EFFECT OF REPLACING SOYA BEAN MEAL WITH YELLOW MEALWORM LARVAE MEAL IN A DIET ON PERFORMANCE AND CARCASS CHARACTERISTICS OF ROSS 308 BROILER CHICKENS

By

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DECLARATION

I declare that this mini-dissertation hereby submitted to the University of Limpopo for the degree of Master of Science in Agriculture (Animal Production) has not been submitted by me for a degree at this or any other university, this is my own work in design and execution, and that all materials contained herein has been duly acknowledged.

Signature…Matsobane E Tema. Date………31/05/2021………….

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DEDICATIONS

This work is dedicated to God Almighty for His guidance and blessings throughout the study period.

To my late brother Bonny Tema, may his soul continue to rest in peace.

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ABSTRACT

Two experiments were conducted to determine the effect of replacing soya bean meal with yellow mealworm larvae meal (*Tenebrio molitor*) in a diet on productivity, gut morphology, carcass characteristics and bone morphometrics of Ross 308 broiler chickens aged one to 42 days. In each experiment, a total of 360 Ross 308 broiler chickens were randomly assigned to the five dietary treatments, each treatment having four replications, and 18 chickens per replicate. Five diets were formulated to contain yellow mealworm replacement levels at 0, 25, 50, 75 and 100% to meet the nutrient requirements of Ross 308 broiler chickens. Data was analysed using the General Linear Model procedures of the Statistical Analysis System, Version 9.3.1 software program. Fisher's least significant difference (LSD) test was applied for mean separation where there were significant differences ($P<0.05$). A quadratic regression model was used to determine the levels for optimal responses in the variables measured.

The first experiment determined the effect of replacing soya bean meal with yellow mealworm larvae meal on productivity and gut morphology of unsexed Ross 308 broiler chickens aged one to 21 days. Replacement of soya bean meal with yellow mealworm meal in a diet had no effect ($p > 0.05$) on feed intake, growth rate, FCR, live body weight, ME intake and nitrogen retention of unsexed Ross 308 broiler chickens aged one to 21 days. Replacing soya bean meal with yellow mealworm meal in a diet did not affect ($p > 0.05$) caecum weight of unsexed Ross 308 broiler chickens. However, replacing soya bean meal with yellow mealworm meal in a diet increased ($p < 0.05$) gastro intestinal tract, crop, ileum and large intestine weights. Crop and ileum lengths of unsexed Ross 308 broiler chickens aged 21 days were not affected ($p > 0.05$) by replacement of soya bean meal with yellow mealworm meal in the diet. However, replacing soya bean meal with yellow mealworm meal in a diet increased ($p < 0.05$) gizzard, caecum and large intestine lengths of unsexed Ross 308 broiler chickens aged 21 days. Yellow mealworm meal in a diet did not affect ($p > 0.05$) gut organ digesta pH values of unsexed Ross 308 broiler chickens aged 21 days.

The second experiment determined the effect of replacing soya bean meal with yellow mealworm meal in a diet on productivity, gut morphology, carcass characteristics and bone morphometrics of Ross 308 broiler chickens aged 22 to 42 days. Replacement of soya bean meal with yellow mealworm meal in a diet did not affect ($p > 0.05$) growth rate, FCR, ME intake and nitrogen retention of male Ross 308 broiler chickens aged 22 to 42 days. However, replacing soya bean meal with yellow mealworm meal in a diet affected ($p < 0.05$) feed intake and live body weight of male Ross 308 broiler chickens aged 22 to 42 days. Broiler chickens on diets containing 75 or 100% yellow mealworm meal had higher ($p < 0.05$) intakes than those on diets containing no yellow mealworm meal. Similarly, male broiler chickens on diets having 50% yellow mealworm meal had higher ($p < 0.05$) live body weights than those on diets containing no yellow mealworm. Quadratic equations indicated that feed intake and live body weight of male Ross 308 broiler chickens were optimized at yellow mealworm meal replacement levels of 13 and 61%, respectively. The present study showed that replacing soya bean meal with yellow mealworm meal in a diet did not affect ($p > 0.05$) gut organ digesta pH values, gut organ weights, gut organ lengths, meat colour, meat pH values, bone morphometric values, carcass part weights and meat sensory attributes of male Ross 308 broiler chickens aged 42 days. However, meat from chickens on diets containing yellow mealworm meal was softer ($p < 0.05$) than meat from chickens on diets having 100% soya bean meal.

It is concluded that soya bean meal can be replaced with yellow mealworm larvae meal in a diet at 25, 50, 75 and 100% levels without having adverse effects on production and carcass characteristics of Ross 308 broiler chickens aged one to 42 days.

Key words: Yellow mealworm larvae meal, soya bean meal, Ross 308 broiler chickens, growth rate, live body weight, gut morphology, carcass characteristics.

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LIST OF ABBREVIATIONS

Abbreviation	Definition
ADF	Acid detergent fibre
ADG	Average daily gain
ANOVA	Analysis of variance
AOAC	Association of Analytical Chemists
ARC	Agricultural Research Council
Ca	Calcium
CP	Crude protein
CF	Crude fibre
cm	Centimetre
DM	Dry matter
DMI	Dry matter intake
DMD	Dry matter digestibility
EE	Ether extract
FAO	Food and Agricultural Organisation
FCR	Feed conversion ratio
g	Grams
GE	Gross Energy
GIT	Gastro-intestinal tract
GLM	General linear model
H	Hour
kg	Kilograms
LARS	Limpopo Agro-food Technology station
LSD	Least significant difference
ME	Metabolic energy
mm	Millimetres
min	Minutes
N	Nitrogen
NDF	Neutral detergent fibre

NCR	National Research Council
^0C	Degree centigrade
P	Phosphorus
r^2	Coefficient of determination
SAS	Statistical Analysis System
SE	Standard error
SEM	Standard error of means
WBSF	Warner-Bratzler shear force

CHAPTER ONE

INTRODUCTION

1.1 Background

Demand for poultry products is growing worldwide (Tabata *et al.*, 2017). However, matching nutrition with the development and growth of broiler chickens is a major challenge in poultry production schemes (FOA, 2013). This applies, particularly, to the protein fraction of the diet. Thus, fast-growing broiler chickens require large amount of protein in their diets to ensure optimal productivity. Poor nutrition results in poor growth and development of the chickens (Bovera, 2015). Soya bean meal is the main vegetable protein source used in diet formulations for broiler chickens, mainly because of the high quality and quantity of protein and adequate amino acid profiles (Henry *et al*., 2015). However, due to its ever-increasing price, the sustainability of broiler chicken production chain is becoming critical in a number of countries. There are also environmental concerns attributed to extensive soya bean cultivation. The increased soya bean cultivation causes deforestation, requires high water use and utilization of chemicals (FOA, 2013). There is, therefore, need to find alternative protein feed sources for broiler chickens.

Insects like mealworm larvae (Tenebrio *molitor*) play an important nutritional role as a protein ingredient in broiler chicken diets, while also containing excellent amino acid profiles (Makkar *et al*., 2014). The intake of mealworm by broiler chickens improves gastrointestinal tract, tissue and organ developments (Blallitoc and Sun, 2013; Bovera *et al*., 2016). It also improves digestive and absorptive capacities of the chicken (Ballitoc and Sun, 2013). However, the effects of replacing soya bean meal with yellow mealworm on productivity and carcass characteristics of Ross 308 broiler chickens are not conclusive (Makkar *et al*., 2014; Bovera *et al*., 2016) This requires further investigation.

1.2 Problem statement

Diets not meeting nutrient requirements adversely affect growth rate of broiler chickens (Ravindran and Kong, 2014). This is particularly important for protein requirements. Soya bean meal is the main source of protein for broiler chickens. However, chickens compete with humans for soya bean meal utilization for their protein requirements. Thus, soya bean meals are very expensive (FOA, 2013). There is, therefore, need for alternative protein sources for broiler chickens. The potential of insects like mealworm larvae (*T-molitor*) becoming important diet ingredients in poultry feeds is there. However, yellow mealworm larvae meal contains chitin which may adversely affect diet digestibility in broiler chickens (Biasato *et al*., 2016). This requires further evaluation.

1.3 Motivation

This study will generate data on the replacement of soya bean meal in a diet with yellow mealworm larvae meal on performance and carcass characteristics of Ross 308 broiler chickens. Data on such information will help in formulating feeding strategies that enhance performance of broiler chickens. Optimization of performance and carcass characteristics of broiler chickens may improve economic, nutritional and cultural status of broiler chicken farmers.

1.4 Aim

The aim of the study was to investigate the significance of replacing soya bean meal in a diet with yellow mealworm larvae meal on performance and carcass characteristics of Ross 308 broiler chickens.

1.5 Objectives

The objectives of the study were to determine:

i. the effect of replacing soya bean meal in a diet with yellow mealworm larvae meal on diet intake, digestibility, feed conversion ratio, live weight and gut morphology of Ross 308 broiler chickens aged one to 42 days.
ii. the effect of replacing soya bean meal in a diet with yellow mealworm larvae meal on carcass characteristics of Ross 308 broiler chickens aged 42 days.

1.6 Hypotheses

The hypotheses of the study were as follows:

i. Replacing soya bean meal in a diet with yellow mealworm larvae meal has no effect on diet intake, digestibility, feed conversion ratio, live weight and gut morphology of Ross 308 broiler chickens aged one to 42 days.
ii. Replacing soya bean meal in a diet with yellow mealworm larvae meal has no effect on carcass characteristics of Ross 308 broiler chickens aged 42 days.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Broiler chicken meat is an important protein source in the world compared to other livestock (Boer *et al.*, 2001). The majority of people in Southern Africa, generally, rely on chicken meat to meet their dietary protein requirements (Mwale and Masika, 2009). Chicken meat is considered better than red meat because of low levels of fat and cholesterol and high levels of iron (Jaturasitha *et al.*, 2008). According to Mupeta *et al.* (2003), chicken feed costs account for over 70% of the total production costs. However, the major factors that affect the high cost of poultry feeds are the scarcity of feed ingredients (Khan *et al.,* 2017). Thus, soya bean and fish meal, are mainly used in the poultry feed because they are palatable and rich in proteins (Khatun *et al.,* 2005; Khan *et al.,* 2017). The chicken feed ingredients, such as soya bean and fish meals are expensive sources of protein. However, this is mainly due to competition between human and livestock (Selaledi *et al.,* 2019). Thus, there is need, to consider insects such as black soldier fly larvae, maggot meal, earthworm and mealworm as potential replacements for soya bean and fish meal as protein sources in poultry rations.

Insects are part of the natural diet of chickens. Insects contain between 30 and 70% of protein on a dry matter basis (Veldkamp *et al.,* 2012). Among the different insect species, the yellow mealworm (*Tenebrio molitor, L*) seems to be suitable, efficient and sustainable alternative protein source in poultry diets. Mealworms have high quality protein concentration due to the presence of all the essential amino acids (Collavo *et al.,* 2005). According to Bovera *et al.* (2016), mealworm and insects in general can be used in the diets of chickens without affecting growth rate and diet palatability. There are three species of mealworm: yellow mealworm, giant mealworm and lesser mealworm. Mealworms are the larval stage of *Coleoptera tenebrionidae* (darkling beetles) and its larvae are rich in protein (Bennett and Rhetoric, 2014). However, one major limitation to the use of yellow mealworm is the presence of chitin content which interferes with the digestibility of the protein (Longvah *et al.*, 2011). There is some evidence, that chitin is not degraded and absorbed in the small intestines, and thus can affect the protein digestibility (Bovera *et al.*, 2015). However, such information is limited and contradictory. Thus, it is importance to determine inclusion levels of yellow mealworm for optimal productivity of broiler chickens.

2.2 Structure of soya bean seed

Soybean (*glycine max*), also called soja bean or soya bean, is an annual legume of the family *Fabaceae* and its seeds are edible. The soybean is economically the most important bean in the world, providing vegetable protein for millions of people and ingredients for hundreds of chemical products (Bhalla *et al.,* 2017). The soybean is an erect branching plant and can reach more than 2 metres in height. The self-fertilizing flowers are white or a shade of purple. The seed can be yellow, green, brown, black or bicoloured, though most commercial varieties have brown or tan seeds, with one or four seeds per pod (Bennett and Rhetoric, 2014). Additionally, soybean cultivation is successful in climates with hot summer, with mean ambient temperatures of between 20^0C and 40^0C. The seed (Figure 2.01) has two distinct sections which are seed coat and embryo (cotyledon, epicotyl, plumule, hypocotyl and radicle) (Shurtleff and Akiko, 2015).

2.2.1 Seed coat

The maturing ovule undergoes marked changes in the integuments, generally a reduction and disorganization but occasionally a thickening. The seed coat forms from the two integuments or outer layers of cells of the ovule, which derive from tissue from the mother plant, the inner integument forms the outer form of the seed (Shutov, 2011).

2.2.2 Cotyledon

The cotyledon is a significant part of the embryo within the seed and is defined as the embryonic leaf in seed-bearing plants, one or more of which are the first to appear from a germinating seed. The cotyledons are of primary interest since they contain the storage tissue of the seed. The cotyledon is comprised of palisade-like cell that are filled predominantly with protein and oil (Shurtleff and Akiko, 2015).

2.2.3 Epicotyl

The epicotyl is important for the beginning stage of a plant life. It is the region of an embryo plant. It grows rapidly, showing hypogeal germination and extends the stem above the soil surface. The epicotyl, being closer to the apex of the plant is the first part to emerge after germination (Shurtleff and Akiko, 2015).

2.2.4 Plumule

The plumule is the tip of the epicotyl and has a feathery appearance due to the presence of young leaf primordia at the apex and will become the shoot upon germination (Shutov, 2011).

