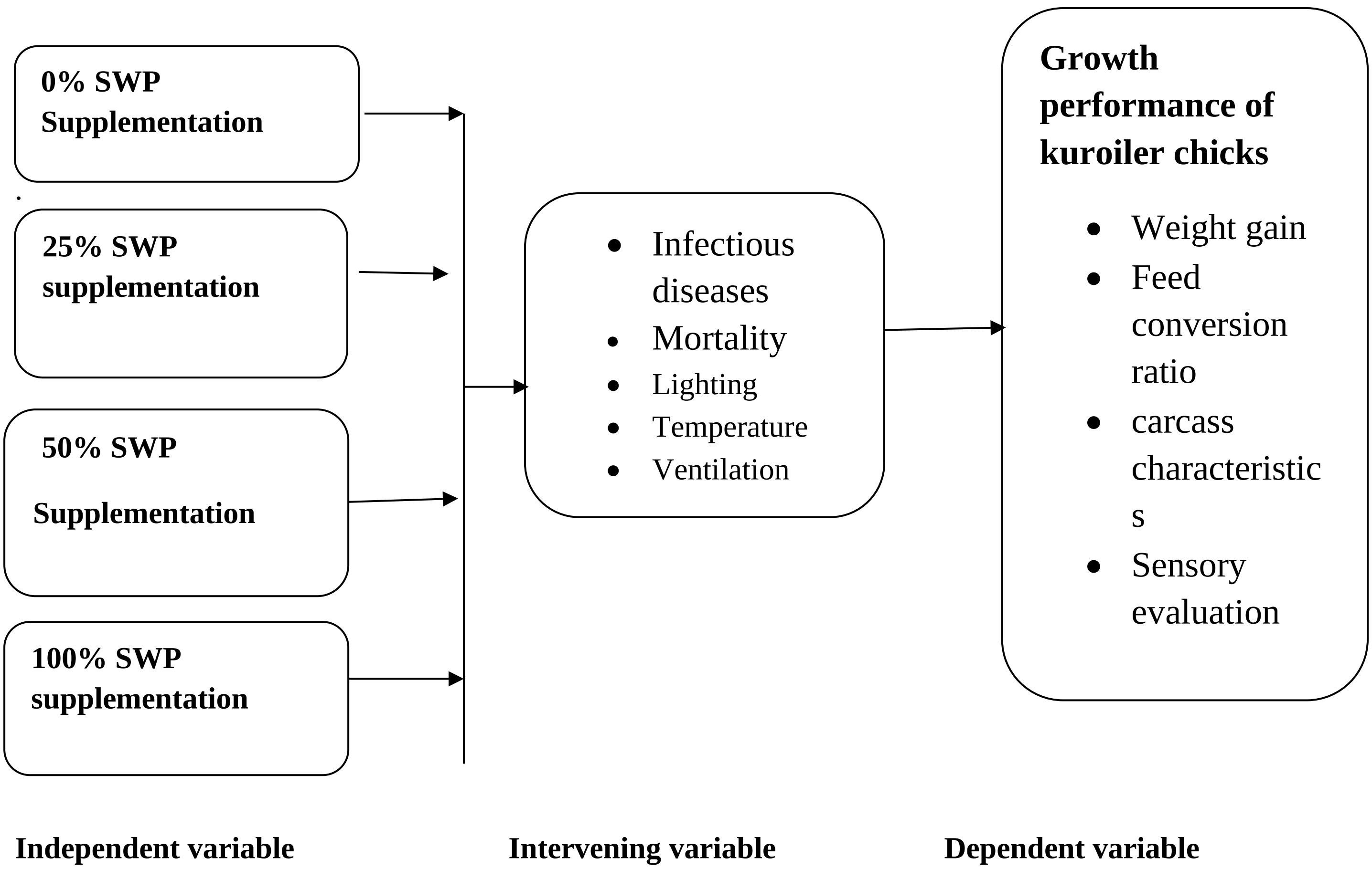

Figure 2. 2: **The conceptual framework**

CHAPTER 3: MATERIALS AND METHODS

3.1 Research Site

The study was conducted at the National Sericulture Research Center under KALRO (Kenya Agricultural and Livestock Research Organization) in Thika. The center is characterized by moderate temperatures ranging between a minimum and maximum temperatures of 15^0C and 25^0C respectively lying on a latitude of $1^0$02' 60.00" S and longitude of $37^0$04' 60.00" E along the Thika-Kandara Road with an altitude of 1629m above sea level.

3.2 Research design

This study adopted a Complete Randomized Design due to the homogeneity of the experimental units and having only one source of variation which was the SWP diets offered. Each treatment had 3 replications with 24 birds amounting to 72 in sum total.

Figure 3. 1 Silkworm pupae meal Source: silk lab, NSRC

3.3 Preparation of the house.

The chicken house was thoroughly cleaned with water and then disinfected. All drinkers and feeders were also thoroughly cleaned and disinfected too before use. Cages were constructed using plywood, timber and wire mesh in a storey form and partitioned into 12 pens to accommodate 6 chicks sufficiently in each treatment separately. Each pen measured 100cm by 60cm with a height of 50cm. Wood shavings were spread in every cage to a thickness of 5 inches for bedding and partially controlled temperatures ranging from 23-27^0C. Separated feeders and drinkers were used in each pen for provision of water and feed. 12, 100 watts bulbs were used to provide warmth to the chicks in each pen and they were hung at the height of 20cm above the brooder. They were used during the experiment to provide warmth and lighting for continuous eating. Every pen had an iron made feeder with 8 small holes allowing the entry of the chick heads alone and a plastic invertible 4L drinker. In the course of their growth, the feeders were changed to suspended plastic feeders. Ventilations were provided to regulate temperatures from causing harm to the chicks and aeration.

