EFFECTS OF REPLACING MAIZE MEAL WITH A LOW TANNIN WHITE SORGHUM MEAL, MACIA ON PRODUCTIVITY 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………………………….. Date……………………………………

Ms Tlou Grace Manyelo

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DEDICATIONS

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ABSTRACT

Two experiments were conducted to determine the effect of replacing maize meal with a low tannin sorghum meal (Macia) 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 160 Ross 308 broiler chickens were assigned to a complete randomized design with 5 treatments, replicated 4 times with 8 chickens per replicate. Five diets were formulated to contain sorghum replacement levels at 0, 25, 50, 75 and 100% to meet the nutrient requirements of Ross 308 broiler chickens. Data was analysed using statistical analysis of variance.

The first experiment determined the effect of replacing maize meal with a low tannin white sorghum meal on productivity and gut morphology of unsexed Ross 308 broiler chickens aged 1 to 21 days. Feed intake, growth rate, feed conversion ratio, live weight, N-retention, caecum and large intestine digesta pH, large intestine lengths, crop, gizzard, caecum and large intestine weights, gut intestinal villi height, crypt depth and villi height to crypt depth ratio of unsexed Ross 308 broiler chickens were not affected (P>0.05) by the treatment effects. However, replacement of maize meal with sorghum meal improved (P<0.05) metabolisable energy intake and small intestine digesta pH values. It was concluded that maize meal can be replaced by a low tannin white sorghum meal in the diet without adverse effects on unsexed Ross 308 broiler chickens aged one to 21 days.

The second experiment determined the effect of replacing maize meal with sorghum meal on productivity, gut morphology, carcass characteristics and bone morphometrics of Ross 308 male broiler chickens aged 22 to 42 days. Replacing maize meal with sorghum meal had no effect (P>0.05) on feed intake, feed conversion ratio (FCR), live weight and nitrogen retention (N-retention) of male Ross 308 broiler chickens aged 22 to 42 days. Replacing maize meal with sorghum meal improved (P<0.05) ME intake and growth rate of the chickens. Caecum and large intestine digesta pH, GIT, caecum and large intestine lengths, small intestine, caecum and large intestine weights, gut intestinal villi height, crypt depth and villi height to crypt depth ratio, drumstick, thigh and wing weights, drumstick, thigh and wing colour, meat sensory evaluation, meat pH and bone morphometrics of male Ross 308 broiler chickens were not affected (P>0.05) by replacement of maize meal with sorghum meal. It was concluded that maize meal can be replaced by a low tannin white sorghum meal at 25, 50, 75 and 100% levels without causing adverse effects on productivity and carcass characteristics of male broiler chickens aged 22 to 42 days.

Key words: Low tannin sorghum meal, Maize meal, Broiler chickens, Growth rate, Carcass characteristics.

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LIST OF ABBREVIATIONS

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.
Cr_2O3	Chromium oxide.
DM	Dry matter.
DMI	Dry matter intake.
DMD	Dry matter digestibility
EE	Ether extract.
FAO	Food and Agricultural Organisation.
FCR	Feed conversion ratio.
g	Gram.
GE	Gross Energy.
GIT	Gastro-intestinal tract.
GLM	General Linear Model.
H	Hour.
kg	Kilograms.
LATS	Limpopo Agro-food Technology Station
LSD	Least significant difference.
ME	Metabolisable energy.
mm	Millimetres.
min	Minutes.
N	Nitrogen.
NDF	Neutral detergent fibre.
NRC	National Research Council.
^0C	Degree centigrade.
P	Phosphorus.
r^2	Coefficient of determination

SAS	Statistical Analysis System.
SEM	Standard error of the means.
WBSF	Warner-Bratzler Shear Force

CHAPTER ONE

INTRODUCTION

1.1 Background

Feed costs constitute about 70% of the total costs for producing broiler chickens (Esonu *et al.,* 2006; Sharif *et al.,* 2012). Maize meal constitutes about 50 to 60% of the diets for broiler chickens (Ajaja *et al*., 2002). Maize meal which forms the major energy source for poultry in South Africa is becoming scarce and expensive because of the decline in its production due to unfavorable climatic conditions (Kwari *et al*., 2011). However, there is, also, high demand for maize meal for human consumption (Magala *et al.,* 2012). High competition for maize meal between human beings and livestock requires an alternative feed source that can be used in livestock diets. Sorghum meal is such a possible replacement (Medugu *et al.,* 2010). Parthasarathy *et al*. (2005) and Issa *et al*. (2007) reported that sorghum meal could play an important role in poultry feeds in parts of Africa. Similarly, Dowling *et al*. (2002) and Travis *et al*. (2006) have shown that sorghum could be a suitable feedstuff in the poultry industry. Provided one influences against the adverse effects of tannins found in the majority of sorghum varieties. Sorghum is a relatively drought resistant crop compared to maize (Ejeta and Knoll, 2007). It is ranked the fifth most important cereal after wheat, rice, maize and barley and its world production is 59 million tons per year (GrainSA, 2016). Sorghum meal is nutritionally comparable to maize meal but it has tannins which adversely affect chicken productivity if included in the diet (Ravindran *et al*., 2006). Nutrient composition of sorghum indicates that it is a good source of energy, proteins, carbohydrates, vitamins and minerals including the trace elements, particularly iron and zinc (Dicko *et al.*, 2006). Development of sorghum lines with low tannin contents has been going on. Such a line has been developed by the International Crops Research Institute for the Semi-Arid Tropics but it has not yet been extensively tested in chicken diets (ICRISAT, 2000).

1.2 Problem statement

Maize meal constitutes about 50 to 60% of the diets for broiler chickens (Ravindran *et al.,* 2006). However, there is also high demand for maize meal for human consumption (Mohammed *et al.,* 2013). Thus, it is important to find maize meal replacements in chicken feeds. Sorghum meal is such a possible replacement (Medugu *et al.,* 2010). However, sorghum meal contains tannins which adversely affect broiler chicken productivity (Kwari, *et al.,* 2011). Sorghum varieties with low tannin levels have been developed, for example, Macia in South Africa. Thus, there is need to test the effects of these varieties on productivity of broiler chickens.

1.3 Motivation

This study will generate information on the utilization of a low tannin white sorghum meal, Macia, by broiler chickens. Data on such information will help in formulating feeding strategies that enhance productivity of broiler chickens. Optimization of productivity of broiler chickens may improve the economic, nutritional and cultural status of broiler chicken farmers.

1.4 Aim

The aim of the study was to determine the effects of replacing maize meal with a low tannin sorghum meal on performance, gut morphology and productivity of Ross 308 broiler chickens.

1.5 Objectives

The objectives of the study were to determine:

i. the effects of replacing maize meal with a low tannin white sorghum meal, Macia, on feed intake, metabolisable energy intake, nitrogen retention, feed conversion ratio, growth rate, live weight and gut morphology of unsexed Ross 308 broiler chickens aged one to 21 days

ii. the effects of replacing maize meal with a low tannin white sorghum meal, Macia, on feed intake, metabolisable energy intake, nitrogen retention, feed conversion ratio, growth rate, live weight, gut morphology and carcass characteristics of male Ross 308 broiler chickens aged 22 to 42 days

iii. the relationship between replacing maize meal with a low tannin white sorghum meal, Macia, and feed intake, metabolisable energy intake, nitrogen retention, feed conversion ratio, growth rate, live weight and gut morphology of Ross 308 broiler chickens aged one to 42 days

1.6 Hypotheses

The hypotheses of the study were:

i. replacing maize meal with a low tannin white sorghum meal, Macia, has no effect on feed intake, metabolisable energy intake, nitrogen retention, feed conversion ratio, growth rate, live weight, gut morphology of unsexed Ross 308 broiler chickens aged one to 21 days
ii. replacing maize meal with a low tannin white sorghum meal, Macia, has no effect on feed intake, metabolisable energy intake, nitrogen retention, feed conversion ratio, growth rate, live weight, gut morphology and carcass characteristics of male Ross 308 broiler chickens aged 22 to 42 days

iii. the is no relationship between maize meal replacement with a low tannin white sorghum meal, Macia, and feed intake, metabolisable energy intake, nitrogen retention, feed conversion ratio, growth rate, live weight and gut morphology of Ross 308 broiler chickens aged one to 42 days

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Sorghum (*Sorghum bicolor*) is known as a drought resistant cereal that is produced worldwide. It is ranked as the fifth most important cereal crop after wheat, rice, maize, and barley (Bryden *et al.,* 2009). In other parts of Africa, sorghum is the second most important cereal grain after millet and just before maize (Taylor, 2003; Sedghi *et al*., 2011). Additionally, sorghum is the primary alternative feedstuff for maize because it is cheaper and accessible in most parts of Africa (Medugu *et al.,* 2010). However, one major limitation to the use of sorghum in poultry feeds is the presence of tannin contents which tend to have negative effects on broiler chickens (Monge *et al.,* 2007; Sannamani *et al.,* 2010). Chemically, there are two classes of tannins, and these are the hydrolysable and condensed tannins. The hydrolysable tannins break down into sugars and a phenolic acid when treated with acid, alkali or some hydrolytic enzymes while condensed tannins are formed biosynthetically by the condensation of single catechin units (Lorenz *et al.,* 2013). Condensed tannins are also referred to as proanthocyanidins because when treated with mineral acids, anthocyanidins are released (Gu *et al.,* 2004). Sorghums with more than 1% condensed tannins are regarded as high levels of tannins in poultry nutrition (Parthasarathy *et al*., 2005). The inclusion of sorghum grain high in condensed tannins in poultry feeds has been shown to have negative effects on live performance of broiler chickens (Oduhu and Baker, 2005). These negative effects include reduced body weight gain and feed efficiency (Monge *et al.,* 2007). There is some evidence that low tannin sorghum has no adverse effect on broiler productivity (Kwari *et al.,* 2011; Mohammed *et al*., 2013). However, such information is limited and contradictory. Thus, it is important to determine inclusion levels of low tannin sorghum for optimal productivity of broiler chickens.

2.2 Structure of maize and sorghum caryopsis

The maize and sorghum caryopsis is composed of three distinct parts, namely, outer layer (pericarp), storage tissue (endosperm) and germ (Figures 2.01 and 2.02, respectively).

Pericarp

The pericarp constitutes 4.3 to 8.7% of the sorghum caryopsis (Waniska and Rooney, 2000). It is subdivided into three tissues: epicarp, mesocarp and endocarp. The epicarp is covered with a thin layer of wax and is usually pigmented (Earp *et al.,* 2004a). The sorghum mesocarp contains starch granules. The tube cells, which are part of the pericarp, conduct water during germination while the cross-cells form a layer that impedes moisture loss (Waniska and Rooney, 2000). The pericarp contains approximately 5 to 8% of the grain protein. Some sorghum cultivars have pigmented sub-coat (testa) located between the pericarp and the endosperm (Earp *et al.,* 2004b) (Figure 2). The pigmented testa contains tannins (proanthocyanidins) (Waniska and Rooney, 2000).

Endosperm

The endosperm is the largest part of the seed. It constitutes 82 to 87% of the sorghum grain (Waniska and Rooney 2000). Maize endosperm ranges between 82-84%. It is composed of aleurone layer, peripheral and floury and corneous areas (Figure 2). According to Watson (2003), large amount of proteins (protein bodies and enzymes), ash (phytin bodies), and oil (spherosomes) are contained by the aleurone layer cells. The peripheral region has several layers of dense cells containing more protein bodies and smaller starch granules than the corneous area (Awika *et al.,* 2002). Taylor *et al.* (2006) in a review of the composition of the sorghum endosperm cells reported that starch granules, protein matrix, protein bodies and the cell walls are predominated by water insoluble glucuronoarabinoxylans (GAX) in the floury and corneous endosperm cells. The endosperm contains approximately 81% of sorghum protein (Waniska and Rooney, 2000).

Germ

The germ of maize and sorghum is known to be the living part of the grain. It consists of two main parts: embryonic axis and scutellum. The embryonic axis contains the new plant (Evers and Millar, 2002). According to Evers and Millar (2002), the radicle forms the primary roots while the plumule forms the shoot during germination and development. The scutellum is the cotyledon and it has reserve nutrients such as oil bodies, protein bodies and only few starch granules, which makes it to have high concentration of lipid (Waniska and Rooney, 2000). The germ contains approximately 15% of the protein in sorghum. It is rich in water-soluble proteins (albumins) and globulins (soluble in dilute salt solution) which are rich in lysine and other essential amino acids (Taylor and Dewar, 2001).

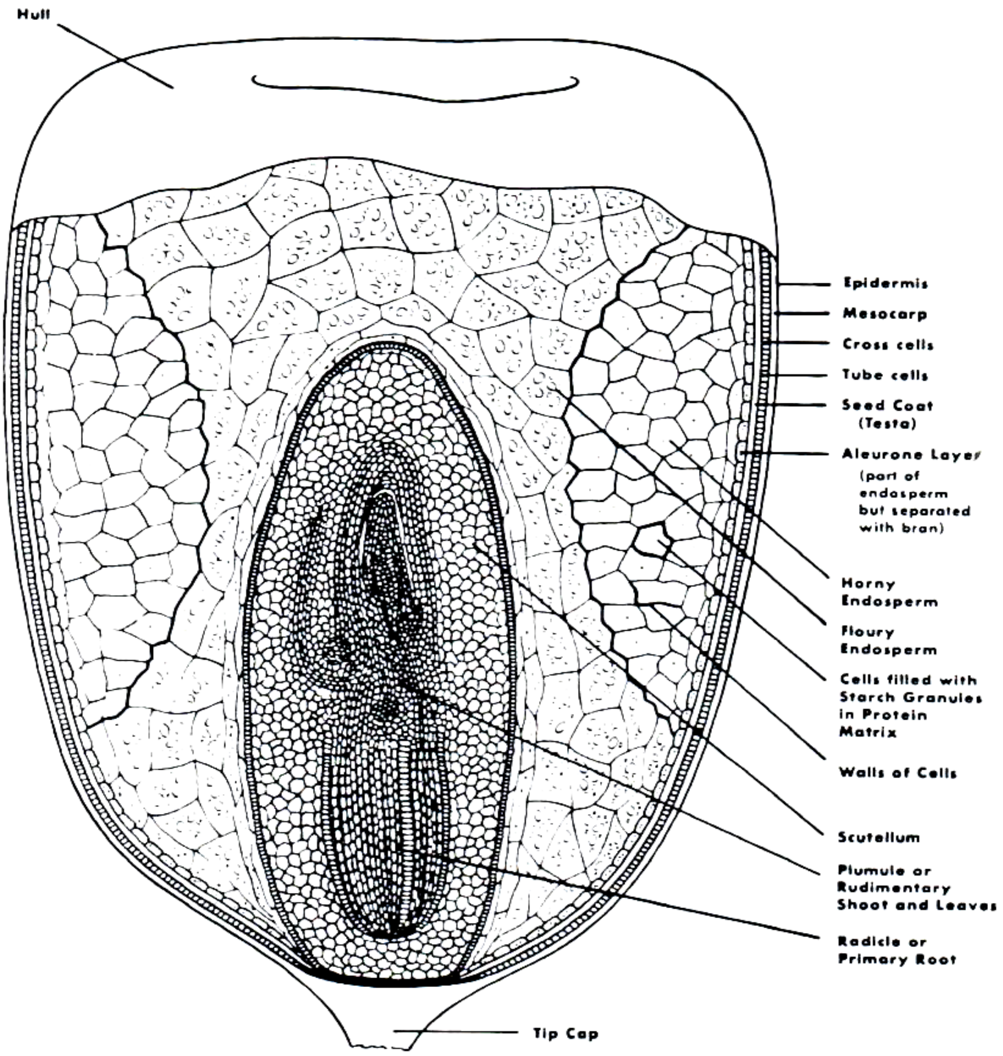


Figure 2.01 The structure of maize seed showing the pericarp, endosperm (aleurone layer, corneous and floury), and germ. Source: Waniska and Rooney (2000)

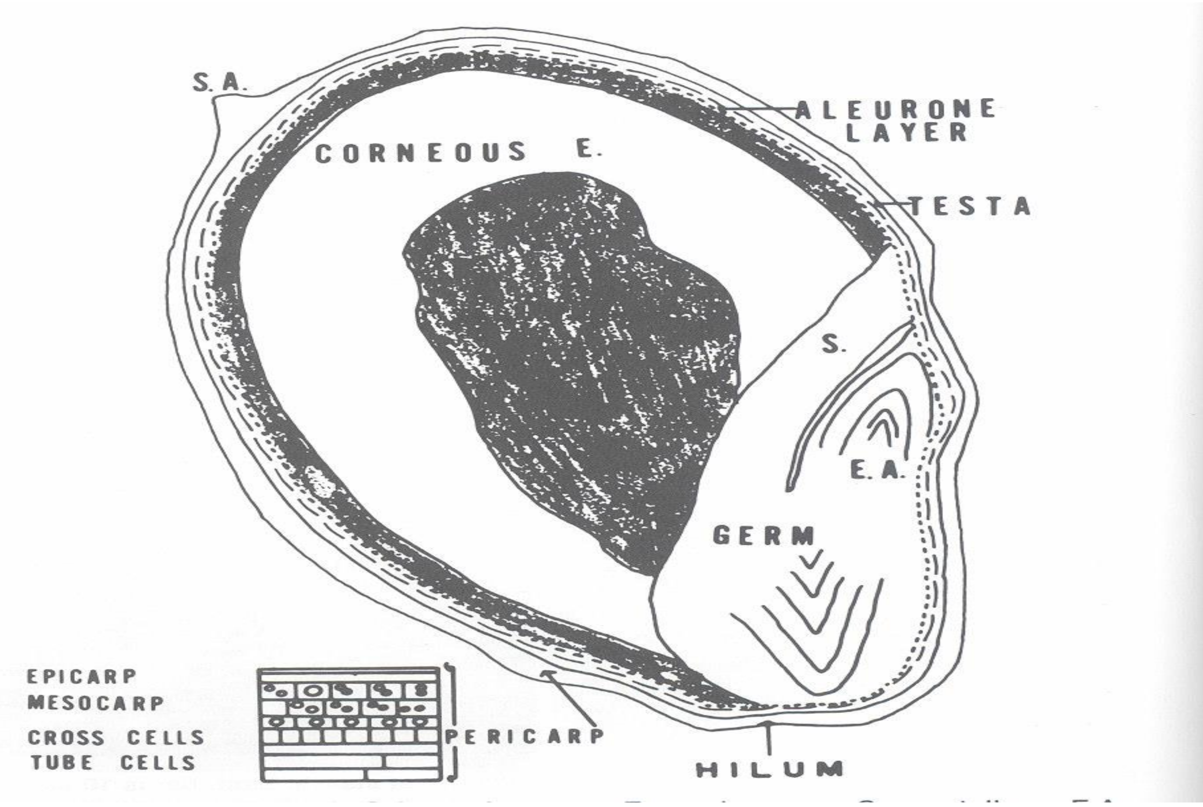


Figure 2.02 The structure of sorghum seed showing the pericarp, endosperm (aleurone layer, corneous and floury), and germ. Source: Evers and Millar (2002)

2.3 Nutritional value and chemical composition of maize and sorghum

Maize is a major source of energy in poultry diets. Although it is produced throughout the world, there is high competition for maize among human beings, livestock and the industry (Mabelebele *et al.,* 2015). Maize is high in energy as compared to other cereal grains and has multiple uses. Maize production requires higher moisture and hence, its use in drier areas such as most parts of Africa may be limited in the future (Travis *et al*., 2006). In comparison to maize, sorghum is drought tolerant and can be grown successfully on relatively poor soils with lower moisture condition (Hadebe *et al.,* 2017). According to Nyamambi *et al.* (2007) the metabolisable energy and percentage crude protein content of sorghum are 3270 kcal /kg and 9.5%, respectively, which is comparable with 3319 kcal/kg metabolisable energy and 10.1% crude protein content of maize. Additionally, the percentage ash and fibre of sorghum are higher than those of maize. It has been documented that sorghum is relatively similar in cost with maize as compared to other cereal such as wheat (Dicko *et al.*, 2006). The whole sorghum grain consists of about 12% protein, 75% starch, 4% fat and 4% minerals (Rajashekher *et al.,* 2003). However, recommendations on the use of sorghum grain in broiler production are complicated due to the presence of condensed tannins.

Table 2.01 Comparison analyses of yellow maize and low tannin sorghum (DM basis)

Nutrient	Maize	Sorghum	Authors
Energy (kcal/kg)	3319	3270	Nyamambi *et al. (*2007)
Crude protein (%)	11.7	13.03	Mohammed *et al. (*2013)
	9.18	-	Hatungima *et al.* (2015)
	-	10.40	Tamburawa *et al.* (2012)
Crude fibre (%)	5.3	3.59	Mohammed *et al*. (2013)
	1.03	-	Hatungima *et al.* (2015)
	-	2.50	Tamburawa *et al.* (2012)
Ether extract (%)	4.2	2.94	Mohammed *et al* (2013)
	4.9	-	Hatungima *et al.* (2015)
	-	3.40	Tamburawa *et al.* (2012)
Dry matter (%)	94.0	94.3	Mohammed *et al. (*2013)
	89.9	-	Hatungima *et al.* (2015)
	-	93.31	Submarian and metta (2010)
Ash (%)	2.2	1.52	Mohammed *et al.* (2013)
	-	6.94	Hatungima *et al.* (2015)
	-	3.80	Tamburawa *et al.* (2012)
NFE (%)	74.14	73.86	Amal *et al.* (2015)
	-	75.80	Tamburawa *et al.* (2012)
	70.60	73.22	Ahmed *et al.* (2013)
Fat (%)	-	35.8	Donkoh and Attoh-Kotoku (2009)
	4.2	2.94	Ahmed *et al.* (2013)
Tannins (%)	ND	1.1	Ochanda *et al.* (2010)
	ND	0.38	Donkoh and Attoh-Kotoku (2009)
	ND	1.54	Medugu *et al.* (2010)

ND - Not Detected

2.4 Effect of sorghum on productivity of chickens

Sorghum grain is an interesting energy ingredient in poultry diets due to its nutritional composition, which is very similar to maize (Rocha *et al.,* 2008). However, studies on the use of sorghum in broiler diets have yielded contradictory results. According to Robertson and Perez-Maldonado (2006), Hassan *et al. (*2003) and Kim and Miller (2005), dietary inclusion of sorghum was associated with low feed conversion efficiency in broilers. In contrast, other studies have shown no responses in chickens fed diets having inclusion of low tannin sorghum meal (Thomas and Ravindran 2008; Garcia *et al.*, 2005; Rocha *et al.* 2008). The responses of broiler chickens at different ages to sorghum inclusion levels are summarized in Table 2. It has been shown that sorghum can be included in broiler chicks aged 1 to 7 days without any adverse effect on their performance (Thomas and Ravindran, 2008). Sanaa *et al.* (2014) recommended an inclusion level of sorghum of up to 50% without any enzyme supplementation in order to achieve optimum weight gain, feed intake and feed conversion ratio (FCR) in broiler chickens aged 1 to 21 days. A major limitation on the use of sorghum in poultry feeds is the presence of tannins which are known to decrease performance of poultry (Medugu *et al.,* 2010). The use of wood ash to treat high tannin sorghum for poultry feeding has shown to improve feed intake, weight gain and FCR of broiler chickens aged 1 to 21 days with 50% of sorghum inclusion (Kyarisiima *et al.* 2004). It has been suggested that sorghum inclusion levels of up to 75% can be used in feed formulation of broiler chickens as energy source to achieve optimal feed intake and FCR (Ibe and Makinde, 2014). According Mohammed *et al*. (2013) to Sorghum grain can be used successfully in combination with yellow maize in broiler ration sup to 50% inclusion level for improved weight gain and FCR. However, Kwari *et al.* (2011) suggested 100% sorghum inclusion level in broiler ration. According to the author, this will minimize the competition between human beings and livestock for maize use. Empirical data on the use of sorghum in place of maize is limited and contradictory in the literature.

