CRUDE FIBRE DIGESTION IN BROILER AND INDIGENOUS VENDA CHICKENS

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CRUDE FIBRE DIGESTION IN BROILER AND INDIGENOUS VENDA CHICKENS

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PROMOTER : PROF JW NG’AMBI

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DECLARATION

I declare that the thesis hereby submitted to the University of Limpopo for the degree of Doctor of Philosophy (Animal Nutrition) has not previously been submitted by me for a degree at this or any other university, that it is my own work in design and execution and that all material contained therein has been duly acknowledged.

05/08/2020

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Ginindza, M.M. Date

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DEDICATION

This thesis is dedicated to my late father, Hynd Dumsani Ginindza. I am forever grateful for the love, encouragement and many life lessons that I was taught. I, also, would like to dedicate this work to all my siblings Sifiso, Themba, Nomcebo and Mabandla Ginindza.

ABSTRACT

A study was conducted to determine the effect of dietary crude (CF) levels of (3, 4, 5 and 7 %) on feed intake, digestibility, growth rate, feed conversion ratio (FCR) and live weight of male Ross 308 broiler and indigenous Venda chickens aged 1 to 42 days. The study, also, determined the effect of dietary CF level on the gastrointestinal morphology and digesta pH of gut organs of male Ross 308 broiler and indigenous Venda chickens aged 42 days.

Dietary CF levels affected ($P<0.05$) feed intake, growth rate and live weight of male Ross 308 broiler and Venda chickens aged 1 to 21 days. A dietary CF level of 3.9 % optimized feed intake, while 4.5 % dietary CF optimized growth rate and live weight in male Ross 308 broiler chickens. However, dietary CF levels of 4.4, 4.8, 5.9 and 4.7 % optimized feed intake, growth rate, FCR and live weight, respectively, of male Venda chickens aged 1 to 21 days. Therefore, dietary CF level for optimal productivity depended on the breed of the chicken and production parameter of interest. Higher dietary CF levels decreased ($P<0.05$) crude protein (CP), neutral detergent fibre (NDF) and acid detergent fibre (ADF) digestibility values in male Ross 308 broiler chickens. Dietary CF levels of 3.8, 3.7 and 4.1 % optimized dry matter (DM) digestibility, metabolizable energy (ME) intake and nitrogen retention, respectively, in male Ross 308 broiler chickens aged 14 to 21 days. Increased dietary CF level, also, decreased ($P<0.05$) NDF and ADF digestibility values in male Venda chickens aged 14 to 21 days. Dry matter and CP digestibility values, ME intake and nitrogen retention of Venda chickens were optimized at dietary CF levels of 3.5, 3.7, 3.3 and 4.1 %, respectively.

Feed intake of male Ross 308 broiler chickens aged 22 to 42 days were affected ($P<0.05$) by dietary CF level; and it was optimized at a dietary CF level of 6.4 %. Increased dietary CF level resulted in poorer growth rate, FCR and live weight of male Ross 308 broiler chickens. However, dietary CF levels of 4.5, 5.8, 6.4 and 5.7 %, optimized feed intake, growth rate, FCR and live weight, respectively, of male Venda chickens aged 22 to 42 days. Dietary CF levels of 3.4, 4.4, 3.7 and 4.4 %, optimized DM, CP and NDF digestibility values, and nitrogen retention, respectively, in male Ross 308 broiler chickens. However, dietary CF levels of 5.1, 5.3, 4.9, 10.1 and 5.1 % optimized DM, CP, NDF and ADF digestibility values, and nitrogen retention, respectively, of male Venda chickens. Therefore, dietary CF level for optimal response in the chickens depended on breed, age and production variable of interest.

The GIT weight of male Ross 308 broiler chickens was optimized at a dietary CF level of 4.1 %. In increased dietary CF level in male Ross 308 broiler chickens increased gizzard weights and decreased small intestine weights ($P<0.05$). Dietary CF levels of 6.3, 5.9 and 8.0 % optimized GIT, gizzard and caecum weights, respectively, in male Venda chickens. The small intestine weight of male Venda chickens was not affected ($P<0.05$) by dietary CF level. Caecum weight of male Venda chickens increased ($P<0.05$) with higher dietary CF level. However, caecum weights of male Ross 308 broiler chickens were not affected ($P>0.05$) by dietary CF level.

The GIT and small intestine lengths were affected ($P<0.05$) by dietary CF level in male Ross 308 broiler chickens. Dietary CF levels of 5.6 and 5.5 % optimized GIT and small intestine lengths, respectively. However, in male Venda chickens, GIT and small intestine lengths were not affected ($P>0.05$) by dietary CF level.

Digesta pH of the proventriculus and gizzard were affected ($P<0.05$) by dietary CF level in male Ross 308 broiler and Venda chickens. Different dietary CF levels of 5.5 and 7.4 % optimized the proventriculus and gizzard digesta pH in male Ross 308 broiler chickens, respectively. However, dietary CF levels of 4.2 and 4.3 % optimized the proventriculus and gizzard digesta pH values, respectively, in male Venda chickens. The two breeds of chickens had similar digesta pH values of the crop, proventriculus, gizzard and large intestines. However, male Venda chickens had higher ($P<0.05$) small intestine digesta pH values than male Ross 308 broiler chickens aged 42 days. Caecum digesta pH values of Ross 308 broiler chickens were higher ($P<0.05$) than those of Venda chickens aged 42 days.

The second study was conducted to determine the effect of sodium bicarbonate supplementation level in the drinking water on feed intake, digestibility, FCR, growth rate, gut organ weight, length and digesta pH of male Ross 308 broiler and Venda chickens aged 22 to 42 days. The study, also, determined the effect of sodium bicarbonate supplementation level in drinking water on types of bacterial species in crop and gizzard digesta, as well as its effect on meat quality of male Ross 308 broiler and indigenous Venda chickens. Increased sodium bicarbonate supplementation level increased ($P<0.05$) water pH. Supplementation levels of 8.9, 2.04, 2.97 and 2.97 g of sodium bicarbonate per litre of drinking water optimized water intake, feed intake, growth rate and live weight of male Ross 308 broiler chickens, respectively. In male Venda chickens, there was a strong and positive relationship between sodium bicarbonate supplementation level and water intake of Venda chickens. A single supplementation level of 3.8 g of sodium bicarbonate per litre of drinking water optimized growth and live weight of male Venda chickens. There was a negative relationship between sodium bicarbonate supplementation level in the drinking water and NDF digestibility of male Ross 308 broiler chickens. Supplementation levels of 2.63, 6.67 and 7.0 g of sodium bicarbonate per litre of drinking water optimized DM and CP digestibility values, and nitrogen retention, respectively, in male Ross 308 broiler chickens. However, supplementation levels of 3.2 and 4.52 g of sodium bicarbonate per litre of drinking water optimized DM and NDF digestibility values, respectively, in male Venda chickens. There were negative relationships between sodium bicarbonate supplementation level in the drinking water and CP digestibility and nitrogen retention of male Venda chickens. Supplementation levels of 5.7, 2.2, 3.8, 7.6 and 7.2 g of sodium bicarbonate per litre of drinking water optimized proventriculus, gizzard and small intestinal weights, and GIT and small intestines lengths, respectively, in male Ross 308 broiler chickens. However, a sodium bicarbonate supplementation level of 2.8 % optimized proventriculus weights of male Venda chickens; the other digestive organ weights and lengths of Venda chickens were not affected ($P>0.05$) by sodium bicarbonate supplementation level.

Sodium bicarbonate supplementation in the drinking water affected bacterial species found in the crops and gizzards of the chickens. There were different bacterial species found in the crop and gizzard digesta of male Ross 308 broiler and Venda chickens. Meat colour (L^*, a^* and b^*) of the breasts and thighs of both breeds of chickens were not affected ($P>0.05$) by sodium bicarbonate supplementation. However, the redness (a^*) values of the breast meat of male indigenous Venda chickens were higher ($P<0.05$) than those of breast meat from male Ross 308 broiler chickens. Sodium bicarbonate supplementation level did not affect ($P>0.05$) breast meat tenderness, juiciness, flavour and overall acceptability values and meat pH of Ross 308 broiler chickens. Supplementation levels of 3.6, 3.2 and 4.7 g of sodium bicarbonate per litre of drinking water optimized meat juiciness, flavour and shear force of male Venda chickens, respectively. It was concluded that sodium bicarbonate supplementation in the drinking water affected growth, NDF digestibility and bacterial species composition of male Ross and Venda chickens. Sodium bicarbonate supplementation level for optimal response in chickens depended on the breed and production variables of interest.

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CHAPTER 1

INTRODUCTION

1.1 Background

Crude fibre (CF) is naturally present in plant-based feed ingredients that makes up a relatively small fraction in poultry diets but has a significant presence (Sadeghi *et al.*, 2015). It contributes to the nutritive value of diets directly as an energy source and indirectly, through its effects on digestive and metabolic processes (Annison, 1993, Choct *et al.*, 1996, Smits *et al.*, 1998,Smits *et al.*, 2000, Jamroz *et al.*, 2002, Montagne *et al.*, 2003). While it is important in ruminant nutrition for deriving energy and other essential nutrients, it is poorly digested in the gut of poultry. Digestibility coefficients vary between avian species and, also, within breeds. There are other factors leading to this poor digestibility and they include age of animals, source of fibre, plant maturity with respect to lignification, nutrient composition of feed ingredient and the presence of other dietary components such feed additives (Beeli *et al.*, 2002; Jimenez-Moreno *et al.*, 2009; McDonald *et al.*, 2010; Svihus, 2010).

Poultry diets contain 60 to 70 % cereal grains. Cereals such as maize (*Zea mays*), sorghum (*Sorghum bicolor*), rice (*Oryza sativa*), wheat (*Triticum aestivum*), oats (*Avena sativa*), rye (*Secale cereale*) and barley (*Hordeum vulgare*) are all used in poultry diets in different parts of the world (Perez-Bonilla *et al.*, 2014). However, they are also demanded for human consumption. Furthermore, the demand for such cereals is exacerbated by the need for them as fuel supply. According to Locke and Henley (2013) the use of grains for biofuel production and animal feed has risen substantially over the last decade for two main reasons: (1) biofuel production has been triggered mainly by the creation of demand for biofuels through fixed mandates and the increased profitability of production in the light of rising oil prices. (2) The expansion of animal feed production has mirrored the rise in intensive animal production systems in both developed and developing countries.

The substantial amount of cereal grains required for poultry nutrition inherently contains substantial amounts of crude fibre, ranging from 3% in maize to 4% in wheat (McDonald *et al.*, 2010). Other sources of fibre include oilseed meals used for energy and also leafy plant (McDonald, *et al*, 2010; Gakuya *et al.*, 2014). These present a problem for chickens since CF is not well digested in poultry (Varastegani and Dahlan, 2014).

Recent studies show evidence that an amount of crude fibre in the diet of chickens is important for growth and development of the gut (Jimenez-Moreno *et al.*, 2009; Gonzalez-Alvarado *et al.,* 2010; Jimenez-Moreno *et al.* 2010; Jimenez-Moreno *et al.,* 2011). Hence, dietary crude fibre requirements for broiler chickens need to be reassessed. On the other hand indigenous chickens scavenge and thrive on a diverse resource base. Indigenous chickens have been found to tolerate high levels of dietary crude fibre. The adaptation of these chickens to such diets is not understood. This ensures better understanding of the usage of feed resources for poultry in order to improve feed efficiency, thus, improving the impact on climate change.

1.2 Problem statement

Broiler and indigenous Venda chickens are economically and nutritionally important to farmers and rural households of South Africa (Alabi *et al.*, 2013). Broiler chickens have been selectively bred for high growth rates (Pauwels *et al.*, 2015). Feeds of high quality are, therefore, required to support their high growth potentials (Dozier *et al.,* 2010). Thus, broiler chickens compete with human beings for cereal grains (Dozier *et al.,* 2010). However, indigenous Venda chickens have low growth rates and sustain themselves on feeds of low quality.

Generally, chicken feeds are based on cereal grains which are high in structural carbohydrates, like cellulose (Blair, 2008). Chickens do not produce enzymes essential for digesting celluloses and hemicelluloses found in cereal grains and other feed ingredients (Sacranie *et al.,* 2012). However, they host microbial organisms in the gut that have the ability to aid fermentation of structural carbohydrates. This potential has not been fully researched and merits further study. High dietary CF leads to low digestibility and intake of diets, resulting in low feeding values (Sacranie *et al.,* 2012). Broiler chickens feeding on such diets have low growth rates (Hetland *et al.,* 2005). A comparison with indigenous chickens show that indigenous chicken breeds tend to digest diets high in CF better than broiler chickens (Goromela *et al.*, 2006; Mabelebele *et al.,* 2014; Varastegani and Dalhan, 2014). Reasons for this advantage are not clear. Some studies indicate that Venda chickens, an undeveloped chicken breed found in South Africa and other Southern African countries, have relatively heavier gizzard weights and higher gut pH values than broiler chickens (Mabelebele *et al.,* 2014). It is, therefore, important to determine whether higher gut pH values in Venda chickens provide advantages which enable them to thrive even on fibrous diets.

Manipulating gut pH values in cattle through supplementation with buffers such as sodium bicarbonate affects cellulolytic microbial populations and hence fibre digestibility (Anantasook *et al.,* 2013; Wanapat *et al.,* 2014). There is little information on the effects of such a buffer on crude fibre digestibility in chickens.

1.3 Aim of the study

The aim of the study was to determine optimal production responses of Ross 308 broiler and indigenous Venda chickens to different dietary crude fibre levels and sodium bicarbonate supplementation levels.

1.4 Objectives

The objectives of the study were to:

I. determine the effect of dietary crude fibre level on feed intake, digestibility, growth rate, feed conversion ratio and mortality of Ross 308 broiler and Venda chickens aged one to 21 days.
II. determine the effect of dietary crude fibre level on feed intake, digestibility, growth rate, feed conversion ratio, enzyme activities, gut pH, gut micro-organisms, haematology and serum biochemistry of Ross 308 broiler and Venda chickens aged 22 to 42 days.
III. determine the effect of bicarbonate of soda supplementation level in drinking water on feed intake, digestibility, growth rate, feed conversion ratio, gut digesta pH and gut micro-organisms of Ross 308 broiler and Venda chickens aged 22 to 42 days.

1.5 Hypotheses

The hypotheses of the study were as follows:

I. Dietary crude fibre level has no effect on feed intake, digestibility, growth rate, feed conversion ratio and mortality of Ross 308 broiler and Venda chickens aged one to 21 days.
II. Dietary crude fibre level has no effect on feed intake, digestibility, growth rate, feed conversion ratio, enzyme activities, gut pH, gut micro-organisms, haematology and serum biochemistry of Ross 308 broiler and Venda chickens aged 22 to 42 days.
III. Sodium bicarbonate supplementation level in drinking water has no effect on feed intake, digestibility, growth rate, feed conversion ratio, gut digesta pH and gut micro-organisms of Ross 308 broiler and Venda chickens aged 22 to 42 days.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Poultry production is an important and diverse component of the agricultural sector that is concerned with producing eggs and meat. These form part of a healthy diet for larger populations all over the world. Chickens are the most popular poultry worldwide irrespective of culture and region (Dessie *et al.*, 2012). The largest proportion of chicken meat and eggs are produced by intensive poultry farming (Nkukwana, 2018). Poultry meat represents almost one-third of meat produced and consumed globally (FAO, 2013).

Domestic chickens are closely associated with humans, and they rely entirely upon humans for their dispersal and indirectly for their survival (Mwacharo *et al.*, 2013). This relationship has long been in existence. Chickens originated from the red jungle fowl (*Gallus gallus*) endemic to sub-Himalayan northern India, southern China and Southeast Asia (Delacour, 1977) and were domesticated over 6 000 to 8 000 years ago (Moreng and Avens, 1985; Crawford, 1990; Sullivan, 1991; Siegel *et al.*, 1992; Fumihito *et al.*, 1994). Its spread to West Asia, Maditerranean and Europe following domestication remains largely unknown. Furthermore, the domestic chickens in Africa, though abundant, were introduced through North Africa, Egypt and the Nile Valley about 2,500 years ago from Asia (Mwacharo *et al.*, 2013).

Today, we have chickens that have been selectively bred for high growth performance (Leeson *et al.*, 1996). Indigenous chickens remain undeveloped and possess qualities that have enabled them to adapt well over time (Leroy *et al.*, 2012). The development of the poultry industry from backyard production and into specialized concentrated poultry farming transitioned in less than a century (Leeson and Summers, 2005). This has been brought about by scientific achievements in poultry breeding and genetics, poultry nutrition, housing, management and disease control (Hunton, 1990).

Poultry production, in Africa, has a significant contribution to food security in most rural communities as well as poultry enterprises in semi-urban areas (Mbajiorgu *et al.,* 2011; Wong *et al.*, 2017). They are raised under different production systems, i.e. extensive and in some cases intensive. About 74 % of the world's poultry meat, and 68 % of eggs are produced through intensive systems (Wong *et al.*, 2017). The products are the protein sources of choice for consumers, which happen to be affordable and available. Furthermore, consumers prefer the taste of chicken and eggs over other protein sources, particularly, indigenous chicken meat (Mulder, 2017). Other by-products that are made available from poultry production include feathers and manure.