Figure 3. 2: The experimental set-up structure and a representation of the day-old chicks during the brooding period and adaptation phase respectively.

3.4 Experimental Diets

Test diets were formulated based on the Kenya Agricultural and Livestock Research Organization guidelines for Kuroiler breed. The diets are as shown below in table 1. Four dietary treatments containing Silkworm Pupae meal were supplemented in various percentage ratios and replicated 3 times. The diets include: Control, T0 (0% SWP meal), and T1 (25% SWP meal), T2 (50% SWP meal), T3 (100% SWP meal). The control T0 contained 100% fish meal without silkworm. The feed was formulated using a Linear Model of Excel Solver.

All the feed ingredients were obtained from Munene Industries in Thika town, drugs and vaccines were sought from J&J Veterinary, other feeding equipment like drinkers and feeding troughs were sourced from Jua kali Section in Thika. Dried silkworm pupae were also derived from the silk lab in the National Sericulture Research Centre, Thika as a by-product of silk reeling. They were ground into fine flour at the feed miller in Munene industries prior to mixing with other ingredients.

The following ingredients were used in formulation: silkworm pupae, whole maize, maize germ, wheat pollard, wheat bran, sunflower cake, Cotton seed cake, soya meal, Lime, Bone meal, Fishmeal, Mycotoxin Binder, salt, Premix, Tryptophan, Lysine, Methionine, Coccidiostat.

3.5 Experimental birds.

The study used 72, one day old Kuroiler chicks obtained from Ziwani poultry farm in Ngoliba and reared for 8 weeks. Initial weights of all the chicks were taken and 6 chicks assigned to each of the 12 pens based on the four treatment diets. The chicks were feather sexed from the hatchery and all were females. The vaccination schedule was followed strictly as specified by KARLO against diseases like Newcastle, Gumboro, fowl typhoid& fowl cholera and was obtained from J&J Veterinary in Thika. The chicks were fed on the silkworm pupae supplemented diet ad libitum comprising of four experimental diets. The feeders and drinkers were washed daily and fresh feed was administered to the chicks each with water *ad libitum*. This experiment lasted for 8 weeks which is the KALRO recommended chick mash period.

3.6 Data collection

Variables that were under study included growth rate, weight gain, feed intake, feed conversion ratio, carcass yield and sensory evaluation. All the weights were measured using the modern digital kern PFB scale.

Initial live weights of birds were measured at day old before the beginning of the experiment. All the chicks in every pen were weighed using electronic scales (Model kern PFB) on weekly basis and their average obtained. Feeds administered daily were weighed on the modern kern weighing balance and recorded. Records on feed consumed were also taken and weight gain recorded daily and weekly respectively for a period of 8 weeks. This is the period recommended by KALRO for chick mash diet which was formulated in this case. Feed intake was monitored and increased weekly by 2kg. Daily feed intake was measured by subtracting the weight of refusals from that of the feed offered per day and difference was divided by total number of birds and was calculated as follows:

Feed intake= Total feed offered (g) – Total feed remainder (g)/ No. of birds

$$\text{Feed Conversion Ratio was calculated as} = \frac{\text{Total amount of feed consumed}}{\text{Total amount of weight gained}}$$

Any mortality was taken to J&J Veterinary for a postmortem to investigate the possible causes of death and ways to avert any further deaths. The mortality rate calculated over the 8 week period was calculated as:

$$\text{Weekly Mortality rate} = \frac{\text{No. of dead birds}}{\text{Total number of chicks}} * 100$$

Growth rate also was obtained by taking weekly weights of all chicks from each replicate and obtaining an average. Eventually before slaughter all birds were weighed to find the final yield in weight due to the diets.

Therefore, growth rate was calculated as:

$$\frac{\text{Final weight- Initial weight}}{\text{No. of days}}$$

Weight gain was also calculated as:

Weight gain (yield) = Final weight- Initial weight

3.7 Carcass Characteristic

At the end of the 8th week on the 57th day, all birds were subjected to an overnight fast to evaluate carcass weight, viscera, breast and thigh weight and internal organs. Slaughtering was done at the Sericulture research site located within the study area. Three birds from each treatment were randomly picked, tagged and their live weight taken. Three birds from each treatment were slaughtered by cervical dislocation at the neck. The feathers of the birds were plucked after scalding in hot water at 70^0C. The legs were carefully cut at the tibia femur joint. The abdomen was incised mid ventral using a sharp knife and the entire gastro intestinal   Carcasses of the birds were weighed, feathers, carcass weight without head and viscera. Internal organs (heart, liver, kidney, gizzard) were also obtained to evaluate their weight. Dressed carcasses were preserved in a freezer for 24 hours. Weights of thigh bone, wings, back and breast were taken to estimate the yield. The percentage of each component was obtained by dividing the weight of the component by the live weight as shown:

$$\% \text{ component} = \frac{\text{weight of the component (g)}}{\text{Dressed weight (g)}} \times 100$$

% Dressing was calculated as:

$$\frac{\text{Carcass weight (g)}}{\text{Dressed weight (g)}} \times 100$$

3.8 Sensory evaluation.

Sensory evaluation involves analyzing, measuring a product's characteristics and features as interpreted by the responses of human senses of smell, taste, touch, sight and tenderness. Based on the 4 diets, a sensory evaluation was undertaken from the kuroiler birds using the breast meat on parameters of colour, taste, odor, texture.