Table 2.02 Optimum feed intake, growth rate and feed conversion ratio of broiler chickens at different ages fed 100% sorghum inclusion level

Age	Feed intake (g/chicken)	Weight gain (g/chicken)	FCR	Authors
1-7 days	151	131	1.16	Thomas and Ravindran (2008)
1-14 days	553	442	1.32	Thomas and Ravindran (2008)
1-21 days	2715	710.8	2.05	Sana *et al.* (2014)
1-21days	527	230	2.23	Kyarisiima *et al. (*2004)
21-42 days	4148	1572	1.751	Sana *et al*. (2014)
21-42 days	3734	-	1.80	Mohammed *et al.* (2013)
42-56 days	79.54	38.66	2.06	Ibe and Makinde (2014)
56-63 days	43.21	20.30	2.39	Kwari *et al.* (2011)

2.5 Effect of sorghum on gut morphology of chickens

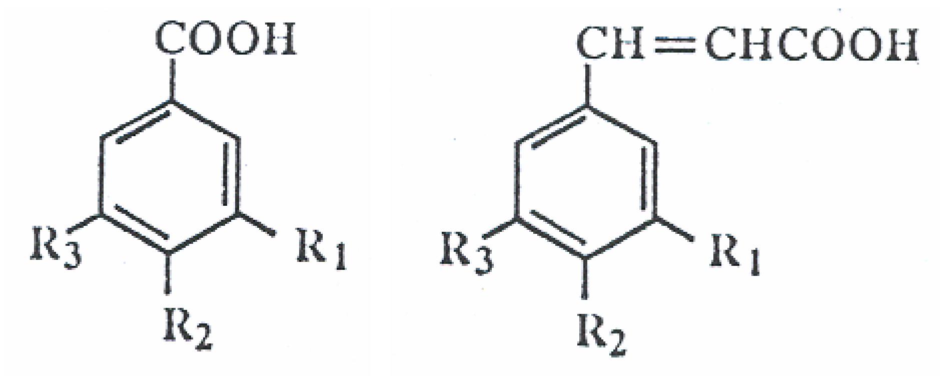
At hatch, the immature digestive tract is physiologically active and primed for the activities of food assimilation (Uni *et al.,* 2003a). Delayed access to feed after hatch creates an abnormal physiological situation and leads to the negative consequences of lack of enteral nutrition (Geyra *et al.,* 2001). Nutrient supply immediately after hatch is a critical factor for gut development in chicks (Noy *et al.,* 2001). Tannins are found in many poultry feedstuffs such as sorghum, millet, barley and faba beans. Tanniniferous diets when given to chicks form soluble or insoluble and sometimes irreversible complexes with proteins, digestive enzymes and possibly starch in the digestive tract of chickens (Thomas and Ravindran, 2008). Tannins present in sorghum may bind and precipitate at least 12 times of their molecular weight of protein (Medugu *et al.,* 2010). Tannins can increase the size of the parotid glands and damage the mucosal lining of the gastro-intestinal tract of chickens (Ibe and Makinde, 2014). Chickens are known to be intolerant of feedstuffs rich in tannins because of very few taste buds in their mouth (Uni *et al.,* 2003). Adverse effects of tannins on palatability, consumption, feed efficiency, growth rate and digestibility of nutrients such as proteins, carbohydrates, lipids and minerals have been reported (Makkar, 2003; Hassan *et al*., 2003; Kim and Miller, 2005). Mabelebele *et al.* (2015) reported that chicks fed diets containing tannins had poor apparent digestibility of amino acids, probably because of an increased excretion of inactivated enzymes and glycoproteins of the gastrointestinal mucosa. There are some indications on the negative influence of tannins in the salivary and intestinal muco-proteins and bile acids. Reports on the effect of these anti-nutrients on poultry are limited and inconclusive (Mansoori and Acamovic, 2000).

2.6 Phenolic compounds in sorghum

Sorghum contains phenolic compounds which may be divided into three categories, phenolic acids, flavonoids and tannins (Waniska, 2000). The term phenolic compound embraces a wide range of plant substances that possess an aromatic ring, bearing one or more hydroxyl substituents (Dlamini *et al.,* 2007). Free phenols are generally rare in plants, and a few that have been reported include catechol, orcinol, phloroglucinol and pyrogallol. These phenols are known to be undesirable in food because they are carcinogenic, hepatotoxic and goitrogenic (Dicko *et al.,* 2006).

Phenolic acids

Phenolic acids are derivatives of benzoic or cinnamic acids derivatives to form hydroxybenzoic and hydroxycinnamic acids, respectively (Dykes and Rooney, 2006) (Figure 2.03). Hydroxybenzoic acids include gallic, *p*-hydroxybenzoic, vanillic, syringic and protocatechuic acids. Hydroxycinnamic acids include coumaric, caffeic, ferulic and sinapic acids. According to Awika and Rooney (2004), phenolic acids exist either in a bound or free form. In the bound form, they are mostly associated with cell walls. Ferulic acid is the most abundant bound phenolic acid in sorghum (Dykes and Rooney, 2006). Free phenolic acids are located in the pericarp, testa and aleurone layers of the kernel. Cinnamic acid is only found in the free form (Hahn *et al.,* 2004). Chromatographic analysis has shown that tannin sorghum has the highest amount of free phenolic acids and white sorghum without a pigmented testa contains the lowest amount of phenolic acids (Dicko *et al.,* 2006). In white sorghum varieties with low levels of flavonoids, bound phenolic acids, are a major source of antioxidant activity and a strong correlation has been found between antioxidant activity and bound ferulic acid in wheat, maize, rice and oats (Adom and Liu, 2002). The composition of phenolic acids and ratio of bound to free phenolic acids is influenced by cultivar differences (Awika and Rooney, 2004).



A **B**

Figure 2.03 Phenolic acids in sorghum. Source: Awika and Rooney (2004)

Flavonoids

Flavonoids form the largest group of phenols in the plant kingdom. The flavonoid compounds consist of two distinct units, a C6-C3 fragment from cinnamic acid which forms the B-ring, and a C-6 fragment from malonyl-Co-A which forms the A-ring (Figure 2.04). Classes of flavonoids include flavanols, flavones, flavonones and anthocyanins. Their structure has a characteristic C6-C3-C6 carbon skeleton (Kong *et al.,* 2003). This feature increases their stability at high pH compared to other common anthocyanins. The two most common 3-deoxyanthocyanidins are apigeninidin and luteolinidin, which confer yellow and red colours, respectively. Other 3-deoxyanthocyanidins reported in sorghum include apigeninidin-5-glucoside, luteolinindin-5-glucoside, 5-methoxy-luteolinidin and 5-methoxyapigeninidin among others (Dykes and Rooney, 2006). Luteolinidin and apigeninidin represent 36 to 50% of total anthocyanin content in black and tannin sorghums and 19% apigeninidin in red sorghums (Awika *et al.,* 2004). Other flavonoids reported in red sorghums are flavan-4-ols such as luteoforol and apiforol. Flavones such as apigenin and luteolin have also been isolated and identified in sorghum and are predominant in tan plant sorghums (Awika *et al.,* 2004).

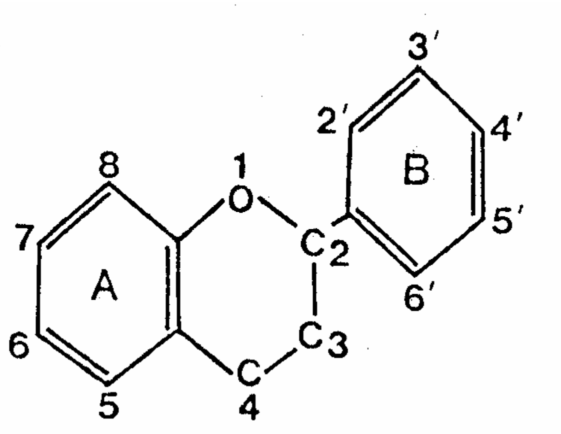


Figure 2.04 Basic flavonoid ring structure. Source: Awika and Rooney (2004)

Tannins

Tannins are water-soluble phenolic metabolites of plants with high molecular weights ranging from 500 to 20.000 daltons with the ability to precipitate gelatine and other proteins from aqueous solution (Dykes *et al.,* 2005). Tannins are a very complex group of plant secondary metabolites, which are soluble in polar solution and are distinguished from other polyphenolic compounds by their ability to precipitate proteins (Silanikove *et al*., 2001). There are two types of soluble tannins present in a large number of plant species. These are the hydrolysable tannins (HTs) and condensed tannins (CTs). Hydrolysable tannins are characterized by a central carbohydrate core with a number of phenolic carboxylic acids bound by ester linkages and they have been no detection of them in sorghum (Awika and Rooney, 2004). Condensed tannins have no carbohydrate core, but rather they are derived from the condensation of flavonoid precursors without participation of enzymes. Condensed tannins are more widely distributed in higher plant species than the hydrolysable variety and are thought to be more active in precipitating proteins (Dykes *et al.,* 2005).

Hydrolysable tannins

Hydrolysable tannins are esters of a sugar, usually glucose and a phenolic acid such as gallic acid in gallotannins (Hartzfeld *et al.,* 2002). The simpler of the two types, hydrolyze into gallic acid, while ellagitannins hydrolyze into ellagic acid. However, ellagitannins are grouped with gallotannins in most literature. They are simply gallotannins that have groups of galloyls that have been oxidatively coupled with the ellagitannin (Hagerman, 2010). These are known to be toxic to ruminants and because of their toxicity, they have received limited attention in animal nutrition studies (Hartzfeld *et al.,* 2002). Recent studies have shown that even where they are not toxic, hydrolysable tannins may have significant effect on animal nutrition because they have inhibitory effect on various enzymes (Yoshida *et al*., 2000). The amount and type of tannins synthesized by plants vary considerably depending on plant species, stage of development and environmental condition (Cornell, 2005).

Condensed tannins

Condensed tannins are naturally occurring compounds found in a number of different plants, including some pasture species (Idso and Idso, 2002). They are made up of groups of polyhydroxyflavan-3 oligomers and polymers linked by carbon-carbon bonds between flavanol subunits (da Silva *et al.,* 2014) (Figure 2.05). The condensed tannins in sorghum are mainly proanthocyanidins (Gu *et al.,* 2004). Proanthocyanidins in poultry may interfere with intake and digestion of the feed in which they occur (Dube *et al*., 2001). Other studies have showed that condensed tannins tend to reduce feed intake (Bryden *et al*., 2009), metabolisable energy (Bryden *et al*., 2009; Perez-Maldonado and Rodrigues, 2007; Sannamani *et al*., 2010; Sedghi *et al*., 2011) and amino acid digestibility (Selle *et al*., 2010; Ebadi *et al*., 2011) in poultry. However, condensed tannins may be beneficial to ruminant production. Makkar (2003) indicated that the nutritional benefit of condensed tannins in ruminant's diet is because of an increased ruminal protein levels, resulting in improved conditions for microbial growth and multiplication. According to Brown *et al.* (2017) increased microbial population results in higher digestibility and intake of the diet. According to Frutos *et al.* (2004) condensed tannins complex with soluble proteins in the rumen and permit subsequent absorption of amino acids in the lower digestive tract thereby facilitating ruminal escape protein utilization. Hervás *et al.* (2000) indicated an improved performance attributable to the condensed tannins in diets fed to sheep. However, the knowledge of these secondary metabolites in poultry nutrition is limited. Understanding of the biological effects of condensed tannins in sorghum and devising feeding strategies that enhance the positive effects is essential for improving productivity of broiler chickens.

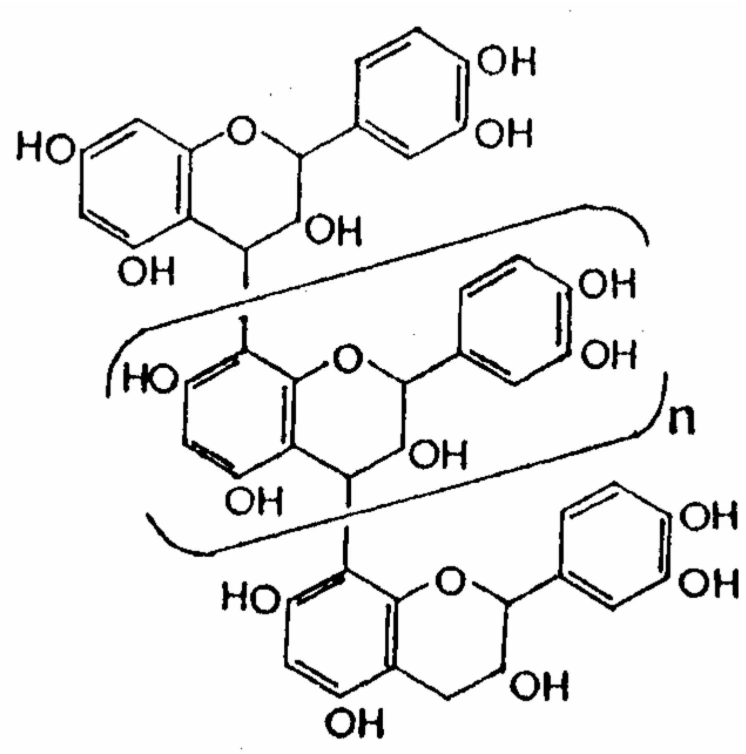


Figure 2.05 Structure of condensed tannin in sorghum. Source: Awika *et al.* (2003b)

2.7 Improving nutritive value of sorghum 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 metabolisim of absorbed nutrients and the quantity of nutrients ingested by the animal (Adesogen *et al.,* 2006). Feeds of high nutritive value promote high levels of production. Improving the nutritive value of tanniniferous sorghum will promote high levels of production. Sorghum tannins can be processed by using chemical and mechanical methods as well as enzyme and mineral supplementation (Amal *et al.,* 2015). However, during the last two decades, processing sorghum grain by grinding has been popular. Grinding grains before mixing into diets is one of the mechanical method known to improve feed homogeneity, increase surface area for enzymatic degradation, and reduce selective feeding (Behnke and Beyer, 2002). Water treatment of sorghum grain is also a famous indigenous method of treating sorghum tannins and improving its nutritional value. This has resulted in a significant reduction in tannin content. Akinmutimi *et al.* (2000) also observed a significant reduction in tannin contents when sorghum grain was treated with water and urea. According to Torki and Farahmand-Pour (2007) and Sharif *et al.* *(*2012), tannin content in water treated sorghum was reduced from 39 to 6 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 tannin sorghum (Ibe and Makinde, 2014; Kyarisiima *et al.,* 2004). Beta *et al.* (2000) used 0.4% sodium hydroxide to reduce tannin concentration in high-tannin sorghum and the results showed to be more effective, while Banda-Nyirenda and Vohra (1990) suggested putting high-tannin sorghum in sodium bicarbonate at 25 ºC for 2 days. This tends to reduce tannin level in grains. Kyarissima *et al.* (2004) reported a 62% tannin reduction with the wood ash method; however, sprouting after wood ash treatment improved tannin reduction to 85%.

Other ways of detoxifying the adverse effects of tannins in sorghum grains include using heat treatment (cooking, roasting etc.), urea treatment, enzyme treatment, and using tannin chelating agents such as polyethylene glycol (Torki and Farahmand-Pour, 2007; Ravindran *et al.,* 2006). Polyethylene glycol has been shown to bind with tannins and hence rendering them inactive to the animals (Jones and Mangan, 2007). However, much of this work has been done in ruminants and not in chickens.

2.8 Conclusion

Sorghum meal plays an important role in chicken diets as the alternative and accessible source of energy as compared to maize in poultry feeds. Information on the inclusion levels of low tannin sorghum on performance and carcass characteristics of broiler chickens is not extensive and inconclusive. It is, therefore, important to determine the effect of replacing maize meal of sorghum 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 Animal unit (latitude 27.55°S and 24.77°E). The ambient temperatures around the study area range between 20°C and 36°C during summer and between -5°C and 28°C during winter (Shiringani, 2007).

3.2 Preparation of the house

The experimental house was cleaned properly with water and a disinfectant (Jeyes fluid). The house was left for 7 days after cleaning to break the life cycle of any disease-causing organisms that were not killed by the disinfectant. After proper drying, the house was divided into 20 floor pens. Fresh saw dust was placed on the floor to a level of 7cm. 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. Commercial yellow maize and white low tannin Macia sorghum grains were acquired from ARC-Small Grain Institute, Potchefstroom. House hold disinfectant, 250 watts infrared lights, feeders and drinkers were acquired from NTK, Polokwane, South Africa.

3.4 Experimental procedures, dietary treatments and design

This study consisted of two experiments.

Experiment 1

One hundred and sixty day-old unsexed Ross 308 broiler chicks were used in the first experiment. 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 41.8 ± 6g. Thereafter, the chicks were weighed weekly until they were 21 days old. Feed intake was measured every day. Chicks were assigned to 5 different treatments (Table 3.01) in a complete randomized design, with 4 replicates and 8 chicks in each replicate. The experimental chicks were fed a formulated starter diet (Table 3.02). Chicks were allowed to feed and drink water *ad libitum*. Light was provided for 24 hours per day throughout the experiment and deaths were observed everyday throughout the study.

Table 3.01 Dietary treatments for Experiment 1

Diet code	Diet description
$SM_{100}S_{0}$	Unsexed Ross 308 broiler chickens aged 1 to 21 days fed a starter diet having 100% maize meal.
$SM_{75}S_{25}$	Unsexed Ross 308 broiler chickens aged 1 to 21 days fed a starter diet having 25% maize meal replaced by a low tannin sorghum meal.
$SM_{50}S_{50}$	Unsexed Ross 308 broiler chickens aged 1 to 21 days fed a starter diet having 100% maize meal replaced by a low tannin sorghum meal.
$SM_{25}S_{75}$	Unsexed Ross 308 broiler chickens aged 1 to 21 days fed a starter diet having 75% of maize meal replaced by a low tannin sorghum meal.
$SM_{0}S_{100}$	Unsexed Ross 308 broiler chickens aged 1 to 21 days fed a starter diet having 100% maize meal replaced by a low tannin sorghum meal.

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

Feed Ingredient	Treatment				
	$SM_{100}S_0$	$SM_{75}S_{25}$	$SM_{50}S_{50}$	$SM_{25}S_{75}$	SM_0S_{100}
Yellow maize (%)	57.92	45	26.49	12.26	0.00
Sorghum (%)	0.00	10.49	30	45	57.92
Soyabean (%)	33.92	36.68	35.55	34.67	33.92
Oil- Sunflower (%)	4.50	4.29	4.37	4.44	4.50
Limestone (%)	1.09	1.09	1.09	1.09	1.09
Dicalphosphate (%)	1.69	1.64	1.66	1.68	1.69
Salt (%)	0.33	0.33	0.33	0.33	0.33
Sodium bicarbonate (%)	0.001	0.001	0.001	0.001	0.001
Vitamins+ minerals Premix (%)	0.2	0.2	0.2	0.2	0.2
DL methionine (%)	0.16	0.15	0.16	0.16	0.16
L lysine (%)	0.18	0.12	0.15	0.16	0.18
Total	100	100	100	100	100
Analysed nutrient composition					
Crude Protein (%)	21.5	21.5	21.5	21.5	21.5
Energy (MJ/kg DM)	16.5	16.5.	16.5	16.5	16.5
Lysine (%)	1.15	1.15	1.15	1.08	1.15
Methionine (%)	0.47	0.47	0.47	0.47	0.53
Threonine (%)	0.66	0.68	0.67	0.66	0.89
ADF (%)	9.86	8.38	9.09	13.84	16.65
NDF (%)	24.39	24.75	24.89	26.31	29.15
Fat (%)	3.58	3.94	4.01	4.34	5.19
Ash (%)	5.72	5.75	6.54	5.97	6.62
Ca (%)	0.56	0.60	0.69	0.76	0.81
Condensed tannins[#]	ND	0.03	0.06	0.09	0.12
Total phenols[##]	ND	ND	ND	ND	0.01

#: Condensed tannins as percentage DM leucocyanidin equivalent; ##: Expressed as tannic acid equivalent (%); ND: Not detected

Experiment 2

In the second part of the study, one hundred and twenty male Ross 308 broiler chickens aged 22 days were used. The chickens were weighed and the initial mean live weight was 522 ± 5g. The chickens were weighed weekly until they were 42 days old. The chickens were fed formulated grower diets (Table 3.03) with feed intake being measured every day. The chickens were randomly assigned to five treatments as in the first experimental part. Each treatment had 4 replicates, with 6 chickens per replicate. Ingredients and nutrient composition of the diets are indicated in Table 3.04. The chickens were allowed to feed and drink water *ad libitum.*

Table 3.03 Dietary treatments for Experiment 2

Diet code	Diet description
$GM_{100}S_0$	Male Ross 308 broiler chickens aged 22 to 42 days fed a diet having 100% maize meal.
$GM_{75}S_{25}$	Male Ross 308 broiler chickens aged 22 to 42 days fed a diet having 25% maize meal replaced by a low tannin sorghum meal.
$GM_{50}S_{50}$	Male Ross 308 broiler chickens aged 22 to 42 days fed a diet having 100% maize meal replaced by a low tannin sorghum meal.
$GM_{25}S_{75}$	Male Ross 308 broiler chickens aged 22 to 42 days fed a diet having 75% of maize meal replaced by a low tannin sorghum meal.
GM_0S_{100}	Male Ross 308 broiler chickens aged 22 to 42 days fed a diet having 100% maize meal replaced by a low tannin sorghum meal.

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

Feed Ingredient	Treatment				
	$GM_{100}S_0$	$GM_{75}S_{25}$	$GM_{50}S_{50}$	$GM_{25}S_{75}$	GM_0S_{100}
Yellow maize (%)	61.65	46.14	28.93	15.21	0.00
Sorghum (%)	0.00	13.51	31.27	46.14	61.65
Soyabean (%)	30.98	33.65	32.81	31.56	30.98
Oil- Sunflower (%)	4.00	3.36	3.69	3.75	4.00
Limestone (%)	0.93	0.93	0.93	0.93	0.93
Dicalphosphate (%)	1.62	1.57	1.58	1.61	1.62
Salt (%)	0.35	0.35	0.35	0.35	0.35
Sodium bicarbonate (%)	0.001	0.001	0.001	0.001	0.001
Vitamins+ minerals Premix (%)	0.13	0.13	0.13	0.13	0.13
DL methionine (%)	0.15	0.14	0.15	0.15	0.15
L lysine (%)	0.19	0.13	0.16	0.17	0.19
Total	100	100	100	100	100
Analysed nutrient composition					
Crude Protein (%)	20.00	20.00	20.00	20.00	20.00
Energy (MJ/kg DM)	17.5	17.5.	17.5	17.5	17.5
Lysine (%)	1.17	1.17	1.17	1.10	1.17
Methionine (%)	0.49	0.49	0.49	0.49	0.55
Threonine (%)	0.68	0.68	0.68	0.70	0.91
ADF (%)	8.38	8.11	9.42	12.44	13.69
NDF (%)	20.90	23.34	25.08	34.12	36.46
Fat (%)	3.68	4.28	4.70	5.07	5.11
Ash (%)	5.90	6.62	6.73	7.06	7.40
Ca (%)	0.56	0.60	0.69	0.76	0.81
Condensed tannins#	ND	0.03	0.06	0.09	0.12
Total phenols#	ND	ND	ND	ND	0.01

#: Condensed tannins as percentage DM leucocyanidin equivalent; ##: Expressed as tannic acid equivalent (%); ND: Not detected

3.5 Data collection

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 divided by the number of days. The voluntary feed intake was measured by subtracting the difference in weight of leftovers from that offered per day and the total was divided by the total number of chickens per pen. The feed offered per day and leftovers were measured using the electronic weighing balance used. Daily average feed intake and weight gain were used to calculate feed conversion ratio. Average feed intake was divided by average weight gain to find the FCR value (McDonald *et al.*, 2010). Feed conversion ratio (g DM feed/g live weight gain) = Average feed intake/average weight gain.