There is, also, need to ensure that production of chickens is done in a sustainable manner (Adesiji and Baba, 2013). There are great concerns about greenhouse gas emissions from poultry production that impact on climate change (Mengesha, 2011; Leinonen, 2016). Such elements are forcing poultry producers to provide conditions that optimize productivity, feed utilization being one of the key factors.

2.2 Broiler chicken production in South Africa

South Africa is the largest commercial poultry-producing country on the African continent, followed by Egypt, Morocco, Nigeria and then Algeria, in that order (Nkukwana, 2018). The industry is the largest segment of the country's agricultural sector, contributing more than 19.6% of its share of gross domestic product and 42.8 % of animal product gross value (SAPA, 2017). The industry provides employment, directly and indirectly, for about 108 000 people throughout its value chain and related industries (SAPA, 2017). The poultry industry in South Africa comprises mostly of chickens, ostrich, turkey and ducks. However, of all the poultry species, chickens are the most common and raised commercially. Poultry production in South Africa has increased in the past decade from 1 200 000 to over 1 600 000 tonnes of meat per year (DAFF, 2017). The consumption of poultry products in South Africa is relatively high with 38 kg per capita per year (OECD/FAO, 2016). Approximately 76 % of the chickens in the South African poultry industry are used for meat production, while the remaining 24 % are used in the egg industry. Commercial farming of chickens used for meat production is characterised by the use of broiler chickens of selected breeds and to a small extent indigenous chicken breeds. Broiler chicken production mainly occurs throughout South African provinces with North-West, Western Cape, Mpumalanga and KwaZulu–Natal Provinces being the largest producers accounting for approximately 79% of total production (DAFF, 2017). The broiler industry in South Africa has predominantly two breeds: the Cobb 500 and the Ross 308 (DAFF, 2017).

South Africa is unable to produce sufficient quantities of broiler meat to satisfy the demand for poultry products (DTI, 2017). Thus, it is a net importer of poultry meat. In 2016, poultry imports made up 26% of poultry meat consumption (SAPA, 2017). Sustainable production is often hampered by high feed costs, which make up 75% of total production costs (Nkukwana, 2018). This may be due to an insufficient supply of locally grown, affordable feed inputs, i.e. maize and soya beans (SAPA, 2017).

According to predictions of the Food Agricultural Organisation (FAO), a greater demand for poultry products (meat and eggs) is anticipated in the next decade especially in developing countries (OECD/FAO, 2016). Therefore, greater challenges reset on producers and nutritionists to ensure sustainable production of chickens and other poultry products.

Improving feed efficiency is a major factor in reducing the costs of poultry production. Many genetic studies have shown that feed efficiency could be improved through selection (Crawford, 1990; Rougiere and Carre, 2010; de Verdal *et al.*, 2010). Even the use of exogenous enzymes and other feed additives has been shown to affect feed utilization in poultry diets. However, there is need to ascertain the effects of dietary crude fibre in poultry in order to advance strategies that may help reduce production costs.

2.3 Indigenous chicken production in South Africa

Indigenous chickens have high genetic variability (Mtileni *et al.*, 2009). They have desirable traits which through intervention require preservation and also application on modern chickens. Indigenous chicken breeds common in South Africa include Potchefstroom koekoek, Venda, Naked neck, Ovambo, Natal game, Zulu and Nguni chickens (Grobbelaar *et al.*, 2010). These chickens are known to be resilient and can fend for themselves (Bosch, 2011). They are well adapted to the tropical environment and resistant to diseases (Roothaert *et al.*, 2011). Most farmers keep these chickens under extensive production systems characterised by minimum input (Grobbelaar *et al.*, 2010). The contribution of indigenous chickens to the nutritional and economic status of rural and even urban households of South Africa is gaining recognition (Norris and Ng'ambi, 2006). Indigenous chickens have to scavenge in order to meet their nutritional needs (Nhleko *et al.*, 2003). Other challenges to their production include high prevalence of diseases and parasites, poor housing, predation, and low availability of feed resources (King'ori *et al.*, 2010). Hence, productivity of these chickens is limited. There is need for innovative and appropriate strategies to address these challenges. Some work has been done to determine nutrient requirements for chickens popular in Limpopo Province (South Africa). The research efforts are aimed at improving productivity of these chickens through determination of their nutrient requirements (Mbajiorgu *et al.*, 2011; Alabi *et al.*, 2013; Mabelebele *et al.*, 2014; Okoro *et al.*, 2017).

According to Mabelebele *et al.* (2014), indigenous Venda chickens are adapted to diets containing high crude fibre levels. However, dietary CF levels that optimize their productivity have not been reported in these chickens. Furthermore, an understanding of the unique ability of these chickens to adapt to fibrous diets is essential before advancing strategies for improved nutrient utilization even in broiler chicken diets. Hence, this information would benefit the industry at large.

2.4 Feed utilization by chickens

Feed costs represent a high proportion in poultry production (de Verdal *et al.*, 2010). Poultry feed consumed by commercial is significantly high. According to SAPA 2017, 3 275 271 tonnes of feed was produced for poultry in 2016. Not everything ingested by animals is absorbed in the gut. The dry matter digestibility of chickens ranges between 62 and 85 % (Sobayo *et al.*, 2012). This is subject to several factors that determine the efficiency of the GIT (Choct, 2015). These include animal factors (physiological stage of growth, breed and health status) and food factors (diet composition, anti-nutritional factors and feed additives such as exogenous enzymes).

Usage of relatively abundant non-conventional feed ingredients offer alternatives for poultry nutritionists in the reduction of feed costs (Table 2.1). Non-conventional feed resource often have less competition with humans. Examples of these include agricultural by-products such as hulls from leguminous grains, bran from cereals, oil seed cakes and also kernel meals (Makinde and Inuwa, 2015; Al-Harthi, 2016). However, such ingredients contain anti-nutrients, such as variable levels of crude fibre which may adversely affect diet utilization by chickens (Hamedi *et al.*, 2011). Hence, the application of exogenous enzymes in some animal feed production industries. The utilization of these non-conventional feed resources is important in enhancing sustainable poultry production (Vaarst *et al.*, 2017).

Indigenous chickens, which form a smaller proportion in the South African poultry industry, have been reported to have adapted to diets with variable levels of crude fibre levels (Mabelebele *et al.,* 2014). However, evidence on this regard remains scanty and inconclusive. Indigenous chickens are commonly kept under traditional management systems characterized by small flock sizes, low input and output and periodic devastation of the flock by disease (Mtileni *et al.*, 2009).

Table 2.1 Composition of some non-conventional resources for indigenous chickens

Feedstuff	Crude protein	Ether extract (%)	Crude fibre	Metabolizable energy (MJ/kg DM)
Neem leaves	17.5	4.2	12.3	3.15
Amaranth seeds	16.0	0.2	5.5	3.86
Soybean hulls	16.6	4.0	25.4	8.77
Cowpea hulls	17.0	2.6	20.3	4.21
Melon pulp	8.6	4.3	31.1	4.81
Plantain pulp	4.1	0.6	0.1	4.20
Cassava				
Meal sievings	0.8	1.5	9.0	7.48
Fermented chaff	1.4	1.1	10.2	14.38
Peel meal	2.2	1.1	4.3	10.30
Yam meal sievings	3.5	1.0	5.0	8.85
Yam peel meal	6.4	5.0	7.3	5.72
Starch residue				
Maize				
Fresh	16.8	7.8	4.2	6.87
Sun-dried	14.7	3.8	5.7	13.8
Millet	18.0	7.3	6.5	4.67
Sorghum	29.4	9.5	8.2	9.0
Blood meal mixture				
Rice bran/blood	25.6	-	21.3	-
Maize cob/blood	28.9	-	19.5	-
Palm kernel /blood	38.5	5.0	-	-
Fish by-products	44.3	29.1	0.0	-

Adapted from Sonaiya, 2002

The low productivity of the indigenous chickens is mainly attributed to lack of genetic improvement, incidence of diseases and predation and management factors (Sonaiya, 2002; Molla, 2010). Mostly indigenous breed/strains of chickens are kept with little or no controlled breeding (Horst, 1990). Feed resources for the chickens include household refuse, homestead pickings, crop residues, herbage, seeds, green grasses and small plants, earthworms, insects and small amount of supplemented feeds offered by the flock owner (Table 2.1).

2.5 Crude fibre in chicken diets

2.5.1 Definition of crude fibre

Crude fibre analysis is a method that was developed in the early 1800’s (Van Soest and McQueen, 1973). It has long been used as the standard method for fibre determination. Other methods are available for fibre analysis (Figure 2.1). However, this one attempts to estimate the residue of defatted plant material remaining after sequential solvent extraction with dilute acid and alkali, H_2SO_4 and NaOH, respectively, followed by oven-drying at 104ºC overnight and ignition in muffle furnace at 600ºC for 3 hours (McDonald *et al.*, 2010). Figure 2.1 shows some of the components that are determined under the crude fibre methods, cellulose, lignin and also hemicellulose. The compounds removed are predominantly protein, sugar, starch and lipids (Van Soest, 1963; Van Soest and Wine, 1967).

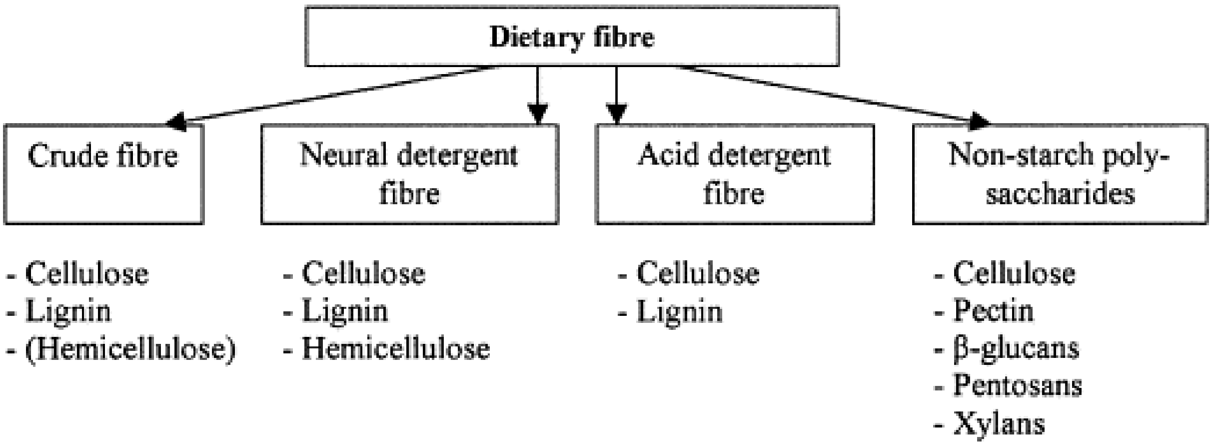


Figure 2.1 Methods used in the determination of fibre in animal diets (Souffrant, 2001)

Crude fibre is part of the feed that is resistant to digestion by endogenous enzymes (Sarikhan *et al.*, 2010). Other authors describe CF as the plant cell wall material which comprises of insoluble non-starch polysaccharides and lignin (Theander *et al.,* 1993; Choct *et al.*, 1996).

The last two decades have seen fibre determination techniques evolve. The crude fibre determination method has been reported to under-estimate the contents of some of the cell wall constituents in feedstuffs, i.e. hemicellulose, pectins and hydrocolloids partly digested by the alkali and acid (Knudsen *et al.*, 1997). Hence, Choct *et al.* (2010) and Choct (2015) argued that crude fibre may not a good indicator of the true fibre in feedstuffs. Hence, methods which determine non-starch polysaccharides are preferred.

Crude fibre is contained by all plant material used as ingredients in poultry feeds. Feed ingredients such as maize, wheat, oats, soyabean, brans and hulls from various grains inherently contribute to the fibre content of a diet (Hetland *et al.*, 2005; Svihus, 2010; Sacraine *et al.,* 2012; Walugembe *et al.*, 2014). Thus, diets formulated with the usage of plant based products will contain certain levels of crude fibre.

Fibre is important in the gut of chickens (Michard, 2011). There is a large body of literature that supports this assertion. In cases where diets were formulated to contain very low levels of CF, chickens have been reported to ingest litter material (wood-shavings) and even feathers in order to compensate for the lack thereof (Hetland *et al.,* 2005; Mateos *et al.*, 2012; Ling *et al.*, 2014). Dietary CF has implications on the development of the GIT which ultimately affects growth performance of chickens. There is, therefore, need to investigate this assertion in the context of South African broiler and indigenous chickens.

Diets of indigenous chickens are composed of fibrous feed ingredients. Evidence from the crop contents of growing indigenous chickens (pullets and cockerels) under extensive systems (free range) show that they survive on feed ingredients such as maize straws, kitchen waste, maize by-products and brewers' waste residues to mention a few (Raphulu *et al.*, 2015; Hayat *et al.*, 2016) (Table 2.2). Most of the materials available for scavenging have a relatively low concentration of energy since they contain high levels of crude fibre (Sonaiya, 2002).

The nutrient composition from the crop contents indicate that these chickens thrive despite the relatively higher CF levels (Table 2.3). The adaptation of these chickens to such diets has not been investigated and further studies are necessary to determine dietary CF levels that optimize the productivity of these chickens.

2.5.2 Effect of dietary crude fibre level on growth performance of chickens

Crude fibre in the diet of chickens influences diet intake. Increased levels of CF increase the volume or bulkiness of a diet. Michard (2011) and Mateos *et al.* (2012) described CF as a nutrient diluent that impacts negatively on feed intake. These authors found that voluntary feed intake increases when dietary nutrients are lowly concentrated, as animal feed to satisfy their nutrient requirements.

Table 2.2 Live weight*, crop content weights and major components of crop contents of Ethiopian indigenous chickens aged 3 to 5 months in free range systems (Hayat *et al.*, 2016).

Item	Pullets	Cockerels
Live weight (kg)	1.1 ± 0.15	1.4 ± 0.12
Fresh crop content (g)	21.8 ± 15.16	20.2 ± 10.82
Components of crop contents (%)		
Grains (maize, sorghum and teff)	38	36
Kitchen waste	15	15
Green forage (grass and leaves)	17	20
Worms, ants and snails	28	27
Others (soil and unidentifiables)	2	2

*: Means ± standard error

However, with indigenous Venda chickens there is evidence that they tend to feed in order to meet the most limiting nutrients in the diets either crude protein or metabolizable energy (Mbajiorgu *et al.*, 2011). These effects need to be further examined and compared between these breeds as they are influenced by dietary CF levels. Mossami (2011), also, showed that 4 to 5 % CF improved feed intake and FCR of broiler chickens aged 35 days old. In the adult chickens, dietary CF levels of 6 % improved live body weight, weight gain and feed conversion ratio (Abdallah *et al.,* 2015). Sarikhan *et al.* (2010) also reported that increasing dietary CF levels from 3.3 to 3.8 % improved feed intake, growth rate and FCR of 42 day old chickens. These authors suggested that these improvements in performance with limited dietary CF levels in the birds were associated with increased digestibility (Jimenez-Moreno *et al.,* 2013). However, Walugembe *et al.* (2014) reported contrary findings in younger birds. These authors indicated that increased dietary CF level had no effect on feed intake of broiler chickens aged 21 days. The average daily gain was, also, reduced by increasing dietary CF levels. These authors suggested that higher dietary CF levels impede the nutrient digestion and absorption process which is evidenced through poor growth performance (Krogdahl, 1986). There is, however, a paucity of information on the effect of dietary CF level on growth production of indigenous Venda chickens.

These inconsistencies, therefore, need to be ascertained in broiler and indigenous chickens.

Table 2.3 Nutrient composition of crop and gizzard contents from indigenous chickens at different stages of growth

Stage of growth	CF (%)	CP (%)	ME (MJ/kg DM)	Reference
Grower	6.40 ± 1.30	9.9 ±1.59	11.5 ± 1.84	Rashid *et al*., 2004
	6.66	13.4	14.5	Mekonnen *et al.,* 2010
	8.23 ± 0.76	12.2 ± 1.79	10.9 ± 1.05	Momoh *et al.,* 2010
Layer	6.04 ± 2.98	11.7 ± 2.53	11.6 ±1.41	Rashid *et al*., 2004
	5.04	15.0	14.8	Mekonnen *et al.,* 2010
	8.55 ± 1.05	11.3 ± 2.09	9.8 ± 1.08	Momoh *et al.,* 2010
Adult	5.8 ± 2.7	10.4 ± 4.37	-	Mwalusanya *et al., 2*002
	7.1 ± 1.57	8.0 ± 0.23	10.1 ± 0.5	Goromela *et al.,* 2007

* : Means ± standard error

CF : Crude fibre

CP : Crude protein

ME : Metabolizable energy

2.5.3 Effect of dietary crude fibre on digestive organs of chickens

Dietary CF has an impact on the development of the GIT. Parts of the digestive organs are affected differently with increases in dietary CF. Mossami (2011) reported that dietary CF increases to 5.3 % resulted in increased the weight of the whole GIT. Several studies have reported increases in the size of the gizzard when structural components, such as hulls and also whole grains, are included in the diet of chickens. Dietary CF stimulate the gizzard and make it more muscular due to the increased resistance when grinding. A well-developed gizzard improves gut motility, favours gastroduodenal refluxes, and stimulates the secretion of pancreatic enzymes (Duke, 1992; Svihus *et al.*, 2004). The improved grinding activity together with the increase in reverse anti-peristalsis, facilitates the mixing of the digestive juices with the digesta, which might explain the positive effects on the digestibility dietary components (Gonzalez-Alvarado *et al.*, 2007).