3.9 Meat preparation

The thigh and breast muscles were used for sensory evaluation. After the carcass was defrosted in running water and the carcass components obtained, they were subjected to heat treatment at 200^0C for 45 minutes, boiled without any additive or spice in a pan and thereafter chopped into small sizes and wrapped in disposable plates.

3.10 Panelists' selection and training

13 semi-trained volunteers took part in the sensory evaluation and they were captive audience. The panelists consisted of 6 females and 7 males with ages ranging between 20 and 55 years recommendable for Laboratory/ Analytical method. Room temperature water was provided to each panelist for cleansing their palates in between samples to prevent carryover tastes with a resting period of 40 seconds in between the samples according to Lawless (2013). Every panelist was

given serviettes and small containers into which samples of the meat from all the diets were spit. Questionnaires were given to panelists to demonstrate their degree of satisfaction to the samples. Panelists were advised to gargle water in their mouth. A 9-point hedonic scale sensory score card was given and used by the panelists to give a score of their reactions. The sensory parameters under study included taste, aroma, texture and color evaluated as follows: 9-Like extremely 8-Like very much 7-Like moderately 6- Like slightly 5-Neither like nor dislike 4-Dislike slightly 3-Dislike moderately 2-Dislike very much 1-Dislike extremely.

3.11 Chemical Analysis.

A chemical composition of the treatment diets and silk worm pupae meal was done prior to feeding using the procedures developed by the Association of Official Analytical Chemists (AOAC, 1990). Formulated feed and silkworm pupae were subjected for quality tests at KALRO- HRI and Spectra lab laboratories respectively as indicated by NRC (1994).

The dry matter content was first determined by weighing the samples and thereafter placed in a 105^0C oven for 12-16 hours. The samples were reweighed and the dry matter and moisture were obtained. Ash content was obtained by burning the samples at 600^0C for 3 hours in a muffle furnace. The Kjeldahl method was used to measure the crude protein content of the sample involving an automatic Kjeldahl digestion unit- DKL/20 combined with UDK 159 automatic Kjeldahl analyzer. The nitrogen content of the sample was first obtained then converted to a crude protein estimate by multiplying the nitrogen content by 6.25. For crude fiber, the deffated dry sample was placed in boiling sulphuric acid solution of concentration (1.25%). Sulfuric acid and Pottasium hydroxide were mixed to measure the crude fiber content. Crude fat was determined by systematically extracting two replicates of 5.0^-g samples in the Soxhlet apparatus using petroleum ether (bp 40–60°C) as the extractant as per AOAC (1990) Methods. The energy content was calculated by multiplying the mean values of crude protein, crude fat and total carbohydrate by the Atwater factors of 4, 9 and 4, respectively, taking the sum of the products and expressing the result in kcal $100g^-1$ sample.

3:12 Chemical composition of silkworm pupae (SWP) meal and fish meal

The Table 3.1 is a proximate analysis of the crucial parameters in both fish meal and silkworm pupae which are the vital ingredients being substituted in this study. From the results comparing between the two animal protein ingredients, it can be deduced that crude protein which is the most considered nutrient in this study was found to be higher in silkworm pupae than in fish meal and also a very high metabolizable energy was noted. Fish meal was found to possess higher levels of crude fiber, crude ash, crude fat but low metabolizable energy (Kcal/kg).

Table 3. 1: Chemical composition of SWP and fish meal

	SWP	**Fish meal (*Rastrineobola argentea*)**
Dry matter (DM)	91.65	93.05
Moisture	8.34	10.11
Crude Ash	4.64	50.24
Crude fat	27.60	29.45
Crude fiber	3.19	21.36
Crude protein (CP)	57.85	50.03
Metabolizable Energy (Kcal/kg)	4318.8732	2948

3.13 Chemical composition of experimental diets.

Table 4.2 shows results obtained from the chemical composition analysis of the 4 diets that were used. From the results, all the four diets attained the recommended minimum requirement needed when formulating chick mashes of 18% - 21% with a higher protein percentage noted in 100% SWP substitution followed by 0% fish meal substitution, 50% substitution and finally 25% substitution. Crude fiber and crude fat also demonstrated a similar pattern in the laboratory analysis findings. Energy was also found to be higher in 0% substitution and lower in 50% SWP substitution which was similar in dry matter and crude ash.

The crude protein percentage obtained was uniform across all the treatments with no significant difference indicating the quality of the raw materials used and showed that they could have been sourced from a similar place. The high fiber can be attributed to the chitin that forms the exoskeleton of the pupae and the storage conditions in which the cocoons were kept causing drying and hardening of the pupae. The slightly high ash content in 0%, 50% and 25% substitutions could have been due to fish meal which contained some impurities or foreign substances that came along from the fishing ground.

Table 3. 2: Chemical composition of the treatment diets

	0%SWP	25%SWP	50%SWP	100%SWP
Crude protein	18.45	18.14	18.31	18.92
Crude fiber	8.51	8.45	8.23	8.78
Dry matter	91.21	90.38	90.17	90.42
Crude ash	8.57	8.69	8.46	8.27
Crude oil	5.95	5.64	5.44	6.59
Energy Kcal/kg	2989.54	2845.40	2843.80	2857.45

3.14. Statistical analysis

The data on weight gain, feed intake and carcass characteristics, sensory evaluation was analyzed and presented using one way analysis of variance (ANOVA) and the SWP inclusion levels of 25%, 50% and 100% treatments. The statistical package R i386 3.5.3 version software was employed for data analysis and presentation. The significance between treatment means was tested at a significance level of 5%. Least Significant Difference (LSD) test was used to compare means and finding the level of significance at ($P<0.05$) within treatments.