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. Chromium oxide (Cr_2O_3) at 0.5% was added to each of the five experimental diets to determine digestibility. Faeces voided were collected and weighed. Care was taken to avoid contamination from feathers, scales, debris and feeds. Samples were held on ice, frozen (-15^{o}C) and stored for analysis. Metabolisable energy and N-retention were calculated according to the procedures of McDonald *et al*. (2010).

Chickens were slaughtered for the determination of carcass characteristics (carcass and organ weights, organ pH and gastro-intestinal length measurements). The chickens were killed 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 few 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 was 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. Samples of the ileum were taken for villi height determination. The villi samples (2.5 cm) were taken from a section of the ileum (5 cm away from the ilio-caecal junction). The samples were cut lengthwise along the line of mesentery, pinned at four corners to a piece of cardboard and then transferred into containers with formalin. Samples were subjected to a series of alcohol with different concentrations and then embedded in liquid paraffin to make blocks. From the waxed tissue samples, cross-sections (6.0 µm) were cut using a rotary microtome and stained with hematoxilin and eosin and transferred onto glass slides. Four slides per intestine segment of each bird were made for the determination of histological parameters. slides were viewed using microscope (Leica, DM 500) and images were captured using a computer software. Images were analysed using ImageJ to determine villi height and crypt depth. The color of the breasts, drumsticks, thighs and wings was measured using HunterLab test (L*, a*, and b*) system, wherein L* is the lightness, a* is the redness and b* is the yellowness. The measuring probe was placed in contact with the surface of the muscle from the breast, drumsticks, thighs and wings at three different points, and the average was calculated for each portion.

3.6 Chemical analysis

Dry matter contents of feeds and faeces were determined by drying the sample in the oven over night at a temperature of 105°C. Gross energy values for feeds and faeces were determined using an adiabatic bomb calorimeter according to the method previously described by Association of Analytical Chemists (AOAC) (2000) at the University of Limpopo Animal Nutrition Laboratory. A full analysis for faeces and feeds was performed at the Pietermartizburg laboratory, Kwa-Zulu Natal, South Africa according to AOAC (2000).

3.7 Sensory evaluation

Meat samples which were previously frozen at -40°C for 4 days were thawed for 7 hours at room temperature prior to cooking. Breast meat was prepared and the skin was left on the meat samples. Nothing was added to the meat samples to add taste. An oven set at 105ºC 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 put 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. Individual breast meat was selected for sensory evaluation. The meat was then evaluated for its tenderness, flavour and juiciness preferences using 25 panellists to rank each part on a 5-point ranking scale (Table 3.05). The method adopted by Pavelková *et al*. (2013) was used to cook the meat samples.

Table 3.05 Evaluation scores used by panellists

	Meat		
Score	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 samples (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 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 morphometrics

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. 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 Data analysis

Data on feed intake, feed conversion ratio, growth rate, live weight, ME, nitrogen retention, gastro-intestinal morphology, shear force, sensory evaluation, carcass characteristics, meat color and bone morphometric of Ross 308 broiler chickens was analyzed by analysis of variance (ANOVA) using a SAS Version 9.3.1 software program (SAS, 2008). The responses in optimal small intestine pH, L* and b* meat color changes to sorghum 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 = sorghum replacement level and $-b_1/2b_1$ = 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-intestinal morphology, metabolisable energy, nitrogen retention, carcass weight, shear force and sensory evaluation and sorghum replacement levels were modeled 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 color and shear force = intercept, b = coefficient of the linear equation and x = sorghum replacement level.

CHAPTER FOUR

RESULTS

Experiment 1

Results of the effects of replacing maize meal with sorghum meal on feed intake, growth rate, feed conversion ratio (FCR), live 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 maize meal with sorghum meal in the diet had no effect ($P>0.05$) on feed intake, growth rate, FCR, live weight and N-retention of unsexed Ross 308 broiler chickens. Unsexed Ross 308 broiler chickens on diets having 50% of maize meal replaced by sorghum meal ($SM_{50}S_{50}$), 75% of maize meal replaced by sorghum meal ($SM_{25}S_{75}$) or 100% of maize meal replaced by sorghum meal ($SM_{0}S_{100}$) had higher ($P<0.05$) metabolisable energy (ME) intake than those on diets having 100% maize meal ($SM_{100}S_{0}$) or 25% of maize meal replaced by sorghum meal ($SM_{75}S_{25}$). Broiler chickens on diets having 50% of maize meal replaced by sorghum meal ($SM_{50}S_{50}$), 75% of maize meal replaced by sorghum meal ($SM_{25}S_{75}$) or 100% of maize meal replaced by sorghum meal ($SM_{0}S_{100}$) had similar ($P>0.05$) metabolisable energy intakes. Similarly, chickens on a diet having 100% of maize meal ($SM_{100}S_{0}$) or 25% of maize meal replaced by sorghum meal ($SM_{75}S_{25}$) had the same ($P>0.05$) metabolisable energy intakes. There were no deaths of chickens during this part of the study.

Table 4.01 Effect of replacing maize meal with sorghum 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/b/d) of unsexed Ross 308 chickens aged one to 21 days

Variable	*Diet				
	$SM_{100}S_0$	$SM_{75}S_{25}$	$SM_{50}S_{50}$	$SM_{25}S_{75}$	SM_0S_{100}
Feed intake	52.7±1.36	54.3±1.17	53.8±1.44	55.1±1.23	55.7±1.18
Growth rate	19.0 ±0.32	19.6 ±0.32	21.4±0.49	21.0±0.31	19.8±0.33
FCR	2.8±0.07	2.8±0.06	2.5±0.07	2.7±0.06	2.8±0.06
Live weight	400±34.21	411±18.25	449±21.21	441±24.75	415±19.24
ME	11.0^b±0.15	10.68^b±0.13	11.9^a±0.16	11.9^a±0.13	12.3^a±0.13
N-retention	1.17±0.095	1.28±0.083	1.15±0.100	0.95±0.086	0.87±0.082

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

* : Diet codes are described in Chapter 3, Section 3.4

Results of the effects of replacing maize meal with a low tannin white sorghum meal (Macia) (sorghum meal) on gut digesta pH, gut organ lengths and weights of unsexed Ross 308 broiler chickens aged 21 days are presented in Table 4.02. Replacing maize meal with sorghum meal in the diet had no effect (P>0.05) on caecum and large intestine digesta pH values. Unsexed Ross 308 broiler chickens on a diet having 100% maize meal replaced by sorghum meal (SM_0S_{100}) had higher (P<0.05) crop digesta pH values than those on diets having 100% maize meal ($SM_{100}S_0$), 25% of maize meal replaced by sorghum meal ($SM_{75}S_{25}$), 50% of maize meal replaced by sorghum meal ($SM_{50}S_{50}$) or 75% of maize meal replaced by sorghum meal ($SM_{25}S_{75}$). Similarly, chickens on a diet having 75% of maize meal replaced by sorghum meal ($SM_{25}S_{75}$) had higher (P<0.05) crop digesta pH values than those on diets having 100% maize meal ($SM_{100}S_0$), 50% of maize meal replaced by sorghum meal ($SM_{50}S_{50}$) or 25% of maize meal replaced by sorghum meal ($SM_{75}S_{25}$). Unsexed broiler chickens on diets having 100% maize meal replaced by sorghum meal (SM_0S_{100}) or 75% of maize meal replaced by sorghum meal ($SM_{75}S_{25}$) had similar (P>0.05) crop diegesta pH values. Similarly, broiler chickens on diets having 100% maize meal ($SM_{100}S_0$), 25% of maize meal replaced by sorghum meal ($SM_{75}S_{25}$) or 50% of maize meal replaced by sorghum meal ($SM_{50}S_{50}$) had same (P>0.05) crop digesta pH values.

Unsexed broiler chickens on a diet containing 100% of maize meal replaced by sorghum meal (SM_0S_{100}) had higher (P<0.05) gizzard digesta pH values than those on diets having 100% maize meal ($SM_{100}S_0$), 25% of maize meal replaced by sorghum meal ($SM_{75}S_{25}$) or 50% of maize meal replaced by sorghum meal ($SM_{50}S_{50}$). Similarly, chickens on diets having 100% maize meal ($SM_{100}S_0$) or 75% maize meal replaced by sorghum meal ($SM_{25}S_{75}$) had higher (P<0.05) gizzard digesta pH values than those on diets having 25% of maize meal replaced by sorghum meal ($SM_{75}S_{25}$). However, chickens on diets having 100% maize meal ($SM_{100}S_0$), 50% of maize meal replaced by sorghum meal ($SM_{50}S_{50}$) or 75% of maize meal replaced by sorghum meal ($SM_{25}S_{75}$) had similar gizzard digesta pH values. Similarly, chickens on diets containing 75 ($SM_{25}S_{75}$) or 100 (SM_0S_{100}) % of maize meal replaced by sorghum meal had same (P>0.05) gizzard digesta pH values. Chickens on diets having 25% ($SM_{75}S_{25}$) of maize meal replaced by sorghum meal or 50% ($SM_{50}S_{50}$) of maize meal replaced by sorghum meal had similar (P>0.05) gizzard digesta pH values.

Unsexed broiler chickens on diets containing 75% of maize meal replaced by sorghum meal ($SM_{25}S_{75}$), 50% of maize meal replaced by sorghum meal ($SM_{50}S_{50}$), 25% of maize meal replaced by sorghum meal ($SM_{75}S_{25}$) or 100% of maize meal replaced by sorghum meal (SM_0S_{100}) had higher (P<0.05) small intestine digesta pH values than those on a diet having 100% maize meal replaced by sorghum meal (SM_0S_{100}). However, broiler chickens on diets having 75% of maize meal replaced by sorghum meal ($SM_{25}S_{75}$), 50% of maize meal replaced by sorghum meal ($SM_{50}S_{50}$), 25% of maize meal replaced by sorghum meal ($SM_{75}S_{25}$) or 100% of maize meal replaced by sorghum meal (SM_0S_{100}) had similar (P>0.05) small intestine digesta pH values.

Positive relationships (r^2 = 0.840 and 0.798, respectively) were observed between level of replacement of maize meal with sorghum meal and crop and gizzard digesta pH values of unsexed Ross 308 broiler chickens aged 21 days (Figures 4.01 and 4.02, respectively, and Table 4.03). Small intestine pH values of unsexed Ross 308 broiler chickens aged 21 days were optimized (r^2 = 0.972) at a sorghum replacement level of 82.5 (Figure 4.03).

Replacing maize meal with sorghum meal had no effect (P>0.05) on large intestine lengths of unsexed Ross 308 broiler chickens aged 21 days (Table 4.02). Unsexed broiler chickens on diets containing 75% of maize meal replaced by sorghum meal ($SM_{25}S_{75}$) or 100% of maize meal replaced by sorghum meal ($SM_{0}S_{100}$) had longer (P<0.05) gastro-intestinal tracts (GIT) and small intestines than those on diets having 100% maize meal ($SM_{100}S_{0}$), 25% of maize meal replaced by sorghum meal ($SM_{75}S_{25}$) or 50% of maize meal replaced by sorghum meal ($SM_{50}S_{50}$). Unsexed broiler chickens on diets having 75% of maize meal replaced by sorghum meal ($SM_{25}S_{75}$) or 100% maize meal replaced by sorghum meal ($SM_{0}S_{100}$) had similar (P>0.05) GIT and small intestine lengths. Similarly, broiler chickens on diets having 100% of maize meal ($GM_{100}S_{0}$), 25% of maize meal replaced by sorghum meal ($GM_{75}S_{25}$) or 50% of maize meal replaced by sorghum meal ($GM_{50}S_{50}$) had same (P>0.05) GIT and small intestine lengths.

Positive relationships (r^2 = 0.574 and 0.571, respectively) were observed between level of replacement of maize meal with sorghum meal and GIT and small intestine lengths of unsexed Ross 308 broiler chickens aged 21 days (Figures 4.04 and 4.05 respectively, and Table 4.03).

Replacing maize meal with sorghum meal had no effect (P>0.05) on crop, gizzard, caecum and large intestine weights of unsexed Ross 308 broiler chickens aged 21 days (Table 4.02). Unsexed broiler chickens on diets containing 75% of maize meal replaced by sorghum meal ($SM_{25}S_{75}$) or 100% of maize meal replaced by sorghum meal ($SM_{0}S_{100}$) had heavier (P<0.05) small intestine weights than those on diets having 100% maize meal ($SM_{100}S_{0}$), 25% of maize meal replaced by sorghum meal ($SM_{75}S_{25}$) or 50% of maize meal replaced by sorghum meal ($SM_{50}S_{50}$). Unsexed broiler chickens on diets having 25% of maize meal replaced by sorghum meal ($SM_{25}S_{75}$), 50% of maize meal replaced by sorghum meal ($SM_{50}S_{50}$) or 100% maize meal ($SM_{100}S_0$) had similar (P>0.05) small intestine weights. Similarly, broiler chickens on diets having 100% of maize meal replaced by sorghum meal (SM_0S_{100}) or 75% of maize meal replaced by sorghum meal ($SM_{25}S_{75}$) had same (P>0.05) small intestine weights.

A Positive relationship ($r^2 = 0.843$) was observed between level of replacement of maize meal with sorghum meal and small intestine weights of unsexed Ross 308 broiler chickens aged 21 days (Figure 4.06 and Table 4.03).

Replacing maize meal with sorghum meal had no effect (P>0.05) on gut intestinal villi height, crypt depth and villi height to crypt depth ratio of unsexed Ross 308 broiler chickens aged 21 days (Table 4.02 and Figure 4.07).

Table 4.02 Effect of replacing maize meal with a low tannin white sorghum meal on gut digesta pH, length (cm), height (cm) and weight (g) of gut organs of Ross 308 broiler chickens aged 21 days

Variable	*Diet				
	$SM_{100}S_0$	$SM_{75}S_{25}$	$SM_{50}S_{50}$	$SM_{25}S_{75}$	SM_0S_{100}
Gut digesta pH					
Crop	4.3^c±0.21	4.3^c±0.18	4.5^c±0.19	5.6^b±0.36	6.2^b±0.23
Gizzard	3.0^b±0.24	2.7^c±0.61	3.1^{bc}±0.42	3.7^{ab}±0.27	4.3^a±0.60
Small intestines	4.8^b±0.45	5.8^a±0.81	5.9^a±0.32	6.2^a±0.40	6.2^a±0.47
Caecum	6.0±0.41	6.1±0.29	5.6±0.29	6.1±0.29	6.1±0.26
Large intestines	6.2±0.30	6.5±0.40	6.2±0.39	6.6±0.30	6.2±0.27
Gut organ length					
GIT	167^b±4.16	165^b±3.62	161^b±4.40	184^a±3.75	184^a±3.59
Small intestines	142^b±2.8	140^b±2.5	136^b±3.9	157^a±3.3	158^a±3.2
Caecum	15.5^b±1.02	15.4^b±0.89	15.1^c±1.08	16.3^{ab}±0.92	15.8^a±0.87
Large intestines	8.6±0.58	9.0±0.51	9.3±0.62	10.8±0.53	9.1±0.50
Gut organ weight					
Crop	24.0^c±1.8	25.0^{bc}±1.57	23.5^{bc}±1.91	28.0^b±1.63	29.4^a±1.56
Gizzard	54.1±3.88	54.4±3.38	55.6±4.10	55.8±3.50	64.9 ±3.35
Small intestines	142^b±2.8	140^b±2.5	136^b±3.9	157^a±3.3	158^a±3.2
Caecum	8.8±1.13	8.0±0.99	7.3±1.20	9.5±1.02	8.2±0.98
Large intestines	2.3±0.67	3.3±0.58	2.1±0.71	3.6±0.60	2.9±0.58
Gut intestinal villi height, crypt depth and height to crypt depth ratio					
Villi height	1014±230.8	1052±545.3	653±524.0	862±306.6	971±431.8
Crypt depth	892±223.5	783±528.1	599±507.5	797±297.2	879±418.2
Ratio	1.1±0.23	0.8±0.54	0.8±0.52	0.8±0.31	1.1±0.43

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, Section 3.4

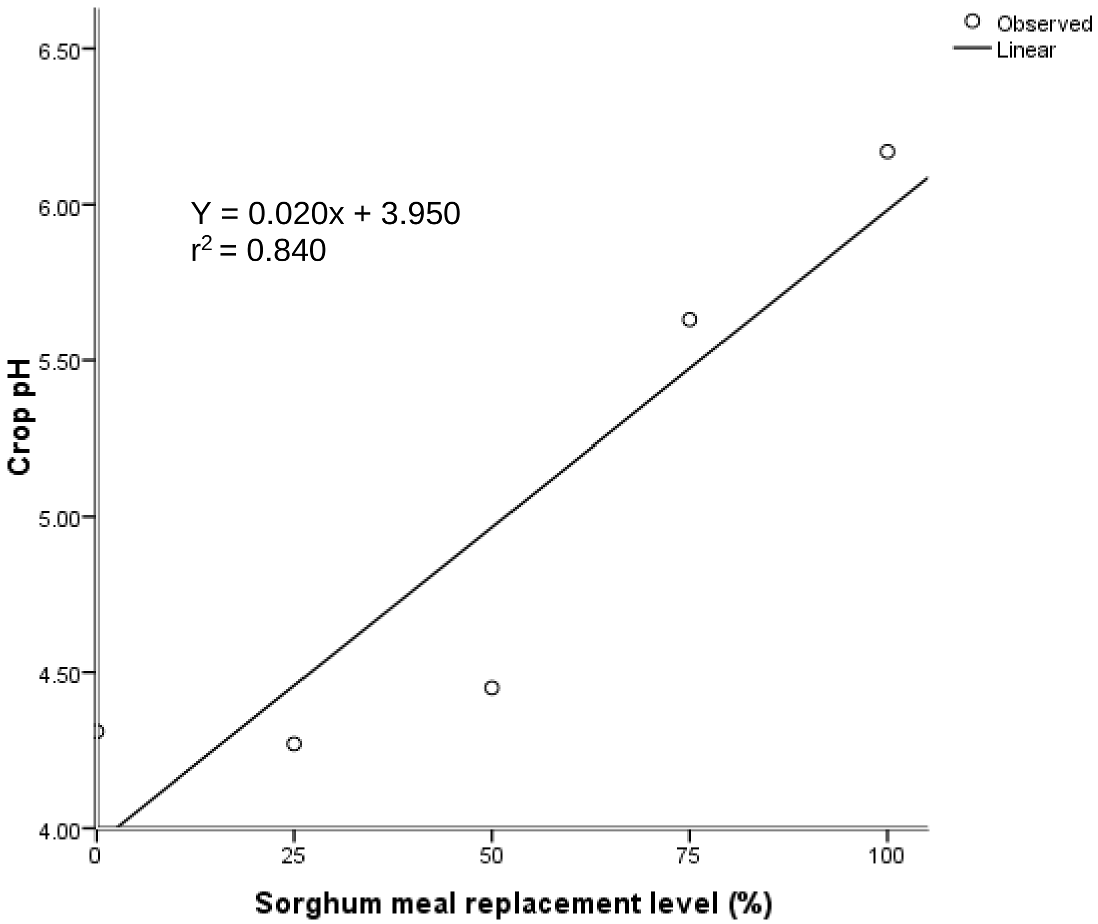


Figure 4.01 Relationship between sorghum meal replacement level and crop pH of unsexed Ross 308 broiler chickens aged 21 days

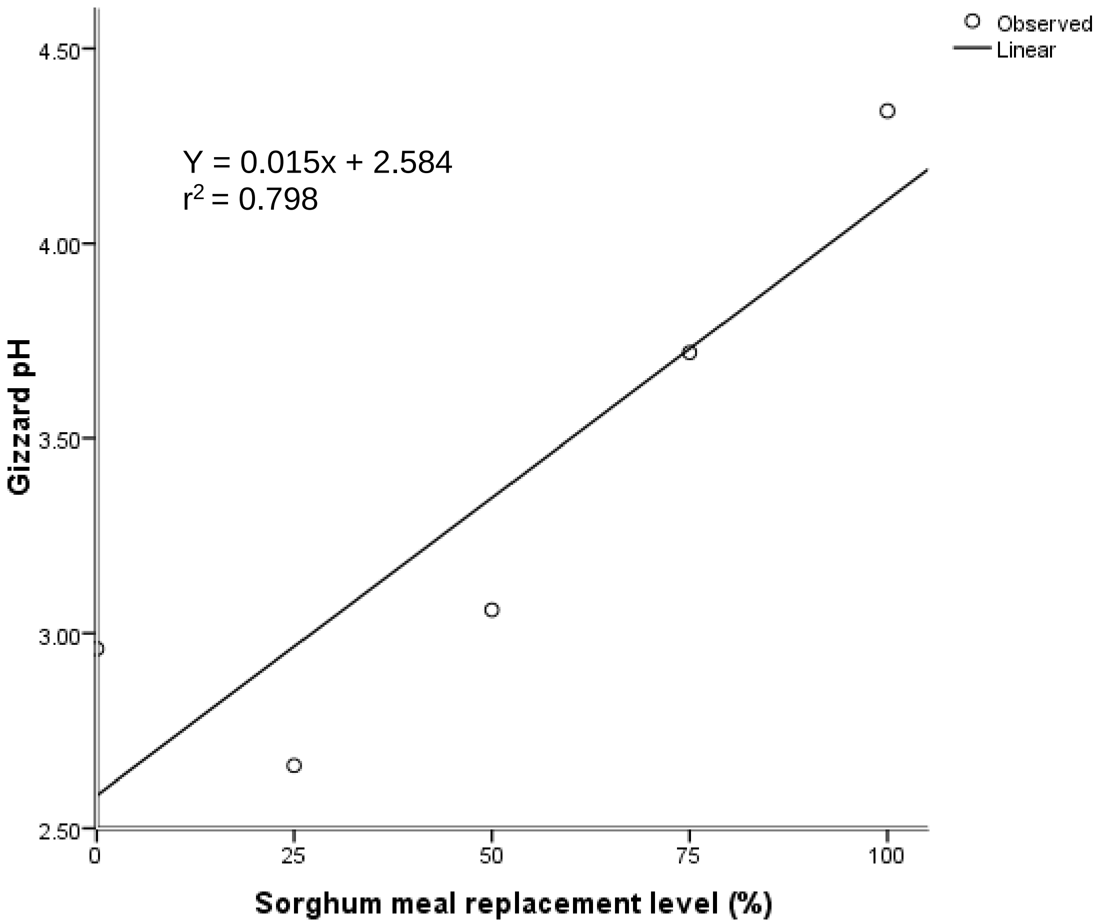


Figure 4.02 Relationship between sorghum meal replacement level and gizzard pH of unsexed Ross 308 broiler chickens aged 21 days