Other parts of the GIT that are affected by the dietary CF includes the small intestines. Mossami (2011) reported increases in the length and weight of the ileum, jejunum and colon in broiler chickens aged 35 days old when hulls were included in the diets of birds as a source of fibre. Borin *et al.* (2006) suggested that the increased organ volume may be consistent with improved digestive capacities.

There are no studies available on the effect of dietary crude fibre level on digestive organs of indigenous chickens. Hence a comparison between these organs is necessary.

2.5.4 Effect of dietary crude fibre on the microflora in gastrointestinal tracts of chickens

The GIT of chickens, like other vertebrates, has a community of micro-organisms dominated by bacteria (Wei *et al.,* 2013). There is a diverse range of bacteria found in the intestines, including members of genera such as *Bacteroides, Prevotella*, *Eubacterium, Lactobacillus, Fusobacterium, Peptostreptococcus, Selenomonas, Megasphaera, Veillonella* and *Streptococcus* (Canny and McCormick, 1999). They are distributed throughout the GIT of poultry, but due to differences in morphology, functionality, metabolic interactions, and microenvironment, heterogeneity in community composition is observed along the different GIT segments (Yeoman *et al.*, 2012). The bacterial concentration gradually increases along the intestinal tract ranging from 10^5 bacterial cells/g of luminal content in the duodenum to 10^7–10^{12} bacterial cells/g of luminal content in ileum to the colon, as illustrated in Figure 2.2. Extensive research shows that microbial colonization of the GIT yields a number of benefits to the host chickens (Jin *et al.*, 1998; McCleary, 2003; Angelakis and Raoult, 2010; Stanley *et al.*, 2013). Gut microorganisms are responsible for the degradation of complex substrates such as non-starch polysaccharides through hydrolytic enzymes which the gut of chicken is incapable of producing (Knudsen, 2014). Gut microorganisms form a protective barrier by attaching to the epithelial walls of the enterocyte and thus reduce the opportunity for the colonization of pathogenic bacteria (Yegani and Korver, 2008). Stevens and Hume (1998) called this competitive exclusion, whereby non-pathogenic bacteria attach to the brush border of gut cells and obstruct pathogens from attachment and even entry into the cell (Yadav and Jha, 2019). The activity of the beneficial microorganisms result in the production of short chain fatty acids (SCFA), amino acids, vitamins B and K which, in turn, may become available for the host (Stevens and Hume, 1998).

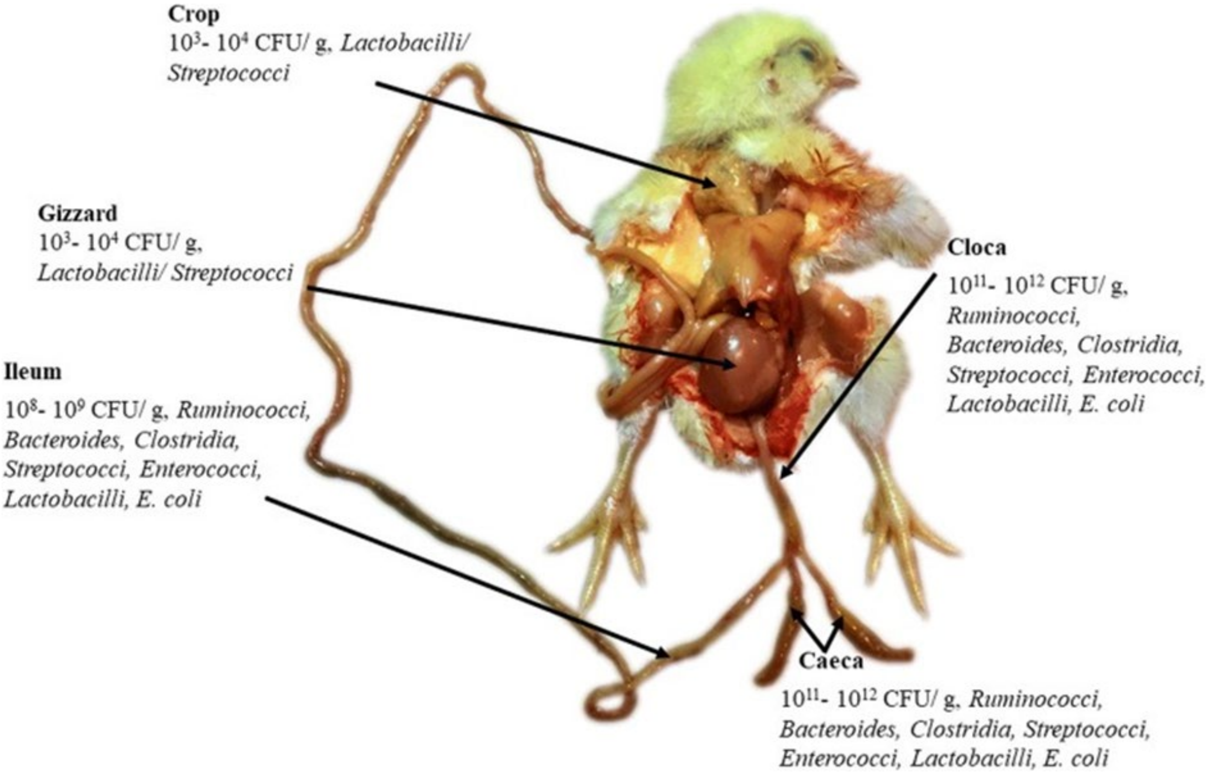


Figure 2.2 Major bacterial habitats and concentration in the gastrointestinal tract of chicken (Yadav and Jha, 2019)

Many intestinal bacteria can hydrolyze indigestible dietary polysaccharides, oligosaccharides, and disaccharides to their compositional sugars, which can then be fermented by intestinal bacteria, yielding short chain fatty acids (SCFAs), primarily acetate, propionate, and butyrate (Pan and Yu, 2014). Cellulolytic bacteria are fundamental for the transformation of cellulose into sugars that are essential nutrients for various organisms, a process called cellulolysis, by cellulases (Lynd *et al.*, 2002). Cellulase enzymes in the monofunctional enzyme system comprise of three classes: endoglucanases (β-1, 4-endoglucanase), cellobiohydrolase (β-(1, 4)-d-exoglucanase) and β-D-glucosidase (β-D-glucoside glucohydrolase) (Walker and Wilson, 1991). The bacterial composition is species-specific (Shewale, 1982) and varies depending on age, physiological state, section of the gut, as well as the diet composition and especially the presence and nature of fibre which is the main bacterial substrate (Borda-Molina *et al.*, 2018).

The inclusion of fibre in the diet was shown to enhance intestinal function and modify the composition and quantity of the gut microflora population in the GIT of poultry (Shakour *et al*., 2006). Jimenez-Moreno *et al.* (2010) studied the effects of including 5% oat hulls or sugar beet pulp in the diets of broilers on *Lactobacillus* counts in the crop and ceca. The authors recorded that *Lactobacillus* counts in the crop increased with the inclusion of sugar beet pulp, but not with the inclusion of oat hulls. However, no effects of dietary CF on *Lactobacillus* counts were detected in the ceca. In indigenous chickens, studies on the effects of dietary CF level on gut microbial organisms are limited. Therefore, there is a need to compare these effects between chicken breeds in order to determine mechanisms that indigenous chickens use in order to cope with fibrous diets.

2.6 Optimization of crude fibre contents in chicken diets

There are several ways used in mitigating the effects of high CF in chicken diets. These include pelleting, reducing the size of feed particles as well as supplementation of poultry diets with exogenous enzymes (Mavromichalis *et al.*, 2000; Kim *et al.*, 2005; Brufau *et al.*, 2006). These methods have been thoroughly examined. However, the alterations in the digesta pH of chickens is another way that may be advantageous for broiler chickens in the utilization of available feed resources containing variable levels of crude fibre.

2.6.1 Digesta pH manipulations

The differences in digesta pH of organs provide an environment unique for the establishment of microorganisms (bacteria) throughout the gastrointestinal tract. The identification of these microorganisms is a rather complex one. This is because researchers apply different methodologies in determining microorganisms (Kheravii *et al.*, 2018). Furthermore, the diets and environmental conditions used may not be similar. However, the identification of cellulolytic microbes would yield more information.

Other studies have shown that gut pH may be manipulated through usage of acidic substances (Khosravinia *et al.*, 2015), which have resulted in better feed utilization and growth performance. However, there is no evidence which suggest that increasing digesta pH is detrimental to nutrient digestibility and growth performance. Diets of indigenous chickens have been reported to contain higher crude fibre levels.

Mabelebele *et al.* (2014) showed that the digestive organs of indigenous Venda chickens had lower pH values, particularly, the crop, gizzard and small intestines when compared to Ross 308 broiler chickens. Mabelebele *et al.* (2017) reported that the jejunum and ileum pH values were lower in indigenous Venda chickens compared to Ross 308 broiler chickens. Hence, the authors suggested that the tolerance of indigenous chickens to high dietary CF levels may be associated with the low gut pH values. Digesta pH may be increased using sodium bicarbonate.

2.6.2 Use of sodium bicarbonate in poultry diets

Sodium bicarbonate ($NaHCO_3$) is a chemical compound, a salt composed of sodium ions (Na+) and bicarbonate ions (HCO_3-). It is a white crystalline solid that appears as a fine powder. Sodium bicarbonate is widely used as a regulatory agent for chickens to alleviate the deleterious effect of heat stress by maintaining electrolyte and acid-base balance (Puron *et al.*, 1997; Hayat *et al.*, 1999; Borges *et al.*, 2003; Borges *et al.,* 2007). These authors supported that sodium bicarbonate was effective in alleviating effects of heat stress in chickens at 42 days of age. Furthermore, inclusion of 4 % sodium bicarbonate in the diet improved feed intake, body weight gain and feed conversion ratio.

2.7 Summary

Diets contain varied levels of CF and in birds fibre is not as important for nutrition as it is in ruminants. The lack endogenous enzymes for digestion of crude fibre. Unfortunately, diets of chickens are made from plant products, which have cell wall.

Crude fibre in the diet of chickens has advantages. For a long time, nutritionists have formulated poultry diets to have minimal levels of CF. However, a growing body of literature has shown the importance of including levels CF in the diet of even young chickens. On the other hand, CF has disadvantages such as lowered nutrient concentration, forming the bulkiness of the digesta and enhancing nutrient digestibility. This, however, is not conclusive. Therefore determining CF levels for optimal productivity is essential.

Ways to improve chicken performance need to be investigated. Altering digesta pH may offer another alternative to this. This is important because the ideal digesta pH may favour establishment of the essential (cellulose degrading) microbes for the host to better utilise the fibre fraction in the host diets which may consequently result in better growth performance.

CHAPTER 3

EFFECT OF DIETARY CRUDE FIBRE LEVEL ON PERFORMANCE AND CARCASS CHARACTERISTICS OF MALE ROSS 308 BROILER AND VENDA CHICKENS AGED 1 TO 42 DAYS

Abstract

A study was conducted to determine the effect of dietary crude fibre (CF) level on feed intake, digestibility, growth rate, feed conversion ratio (FCR) and live weight of male Ross 308 broiler and indigenous Venda chickens aged 1 to to 42 days. The study, also, determined the effect of dietary CF level on the gastrointestinal morphology and digesta pH of gut organs of male Ross 308 broiler and indigenous Venda chickens aged 42 days. Dietary CF levels affected ($P<0.05$) feed intake, growth rate and live weight in male Ross 308 broiler chickens aged 1 to 21 days. Increases in dietary CF level, also, had effect ($P>0.05$) on feed intake, growth rate, FCR and live weight of male Venda chickens aged 1 to 21 days. A single dietary CF level of 4.5 % optimized growth rate and live weight of male Ross 308 broiler chickens aged 1 to 21 days. While dietary CF levels of 4.7 and 4.8 % optimized growth rate and live weight, respectively, in male Venda chickens. Higher dietary CF level resulted in linear decreases ($P<0.05$) in crude protein (CP), neutral detergent fibre (NDF) and acid detergent fibre (ADF) digestibility values in male Ross 308 broiler chickens. Dietary CF levels of 3.8 and 3.7 % optimized dry matter (DM) digestibility and metabolizable energy (ME) intake; while nitrogen retention was optimized at a higher dietary CF level of 4.4 % in male Ross 308 broiler chickens. Different dietary CF levels of 3.5, 3.7, 3.3 and 4.1 % optimized DM and CP digestibility values, ME intake and nitrogen retention, respectively, in male Venda chickens.

Feed intake of male Ross 308 broiler and Venda chickens aged 22 to 42 days were optimized at different dietary CF levels of 6.4 and 4.5 %, respectively. There were negative correlations between dietary CF level and growth rate and body weight of male Ross 308 broiler chickens. Feed conversion ratio of male Ross 308 broiler chickens was adversely affected ($P<0.05$) by increases in dietary CF levels. In male Venda chickens, different dietary CF levels of 5.8, 6.4 and 5.7 % optimized growth rate, FCR and live weight, respectively. Dry matter, CP and NDF digestibility values and nitrogen retention were optimized at different dietary CF levels of 3.4, 4.4, 3.7 and 4.4 % in male Ross 308 broiler chickens. However, in male Venda chickens, DM, CP and NDF digestibility values and nitrogen retention were optimized at dietary CF levels of 5.1, 5.5, 4.9 and 5.1 %.

A dietary CF level of 4.1 % optimized GIT weight of male Ross 308 broiler chickens aged 42 days. Higher dietary CF levels resulted in increases (P<0.05) in gizzard weight; while small intestine weight was decreased (P<0.05) by higher dietary CF levels in male Ross 308 broiler chickens. Different dietary CF levels of 6.3, 5.9 and 8.0 % optimized GIT, gizzard and caecum weights of male Venda chickens, respectively. Dietary CF levels of 5.6 and 5.5 % optimized GIT and small intestine lengths, respectively, in male Ross 308 broiler chickens. The GIT and small intestine lengths of Venda chickens were not affected (P>0.05) by dietary CF level.

Digesta pH of the proventriculus and gizzard were affected (P<0.05) by dietary CF level in male Ross 308 broiler and Venda chickens. Different dietary CF levels of 5.5 and 7.4 % optimized the proventriculus and gizzard digesta pH, respectively, in male Ross 308 broiler chickens. However, dietary CF levels of 4.2 and 4.3 % optimized the proventriculus and gizzard digesta pH values, respectively, in male Venda chickens. The digesta pH of the crop, proventriculus, gizzard and large intestines were similar (P>0.05) between breeds. However, male Venda chickens had higher (P<0.05) small intestine digesta pH values than male Ross 308 broiler chickens aged 42 days. Caecum digesta pH of male Ross 308 broiler chickens was higher (P<0.05) than those of male Venda chickens aged 42 days.

It is concluded that dietary CF level for optimal productivity depend on the breed, age and production parameter of interest.

3.1 Introduction

The world population is predicted to increase from 7.6 to 8.6 billion by 2030 and this increase will take place largely in the developing countries (UN, 2017). As the population grows, there is no corresponding growth predicted to meet the required food supply, especially animal protein (Kastner *et al.*, 2012). Chicken meat and eggs may offer alternatives for meeting nutritional demands of the increasing population (FAO, 2013). Chickens are important that they have significant economic and cultural roles (Alabi *et al.*, 2013; Padhi, 2016). Production of chickens improves food security, especially in developing countries (Reta, 2009). Despite the rapid development of commercial poultry systems worldwide, more than 80 % of the global poultry production still occurs in local or traditional family-based production systems and it constitutes up to 90 % of the total poultry products in many countries (Mack *et al.,* 2005). Indigenous chickens are generally hardy and better adapted to local climatic conditions than the commercial breeds, making them better suited for extensive production (Menge, 2011; Kriel, 2018). Such characteristics make-up the uniqueness of these chickens which at times supersedes those of broiler chickens. Familiar breeds in South Africa include the Boschveld, Naked neck, Ovambo, Potchefstroom koekoek and Venda chickens (Kriel, 2018). Exploring biological reasons for adaptation may be beneficial for broiler production. More so, because of the contribution of livestock production towards climate change producers need to adopt more effective but sustainable methods even in poultry production (Gerber *et al.*, 2013).

In South Africa, poultry production is the largest agricultural sector which contributes significantly to the economy and provides jobs for many. Consumption of poultry meat has increased from 21.5 kg per capita in 2001 to 38 kg in 2017 (DAFF, 2018). Imported poultry breeds have dominated the industry in the supply of animal protein (DAFF, 2018). However, feed production costs remain high. Limitations in feed utilization contribute to this problem. The presence of antinutritional factors such as high crude fibre (CF) in diets may hinder productivity as chickens do not have the capacity to produce digestive enzymes for fibre. Thus, diets formulated for broiler chicken production contained CF levels ranging from 3 to 5 % (Jimenez-Moreno *et al*, 2009). Therefore, diets that contain higher CF levels greater than 5 % are considered to be detrimental to broiler chicken production. However, diets of indigenous chickens contain varying CF levels (Sonaiya, 2002). Dietary CF levels for optimal productivity in indigenous chickens are not known. Crop contents of these chickens have 6 to 11 % CF, depending on the season (Goromela *et al.*, 2007). Hence, this may suggest that indigenous chickens are adapted to such diets.. Mabelebele *et al.* (2014) found that indigenous Venda chickens have digestive systems that may have evolved for better utilization of diets high in CF compared to Ross 308 broiler chickens. This adaptation, however, has not been thoroughly investigated and needs to be ascertained in order to be able to advance strategies for improving CF utilization in broiler chickens. There is, therefore, need to determine the effect of dietary CF levels for optimal performance of Ross 308 broiler and Venda chickens.