3.15 Statistical model

A one-way analysis of covariance (ANCOVA) was conducted to examine whether growth performance indicators (weights) were different among the treatment and the control groups while controlling for time in weeks(x). In general, since variations in owing to temperature and other factors influence errors that cannot be randomized, they cannot be regulated in the experiment, they should be observed in tandem with growth performance indicators (weight (y). Therefore, the covariate in this one-way analysis of covariance (ANCOVA) is time in weeks (x). The treatment and control groups are the independent variables, and the growth performance indicators (weight) are the dependent variables. By controlling for time in weeks (x), the ANCOVA is able to examine whether the growth performance indicators are different among the treatment and the control groups.

Assuming a linear relationship between x and y the appropriate statistical model was:

$$Y_{ij} = \mu + t_i + \boldsymbol{\beta}(\boldsymbol{X_{ij}} - \boldsymbol{\chi}..) + \varepsilon_{ij}$$

Where:

Y_{ij}– is the growth performance as the response variable (weight) (the jth observation on the response taken under the ith treatment); i=1, 2… a and j= 1, 2… n

$(\boldsymbol{X_{ij}} - \boldsymbol{\chi}..)$ – is the covariate or the variable used in the control of error and adjustment of the means

μ - Is the initial or overall mean of the growth performance indicator (weight gain)

t_i - is the effect of the ith treatment (i.e., the treatment levels)

β is the linear regression coefficient indicating the dependency of Y_{ij} on $\boldsymbol{X_{ij}}$

ε_{ij} - is the random error component.

From the equation, the analysis of covariance model is a combination of linear models employed in the analysis of variance and regression. This means that we have treatment effects t_i in one-way classification analysis of variance and a regression coefficient **β** in regression analysis. The covariate is expressed as $(\boldsymbol{X_{ij}} - \boldsymbol{\chi}..)$ so that the parameter μ is preserved as the overall mean.

3.16 Ethical Considerations

The number of birds used in the study which were 6 per cage was adequate and properly spaced without congestion. The slaughtering was also done in consideration with the animal handling rights without harming the experimental subjects.

All the panelists who participated in the sensory evaluation were informed about the product and disclosure was made that the chicken fed on silkworm pupae in different substitutions. Their consent was also sought and participation was voluntary.

This research was approved for study by the Jaramogi Oginga Odinga Ethics Review Committee on March 2020 and assigned approval number 7/14/ERC/11/19-7. The letter is attached in appendix 29.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Objective 1: To evaluate the potential of SWP as a protein supplement on growth performance in Kuroiler diet.

4.1.1 Kuroiler chicks' growth performance

The effect of supplementing fish meal with silkworm pupae on various Kuroiler chick weights is shown in Table 4.1. A linear increase in chick weight was observed from all the four treatment diets with week 1 and 2 showing no noticeable differences in terms of all chick weights. However, from week 3 there were differences in terms of chick weights with T1 substitution demonstrating a low weight gain whereas the other substitutions showed an exponential increase in weekly weight gain. At the close of the 8^{th} week, a higher weight gain was denoted in T3 supplementation followed closely with T0 then T2 and lastly T1. Table 4.1 and Anova table 4.2 shows the effect of the silkworm supplemented diets on chick weights. There was no significant difference noted on initial chick weight at the start of the experiment ($p>0.05$) but the final weights show a significant difference ($p<0.05$).

Table 4. 1: Effect of supplementing silkworm pupae in Kuroiler diets on chick weights

	Week1	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**	**Week 7**	**Week 8**
Treatment	**Mean ±SE**	**Mean ±SE**	**Mean ±SE**	**Mean ±SE**	**Mean ±SE**	**Mean ±SE**	**Mean ±SE**	**Mean ±SE**
0%SWP	$68±7.2^{a}$	$140±8.3^{a}$	$247±6.9^{a}$	$319±21.8^{ab}$	$516±20.3^{a}$	$661±23.7^{a}$	$762±36.2^{a}$	$995±50.8^{a}$
25% SWP	$70±2.2^{a}$	$146±13.2^{a}$	$192±13.8^{b}$	$257±30^{b}$	$395±14.6^{b}$	$474±20.6^{c}$	$640±25.6^{b}$	$780±11.1^{c}$
50% SWP	$72±2.9^{a}$	$118±9.8^{a}$	$261±9.8^{a}$	$349±21.35^{a}$	$502±49.2^{ab}$	$606±41.2^{a}$	$755±51.4^{a}$	$912±24.7^{b}$
100% SWP	$76±6.0^{a}$	$140±8.1^{a}$	$250±20.8^{a}$	$332±29.8^{ab}$	$476±40.7^{ab}$	$561±43.4^{ab}$	$746±85.9^{a}$	$1014±51.6^{a}$
LSD	16.48	33.38	45.86	85.17	111.81	110.30	178.59	126.11
P-Value	0.751	0.304	0.0307	0.148	0.133	0.0249	0.399	0.01

Means with a similar superscript letter are not significantly different. ($p>0.05$)

Table 4. 2: Analysis of variance table of chick weights

Source of variation	DF	Sum of squares	Mean sum of squares	F value	Pr(>F)
Treatment	3	117024	39008	6.962	0.000266*
Week	1	8766465	8766465	1564.58	<2e-16*
Treatment: week	3	83957	27986	4.995	0.002863*
Residuals	100	560306	5603		

4.1.2 Effect of treatment diets on feed intake

Feed intake is used in determining the feed conversion ratio and even ascertaining whether the chicks prefer the feed. The lower the feed conversion, the better and efficient the feed. There was no significant difference in terms of feed intake for the first three weeks of the experiment ($p>0.05$) but from week 4 the study showed a significant difference in terms of feed intake across the four diets ($p<0.05$) as shown in table 4.3. Supplementation levels of T0 and T1 recorded lower FCRs than silkworm pupae substituted treatments of T2 and T3. There was a significant difference of silkworm pupae supplemented diet on feed intake across treatment levels ($p<0.05$).