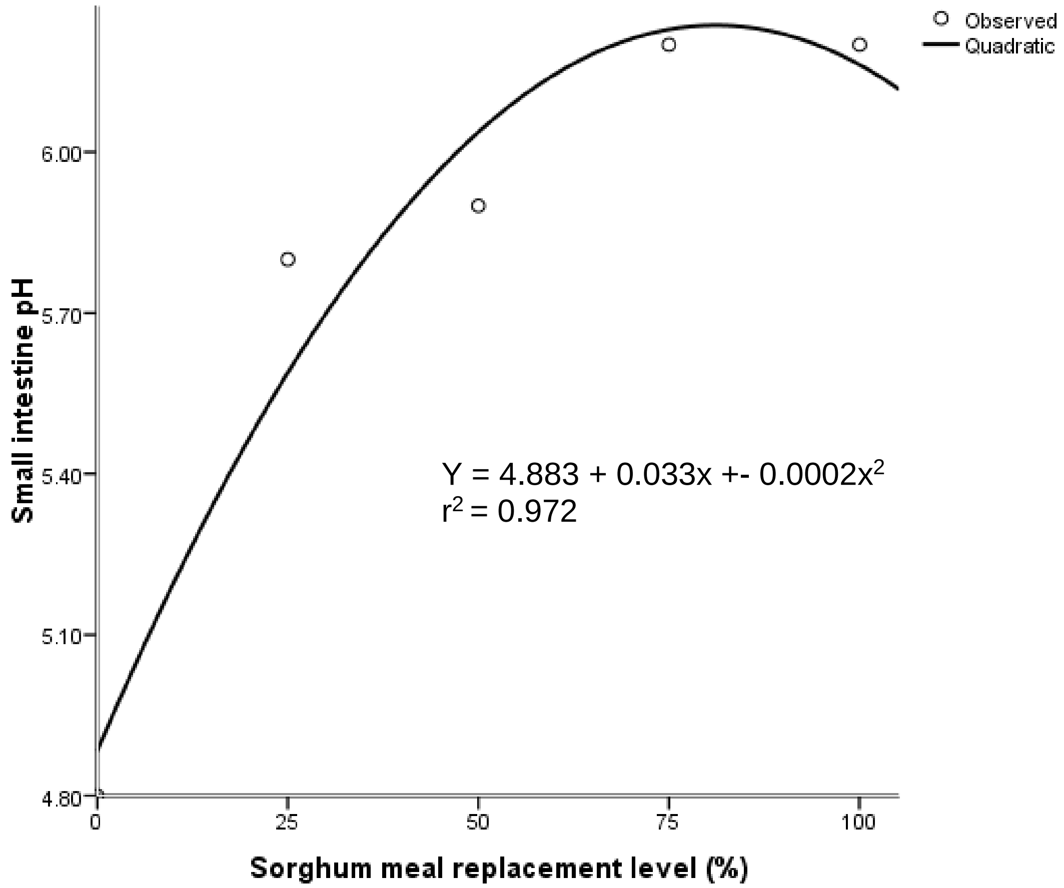


Figure 4.03 Effect of replacing maize meal with sorghum meal on small intestine pH of unsexed Ross 308 broiler chickens aged 21 days

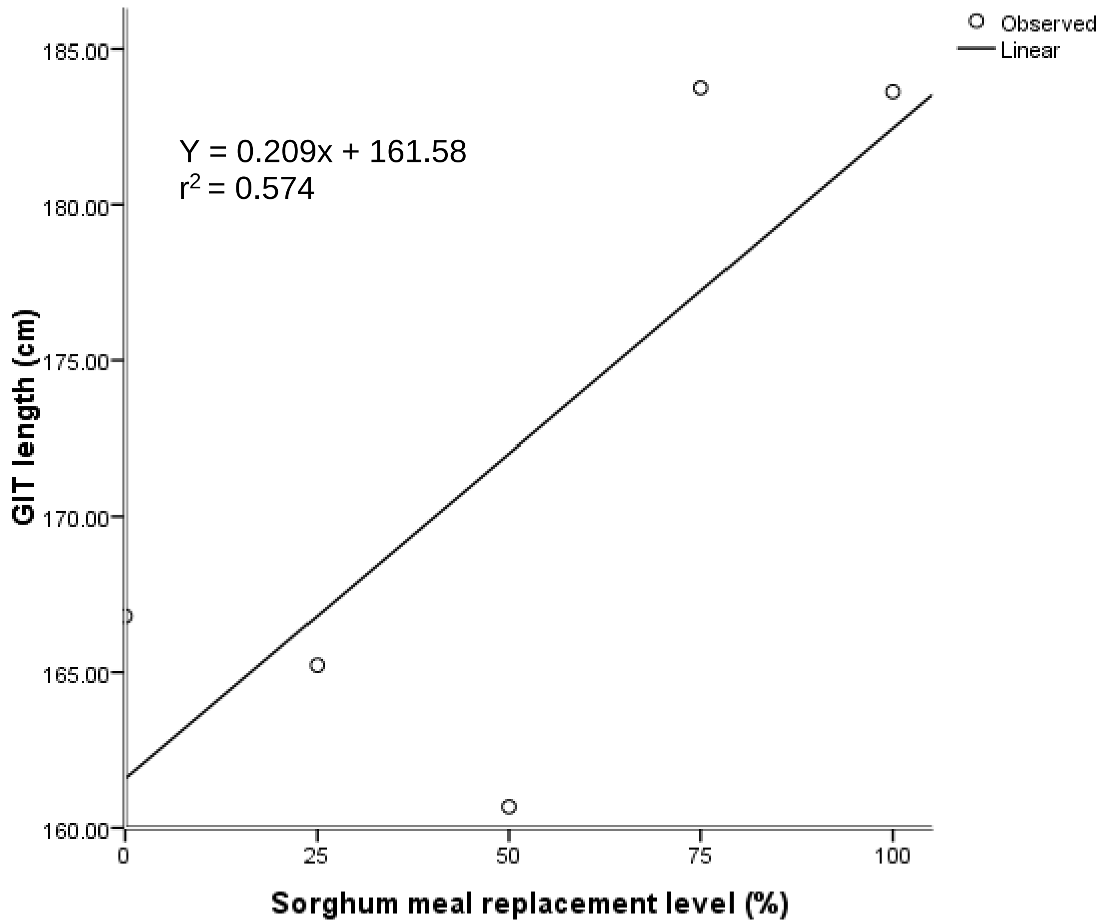


Figure 4.04 Relationship between sorghum meal replacement level and GIT length of unsexed Ross 308 broiler chickens aged 21 days

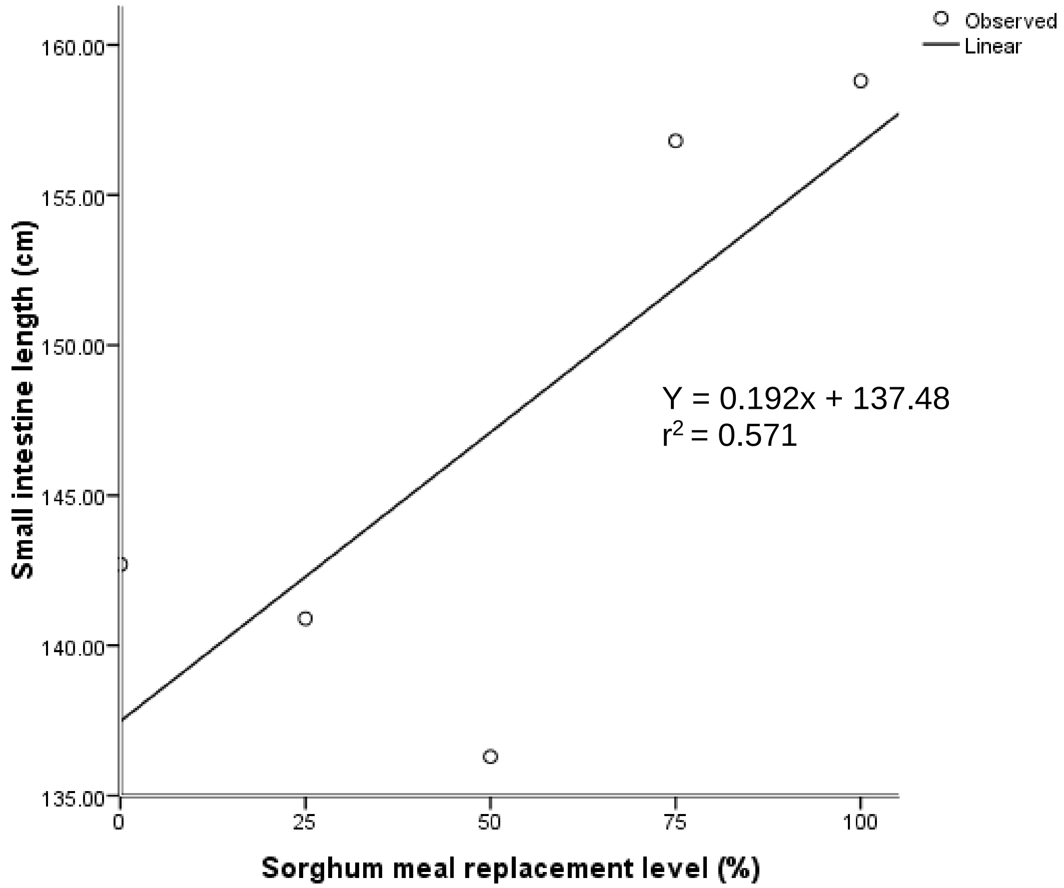


Figure 4.05 Relationship between sorghum meal replacement level and small intestine length of unsexed Ross 308 broiler chickens aged 21 days

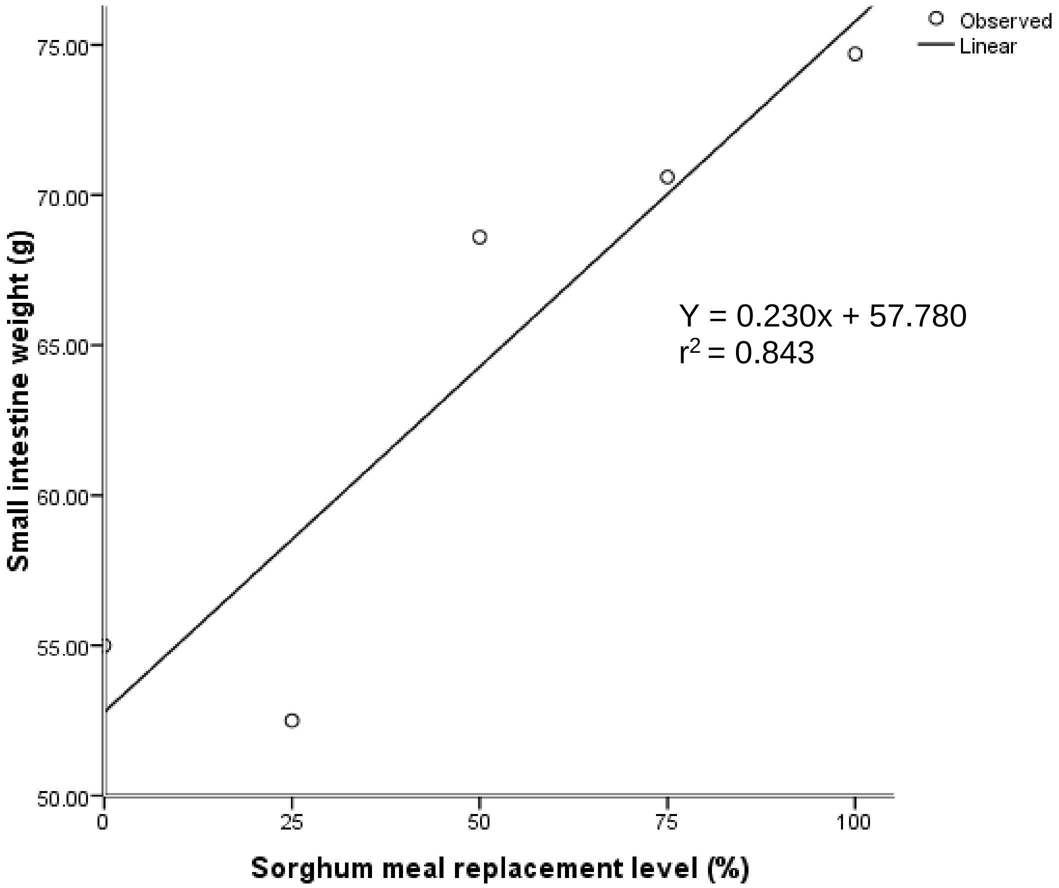


Figure 4.06 Relationship between sorghum meal replacement level and small intestine weight of unsexed Ross 308 broiler chickens aged 21 days

Table 4.03 Relationships between replacement level of maize with sorghum meal crop and gizzard pH, GIT and small intestine lengths and small intestine weights of unsexed Ross 308 broiler chickens aged 21 days

Variable	Formula	r^2	Probability
Crop pH	Y = 0.020x + 3.950	0.840	0.029
Gizzard pH	Y = 0.015x + 2.584	0.798	0.041
GIT lengths	Y = 0.209x + 161.58	0.574	0.007
Small intestine lengths	Y = 0.192x + 137.48	0.571	0.014
Small intestine weights	Y = 0.230x + 57.780	0.843	0.028

r^2 : Coefficient of determination

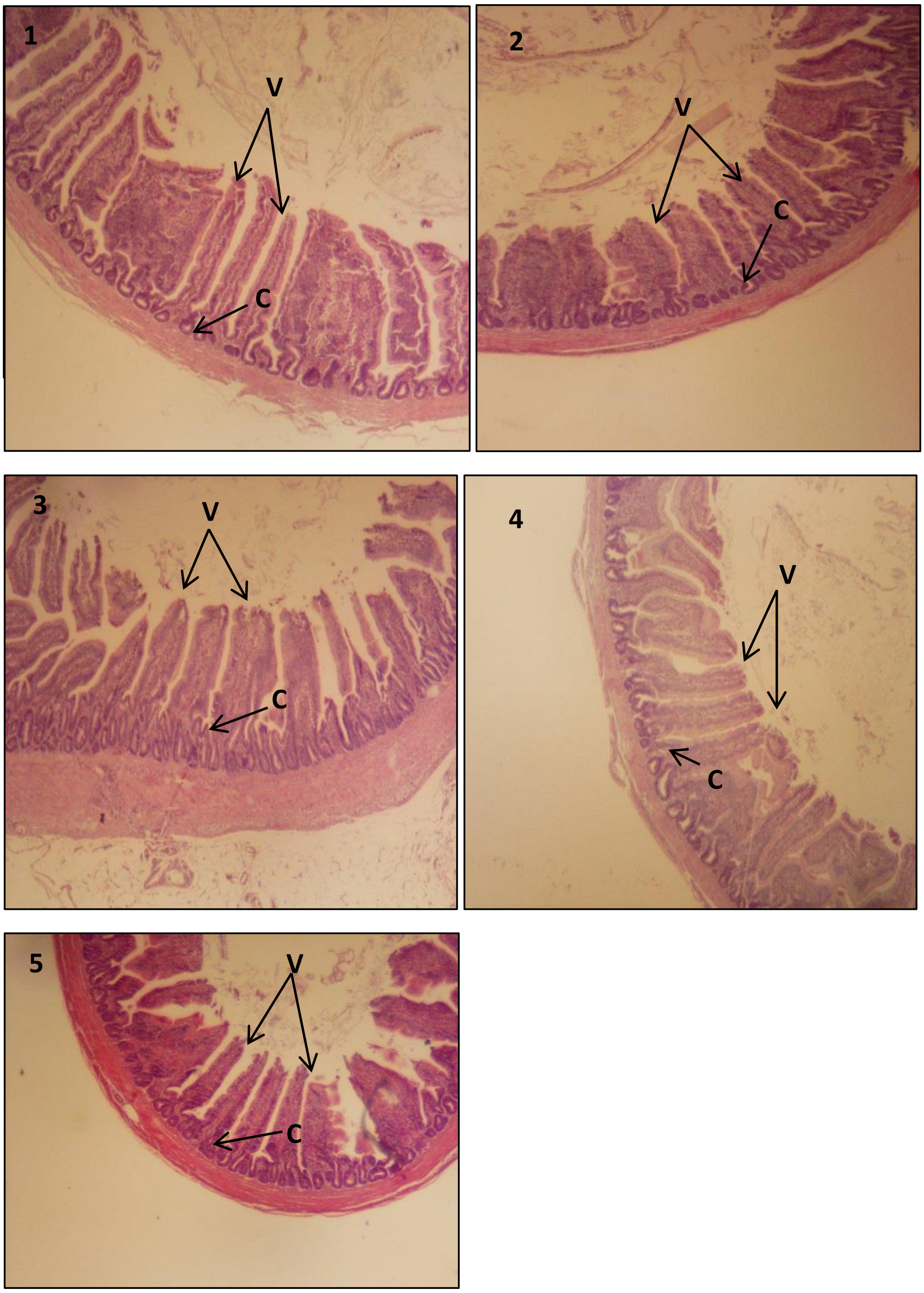


Figure 4.07 Villi height (V) and crypt depth (C) of ileum (40x) from 22 days old Ross 308 broiler chickens fed diets containing different levels of sorghum meal as a replacement for maize meal. 1: (SM100S0), 2: (SM75S0), 3: (SM50S50), 4: (SM25S75) and 5: (SM0S100)

Experiment 2

Results of the effects of replacing maize meal with a low tannin white sorghum meal on feed intake, growth rate, feed conversion ratio (FCR), live 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 4.04. Replacing maize meal with sorghum meal had no effect (P>0.05) on feed intake, feed conversion ratio (FCR), live weight and nitrogen retention (N-retention) of male Ross 308 broiler chickens aged 22 to 42 days. Male broiler chickens on diets containing 75% of maize meal replaced by sorghum meal ($SM_{25}S_{75}$) or 100% of maize meal replaced by sorghum meal (SM_0S_{100}) had higher (P<0.05) growth rates and metabolisable energy (ME) intakes than those on diets having 100% maize meal ($SM_{100}S_0$), 25% of maize meal replaced by sorghum meal ($SM_{75}S_{25}$) or 50% of maize meal replaced by sorghum meal ($SM_{50}S_{50}$). Male broiler chickens on diets having 75% of maize meal replaced by sorghum meal ($SM_{25}S_{75}$) or 100% maize meal replaced by sorghum meal (SM_0S_{100}) had similar (P>0.05) growth rates and metabolisable energy intakes. Similarly, broiler chickens on diets having 100% of maize meal ($GM_{100}S_0$), 25% of maize meal replaced by sorghum meal ($GM_{75}S_{25}$) or 50% of maize meal replaced by sorghum meal ($GM_{50}S_{50}$) had same (P>0.05) growth rates and metabolisable energy intakes.

Positive relationships (r^2 = 0.714 and 0.756 respectively) were observed between replacement level of maize meal with a low tannin sorghum meal and growth rates and ME intakes of male Ross 308 broiler chickens aged 22 to 42 days (Figures 4.08 and 4.09, respectively and Table 4.05).

Table 4.04 Effect of replacing maize meal with a low tannin white sorghum meal on feed intake (DM g/bird/day), growth rate (g/bird/day), feed conversion ratio (FCR) (g DM feed/g live weight gain), live weight (g/bird/day aged 42 days), metabolisable energy (ME) intake (MJ/kg DM) and nitrogen retention (N-retention) (g/bird/day) of male Ross 308 chickens aged 22 to 42 days

Variable	*Diet				
	$GM_{100}S_0$	$GM_{75}S_{25}$	$GM_{50}S_{50}$	$GM_{25}S_{75}$	GM_0S_{100}
Feed intake	179.9±1.97	180.3±1.95	180.2±2.08	179.7±2.49	179.7±2.26
Growth rate	52.3^b ±0.56	51.3^b±0.59	51.56^b±0.60	56.8^a±0.96	58.1^a±0.77
FCR	3.44±0.041	3.54±0.399	3.51±0.043	3.17±0.051	3.11±0.046
Live weight	2197±87.04	2156±84.76	2166±83.25	2384±83.35	2439±83.29
ME	11.2^b±0.25	10.7^b±0.25	11.3^b±0.26	12.3^a±0.32	12.7^a±0.29
N-retention	1.09±0.076	1.19±0.075	1.07±0.080	0.88±0.096	0.81±0.087

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

* : Diet codes are described in Chapter 3, Section 3.4

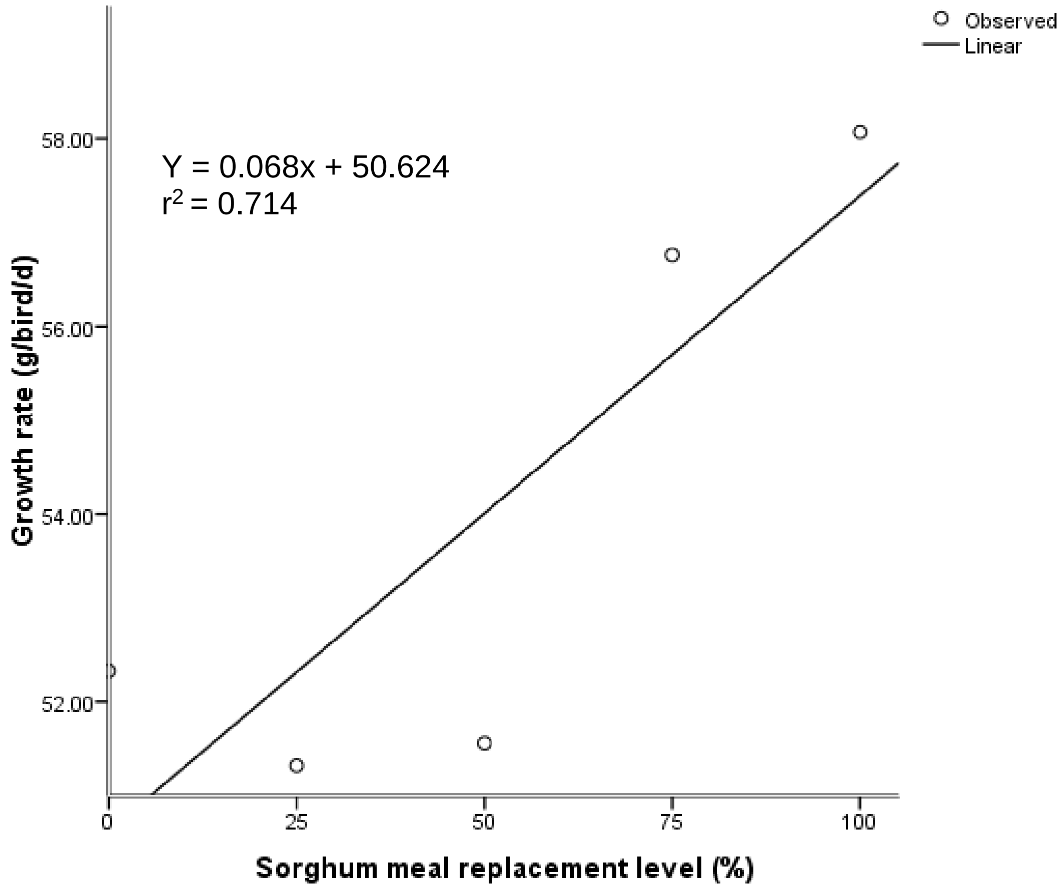


Figure 4.08 Relationship between replacement level of maize meal with sorghum meal and growth rate of male Ross 308 broiler chickens aged 22 to 42 days