3.2 Objectives

The objectives of the study were to determine:

i. the effect of dietary crude fibre level on feed intake, digestibility, growth rate, feed conversion ratio and live weight of male Ross 308 broiler and indigenous Venda chickens aged 1 to 21 days.
ii. the effect of dietary crude fibre level on feed intake, digestibility, growth rate, feed conversion ratio and live weight of male Ross 308 broiler and indigenous Venda chickens aged 22 to 42 days.
iii. the effect of dietary crude fibre level on gastrointestinal morphology and pH of gut organ digesta of male Ross 308 broiler and indigenous Venda chickens aged 42 days.

3.3 Hypotheses

The hypotheses of the study were as follows:

i. Dietary crude fibre level has no effect on feed intake, digestibility, growth rate, feed conversion ratio and live weight of male Ross 308 broiler and Venda chickens aged 1 to 21 days.
ii. Dietary crude fibre level has no effect on feed intake, digestibility, growth rate, feed conversion ratio and live weight of male Ross 308 broiler and Venda chickens aged 22 to 42 days.
iii. Dietary crude fibre level has no effect on gastrointestinal morphology and pH of gut organ digesta of male Ross 308 broiler and Venda chickens aged 42 days.

3.4 Materials and methods

3.4.1 Study area

The study was conducted at the University of Limpopo Livestock Unit. The GPS coordinates are latitude: -23° 53' 9.60" S, longitude: 29° 44' 16.80" E. Ambient temperatures of the study site are 20 to 36 ºC during summer and 5 to 25 ºC during the winter seasons (Kutu and Asiwe, 2010).

3.4.2 Experimental procedures, treatments and design

A total of 320 day old chickens (160 male Ross 308 broiler and 160 male Venda chickens) were used for this study. The chickens were offered experimental diets for 21 days. The diets were formulated to contain similar levels of crude protein and energy, 230 g CP/kg DM and 16 MJ GE/kg DM, respectively. However, the diets had different levels of CF of 3, 4, 5 or 7 %. The feed compositions of the experimental diets are given on Table 3.1. The experimental treatments comprised of four dietary CF levels and two breeds of chickens, thus, a 2 X 4 factorial arrangement in a completely randomised design was used. Treatments were replicated 4 times, each replicate had 10 chickens that were put in pens measuring 1.5 m^2 each. All the chickens were vaccinated against Newcastle, infectious bronchitis and gumboro according to their specific dates (McDonald *et al.*, 2010). Feed and water were made available *ad libitum* while heating and lighting were provided throughout the 21-day period.

The second part of the study commenced with 192 twenty two years old male chickens (96 male Ross 308 broiler and 96 male Venda chickens). The chickens were raised on a starter diet prior to the commencement of the experiment when they were aged 1 to 21 days. The nutrient composition of the starter diet is presented in Table 3.2. The starter diet contained 16 MJ GE/kg DM and 233 g CP/kg DM according to NRC recommendations (NRC, 1994). Experimental diets were formulated to contain varying levels of CF (3, 4, 5 or 7 %) while being isonitrogenic and isocaloric (220g CP/kg DM and 16 MJ GE/kg DM, respectively). The feed composition of the diets is presented in Table 3.3. The experiment had 4 dietary treatments that were replicated 3 times. Each of the replicates was confined in a pen measuring 1 m^2. A 2 (breeds) X 4 (dietary CF levels) factorial arrangement in a completely randomised design was used. Feed and water were made available *ad libitum* while lighting was provided 24 hours daily.

Table 3.1 Feed composition of the experimental diets used in Experiment 1

Ingredients	Diet (% crude fibre)			
	3	4	5	7
Maize (%)	49.74	49.14	50.28	50
Maize gluten (%)	7.92	4.72	4.67	13.71
Soyabean meal (%)	27.95	29.64	27.28	12.32
Wheat bran (%)	0	2	2	2
Maize bran (%)	3	1.72	7.11	11.42
Potato protein (%)	2	5	1.1	2
Di-SODIUM phosphate (%)	0.19	0	0	0
Calcium carbonate (%)	3.78	0	0	0
Salt (%)	0.22	0.32	0.31	0.26
Dicalcium phosphate (%)	1.77	4	4.10	4.15
Sodium bicarbonate (%)	0.2	0	0	0.07
DL methionine (%)	0.2	0.11	0.1	0.1
L-lysine HCl (%)	0.17	0.1	0.1	0.1
L-threonine (%)	0.05	0.05	0.05	0.05
Vitamin + mineral premix[1] (%)	1	1	1	1
Sunflower oil (%)	2	2.2	1.9	2.81

[1] Supplied per kilogram diet: iron (ferrous sulphate), 60 mg; manganese (manganese sulphate and manganese oxide), 120 mg; zinc (zinc oxide), 100 mg; iodine (calcium iodate), 1 mg; copper (copper sulphate), 8 mg; selenium (sodium selenite), 0.3 mg, vitamin A, 9,600 IU; vitamin D3 3,600 IU; vitamin E, 18 mg; vitamin B12, 15 µg; riboflavin, 10 mg; niacin, 48 mg; D-pantothenic acid, 18 mg; vitamin K, 2 mg; folic acid, 1.2 mg; vitamin B6, 4 mg; thiamine, 3 mg; D-biotin, 72 µg.

3.4.3 Data collection

All the chickens (Ross 308 broiler and Venda chickens) were weighed at the start of the experimental trial using an electronic sensitive weighing balance (Radwag, PS 4500/C/2) thereafter, weekly measurements were taken to determine growth rates. Feed intake was determined by subtracting the feed refusals from the total feed given. The feed conversion ratio (FCR) was determined through dividing feed intake by growth rate for the 3-week period with the consideration of the mortality. The FCR was calculated as follows:

$$\text{Feed conversion ratio} = \frac{\text{Feed intake}}{\text{Weight gain} + \text{Weight gain of mortality}}$$

The mortality rate was calculated by dividing the sum of deaths by the number of live chickens alive at the end of the experiment, multiplied by 100.

Table 3.2 Nutrient composition of the starter diet fed to broiler and Venda chickens aged 1 to 21 days

Nutrient	Starter diet
Dry matter (g/kg)	880
Crude protein (g/kg DM)	233.0
Crude fibre (g/kg DM)	48
Calcium (g/kg DM)	12
Phosphorus (g/kg DM)	6.0
Lysine (g/kg DM)	11.0
Crude Fat (g/kg DM)	25
Gross energy (MJ /kg DM)	16.0

3.4.3.1 Digestibility trial

On day 14 or 35, one chicken per replicate was transferred to a metabolic cage equipped with feed and water troughs. A four-day acclimatization period was allowed before a daily faecal collection period of 3 days commenced. Faeces voided by each bird were collected at 0900hrs and weighed daily. Care was taken to avoid contamination from feathers, feed, scales and other debris. Both samples of feed and faeces were analysed for nutrient composition for the determination of nutrient digestibility.

The following equation was used (McDonald *et al.*, 2010):

$$\text{Nutrient digestibility (\%)} = \frac{(\text{Nutrient consumed} - \text{Nutrient voided})}{\text{Nutrient consumed}} \times 100$$

3.4.3.2 Gut organ weights and lengths, and organ digesta pH

At the termination of this trial, one chicken per replicate was sacrificed for measurements of digestive organ weights and lengths. The digesta pH was measured at each segment of the GIT using a digital pH meter (Crison, Basic 20 pH meter) prior to the emptying of the digesta. The gut organs included the crop, proventriculus, gizzard and small intestines (at the Meckel's diverticulum). Measurements were performed by inserting the pH meter probe into each segment of the GIT. The crop, proventriculus, gizzard, small intestines, caeca and large intestines were flushed with distilled water to clean the internal part of the organ and weighed. The carcass weights were also collected. The total length of the GIT, small intestines, caeca and large intestines were measured.

Table 3.3 Feed ingredient composition of experimental diets used in Experiment 2

Ingredients	Diet (% crude fibre)			
	3	4	5	7
Maize (%)	54.74	52.14	50.28	50
Maize gluten (%)	3.92	4.72	6.67	13.71
Soyabean meal (%)	27.95	27.64	24.28	12.32
Wheat bran (%)		2	2	2
Maize bran (%)	0	1.85	5.11	11.42
Potato protein (%)	2	2	2	2
Disodium phosphate (%)	0.19	0	0	0
Calcium carbonate (%)	3.78	0	0	0
Salt (%)	0.22	0.322	0.32	0.26
Dicalcium phosphate (%)	1.77	4	4.09	4.15
Sodium bicarbonate (%)	0.2	0	0	0.07
DL methionine (%)	0.2	0.11	0.1	0.1
L-lysine HCl (%)	0.17	0.1	0.1	0.1
L-threonine (%)	0.05	0.05	0.05	0.05
Vitamin + mineral premix[1] (%)	1	1	1	1
Sunflower oil (%)	4	4	4	2.81

[1] Supplied per kilogram diet: iron (ferrous sulphate), 60 mg; manganese (manganese sulphate and manganese oxide), 120 mg; zinc (zinc oxide), 100 mg; iodine (calcium iodate), 1 mg; copper (copper sulphate), 8 mg; selenium (sodium selenite), 0.3 mg, vitamin A, 9,600 IU; vitamin D3 3,600 IU; vitamin E, 18 mg; vitamin B12, 15 µg; riboflavin, 10 mg; niacin, 48 mg; D-pantothenic acid, 18 mg; vitamin K, 2 mg; folic acid, 1.2 mg; vitamin B6, 4 mg; thiamine, 3 mg; D-biotin, 72 µg.

3.4.4 Chemical analysis

Determination of dry matter (AOAC, 2005): Thoroughly cleaned crucibles were placed in an oven at 105 ºC for 30 minutes and then transferred to a desiccator and cooled to room temperature (25 ºC). The crucibles were then weighed. Samples were weighed and placed into crucibles and placed in the oven overnight at 105 ºC. The crucibles and contents were weighed as soon as possible to prevent moisture absorption. Dry matter percentage was calculated as follows:

DM (%) = Weight of the sample before drying/Weight of the sample after drying x 100

Determination of ash content (AOAC, 2005): Air-dried plant samples (2 g) were weighed and placed in pre-weighed clean-labelled crucibles. The sample plus the crucibles were placed in the muffle furnace at 550 ºC overnight. The beaker and content were weighed as soon as possible to prevent moisture absorption. Ash determination was as follows:

Ash weight = (Weight of crucibles + ash) - (Weight of crucibles)

$$\text{Ash (\%, DM basis)} = \frac{\text{Ash weight}}{\text{Dry sample weight}} \times 100$$

Determination of nitrogen content (AOAC, 2005): Nitrogen contents of the feed samples were determined using the Kjeldahl procedure. The formula for nitrogen content was as follows:

N (%) = (ml acid titrated - ml blank titrated) x (Acid N x 0.014 x 100)/Weight of sample in grams (g).

Determination of neutral detergent fibre content (Van Soest, 1994): Neutral detergent fibre (NDF) was determined by weighing 1.0 g of the sample into a digestion tube, and 100 ml neutral detergent solution was added and heated to boil. Heat was reduced as boiling commenced to prevent foaming. From the onset of boiling, the mixing was refluxed for 60 minutes. Sintered glass crucibles (porosity number 1) were weighed and placed on filtering apparatus (Buchner flask). Contents of digestion tubes were transferred to the crucibles and filtered with a low vacuum initially, and then with a gradual increase of the vacuum. Samples were rinsed into the crucibles with a minimum of distilled hot water. The vacuum was then shut off, residues broken up and washed with hot water followed by two washes with acetone. The crucibles were dried at 105 °C overnight and weighed. Recovered cell wall residues were reported as neutral detergent fibre. The formula used for neutral detergent fibre determination was as follows:

$$\text{NDF (\%)} = \frac{\text{(Crucible Weight + residue) - Crucible Weight}}{\text{Sample weight}} \times 100$$

$$\text{NDF (\%, DM basis)} = \frac{\text{NDF \% on as fed basis}}{\text{DM \% of sample}} \times 100$$

Determination of acid detergent fibre (Van Soest, 1994): Acid detergent fibre (ADF) was determined by accurately weighing 1.0 g of the sample into a digestion tube; 100 ml acid detergent was added and heated to boil. From onset to boiling, the mixture was refluxed for 60 minutes. The light solutions were filtered through sintered glass crucibles (porosity number 1). Residues were broken up carefully and washed with hot water, rinsing sides of crucibles. The residues were then washed again twice with acetone and finally with hexane. The residue was filtered and dried in an oven at 105 °C overnight. The residues were then cooled in a desiccator and weighed. The formula for acid detergent fibre determination was as follows:

$$\text{ADF (\%)} = \frac{\text{(Crucible Weight + residue) - Crucible Weight}}{\text{sample weight}} \times 100$$

$$\text{ADF (\%, on a DM basis)} = \left[\frac{\text{(ADF \% on as fed basis)}}{\text{DM \%}}\right] \times \mathbf{100}$$

Determination of gross energy (AOAC, 2005): Gross energy values for feeds and faeces were determined using an adiabatic bomb calorimeter.

3.4.5 Statistical analyses

All data on productivity, nutrient digestibility and digestive organ measurements of chickens were analysed using the General Linear Model procedures of SAS (2010). The following model was used for both trials:

$$Y = \mu + W_0 + Brd + CF + (Brd \text{ X } CF) + e$$

Where Y = observation; μ = overall mean; W_0 = initial bird weight; Brd = breed effect; CF = dietary crude fibre level; Brd X dietary CF = interaction effect and e = random error.

Fisher’s least significant difference (LSD) test was applied for mean separation where there were significant differences ($P<0.05$). The responses in production performance, nutrient digestibility, nitrogen retention, ME intake, gut organ weight and length and digesta pH to dietary CF level were modelled using the following quadratic equation:

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

Where Y = production performance, nutrient digestibility, nitrogen retention, ME intake, gut organ weight and length and digesta pH; a = intercept; b_1 and b_2 = coefficients of the quadratic equation; x = dietary crude fibre level and $–b_1/2b_2$ = x value for optimal response. The quadratic model was used because it gave the best fit. The quadratic model was fitted to the experimental data by means of the NLIN procedure of SAS (2010).

The linear relationships between dietary CF level and responses in production performance, digestibility, gut weight and gut digesta pH were modelled using the following linear equation:

$$Y = a + bx + e$$

Where Y = production performance, digestibility, gut weight and gut organ digesta pH; a = intercept; b = coefficient of the linear equation; X = dietary CF level.

3.5 Results

3.5.1 Production performance of chickens aged one to 21 days

Nutrient composition of diets offered to male Ross 308 broiler and Venda chickens aged 1 to 21 days are presented in Table 3.4. Diets were isonitrogenous and isocaloric, however, they contained increasing levels of crude fibre (NDF and ADF contents).