Table 4. 3: Effect of substituting silkworm pupae with fish meal on feed intake

Treatment	Week 1 Mean ±SE	Week 2 Mean ±SE	Week 3 Mean ±SE	Week 4 Mean ±SE	Week 5 Mean ±SE	Week 6 Mean ±SE	Week 7 Mean ±SE	Week 8 Mean ±SE	FCR
T0	136.07 ±17.93[a]	173.62± 19.79[a]	308.72 ± 18.10[a]	404.88 ±40.36[a]	362.7± 50.19[a]	426.27 ±62.40[a]	528.3± 62.21[a]	574.4± 25.27[a]	2.72
T1	111.13 ±25.20[a]	123.09± 21.54[a]	265.44 ±37.96[a]	239.66 ±6.84[b]	187.95 ±12.9[b]	205.44 ±16.63[b]	300.2± 16.61[b]	300.2± 23.98[b]	2.30
T2	101.21 ±11.78[a]	141.97± 13.54[a]	236.97 ±52.87[a]	385.8± 39.71[ab]	422.94 ±45.7[a]	529.11 ±30.67[a]	547.24 ±4.77[a]	528.3± 19.90[a]	2.95
T3	100.76 ± 9.45[a]	147.26± 14.34[a]	276.14± 38.97[a]	366.44 ±53.84[a]	420.48 ±51.1[a]	503.11 ±19.79[a]	574.43 ±7.48[a]	547.2± 17.17[a]	2.92
LSD	56.10	57.55	127.18	127.89	140.22	120.96	105.99	71.18	0.71
P-value	0.471	0.313	0.646	0.0643	0.0147	0.0010	0.0012	0.0105	0.21

4.2 Objective 2: To analyze the carcass yield of Kuroiler chicken fed on a diet supplemented with silkworm pupae protein.

4.2.1 Kuroiler chicken carcass evaluation

The effect of supplementation of Silkworm pupae in Kuroiler diets on carcass characteristics is as shown in Table 4.4. A higher carcass weight was noted in 100%SWP while 25% SWP recorded the lowest. Similar results were also obtained for dressed weight. The weight of the internal organs was also weighed and T3 had higher weight in terms of heart, liver, kidney, gizzard, thigh, wings, back, breast and viscera and T1 weighed the least. Similar results were noted in the percentage yield obtained.

Both the pre-slaughter and dressed weight had a p-value less than 0.05 ($p<0.05$) denoting a significant difference in their weights. However, there was no significant difference in the carcass components that included the internal organs ($p>0.05$) see appendix 6-14.

In the study dressed weight was affected by the supplementation of fish meal with silkworm pupae ($p<0.05$). There was no significant difference noted on SWP meal addition on the chicken carcass components like the heart ($p=0.463$), liver ($p=0.118$), wings ($p=0.155$), back ($p=0.102$), breast ($p=0.155$) weights upon treatments. The ANOVA tables detailing the carcass components are in Appendix 18-26 showing no significant difference.

Table 4. 4: The effect of supplementation of silkworm pupae on the carcass characteristics

	T0		**T1**		**T2**		**T3**		**LSD**	***P*-value**
Pre-slaughter weight	989.07		815.85		948.43		1046.67		125.08	0.0152
Dressed weight	859		698		835		923		127.25	0.02
Weight in gms	**Wt(g)**	**%**	**Wt(g)**	**%**	**Wt (g)**	**%**	**Wt(g)**	**%**		
Heart	5.55	0.65	4.32	0.62	5.14	0.62	4.89	0.52	1.72	0.46
Liver	17.23	2.00	14.20	2.03	18.96	2.27	17.83	1.93	4.05	0.12
Kidney	7.21	0.84	4.79	0.68	7.21	0.86	6.79	0.74	1.49	0.13
Gizzard	41.37	4.82	31.66	4.54	41.37	4.95	44.27	4.79	7.62	0.25
Thigh	103.71	12.07	84.28	12.07	103.71	12.42	111.98	12.13	11.63	0.34
Wings	43.91	5.11	33.38	4.78	43.91	5.26	42.78	4.63	10.82	0.15
Back	144.28	104.79	104.85	15.02	144.28	17.28	138.83	15.40	34.93	0.10
Breast	171.44	19.96	125.92	18.04	206.59	22.38	125.92	18.04	72.93	0.16
Viscera	155.86	14.88	125.36	15.36	161.68	16.34	125.36	15.36	13.82	0.13

%= percentage of the dressed component
(g)- Weight in grams

4.2.2 Sensory evaluation of the Kuroiler carcasses based on different treatments.

Table 4.5 shows parameters of colour, taste, odor and texture that were under study using the panelists and how the cooked carcasses from the four treatment diets were scored on a 9-point hedonic scale with the Score card: 0- Dislike extremely 9- Like extremely. The p-value across both treatments was greater than 0.05(p>0.05). The SWP meal supplementation percentages in the Kuroiler bird's diet had no significant difference on color, taste, odor and texture using the cooked breast meat. In terms of colour, T0 and T1 had the highest score in terms of colour while T3 had the lowest score across the panelists. Taste/flavor was also rated high in 0%SWP and lowest in 50%SWP. Odor/smell got the highest liking in T1. Texture/Mouth feel were similar in T0, T1 and T3.