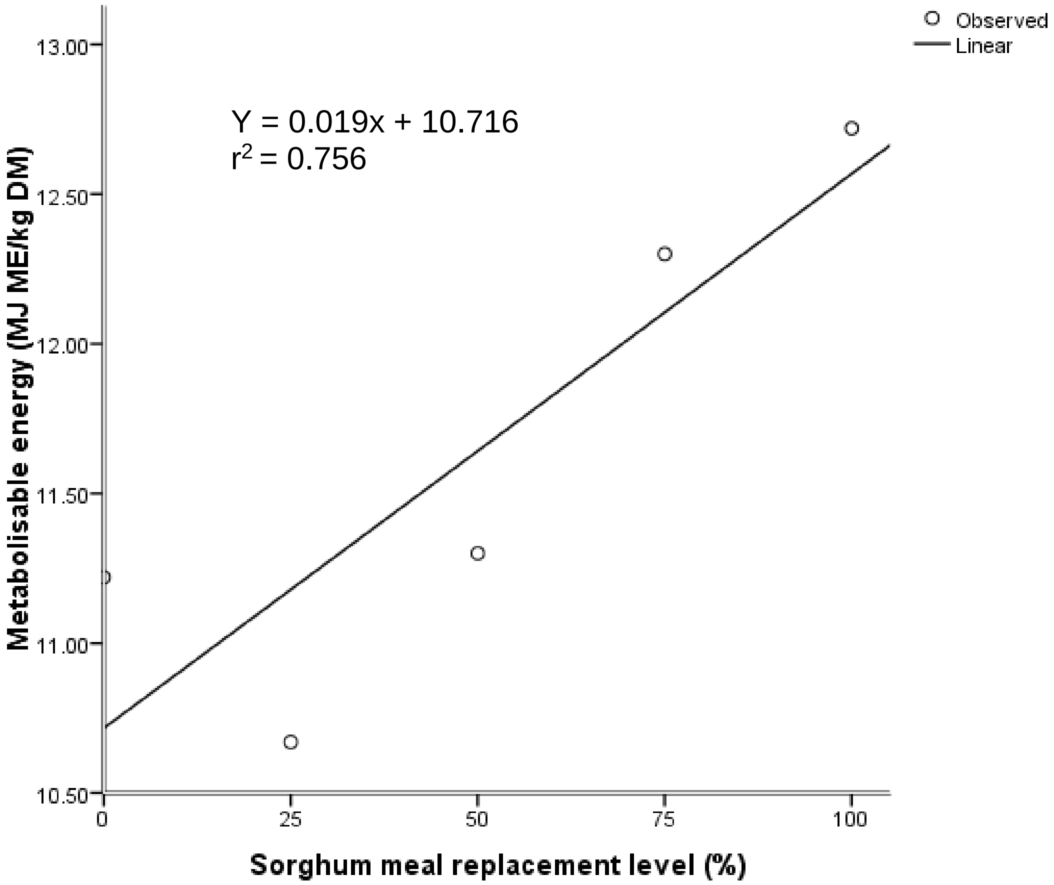


Figure 4.09 Relationship between replacement level of maize meal with sorghum meal and metabolisable energy of male Ross 308 broiler chickens aged 22 to 42 days

Table 4.05 Relationships between replacement level of maize meal with sorghum meal and growth rate (g/bird/day), live weight (g/bird aged 21 days) and metabolisable energy (ME) (MJ/kg DM feed) of male Ross 308 broiler chicken aged one to 21 days

Variable	Formula	r^2	Probability
Growth rate	Y = 0.068x + 50.624	0.714	0.042
ME	Y= 0.019x +10.716	0.756	0.031

r^2 : Coefficient of determination

Results of the effects of replacing maize meal with a low tannin white sorghum meal on gut digesta pH values, lengths and weights of gut organs of male Ross 308 broiler chickens aged 42 days are presented in Table 4.06. Replacing maize meal sorghum meal had no effect (P>0.05) on caecum and large intestine digesta pH values of male Ross 308 broiler chickens aged 42 days. Male Ross 308 broiler chickens fed a diet having 25% of maize meal replaced by sorghum meal ($GM_{75}S_{25}$) had higher (p<0.05) crop pH values than those on a diet having 100% maize meal ($GM_{100}S_0$). However, chickens on diets having 100% maize meal ($GM_{100}S_0$), 50% of maize meal replaced by sorghum meal ($GM_{50}S_{50}$), 75% of maize meal replaced by sorghum meal ($GM_{25}S_{75}$) or 100% of maize meal replaced by sorghum meal (GM_0S_{100}) had similar (P>0.05) crop digesta pH values. Similarly, chickens on diets having 25% of maize meal replaced by sorghum meal ($GM_{75}S_{25}$), 50% of maize meal replaced by sorghum meal ($GM_{50}S_{50}$), 75% of maize meal replaced by sorghum meal ($GM_{25}S_{75}$) or 100% of maize meal replaced by sorghum meal (GM_0S_{100}) had same (P>0.05) crop digesta pH values.

Male broiler chickens on diets having 100% maize meal ($GM_{100}S_0$) or 25% of maize meal replaced by sorghum meal ($GM_{75}S_{25}$) had higher (P<0.05) gizzard digesta pH values than those on diets having 75% of maize meal replaced by sorghum meal ($GM_{25}S_{75}$) or 100% of maize meal replaced by sorghum meal (GM_0S_{100}). However, broiler chickens on diets having 50% of maize meal replaced by sorghum meal ($GM_{50}S_{50}$) or 100% of maize meal replaced by sorghum meal (GM_0S_{100}) had similar (p<0.05) gizzard digesta pH values. Similarly, chickens on diets having 100% maize meal ($GM_{100}S_0$), 25% of maize meal replaced by sorghum meal ($GM_{75}S_{25}$) or 50% of maize meal replaced by sorghum meal ($GM_{50}S_{50}$) had same gizzard digesta pH values. Chickens on diets having 75% of maize meal replaced by sorghum meal ($GM_{25}S_{75}$) or 100% of maize meal replaced by sorghum meal (GM_0S_{100}) had similar gizzard digesta pH values.

Male broiler chickens on a diet having 75% of maize meal replaced by sorghum meal ($GM_{25}S_{75}$) had higher (P<0.05) small intestine digesta pH values than those on diets having 100% maize meal ($GM_{100}S_0$) or 25% of maize meal replaced by sorghum meal

($GM_{75}S_{25}$). Similarly, chickens fed a diet having 25% of maize meal replaced by sorghum meal ($GM_{75}S_{25}$) had higher (P<0.05) small intestine digesta pH values than those fed a diet having 100% maize meal ($GM_{100}S_{0}$). Broiler chickens on diets having 75% of maize meal replaced by sorghum meal ($GM_{25}S_{75}$), 50% of maize meal replaced by sorghum meal ($GM_{50}S_{50}$) or 100% of maize meal replaced by sorghum meal ($GM_{0}S_{100}$) had similar small intestine digesta pH values. Similarly, chickens on diets having 25% of maize meal replaced by sorghum meal ($GM_{75}S_{25}$), 50% of maize meal replaced by sorghum meal ($GM_{50}S_{50}$) or 100% of maize meal replaced by sorghum meal ($GM_{0}S_{100}$) had same (P>0.05) small intestine digesta pH values.

Replacing maize meal with sorghum meal had no effect (P>0.05) on GIT, caecum and large intestine lengths of male Ross 308 broiler chickens aged 42 days. Broiler chickens on diets having 50% of maize meal replaced by sorghum meal ($GM_{50}S_{50}$), 75% of maize meal replaced by sorghum meal ($GM_{25}S_{75}$) or 100% of maize meal replaced by sorghum meal ($GM_{0}S_{100}$) had longer (P<0.05) small intestine lengths than those on a diet having 100% maize meal ($GM_{100}S_{0}$). However, chickens on diets having 100% maize meal ($GM_{100}S_{0}$) or 25% of maize meal replaced by sorghum meal ($GM_{75}S_{25}$) had similar small intestine lengths. Similarly, chickens on diets having 25% of maize meal replaced by sorghum meal ($GM_{75}S_{25}$), 50% of maize meal replaced by sorghum meal ($GM_{50}S_{50}$), 75% of maize meal replaced by sorghum meal ($GM_{25}S_{75}$) or 100% of maize meal replaced by sorghum meal ($GM_{0}S_{100}$) had same (P>0.05) small intestine lengths (Table 4.06).

Replacing maize meal with sorghum meal had no effect (P>0.05) on caecum, small intestine and large intestine weights of unsexed Ross 308 broiler chickens aged 42 days (Table 4.06). Male Ross 308 broiler chickens fed a diet having 100% of maize meal replaced by sorghum meal ($GM_{0}S_{100}$) had heavier (P<0.05) crop weights than those on diets having 100% maize meal ($GM_{100}S_{0}$), 50% of maize meal replaced by sorghum meal ($GM_{50}S_{50}$), 25% of maize meal replaced by sorghum meal ($GM_{75}S_{25}$) or 75% of maize meal replaced by sorghum meal ($GM_{25}S_{75}$). However, chickens on diets having 50% of maize meal replaced by sorghum meal ($GM_{50}S_{50}$), 25% of maize meal replaced by sorghum meal ($GM_{75}S_{25}$) or 75% of maize meal replaced by sorghum meal ($GM_{25}S_{75}$) had similar (P>0.05) crop weights. Similarly, chickens on diets having 25% of maize meal replaced by sorghum meal ($GM_{75}S_{25}$) or 50% of maize meal replaced by sorghum meal ($GM_{50}S_{50}$) had same (P>0.05) crop weights. Chickens on diets having 100% maize meal ($GM_{100}S_{0}$), 25% of maize meal replaced by sorghum meal ($GM_{75}S_{25}$) or 50% of maize meal replaced by sorghum meal ($GM_{50}S_{50}$) had similar (P>0.05) crop weights. Broiler chickens on diets having 100% of maize meal replaced by sorghum meal ($GM_{0}S_{100}$) or 75% of maize meal replaced by sorghum meal ($GM_{25}S_{75}$) had heavier (P<0.05) gizzard weights than those on diets having 50% of maize meal replaced by sorghum meal ($GM_{50}S_{50}$). Similarly, chickens on diets having 100% maize meal ($GM_{100}S_{0}$), 50% of maize meal replaced by sorghum meal ($GM_{50}S_{50}$), 100% of maize meal replaced by sorghum meal ($GM_{0}S_{100}$) or 75% of maize meal replaced by sorghum meal ($GM_{25}S_{75}$) had similar (P>0.05) gizzard weights.

Replacing maize meal with sorghum meal had no effect (P>0.05) on gut intestinal villi height, crypt depth and villi height to crypt depth ratio of unsexed Ross 308 broiler chickens aged 42 days (Table 4.06 and Figure 4.10).

A negative relationship (r^2 = 0.889) was observed between sorghum meal replacement level and gizzard digesta pH of male Ross 308 broiler chickens aged 42 days (Figure 4.10 and Table 4.07). Small intestine digesta pH of Ross 308 broiler chickens were optimized (r^2 = 0.958) at sorghum replacement levels of 82.50 (Figures 4.11). A positive relationship (r^2 = 0.692) was observed between sorghum meal replacement level and small intestine lengths of male Ross 308 broiler chickens aged 42 days (Figure 4.12 and Table 4.07). Positive relationships (r^2 = 0.984 and r^2 = 0.521, respectively) were observed between sorghum meal replacement level and crop and gizzard weights of male Ross 308 broiler chickens aged 42 days (Figure 4.13 and Figure 4.14, respectively Table 4.07).

Table 4.06 Effect of replacing maize meal with a low tannin white sorghum meal on gut digesta pH, length (cm), height (cm) and weight (g) of gut organs of Ross 308 broiler chickens aged 42 days

Variable	*Diet				
	$GM_{100}S_0$	$GM_{75}S_{25}$	$GM_{50}S_{50}$	$GM_{25}S_{75}$	GM_0S_{100}
Gut digesta pH					
Crop	$4.9^b±1.42$	$5.7^a±0.49$	$5.0^{ab}±0.29$	$5.4^{ab}±0.36$	$5.6^{ab}±0.41$
Gizzard	$3.4^a±0.22$	$3.3^a±0.20$	$3.0^b±0.15$	$2.4^c±0.35$	$2.4^c±0.28$
Small intestines	$5.2^c±0.13$	$5.9^b±0.11$	$6.0^{ab}±0.10$	$6.2^a±0.17$	$6.0^{ab}±0.11$
Caecum	6.3±0.28	6.3±0.56	6.3±0.23	6.0±0.24	6.3±0.25
Large intestines	6.4±0.16	6.4±0.33	6.4±0.14	6.3±0.14	6.2±0.15
Gut organ length					
GIT	182±11.7	171±11.8	192±12.4	185±14.8	175±13.4
Small intestines	$67.2^b±3.63$	$78.0^{ab}±3.58$	$83.3^a±3.83$	$79.0^a±4.58$	$85.0^a±4.16$
Caecum	17.0±0.79	17.9±0.78	18.7±0.83	18.5±0.99	19.2±0.91
Large intestines	10.3±0.71	9.9±0.70	11.0±0.75	11.1±0.89	11.5±0.81
Gut organ weight					
Crop	$29.7^c±2.50$	$33.5^{bc}±2.47$	$42.8^{bc}±2.64$	$50.6^b±3.16$	$55.5^a±2.87$
Gizzard	$72.9^{ab}±4.44$	$73.6^{ab}±5.37$	$63.6^b±5.75$	$89.6^a±6.88$	$93.3^a±6.24$
Small intestines	86.7±6.19	87.4±6.10	90.5±6.53	86.4±7.81	93.6±7.09
Caecum	12.8±1.18	9.4±1.16	12.0±1.24	12.6±1.49	12.9±1.35
Large intestines	3.16±0.769	2.52±0.749	2.52±0.802	2.31±0.959	2.52±0.869
Gut intestinal villi height, crypt depth and height to crypt depth ratio					
Villi height	1143±427.7	1528±502.9	936±479.2	718±391.2	1040±440.0
Crypt depth	1285±248.6	1423±292.4	854±278.5	1234±227.4	895±255.8
Ratio	0.81±0.329	1.08±0.384	0.83±0.366	0.55±0.299	0.90±0.336

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, Section 3.4

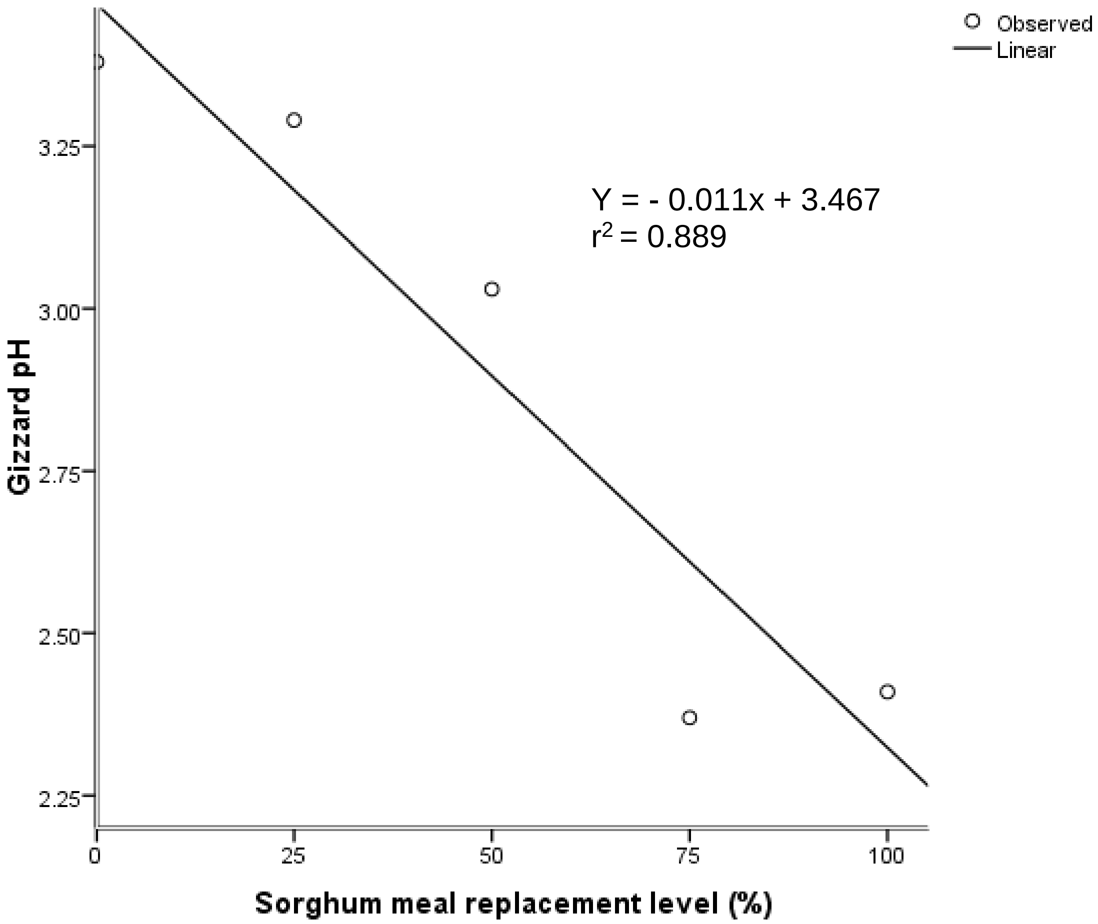


Figure 4.10 Relationship between replacement level of maize meal with sorghum meal and gizzard pH of male Ross 308 broiler chickens aged 42 days

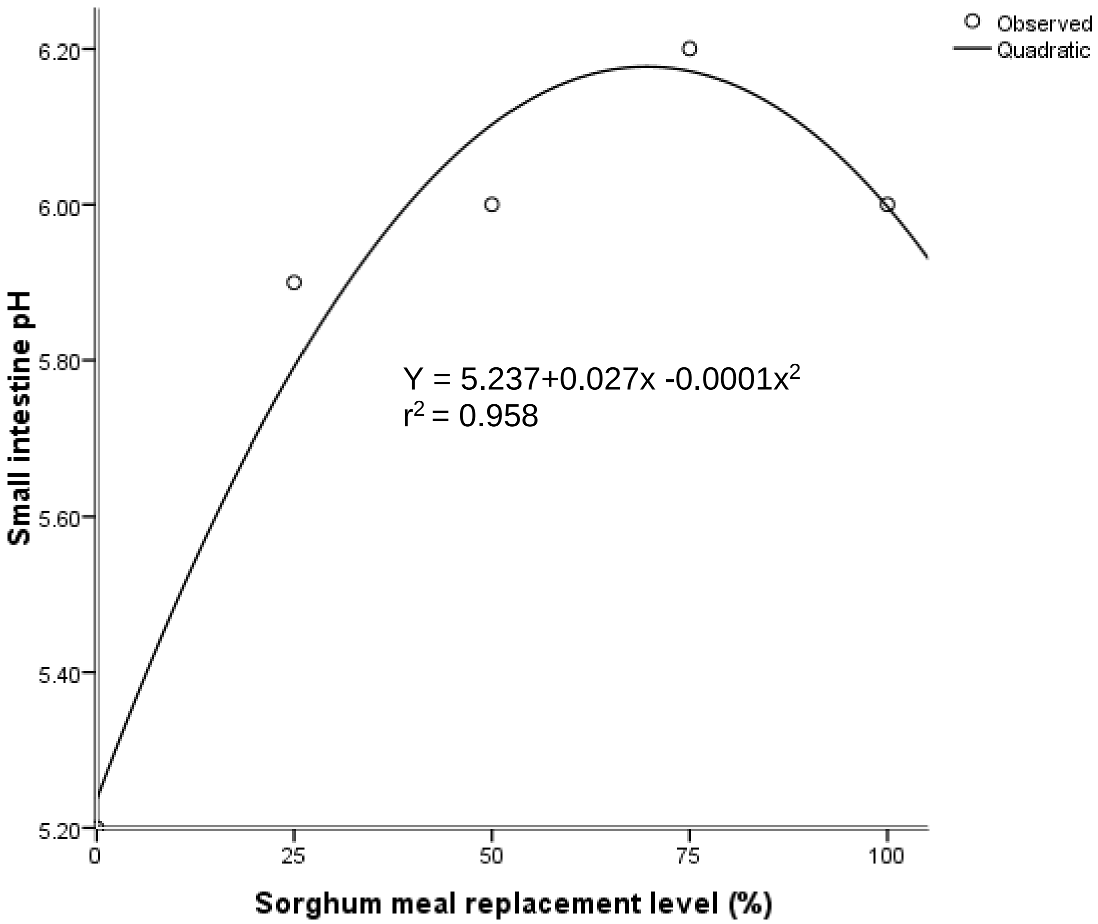


Figure 4.11 Effect of replacing maize meal with sorghum meal on small intestine pH of male Ross 308 broiler chickens aged 42 days

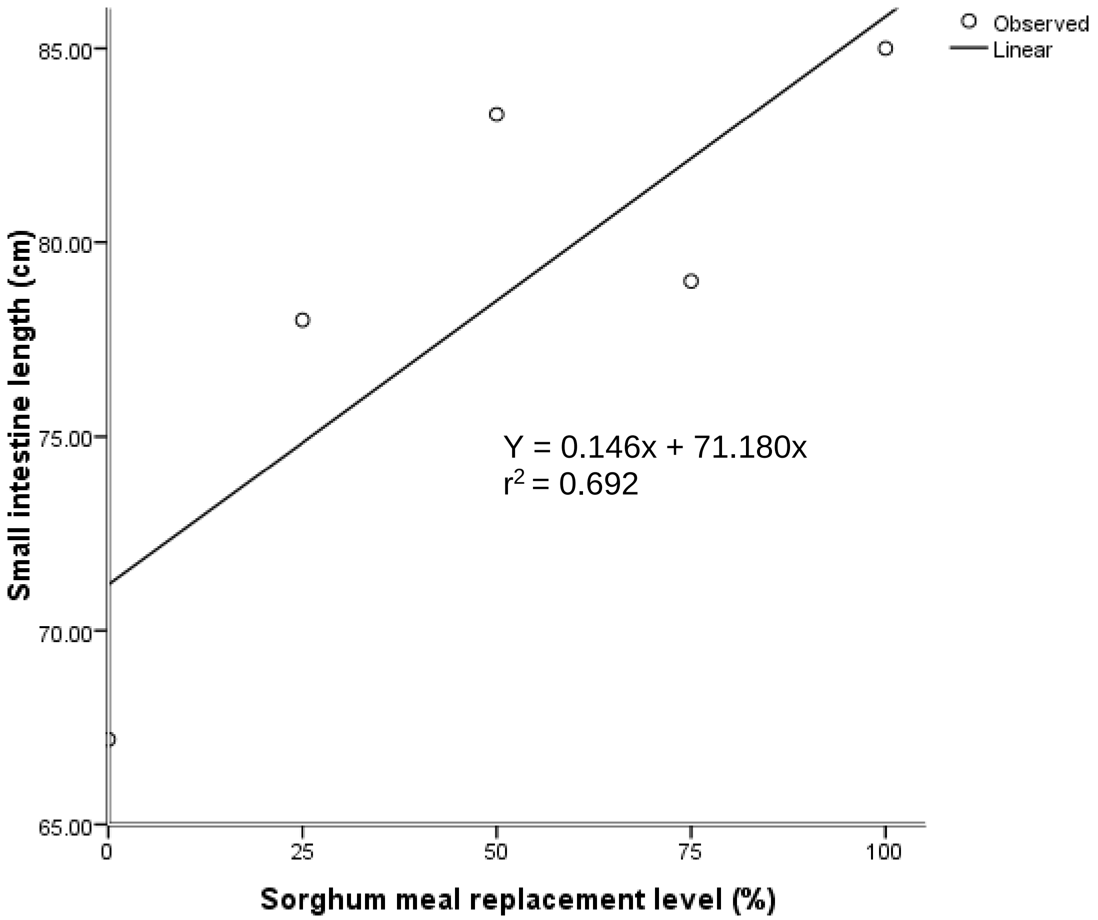


Figure 4.12 Relationship between replacement level of maize meal with sorghum meal and small intestine length of male Ross 308 broiler chickens aged 42 days