Table 3.4 Nutrient composition of experimental diets fed to male Ross 308 broiler and Venda chickens aged one to 21 days

Nutrient	Diet (% CF)			
	3	4	5	7
Dry matter (g/kg)	892^{a} ± 1.8	882^{a} ± 1.2	905^{a} ± 4.2	900^{a} ± 1.0
Crude protein (g/kg DM)	230^{a} ± 0.5	230^{a} ± 0.4	230^{a} ± 0.4	230^{a} ± 0.6
Gross energy (MJ/kg DM)	16.0^{a} ± 0.1	16.0^{a} ± 0.2	16.0^{a} ± 0.3	16.0^{a} ± 0.3
NDF (g/kg DM)	88.4^{d} ± 2.6	91.0^{c} ± 8.7	116.7^{b} ± 3.6	133.1^{b} ± 9.1
ADF (g/kg DM)	22.1^{d} ± 2.1	28.2^{c} ± 1.0	34.0^{b} ± 2.4	42.8^{b} ± 1.2
Ash (g/kg DM)	77^{a} ± 0.8	77^{a} ± 0.3	76^{a} ± 0.8	79^{a} ± 0.9

CF : Crude fibre
DM : Dry matter
NDF : Neutral detergent fibre
ADF : Acid detergent fibre

Results of the effect of dietary CF level on production performance of male Ross 308 broiler and Venda chickens aged 1 to 21 days are presented in Table 3.5. Feed intake, growth rate and live weight of male Ross 308 broiler chickens were similarly (P>0.05)

Table 3.5 Effect of dietary crude fibre level on production performance* of male Ross 308 broiler and indigenous Venda chickens aged 1 to 21 days

Treatment		Variable				
	CF (%)	Feed intake (g/b/d)	Growth (g/b/d)	FCR	Live weight (g)	Mortality (%)
Male Ross 308 chickens	3	46^{a} ± 0.41	29.0^{a} ± 0.51	1.6^{c} ± 0.11	650^{a} ± 24.0	2.5^{a} ± 0.22
	4	46^{a} ± 0.52	30.2^{a} ± 0.41	1.5^{c} ± 0.10	675^{a} ± 25.1	3.0^{a} ± 0.30
	5	46^{a} ± 0.61	30.3^{a} ± 0.32	1.5^{c} ± 0.13	678^{a} ± 23.0	3.1^{a} ± 0.21
	7	39^{b} ± 0.82	26.7^{b} ± 0.52	1.5^{c} ± 0.12	600^{b} ± 17.2	3.0^{a} ± 0.31
Male Venda chickens	3	26^{d} ± 0.41	6.9^{d} ± 0.34	3.8^{a} ± 0.33	375^{c} ± 20.4	2.5^{a} ± 0.02
	4	29^{c} ± 0.51	9.8^{c} ± 0.31	3.0^{b} ± 0.20	517^{a} ± 100.3	2.5^{a} ± 0.05
	5	26^{d} ± 0.32	7.5^{d} ± 0.42	3.6^{a} ± 0.30	395^{c} ± 18.5	2.5^{a} ± 0.10
	7	25^{d} ± 0.91	6.9^{d} ± 0.33	3.6^{a} ± 0.29	374^{c} ± 26.1	2.5^{a} ± 0.41
Breed						
Ross 308		44.3^{a} ± 0.61	29.1^{a} ± 0.41	1.5^{b} ± 0.12	651^{a} ± 24.3	2.9^{a} ± 0.30
Venda		26.5^{b} ± 0.51	7.8^{b} ± 0.52	3.5^{a} ± 0.31	415^{b} ± 50.1	2.5^{a} ± 0.32
Probabilities						
CF level		0.0350	0.0419	0.0452	0.0312	0.1505
Breed		0.0010	0.0017	0.0018	0.0017	0.2317
CF level X breed interactions		0.0783	0.1326	0.1719	0.0722	0.0812

$^{a, b, c, d}$: Means in a column having different superscripts are significantly different ($P<0.05$)

* : Mean ± standard error

FCR : Feed conversion ratio

CF : Crude fibre

affected by dietary CF level. Male Ross 308 broiler chickens offered a diet containing 7 % CF had lower ($P<0.05$) feed intake, growth rate and live weight than those offered diets containing 3, 4 or 5 % CF. However, male Ross 308 broiler chickens offered diets containing 3, 4 or 5 % CF had similar ($P>0.05$) feed intake, growth rate and live weight. A dietary CF level of 3.9 % optimized ($r^2 = 0.988$) feed intake of male Ross 308 broiler chickens (Table 3.6), however, 4.5 % dietary CF optimized ($r^2 = 0.991$) growth rate and live weight (Table 3.6) of male Ross 308 broiler chickens. Feed conversion ratio of male Ross 308 broiler chickens was not affected ($P>0.05$) by dietary CF level. Male Venda chickens fed a diet containing 4 % CF had higher ($P<0.05$) feed intake, growth rate and live weight than those fed diets containing 3, 5 or 7 % CF. However, male Venda chickens fed diets containing 3, 5 or 7 % CF had similar ($P>0.05$) feed intake, growth rate and live weight. Dietary CF levels of 4.4, 4.8 and 4.7 % optimized (r^2= 0.466, 0.388 and 0.335, respectively) feed intake, growth rate and live weight of male Venda chickens aged 1 to 21 days (Table 3.6).

Table 3.6 Dietary crude fibre levels for optimal production performance of male Ross 308 broiler and Venda chickens aged one to 21 days

Variable	Formula	r^2	CF level (%)	Optimal Y-level
Ross 308 Broiler chickens				
Feed intake	$Y = 34.164 + 6.268X - 0.795X^2$	0.988	3.9	46.5
Growth rate	$Y = 17.955 + 5.498X - 0.607X^2$	0.991	4.5	30.4
Live weight	$Y = 412.564 + 118.118X - 13.045X^2$	0.991	4.5	679.9
Venda chickens				
Feed intake	$Y = 19.891 + 3.405X - 0.386X^2$	0.466	4.4	34.8
Growth rate	$Y = 0.142 + 3.549X - 0.373X^2$	0.388	4.8	8.6
FCR	$Y = 5.469 - 0.865X + 0.086X^2$	0.264	5.0	3.3
Live weight	$Y = 81.273 + 157.114X - 16.659X^2$	0.335	4.7	908.6

r^2 : Coefficient of determination

CF : Crude fibre

Male Venda chickens fed a diet having 4 % CF had better feed conversion ratio than those fed diets having 3, 5 or 7 % CF. A dietary CF level of 5.0 % optimized ($r^2 = 0.264$) feed conversion ratio of male Venda chickens (Table 3.6). Mortality was not affected ($P>0.05$) by dietary CF level in Ross 308 broiler and Venda chickens. There were no breed differences in mortalities between male Ross 308 broiler and Venda chickens.

However, male Ross 308 broiler chickens had higher ($P<0.05$) feed intake, growth rate, live weight and better feed conversion ratio than male Venda chickens aged one to 21 days.

3.5.2 Nutrient digestibility, metabolizable energy intake and nitrogen retention of chickens aged 14 to 21 days

The effect of dietary CF level on nutrient digestibility, metabolizable energy intake and nitrogen retention of Ross 308 broiler and Venda chickens aged 14 to 21 days are given in Table 3.7. Male Ross 308 broiler chickens offered diets containing 3, 4 or 5 % CF had higher ($P<0.05$) DM digestibility values than those offered a diet containing 7 % CF. However, male Ross 308 broiler chickens offered diets containing 3, 4 or 5 % CF had similar ($P>0.05$) DM digestibility values. Male Venda chickens offered diets containing 3 or 4 % CF had higher ($P<0.05$) DM digestibility values than those offered diets containing 5 or 7 % CF. However, male Venda chickens offered diets containing 3 or 4 % CF had the same ($P>0.05$) DM digestibility values. Similarly, male Venda chickens offered diets having 5 or 7 % CF had the same ($P>0.05$) DM digestibility values. A dietary CF level of 3.8 % optimized ($r^2 = 0.988$) DM digestibility in male Ross 308 broiler chickens (Table 3.8). However, a dietary CF level of 3.5 % optimized ($r^2 = 0.722$) DM digestibility in male Venda chickens (Table 3.8). Crude protein digestibility values of male Ross 308 broiler chickens fed diets containing 3 or 4 % CF were higher ($P<0.05$) than of those fed diets containing 5 or 7 % CF. Similarly, male Ross 308 broiler chickens offered a diet containing 5 % CF had higher ($P<0.05$) CP digestibility values than those offered a diet containing 7 % CF. However, male Ross 308 broiler chickens offered diets containing 3 or 4 % CF had similar ($P>0.05$) CP digestibility values. There was a negative linear relationship ($r = -0.984$) between dietary CF level and CP digestibility in male Ross 308 broiler chickens (Table 3.9). Male Venda chickens offered diets having 3, 4 or 5 % CF had higher ($P<0.05$) CP digestibility values than those offered a diet having 7 % CF. However, male Venda chickens offered diets having 3, 4 or 5 % CF had similar ($P>0.05$) CP digestibility values. A dietary CF level of 3.7 % optimized ($r^2 = 0.945$) CP digestibility values in male Venda chickens aged 14 to 21 days (Table 3.8).

Table 3.7 Effect of dietary crude fibre level on nutrient digestibility, metabolizable energy intake and nitrogen retention of male Ross 308 broiler and Venda chickens aged 14 to 21 days*

Treatment		Nutrient digestibility				ME intake (MJ/kg DM)	Nitrogen retention (g/b/d)
		DM (%)	CP (%)	NDF (%)	ADF (%)		
	CF (%)						
Male Ross 308 chickens	3	77.2^{a} ± 0.85	71.2^{a} ± 0.91	32.9^{c} ± 4.12	26.1^{a} ± 2.13	12.1^{a} ± 0.65	1.62^{a} ± 0.07
	4	78.6^{a} ± 1.10	70.0^{a} ±1.45	33.2^{c} ±4.51	26.0^{a} ± 1.31	12.2^{a} ± 0.85	1.74^{a} ± 0.04
	5	76.0^{a} ± 1.92	66.7^{b} ± 1.20	27.7^{c} ± 1.61	20.0^{bc} ± 2.32	11.9^{a} ± 0.50	1.61^{a} ± 0.08
	7	60.0^{c} ± 1.67	59.0^{c} ± 0.72	25.1^{d} ± 0.32	18.0^{bc} ± 2.41	10.5^{b} ± 0.45	1.30^{b} ± 0.13
Male Venda chickens	3	68.5^{b} ± 2.60	64^{b} ± 2.4	36.3^{b} ± 1.02	27.4^{a} ± 0.61	9.4^{c} ± 0.17	0.43^{c} ± 0.04
	4	73.9^{b} ± 2.90	68^{b} ± 5.17	38.7^{a} ± 0.84	26.5^{a} ± 0.41	9.7^{c} ± 0.30	0.51^{c} ± 0.05
	5	65.1^{c} ± 6.4	61^{b} ± 3.49	34.7^{bc} ± 0.58	24.2^{b} ± 0.67	8.8^{cd} ± 0.70	0.42^{c} ± 0.04
	7	59.0^{c} ± 3.2	49^{c} ± 2.74	31.6^{c} ± 2.70	19.2^{c} ± 0.97	7.2^{d} ±0.95	0.32^{d} ± 0.043
Breed							
Ross 308		74.9^{a} ± 1.36	66.7^{a} ± 1.69	29.7^{b} ± 3.21	22.5^{b} ± 1.98	11.7^{a} ± 0.40	1.60^{a} ± 0.078
Venda		66.3^{b} ± 3.46	60.5^{b} ± 3.90	35.0^{a} ±1.17	24.3^{a} ± 0.84	8.8^{b} ± 0.64	0.42^{b} ± 0.04
Probabilities							
CF level		0.0243	0.0012	0.0407	0.0149	0.0501	0.0013
Breed		0.0349	0.0473	0.0041	0.0415	0.0243	0.0342
CF level X breed interactions		0.0578	0.0674	0.0561	0.0628	0.1741	0.2671

$^{a, b, c}$: Means in a column having different superscripts are significantly different ($P<0.05$)
* : Mean ± standard error
CP : crude protein
NDF : Neutral detergent fibre
ADF : Acid detergent fibre
CF : Crude fibre

Male Ross 308 broiler chickens offered diets having 3, 4 or 5 % CF had higher ($P<0.05$) NDF digestibility values than those offered a diet having 7 % CF. However, male Ross 308 broiler chickens offered diets having 3, 4 or 5 % CF had similar($P>0.05$) NDF digestibility values. Male Venda chickens offered a diet having 4 % CF had higher NDF digestibility values than those offered diets having 3, 5 or 7 % CF. Similarly, male Venda chickens offered a diet having 3 % CF had higher NDF digestibility values than those offered a diet with 7 % CF. However, male Venda chickens given diets having 3 or 5 % CF had similar ($P>0.05$) NDF digestibility values. Also, those fed diets with 5 or 7 % CF had similar ($P>0.05$) NDF digestibility values. Strong and negative relationships between dietary CF level and NDF digestibility in male Ross 308 broiler and Venda chickens ($r = -0.934$ and -0.834, respectively) were observed (Table 3.9).

Table 3.8 Dietary crude fibre levels for optimal nutrient digestibility, metabolizable energy intake and nitrogen retention of male Ross 308 broiler and Venda chickens aged 14 to 21 days

Variable	Formula	r^2	CF level (%)	Optimal Y-level
Male Ross 308 Broiler chickens				
DMD	$Y = 51.029 + 14.325X – 0.864X^2$	0.998	3.8	78.6
ME	$Y = 10.076 + 1.142X – 0.155X^2$	0.999	3.7	12.2
N-retention	$Y = 0.944 + 0.368X – 0.045X^2$	0.958	4.1	1.69
Male Venda chickens				
DMD	$Y = 58.578 + 6.656X – 0.952X^2$	0.722	3.5	70.2
CPD	$Y = 45.182 + 11.159X – 1.523X^2$	0.945	3.7	65.6
ME	$Y = 7.725 + 1.097X – 0.168X^2$	0.965	3.3	11.1
N-retention	$Y = 0.168 + 0.147X – 0.018X^2$	0.826	4.1	0.468

r^2 : Coefficient of determination

DMD : Dry matter digestibility

CPD : Crude protein digestibility

ME : Metabolizable energy

N : Nitrogen

CF : Crude fibre

Table 3.9 Relationships between dietary crude fibre level (%) and nutrient digestibility (%) of male Ross 308 broiler and Venda chickens aged 14 - 21 days

Variable	Formula	r	Probability
Male Ross 308 broiler chickens			
Crude protein	Y = 81.749 – 3.163X	-0.984	0.016
Neutral detergent fibre	Y = 40.080 – 2.180X	-0.934	0.045
Acid detergent fibre	Y = 33.206 – 2.249X	-0.925	0.052
Male Venda chickens			
Neutral detergent fibre	Y = 42.260 – 1.460X	-0.837	0.016
Acid detergent fibre	Y = 34.409 – 2.123X	-0.987	0.013

r : Correlation coefficient

Male Ross 308 broiler chickens given diets having 3 or 4 % CF had higher (P<0.05) ADF digestibility values than those offered diets having 5 or 7 % CF. However, male Ross 308 broiler chickens offered diets having 3 or 4 % CF had similar (P>0.05) ADF digestibility values. Similarly, male Ross 308 broiler chickens given diets having 5 or 7 % CF had the same (P>0.05) ADF digestibility values. Male Venda chickens fed diets having 3 or 4 % CF had higher (P<0.05) ADF digestibility values than those fed diets having 5 or 7 % CF. Similarly, male Venda chickens offered a diet having 5 % CF had higher (P<0.05) ADF digestibility values than those offered a diet having 7 % CF. However, male Venda chickens fed diets having 3 or 4 % CF had the same (P>0.05) ADF digestibility values. There were negative relationships between dietary CF level and ADF digestibility of male Ross 308 broiler and Venda chickens (r = -0.925 and -0.987, respectively) aged 14 to 21 days (Table 3.9).

Male Ross 308 broiler chickens offered diets having 3, 4 or 5 % CF had higher (P<0.05) metabolizable energy intake than those offered a diet having 7 % CF. However, male Ross broiler chickens offered diets having 3, 4 or 5 % CF had similar (P>0.05) metabolizable energy intakes. Male Venda chickens fed diets having 3 or 4 % CF had higher (P<0.05) metabolizable energy intake than those fed a diet having 7 % CF; however, male Venda chickens fed diets having 3, 4 or 5 % CF had similar (P>0.05) metabolizable energy intakes. Similarly, male Venda chickens offered diets having 5 or 7 % CF had similar (P>0.05) metabolizable energy intakes. Dietary CF levels of 3.7 and 3.3 % optimized (r^2 0.999 and 0.965, respectively) metabolizable energy intake in Ross 308 broiler and Venda chickens, respectively (Table 3.8).

Nitrogen retention values in male Ross 308 broiler and Venda chickens were similarly affected ($P<0.05$) by dietary CF level. Chickens that were offered diets having 3, 4 or 5 % CF had higher ($P<0.05$) nitrogen retention values than those offered a diet having 7 % CF. Male Ross 308 broiler and Venda chickens offered diets having 3, 4 or 5 % CF had similar ($P>0.05$) nitrogen retention values. A dietary CF level of 4.1 % optimized nitrogen retention in both male Ross 308 broiler chickens and male Venda chickens (r^2 = 0.95 and 0.826, respectively) (Table 3.8).

Male Ross 308 broiler chickens had higher ($P<0.05$) DM and CP digestibility values, metabolizable energy intake and nitrogen retention than Venda chickens (Table 3.7). However, male Venda chickens had higher ($P<0.05$) NDF and ADF digestibility values than male Ross 308 broiler chickens. There were no ($P>0.05$) interactions between breed and dietary CF level on DM, CP, NDF and ADF digestibility values, metabolizable energy intake and nitrogen retention.

3.5.3 Production performance for chickens aged 22 to 42 days

An analysis of the experimental diets used in the study is presented in Table 3.10. Diets contained similar levels of gross energy (16 MJ/kg DM) and CP (220 g/kg DM). However, as dietary CF level increased from 3 to 7 % the NDF and ADF contents increased from 86.4 to 147.3 and 24.3 to 53.9 g/kg DM, respectively.