Table 4. 5: Sensory evaluation based on the cooked carcasses obtained from the treatments.

	Experimental diets				**Kruskal wallis**	
	0%SWP	**25% SWP**	**50% SWP**	**100% SWP**	**Chi-square(df)**	***P-Value***
Color (Appearance)	8±0.5[a]	8±1.25[a]	6±1.25[a]	7±0.5[a]	2.68(3)	0.44
Taste/Flavor	8±0.5[a]	7±0.75[a]	7±1.25[a]	7±0.5[a]	2.10(3)	0.55
Odor/Smell	8±1[a]	7±0.5[a]	7±0.75[a]	8±1[a]	4.48(3)	0.21
Texture/Mouth feel	8±0.5[a]	8±1.25[a]	7±1.25[a]	8±0.75[a]	2.74(3)	0.43

NB: The numbers are represented as median ± interquartile range at 5% level of significance

CHAPTER FIVE: DISCUSSION

5.1 Objective 1: To evaluate the potential of SWP as a protein supplement on growth performance in Kuroiler diet.

5.1.1 Evaluation of Kuroiler chicks growth performance

From the tabulated results, there was no significant difference in chick weights in weeks 1,2,4,5 and 7 ($p>0.05$) which can also be noted from the Anova tables in Appendices 4, 5, 6 and 7. The mean weights from week 2 were significantly different due to the growth spurt in this period. From the 8th week it can be deduced that silkworm pupae supplementation levels had a significant effect on chick weights ($P<0.05$). This concurs with the findings of Ullah et. al., (2017) and Khatun et. al., (2005) who found out that silkworm pupae supplementation at different levels had a positive significant effect on the final live weight of the poultry birds. These findings however contradict with Ijaiya & Eko (2009) who found no significant difference in supplementing fish meal with different levels of silkworm pupae on the growth of finishing broiler chicken. The difference with this study could be as a result of the age of the birds, the period of the experiment, the breed and the different climatic regions in which the experiment was conducted in.

5.1.2 Effect of treatment diets on feed intake

In this study feed intake were noted to be higher at 100% silkworm pupae replacement with fish meal. This is in line with the finding of Khan et.al., (2015) and Ullah et. al., (2017) who found out that substitution levels above 50% yielded better results than fish meal or soybean. This high growth performance could be attributed to a sufficient supply of essential amino acids most importantly tryptophan, digestibility of nutrients and an improved rate of protein retention supporting this study which had the best performing substitution at 100% which is above 50% (Ullah et. al., 2017).

There was no significant effect ($p>0.05$) in the feed conversion rate across the treatment levels with an increased FCR for every increase in silkworm pupae. This is in line with the findings of (Ijaiya &Eko, 2009; Ullah et. al, 2017; Khatun et. al., 2003).

5.2 Objective 2: To analyze the carcass yield of Kuroiler chicken fed on a diet supplemented with silkworm pupae protein

5.2.1 Carcass quality evaluation

There was no significant difference noted on SWP meal addition on the chicken carcass components like the heart (p=0.463), liver (p=0.118), wings (p=0.155), back (p=0.102), breast (p=0.155) weights upon treatments. The ANOVA tables detailing the carcass components are in Appendix 18-26 showing no significant difference.

Similar results were obtained by Ullah et. al. (2017) where silkworm pupae was included in a broiler finisher ration and Miah et. al., (2020). The dressing percentages could be lower than most studies that used broilers chicks due to the age and level of maturity of the chicks at slaughter and considering they are genetically improved from the indigenous chicken.

5.2.2 Breast meat sensory evaluation

Poultry meat colour is largely influenced by the haem iron rich compounds like myoglobin, haemoglobin and cytochrome. Differences in meat colour may be associated with myoglobin content, composition of the diet and bird sources (Wideman et al., 2016). The taste and flavor also had no significant differences across the diets with the control being the most preferred due to the rich amino acids and fatty acids from fish meal which happen to be deficient or in low amounts in silkworm pupae meal. Mentang et. al. (2013) also obtained the same results when they used 18 trained assessors who couldn’t identify any significant difference between the diets up to 100% substitution.

The smell/ odor was higher in 0% SWP because of the effects of fish meal that has a strong odor even before it was included in the formulation of the treatment diets whereas silkworm pupae had a very faint odor that could not easily be smelled when ground. Therefore, such odors could have trickled into the carcass. The texture and mouth feel properties were better in 100% SWP majorly due to the cooking loss or reduced moisture content since most studies have found meat products with decreased cooking loss having high value of hardness (Park et al., 2017).

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 Growth performance of Kuroiler birds fed on various substitution ratios of silkworm pupae meal with Fish meal diet.

In this study, four diets were formulated by supplementing silkworm pupae at 25%, 50%, 100%, and 0% and fed on day old Kuroiler chicks ad libitum. Using a modern digital kern weight, data was collected on the weekly chick weights for the entire 8 weeks from the beginning of the experiment to the end of it. Feed intake was also weighed daily and their refuse. The data assisted in finding the feed conversion ratio. Feed intake also recorded a strong statistical significance ($p<0.05$) with a higher feed intake noted in 0%SWP. Their feed conversion ratios though were not significant across the treatment levels ($p>0.05$) with 25% substitution having the lowest FCR which is the most effective feed in terms of conversion to weight. For this variables, null hypothesis was rejected. From the findings silkworm pupae-based feed had a statistically significant difference on chick weights ($p<0.05$). There was a significant increase in chick weights upon increasing the substitution level of silkworm pupae. SWP supplementation in 100% recorded the highest weight gain.