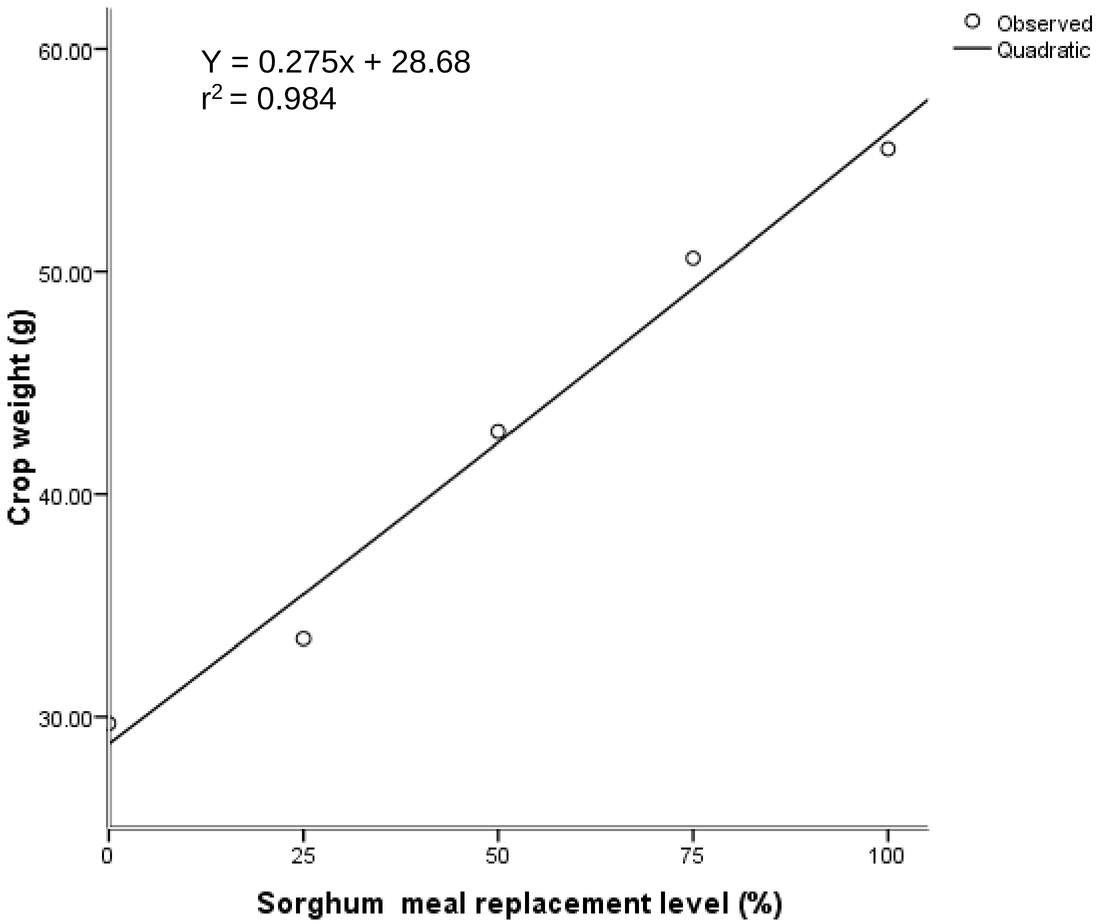


Figure 4.13 Relationship between replacement level of maize meal with sorghum meal and crop weight of male Ross 308 broiler chickens aged 42 days

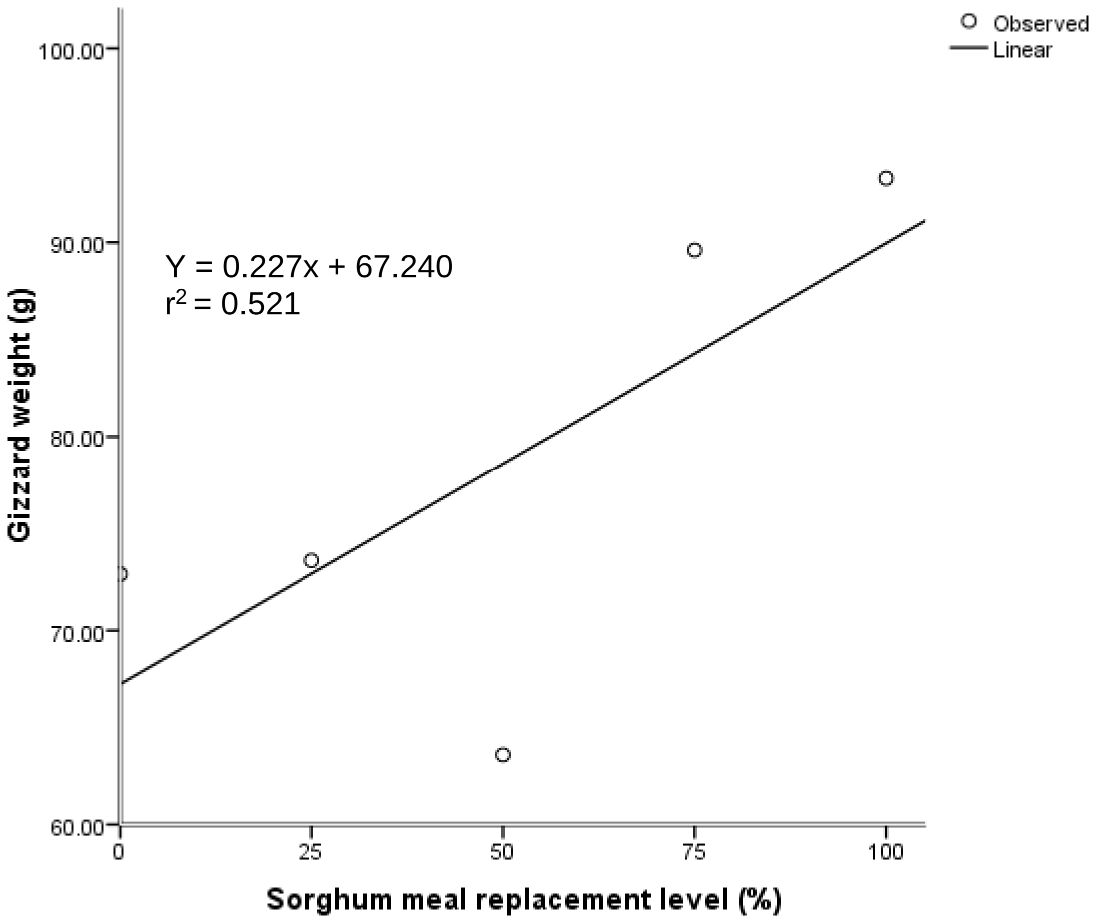


Figure 4.14 Relationship between replacement level of maize meal with sorghum meal and gizzard weight of male Ross 308 broiler chickens aged 42 days

Table 4.07 Relationships between replacement level of maize meal and crop, gizzard pH, small intestine lengths, crop and gizzard weight of male Ross 308 broiler chickens aged 42 days

Gut organ	Formula	r^2	Probability
Gizzard pH	Y = - 0.011x + 3.467	0.889	0.016
Small intestines length	Y= 0.146x + 71.180	0.692	0.080
Crop weight	Y= 0.275x + 28.68	0.984	0.001
Gizzard weight	Y= 0.227x + 67.240	0.521	0.016

r^2 : Coefficient of determination

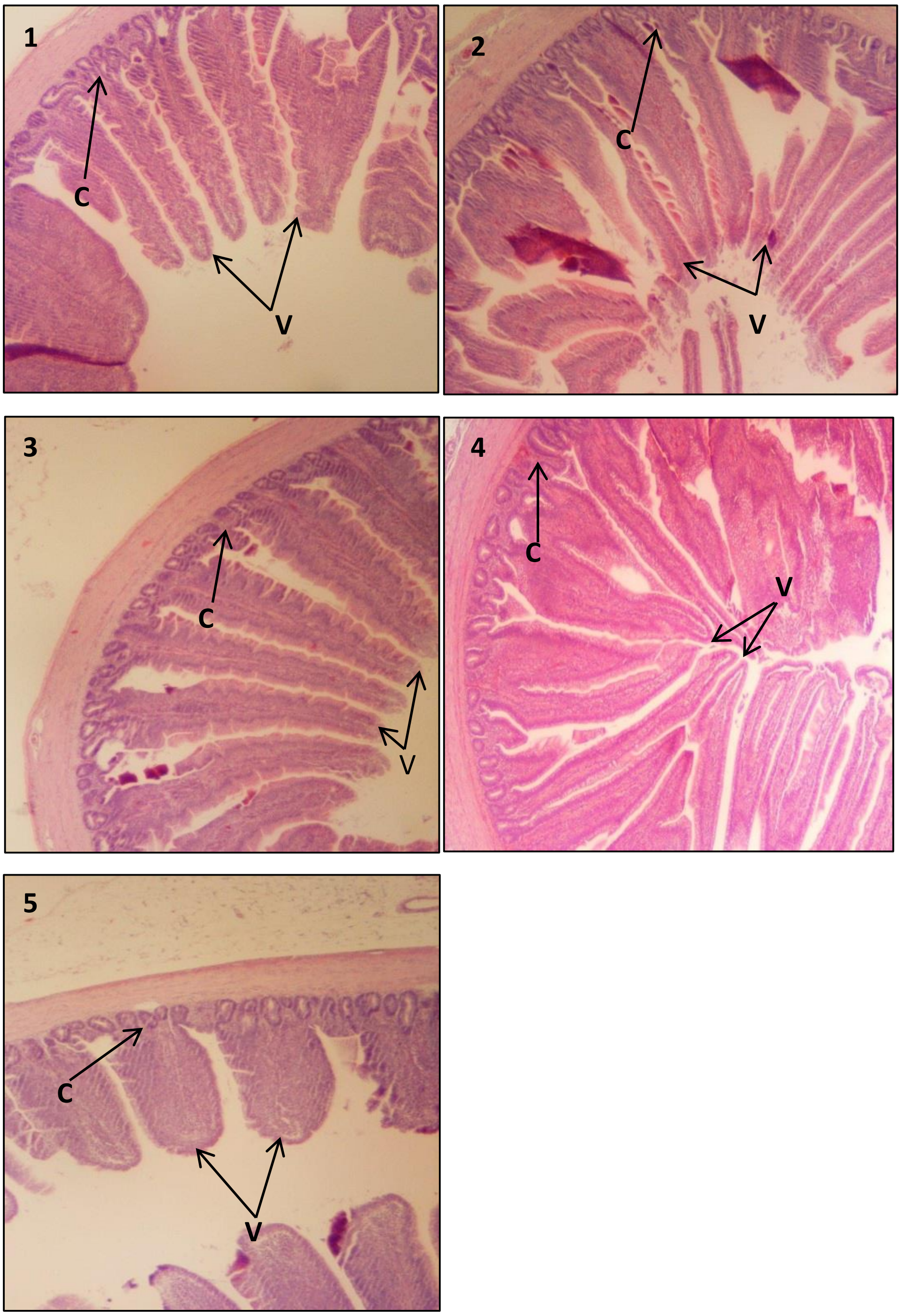


Figure 4.15 Villi height (V) and crypt depth (C) of ileum (40x) from 42 days old Ross 308 broiler chickens fed diets containing different replacement levels of maize meal with sorghum meal. 1 ($SM_{100}S_0$), 2 ($SM_{75}S_0$), 3 ($SM_{50}S_{50}$), 4 ($SM_{25}S_{75}$) and 5 (SM_0S_{100})

Results of the effects of replacing maize meal with a low tannin white low tannin sorghum meal on carcass weights of male Ross 308 broiler chickens aged 42 days are presented in Table 4.08. Replacing maize meal with sorghum meal had no effect (P>0.05) on breast, drumstick, thigh and wing weights of Ross 308 broiler chickens. Male Ross 308 broiler chickens on diets having 100 (GM_0S_{100}) or 75 ($GM_{25}S_{75}$) % of maize meal replaced by sorghum meal had higher (P<0.05) carcass weight values than those on diets containing 100% maize meal ($GM_{100}S_0$) or 25% of maize meal replaced by sorghum meal ($GM_{75}S_{25}$). However, chickens on diets having 25% of maize meal replaced by sorghum meal ($GM_{75}S_{25}$) or 50% of maize meal replaced by sorghum meal ($GM_{50}S_{50}$) had similar (P>0.05) carcass weight values. Similarly, chickens on diets having 50% of maize meal replaced by sorghum meal ($GM_{50}S_{50}$), 75% of maize meal replaced by a low tannin white sorghum meal ($GM_{25}S_{75}$) or 100% of maize meal replaced by sorghum meal (GM_0S_{100}) had same (P>0.05) carcass weight values. Broiler chickens on diets having 100% maize meal ($GM_{100}S_0$) or 25% of maize meal replaced by sorghum meal ($GM_{75}S_{25}$) had same (P>0.05) carcass weight values.

Positive relationships (r^2 = 0.938 and r^2 = 0.899, respectively) were observed between sorghum meal replacement level and carcass and breast weights of male Ross 308 broiler chickens aged 42 days (Figures 4.16 and 4.17, respectively, and Table 4.09).

Table 4.08 Effect of replacing maize meal with sorghum meal on carcass part weights (g) of male Ross 308 broiler chickens

	*Diet				
Variable	$GM_{100}S_0$	$GM_{75}S_{25}$	$GM_{50}S_{50}$	$GM_{25}S_{75}$	GM_0S_{100}
Carcass	1885^c±92.8	1948^{bc}±91.5	2180^{ab}±98.0	2246^a± 117.3	2302^a ±106.3
Breast	468^b±31.9	496^b±31.5	513^b±33.7	656^a±40.28	706^a±36.53
Drumstick	115±4.69	119±4.62	117±4.95	130±5.92	136±5.37
Thigh	147±7.92	151±7.82	140±8.36	152±10.01	148±9.07
Wing	79±6.12	106±6.04	99±6.46	109±7.73	118±7.01

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, Section 3.4

Table 4.09 Relationships between replacement levels of maize with sorghum meal with sorghum meal and carcass and breast weight (g) of male Ross 308 broiler chickens

Variable	Formula	r^2	Probability
Carcass	Y = 4.769x + 1868.025	0.938	0.023
Breast	Y = 2.544x + 440.6	0.899	0.014

r^2 : Coefficient of determination

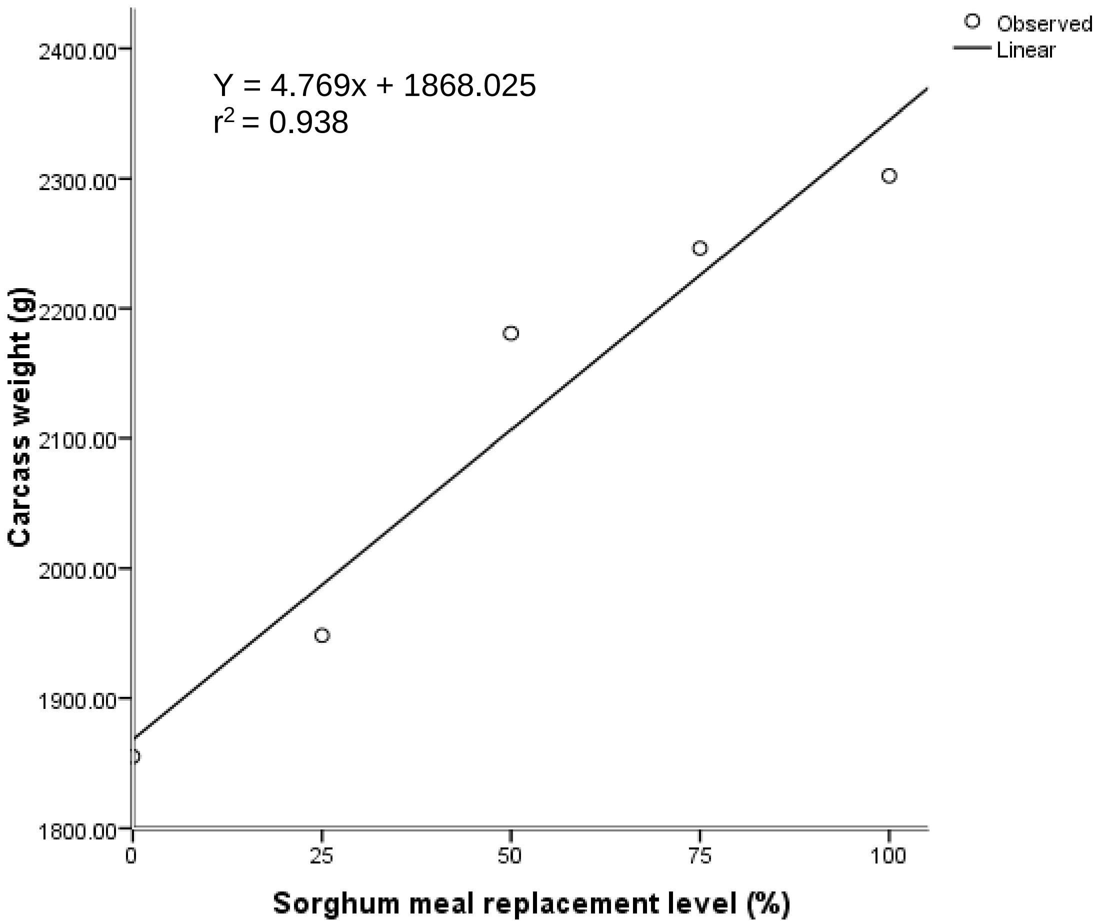


Figure 4.16 Relationship between replacement levels of maize meal with sorghum meal and carcass weight (g) of male Ross 308 broiler chickens

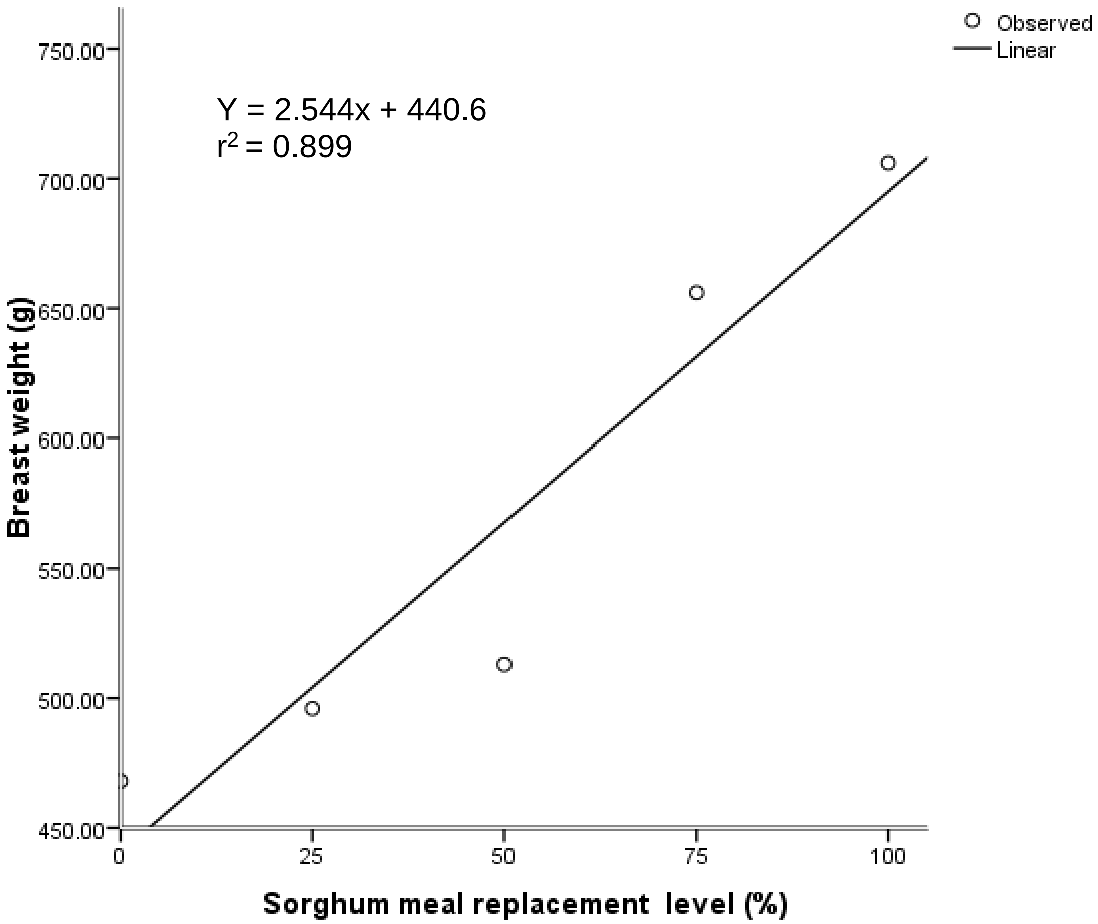


Figure 4.17 Relationship between replacement levels of maize meal with sorghum meal and breast weight (g) of male Ross 308 broiler chickens

Results of the effect of replacing maize meal with sorghum meal on colour of male Ross 308 broiler chicken meat are presented in Table 4.10. Replacing maize meal with sorghum meal had no effect on drumstick, wing and thigh colour of male Ross 308 broiler chicken meat. Male Ross 308 broiler chickens on a diet containing 50% of maize meal replaced by sorghum meal ($GM_{50}S_{50}$) had lighter ($P<0.05$) breast meat colour than those on diets containing 100% maize meal ($GM_{100}S_{0}$) or 75% of maize meal replaced by sorghum meal ($GM_{25}S_{75}$). However, chickens on diets containing 100% maize meal ($GM_{100}S_{0}$), 25% of maize meal replaced by sorghum meal ($GM_{75}S_{25}$), 75% of maize meal replaced by sorghum meal ($GM_{25}S_{75}$) or 100% of maize meal replaced by sorghum meal ($GM_{0}S_{100}$) had breast meat with similar ($P>0.05$) light colour. Chickens on diets containing 25% of maize meal replaced by sorghum meal

($GM_{75}S_{25}$), 50% of maize meal replaced by sorghum meal ($GM_{50}S_{50}$) or 100% of maize meal replaced by sorghum meal (GM_0S_{100}) had breast meat with the same ($P>0.05$) lightness colour.

Male broiler chickens on a diet containing 100% of maize meal ($GM_{100}S_0$) had breast meat with more ($P<0.05$) red colour than those on a diet containing 50% of maize meal replaced by sorghum meal ($GM_{50}S_{50}$). However, chickens on diets having 25% of maize meal replaced by sorghum meal ($GM_{75}S_{25}$), 50% of maize meal replaced by sorghum meal ($GM_{50}S_{50}$), 75% of maize meal replaced by sorghum meal ($GM_{25}S_{75}$) or 100% of maize meal replaced by sorghum meal (GM_0S_{100}) had breast meat with similar ($P>0.05$) red colour. Similarly, chickens on diets containing 100% maize meal ($GM_{100}S_0$), 25% of maize meal replaced by sorghum meal ($GM_{75}S_{25}$), 75% of maize meal replaced by sorghum meal ($GM_{25}S_{75}$) or 100% of maize meal replaced by sorghum meal (GM_0S_{100}) had breast meat with the same ($P>0.05$) red colour (Table 4.10).