Table 3.10 Nutrient composition of experimental diets fed to male Ross 308 broiler and Venda chickens aged 22 to 42 days

Nutrient	Diet (% CF)			
	3	4	5	7
Dry matter (g/kg)	$912^{a} \pm 10.5$	$922^{a} \pm 10.7$	$915^{a} \pm 6.8$	$900^{a} \pm 12.1$
CP (g/kg DM)	$219^{a} \pm 2.1$	$221^{a} \pm 4.2$	$218^{a} \pm 3.1$	$218^{a} \pm 3.4$
GE (MJ/kg DM)	$16.2^{a} \pm 0.20$	$16.0^{a} \pm 0.12$	$15.6^{a} \pm 0.72$	$15.7^{a} \pm 0.55$
NDF (g/kg DM)	$86.4^{d} \pm 5.31$	$97.3^{c} \pm 3.41$	$126.8^{b} \pm 6.75$	$147.3^{a} \pm 10.32$
ADF (g/kg DM)	$24.3^{d} \pm 3.13$	$31.2^{c} \pm 2.91$	$42.8^{b} \pm 4.77$	$53.9^{a} \pm 5.13$
Ash (g/kg DM)	$82^{a} \pm 2.1$	$78^{a} \pm 3.7$	$84^{a} \pm 4.4$	$72^{a} \pm 7.3$

$^{a, b, c, d}$: Means in a column having different superscripts are significantly different ($P<0.05$)

CF : Crude fibre

CP : Crude protein

GE : Gross energy
NDF : Neutral detergent fibre
ADF : Acid detergent fibre

Results of the effect of dietary CF level on production performance of male Ross 308 broiler and indigenous chickens aged 22 to 42 days are presented in Table 3.11. Feed intake of male Ross 308 broiler chickens offered a diet having 5 % CF was higher ($P<0.05$) than those offered diets with 3 or 4 % dietary CF. However, male Ross 308 broiler chickens given diets having 3, 4 or 7 % CF had similar ($P>0.05$) feed intakes. Similarly, male Ross 308 broiler chickens offered diets having 5 or 7 % CF had similar ($P>0.05$) feed intakes. Feed intake of male Ross 308 broiler chickens was optimized ($r^2 = 0.680$) at a dietary CF level of 6.4 % (Table 3.12). Male Venda chickens offered diets having 4 or 5 % CF had higher ($P<0.05$) feed intakes than those offered diets having 3 or 7 % CF. Similarly, male Venda chickens offered a diet having 3 % CF had higher ($P<0.05$) feed intakes than male Venda chickens offered a diet having 7 % CF. However, male Venda chickens offered diets having 4 or 5 % CF had the same ($P>0.05$) feed intakes. Feed intakes of male Venda chickens were optimized ($r^2 = 0.980$) at a dietary CF level of 4.5 % (Table 3.12).

Male Ross 308 broiler chickens given a diet containing 4 % CF had higher ($P<0.05$) growth rates compared to those given diets with 3, 5 or 7 % CF. Similarly, male Ross 308 chickens offered a diet having 3 % CF had higher ($P<0.05$) growth rates than those offered diets having 5 or 7 % CF. However, male Ross 308 broiler chickens given diets having 5 or 7 % CF had the same ($P>0.05$) growth rates. Dietary CF level had a negative linear relationship ($r = -0.647$) with growth rate of male Ross 308 broiler chickens (Table 3.13). Male Venda chickens offered diets having 5 or 7 % CF had higher ($P<0.05$) growth rates than those offered diets having 3 or 4 % CF. However, male Venda chickens given diets having 5 or 7 % CF had the same ($P>0.05$) growth rates. Similarly, male Venda chickens given diets having 3 or 4 % CF had the same ($P>0.05$) growth rates. A dietary CF level of 5.8 % optimized ($r^2 = 0.957$) growth rate of male Venda chickens (Table 3.12).

Table 3.11 Effect of dietary crude fibre level on production performance* of male Ross 308 broiler and indigenous Venda chickens aged 22 to 42 days

Treatment		Variable				
		Feed intake (g/b/d)	Growth (g/b/d)	FCR	Live weight (g)	Mortality (%)
	CF (%)					
Male Ross 308 chickens	3	149.5^{b} ± 0.30	77.8^{b} ± 0.27	1.91^{d} ± 0.142	2095^{a} ±12.1	3.0^{a} ± 0.03
	4	148.9^{b} ± 6.12	88.7^{a} ± 4.23	1.69^{d} ± 0.166	2217^{a} ±90.5	3.0 ^{a}±0. 02
	5	163.0^{a} ± 1.44	68.8^{c} ± 0.13	2.37^{b} ± 0.269	1899^{b} ±45.7	3.2^{a} ± 0.01
	7	160.5^{ab} ± 4.64	68.3^{c} ± 1.35	2.35^{b} ± 0.441	1895^{b} ±21.1	3.2 ^{a}± 0.10
Male Venda chickens	3	82.1^{d} ± 0.08	22.8^{e} ± 2.04	3.66^{a} ± 0.355	666^{d} ± 28.8	4.0^{a} ± 0.03
	4	84.9^{c} ± 0.38	28.0^{e} ± 2.39	3.03^{a} ± 0.262	794^{cd} ± 29.6	4.0^{a} ± 0.02
	5	85.1^{c} ± 0.09	37.1^{d} ± 2.71	2.29^{c} ± 0.46	904^{c} ± 73.2	4.0^{a} ± 0.02
	7	76.0^{e} ± 0.18	34.8^{d} ± 2.31	2.18^{c} ± 0.17	849^{c} ± 73.6	4.0^{a} ± 0.01
Breed						
Ross 308		155.5^{a} ± 3.66	75.9^{a} ± 4.80	2.15^{b} ± 0.132	2026^{a} ± 78.6	3.1^{b} ± 0.01
Venda		82.0^{b} ± 2.13	30.7^{b} ± 3.16	2.82^{a} ± 0.339	803^{b} ± 51.0	4.0^{a} ± 0.05
Probabilities						
CF level		0.0496	0.0006	0.0484	0.0059	0.0697
Breed		0.0001	0.0015	0.0277	0.0001	0.0496
CF level X breed interaction		0.0776	0.0647	0.0743	0.2374	0.6743

$^{a, b, c}$: Means in a column having different superscripts are significantly different ($P<0.05$)

* : Mean ± standard error

FCR : Feed conversion ratio

CF : Crude fibre

Feed conversion ratios (FCR) of male Ross 308 broiler and indigenous Venda chickens were affected ($P<0.05$) by dietary CF level. Male Ross 308 broiler chickens offered diets having 3 or 4 % CF had better ($P<0.05$) FCR than those given diets containing 5 or 7 % CF. Male Ross 308 broiler chickens offered diets with 3 or 4 % CF had similar ($P>0.05$) FCR values. Similarly, male Ross 308 broiler chickens given diets with 5 or 7 % CF had similar ($P>0.05$) FCR values. The FCR of male Ross 308 broiler chickens had a positive relationship ($r = 0.922$) with dietary CF level (Table 3.13). Male Venda chickens offered diets containing 5 or 7 % CF had better ($P<0.05$) FCR than those offered diets containing 3 or 4 % CF. However, male Venda chickens offered diets having 3 or 4 % CF had similar ($P>0.05$) FCR. Similarly, male Venda chickens offered diets having 5 or 7 % CF had the same ($P>0.05$) FCR. A dietary CF level of 6.4 % optimized ($r^2 = 0.970$) FCR of male Venda chickens aged 21 – 42 days (Table 3.12).

Table 3.12 Dietary crude fibre levels for optimal production performance of male Ross 308 broiler and Venda chickens aged 22 to 42 days

Variable	Formula	r^2	CF level (%)	Optimal Y-level
Ross 308 Broiler chickens				
Feed intake	$Y = 112.99 + 14.96X – 1.16X^2$	0.680	6.4	161.2
Venda chickens				
Feed intake	$Y = 55.04 + 13.51X – 1.503X^2$	0.980	4.5	85.4
Growth rate	$Y = -25.22 + 21.13X - 1.807X^2$	0.957	5.8	36.6
FCR	$Y = 7.764 – 1.766X + 0.139X^2$	0.970	6.4	2.2
Live weight	$Y = -199.25 + 388.50X – 34.06X^2$	0.993	5.7	908.6

r^2 : Coefficient of determination

CF : Crude fibre

Dietary CF level affected live weights of male Ross 308 broiler chickens aged 42 days. Male Ross 308 broiler chickens offered diets containing 3 or 4 % CF weighed more ($P<0.05$) than those offered diets having 5 or 7 % CF. However, male Ross 308 broiler chickens offered diets containing 3 or 4 % CF had the same ($P>0.05$) live weights. Similarly, male broiler chickens on diets containing 5 or 7 % CF had the same ($P>0.05$) live weights at 42 days of age. There was a negative linear relationship ($r = -0.647$) between dietary CF level and live weight of male Ross 308 broiler chickens (Table 3.13).

Male Venda chickens offered diets containing 5 or 7 % CF had higher ($P<0.05$) live weights at 42 days of age than those on a diet containing 3 % CF. Male Venda chickens offered diets containing 4, 5 or 7 % CF had similar ($P>0.05$) live weights at 42 days of age. Similarly, male Venda chickens offered diets containing 3 or 4 % CF had the same ($P>0.05$) live weights at 42 days of age. A dietary CF level of 5.7 % optimized ($r^2 = 0.993$) live weights of Venda chickens (Table 3.12). Male Ross 308 broiler chickens had higher ($P<0.05$) feed intakes, growth rates and live weights, and better FCR values than male Venda chickens aged 22 to 42 days. No interactions ($P>0.05$) between breed and dietary CF levels were observed (Table 3.11).

Table 3.13 Relationships between dietary crude fibre level (%) and production performance of male Ross 308 broiler chickens aged 22 to 42 days

Variable	Formula	r	Probability
Growth rate	Y = 93.181 – 3.638X	-0.647	0.3530
Feed conversion ratio	Y = 1.471 + 0.147X	0.922	0.0371
Live weight	Y = 2346 – 67.4X	-0.647	0.0567

r : Correlation coefficient

3.5.4 Nutrient digestibility, metabolizable energy intake and nitrogen retention of chickens aged 35 to 42 days

Results of the effect of dietary CF level on dry matter, crude protein, neutral detergent fibre and acid detergent fibre digestibility values, metabolizable energy intake and nitrogen retention of male Ross 308 broiler and indigenous Venda chickens aged 35 to 42 days are presented in Table 3.14. Male Ross 308 broiler chickens offered a diet having 4 % CF had higher ($P<0.05$) DM digestibility than those offered diets having 3, 5 or 7 % CF. However, male Ross 308 broiler chickens offered diets containing 3, 5 or 7 % CF had similar ($P>0.05$) DM digestibility values. A dietary CF level of 3.4 % optimized ($r^2 = 0.132$) DM digestibility values of male Ross 308 broiler chickens (Table 3.15).

Table 3.14 Effect of dietary crude fibre level on nutrient digestibility, metabolizable energy intake and nitrogen retention of male Ross 308 broiler and Venda chickens aged 35 to 42 days*

Treatment		Nutrient digestibility				ME intake	Nitrogen
		DM (%)	CP (%)	NDF (%)	ADF (%)	(MJ/kg DM)	retention (g/b/d)
	CF (%)						
Male Ross 308 chickens	3	73^{c} ± 0.3	69^{bc} ± 1.4	44^{cd} ± 0.2	32^{b} ± 1.2	12.0^{a} ± 0.31	2.6^{b} ± 0.14
	4	84^{a} ± 2.5	72^{b} ± 1.0	46^{c} ± 0.1	34^{b} ± 0.6	11.9^{a} ± 0.06	3.0^{a} ± 0.02
	5	69^{c} ± 4.3	70^{b} ± 1.9	43^{cd} ± 1.9	32^{b} ± 1.7	11.7^{a} ± 0.03	2.7^{b} ± 0.04
	7	72^{c} ± 3.7	65^{c} ± 1.6	41^{d} ± 1.6	30^{b} ± 0.6	11.8^{a} ± 0.10	2.2^{d} ± 0.03
Male Venda chickens	3	64^{d} ± 1.2	61^{d} ± 0.4	41^{d} ± 0.3	32^{b} ± 0.9	11.9^{a} ± 0.1	1.9^{e} ± 0.13
	4	70^{c} ± 0.6	66^{c} ± 1.1	48^{b} ± 0.9	39^{a} ± 0.1	11.5^{a} ± 0.1	2.0^{b} ± 0.12
	5	78^{b} ± 0.5	76^{a} ± 2.3	52^{a} ± 1.4	32^{b} ± 0.5	12.0^{a} ± 0.0	2.4^{c} ± 0.1
	7	62^{d} ± 1.3	66^{c} ± 1.7	39^{d} ± 1.7	37^{ab} ± 0.3	11.2^{a} ± 0.1	1.9^{e} ± 0.19
Breed							
Ross 308		74^{a} ± 3.3	69^{a} ± 1.5	44^{a} ± 1.0	32^{a} ± 0.8	11.8^{a} ± 0.1	2.6^{a} ± 0.2
Venda		68^{b} ± 3.6	67^{a} ± 3.1	45^{a} ± 3.0	35^{a} ± 1.8	11.7^{a} ± 0.2	2.0^{b} ± 0.1
Probabilities							
CF level		0.0001	0.0004	0.0012	0.0006	0.0891	0.0022
Breed		0.0105	0.1225	0.2757	0.8212	0.2576	0.0508
CF level X breed interaction		0.0776	0.0847	0.1745	0.0174	0.3421	0.3214

$^{a, b, c}$: Means in a column having different superscripts are significantly different ($P<0.05$)
* : Mean ± standard error
DM : Dry matter
CP : Crude protein
NDF : Neutral detergent fibre
ADF : Acid detergent fibre
ME : Metabolizable energy
CF : Crude fibre

Male indigenous Venda chickens offered a diet containing 5 % CF had higher ($P<0.05$) DM digestibility values than those offered diets having 3, 4 or 7 % CF. Similarly, male indigenous Venda chickens offered a diet having 4 % CF had higher ($P<0.05$) DM digestibility than those given diets containing 3 or 7 % CF. However, those offered diets having 3 or 7 % CF had similar ($P>0.05$) DM digestibility values. A dietary CF level of 5.1 % optimized ($r^2 = 0.909$) DM digestibility values of male Venda chickens (Table 3.15).

Crude protein digestibility values of male Ross 308 broiler chickens fed diets containing 4 or 5 % CF were higher ($P<0.05$) than those of male broiler chickens offered diets containing 7 % CF (Table 3.14). However, male Ross 308 broiler chickens fed diets containing 3, 4 or 5 % CF had the same ($P>0.05$) crude protein digestibility values. Similarly, broiler chickens that were fed diets containing 3 or 7 % CF had the same ($P>0.05$) crude protein digestibility values. A dietary CF level of 4.4 % optimized ($r^2 = 0.931$) crude protein digestibility values of male Ross 308 broiler chickens (Table 3.15). Male Venda chickens offered a diet having 5 % CF had higher ($P<0.05$) crude protein digestibility values than those offered diets containing 3, 4 or 7 % CF. Similarly, male Venda chickens offered diets having 4 or 7 % CF had higher ($P<0.05$) crude protein digestibility values than those offered a diet having 3 % CF. However, male Venda chickens given diets having 4 or 7 % CF had similar ($P>0.05$) crude protein digestibility values. A dietary CF level of 5.3 % optimized ($r^2 = 0.845$) CP digestibility values of male Venda chickens (Table 3.15).

Male Ross 308 broiler chickens fed a diet containing 4 % CF had higher ($P<0.05$) NDF digestibility values than those fed a diet containing 7 % CF (Table 3.14). However, broiler chickens offered diets containing 3, 4 or 5 % CF had similar ($P>0.05$) NDF digestibility values. Similarly, those fed diets containing 3, 5 or 7 % CF had the same ($P>0.05$) NDF digestibility values. A dietary CF level of 3.7 % optimized ($r^2 = 0.748$) NDF digestibility values of Ross 308 broiler chickens (Table 3.15). Male Venda chickens offered a diet having 5 % CF had higher ($P<0.05$) NDF digestibility values than those offered diets having 3, 4 or 7 % CF. Similarly, Venda chickens offered a diet containing 4 % CF had higher ($P<0.05$) NDF digestibility values than those offered diets containing 3 or 7 % CF. Male Venda chickens fed diets 3 or 7 % CF had similar ($P>0.05$) NDF digestibility values. A dietary CF level of 4.9 % optimized ($r^2 = 0.938$) NDF digestibility values of male Venda chickens (Table 3.15).

Acid detergent fibre digestibility values of Ross 308 broiler chickens were not affected ($P>0.05$) by dietary CF level (Table 3.14). However, male Venda chickens fed a diet having 4 % dietary CF had higher ($P<0.05$) ADF digestibility than those given diets having 3 or 5 % CF. Male Venda chickens offered 4 or 7 % CF had similar ($P>0.05$) ADF digestibility values. Male Venda chickens fed diets containing 3 or 7 % CF, also, had similar ($P>0.05$) ADF digestibility values. A dietary CF level of 10.1 % optimized ($r^2 = 0.110$) ADF digestibility values of male Venda chickens (Table 3.15)

Metabolizable energy intake was not affected ($P>0.05$) by dietary CF level in both chicken breeds. However, nitrogen retention was affected ($P<0.05$). Male Ross 308 broiler chickens given a diet containing 4 % CF had higher ($P<0.05$) nitrogen retention values than male broiler chickens given diets containing 3, 5 or 7 % CF. Similarly, broiler chickens given diets having 3 or 5 % CF had higher ($P<0.05$) nitrogen retention values than those given a diet containing 7 % CF. Male Ross 308 broiler chickens fed diets having 3 or 5 % CF had the same ($P>0.05$) nitrogen retention values. A dietary CF level of 4.4 % optimized ($r^2 = 0.866$) nitrogen retention of male Ross 308 broiler chickens (Table 3.15). Male Venda chickens fed a diet having 5 % CF had higher ($P<0.05$) nitrogen retention values than those fed diets having 3, 4 or 7 % CF. However, male Venda chickens fed diets having 3, 4 or 7 % had similar ($P>0.05$) nitrogen retention values. A dietary CF level of 5.1 % optimized ($r^2 = 0.741$) nitrogen retention of male Venda chickens (Table 3.15).