2.2.5 Hypocotyl

The hypocotyl is the region of the stem between the point of attachment of the cotyledons and the root. The hypocotyl forms a hook during hypogeal germination and pushes out the soil, allowing the more delicate tissues of the plumules and apical meristem to avoid damage from pushing through the soil (Bennett and Rhetoric, 2014).

2.2.6 Radicle

The radicle is the basal tip of the hypocotyl which grows into the primary root (Shutov, 2011).

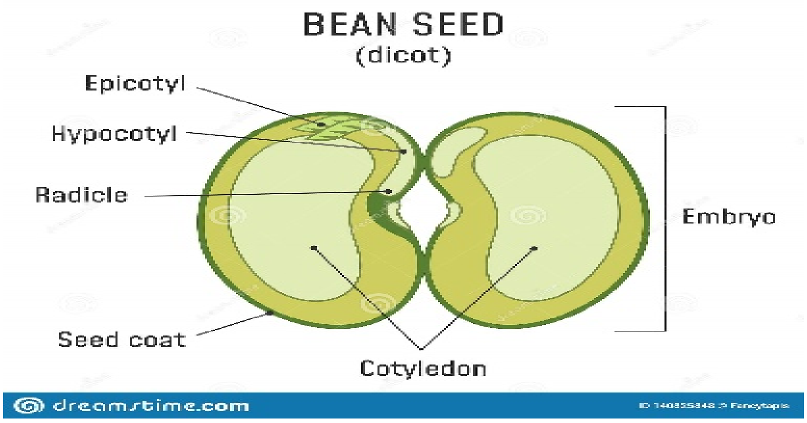

Figure 2.01 Structure of soybean (*glycine max*) showing seed coat and embryo. Source: Bennett and Rhetoric (2014).

2.3 Structure of yellow mealworm larvae

Mealworms are the larval forms of the mealworm beetle, species of darkling beetle. Like all holometabolic insects, they grow through four life stages: egg, larva, pupa and adult. The larvae typically measure about 2.5 cm or more, whereas adults are generally between 1.25 and 1.8 cm in length (Schmidt and Helmut, 2018). Additionally, the species normally overwinters in the larval stage and pupation occurs in spring and early summer at which time adults begin to appear (Hussain *et al.,* 2017). Yellow mealworm is a worm-like larva with a hard exoskeleton. Its body is designed to burrow, eat and store fat. There are three distinct sections which are the head, thorax, and abdomen (Figure 2.02) (Finke and Winn, 2004).

2.3.1 Head

The head of the mealworm has the mouth and labrum, a lip-like mouth part, to aid in its voracious eating habits. The mouth and its parts are quite small and designed to eat small pieces of food (Schmidt and Helmut, 2018). There is also a pair of antennae and larval eyes. The antennae act as feelers for the worm as it digs in search of food. The eyes are small and poorly developed due to the insect's burrowing nature (Rantala, 2012).

2.3.2 Thorax

The thorax consists of three segments called the prothorax, mesothorax, and metathorax. Each segment has a pair of short legs. A mealworm does not walk very well, but its legs and claws are perfectly suited for burrowing (Rantala, 2012).

2.3.3 Abdomen

The abdomen has nine segments with the last segment containing the anus and a spine. The abdomen contains the digestive tract and stores lots of fat from all the food the mealworm eats. This fat will eventually be used for the worm's transformation into a pupa and then a beetle (Wakefield, 2005).

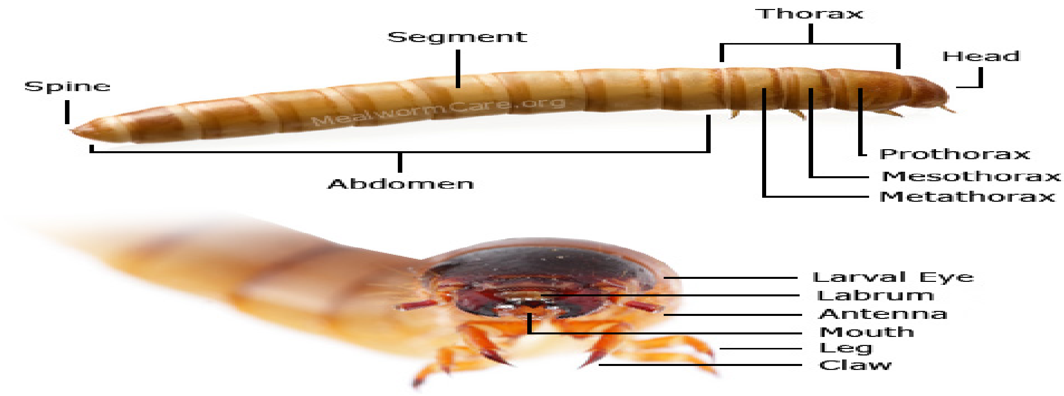

Figure 2.02 The structure of yellow mealworm (*T. molitor*) showing head, thorax, and abdomen. Source: Schmidt and Helmut (2018).

2.4 Nutritional requirements of chickens

Chickens require adequate amount of all the nutrients for them to be healthy and productive. According to Richard (2005), nutritional deficiencies lead to poor productivity and increased susceptibility to infection while nutritional excesses lead to nitrogen build-up and nutritional disorder. Thus, formulating balanced rations for optimal productivity is essential. Proper management including nutrition and health in chickens is an essential factor in poultry production. According to McDonald *et al.* (2011), nutrition plays a vital role in influencing growth in livestock. Carbohydrates, fats and proteins that the chicken utilizes as sources of energy are essential requirements for growth. Mbajiorgu (2010) reported that chickens can adjust their feed intake over a considerable range of feed energy levels to meet their daily energy requirements. Thus, dietary energy levels are used to set the levels of other nutrients, including protein and amino acids. For productivity to be improved and maximized, the nutritional needs of the chickens must be met optimally in terms of energy and protein requirements. Alabi (2013) stated that changes in dietary energy concentration affect feed conversion efficiency in various ways, firstly, increasing dietary energy improves feed conversion ratio as less feed is taken in to satisfy the energy needs. Secondly, the growth rate is increased by increasing levels of dietary energy (Alabi, 2013). The amino acids obtained from dietary protein are used by chickens to fulfil a diversity of functions such as growth, meat or egg production. Therefore, yellow mealworm can be practically added in place of soya bean to poultry diets for optimal growth performance due to high nutrients.

2.5 Nutritional value and chemical composition of soya bean and yellow mealworm

Soya bean is a major source of protein in poultry diets. Although it is produced throughout the world, there is high competition for soya bean among human beings, livestock and the industry (Sebre *et al*., 2012). Soya bean is high in protein as compared to other grain legumes and has multiple uses such as soya milk and cheese as an option for dairy alternatives (McConnell *et al*., 2012). Soya bean production requires higher water consumption, use of chemicals and hence, its production in drier areas such as most of Africa may be limited (Sebre *et al*., 2012). In comparison to soya bean, yellow mealworm production requires much less space and energy for cultivation and can be grown successfully on dried and cooked waste materials from fruits, vegetables and cereals in various combinations. According to Bovera *et al*. (2015), mealworm meal contains 51.93% crude protein, which is comparable to 44.51% crude protein content of soya bean meal but lower than that of fishmeal which is 70.2% crude protein content (Table 2.01). These results are in line with those of Barker e*t al*. (1998), who reported that the crude protein values of mealworm meal are between 45 and 68.9%. However, the percentage ash and fibre of yellow mealworm meal are higher than those of soya bean meal. It has been documented that yellow mealworm is relatively similar in cost with soya bean as compared to other insects such as black solider fly (Hussain *et al.,* 2017). The whole dried yellow mealworm insect consists of about 50.7% crude protein, 28.2% fat, 3.8% carbohydrates and 3.2% ash contents on a dry weight basis (Finke *et al*., 2015). Soya bean and yellow mealworm nutrient compositions are presented in Table 2.01. However, recommendations on the use of yellow mealworm insect in broiler chicken production are complicated due to the presence of chitin.

Table 2.01 Nutrient composition of yellow mealworm and soya bean (on DM basis)

Nutrient	Soya bean	Yellow mealworm	Authors
Energy (kcal/kg)	446	427	Ghulam *et al.* (2017)
Protein (%)	45.5	53.8	Khan *et al.* (2017)
	46.8	46.4	Ravzanaadii *et al.* (2012)
		45.4	Jozefiak *et al.* (2016)
Crude fibre (%)	37.3	40.3	Hussain *et al.* (2017)
	-	38.6	Khan *et al.* (2017)
	34.6	-	Christensen *et al.,* (2009)
Dry matter (%)	95	93	Jozefiak *et al.* (2016)
Ash (%)	4.5	2.7	Siemianowska *et al.* (2013)
	3.7	2.5	Simon *et al*. (2013)
	-	3.69	Khan *et al.* (2017)
Fat (%)	18.4	25.9	Ravzanaadii *et al.* (212)
	-	22.2	Christensen *et al.* (2009)
	19.6	20.2	Khan *et al.* (2017)
Nitrogen-free extract (NFE), (%)	46.2	32.9	McConnell *et al.* (2012)
	23.8	18.3	Christensen *et al.* (2009)

2.6 Effect of yellow mealworm on productivity of chickens

Yellow mealworm insect is an interesting protein ingredient in poultry diets due to its nutritional composition, which is very similar to soya bean meal (Bovera *et al.,* 2015). However, studies on the use of yellow mealworm in broiler chicken diets have yielded contradictory results. According to Dietary inclusion of mealworm meal is associated with low feed conversion efficiency in broiler chickens (Ballitoc and Sun, 2013; Bovera *et al*., 2016; Khan *et al*., 2018). In contrast, other studies have shown no responses in chickens fed diets having inclusion of yellow mealworm larvae meal (Van Huis *et al.,* 2013; khan *et al.,* 2016; Collavo *et al.,* 2005). The responses of broiler chickens at different ages to yellow mealworm larvae meal inclusion levels are summarized in Table 2.02. Thus, yellow mealworm larvae meal can be included in diets of broiler chickens aged 1 to 7 days without any adverse effect on their performance (Harrell and bailer, 2004). Brovera *et al.* (2016), recommended an inclusion level of yellow mealworm larvae meal of up to 50% without any enzyme supplementation in order to achieve optimal weight gains, feed intake and feed conversion ratio (FCR) in broiler chickens aged 1 to 21 days. A major limitation on the use of yellow mealworm larvae meal in poultry feed is the presence of chitin which is known to decrease performance of broiler chickens (Polkki *et al.,* 2012). The use of wood ash to treat chitin for poultry feeding has shown to improve feed intake, weight gain and FCR of broiler chickens aged 1 to 21 days with 50% of yellow mealworm inclusion (Jozefiak *et al*., 2016). It has been suggested that yellow mealworm meal inclusion level of up to 75% can be used in feed formulation of broiler chickens as protein source to achieve optimal feed intake and feed conversion ratio (Oonincx and De Boer, 2012). According to Laconisi *et al*. (2017), yellow mealworm insect can be used successfully in combination with yellow maize in broiler rations up to 50% inclusion level for improved weight gain and FCR. However, Li *et al*. (2013), suggested 100% yellow mealworm larvae meal inclusion level in broiler chicken rations. The authors indicated that this may minimize the competition between human beings and livestock for soya bean meal use. Thus, empirical data on the use of yellow mealworm meal in place of soya bean is limited and contradictory in the literature.

Table 2.02 Optimal values of feed intake, growth rate and feed conversion ratio in broiler chickens at different ages fed different yellow mealworm meal inclusion levels

Age	Feed intake (g/chicken)	Weight gain (g/chicken)	FCR (g DM feed/g live weight gain)	Authors
1-7 days	150	230	1.17	Bovera *et al.* (2016)
1-14 days	554	539	1.14	Laconisi *et al.* (2017)
1-21 days	2715	1763.5	2.05	Li *et al.* (2013)
21-42 days	537	1572	1.81	khan *et al.* (2016)
42-56 days	78.53	45.56	2.01	Jozefiak *et al.* (2016)
56-63 day	43.23	52.30	1.99	Polkki *et al.* (2012)

2.7 Effect of yellow mealworm meal on gut morphology of chickens

At hatch, the immature digestive tract of chickens is physiologically active and primed for the activities of food assimilation (Belforti *et al.,* 2015). Delayed access to feed after hatch creates an abnormal physiological situation and leads to the negative consequences of lack of enteral nutrition (Piccolo *et al.,* 2017). Nutrient supply immediately after hatch is a critical factor for gut development in chicks (Ballitoc and Son, 2013). Chitin is found in many poultry feedstuffs such as yellow mealworm meal, black solider fly larvae meal, maggot meal and fish meal. Diets having chitin, when given to chicks, form soluble or insoluble and sometimes irreversible complexes with protein, digestive enzymes and possibly starch in the digestive tract of chickens (Berggreen *et al*., 2018). Chitin present in yellow mealworm may bind and precipitate at least 12 times of their molecular weight of protein (Biasato *et al*., 2016). Chitin can increase the size of the parotid glands and damage the mucosal lining of the gastro-intestinal tract of chickens (Hardouin and Mahoux, 2003). Chickens are known to be intolerant of feedstuffs rich in chitin because of very few taste buds in their mouth (Simon *et al*., 2013). Adverse effect of chitin on palatability, consumption, feed efficiency, growth rate and digestibility of nutrients such as protein, carbohydrates, lipids and minerals have been reported (Simon *et al*., 2013; Makkar *et al.,* 2014; Bovera *et al*., 2015; Khan *et al*., 2017). Khempaka *et al*. (2011) reported that chicks fed diets containing chitin had poor apparent digestibility of amino acids, probably because of an increased excretion of inactivated enzyme and glycoproteins of the gastrointestinal mucosa. There are some indications on the negative influence of chitin in the salivary and intestinal muco-protein and bile acids. However, reports on the effects of these anti-nutrient activities on poultry are limited and inconclusive (Oonincx and De Boer, 2012).