Male broiler chickens on a diet having 25% of maize meal replaced by sorghum meal ($GM_{75}S_{25}$) had higher ($P<0.05$) yellow breast meat colour than those on a diet containing 100% of maize meal replaced by sorghum meal (GM_0S_{100}). However, chickens on diets containing 100% maize meal ($GM_{100}S_0$), 50% of maize meal replaced by sorghum meal ($GM_{50}S_{50}$), 75% of maize meal replaced by sorghum meal ($GM_{25}S_{75}$) or 100% maize meal replaced by sorghum meal had similar ($P>0.05$) yellow breast meat colour. Similarly, chickens on diets having 100% maize meal ($GM_{100}S_0$), 25% of maize meal replaced by sorghum meal ($GM_{75}S_{25}$), 50% of maize meal replaced by sorghum meal ($GM_{50}S_{50}$), 75% of maize meal replaced by sorghum meal ($GM_{25}S_{75}$) had same ($P>0.05$) yellow breast meat colour.

The yellow colours of breast meat of male Ross 308 broiler chickens were optimized ($r^2 = 0.945$) at sorghum replacement levels of 3.60% (Figure 4.18). Increasing the amount of sorghum meal replacing maize meal in the diet reduced ($r^2 = 0.793$) the red colour of breast meat of male Ross 308 broiler chickens (Figure 4.19).

Table 4.10 Effect of replacing maize meal with sorghum on the colour of male Ross 308 broiler chicken meat

Variable	*Diet				
	$GM_{100}S_0$	$GM_{75}S_{25}$	$GM_{50}S_{50}$	$GM_{25}S_{75}$	GM_0S_{100}
Breast					
L^*	47.2^b±1.61	51.5^{ab} ±1.72	53.8^a±1.33	48.7^b±1.35	51.2^{ab}±1.48
a*	5.53^a±0.706	4.79^{ab}±0.754	3.91^b±0.583	4.48^{ab}±0.593	4.62^{ab}±0.652
b*	11.5^{ab}±0.84	12.6^a±0.906	11.9^{ab}±0.701	11.0^{ab}±0.713	9.7^b±0.784
Drumstick					
L^*	50.3±1.46	52.1±1.933	53.8±1.893	51.0±3.047	50.2±3.221
a^*	5.79±0.532	4.94±0.557	5.33±0.546	4.75±0.878	5.32±0.928
b^*	7.79±1.032	8.04±1.080	5.81±1.058	6.35±1.703	7.56±1.801
Thigh					
L^*	45.44±1.397	46.14±1.364	48.20±1.344	46.99±1.518	45.17±1.461
a^*	6.61±0.793	6.67±0.774	5.25±0.763	5.35±0.862	6.13±0.830
b^*	8.04±0.933	8.92±0.910	7.62±0.897	7.56±1.013	7.62±0.975
Wing					
L^*	46.39±1.457	47.10±1.557	48.96±1.629	47.66±1.380	48.86±1.888
a^*	9.54±0.877	8.36±0.938	6.18±0.981	8.35±0.831	10.05±1.137
b^*	9.54±1.081	10.59±1.155	8.78±1.209	9.86±1.024	10.74±1.404

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

HunterLAB test: L^*: lightness; a^*: redness and b^*: yellowness

* : Diet codes are described in Chapter 3, Section 3.4

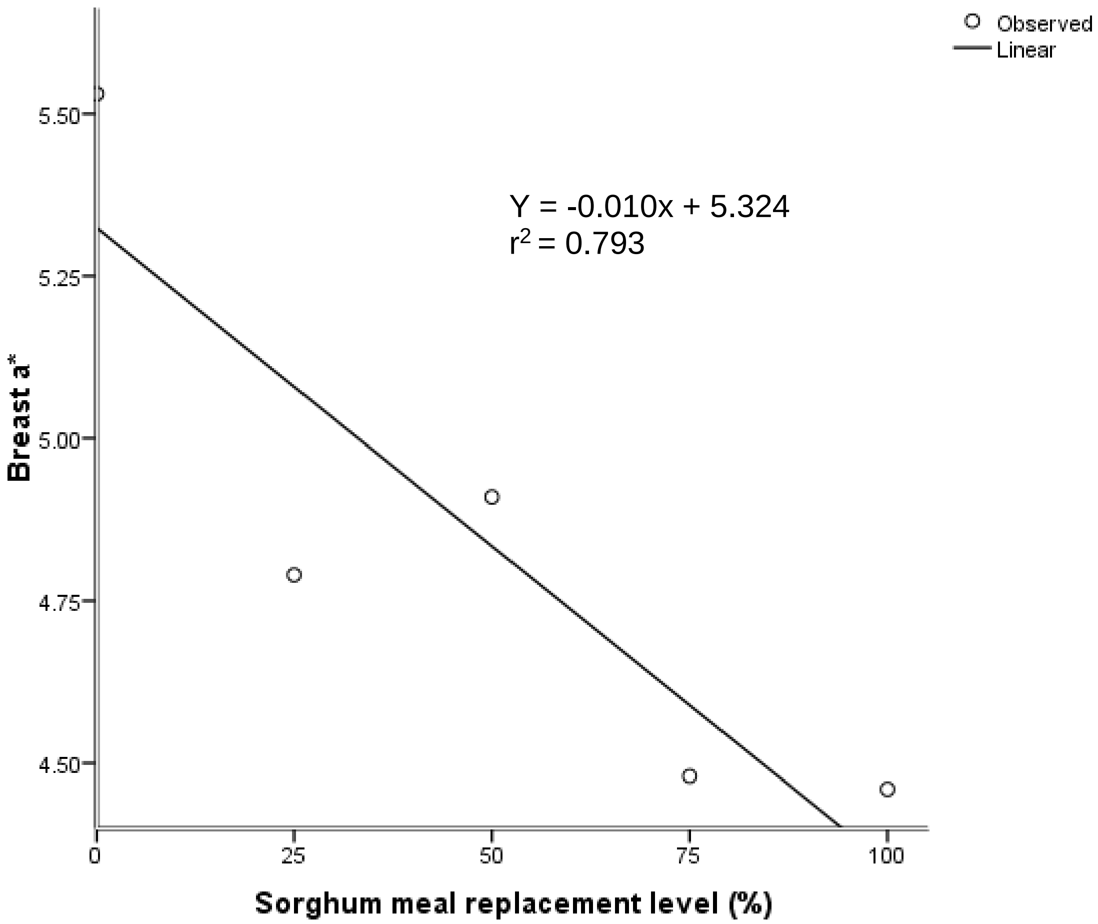


Figure 4.18 Relationship between replacement level of maize meal with white sorghum meal and red colour of breast meat of male Ross 308 broiler chickens

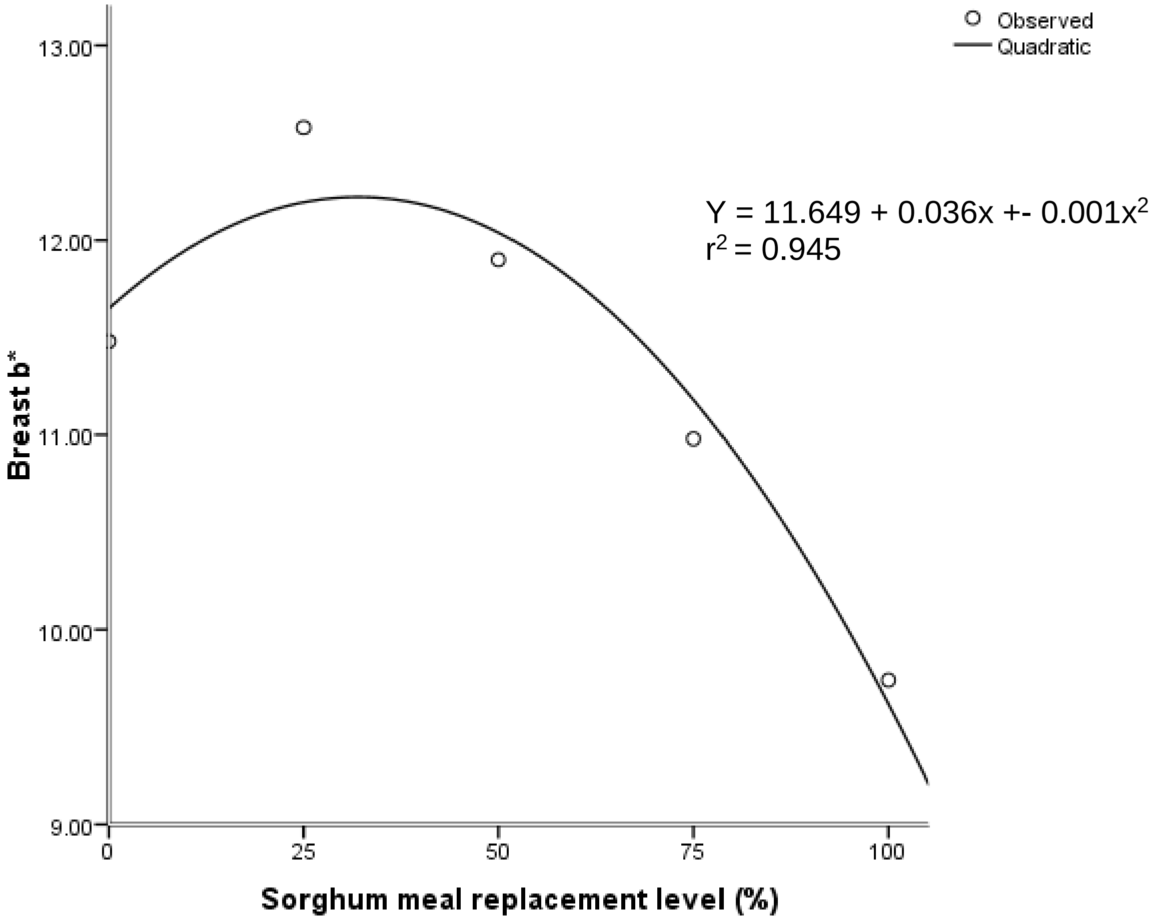


Figure 4.19 Effect of replacing maize meal with sorghum meal on yellow colour of breast meat of male Ross 308 broiler chickens

Results of the effects of replacing maize meal with sorghum meal on flavour, tenderness and juiciness and shear force of male Ross 308 broiler chicken meat are presented in Table 4.11. Replacing maize meal with sorghum meal in the diet had no effect (P>0.05) on flavour, tenderness and juiciness of male Ross 308 broiler chicken meat. Male Ross 308 broiler chickens on diets containing 100% maize meal ($GM_{100}S_0$) or 50% of maize meal replaced by sorghum meal ($GM_{50}S_{50}$) had higher (P<0.05) shear force values than those on diets having 75% of maize meal replaced by sorghum meal ($GM_{25}S_{75}$) or 100% of maize meal replaced by sorghum meal (GM_0S_{100}). However, chickens on diets having 100% of maize meal ($GM_{100}S_0$), 25% of maize meal replaced by sorghum meal ($GM_{75}S_{25}$), 50% of maize meal replaced by sorghum meal ($GM_{50}S_{50}$) had similar (P>0.05) shear force values. Similarly, chickens on diets having 25% of maize meal replaced by sorghum meal ($GM_{75}S_{25}$) or 75% of maize meal replaced by sorghum meal ($GM_{25}S_{75}$) had same (P>0.05) shear force values. Broiler chickens on diets having 75% of maize meal replaced by sorghum meal ($GM_{25}S_{75}$) or 100% of maize meal replaced by sorghum meal ($GM_{0}S_{100}$) had similar shear force values.

A negative relationship ($r^2 = 0.910$) was observed between sorghum meal replacement level and shear force of male Ross 308 broiler chicken meat (Figure 4.20).

Table 4.11 Effect of replacing maize meal with a low tannin white sorghum meal on meat flavour, tenderness and juiciness and shear force of male Ross 308 broiler chicken meat

	*Diet				
Variable	$GM_{100}S_0$	$GM_{75}S_{25}$	$GM_{50}S_{50}$	$GM_{25}S_{75}$	GM_0S_{100}
Flavour	3.20±0.197	2.78±0.207	2.56±0.222	2.68±0.213	3.18±0.198
Tenderness	3.53±0.321	3.09±0.243	2.64±0.261	3.03±0.251	2.84±0.233
Juiciness	3.34±0.212	3.00±0.223	2.45±0.240	2.50±0.230	2.73±0.214
Shear force	11.1^{a}±0.55	10.1^{ab}±0.55	10.2^{a}±0.58	8.7^{bc}±0.70	7.5^{c}±0.63

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, Section 3.4

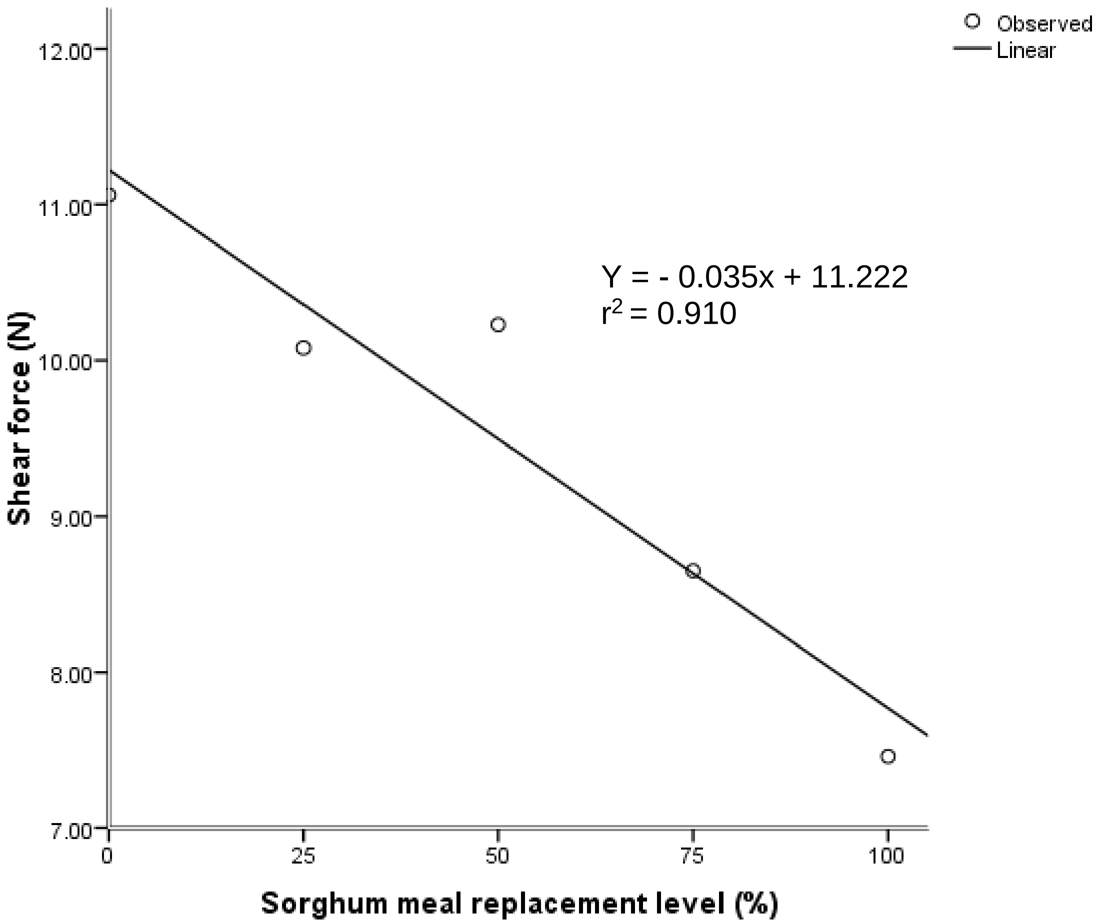


Figure 4.20 Relationship between replacement level of maize meal with sorghum meal and shear force (N) of male Ross 308 broiler chicken meat

Replacing maize meal with sorghum meal had no effect (P>0.05) on pH values of male Ross 308 broiler chicken meat (Table 4.12). Replacing maize meal with sorghum meal had no effect (P>0.05) on weight, length and diameter, ash, calcium and phosphorus contents of right tibia bone of male Ross 308 broiler chickens (Figure 4.21 and Table 4.13).

Table 4.12 Effect of replacing maize meal with sorghum meal on pH of male Ross 308 broiler chicken meat

Variable	*Diet				
	$GM_{100}S_0$	$GM_{75}S_{25}$	$GM_{50}S_{50}$	$GM_{25}S_{75}$	GM_0S_{100}
Breast	6.02±0.886	6.04±0.345	5.97±0.468	5.96±0.387	5.87±0.599
Drumstick	6.38±0.074	6.36±0.054	6.41±0.106	6.43±0.062	6.02±0.082
Thigh	6.37±0.080	6.36±0.082	6.38±0.089	6.42±0.083	6.43±0.080
Wing	6.35±1.044	6.42±0.063	6.45±0.062	6.42±0.070	6.45±0.118

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

* : Diet codes are described in Chapter 3, Section 3.4

Table 4.13 Effect of replacing maize meal with sorghum meal on weight (g), length (cm) and diameter (mm), and ash, calcium and phosphorus contents of right tibia bones of male Ross 308 broiler chickens

Variable	*Diet				
	$GM_{100}S_0$	$GM_{75}S_{25}$	$GM_{50}S_{50}$	$GM_{25}S_{75}$	GM_0S_{100}
Weight	14.00±0.549	14.33±0.541	13.06±0.579	14.44±0.693	13.54±0.629
Length	9.59±0.094	9.50±0.093	9.13±0.099	9.44±0.119	9.31±0.108
Diameter	8.90±0.354	8.69±0.349	8.96±0.374	8.64±0.447	9.12±0.406
Ash (%)	43.09±6.230	45.83±6.478	42.90±9.422	39.75±7.275	47.33±6.763
Ca(mg/L)	1338±113.6	1408±120.6	1183±117.0	1480±117.8	1293±123.1
P(mg/L)	471.8±52.87	513.3±120.63	433.3±79.95	520.5±61.73	475.3±57.40

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

* : Diet codes are described in Chapter 3, Section, 3.4

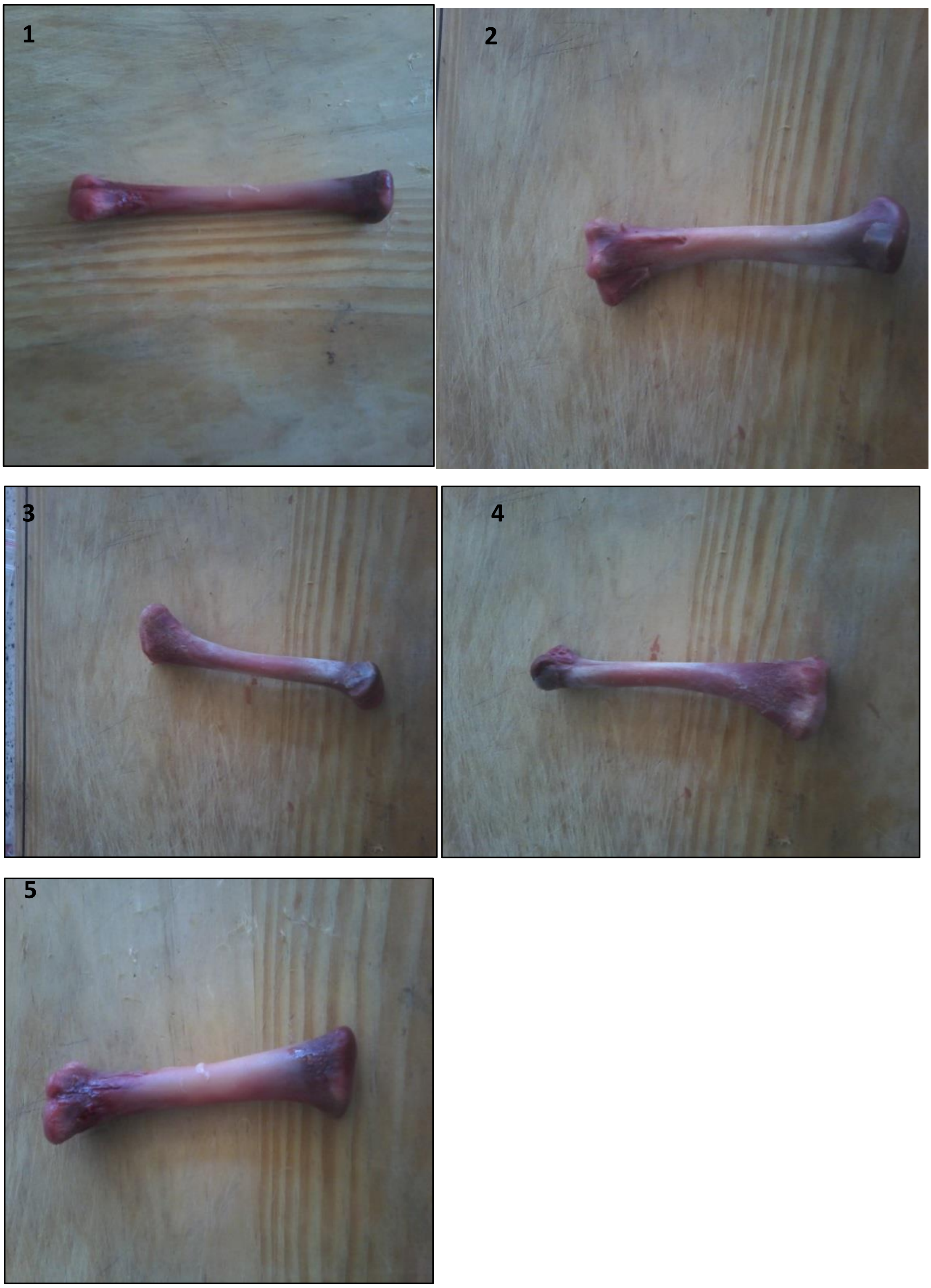


Figure 4.21 Right tibia images from 42 days old Ross 308 broiler chickens fed diets containing different levels of sorghum meal as a replacement for maize meal. 1 ($GM_{100}S_0$), 2 ($GM_{75}S_0$), 3 ($GM_{50}S_{50}$), 4 ($GM_{25}S_{75}$) and 5 (GM_0S_{100})

CHAPTER 5

DISCUSSION, CONLUSIONS AND RECOMMENDATIONS

5.1 Discussion

In the present study, white sorghum meal had higher energy, CP, ash and fat contents than yellow maize meal. This is similar to the observation made by Ahmed *et al.* (2013) that ME and CP of sorghum meal are higher than those of yellow maize meal. Yellow maize meal had higher ADF and NDF contents than sorghum meal. This is similar to the observation made by NRC (2012). The white sorghum meal had low contents of tannins, averaging 3.76%. Thus, traces of tannins were found in the diets where maize meal was replaced by sorghum meal at 25, 50, 75 or 100%. However, no traces of tannins were found in the diets containing 100% maize meal. The low levels of tannins found in the sorghum meal in the present study are similar to those reported by Kaijage *et al.* (2014) on the same sorghum line. The starter diets were formulated to have 21.5% crude protein and 16.5MJ of energy per kg DM. The diets met the nutrient requirements for broiler chickens as specified by McDonald *et al*. (2010) and ARC (1994).

Replacing maize meal with sorghum meal did not affect feed intake, growth rate, FCR, nitrogen retention (N-retention) and live weights of unsexed Ross 308 broiler chickens aged one to 21 days, possibly indicating that maize meal can be replaced by the low tannin white sorghum meal in a starter diet for broiler chickens without causing any adverse effects on the productivity of the chickens. This may be indicating that the tannins in the sorghum meal were very low to adversely affect diet intake, growth rate, FCR, live weight and nitrogen retention of the chickens. This is similar to the observation made by Nyamambi *et al.* (2007) and Ambula *et al.* (2001) that sorghum varieties with low tannin contents or detanninified sorghum meal can replace maize meal in the diets of broiler chickens without adversely affecting diet intake, growth rate, FCR, N-retention and live weight. Similar observations were made by Kwari *et al.* (2012) and Sharif *et al.* (2012). However, the present finding is contrary to the results of Garcia *et al.* (2005) who observed that replacing maize meal with sorghum 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 tannins found in sorghum meals used. Tannins bind with nutrients, thus rendering them unavailable for digestion (Makkar, 2003). However, Jama *et al.* (2014) observed that replacing maize meal with sorghum meal increased growth rates and live weights of chickens aged one to 21 days. The authors indicated that increased growth rates and live weights were due to increased feed intakes. However, Hassan *et al.* (2003) observed that sorghum meal with high tannin contents resulted in reduced energy, protein and specific amino acid utilization which resulted in poor FCR and growth rates of broiler chickens.