Ross 308 broiler chickens had higher ($P<0.05$) dry matter digestibility and nitrogen retention values compared to indigenous Venda chickens (Table 3.14). However, crude protein, NDF and ADF digestibility values and metabolizable energy intakes were similar ($P>0.05$) between breeds. Interactions were not ($P>0.05$) observed between breed and dietary CF level.

Table 3.15 Dietary crude fibre levels for optimal nutrient digestibility and nitrogen retention of male Ross 308 broiler and Venda chickens aged 35 to 42 days

Variable	Formula	r^2	CF level (%)	Optimal Y-level
Male Ross 308 Broiler chickens				
DMD	$Y = 71.691 + 2.605X – 0.386X^2$	0.132	3.4	76.0
CPD	$Y = 53.673 + 7.964 – 0.909X^2$	0.931	4.4	71.1
NDFD	$Y = 40.127 + 2.486X – 0.341X^2$	0.748	3.7	44.7
N-retention	$Y = 0.920 + 0.880X – 0.100X^2$	0.866	4.4	2.86
Male Venda chickens				
DMD	$Y = 0.509 + 29.45X – 2.864X^2$	0.909	5.1	76.2
CPD	$Y = 0.091 + 27.795X – 2.614X^2$	0.845	5.3	74.0
NDFD	$Y = -18.291 + 28.245X – 2.864X^2$	0.938	4.9	51.3
ADFD	$Y = 30.145 + 1.377X – 0.068X^2$	0.110	10.1	37.1
N-retention	$Y = -0.320 + 1.020X – 0.10X^2$	0.741	5.1	2.28

r^2 : Coefficient of determination
CF : Crude fibre
DMD : Dry matter digestibility
CPD : Crude protein digestibility
NDFD : Neutral detergent fibre digestibility
ADFD : Acid detergent fibre digestibility
N : Nitrogen

3.5.5 Gut organ weights

Effect of dietary CF level on digestive organ weights of male 308 broiler and indigenous Venda chickens are presented in Table 3.16. Dietary CF level did not affect ($P<0.05$) crop, proventriculus and large intestine weights of male Ross 308 broiler chickens. The GIT, gizzard and caeca weights were affected ($P<0.05$) by dietary CF level. Male Ross 308 broiler chickens fed diets containing 3, 4 or 5 % CF had higher ($P<0.05$) GIT weights than male broiler chickens fed a diet containing 7 % CF. However, those that were fed diets having 3, 4 or 5 % CF had similar ($P>0.05$) GIT weights. The GIT weights of male Ross 308 broiler chickens were optimized (r^2 = 0.988) at a dietary CF level of 4.1 % (Table 3.17). Male Venda chickens fed diets having 5 or 7 % CF had higher ($P<0.05$) GIT weights than those fed diets having 3 or 4 % CF. However, male Venda chickens given diets containing 5 or 7 % the same

Table 3.16 Effect of dietary crude fibre level on gut organ weights* (g) of male Ross 308 broiler and indigenous Venda chickens aged 42 days

Treatment		GIT	Gut organ					
			Crop (g)	Proventriculus (g)	Gizzard (g)	Small intestines (g)	Caecum (g)	Large intestines (g)
	CF (%)							
Male Ross 308 broiler	3	250^{a} ± 6.3	15.8^{a} ± 2.13	11.9^{a} ± 0.85	47.5^{cd} ± 1.90	130.7^{a} ± 3.25	19.1^{a} ± 2.40	19.0^{a} ± 1.85
	4	254^{a} ± 19.0	15.5^{a} ± 0.45	10.2^{a} ± 0.90	51.8^{c} ± 2.65	122.3^{a} ± 0.40	16.9^{a} ± 1.60	15.7^{a} ± 3.35
	5	250^{a} ± 22.4	13.4^{a} ± 0.35	10.4^{a} ± 0.70	52.2^{c} ± 3.15	109.1^{ab} ±0.02	16.0^{a} ±1.70	18.6^{a} ± 1.75
	7	235^{b} ± 10.0	15.0^{a} ± 1.55	9.6^{a} ± 0.65	61.9^{b} ± 6.62	86.4^{b} ± 3.21	19.3^{a} ± 0.24	17.0^{a} ± 0.64
Male Venda chickens	3	143^{d} ± 4.0	14.1^{a} ± 0.50	7.7^{a} ± 7.73	49.4^{c} ± 3.24	46.4^{c} ± 5.74	9.5^{d} ± 1.33	16.4^{a} ± 0.47
	4	157^{d} ± 4.6	15.4^{a} ± 1.62	6.9^{a} ± 0.97	54.3^{c} ± 4.50	44.1^{c} ± 2.99	10.7^{cd} ±0.65	12.4^{a} ± 1.28
	5	218^{c} ±9.4	13.5^{a} ± 0.87	6.6^{a} ± 0.80	67.9^{a} ± 2.22	50.2^{c} ± 1.11	12.8^{bc} ±0.44	16.8^{a} ± 0.81
`	7	210^{c} ± 5.2	15.0^{a} ± 0.09	8.8^{a} ± 0.55	63.5^{a} ± 3.25	49.9^{c} ± 5.05	14.0^{b} ± 1.90	15.8^{a} ± 1.75
Breed								
Ross 308		245^{a} ± 6.6	15.3^{a} ± 0.73	10.3^{a} ±2.43	53.4^{b} ± 3.69	106.9^{a} ± 6.81	18.1^{a} ± 0.69	17.5^{a} ± 0.78
Venda		181^{b} ± 9.6	14.5^{a} ± 0.47	7.3^{a} ± 1.44	58.8^{a} ± 3.32	47.7^{b} ± 2.54	11.5^{b} ± 0.65	15.6^{a} ± 0.94
Probabilities								
CF level		0.0017	0.0973	0.6279	0.0228	0.0453	0.0365	0.1335
Breed		0.0001	0.1105	0.1225	0.0457	0.0012	0.0256	0.1548
CF level X breed		0.0611	0.0776	0.0847	0.0505	0.2174	0.3421	0.3214

$^{a, b, c}$: Means in a column having different superscripts are significantly different ($P<0.05$)
* : Mean ± standard error
GIT : Gastrointestinal tract;
CF : Crude fibre

(P>0.05) GIT weights. Similarly, male Venda chickens given diets containing 3 or 4 % CF had the same (P>0.05) GIT weights. The GIT weights of male Venda chickens were optimized (r^2 = 0.842) at a dietary CF level of 6.3 % (Table 3.17).

Gizzard weights of male Ross 308 broiler chickens offered a diet containing 7 % CF were heavier (P<0.05) than those of male broiler chickens given diets containing 4 or 5 % CF. However, broiler chickens fed diets containing 3, 4 or 5 % CF had similar (P>0.05) gizzard weights. There was a strong and positive linear relationship (r = 0.974) between dietary CF level and gizzard weight (Table 3.18).

Male Venda chickens offered diets containing 5 or 7 % CF had heavier (P<0.05) gizzard weights than those offered diets containing 3 or 4 % CF. However, Venda chickens fed diets containing 3 or 4 % CF had similar (P>0.05) gizzard weights. Similarly, those offered diets containing 5 or 7 % CF had the same (P>0.05) gizzard weights. A dietary CF level of 5.9 % optimized (r^2 = 0.858) gizzard weights of male Venda chickens aged 42 days (Table 3.17).

Male Ross 308 broiler chickens offered diets containing 3 or 4 % CF had higher (P<0.05) small intestine weights than male broiler chickens fed a diet containing 7 % CF. However, male broiler chickens fed diets containing 3, 4 or 5 % CF had similar (P>0.05) small intestine weights. Similarly, those that were fed diets containing 5 or 7 % CF had the same (P>0.05) small intestine weights. There was a negative linear relationship (r = -0.998) between dietary CF level and small intestine weights of male Ross 308 broiler chickens (Table 3.18). Small intestine weights of male Venda chickens were not affected (P>0.05) by dietary CF level.

Caecum weights of male Ross 308 broiler chickens were not affected (P>0.05) by dietary CF level (Table 3.16). However, male Venda chicken caecum weights were affected (P<0.05). Caecum weights of male Venda chickens fed a diet containing 7 % CF were higher (P<0.05) than those of male Venda chickens fed diets containing 3 or 4 % CF. However, caecum weights of male Venda chickens fed diets containing 5 or 7 % CF were similar (P>0.05). Similarly, indigenous Venda chickens fed diets containing 3 or 4% CF had the same (P>0.05) caecum weights. A dietary CF level of 8.0 % optimized (r^2 = 0.976) caecum weights of male Venda chickens aged 42 days (Table 3.17).

Table 3.17 Dietary crude fibre levels for optimal gut organ weights of male Ross 308 broiler and Venda chickens aged 42 days

Variable	Formula	r^2	CF level (%) for optimal Y	Optimal Y-level (g)
Male Ross 308 Broiler chickens				
GIT	$Y = 218.745 + 16.777X – 2.068X^2$	0.988	4.1	252.8
Male Venda chickens				
GIT	$Y = -75.236 + 92.168X – 7.296X^2$	0.842	6.3	215.8
Gizzard	$Y = -10.665 + 26.118X – 2.207X^2$	0.858	5.9	66.6
Caecum	$Y = 1.662 + 3.154X – 0.198X^2$	0.976	8.0	14.2

r^2 : Coefficient of determination

CF: Crude fibre

Table 3.18 Relationships between dietary crude fibre level and gizzard and small intestine weights of male Ross 308 broiler chickens aged 42 days

Variable	Formula	r	Probability
Gizzard	$Y = 36.874 + 3.469X$	0.998	0.026
Small intestines	$Y= 165.7- 11.29X$	-0.842	0.002

r : Correlation coefficient

The GIT, gizzard, small intestine and caecum weights of male Ross 308 broiler chickens aged 42 days were heavier ($P<0.05$) than those of male Venda chickens aged 42 days. However, crop, proventriculus, and large intestine weights of male Ross 308 broiler and Venda chickens were similar ($P>0.05$).

3.5.6 Gut organ lengths

The effect of dietary CF level on the lengths of the GIT, small intestines, caecum and large intestines of male Ross 308 broiler and indigenous Venda chickens aged 42 days are presented in Table 3.19. Male Ross 308 broiler chickens offered a diet containing 5 % CF had longer ($P<0.05$) GIT and small intestines than of those offered diets containing 3 or 4 % CF. However, male broiler chickens fed diets having 5 or 7 % CF had similar ($P>0.05$) GIT and small intestine lengths. Similarly, male broiler chickens offered diets containing 3, 4 or 7 % CF had the same ($P>0.05$) GIT and small

Table 3.19 Effect of dietary crude fibre level on gut organ length* (cm) of male Ross 308 broiler and Venda chickens aged 42 days

Treatment		GIT	Gut organ		
			Small intestines	Caecum	Large intestines
	CF (%)				
Male Ross 308 chickens	3	144.7^{b} ± 18.4	120.6^{b} ± 60.9	16.1^{a} ± 0.93	11.6^{a} ± 0.34
	4	138.3^{b} ± 26.1	114.7^{b} ± 23.9	16.4^{a} ± 0.78	11.4^{a} ± 0.75
	5	164.0^{a} ± 17.4	136.3^{a} ± 17.4	16.7^{a} ± 0.68	11.7^{a} ± 0.17
	7	150.5^{ab} ± 5.0	123.5^{ab} ± 35.0	17.0^{a} ± 0.1	11.4^{a} ± 0.40
Male Venda chickens	3	139.2^{ab} ± 12.5	111.9^{ab} ± 17.5	15.7^{a} ± 0.90	11.0^{a} ± 0.10
	4	146.4^{ab} ± 13.5	121.7^{ab}± 20.5	16.5^{a} ± 2.08	11.0^{a} ± 0.50
	5	155.9^{ab} ± 11.80	126.8^{ab} ± 17.5	17.7^{a} ± 0.40	11.3^{a} ± 0.30
	7	146.9^{ab} ± 27.6	116.4^{ab} ± 15.9	13.2^{a} ± 0.7	11.0^{a} ± 0.40
Breed					
Ross 308		149.4^{a} ± 37.2	123.80^{a} ± 32.2	16.6^{a} ± 0.74	11.5^{a} ± 0.16
Venda		147.1^{a} ± 34.5	119.2^{a} ± 29.8	15.8^{a} ± 0.36	11.1^{a} ± 0.25
Probabilities					
Dietary crude fibre level		0.0245	0.0456	0.1209	0.2486
Breed		0.8081	0.3557	0.1349	0.1593
CF level X breed interaction		0.0938	0.0928	0.0607	0.9162

* : Mean ± standard error

[a, b] : Means in a column having different superscripts are significantly different ($P<0.05$)

GIT : Gastrointestinal tract

CF : Crude fibre

intestine lengths. The GIT length of male Ross 308 broiler chickens was optimized ($r^2 = 0.343$) at a dietary CF levels 5.6 % (Table 3.20), and small intestine length was optimized ($r^2 = 0.301$) at 5.5 % CF (Table 3.20). Dietary CF level did not have effects (P>0.05) on GIT, small intestines, caeca and large intestines of male Venda chickens aged 42 days. The GIT, small intestine, caeca and large intestine lengths of male Ross 308 broiler and Venda chickens were similar (P>0.05).

Table 3.20 Dietary crude fibre levels (%) for optimal gut organ lengths of male Ross 308 broiler chickens aged 42 days

Variable	Formula	r^2	CF level (%) for optimal Y level	Optimal Y-level (cm)
Ross 308 Broiler chickens				
GIT	$Y = 83.93 + 25.59X – 2.268X^2$	0.343	5.6	156
Small intestines	$Y= 69.109 + 21.87X – 1.989X^2$	0.301	5.5	129.2

r^2 : Coefficient of determination

GIT: Gastrointestinal tract

CF : Crude fibre

3.5.7 Gut organ digesta pH values

Results of the effect of dietary CF level on gut organ digesta pH values of male Ross 308 broiler and Venda chickens aged 42 days are presented in Table 3.21. Dietary CF level had no effect (P<0.05) on crop, small intestine, caecum and large intestine digesta pH values of broiler and Venda chickens. However, dietary CF level had effect (P<0.05) on proventriculus and gizzard digesta pH values of male Ross 308 broiler and indigenous Venda chickens aged 42 days. Male Ross 308 broiler chickens fed a diet containing 3 % CF had higher (P<0.05) proventriculus digesta pH values than those fed diets containing 4, 5 or 7 % CF. However, male Ross 308 broiler chickens fed diets having 4, 5 or 7 % CF had similar (P>0.05) proventriculus pH Values. A dietary CF level of 5.5 % optimized ($r^2 = 0.981$) the digesta pH of the proventriculus of male Ross 308 broiler chickens (Table 3.22).

Male Venda chickens fed diets containing 3, 4 or 5 % CF had higher proventriculus digesta pH values than chickens fed a diet having 7 % CF. Those fed diets having 3, 4 or 5 % CF had similar proventriculus digesta pH values. The digesta pH value of the proventriculus of male Venda chickens was optimized ($r^2 = 0.957$) at a CF level of 4.2

% (Table 3.22). Male Ross 308 broiler chickens given diets having 3 or 4 % CF had higher ($P<0.05$) gizzard digesta pH values than those given diets having 5 or 7 % CF. However, broiler chickens fed diets containing 3 or 4 % CF had similar ($P>0.05$) gizzard digesta pH values. Similarly, those fed diets containing 5 or 7 % CF, also, had similar ($P>0.05$) gizzard digesta pH values. A dietary CF level of 7.4 % optimized ($r^2 = 0.582$) gizzard digesta pH values of male Ross 308 broiler chickens (Table 3.22).

Male Venda chickens fed diets containing 3, 4 or 5 % CF had higher ($P<0.05$) gizzard digesta pH values than Venda chickens fed a diet containing 7 % CF. However, those given diets containing 3, 4 or 5 % CF had gizzard digesta pH values that were similar ($P>0.05$). A dietary CF level of 4.3 % optimized the digesta pH values of gizzards of male Venda chickens (Table 3.22).

Ross 308 broiler and Venda chickens aged 42 days had similar ($P>0.05$) crop, proventriculus, gizzard, and large intestine digesta pH values. However, male Venda chickens had higher ($P<0.05$) small intestine digesta pH values than Ross 308 broiler chickens. The caecum contents of male Ross 308 broiler chickens had higher ($P<0.05$) digesta pH values than those of caeca of male Venda chickens.