2.8 Chitin compound in yellow mealworm

Chitin, $(C_8H_{13}O_5N)_n$, is a large-chain polymer of N-acetylglucosamine, a derivative of glucose (Figure 2.03). This polysaccharide is a primary component of cell walls in fungi, exoskeletons of arthropods (crustaceans and insects), radulae of molluscs, cephalopod beaks and scales of fish (Tang and Sohn, 2015). The structure of chitin is comparable to another polysaccharide, cellulose, forming crystalline nanofibrils or whiskers. In terms of function, it may be compared to the protein keratin. Chitin has proved useful for several medicinal, industrial and biotechnological purposes (Tang and Sohn, 2015).

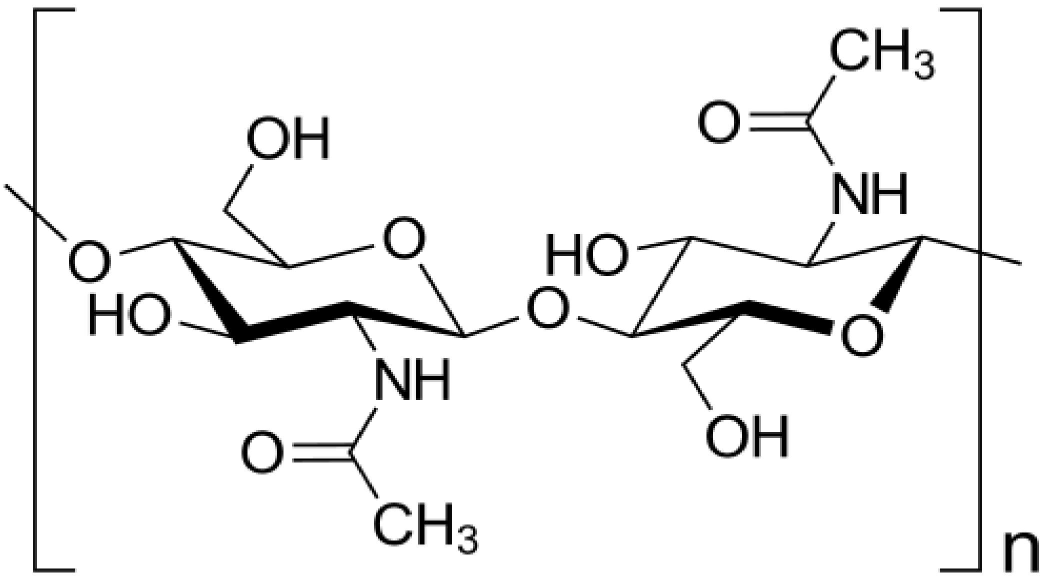

Figure 2.03 Structure of chitin compound in mealworm showing chitin molecule. Source: Tang and Sohn (2015)

2.9 Chemistry, physical properties and biological function of chitin compound

Chitin is a modified polysaccharide that contains nitrogen. It is synthesized from units of N-acetyl-D-glucosamine (Gilbert, 2009). These units form covalent linkages (like linkages between glucose units forming cellulose). Therefore, chitin may be described as cellulose with one hydroxyl group on each monomer replaced with an acetyl amine group. This allows for increased hydrogen bonding between adjacent polymers, giving the chitin-polymer matrix increased strength (Finney and Jay, 2008).

In its pure unmodified form, chitin is translucent, pliable, resilient and quite tough. In most arthropods, however, it is often modified occurring largely as a composite material such as in sclerotin, a tanned proteinaceous matrix which forms much of the exoskeleton of insects. Combined with calcium carbonate as in the shell of crustaceans and molluscs, chitin produces a much stronger composite. This composite material is much harder and stiffer than pure chitin and is tougher and less brittle than pure calcium carbonate (Campbell, 1996). Another difference between pure and composite forms can be seen by comparing the flexible body wall of a caterpillar (mainly chitin) to the stiff, light elytron of a beetle (containing a large proportion of sclerotin) (Gilbert, 2009).

In butterfly wing scales, chitin is organized into stacks of gyroids constructed of chitin photonic crystals that produce various iridescent colours serving phenotypic signalling and communication for mating and foraging (Saranathan, 2010). The elaborate chitin gyroid construction in butterfly wings creates a model of optical devices having potential for innovations in biomimicry (Saranathan, 2010). Scarab beetles in the genus *cyphochilus* also utilize chitin to form extremely thin scales (five to fifteen micrometres thick) that diffusely reflect white light. These scales are networks of randomly ordered filaments of chitin with diameters on the scale of hundreds of nanometres, which serve to scatter light. The multiple scattering of light is thought to play a role in the unusual whiteness of the scale (Burresi and Matteo, 2014; Dasi, 2014).

2.10 Improving nutritive value of yellow mealworm in chicken diets

The feeding value of any feed material depends on the balance between nutritive components of the feed, the digestibility of such nutrients, the metabolism of absorbed nutrients and the quantity of nutrients ingested by the animal (Klunder and Wolkers, 2012). Improving the nutritive value of yellow mealworm meal will promote high levels of production. Yellow mealworm can be processed by using chemical and mechanical methods as well as enzyme and mineral supplementation (Spencer and Spencer, 2006). However, processing yellow mealworm insect by drying and grinding has been popular. Drying yellow mealworm via heating seems to be suitable for feed production. Thus, proper insect processing makes it gluten-free. Grinding dried yellow mealworm insect before mixing into diets is one of mechanical method known to improve feed homogeneity, increase surface area for enzymatic degradation and reduce selective feeding (Van der Klis and Jansman, 2002). In addition, the presence of digestive enzymes in insects could also influence protein properties after grinding (Broekman *et al*., 2015). Water treatment of yellow mealworm is also a famous indigenous method of improving its nutritional value. This has resulted in a significant reduction in chitin content. Siemianowska *et al*. (2013), also observed a significant reduction in chitin contents when mealworm insects were treated with water and urea. According to

Veldkamp *et al*. (2012), chitin content in water treated mealworm was reduced from 29 to 4 g/kg DM.

An alkali treatment (sodium hydroxide, sodium bicarbonate and wood ash) is one of the chemical methods which has also been used to improve nutritional value of mealworm (Oonincx, 2010). Reckler *et al*. (2015), used 0.4% sodium hydroxide to reduce chitin concentration in mealworm and the result showed to be more effective, while Ballitoc and Sun (2013), Huis (2010) and Miglietta *et al*. (2015) suggested putting high-chitin mealworm in sodium bicarbonate at 25 ^{0}C for 2 days. This tends to reduce chitin level in insects. Grau *et al*. (2017) and Reckler *et al*. (2015), reported a 62% chitin reduction with the wood ash method.

Other ways of detoxifying the effect of chitin in yellow mealworm insect meal include using heat treatment (cooking, roasting etc.), urea treatment, enzyme treatment and using chitin chelating agents such as chitinase enzyme (Islam and Yang, 2016). Chitinase enzyme has been shown to bind with chitin and hence rendering it inactive in the animal (Biasato *et al*., 2016). However, much of this work has been done in ruminants and not in chickens.

2.11 Conclusion

Yellow mealworm larvae meal is rich in proteins. Protein levels in yellow mealworm larvae meal are comparable to those in soya bean meal. However, it contains high amounts of chitin which tends to reduce diet digestibility and hence intake in broiler chickens. There are ways of reducing the amount of chitin in yellow mealworm meal. These include heating, cooking or watering the meal. There are chemical means available for reducing chitin amount in yellow mealworm meal (urea treatment, enzyme treatment and using chitin chelating agents such as chitinase enzyme). However, results of yellow mealworm meal inclusion levels in the diets on performance of broiler chickens are limited and inconclusive. It is, therefore, important to determine the effect of replacing soya bean with yellow mealworm larvae meal on productivity and carcass characteristics of Ross 308 broiler chickens.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study site

The study was conducted at the University of Limpopo Livestock Unit (latitude 27.55^{0}S and longitude 24.77^{0}E), Limpopo province, South Africa. The ambient temperature around the study area ranges between 20 and 36^{0}C during summer and between -5 and 28^{0}C during winter (Kutu and Asiwe, 2010).

3.2 Preparation of the house

The poultry house was cleaned properly with water and then disinfected using a Vet GL 20 disinfectant (NTK, Polokwane). Drinkers and feeders were cleaned and disinfected with Vet GL 20 before use. The house was left empty for 7 days after cleaning to eradicate the population of infectious microorganisms that had not been killed by the disinfectant. After proper drying, the experimental house was divided into 20 floor pens. Fresh saw dust was placed on the floor to a level of 7.5 cm. The heating of the house was done using 250 watt-infrared lights.

3.3 Acquisition of materials and chickens

Ross 308 broiler chicks were acquired from Lufafa hatchery, Tzaneen, South Africa. The chicks were vaccinated at the hatchery with the Vitabron vaccine strain for prevention of Newcastle and infectious bronchitis diseases. Commercial soya bean meal and yellow maize were acquired from AFGRI, Mokopane. Yellow mealworm was acquired from the Council for Scientific and Industrial Research (CSIR), Pretoria. Vet GL 20 disinfectant, 250 watts infrared lights, feeders and drinkers were acquired from NTK, Polokwane, South Africa.

3.4 Experimental procedures, dietary treatments and design

The first part of the study involved Ross 308 broiler chickens aged one to 21 days. Three-hundred-and-sixty-day-old and unsexed Ross 308 broiler chicks were used. The experiment was carried out for a period of 21 days. The initial live weights of the chickens were taken using an electronic weighing balance and their initial mean live weight was 42.6 ± 8g. The chicks were assigned to 5 different treatments where yellow mealworm meal replaced soya bean meal at 0, 25, 50, 75 or 100% (Table 3.01) in a completely randomized design, with 4 replicates and 18 chicks in each replicate. The experimental chicks were fed formulated starter diets (Table 3.02). The chickens had *ad libitum* access to feed and water. Light was provided for 24 hours throughout the experiment, and deaths were observed everyday throughout the study.

Table 3.01 Dietary treatments for Experiment 1

Diet code	Diet description
$SB_{100}TM_0$	Unsexed Ross 308 broiler chickens aged 1 to 21 days fed a starter diet having 100% soya bean meal and no yellow mealworm meal (*Tenebrio molitor, L.*)
$SB_{75}TM_{25}$	Unsexed Ross 308 broiler chicken aged 1 to 21 days fed a starter diet having 25% of soya bean meal replaced by yellow mealworm meal (*Tenebrio molitor, L.*)
$SB_{50}TM_{50}$	Unsexed Ross 308 broiler chicken aged 1 to 21 days fed a starter diet having 50% of soya bean meal replaced by yellow mealworm meal (*Tenebrio molitor, L.*)
$SB_{25}TM_{75}$	Unsexed Ross 308 broiler chicken aged 1 to 21 days fed a starter diet having 75% of soya bean meal replaced by yellow mealworm meal (*Tenebrio molitor, L.*)
SB_0TM_{100}	Unsexed Ross 308 broiler chicken aged 1 to 21 days fed a starter diet having 100% of soya bean meal replaced by yellow mealworm meal (*Tenebrio molitor*)

Table 3.02 Ingredient and nutrient composition of the starter diets for Experiment 1

Feed Ingredient	Treatment				
	$SM_{100}TM_{0}$	$SB_{75}TM_{25}$	$SB_{50}TM_{50}$	$SB_{25}TM_{75}$	$SB_{0}TM_{100}$
Yellow maize (%)	55	55	55	55	55
Wheat bran (%)	3	3	3	3	3
Maize gluten meal (%)	4	4	4.05	4	4.21
Soya bean meal (%)	56.87	44.96	28.49	12.26	0.00
Fish meal (%)	1	1	5	5	3
Mealworm (%)	0.00	11.46	30.14	44.96	56.87
Rapeseed oil (%)	3.06	2.87	2.53	2.31	0.26
Ca carbonate (%)	2	2	2	2	0.5
Salt (%)	0.1	0.1	0.1	0.1	0.1
Di-Ca phosphate (%)	0.5	0.5	0.5	0.5	0.5
Na bicarbonate (%)	6.51	6.51	5.59	5.51	0
DL-Methionine (%)	0.1	0.15	0.15	0.15	0.1
L-Lysine_HCL (%)	0.15	0.15	0.15	0.11	0.1
L-Threonine (%)	0.05	0.15	0.15	0.15	0.05
Premix (%)	0.1	0.1	0.1	0.1	0.1
Total (%)	100	100	100	100	100
Analysed nutrient composition					
Dry matter (Decimal)	0.90	0.90	0.89	0.89	0.88
Energy (MJ/kg DM)	12	12	12	12	12
Crude protein (%)	22	22	22	22	22
Lysine (%)	10.99	10.95	11.08	11.11	11.10
Methionine (%)	5.08	5.11	5.51	5.61	5.73
Threonine (%)	9.12	9.13	9.02	9.15	9.03

The second part of the study involved three hundred and sixty male Ross 308 broiler chickens aged 22 days old. The chickens had been raised on a commercial broiler starter diet up to the age of 21 days. Initial mean live body weight was 580 ± 6 g. The experimental chickens were fed formulated grower diets (Table 3.03). The chickens were randomly assigned to five treatments where yellow mealworm replaced soya bean meal at 0, 25, 50, 75 and 100%. Each treatment had 4 replicates, with 18 chickens per replicate. Ingredients and nutrient composition of the diets are indicated in Table 3.04. The chickens had *ad libitum* access to feed and water. Light was provided for 24 hours throughout the experiment, and deaths were observed everyday throughout the study.