In the present study, replacing maize meal with sorghum meal improved ME intake by chickens except that similar ME intakes were observed when 25% of maize meal was replaced by sorghum meal. The reasons for no improvement in ME intake when 25% of the maize meal was replaced by sorghum meal are not clear. However, these results indicate that low tannin white sorghum meal can replace maize meal in the diets of broiler chickens aged one to 21 days without causing a reduction in ME intake. In fact, higher replacement levels of 75 and 100% sorghum meal increased ME intakes of the chickens. These results are similar to the observation made by Sonia *et al.* (2015). However, the present finding is contrary to the results of Kumar *et al.* (2007) and Antunes *et al.* (2006) who observed that replacing maize meal with sorghum meal reduced ME intake by broiler chickens. The authors indicated that high tannin levels in sorghum meal used tended to reduce diet digestibility and this adversely affected diet ME intake.

It is concluded that maize meal in the diets of broiler chickens aged one to 21 days can be replaced by a low tannin white sorghum meal at 25, 50, 75 and 100% levels without having adverse effects on productivity of the chickens.

Results of the present study showed that replacing maize meal with a low tannin white sorghum meal did not affect caecum and large intestine digesta pH values of unsexed Ross 308 broiler chickens aged 21 days, indicating that maize meal can be replaced by a low tannin white sorghum meal in a starter diet for broiler chickens without causing any adverse effects on caecum and large intestine digesta pH values. This may also be indicating that the tannins in the sorghum meal were very low to adversely affect caecum and large intestine digesta pH of unsexed Ross 308 broiler chickens. However, Shakouri *et al.* (2008) and Taylor and Jones (2004) found that replacing maize meal with sorghum 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 tannins which adversely affected changes in intestinal morphology, enzyme activities, gut microflora and nutrient digestibility.

Replacing maize meal with sorghum meal affected crop, gizzard and small intestine digesta pH of unsexed Ross 308 broiler chickens aged 21 days. Higher pH values were observed in these segments with higher sorghum meal inclusion levels. Reasons for this increase in crop, gizzard and small intestine pH values might possibly be because of a decrease in lactic acid production due to the tannins binding with proteins and other nutrients resulting in more digestion of fibrous materials which tends to favour high pH values (Amerah *et al.,* 2009; Perez *et al.,* 2011). This may have resulted in more cellulolytic bacteria that digest crude fibre (Ginindza *et al.,* 2017). This is similar to the observations made by Rodgers *et al.* (2005) who observed increased duodenum pH when chickens aged 21 to 42 days were fed diets having maize meal replaced by sorghum meal. However, the present findings are contrary to the results of Hinton *et al.* (2000) and Rodgers *et al.* (2005) who observed that sorghum meal reduced crop, gizzard and small intestine pH values of unsexed broiler chickens aged 21 days.

Results of the present study showed that replacing maize meal with a low tannin sorghum meal did not affect large intestine lengths of Ross 308 broiler chickens aged one to 21 days. This is similar to the observations made by Fernandez *et al.* (2013) that sorghum meal can replace maize meal in diets without adversely affecting large intestine lengths of broiler chickens. Garcia *et al.* (2005) observed that sorghum meals having low or high tannins had no influence on caecum length of broiler chickens. However, the present finding is contrary to the results of Thomas *et al.* (2007) and Campos *et al.* (2006) who reported decreased intestinal lengths of broiler chickens fed dried green tea leaves rich in tannins. The authors reported that tannins in dried green tea leaves might have inhibited gut growth in broiler chickens. Replacing maize meal with sorghum meal increased GIT, small intestine and caecum lengths of the chickens, possibly indicating longer times the digesta stays in the gut. The present findings are contrary to the results of Brenes *et al.* (2010) who observed decreased small intestine lengths of broiler chicks fed grape extracts which contained phytochemicals.

In the present study, replacing maize meal with sorghum meal did not affect crop, gizzard, caecum and large intestine weights of Ross 308 broiler chickens aged one to 21 days. This may be indicating that tannins were too low to adversely affect diet digestibility and hence gut organ weights of the chickens. This is similar to the observations made by Garcia *et al. (*2005) that low tannin sorghum meal can replace maize meal in the diets without causing any negative effect on gut organ weights. However, the present observations are contrary to the results of Nyamambi *et al.* (2007) who observed that replacing maize meal with sorghum meal reduced gut organ weights of broiler chickens aged one to 21 days. The present study indicates that replacing maize meal with a low tannin sorghum meal increased small intestine weights of unsexed broiler chickens aged one to 21 days. However, the present findings are contrary to the results of Nyamambi *et al.* (2007) who observed that sorghum meal inclusions reduced small intestine weights of broiler chickens aged one to 21 days.

Results of the present study indicate that replacing maize meal with sorghum meal did not affect villi height, crypt depth and villi height to crypt depth ratio of Ross 308 broiler chickens aged one to 21 days. The reason might be that tannin contents in the sorghum were too low to adversely affect diet digestibility, and hence the villi length and depth of chickens. This is similar to observations made by Torres *et al.* (2012) and Fernandez *et al.* (2013) that there were no differences in villi heights and crypt depths when dietary maize meal was replaced by sorghum meal in broiler chickens aged one to 21 days. However, the results of the present study are contrary to those of Nyamambi *et al.* (2007) who observed that replacing maize meal with sorghum meal decreased villi heights and crypt depths in broiler chickens fed diets differing in condensed tannin levels. The authors indicated that reduced villi height and crypt depth were due to the presence of condensed tannins which might have damaged the intestinal villi.

The grower diets were formulated to contain 20% crude protein and 17.5MJ of energy per kg DM. The diets met the nutrient requirements for broiler chickens as specified by McDonald *et al*. (2010). The sorghum meal used in this experiment was the same as that used in the starter experiment and described earlier, Chapter 5.1. In the present study, replacing maize meal with a low tannin sorghum meal did not affect feed intake, FCR, live weight and nitrogen retention (N-retention) of male Ross 308 broiler chickens aged 22 to 42 days. This, may, possibly be indicating that maize meal can be replaced by a low tannin white sorghum meal in diets for broiler chickens aged 22 to 42 days without causing any adverse effects on intake, FCR, live weight and N-retention. This may, also, be indicating that the tannins in the sorghum meal were too low to adversely affect nitrogen retention, diet intake, FCR and live weight of the chickens. This is similar to the findings made by Hernandez *et al.* (2011) and Sana *et al.* (2014) that sorghum varieties with low tannin contents can replace maize meal in the diets of broiler chickens without adversely affecting nitrogen retention, diet intake, FCR and live weight. However, the present findings are contrary to the observations that broiler chickens fed sorghum meal had decreased nitrogen retention (Selle *et al.*, 2010), poor FCR and decreased live weight (Crisol Martines *et al.,* 2017) and decreased diet intake (Yunusa *et al.,* 2015). Selle *et al.* (2010) indicated that tannins contained in sorghum bind with proteins in the gut, resulting in reduced nitrogen retention. Yunusa *et al.* (2015) indicated that reduced intake and live weights of broilers on sorghum diets might be due to poor nutrient digestibility as a result of high levels of tannins which bind with other nutrients, making such nutrients indigestible. Stanley *et al.* (2016) reported that sorghum-based diets with moderate digestibility values tend to show poor FCR values and decreased live weights because of low intakes.

Results of the present study showed that replacing maize meal with a low tannin sorghum meal did not adversely affect growth rate of male Ross 308 broiler chickens aged 22 to 42 days. In fact, higher inclusion levels of 75 and 100% increased growth rates of the chickens. This might be because low tannin contents in the sorghum did not adversely affect nutrient availability in the gut. It is, also, possible that low levels of tannins in a diet may have beneficial effects on growth rates of chickens (Torres *et al.,* 2012). This is similar to the results of Fernandez *et al.* (2008) which showed that inclusion of low tannin sorghum meal had no effect on growth rates of broiler chickens aged 22 to 42 days. However, the present results are contrary to the observations made by Selle *et al.* (2010) that tanniniferous sorghum meal reduces growth rates of broiler chickens. The authors indicated that tannins, phytates and kaffirins found in sorghum meal reduce nutrient availability which results in reduced growth rates.

Replacing maize meal with a low tannin white sorghum meal tended to improve ME intake by broiler chickens aged 22 to 42 days. Increased ME intakes were observed when 75 or 100% of maize meal was replaced by the low tannin white sorghum meal. The reasons for increased ME intake might have been that tannins present in sorghum were too low to adversely affect nutrient availability in the diets when 75 or 100% of the maize meal was replaced by sorghum meal. It may, also, be an indication that low tannin levels may be having beneficial effects on ME intake. This is similar to the findings of Black *et al.* (2005) who observed increased ME intake in broiler chickens fed low tannin sorghum-based diets. However, the present finding is contrary to the results of Sultan *et al.* (2014) and Selle *et al.* (2010) who observed that replacing maize meal with sorghum meal reduced ME intake by broiler chickens. The authors indicated that high tannins in sorghum meal tended to reduce diet digestibility which adversely affected diet ME intake.

It is concluded that maize meal in the diets of broiler chickens aged 22 to 42 days can be replaced by a low tannin white sorghum meal at 25, 50, 75 and 100% levels without causing adverse effects on productivity of the chickens. Higher replacement levels of 75 or 100% tended to increase ME intakes and hence growth rates of the chickens.

Results of the present study showed that replacing maize meal with a low tannin white sorghum meal did not affect caecum and large intestine digesta pH values of male Ross 308 broiler chickens aged 42 days, possibly indicating that maize meal can be replaced by the low tannin white sorghum meal in a grower diet for broiler chickens without any adverse effects on pH values. This may also be indicating that the tannins in the sorghum meal were low to adversely affect caecum and large intestine digesta pH values of the chickens. Thus, sorghum meal can be used to replace maize meal in broiler chickens. Replacing maize meal with sorghum meal affected crop, gizzard and small intestine digesta pH values in broiler chickens aged 42 days. Increases in crop and small intestine digesta pH values were observed with increases in sorghum inclusion levels. Reasons for these increases in the crop and small intestine digesta pH values might be due to the tannins binding with proteins and other nutrients which resulted in decrease in lactic acid production which favoured cellulolytic digestion. This is similar to the observation made by Hinton *et al.* (2000) that high crop pH values were recorded in broiler chickens fed diets with high levels of sorghum meal. However, a lower gizzard digesta pH was observed when sorghum meal replacement levels were at 75 and 100%. The reasons for these decreases as sorghum meal levels increased are not clear. This is similar to the observations made by Nkukwana *et al.* (2015) who found acidic conditions in gizzards of chickens fed *Moringa oleifera* leaf meals which contained phytochemicals which contained to tannins.

Results of the present study showed that replacing maize meal with a low tannin sorghum meal did not affect gastro-intestinal tract (GIT), caecum and large intestine lengths of Ross 308 broiler chickens aged 42 days. This may be indicating that tannin levels in sorghum meal were too low to adversely affect GIT, caecum and large intestine lengths of broiler chickens. Garcia *et al.* (2005), also, found no effect of sorghum meal on caecum lengths of broiler chickens. Silva *et al.* (2013) and Garcia *et al*. (2005) reported that sorghum meal with low tannins can replace maize meal in diets without adversely affecting duodenum, jejunum and large intestine lengths. However, replacing maize meal with sorghum meal, in the present study, increased small intestine lengths. These results are contrary to those reported by Fernandes *et al.* (2008), who observed no effects of replacing maize meal with sorghum meal on small intestine lengths of broiler chickens.

In the present study, replacing maize meal with sorghum meal did not affect small intestine, caecum and large intestine weights of Ross 308 broiler chickens aged 42 days. This may be indicating that the tannins were too low to adversely affect gut organ weights of the chickens. Silva *et al.* (2013), Kumar *et al.* (2005) and Tyagi *et al.* (2003) observed similar results in broiler chickens. However, the present findings are contrary to the results of Fernandes *et al.* (2008) who observed increases in small intestine weights of broiler chickens aged 42 days with increases in sorghum meal replacement levels. Similarly, Adamu *et al.* (2002) and Gebeyew *et al. (*2015) observed increases in large intestine weights with increases in sorghum meal replacement levels. Replacing maize meal with sorghum meal increased crop and gizzard weights of male

Ross 308 broiler chickens. The reason for the increases in crop and gizzard weights might be that chickens found it hard to digest tannins present in the diet and, thus, stimulated an increase in grinding power which resulted in heavier organ weights. The present findings are similar to the results of Sannamani (2002) who reported significantly higher gizzard weights in broiler chickens fed red sorghum-based diets.

Replacing maize meal with sorghum meal, in the present study, did not affect villi height, crypt depth and villi height to crypt depth ratio of Ross 308 broiler chickens aged 42 days. The reason may be that tannin contents in the sorghum meal were too low to adversely affect the villi height of the chickens. This is similar to the findings by Silva *et al.* (2015) and Campos (2006) who observed no differences in villi heights and crypt depths in broiler chickens. However, Kavoi *et al. (*2017) observed a deepening in crypt depth and shorter villi height. These authors reported that phytochemicals in *Moringa oleifera* leaves disrupt mitotic activity within the crypts resulting in lack of epithelial cell replacement, resulting in the absence of the mitotic and goblet cells. Furthermore, deepening of the crypt and lengthening of the villus cannot take place in the absence of activated cell mitosis (Sahin *et al.,* 2006).

Results of the present study showed that replacing maize meal with a low tannin white sorghum meal did not affect drumstick, thigh and wing weights of Ross 308 broiler chickens aged 22 to 42 days. This means sorghum meal can replace maize meal in the diets without any adverse effects on drumstick, thigh and wing weights. This is contrary to the observation made by Gebeyew *et al.* (2015) who found that replacement of maize meal with tanniniferous sorghum meal resulted in smaller drumstick and thigh weights. In the present study, replacing maize meal with sorghum meal increased carcass and breast weights of male Ross 308 broiler chickens aged 22 to 42 days. An increase in sorghum meal inclusion level resulted in heavier carcass and breast weights. This means that maize meal can be replaced with sorghum meal in the diets of broiler chickens aged 22 to 42 days. The results of the present study are contrary to those of Torres *et al.* (2013) and Kumar *et al.* (2005) who found that carcass and breast yields were not affected by different levels of tannins in sorghum meal.

The present study showed that replacing maize meal with a low tannin white sorghum meal did not affect colour of drumstick, thigh and wing meat of Ross 308 broiler chickens aged 42 days. This means that sorghum meal can replace maize meal without causing any adverse effects on the colour of drumstick, thigh and wing meat. However, maize meal with sorghum meal affected the colour of breast meat of Ross 308 broiler chickens aged 42 days. Chickens on diets with sorghum meal had lighter breast meat than those on 100% maize meal diet. A 65.30% inclusion level was calculated to produce optimal breast meat lightness. According to Garcia (2005) light colour is an indication of meat freshness and directly influences the consumer's final purchase decision. Therefore, maize meal can be replaced by sorghum meal without having any negative effect on lightness of breast meat of broiler chickens. Replacing maize meal with sorghum meal in the diets of broiler chickens resulted in having breast meat with lower redness colour values. The present results are contrary to the observation made by Garcia (2013) who observed redness colour value increased with sorghum inclusion increased. Sorghum meal inclusions in the diets affected breast meat yellowness. The sorghum meal inclusion levels of 32% optimized breast meat yellow. The present results are contrary to observations made by Souza *et al.* (2015) who found a linear increase in the b* values of broiler chickens breast meat in sorghum-containing diets.

Replacing maize meal with a low tannin white sorghum meal, in the present study, did not affect meat pH 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 broiler were not affected by the substitution of corn with sorghum meal in the diet. According to Fletcher *et al.* (2000), the pH of normal chicken breast meat ranges between 5.7 and 5.96 and between 6.10 and 6.20 for normal chicken thigh meat. The pH values obtained in the present study are within the normal values as stated by Fletcher *et al.* (2000). Thus, sorghum meal can replace maize meal in the diets without any effect on meat pH values of broiler chickens.

Results of the present study showed that replacing maize meal with a low tannin white sorghum meal did not affect meat flavour, tenderness and juiciness of Ross 308 broiler chickens aged 42 days. This is similar to the results of Moreki *et al.* (2012) who observed no difference on aroma, tenderness and flavour of guinea fowls fed maize meal replaced by sorghum meal. Results of the present study indicate that replacement of maize meal with sorghum meal in the diets affected broiler chicken meat shear force values. Meat from chickens on diets having higher sorghum meals (75% or 100% replacement levels) tended to be softer than the meat from chickens on diets having 100% maize meal. No similar study was found in chickens. However, Moyo *et al.* (2014) found that goats fed *Moringa olifera* which is rich in tannins have softer meat.

Results of the present study showed that replacing maize meal with a low tannin white sorghum meal did not affect weight, length, diameter, ash, calcium and phosphorus contents of right tibia bones of male Ross 308 broiler chickens aged 42 days. The current results are consistent with the results of Chiripasi *et al.* (2013) who did not find any significant differences on bone lengths and widths of broiler chickens fed sorghum, millet or maize-based diets. However, in contrary Chiripasi *et al.* (2013) found a decrease Ca and P content in birds fed diets containing sorghum compared to birds fed millet or maize-based diets. However, sorghum is known to contain anti-nutritional factors such as tannins and phytates which reduce availability and utilisation of minerals to the guinea fowl (Pinter *et al.,* 2005). The present results are contrary with those of Moreki *et al.* (2011a) who reported that tibia lengths in broiler chickens fed sorghum-based diets increased with an increase in sorghum inclusion levels. The current results on bone ash are contrary to those of Moreki and Kelemogile (2012) who reported a decrease of bone ash in broilers. The authors indicated that a decline in bone ash could be associated with an increase in cereal grains (maize, millet and sorghum) in the diets of the birds which tend to displace calories provided by other feed ingredients thus, disrupting adequate nutritional balance which affects 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 the broiler chickens. Thus, any differences in responses must have been due to sorghum meal that replaced maize meal in the diets. Replacement of maize meal with sorghum meal had no effect on feed intake, growth rate, FCR, nitrogen retention and live weights of unsexed Ross 308 broiler chickens aged one to 21 days. However, higher replacement levels of maize meal with sorghum meal improved ME intake of unsexed broiler chickens. Further studies are recommended to determine why improved ME intake did not result in higher growth rates and live weights of unsexed Ross 308 broiler chickens aged one to 21 days. Replacing maize meal with sorghum meal did not affect caecum and large intestine digesta pH values, large intestine lengths, and crop, gizzard, caecum and large intestine weights of unsexed Ross 308 broiler chickens. Replacing maize meal with sorghum meal did not affect villi height, crypt depth and villi height to crypt depth ratio of Ross 308 broiler chickens aged one to 21 days. It is concluded that maize meal in the diets of broiler chickens aged one to 21 days can be replaced by a low tannin white sorghum meal at 25, 50, 75 and 100% levels without having adverse effects on productivity of the chickens.

Replacing maize meal with a low tannin sorghum meal did not affect feed intake, FCR, live weight and nitrogen retention of male Ross 308 broiler chickens aged 22 to 42 days. However, replacement of maize meal with sorghum meal improved ME intake of male broiler chickens. It is concluded that maize meal in the diets of broiler chickens aged 22 to 42 days can be replaced by a low tannin white sorghum meal at 25, 50, 75 and 100% levels without causing adverse effects on productivity of the chickens. Higher replacement levels of 75 or 100% increased ME intakes and hence growth rates of the chickens aged 21 to 42 days. Further studies are recommended to determine why higher ME intakes and growth rates did not result in higher live weights of male Ross 308 broiler chickens aged 22 to 42 days.

Replacing maize meal with a low tannin white sorghum meal did not affect caecum and large intestine digesta pH, gastro-intestinal tract (GIT), caecum and large intestine lengths, small intestine, caecum and large intestine weights, villi length, crypt depth and villi length to crypt depth ratio of male Ross 308 broiler chickens aged 22 to 42 days. However, an increase in sorghum inclusion level increased crop, gizzard and small intestine digesta pH, small intestine lengths, and crop and gizzard weights of male Ross 308 broiler chickens. Replacing maize meal with a low tannin white sorghum meal did not affect drumstick, thigh and wing weights, colour of drumstick, thigh and wing meat, breast, drumstick, thigh and wing meat pH of Ross 308 broiler chickens. Therefore, maize meal can be replaced by a low tannin sorghum meal in chicken diets without having any adverse effects on broiler chicken meat weight, colour and pH. There is need to do further studies on this to determine factors that tend to differently affect productivity responses, depending on the parameter, to sorghum meal replacement levels.

Replacing maize meal with sorghum meal in the diets did not affect male Ross 308 broiler chicken meat tenderness, juiciness and flavour. Replacing maize meal with a low tannin white sorghum meal reduced meat shear force values. Thus, low tannin white sorghum meal can replace maize meal in the diet without affecting chicken meat sensory attributes.

5.3 General conclusions and recommendations

Replacing maize meal with sorghum meal did not affect diet intake, FCR, N-retention and live weight of Ross 308 broiler chickens aged one to 21 days and those aged 22 to 42 days. Higher sorghum meal replacement levels improved ME intake of broiler chickens at both grower and finisher phases. Replacing maize meal with sorghum meal did not affect growth rate of broiler chickens aged one to 21 days. However, chickens aged 22 to 42 days reacted differently to sorghum replacements. Growth rate of broiler chickens age 22 to 42 days increased with increase in sorghum meal replacement level, indicating some beneficial effects of a low tannin white sorghum meal. Thus, maize meal can be replaced by a low tannin white sorghum meal in the diets of broiler chickens at the starter and grower phases without any adverse effects on growth rate and live weight of the chickens.

Replacing maize meal with sorghum meal affected gut organ digesta pH values. Replacing maize meal with sorghum in the digest increased crop, gizzard and small intestine digesta pH values of chickens aged one to 21 days. However, replacing maize meal with sorghum meal decreased gizzard digesta pH in chickens aged 22 to 42 days. Sorghum meal replacement levels of 76 and 65% optimized small intestine digesta pH of broiler chickens aged one to 21 days and 22 to 42 days, respectively. Thus, there is some indication that chickens reacted differently to replacement of maize meal with sorghum meal depending on the age of the chickens.

Replacing maize meal with sorghum meal affected GIT and intestinal lengths differently, depending on the age of the chickens. Gastro-intestinal tract lengths of the chickens aged one to 21 days increased with increase in sorghum meal replacement level while GIT lengths of chickens aged 22 to 42 days were not affected by sorghum replacement level. Gizzard and crop weights of broiler chickens aged one to 21 days were not affected by sorghum meal replacement level while gizzard and crop weights of broiler chickens aged 22 to 42 days increased with increase in sorghum meal replacement level. Replacing maize meal with sorghum meal did not affect villi height, crypt depth and villi height to crypt depth ratio of broiler chickens aged one to 42 days.

It is concluded that maize meal can be replaced with a low tannin white sorghum meal in the diet without having adverse effects on productivity of Ross of boiler chickens aged one to 42 days. However, age of the chicken defined some responses to replacement of maize meal with a low tannin white sorghum meal. Further studies are recommended to determine why age of the chicken defines responses to replacing maize meal with a low tannin white sorghum meal.

CHAPTER 6

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