6.2 Carcass quality of Kuroiler chicken fed on silkworm pupae formulated feed.

The findings of the study collected from the four diets based on the various substitution levels noted that slaughtering at the end of the 8th week showed a significant effect on dressed weight however various carcass components showed no significant effect based on the four diets. Since 100%SWP substitution recorded the highest carcass yield. Sensory evaluation done on the cooked carcass also found out that there was no significant effect on the meat texture, taste, colour and odor. The panelists could not differentiate between the four carcasses which can be concluded that silkworm pupae inclusion in any substitution level does not affect the sensory characteristics. Therefore, the null hypothesis failed to be rejected.

6.3 Conclusion

Based on the findings on Kuroiler growth performance under SWP based feed; it shows that SWP has a positive significant effect on growth performance parameters like feed intake, weight and daily feed intake. Therefore, the study concluded that silkworm pupae can be used effectively to replace fish meal while influencing growth positively.

On the second hypothesis, the study found out that the SWP based diets had a significant effect on the carcass yield but did not have any effect on the carcass components and even the sensory evaluation. This study therefore concluded that an increase in SWP in partial or total replacement of fish meal will not affect negatively the carcass characteristics and its sensory parameters.

6.4 Recommendation

Based on objective one, the study found out that SWP inclusion in diet had a positive significant effect on growth performance. This study recommends the utilization of silkworm pupae-based feeds in 100% total replacement in order to realize optimum results on growth parameters. This is due to the high protein nature contained in the silkworm pupae providing a suitable alternative to the challenge of declining and poor-quality fish meal which may be detrimental to the mono-gastric animals. Instead of farmers discarding the pupae as waste, it can be effectively utilized as feed especially for locally improved poultry species in Kenya which most of the time are left to scavenge for kitchen wastes and left over hence crippling their productivity.

The second objective also found out that silkworm pupae inclusion in Kuroiler feeds did not affect the carcass characteristics and sensory parameters significantly with 100% SWP inclusion being the best level to optimize production. The diet and age of birds at slaughter being critical factors in determining the taste, colour, texture and odor; SWP can be used in Kuroiler birds' diet while maintaining the required parameters by the consumers. This shows that SWP is synthesized well into the bird's system and integrates well with the haem compounds like myoglobin and hemoglobin.

Utilizing SWP as a partial or total supplementation for fish meal will spur production in the poultry industry in terms of meat production and diversify the protein alternatives while maintaining the growth performance indicators. The Kuroiler breed, which has an improved genetic potential than the usual local indigenous chicken holds the potential to foster and achieve household food security due to its active scavenging nature and the availability of alternative protein feed sources apart from fish meal which constrain most farmers. The study therefore recommends that inclusion of SWP in different levels of substitution in poultry diets will still be ideal to both carcass yield and the consumer appeal.

6.5 Suggestions for further research

Future studies should conduct the experiment up to maturity and analyze the carcass in a period of more than 8 months. Such studies could serve to inform whether there will be any noticeable differences from chick mash, growers mash and laying mash. This is vital to the poultry industry which is competing for fish meal alongside other livestock sectors.

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APPENDICES

Appendix 1: Analysis of variance table on chick weights on the treatment levels

	Df	Sum Sq	Mean Sq	F-value	Pr(>F)
Treatment	3	117024	39008	6.962	0.000266 ***
Week	1	8766465	8766465	1564.585	< 2e-16 ***
Treatment: week	3	83957	27986	4.995	0.002863 **
Residuals	100	560306	5603		

Appendix 2: Chick weight means for the 8 weeks

Weeks	0	1	2	3	4	5	6	7	8
Weight in gms	39.90[a]	71.87[a]	136.35[b]	237.95[c]	314.87[d]	472.59[e]	576.08[f]	726.28[g]	925.72[h]

Appendix 3: Mean feed intake across treatment levels

Treatment levels	Mean ±SE
T0	364±6.61
T1	374±7.72
T2	366±7.60
T3	237±4.68

Appendix 4: Mean final live weight and standard Error

Treatment	**Mean± SE**
T0	1047±24.1
T1	989±17.3
T2	948±26.9
T3	816±18.9

Appendix 5: Mean carcass yield weight and standard Error

Treatment	**Mean ±SE**
T0	923±23.4
T1	859±12.0
T2	835±30.0
T3	698±21.0

Appendix 6: Analysis of variance on final live weight

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	LSD
Treatment	3	86611	28870	6.541	0.0152 *	125.08
Residuals	8	35309	4414			

Appendix 7: Analysis of variance on carcass yield weight

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	LSD

Treatment	3	80854	26951	5.901	0.02 *	127.248
Residuals	8	36540	4567			

Appendix 8: Analysis of variance on viscera yield weight

	Df	Sum Sq	Mean Sq	F value	Pr (> F)	LSD
Treatment	3	2340.8	780.3	14.49	0.00134 **	13.81
Residuals	8	430.8	53.8			

Appendix 9: Analysis of variance on carcass without viscera yield weight

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	LSD
Treatment	3	56942	18981	4.463	0.0403 *	122.78
Residuals	8	34021	4253			