Table 3.03 Dietary treatments for Experiment 2

Diet code	Diet description
$SB_{100}TM_0$	Male Ross 308 broiler chickens aged 22 to 42 days fed a grower diet having 100% soya bean meal and no yellow mealworm meal.
$SB_{75}TM_{25}$	Male Ross 308 broiler chickens aged 22 to 42 days fed a grower diet having 25% of soya bean meal replaced by yellow mealworm meal.
$SB_{50}TM_{50}$	Male Ross 308 broiler chickens aged 22 to 42 days fed a grower diet having 50% of soya bean meal replaced by yellow mealworm meal.
$SB_{25}TM_{75}$	Male Ross 308 broiler chickens aged 22 to 42 days fed a grower diet having 75% of soya bean meal replaced by yellow mealworm meal.
SB_0TM_{100}	Male Ross 308 broiler chickens aged 22 to 42 days fed a grower diet having 100% of soya bean meal replaced by yellow mealworm meal.

Table 3.04 Ingredient and nutrient composition of the grower diets for Experiment 2

	Treatments				
Feed Ingredient	$SM_{100}TM_{0}$	$SB_{75}TM_{25}$	$SM_{50}TM_{50}$	$SB_{25}TM_{75}$	$SM_{0}TM_{100}$
Soya bean meal (%)	60.85	46.13	28.94	15.21	0.00
Mealworm-T.molitor (%)	0.00	13.54	30.72	46.13	60.85
Yellow maize meal (%)	59.42	59.46	62.98	61.0	61.0
Wheat bran (%)	5	5	3.5	3.5	3.5
Maize gluten meal (%)	6	6	4	4	4
Fish meal 2-8 % fat (%)	2	2	2	2	2.64
Rapeseed oil (%)	2.77	2.69	2.54	3.35	3.07
Di sodium phosphate (%)	0	0	0	0	0.07
Calcium carbonate (%)	1.7	1.61	1.45	1.32	1.19
Salt (%)	0.11	0.13	0.15	0.17	0.18
Di calcium phosphate (%)	0.9	1.02	1.27	1.34	1.4
Sodium bicarbonate (%)	0.5	0.5	0.5	0.5	0.5
DL-methionine (%)	0.2	0.2	0.2	0.2	0.2
L- Lysine_HCL (%)	0.25	0.25	0.25	0.4	0.4
L-threonine (%)	0.15	0.15	0.15	0.15	0.15
VIT. Trace EL: premix (%)	1	1	1	1	1
Total (%)	100	100	100	100	100
Analysed nutrient composition					
Dry matter (Decimal)	0.89	0.89	0.89	0.88	0.88
Energy (MJ/kg DM)	12.5	12.5	12.5	12.5	12.5
Crude protein (%)	21.12	21.10	21.0	20.9	20.8
Lysine (%)	9.53	9.68	9.86	9.83	9.79
Methionine (%)	5.61	5.62	5.56	5.61	5.53
Threonine (%)	8.10	8.11	8.09	8.12	8.11

3.5 Data collection

3.5.1 Growth parameters

Mean live weights were calculated from the weekly measurements by dividing the total weight with the number of chickens in that pen. Average daily gains were calculated by subtracting the initial weight of the chicken from the final weight and the answer was then divided by the number of days. Daily voluntary feed intake was measured by subtracting the difference in weight of leftovers from that offered per day and the amount was divided by the number of chickens per pen. The feed offered per day and leftovers were measured using the electronic weighing balance. Daily average feed intake and weight gain were used to calculate feed conversion ratio (FCR). Average feed intake was divided by average weight gain to find the FCR value (McDonald *et al*., 2010).

3.5.2 Digestibility

Digestibility measurements were carried out when the chickens were between the ages of 15 and 21, and 37 and 42 days for Experiments 1 and 2, respectively. Faeces voided were collected and weighed. Care was taken to avoid contamination from feathers, scales, debris and feeds. Faecal samples were dried and stored for analysis. Metabolisable energy and N-retention were calculated according to the procedures of McDonald *et al.* (2010).

3.5.3 Carcass characteristics

Chickens were slaughtered for the determination of carcass characteristics (carcass and organ weights, organ digesta pH and gastro-intestinal length measurements). The chickens were slaughtered by cervical dislocation as advised by the Animal Research Ethics Committee of the University of Limpopo. The carcasses were then put inside a bucket containing hot water for five seconds and they were then taken out. The carcasses were then put on a table for defeathering with hands. The carcasses were cut open at the abdominal site and the digestive tracts were removed from the abdominal cavities of the chickens. The digesta pH of gizzard, crop, small intestine, caecum and large intestines, and meat pH were measured using Crison, Basic 20 pH meter. The digesta pH were measured at each segment prior to the emptying of the digesta for weight measurement. The whole gastro-intestinal tract's length was measured. In addition, the length of small intestines, large intestines and caecum were measured separately. The gizzard, small intestines, caecum and large intestines were weighed using an electronic weighing balance. The colour of the breasts, drumsticks, thighs and wings were measured using Hunter Lab test (L^*, a^*, and b^*) system, wherein L^* is the lightness, a^* is the redness and b^* is the yellowness. The measuring probes were placed in contact with the surface of the muscles of the breast, drumstick, thigh and wing at three different points and the average was calculated for each portion (Dawson *et al*., 1991).

3.6 Chemical analysis

Dry matter contents of the feeds, feed refusals, excreta and meat samples were determined by drying the sample at the temperature of 105°C for 24 hours. Ash content of the feeds, faeces, feed refusals and meat samples were analysed by ashing the sample at 600°C in a muffle furnace overnight. Nitrogen content of the sample was determined by a micro-Kjedahl method (AOAC, 2008). Amino acid and fatty acid contents of feeds and meat were analysed by ion-exchange chromatography at the University of Limpopo. Gross energy values for feeds, feed refusal and faeces were determined using an adiabatic bomb calorimeter at the University of Limpopo Animal Nutrition Laboratory, according to the method described by the Association of Analytical Chemists (AOAC, 2010). A full analysis for faeces and feeds was performed at the Pietermaritzburg laboratory, Kwa-Zulu Natal, South Africa, according to AOAC (2012)

3.7 Sensory evaluation

Meat samples which were previously frozen at -40^0C for 4 days were thawed for 7 hours at room temperature prior to cooking. The breast meat was prepared and the skin was left on the meat samples. The method adopted by Pavelkova *et al.* (2013) was used for sensory evaluation of the meat. The following sensory attributes were evaluated by the sensory panel: tenderness, juiciness and flavour of meat samples. The sensory panel consisted of 20 trained panellists. Each panellist was offered to drink lemon juice after tasting meat sample from each treatment before proceeding to the next treatment as to wash out the previous treatment to avoid confusion of tastes. The five-point ranking scores used are as indicated in Table 3.5. Nothing was added to the meat sample so as not to affect the taste. An oven set at 105^0C was allowed to preheat prior to cooking. The meat samples were put in trays and they were covered with aluminium foil to prevent water loss. Thereafter, the trays with meat were putt in an oven for approximately 60 minutes and the meat samples were turned after every 10 minutes. Samples were cut into small 5 cm cubic pieces and served immediately after cooking. The individual breast meat was selected for sensory evaluation because of ease of handling.

Table 3.05 Evaluation scores used by the sensory panellists

Score	Sensory attribute		
	Flavour	Tenderness	Juiciness
1	Very bad flavour	Too tough	Extremely dry
2	Poor flavour	Tough	Dry
3	Neither bad nor good flavour	Neither tough nor tender	Neither dry nor juicy
4	Good flavour	Tender	Juicy
5	Very good flavour	Too tender	Too juicy

Source : Pavelková *et al*. (2013)

3.8 Shear force

Shear force assessment was done according to Warner-Bratzler Shear Force determination procedures (Dawson *et al.,* 1991). Frozen samples of chicken breast meat were thawed for 24h at 2°C. The samples were removed, tagged and used for cooked Warner Bratzler Shear Force (WBSF) measurements. Cooked meat was prepared by boiling breast cuts in a cylindrical pot using an electric stove. An electric stove was set on for 25 min prior to preparation. The cuts were boiled to an internal temperature of 35°C, then turned and finished at 70°C. Cooked cuts were cooled down to room temperature (18°C) for at least 2 hours before WBSF measurements. Three cylindrical sample (12.5 mm core diameter) of each cut were cored parallel to the grain of the meat, and sheared perpendicular to the fibre direction using a Warner-Bratzler shear force device mounted on a Universal Instron Apparatus (cross head speed = 200 mm/min, one shear in the centre of each core). The reported value in kg represents the average of three peak force measurements of each sample.

3.9 Bone morphometric

Bones were excised and defleshed without boiling. Thereafter, bones were analysed for physical bone characteristics (weight, length and diameter) using an electronic balance scale, measuring tape and calliper, respectively. Thereafter, bone samples were ashed in a muffle furnace at 550°C for 8 hours. Approximately 1 g of each bone ash sample was then dissolved in 10 ml of 3M hydrochloric acid and boiled for 10 minutes. The samples were allowed to cool and filtered into a 100ml volumetric flask. Thereafter, the volume was topped to 100 ml with deionised water and analysed for minerals (AOAC, 2012).

3.10 Statistical analysis

Data on feed intake, feed conversion ratio, growth rate, live weight, ME, nitrogen retention, gastro-intestine morphology, shear force, sensory evaluation, carcass characteristics, meat colour and bone morphometrics of Ross 308 broiler chickens were analysed by analysis of variance (ANOVA) using a Statistical Analysis System, Version 9.3.1 software program (SAS, 2008). Where there was a significant difference ($P<0.05$), Fisher's least significant difference (LSD) test was used for mean separation. The model $Y_{ij} = \mu + T_i + e_{ij}$ was applied where Yij = response variables in feed intake, digestibility, feed conversion ratio, growth rate, body weight and body linear measurements; μ = constant; Ti = effect of yellow mealworm meal replacement of soya bean meal at 0, 25, 50, 75 or 100% level; eij = random error.

The responses in optimal small intestine pH, L^* and b^* meat colour changes to yellow mealworm larvae meal replacement level were modelled using the following quadratic equation:

$$Y = a + b_1x + b_2x^2 + e$$

Where Y = optimum, a = intercept; b = coefficients of the quadratic equation; x = yellow mealworm larvae meal replacement level and $-b_1/2b_2$ = x value for optimal response; e = random error. The quadratic equation was preferred because it gave the best fit. The relationship between optimal responses in feed intake, feed conversion ratio, growth rate, live weight, pH, gastro-intestine morphology, metabolisable energy, nitrogen retention, carcass weight, shear force and sensory evaluation and yellow mealworm larvae meal replacement level were modelled using linear regression equation (SAS, 2008) in the form of:

$$Y = a + bx$$

Where Y = growth rate, metabolisable energy, pH, length and weight of digestive organs, carcass and breast weight, a^* meat colour and shear force = intercept, b = coefficient of the linear equation and x = yellow mealworm larvae meal replacement levels.

CHAPTER FOUR

RESULTS

4.1 Effect of replacing soya bean meal with yellow mealworm larvae meal in a diet on production performance and gut morphology of unsexed Ross 308 broiler chickens aged one to 21 days

4.1.1 Effect of replacing soya bean meal with yellow mealworm larvae meal in a diet on production performance of unsexed Ross 308 broiler chickens aged one to 21 days

Results of the effects of replacing soya bean meal with yellow mealworm meal on feed intake, growth rate, feed conversion ratio (FCR), live body weight, metabolisable energy (ME) intake and nitrogen retention (N-retention) of unsexed Ross 308 broiler chickens aged one to 21 days are presented in Table 4.01. Replacing soya bean meal with yellow mealworm meal in the diet had no effect ($p > 0.05$) on feed intake, growth rate, FCR, live body weight, ME intake and nitrogen retention of unsexed Ross 308 broiler chickens. There were no deaths of chickens during this part of the study.

Table 4.01 Effect of replacing soya bean meal with yellow mealworm larvae meal in a diet on DM feed intake (g/bird/day), growth rate (g/bird/day), feed conversion ratio (FCR) (g DM feed/g live weight gain), live weight (g/bird aged 21 days), metabolisable energy (ME) intake (MJ/kg DM) and nitrogen retention (N-retention) (g/bird/day) of unsexed Ross 308 broiler chickens aged one to 21 days

	Diet* #				
Variable	$SB_{100}TM_0$	$SB_{75}TM_{25}$	$SB_{50}TM_{50}$	$SB_{25}TM_{75}$	SB_0TM_{100}
Feed intake	$123^a \pm 7.7$	$130^a \pm 14.6$	$122^a \pm 4.0$	$122^a \pm 4.9$	$114^a \pm 6.5$
Growth rate	$71.0^a \pm 12.82$	$82.7^a \pm 4.16$	$86.1^a \pm 4.10$	$87.2^a \pm 4.61$	$79.5^a \pm 5.42$
FCR	$1.8^a \pm 0.24$	$1.6^a \pm 0.41$	$1.4^a \pm 0.33$	$1.4^a \pm 0.31$	$1.3^a \pm 0.37$
Live weight	$643^a \pm 16.6$	$643^a \pm 16.91$	$630^a \pm 16.81$	$625^a \pm 19.82$	$705^a \pm 75.73$
ME Intake	$11.5^a \pm 0.56$	$11.0^a \pm 0.27$	$11.2^a \pm 0.27$	$10.6^a \pm 0.86$	$11.1^a \pm 0.35$
N-retention	$1.1^a \pm 0.04$	$1.1^a \pm 0.03$	$1.1^a \pm 0.03$	$1.1^a \pm 0.03$	$1.1^a \pm 0.03$

* : Values presented as a mean ± standard error (SE)

a, b, c, : Means in the same row sharing a common superscript are significantly similar ($p > 0.05$)

#	: Diet codes are described in Chapter 3, Table 3.01(The treatments were replacement of soya bean meal in a diet with yellow mealworm larvae meal at 0, 25, 50, 75 or 100%)
N-retention	: Nitrogen retention

4.1.2 Effect of replacing soya bean meal with yellow mealworm larvae meal in a diet on gut morphology of unsexed Ross 308 broiler chickens aged 21 days

Results of the effects of replacing soya bean meal with yellow mealworm meal in the diet on gut organ weight, length and digesta pH values of unsexed Ross 308 broiler chickens aged 21 days are presented in Table 4.02. Replacing soya bean meal in a diet with yellow mealworm meal did not affect ($p > 0.05$) caecum weights of unsexed Ross 308 broiler chickens aged 21 days. However, replacing soya bean meal in a diet with yellow mealworm meal affected ($p < 0.05$) gut intestinal tract (GIT), gizzard, crop, ileum and large intestine weights of Ross broiler chickens aged 21 days. Unsexed Ross 308 broiler chickens on diets having 25% of soya bean meal replaced by yellow mealworm meal had heavier ($p < 0.05$) gut intestinal tracts (GIT) than those on diets having 0 or 25% yellow mealworm meal. Diets containing 75 or 100% yellow mealworm meal produced broiler chickens with heavier ($p < 0.05$) GIT than those on diets having no yellow mealworm meal. Similarly, broiler chickens on diets having 50% yellow mealworm meal had heavier ($p < 0.05$) GIT than those on diets having no yellow mealworm meal. However, broiler chickens on diets having 25, 75 or 100% of soya bean meal replaced by yellow mealworm meal had similar ($p > 0.05$) GIT weights. Similarly, diets having 50, 75 or 100% yellow mealworm meal produced broiler chickens with similar ($p > 0.05$) GIT weights. Ross 308 broiler chickens on diets containing 25% yellow mealworm meal had heavier ($p < 0.05$) crops than those on diets having 0, 50, 75 or 100% yellow mealworm meal. Broiler chickens on diets having 50% yellow mealworm meal had heavier ($p < 0.05$) crops than those on diets containing 0, 75 or 100% yellow mealworm meal. Similarly, diets containing 75 or 100% yellow mealworm meal produced broiler chickens with heavier ($p < 0.05$) crops than those on diets having no yellow mealworm meal. However, unsexed broiler chickens on diets having 75 or 100% yellow mealworm meal had crops with similar ($p > 0.05$) weights. Unsexed broiler chickens on diets having 25, 50, 75 or 100% of soya bean meal replaced by yellow mealworm meal had heavier ($p < 0.05$) ileum, gizzards and large intestines than those on diets having no yellow mealworm meal. However, broiler chickens on diets having 25, 50, 75 or 100% of soya bean meal replaced by yellow mealworm meal had similar ($p > 0.05$) ileum, gizzard and large intestine weights.

Replacing soya bean meal in a diet with yellow mealworm meal did not affect ($p > 0.05$) ileum and crop lengths of unsexed Ross 308 broiler chickens aged 21 days (Table 4.02). However, replacing soya bean meal in a diet with yellow mealworm meal affected ($p < 0.05$) lengths of gizzards, caecum and large intestines of Ross broiler chickens aged 21 days. Unsexed Ross 308 broiler chickens on diets having 25, 50, 75 or 100% of soya bean meal replaced by yellow mealworm meal had longer ($p < 0.05$) gizzards, caecum and large intestines than those on diets having no yellow mealworm meal. However, broiler chickens on diets having 25, 50, 75 or 100% of soya bean meal replaced by yellow mealworm meal had similar ($p > 0.05$) gizzard, caecum and large intestine lengths.

The effects of replacing soya bean meal with yellow mealworm meal in the diet on gut organ digesta pH values of unsexed Ross 308 broiler chickens aged 21 days are presented in Table 4.02. Replacing soya bean meal with yellow mealworm meal in the diet had no effect ($p > 0.05$) on pH values of crop, gizzard, ileum, caecum and large intestine digesta values of unsexed Ross 308 broiler chickens aged 21 days.

Table 4.02 Effect of replacing soya bean meal with yellow mealworm larvae meal in a diet on gut organ weight (g), length (cm) and digesta pH values of unsexed Ross 308 broiler chickens aged 21 days

Variable	Diet* #				
	$SB_{100}TM_{0}$	$SB_{75}TM_{25}$	$SB_{50}TM_{50}$	$SB_{25}TM_{75}$	$SB_{0}TM_{100}$
Gut organ weights					
GIT	$88^{c} \pm 9.7$	$145^{a} \pm 9.7$	$128^{b} \pm 7.0$	$137^{ab} \pm 8.1$	$133^{ab} \pm 10.4$
Crop	$11.6^{d} \pm 0.89$	$23.3^{a} \pm 1.82$	$20.5^{b} \pm 0.90$	$13.6^{c} \pm 1.00$	$15.8^{c} \pm 1.23$
Gizzard	$23.0^{b} \pm 0.64$	$25.5^{a} \pm 1.89$	$24.8^{a} \pm 1.03$	$27.9^{a} \pm 2.55$	$25.0^{a} \pm 1.52$
Ileum	$5.9^{b} \pm 1.02$	$11.7^{a} \pm 4.31$	$12.8^{a} \pm 3.34$	$16.0^{a} \pm 1.70$	$16.3^{a} \pm 0.87$
Caecum	$3.7^{a} \pm 0.74$	$3.8^{a} \pm 0.44$	$3.8^{a} \pm 0.47$	$4.1^{a} \pm 0.46$	$4.1^{a} \pm 0.53$
Large intestines	$3.8^{b} \pm 0.84$	$6.2^{a} \pm 1.93$	$6.1^{a} \pm 2.32$	$7.9^{a} \pm 0.70$	$8.9^{a} \pm 0.78$
Gut organ lengths					
Crop	$5.3^{a} \pm 0.48$	$5.3^{a} \pm 0.86$	$5.3^{a} \pm 0.46$	$5.5^{a} \pm 0.57$	$5.9^{a} \pm 0.52$
Gizzard	$2.7^{b} \pm 0.13$	$3.2^{a} \pm 0.14$	$3.2^{a} \pm 0.14$	$3.3^{a} \pm 0.14$	$3.1^{a} \pm 0.14$
Ileum	$6.2^{a} \pm 0.31$	$6.5^{a} \pm 0.37$	$6.5^{a} \pm 0.32$	$6.3^{a} \pm 0.30$	$6.8^{a} \pm 0.31$
Caecum	$6.0^{b} \pm 0.21$	$6.6^{a} \pm 0.21$	$6.7^{a} \pm 0.22$	$6.7^{a} \pm 0.20$	$6.7^{a} \pm 0.18$
Large intestines	$6.1^{b} \pm 0.15$	$6.7^{a} \pm 0.16$	$6.8^{a} \pm 0.16$	$6.7^{a} \pm 0.16$	$6.6^{a} \pm 0.15$
Gut digesta pH					
Crop	$4.0^{a} \pm 0.48$	$4.0^{a} \pm 0.06$	$4.0^{a} \pm 0.46$	$4.1^{a} \pm 0.57$	$4.1^{a} \pm 0.52$
Gizzard	$2.6^{a} \pm 0.33$	$2.6^{a} \pm 0.34$	$2.8^{a} \pm 0.14$	$2.8^{a} \pm 0.14$	$2.9^{a} \pm 0.04$
Ileum	$6.5^{a} \pm 0.31$	$6.1^{a} \pm 0.30$	$6.5^{a} \pm 0.32$	$6.5^{a} \pm 0.37$	$6.2^{a} \pm 0.31$
Caecum	$6.1^{a} \pm 0.21$	$6.4^{a} \pm 0.21$	$6.4^{a} \pm 0.22$	$6.4^{a} \pm 0.20$	$6.4^{a} \pm 0.20$
Large intestines	$6.6^{a} \pm 0.15$	$6.6^{a} \pm 0.16$	$6.8^{a} \pm 0.16$	$6.7^{a} \pm 0.16$	$6.6^{a} \pm 0.15$

[*] : Values presented as a mean ± standard error (SE)

[a, b, c,] : Means in the same row not sharing a common superscript are significantly different ($p < 0.05$)

[#] : Diet codes are described in Chapter 3, Table 3.03 (The treatments were replacement of soya bean meal in a diet with yellow mealworm larvae meal at 0, 25, 50, 75 or 100%)

4.2 Effect of replacing soya bean meal with yellow mealworm larvae meal in a diet on production performance, gut morphology and carcass characteristics of male Ross 308 broiler chickens aged 22 to 42 days

4.2.1 Effect of replacing soya bean meal with yellow mealworm larvae meal in a diet on production performance male Ross 308 broiler chickens aged 22 to 42 days

Results of the effects of replacing soya bean meal with yellow mealworm meal on feed intake, growth rate, feed conversion ratio (FCR), live body weight, metabolisable energy (ME) intake and nitrogen retention (N-retention) of male Ross 308 broiler chickens aged 22 to 42 days are presented in Table 4.03. Replacing soya bean meal with yellow mealworm meal had no effect ($p > 0.05$) on growth rate, feed conversion ratio (FCR), metabolisable energy (ME) intake and nitrogen retention (N-retention) of male Ross 308 broiler chickens. However, replacing soya bean meal with yellow mealworm meal in the diet had effects ($p < 0.05$) on feed intake and live body weight of male Ross 308 broiler chickens. Replacing soya bean meal in a diet with yellow mealworm meal affected ($p < 0.05$) feed intake of male broiler chickens. Male Ross 308 broiler chickens on diets having 75% of soya bean meal replaced by yellow mealworm meal had higher ($p < 0.05$) feed intake than those on diets having 0 or 25% yellow mealworm meal. Similarly, broiler chickens on diets having 100% of soya bean meal replaced by yellow mealworm meal had better ($p < 0.05$) feed intakes than those on diets having no yellow mealworm meal. However, broiler chickens on diets having 0, 25 or 50% of soya bean meal replaced by yellow mealworm meal had similar ($p > 0.05$) feed intakes. Broiler chickens on diets having 50, 75 or 100% of soya bean meal replaced by yellow mealworm meal had similar ($p > 0.05$) feed intakes. Similarly, broiler chickens on diets having 25, 50 or 100% of soya bean meal replaced by yellow mealworm meal had the some ($p > 0.05$) feed intakes.

Male broiler chickens on diets having 50% of soya bean meal replaced by yellow mealworm meal were heavier ($p < 0.05$) than those on diets having no yellow mealworm meal. Similarly, male broiler chickens on diets having no yellow mealworm meal had better ($p < 0.05$) live body weight than those on diets having 75% of soya bean meal replaced by yellow mealworm meal. However, broiler chickens on diets having 0, 25 or 100% of soya bean meal replaced by yellow mealworm meal had similar ($p > 0.05$) live body weights. Similarly, broiler chickens on diets having 25, 75 or 100% of soya bean meal replaced by yellow mealworm meal had similar ($p > 0.05$) live body weights.

Feed intake and live body weight of male Ross 308 broiler chickens were optimized ($r^2 = 0.761$ and 0.178, respectively) at yellow mealworm larvae meal replacement levels of 13 and 61%, respectively (Table 4.04).

Table 4.03 Effect of replacing soya bean meal with yellow mealworm larvae meal in a diet on DM feed intake (g/bird/day), growth rate (g/bird/day), feed conversion ratio (FCR) (g DM feed/g live weight gain), live body weight (g/bird aged 42 days), metabolisable energy (ME) intake (MJ/kg DM) and nitrogen retention (N-retention) (g/bird/day) of male Ross 308 broiler chickens aged 22 to 42 days

		Diet* #			
Variable	$SB_{100}TM_0$	$SB_{75}TM_{25}$	$SB_{50}TM_{50}$	$SB_{25}TM_{75}$	SB_0TM_{100}
Feed intake	$130^c \pm 3.4$	$133^{bc} \pm 3.3$	$134^{abc} \pm 3.5$	$144^a \pm 3.3$	$139^{ab} \pm 3.3$
Growth rate	$108^a \pm 3.73$	$106^a \pm 3.72$	$112^a \pm 3.39$	$111^a \pm 3.73$	$113^a \pm 3.76$
FCR	$1.2^a \pm 0.09$	$1.3^a \pm 0.08$	$1.3^a \pm 0.09$	$1.3^a \pm 0.09$	$1.2^a \pm 0.08$
Live weight	$2296^b \pm 30.7$	$2228^{bc} \pm 30.9$	$2453^a \pm 32.6$	$2186^c \pm 30.5$	$2233^{bc} \pm 30.6$
ME Intake	$12.1^a \pm 0.26$	$12.0^a \pm 0.26$	$11.9^a \pm 0.45$	$11.6^a \pm 0.75$	$12.6^a \pm 0.26$
N-retention	$1.3^a \pm 0.08$	$1.3^a \pm 0.08$	$1.3^a \pm 0.08$	$1.4^a \pm 0.03$	$1.3^a \pm 0.08$

* : Values presented as a mean ± standard error (SE)

a, b, c : Means in the same row not sharing a common superscript are significantly different ($p < 0.05$)

: Diet codes are described in Chapter 3, Table 3.03 (The treatments were replacement of soya bean meal in a diet with yellow mealworm larvae meal at 0, 25, 50, 75 or 100%)

N-retention : Nitrogen retention

Table 4.04 Yellow mealworm larvae meal replacement levels for optimal feed intake (g/chicken aged 22 to 42 days) and live weight (g/chicken aged 42 days) of male Ross 308 broiler chickens ($Y = a + b_1 + b_2x + e$)

Variable	Formula	X-value	Y-value	r^2
Feed intake	$Y = 140.54 + - 0.03x + - 0.001x^2$	13	140	0.761
Live weight	$Y = 1207.71 + 3.68x + -0.03x^2$	61	1320	0.178

r^2 : coefficient of determination

4.2.2 Effect of replacing soya bean meal with yellow mealworm larvae meal in a diet on gut morphology of male Ross 308 broiler chickens aged 42 days

The effects of replacing soya bean meal with yellow mealworm meal in a diet on gut organ weight, length and digesta pH values of male Ross 308 broiler chickens aged 42 days are presented in Table 4.05. Replacing soya bean meal with yellow mealworm meal in the diet had no effect ($p > 0.05$) on gut organ weight, length and digesta pH values of male Ross 308 broiler chickens aged 42 days.