Appendix 10: Analysis of variance on heart yield weight

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	LSD
Treatment	3	2.366	0.7887	0.946	0.463	1.72
Residuals	8	6.669	0.8337			

Appendix 11: Analysis of variance on liver yield weight

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	LSD
Treatment	3	37.20	12.401	2.683	0.118	4.05
Residuals	8	36.98	4.622			

Appendix 12: Analysis of variance on kidney yield weight

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	LSD
Treatment	3	13.033	4.344	6.893	0.0131 *	1.49
Residuals	8	5.042	0.630			

Appendix 11: Analysis of variance on breast muscle weight

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	LSD
Treatment	3	10328	3443	2.295	0.155	72.93
Residuals	8	12001	1500			

Appendix 12: Summary statistics of the weights in weeks

Week	**Mean weight ± SE**
0	39.9±0.135[a]
1	71.9±0.668[a]
2	136±1.56[b]
3	238±2.93[c]
4	315±4.41[d]
5	473±5.87[e]
6	576±7.25[f]
7	726±8.03[g]

Appendix 13: ANOVA's table on feed intake

	Df	**Sum Sq**	**Mean Sq**	**F-Value**	**Pr(>F)**
Treatment	3	308860	102953	24.24	1.59e-11 ***
Week	1	1930329	1930329	454.52	< 2e-16 ***
Treatment: week	3	118871	39624	9.33	2.02e-05 ***
Residuals	88	373729	4247		

Appendix 14:Anova table on FCR

	Df	**Sum Sq**	**Mean Sq**	**F-Value**	**Pr(>F)**
Treatment	3	0.8083	0.2694	1.913	0.206
Residuals	8	1.1270	0.1409		

APPENDIX 15: SENSORY EVALUATION FORM

Sensory evaluation form for trained panelist on silkworm pupae fed chicken

Introduction

I am a master student of Jaramogi Oginga Odinga University of Science and Technology. I am currently conducting research on **"Dietary supplementation with silkworm pupae on growth and meat quality of kuroiler birds".** You have been identified as a potential respondent in this research. The chicken meat has been derived from 8 weeks old Kuroiler birds fed on various substitution percentages of silkworm pupae.

The ingredients used have been carefully handled and processed and therefore deemed safe for consumption. Those with any allergic reactions to any poultry products are exempted from this evaluation. Feel free and make a decision whether to participate or not. The information you will give is purposely for research. Thank you.

Step 1; Fill in your details in section A by putting a tick **(**√**)** in the boxes where appropriate.

SECTION A: PERSONAL DETAILS

Name: ……………………………… Phone Number…………………………….

County………………… Gender……………. Sub-county……………………………

Level of education………………Age: 20-30 __30-40__40-50__ 50-60__

SECTION B: PANELIST SENSORY EVALUTION

Step 2; Take time to read and understand the 9-point hedonic rating scale provided and use it to give score to each parameter of the sample formulations you are provided with. The rating scale is as follows;

9-Like extremely 8-Like very much 7-Like moderately 6- Like slightly 5-Neither like nor dislike 4-Dislike slightly 3-Dislike moderately 2-Dislike very much 1-Dislike extremely.

Enter the ratings for each category of sample.

Category Sample	T0	T1	T3	T2
Colour (Appearance)				
Taste/Flavor				
Odor/Aroma				
Texture/Mouth-feel				

OPTIONAL				
Any other information on the samples.				

Step4: Which of the four sample products do you prefer

……………………………………………………………………………………………………

……………………………………………………………………………………………………

Step5:

Comments/Explanations**…**

……………………………………………………………………………………………………

………………………………………………………………………………………

Date………………………………… Signature…………………………………….

Appendix 16: JOOUST Ethics review 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

7th November, 2019

OUR REF: JOOUST/DVC-RIO/ERC/E2

Wycliffe Orwoba Nyanchoka
SAFS
JOOUST

Dear Mr. Nyanchoka,

RE: APPROVAL TO CONDUCT RESEARCH TITLED *"EFFECTS OF SILKWORM PUPAE BASED FEED PERFORMANCE OF KUROILER CHICKEN AS ALTERNATIVE SOURCE"*

This is to inform you that JOOUST ERC has reviewed and approved your above research proposal. Your application approval number is **7/14/ERC/11/19-7.** The approval period is from 6th November, 2019 – 5th November, 2020.

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,

Prof. Francis Anga'wa
Chairman, JOOUST ERC

Copy to: Deputy Vice-Chancellor, RIO - to note on file

Appendix 17:JOOUST of introduction

JARAMOGI OGINGA ODINGA UNIVERSITY OF SCIENCE & TECHNOLOGY

BOARD OF POSTGRADUATE STUDIES

Office of the Director

Tel. 057-2501804 P.O. BOX 210 - 40601

Email: bps@jooust.ac.ke **BONDO**

Our Ref: A451/4251/2018 **Date**: 28th November 2019

TO WHOM IT MAY CONCERN

RE: WYCLIFFE ORWOBA NYANCHOKA - A451/4251/2018

The above person is a bona fide 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. He has been authorized by the University to undertake research on the topic: "***Effects of Silkworm Pupae Based Feed on Performance of Kuroiler Chicken as an Alternative Source***".

Any assistance accorded to him shall be appreciated.

Thank you.

JARAMOGI OGINGA ODINGA
DIRECTOR BOARD OF
POST GRADUATE STUDIES
DATE ....
P. O. BOX 210 - 40601, BONDO.
UNIVERSITY OF SCIENCE & TECHNOLOGY

Prof. Dennis Ochuodho

DIRECTOR, BOARD OF POSTGRADUATE STUDIES