Table 4.05 Effect of replacing soya bean meal t with yellow mealworm larvae meal on gut organ weight, length and digesta pH values of male Ross 308 broiler chickens aged 42 days

	Diet* #				
Variable	$SB_{100}TM_0$	$SB_{75}TM_{25}$	$SB_{50}TM_{50}$	$SB_{25}TM_{75}$	SB_0TM_{100}
Gut organ weights (g)					
GIT	$217^a \pm 14.2$	$234^a \pm 13.7$	$236^a \pm 17.7$	$227^a \pm 13.6$	$235^a \pm 13.2$
Crop	$21.9^a \pm 1.89$	$22.5^a \pm 2.05$	$22.8^a \pm 1.71$	$23.1^a \pm 1.73$	$23.3^a \pm 2.15$
Gizzard	$41.5^a \pm 1.89$	$42.3^a \pm 1.82$	$42.7^a \pm 2.11$	$43.5^a \pm 1.76$	$40.8^a \pm 1.76$
Ileum	$27.3^a \pm 1.42$	$27.8^a \pm 1.50$	$27.7^a \pm 1.79$	$27.3^a \pm 1.43$	$26.8^a \pm 1.44$
Caecum	$9.4^a \pm 0.65$	$9.8^a \pm 0.65$	$9.0^a \pm 0.67$	$9.7^a \pm 0.64$	$8.6^a \pm 0.65$
Large intestines	$13.1^a \pm 0.94$	$13.8^a \pm 0.98$	$13.3^a \pm 1.11$	$13.8^a \pm 0.97$	$13.0^a \pm 0.94$
Gut organ lengths (cm)					
GIT	$206^a \pm 6.8$	$215^a \pm 6.8$	$219^a \pm 8.1$	$214^a \pm 6.7$	$215^a \pm 6.7$
Duodenum	$15.7^a \pm 0.59$	$15.6^a \pm 0.56$	$15.6^a \pm 0.67$	$15.5^a \pm 0.55$	$15.5^a \pm 0.55$
Ileum	$77.0^a \pm 2.74$	$77.1^a \pm 2.85$	$77.2^a \pm 3.38$	$77.5^a \pm 2.73$	$74.3^a \pm 2.72$
Caecum	$17.3^a \pm 0.75$	$17.2^a \pm 0.75$	$17.0^a \pm 0.84$	$17.2^a \pm 0.73$	$17.1^a \pm 0.73$
Large intestines	$12.5^a \pm 0.55$	$12.2^a \pm 0.56$	$12.0^a \pm 0.58$	$12.0^a \pm 0.53$	$11.5^a \pm 0.65$
Gut digesta pH					
Crop	$4.9^a \pm 0.33$	$5.1^a \pm 0.35$	$5.3^a \pm 0.24$	$4.9^a \pm 0.24$	$5.0^a \pm 0.28$

Gizzard	$3.3^a \pm 0.16$	$3.3^a \pm 0.14$	$3.3^a \pm 0.15$	$3.3^a \pm 0.15$	$3.3^a \pm 0.14$
Ileum	$6.4^a \pm 0.16$	$6.4^a \pm 0.16$	$6.4^a \pm 0.24$	$6.6^a \pm 0.21$	$6.5^a \pm 0.16$
Caecum	$6.4^a \pm 0.19$	$6.4^a \pm 0.19$	$6.5^a \pm 0.19$	$6.4^a \pm 0.19$	$6.4^a \pm 0.15$
Large intestines	$5.9^a \pm 0.19$	$6.1^a \pm 0.19$	$6.2^a \pm 0.12$	$6.2^a \pm 0.18$	$6.0^a \pm 0.19$

[*] : Values presented as a mean ± standard error (SE)

[a, b, c,] : Means in the same row sharing a common superscript are significantly not different ($p > 0.05$)

[#] : Diet codes are described in Chapter 3, Table 3.03 (The treatments were replacement of soya bean meal in a diet with yellow mealworm larvae meal at 0, 25, 50, 75 or 100%)

4.2.3 Effect of replacing soya bean meal with yellow mealworm larvae meal in a diet on carcass parts of male Ross 308 broiler chickens aged 42 days

Replacing soya bean meal with yellow mealworm meal in a diet had no effect ($p > 0.05$) on carcass, breast, drumstick, thigh and wing weights of male Ross 308 broiler chickens aged 42 days (Table 4.06).

Table 4.06 Effect of replacing soya bean meal with yellow mealworm larvae meal in a diet on carcass part weight (g) of male Ross 308 broiler chickens aged 42 days

	Diet*#				
Variable	$SB_{100}TM_0$	$SB_{75}TM_{25}$	$SB_{50}TM_{50}$	$SB_{25}TM_{75}$	SB_0TM_{100}
Carcass	$1068^a \pm 21.8$	$1046^a \pm 60.3$	$1035^a \pm 26.9$	$1081^a \pm 30.9$	$1018^a \pm 33.0$
Breast	$151^a \pm 2.8$	$151^a \pm 3.3$	$150^a \pm 2.8$	$153^a \pm 3.7$	$151^a \pm 2.4$
Drumstick	$128^a \pm 7.2$	$129^a \pm 7.2$	$128^a \pm 6.9$	$128^a \pm 7.2$	$129^a \pm 8.0$
Thigh	$104^a \pm 4.0$	$102^a \pm 2.9$	$104^a \pm 5.0$	$104^a \pm 3.3$	$102^a \pm 4.5$
Wing	$91^a \pm 3.0$	$91^a \pm 3.8$	$91^a \pm 4.9$	$91^a \pm 3.6$	$91.7^a \pm 3.8$

[*] : Values presented as a mean ± standard error (SE)

[a, b, c,] : Means in the same row sharing a common superscript are significantly similar ($p > 0.05$

[#] : Diet codes are described in Chapter 3, Table 3.03 (The treatments were replacement of soya bean meal in a diet with yellow mealworm larvae meal 0, 25, 50, 75 or 100%)

4.2.4 Effect of replacing soya bean meal with yellow mealworm larvae meal in a diet on meat colour of male Ross 308 broiler chickens aged 42 days

Results of the effect of replacing soya bean meal with yellow mealworm larvae meal in a diet on breast, drumstick and thigh meat colours of male Ross 308 broiler chickens aged 22 to 42 days are presented in Table 4.07. Replacing soya bean meal with yellow mealworm meal in a diet did not affect ($p > 0.05$) breast, drumstick and thigh meat colours of male Ross 308 broiler chickens.

Table 4.07 Effect of replacing soya bean meal with yellow mealworm larvae meal in a diet on breast, drumstick and thigh meat colours of male Ross 308 broiler chickens aged 42 days

	Diet* #				
Variable	$SB_{100}TM_0$	$SB_{75}TM_{25}$	$SB_{50}TM_{50}$	$SB_{25}TM_{75}$	SB_0TM_{100}
Breast					
L^*	$48.3^a \pm 1.17$	$48.4^a \pm 1.10$	$48.5^a \pm 1.15$	$48.6^a \pm 1.12$	$48.6^a \pm 1.10$
a^*	$5.2^a \pm 0.11$	$5.3^a \pm 0.09$	$5.3^a \pm 0.11$	$5.3^a \pm 0.09$	$5.3^a \pm 0.09$
b^*	$12.3^a \pm 0.29$	$12.4^a \pm 0.26$	$12.4^a \pm 0.25$	$12.5^a \pm 0.26$	$12.5^a \pm 1.10$
Drumstick					
L^*	$51.2^a \pm 0.93$	$52.8^a \pm 0.91$	$53.3^a \pm 0.96$	$51.3^a \pm 0.93$	$53.8^a \pm 0.92$
a^*	$8.3^a \pm 0.15$	$8.3^a \pm 0.14$	$8.3^a \pm 0.15$	$8.3^a \pm 0.15$	$8.4^a \pm 0.15$
b^*	$8.4^a \pm 0.15$	$8.4^a \pm 0.16$	$8.5^a \pm 0.15$	$8.5^a \pm 0.15$	$8.5^a \pm 0.16$
Thigh					
L^*	$50.5^a \pm 0.78$	$50.6^a \pm 0.75$	$50.6^a \pm 0.86$	$50.6^a \pm 0.73$	$50.6^a \pm 0.73$
a^*	$9.1^a \pm 0.18$	$9.2^a \pm 0.18$	$9.3^a \pm 0.18$	$9.3^a \pm 0.20$	$9.4^a \pm 0.18$
b^*	$12.7^a \pm 0.26$	$12.8^a \pm 0.18$	$12.8^a \pm 0.19$	$12.7^a \pm 0.18$	$12.8^a \pm 0.19$

* : Values presented as a mean ± standard error (SE)

a, b, c, d : Means in the same row sharing a common superscript are significantly similar ($p < 0.05$)

#	: Diet codes are described in Chapter 3, Table 3.03 (The treatments were replacement of soya bean meal in a diet with yellow mealworm larvae meal 0, 25, 50, 75 or 100%)
HunterLAB test	: L^*: lightness; a^*: redness; b^*: yellowness

4.2.5 Effect of replacing soya bean meal with yellow mealworm larvae meal in a diet on meat pH values of male Ross 308 broiler chickens aged 42 days

Results of the effects of replacing soya bean meal with yellow mealworm larvae meal in a diet on meat pH values of male Ross 308 broiler chickens aged 42 days are presented in Table 4.08. Replacing soya bean meal with yellow mealworm meal in the diet had no effect ($p > 0.05$) on pH values of breasts, drumsticks, thighs and wings of male Ross 308 broiler chickens aged 42 days.

Table 4.08 Effect of replacing soya bean meal with yellow mealworm larvae meal in a diet on meat pH values of male Ross 308 broiler chickens aged 42 days

	Diet* #				
Variable	$SB_{100}TM_0$	$SB_{75}TM_{25}$	$SB_{50}TM_{50}$	$SB_{25}TM_{75}$	SB_0TM_{100}
Beast	$5.6^a \pm 0.12$	$5.8^a \pm 0.12$	$5.6^a \pm 0.14$	$5.5^a \pm 0.27$	$5.8^a \pm 0.14$
Drumstick	$6.0^a \pm 0.77$	$6.3^a \pm 0.41$	$6.9^a \pm 0.63$	$6.1^a \pm 0.71$	$6.1^a \pm 0.74$
Thigh	$6.0^a \pm 0.51$	$6.5^a \pm 0.40$	$6.0^a \pm 0.43$	$6.0^a \pm 0.60$	$6.3^a \pm 0.13$
Wing	$6.0^a \pm 0.19$	$6.2^a \pm 0.19$	$6.3^a \pm 0.12$	$6.1^a \pm 0.19$	$6.1^a \pm 0.12$

*	: Values presented as a mean ± standard error (SE)
a, b, c	: Means in the same row sharing a common superscript are not significantly different ($p > 0.05$)
#	: Diet codes are described in Chapter 3, Table 3.03 (The treatments were replacement of soya bean meal in a diet with yellow mealworm larvae meal 0, 25, 50, 75 or 100%)

4.2.6 Effect of replacing soya bean meal with yellow mealworm larvae meal in a diet on sensory and shear force meat values of male Ross 308 broiler chickens aged 42 days

Results of the effects of replacing soya bean meal with yellow mealworm larvae meal on meat flavour, tenderness and juiciness and shear force values of male Ross 308 broiler chickens aged 42 days are presented in Table 4.09. Replacing soya bean meal with yellow mealworm meal in the diet had no effect ($p > 0.05$) on flavour, tenderness and juiciness of male Ross 308 broiler chicken meat. However, replacing soya bean meal with yellow mealworm meal in the diet affected ($p < 0.05$) meat shear force values of male Ross 308 broiler chickens aged 42 days. Male Ross 308 broiler chickens on diets containing 25, 50, 75 or 100% of soya bean meal replaced by yellow mealworm meal had lower ($p < 0.05$) meat shear force values than those on diets having 0% of the soya bean meal replaced by yellow mealworm meal. However, chickens on diets having 25, 50, 75 or 100% of soya bean meal replaced by yellow mealworm meal produced meat with similar ($p > 0.05$) shear force values.

Table 4.09 Effect of replacing soya bean meal with yellow mealworm larvae meal in a diet on flavour, tenderness, juiciness and shear force values of meat of male Ross 308 broiler chickens aged 42 days

	Diet* #				
Variable	$SB_{100}TM_0$	$SB_{75}TM_{25}$	$SB_{50}TM_{50}$	$SB_{25}TM_{75}$	SB_0TM_{100}
Flavour	$4.0^a \pm 0.25$	$4.0^a \pm 0.33$	$4.0^a \pm 0.33$	$4.0^a \pm 0.00$	$4.0^a \pm 0.67$
Tenderness	$3.9^a \pm 0.73$	$3.9^a \pm 0.67$	$3.9^a \pm 0.33$	$3.9^a \pm 0.00$	$3.9^a \pm 0.00$
Juiciness	$3.8^a \pm 0.785$	$3.7^a \pm 0.33$	$3.9^a \pm 0.33$	$3.7^a \pm 0.33$	$3.8^a \pm 0.33$
Shear force	$11.8^a \pm 0.30$	$9.2^b \pm 0.51$	$9.1^b \pm 0.42$	$9.2^b \pm 0.43$	$9.1^b \pm 0.47$

* : Values presented as a mean ± standard error (SE)

a, b, c : Means in the same row not sharing a common superscript are significantly different ($p < 0.05$)

: Diet codes are described in Chapter 3, Table 3.03 (The treatments were replacement of soya bean meal in a diet with yellow mealworm larvae meal 0, 25, 50, 75 or 100%)

4.2.7 Effect of replacing soya bean meal with yellow mealworm larvae meal in a diet on bone morphometric values of male Ross 308 broiler chickens aged 42 days

Results of the effects of replacing soya bean meal with yellow mealworm larvae meal on weight, length and diameter, and ash, calcium and phosphorus contents of right tibia bones of male Ross 308 broiler chickens aged 42 days are presented in Table 4.10. Replacing soya bean meal with yellow mealworm meal in the diet had no effect ($p > 0.05$) on weight, length and diameter, and ash, calcium and phosphorus contents of right tibia bones of male Ross 308 broiler chickens.

Table 4.10 Effect of replacing soya bean meal with yellow mealworm larvae meal in a diet on weight, length and diameter values, and ash, calcium and phosphorus contents of right tibia bones of male Ross 308 broiler chickens aged 42 days

	Diet*				
Variable	$SB_{100}TM_0$	$SB_{75}TM_{25}$	$SB_{50}TM_{50}$	$SB_{25}TM_{75}$	SB_0TM_{100}
Weight (g)	$8.4^a \pm 0.38$	$8.9^a \pm 0.12$	$8.9^a \pm 1.21$	$7.8^a \pm 1.00$	$5.9^a \pm 2.90$
Length (cm)	$9.0^a \pm 0.32$	$8.9^a \pm 0.52$	$9.0^a \pm 0.29$	$9.0^a \pm 0.30$	$8.1^a \pm 0.73$
Diameter (cm)	$5.9^a \pm 0.24$	$5.4^a \pm 0.43$	$5.9^a \pm 0.44$	$5.6^a \pm 0.57$	$5.7^a \pm 0.62$
Ash (%)	$40^a \pm 1.7$	$43^a \pm 1.7$	$43^a \pm 1.7$	$42^a \pm 1.7$	$41^a \pm 1.7$
Ca (mg/L)	$2474^a \pm 35.3$	$2486^a \pm 30.9$	$2503^a \pm 23.4$	$2510^a \pm 23.4$	$2533^a \pm 24.1$
P (mg/L)	$526^a \pm 7.1$	$530^a \pm 7.3$	$526^a \pm 7.2$	$529^a \pm 7.2$	$534^a \pm 7.3$

* : Values presented as a mean ± standard error (SE)

a, b, c : Means in the same row sharing a common superscript are significantly similar ($p > 0.05$)

\# : Diet codes are described in Chapter 3, Table 3.03 (The treatments were replacement of soya bean meal in a diet with yellow mealworm larvae meal 0, 25, 50, 75 or 100%)

CHAPTER 5

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 DISCUSSION

5.1.1 Effect of replacing soya bean meal with yellow mealworm larvae meal in a diet on production performance and gut morphology of unsexed Ross 308 broiler chickens aged one to 21 days

5.1.1.1 Effect of replacing soya bean meal with yellow mealworm larvae meal in a diet on production performance of unsexed Ross 308 broiler chickens aged one to 21 days

In the present study, nutrient contents of the diets containing different replacement levels of soya bean meal with yellow mealworm meal were similar. The starter diets were formulated to have 21.5% crude protein and 16.5 MJ of energy per kg DM. The diets met the nutrient requirements for broiler chickens as specified by McDonald *et al*. (2010) and ARC (1994). However, traces of chitin were found in the diets where soya bean meal was replaced by yellow mealworm meal at 25, 50, 75 or 100%. Yellow mealworm meal contained 3.56% chitin. The low levels of chitin found in the yellow mealworm meal in the present study are similar to those reported by Kaijage *et al*. (2014) on the same mealworm line. Chitin tends to reduce digestibility of diets (Kaijage *et al*., 2014). Thus, it was possible to test the hypothesis that soya bean meal in the diet can be replaced with yellow mealworm meal without having any adverse effects on the performance of Ross 308 broiler chickens. Replacing soya bean meal with yellow mealworm meal in the diets had no effect on feed intake, growth rate, FCR, live body weight, metabolisable energy intake and nitrogen retention of unsexed Ross 308 broiler chickens, possibly indicating that soya bean meal can be replaced by yellow mealworm larvae meal in a starter diet for broiler chickens without causing any adverse effects on the production of chickens. This may, also, be indicating that the chitin contents in the diets were very low to adversely affect diet intake, growth rate, FCR, live body weight, metabolisable energy intake and nitrogen retention of unsexed Ross 308 broiler chickens, This is similar to the observation made by De Marco *et al*. (2015) and Kovitvadhi *et al.* (2019) that yellow mealworm larvae meal with low chitin content can replace soya bean meal in the diets of broiler chickens without adversely affecting diet intake, growth rate, FCR, N-retention and live body weight. Similar observations were made by Bovera *et al*. (2015) and Cullere *et al*. (2016). However, the present findings are contrary to the results of Hussain *et al.* (2017) who observed that replacing soya bean meal with yellow mealworm meal reduced nitrogen retention and diet intake by broiler chickens aged one to 21 days. The authors indicated that reduced nitrogen retention and diet intakes were due to adverse effects of high amounts of chitin found in yellow mealworm meals used. Dutta *et al*. (2012) observed that yellow mealworm meal with high chitin contents resulted in reduced energy, protein and specific amino acid utilization which resulted in poor FCR and growth rates of broiler chickens. Similarly, Bovera *et al*. (2016) and Onsongo *et al*. (2018) observed that replacing soya bean meal with mealworm meal reduced ME intake by broiler chickens. The authors indicated that high chitin levels in mealworm meal used tended to reduce diet digestibility and this adversely affected diet ME intake. Chitin binds with nutrients, thus rendering them unavailable for digestion (Ballito and Sun, 2013). However, Khempaka *et al*. (2011) observed that replacing soya bean meal with yellow mealworm meal increased growth rates and live weights of chickens aged one to 21 days. The authors indicated that increased growth rates and live body weights were due to increased feed intakes.

It is concluded that soya bean meal in the diets of broiler chickens aged one to 21 days can be replaced by yellow mealworm meal at 25, 50, 75 and 100% levels without having adverse effects on production parameters of the chickens.

5.1.1.2 Effect of replacing soya bean meal with yellow mealworm larvae meal in a diet on gut morphology of unsexed Ross 308 broiler chickens aged 21 days

Replacing soya bean meal with yellow mealworm meal in a diet did not affect caecum weights of unsexed Ross 308 broiler chickens aged 21 days, possibly indicating that chitin content in the diet was too low to adversely affect diet digestibility and hence caecum weights of the chickens (Biasato *et al*., 2017). These results are similar to those of Zadeh *et al*. (2019), Biasato *et al*. (2017) and Dutta *et al*. (2012) who observed no effect of increased yellow mealworm meal in the diet on caecum weight. This is, also, similar to the observation made by Schiavone *et al.* (2014) that yellow mealworm meal can replace soya bean meal in the diets without causing any negative effect on gut organ weights. However, in the present study, replacing soya bean meal with yellow mealworm meal in a diet increased GIT, crop, ileum and large intestine weights of unsexed Ross 308 broiler chickens aged 21 days. Simunek *et al*. (2005) also observed increases in small intestine weights of broiler chickens with increases in yellow mealworm meal replacement levels. Similarly, De Marce *et al*. (2015) and Biasato *et al.* (2017) observed increases in large intestine weights with increases in yellow mealworm meal replacement levels. Dutta *et al.* (2012) reported significantly higher gizzard and crop weights in broiler chickens fed yellow mealworm-based diets. The authors attributed this to the high chitin contents in the diets which required heavier gizzards and crops for increased grinding power.

Results of the present study showed that replacing soya bean meal with yellow mealworm meal in a diet did not affect crop and ileum lengths of Ross 308 broiler chickens aged one to 21 days. This is similar to the observations made by Zadeh *et al*. (2019) that yellow mealworm meal can replace soya bean meal in diets without adversely affecting crop and ileum lengths of broiler chickens. Similarly, Biasato *et al.* (2017) observed no effects of replacing soya bean meal with yellow mealworm meal in the diet on gut organ lengths of broiler chickens. Khatun *et al*. (2003) observed that yellow mealworm meals having low or high chitin had no influence on caecum and crop lengths of broiler chickens. Loponte et al. (2016) and Selaledi *et al*. (2019) reported that yellow mealworm meal with low chitin contents can replace soya bean meal in diets without adversely affecting duodenum, jejunum and large intestine lengths. However, results of the present study are contrary to those of Sapcota *et al*. (2003) and Dutta *et al*. (2012) who reported decreased intestinal lengths of broiler chickens fed dried black solder fly rich in chitin. The authors reported that chitin in dried black solder fly might have inhibited gut growth in broiler chickens. Results of the present study indicate that replacing soya bean meal with yellow mealworm meal in a diet increased gizzard, caecum and large intestine lengths of unsexed broiler chickens, possibly indicating longer times the digesta stayed in the gut (Khatun *et al*., 2003). The present findings are contrary to the results of Biasato *et al*. (2017, 2018) who observed decreased large intestine lengths of broiler chicks fed house fly which contained chitin. Simunek *et al*. (2005), also, found no effect of yellow mealworm meal on caecum lengths of broiler chickens.

Replacing soya bean meal with yellow mealworm meal in the diet had no effect on pH values of crop, gizzard, ileum, caecum and large intestine digesta of unsexed Ross 308 broiler chickens aged 21 days, indicating that soya bean meal can be replaced by yellow mealworm meal in a starter diet for broiler chickens without causing any adverse effects on gut organ digesta pH values. This may, also, be indicating that the chitin in the yellow mealworm meal were low to adversely affect broiler chicken gut organ digesta pH values. However, Khatun *et al*. (2003) and Ijaiya and Eko (2009) found that replacing soya bean meal with yellow mealworm meal reduced caecum and large intestine pH values of broiler chickens. The authors indicated that reduced pH values in caecum and large intestines were due to dietary chitin which adversely affected changes in intestinal morphology, enzyme activities, gut microflora and nutrient digestibility. Schiavone *et al*. (2014) also observed increased duodenum digesta pH when broiler chickens were fed diets having soya bean meal replaced by yellow mealworm meal. The authors indicated that the increase in pH values was because of the decrease in lactic acid production due to the ability of chitin to bind with proteins and other nutrients which resulted in more digestion of fibrous materials that tended to favour high pH values (Loponte *et al*., 2017; Veldkamp *et al*., 2012). This results in more cellulolytic bacteria that digest crude fibre (Bovera *et al.,* 2015). However, Awoniyi *et al*. (2003) and Sapcota *et al*. (2003) observed that yellow mealworm meal in the diets reduced crop, gizzard and small intestine digesta pH values of unsexed broiler chickens aged 21 days.

5.1.2 Effect of replacing soya bean meal with yellow mealworm larvae meal in a diet on performance and carcass characteristics of male Ross 308 broiler chickens aged 22 to 42 days

5.1.2.1 Effect of replacing soya bean meal with yellow mealworm larvae meal in a diet on production performance of male Ross 308 broiler chickens aged 22 to 42 days

The grower diets were formulated to contain 20% crude protein and 17.5 MJ of energy per kg DM. The diets met the nutrient requirements for broiler chickens aged 22 to 42 days old as specified by McDonald *et al*. (2010) and ARC (1994). The yellow mealworm meal used in this experiment was the same as that used in the starter experiment and described earlier under Chapter 5.1.1.1. The different replacement levels of soya bean meal with yellow mealworm meal in this study did not affect growth, FCR, ME intake and nitrogen retention of male Ross 308 broiler chickens aged 22 to 42 days, possibly indicating that soya bean meal can be replaced by yellow mealworm meal in the diets for broiler chickens aged 22 to 42 days without having any adverse effects on production parameters. This may, also, be indicating that chitin contents in the diets were too low to adversely affect growth, FCR, ME intake and nitrogen retention of male Ross 308 broiler chickens aged 22 to 42 days. This is similar to the findings of Bovera *et al*. (2015) and Borin *et al*. (2006) that yellow mealworm with low chitin content can replace soya bean meal in the diets of broiler chickens without adversely affecting growth, FCR, ME intake and nitrogen retention of the chickens. Similarly, results of Bahadori *et al.* (2017) showed that inclusion of low chitin mealworm meal diets had no effect on growth rates of broiler chickens aged 22 to 42 days. However, the present findings are contrary to the observations made by Zadeh *et al*. (2019), Khan *et al*. (2017), Jintasataporn (2012) and Khatun *et al*. (2003) that broiler chickens fed yellow mealworm meal had lower growth rates, poor FCR, lower ME intakes and lower nitrogen retention. Zadeh *et al.* (2019) indicated that chitin contained in yellow mealworm binds with proteins in the gut, resulting in reduced nitrogen retention. Bovera *et al*. (2016) indicated that reduced ME intake, growth rate and FCR of broiler chickens on yellow mealworm diets might be due to poor nutrient digestibility as a result of high levels of chitin which binds with other nutrients, making such nutrients indigestible. Loponte *et al*. (2017) and Biasato *et al*. (2017) observed that diets containing high mealworm meal tend to reduce growth rates and ME intakes of broiler chickens. The authors indicated that chitin found in yellow mealworm meal reduced nutrient availability which resulted in reduced growth rates and ME intakes by broiler chickens.

Replacing soya bean meal with yellow mealworm meal in a diet affected feed intake and live body weight of male Ross 308 broiler chickens aged 22 to 42 days. Male Ross 308 broiler chickens on diets having 75 or 100% of soya bean meal replaced by yellow mealworm meal had higher feed intake than those on diets containing no yellow mealworm meal; while male broiler chickens on diets having 50% of soya bean meal replaced by yellow mealworm meal were heavier than those on diets containing no yellow mealworm meal. This might be because low chitin contents in the diets did not adversely affect nutrient availability in the gut (Biasato *et* al., 2018). It is, also, possible that low levels of chitin in a diet may have some beneficial effects on feed intake and live body weight of chickens (Zadeh *et al*., 2019).

It is concluded that soya bean meal in the diets can be replaced by yellow mealworm meal at 25, 50, 75 and 100% levels without causing adverse effects on diet intake, live body weight, growth rate, FCR, nitrogen retention and ME intake of male Ross 308 broiler chickens aged 22 to 42 days, possibly indicating that soya bean meal can be safely replaced by yellow mealworm meal in the diets for broiler chickens.

5.1.2.2 Effect of replacing soya bean meal with yellow mealworm larvae meal in a diet on gut morphology of male Ross 308 broiler chickens aged 42 days

In the present study, replacing soya bean meal with yellow mealworm meal did not affect gastro-intestinal tract, gizzard, ileum, caecum and large intestine weights of male Ross 308 broiler chickens aged 42 days. These results are similar to those of Dutta *et al*. (2012), Zadeh *et al*. (2019) and Biasato *et al*. (2017) who observed no effect of increasing yellow mealworm meal in the diet on ileum, caecum and large intestine weights. However, the present findings are contrary to the results of Simunek *et al*. (2005) who observed increases in small intestine weights of broiler chickens aged 42 days with increases in yellow mealworm meal replacement levels. Similarly, De Marce *et al*. (2015) and Biasato *et al.* (2017) observed increases in large intestine weights with increases in yellow mealworm meal replacement levels. The present findings are contrary to the results of Dutta *et al.* (2012) who reported significantly higher gizzard and crop weights in broiler chickens fed yellow mealworm-based diets. The authors attributed this to the fact that diets high in chitin tend to result in heavier gizzards and crops for increased grinding power.

Replacing soya bean meal with yellow mealworm meal did not affect gastro-intestinal tract (GIT), duodenum, gizzard, ileum, caecum and large intestine lengths of male Ross 308 broiler chickens aged 42 days, possibly indicating that soya bean meal can be replaced by yellow mealworm meal in a grower diet for broiler chickens without any effects on gut organ lengths of Ross 308 broiler chickens aged 42 days. This may be indicating that chitin levels in yellow mealworm meal were too low to adversely affect lengths of these gut organs of broiler chickens. Simunek *et al*. (2005), also, found no effect of yellow mealworm meal on caecum lengths of broiler chickens. Loponte *et al*. (2016) and Selaledi *et al*. (2019) reported that yellow mealworm meal with low chitin contents can replace soya bean meal in diets without adversely affecting duodenum, jejunum and large intestine lengths. Similarly, Biasato *et al.* (2017) observed no effects of replacing soya bean meal with yellow mealworm meal on gut organ lengths of broiler chickens.

Current results indicate that replacing soya bean meal with yellow mealworm meal did not affect crop, gizzard, ileum, caecum and large intestine digesta pH values of male Ross 308 broiler chickens aged 42 days, possibly indicating that soya bean meal can be replaced by yellow mealworm meal in a grower diet for broiler chickens without any adverse effects on gut organ digesta pH values. This is contrary to the observation made by Selaledi *et al*. (2019) that high crop and small intestine digesta pH values were recorded in broiler chickens fed diets high in yellow mealworm meal. The authors attributed this to the effect of chitin binding with proteins and other nutrients, resulting in decreased lactic acid production which favoured high pH values and hence cellulolytic digestion. However, Choi *et al*. (2018) found acidic conditions in gizzards of chickens fed maggot meal which contained high amounts of chitin and phytochemicals.

5.1.2.3 Effect of replacing soya bean meal with yellow mealworm larvae meal in a diet on carcass parts of male Ross 308 broiler chickens aged 42 days

Results of the present study showed that replacing soya bean meal with yellow mealworm meal did not affect carcass, breast, drumstick, thigh and wing weights of

Ross 308 broiler chickens aged 42 days, possibly meaning that yellow mealworm meal levels used can replace soya bean meal in the diets without any adverse effects on carcass part weights of broiler chickens aged 22 to 42 days. The present results are similar to those of Sapcota *et al.* (2003) and Dutta *et al.* (2012) who found that carcass and breast yields of broiler chickens were not affected by different levels of yellow mealworm meal in the diets. However, the present results are contrary to the observation made by Ballitoc and Sun (2010) who found that replacement of soya bean meal with yellow mealworm meal resulted in smaller broiler chicken drumstick and thigh weights. The authors attributed the decline in weight to adverse effects of chitin in yellow mealworm on diet digestibility, absorption and utilization by broiler chickens.

5.1.2.4 Effect of replacing soya bean meal with yellow mealworm larvae meal in a diet on meat colour of male Ross 308 broiler chickens aged 42 days

The present study showed that replacing soya bean meal with yellow mealworm meal in a diet did not affect breast, drumstick and thigh meat colours of male Ross 308 broiler chickens aged 42 days. This means that yellow mealworm meal can replace soya bean meal in a diet without causing any adverse effects on the colour of breast, drumstick and thigh meat. However, Dutta *et al*. (2012) observed increased redness colour value of broiler chickens when yellow mealworm inclusion rate in the diets increased. Similarly, Souza *et al*. (2015) found a linear increase in the yellowness values of the meat from broiler chickens on yellow mealworm-containing diets. The authors did not suggest any reason for the increase in meat yellowness values with increase in yellow mealworm meal in the diets.

5.1.2.5 Effect of replacing soya bean meal with yellow mealworm larvae meal in a diet on meat pH values of male Ross 308 broiler chickens aged 42 days

Replacing soya bean meal with yellow mealworm meal in the diet had no effect on pH values of breast, drumstick, thigh and wing meat of male Ross 308 broiler chickens aged 42 days. This is similar to the results of Garcia *et al.* (2013) who observed that breast and thigh meat pH values of Ross 308 broiler chickens were not affected by the substitution of soya bean meal with yellow mealworm meal in the diet. Fletcher *et al*. (2000) indicated that pH values of normal chicken breast and thigh meat range between 5.7 and 6.20. The pH values obtained in the present study are within the normal values as indicated by Fletcher *et al*. (2000). Thus, yellow mealworm meal can replace soya bean meal in the diets without any effect on broiler chicken meat pH values.

5.1.2.6 Effect of replacing soya bean meal with yellow mealworm larvae meal in a diet on sensory and shear force meat values of male Ross 308 broiler chickens aged 42 days

Results of the present study showed that replacing soya bean meal with yellow mealworm meal did not affect male Ross 308 broiler chicken meat flavour, tenderness and juiciness. This is similar to the results of Dutta *et al.* (2012) who observed no differences in aroma, tenderness and flavour of guinea fowls fed diets having soya bean meal replaced by yellow mealworm meal. However, replacing soya bean meal with yellow mealworm meal in the diet affected meat shear force values of male Ross 308 broiler chickens aged 42 days. Meat from male Ross 308 broiler chickens on diets having yellow mealworm meal was softer than the meat from chickens on diets having 100% soya bean meal. No similar studies on chickens were found.

5.1.2.7 Effect of replacing soya bean meal with yellow mealworm larvae meal in a diet on bone morphometric values of male Ross 308 broiler chickens aged 42 days

Current results show that replacing soya bean meal with yellow mealworm meal in a diet did not affect weight, length and diameter, and ash, calcium and phosphorus contents of right tibia bones of male Ross 308 broiler chickens aged 42 days. However, yellow mealworm is known to contain anti-nutritional factors such as chitin which tend to reduce digestibility, absorption and utilisation of minerals in poultry (Dutta *et al*., 2012). The current results are consistent with the results of Sapcota *et al.* (2003) who did not find any significant differences in bone lengths and widths of broiler chickens fed yellow mealworm, fish or insect-based diets. However, Sapcota *et al.* (2003) found a decrease in tibia Ca and P contents in chickens fed diets containing yellow mealworm compared to those fed fish or insect-based diets. The authors attributed the decrease in tibia Ca and P contents to adverse effects of chitin in yellow mealworm meal on mineral digestion, absorption and utilisation by broiler chickens. The present results are contrary to those of Bovera *et al.* (2016) who reported that tibia lengths in broiler chickens fed yellow mealworm-based diets increased with increase in yellow mealworm inclusion levels. Ballitoc and Sun (2010) also reported a decrease of bone ash in broiler chickens fed diets containing yellow mealworm meal. The authors indicated that a decline in bone ash was associated with increases in yellow mealworm meal in the diets, and this was attributed to the adverse effects of chitin on mineral digestion, absorption and utilization by broiler chickens. The decrease in mineral digestion, absorption and utilization adversely affected bone growth and development.

5.2 Conclusions and recommendations

At each phase, the dietary treatments had similar nutrient content levels and these met the nutrient requirements of broiler chickens. Thus, any differences in responses must have been due to yellow mealworm meal that replaced soya bean meal in the diets. Replacement of soya bean meal with yellow mealworm meal in a diet had no effect on feed intake, growth rate, FCR, live body weight, ME intake and nitrogen retention of unsexed Ross 308 broiler chickens aged one to 21 days, possibly indicating that soya bean meal can be replaced by yellow mealworm meal in a diet without causing any adverse effect on production parameters of unsexed Ross 308 broiler chickens aged one to 21 days. Replacing soya bean meal with yellow mealworm meal in a diet did not affect caecum weight of unsexed Ross 308 broiler chickens aged 21 days. However, replacing soya bean meal with yellow mealworm meal in a diet increased GIT, crop, ileum and large intestine weights, possibly because high chitin contents in the diets required heavier gizzards, crops, ileum and large intestines for increased grinding power. Crop and ileum lengths of unsexed Ross 308 broiler chickens aged 21 days were not affected by replacement of soya bean meal with yellow mealworm meal in the diet. However, replacing soya bean meal with yellow mealworm meal in a diet increased gizzard, caecum and large intestine lengths of unsexed Ross 308 broiler chickens aged 21 days, possibly because longer organs were required for the digestion of hard to digest chitin in yellow mealworm. Replacing soya bean meal with yellow mealworm meal in a diet did not affect gut organ digesta pH values of unsexed Ross 308 broiler chickens aged 21 days. It is concluded that soya bean meal in the diets of broiler chickens aged one to 21 days can be replaced by yellow mealworm meal at 25, 50, 75 and 100% levels without having any adverse effects on production and gut morphology of the chickens.

Replacement of soya bean meal with yellow mealworm meal in a diet did not affect growth rate, FCR, ME intake and nitrogen retention of male Ross 308 broiler chickens aged 22 to 42 days, possibly indicating that soya bean meal can be replaced by yellow mealworm meal in a diet without causing any adverse effect on these production parameters of male Ross 308 broiler chickens aged 22 to 42 days. However, replacing soya bean meal with yellow mealworm meal in a diet affected feed intake and live body weight of male Ross 308 broiler chickens aged 22 to 42 days. Broiler chickens on diets containing 75 or 100% yellow mealworm meal had higher intakes than those on diets containing no yellow mealworm meal. Similarly, male broiler chickens on diets having 50% yellow mealworm meal had higher live body weights than those on diets containing no yellow mealworm. Quadratic equations indicated that feed intake and live body weight of male Ross 308 broiler chickens were optimized at yellow mealworm meal replacement levels of 13 and 61%, respectively. It can be concluded that soya bean meal in the diets of broiler chickens aged 22 to 21 days can be replaced by yellow mealworm meal at 25, 50, 75 and 100% levels with some beneficial effects on feed intakes and live body weights of the chickens. Further studies are recommended to determine why replacement of soya bean meal with yellow mealworm meal did not have effect on growth, FCR, ME intake and nitrogen retention but it improved feed intake and live body weights of male Ross 308 broiler chickens aged 22 to 42 days.

The present study showed that replacing soya bean meal with yellow mealworm meal in a diet did not affect gut organ digesta pH values, gut organ weights, gut organ lengths, meat colour, meat pH values, bone morphometric values, carcass part weights and meat sensory attributes of male Ross 308 broiler chickens aged 42 days.

This may indicate that soya bean meal can be replaced by yellow mealworm meal in diets of male Ross 308 broiler chickens without any adverse effects on the above production parameters. In a very beneficial way, meat from male Ross 308 broiler chickens on diets containing yellow mealworm meal was softer than the meat from chickens on diets having 100% soya bean meal. Further studies are recommended to determine what is in yellow mealworm meal that causes broiler chicken meat to be softer than that from chickens on soya bean meal.

It is concluded that soya bean meal can be replaced with yellow mealworm larvae meal in the diet without having adverse effects on production and carcass characteristics of Ross 308 broiler chickens aged one to 42 days. However, age of the chicken defined some responses to replacement of soya bean meal with yellow mealworm meal. Further studies are recommended to determine why age of the chicken defines responses to replacing soya bean meal with yellow mealworm meal in broiler chicken diets.

CHAPTER 6

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