Table 3.21 Effect of dietary crude fibre level on gut organ digesta pH* in male Ross 308 broiler and indigenous Venda chickens aged 42 days

Treatment		Gut organ					
		Crop	Proventriculus	Gizzard	Small intestines	Caecum	Large intestines
	CF (%)						
Male Ross 308 chickens	3	$4.8^{a} \pm 0.73$	$4.4^{a} \pm 0.62$	$3.4^{a} \pm 0.12$	$5.6^{a} \pm 0.35$	$6.2^{a} \pm 0.34$	$6.6^{a} \pm 0.44$
	4	$4.5^{a} \pm 0.45$	$3.6^{b} \pm 0.98$	$3.6^{a} \pm 0.18$	$5.8^{a} \pm 0.42$	$5.9^{a} \pm 0.28$	$6.0^{a} \pm 0.31$
	5	$4.3^{a} \pm 0.43$	$3.4^{b} \pm 0.74$	$2.7^{b} \pm 0.07$	$5.7^{a} \pm 0.38$	$6.1^{a} \pm 0.47$	$6.1^{a} \pm 0.55$
	7	$4.4^{a} \pm 0.48$	$3.7^{b} \pm 0.78$	$2.8^{b} \pm 0.08$	$5.7^{a} \pm 0.89$	$6.0^{a} \pm 0.38$	$6.2^{a} \pm 0.72$
Male Venda chickens	3	$4.2^{a} \pm 0.91$	$3.4^{b} \pm 0.29$	$2.8^{b} \pm 0.41$	$6.1^{a} \pm 0.78$	$6.2^{a} \pm 0.78$	$6.4^{a} \pm 0.37$
	4	$5.1^{a} \pm 0.40$	$3.4^{b} \pm 0.17$	$2.9^{b} \pm 0.45$	$6.5^{a} \pm 0.62$	$6.4^{a} \pm 0.49$	$6.6^{a} \pm 0.32$
	5	$5.7^{a} \pm 0.78$	$3.5^{b} \pm 0.13$	$3.0^{b} \pm 0.47$	$6.9^{a} \pm 0.49$	$6.5^{a} \pm 0.42$	$6.7^{a} \pm 0.20$
	7	$5.1^{a} \pm 0.20$	$2.8^{c} \pm 0.20$	$2.1^{c} \pm 0.28$	$7.1^{a} \pm 0.67$	$6.6^{a} \pm 0.67$	$7.2^{a} \pm 0.89$
Breed							
Ross 308		$4.5^{a} \pm 0.75$	$3.3^{a} \pm 2.31$	$3.1^{a} \pm 0.23$	$5.8^{b} \pm 0.35$	$6.0^{a} \pm 0.77$	$6.2^{a} \pm 0.78$
Venda		$5.0^{a} \pm 0.56$	$3.3^{a} \pm 3.55$	$2.7^{a} \pm 0.25$	$6.7^{a} \pm 0.29$	$4.8^{b} \pm 0.87$	$6.7^{a} \pm 0.83$
Probabilities							
Dietary CF level		0.4502	0.0021	0.0478	0.1782	0.2231	0.4922
Breed		0.1105	0.1225	0.2757	0.0012	0.0256	0.1548
CF level X breed interaction		0.0776	0.0847	0.1745	0.2174	0.3421	0.3214

$^{a, b}$: Means in a column having different superscripts are significantly different ($P<0.05$)

* : Mean ± standard error

CF : Crude fibre

Table 3.22 Dietary crude fibre levels for gut organ digesta pH of male Ross 308 broiler and Venda chickens aged 42 days

Variable	Formula	r^2	CF level (%) for optimal Y	Optimal Y-level
Male Ross 308 Broiler chickens				
Proventriculus	$Y= 8.540 – 1.915X + 0.175X^2$	0.981	5.5	3.3
Gizzard	$Y = 4.993 – 0.606X + 0.041X^2$	0.582	7.4	2.8
Male Venda chickens				
Proventriculus	$Y= 1.971 + 0.725X - 0.086X^2$	0.957	4.2	3.5
Gizzard	$Y= 0.640 + 1.085X – 0.125X^2$	0.978	4.3	3.0

r^2 : Coefficient of determination

CF : Crude fibre

3.6 Discussion

3.6.1 Effect of dietary CF level on production performance of male chickens aged one to 21 days

The diets contained 16 MJ of energy per kg DM and 230 g of CP per kg DM. This met the recommended requirements for both broiler and slow growing chickens (NRC, 1994). The diets contained similar levels of all the nutrients except dietary CF levels which ranged from 3 to 7 %. Thus, the diets were formulated to be lower, equal or higher than the recommended CF levels of 4 % (NRC, 1994; Adibmoradi *et al.,* 2016) for broiler chickens aged one to 21 days. These diets were, therefore, appropriate to ascertain the CF levels for optimal performance of both male Ross 308 broiler and Venda chickens.

The CF levels used in this study had effect on feed intake in both male Ross 308 broiler and Venda chickens aged one to 21 days. Voluntary feed intake in Ross 308 broiler chickens was optimized at a dietary CF level of 3.9 %. NRC (1994) indicated that diets high in CF contents are poorly digested by chickens. This is because of the lack of gut enzymes for digesting the components of NDF and ADF. Thus, Jimenez-Moreno *et al.* (2013), also, indicated that dietary CF levels of 2 – 4 % optimized feed intake of broiler chickens. A dietary CF level of 4.4 % optimized feed intake in male Venda chickens aged one to 21 days. This dietary CF level for optimal feed intake is lower than 5 – 6 % reported by Mbajiorgu *et al.* (2011) in Venda chickens aged 7 weeks. Hence, younger chickens have a lower dietary CF level for optimal feed intake. The present study indicates that dietary CF levels for optimal feed intake were slightly higher in indigenous Venda chickens than in Ross 308 broiler chickens. This indicates a higher capacity in indigenous Venda chickens to ingest diets high in dietary CF levels than Ross 308 broiler chickens.

Growth rates of both chicken breeds (male Ross 308 broiler and Venda chickens) aged one to 21 days were affected by increases in dietary CF level from 3 to 7 %. A dietary CF level of 4.5 % optimized growth rate in male Ross 308 broiler chickens. Jimenez-Moreno *et al.* (2011) reported a lower dietary CF level for optimal growth rate of 3.4 % in broiler chickens aged one to 21 days. However, in male Venda chickens aged one to 21 days a slightly higher dietary CF level of 4.8 % optimized growth rate. Alabi *et al.* (2013) reported a higher dietary CF level of 5.5 % for optimized growth rate of Venda chickens raised in closed confinement, those chickens were aged 7 weeks. The overall growth rate of Ross 308 broiler chickens was higher than that of Venda chickens. This is due to improved genetic effects as broiler chickens are selectively bred for higher growth performance (Leeson and Summers, 2005).

Dietary CF levels used in the study did not affect FCR of male Ross 308 broiler chickens aged one to 21 days. This was despite the improvement in feed intake. Sarikhan *et al.* (2010) and Adibmoradi *et al.* (2016) reported contrary findings to the current study. These authors reported that dietary CF levels of 3 to 3.9 % optimized FCR in young broiler chickens. The current study, however, indicated that FCR in male Venda chickens was affected by increases in dietary CF level. A dietary CF level of 5.0 % optimized FCR in male Venda chickens. The dietary CF level for optimal FCR in male Venda chickens was, also, higher than that reported by Sarikhan *et al.* (2010) and Adibmoradi *et al.* (2016) in broiler chickens. Indigenous Venda chickens had a poorer FCR when compared to Ross 308 broiler chickens aged one to 21 days. Differences in chicken performance may be associated with genetic potentials of the different breeds (Jaturasitha *et al.*, 2008; Padhi, 2016).

Dietary CF levels used in this study had effect on live weights of both chicken breeds. A dietary CF level of 4.5 % optimized live weight in Ross 308 broiler chickens. Hetland and Svihus (2001), Jimenez-Moreno *et al.* (2013) and Choct (2015) observed lower levels of 3.3 to 3.9 % for optimal live weight of broiler chickens aged 21 days. However, live weights of male Venda chickens aged 1 to 21 days were optimized at a slightly higher dietary CF level of 4.7 %. Thus, in male Venda chickens a higher dietary CF level optimized live weight compared to that of male Ross 308 broiler chickens. The reasons for this may be associated with the generic potential of the breed. However, there are limited studies investigating such differences between fast and slow growing chicken breeds.

3.6.2 Nutrient digestibility, metabolizable energy intake and nitrogen retention of chickens aged 1 to 21 days

Dietary CF levels used in this study adversely affected DM digestibility in both chicken breeds (Ross 308 broiler and Venda chickens) aged 14 to 21 days. Adibmoradi *et al.* (2016) reported similar findings when rice hulls were added to the diets of broiler chickens. Dietary CF reduces nutrient digestibility due to its physiochemical properties (Mustafa and Baurhoo, 2016). Hence, a decreased nutrient digestibility may be associated with an increase in dietary CF level (Rougiere and Carre, 2010). Gonzalez-Alvarado *et al.* (2007) and Jimenez-Moreno *et al.* (2013) reported that increases in dietary CF level from 1.6 to 4.3 % resulted in increased DM digestibility in young broiler chickens. In the current study, different dietary CF levels of 3.8 and 3.5 % optimized DM digestibility in male Ross 308 broiler and Venda chickens, respectively. Reasons for the differences in DM digestibility values between breeds need to be further examined. There were strong and negative relationships between dietary CF level and CP digestibility in male Ross 308 broiler. Jimenez-Moreno *et al.* (2013) and Adibmoradi *et al.* (2016) reported contrary findings to the current study. These authors suggested that increased dietary CF level resulted in improved gizzard function whereby there was thorough mixing of the digesta with hydrochloric acid and pepsin leading to higher protein digestion. This was not supported by the results of the current study. A dietary CF level of 3.7 % optimized CP digestibility in male Venda chickens. No results on slow growing chickens were found.

Higher dietary CF levels decreased NDF digestibility in male Ross 308 broiler chickens aged 14 to 21 days. However, in male Venda chickens a dietary CF level of 4 % resulted in increased NDF digestibility. Thus, male Ross 308 broiler and Venda chickens responded with different NDF digestibility values to increases in dietary CF level. This might be due to different cellulose degrading bacteria in the guts of the chicken breeds (Pan and Yu, 2014). In both Ross 308 broiler and Venda chickens, ADF digestibility decreased with higher dietary CF level. This was due to the inability of chickens to produce fibre digesting enzymes in the gut (Choct, 2015). Thus, there was a strong and negative relationship between dietary CF level and ADF digestibility in male Ross 308 broiler and Venda chickens.

Dietary CF level affected metabolizable energy intake of both chicken breeds (male Ross 308 broiler and Venda chickens) aged 14 to 21 days. A dietary CF level of 3.7 % optimized metabolizable energy intake in male Ross 308 broiler chickens compared to 3.3 % in male Venda chickens. Adibmoradi *et al.* (2016) found no effect of inclusion level of insoluble fibre on ME intake of broiler chicks. However, Jimenez-Moreno *et al.* (2013) reported that dietary CF level affected fat digestibility, a fraction that impacts on metabolizable energy intake. These authors found that there was higher secretion of bile acids when dietary CF level is increased in broiler chickens which improved digestion of fat. Studies investigating the influence of dietary CF on metabolizable energy intake in male Venda chickens are limited.

Dietary CF level had effect on nitrogen retention in Ross 308 broiler and Venda chickens. Dietary fibre has an abrasive effect on the intestinal wall and may result in an increase in endogenous cell losses and nutrients to the lumen, thus, decreasing nitrogen retention in chickens (Leterme *et al.*, 1998). It is, also, possible that, nitrogen may escape digestion because of the increased digesta passage rate with higher dietary CF level (Thacker and Petri, 2011). A single dietary CF level of 4.1 % optimized nitrogen retention in Ross 308 broiler and Venda chickens. This is similar to the value of 4 % CF suggested by NRC (1994).

The results of the study indicate that Ross 308 broiler chickens had higher DM, CP, digestibility values, metabolizable energy intake and nitrogen retention values compared to Venda chickens aged 1 to 21 days. Broiler chickens have been bred to have high nutrient digestibility values when given the right diets (Dozier and Gehring, 2014). The findings of the study indicate that indigenous Venda and broiler chickens aged 1 to 21 days handle dietary CF digestibility in a similar way.

3.6.3 Production performance of chickens aged 22 to 42 days

Experimental diets offered to male broiler Ross 308 and Venda chickens contained 219 g CP/kg DM and 16 MJ/kg DM. Thus, diets were appropriately formulated to meet these nutrient requirements of both male Ross 308 broiler and Venda chickens at this stage of growth (NRC, 1994). The diets varied in CF level ranging from 3 to 7 % and had effect on productive performance of both male Ross 308 broiler and Venda chickens aged 22 to 42 days. Feed intake of male Ross 308 broiler chickens was optimized at a dietary CF level of 6.4 %. However, a dietary CF level of 4.5 % optimized feed intake of male Venda chickens. Feed intake of male Ross 308 broiler chickens was, therefore, optimized at a higher dietary CF level than male Venda chickens. Perhaps Ross 308 broiler chickens aged 22 to 42 days are able to adjust their voluntary feed intake in order to meet their nutrient requirements (Ferket and Grant, 2006; Mbajiorgu *et al.*, 2011). The 6.4 % dietary CF for optimal intake is higher than the 4 % dietary CF suggested by NRC (1994).

Growth rate of male Ross 308 broiler chickens aged 22 to 42 days was adversely affected by dietary CF level. The results indicated a negative growth trend as dietary CF level increased in male Ross broiler chickens. Thus, increasing dietary CF level resulted in poor growth rates. Adibmoradi *et al.* (2016), reported that dietary CF levels of 4.5 to 5 % improved growth rate in broiler chickens aged 22 to 42 days. In the present study, a dietary CF level of 5.8 % optimized growth rate in male Venda chickens. Ayssiwede *et al.* (2010) reported that there were no differences in live weight when dietary CF was increased up to 5.46 % in indigenous Senegal chickens.

Dietary CF levels used in this study affected FCR of male Ross 308 broiler and Venda chickens aged 22 to 42 days. There were strong and positive relationships between dietary CF level and FCR of male Ross 308 broiler chickens. Thus, increases in dietary CF level resulted in poor FCR values in male Ross 308 broiler chickens. Adibmoradi *et al.* (2016) reported that a dietary CF level of 4.5 % optimized FCR in broiler chickens. In male Venda chickens, FCR was optimized at a dietary CF level of 6.4 %. This is higher than values reported for broiler chickens, possibly indicating that male Venda chickens can tolerate higher dietary CF levels (Jimenez-Moreno *et al.*, 2013).

Results of the current study indicate that live weight of male Ross 308 broiler and Venda chickens were affected by dietary CF level. There was a negative relationship between dietary CF level and live weight of male Ross 308 broiler chickens. Hence, increases in dietary CF level resulted in decreased live weights of male Ross 308 broiler chickens aged 42 days. This was expected as growth rate was adversely affected by dietary CF level in broiler chickens in the current study. Diarra *et al.* (2015) reported similar results in broiler chickens fed diets containing cassava copra as a source of fibre. Similarly, Amerah *et al.* (2015) reported that high inclusion of fibrous ingredients such as rapeseed and sunflower seed meal adversely affected the live weight of Ross 308 broiler chickens. However, in male Venda chickens, a dietary CF level of 5.7 % optimized live weight. This was supported by Kassim and Tanganyika (2018) who reported that higher inclusion of maize bran in indigenous chicken diets resulted in improved live weights.

Ross 308 broiler chickens had better feed intake, growth rate, FCR and live weight when compared with male Venda chickens. Pauwels *et al.* (2015) reported similar findings in comparing growth performances of fast growing and slow growing chickens. Fast growing broiler chickens have been selectively bred for improved growth performances (Jaturasitha *et al.*, 2008; Merten, 1992). Thus, Ross 308 broiler chickens had better production performance than Venda chickens.

3.6.4 Nutrient digestibility, metabolizable energy intake and nitrogen retention of chickens aged 35 to 42 days

High dietary CF levels are known to affect the digestibility of poultry diets (Bampidis and Christodoulou, 2011; Khajali and Slominski, 2012). Results of the current study indicate that DM digestibility was affected by dietary CF level in both male Ross 308 broiler and Venda chickens aged 35 to 42 days. Gonzalez-Alvarado *et al.* (2007) and Amerah *et al.* (2009) found similar findings that dietary fibre inclusion level had effects on nutrient digestibility in broiler chickens. This may be due to improved gizzard function (Choct, 2015). A large and well-developed gizzard improves GIT motility, favours gastro-duodenal refluxes and increases cholecystokinin release, which in turn stimulates the secretion of pancreatic enzymes (Duke, 1992; Svihus *et al.*, 2004). A dietary CF level of 3.4 % optimized DM digestibility in Ross 308 broiler chickens. This dietary CF level is similar to that reported by Mateos *et al.* (2012) and Sarikhan *et al.* (2010) in broiler chickens. These authors concluded that certain dietary CF levels are necessary for improved nutrient digestibility. A higher than 3.4 % dietary CF level of 5.1 % optimized DM digestibility in male Venda chickens aged 35 to 42 days. The gizzard weight of the indigenous Venda chickens was heavier than Ross 308 broiler chickens; possibly, this might be a factor that gives Venda chickens the advantage to optimize DM digestibility at a higher dietary CF level.

Dietary CF had effect on CP digestibility of male Ross 308 broiler and Venda chickens aged 35 to 42 days. Crude protein digestibility was optimized at a dietary CF level of 4.4 % in male Ross 308 broiler chickens. This is slightly lower than the findings of Adibmoradi *et al.* (2016) who reported that a dietary CF level of 4.6 % improved CP digestibility. However, CP digestibility in male Venda chickens in the present study was optimized at a dietary CF level of 5.3 %. Thus, indigenous Venda chickens had a higher dietary CF level for optimal CP digestibility than male Ross 308 broiler chickens.

The results of the current study indicate that nitrogen retention in both male Ross 308 broiler and Venda chickens was affected by dietary CF level. A dietary CF level of 4.4 % optimized nitrogen retention in male Ross 308 broiler chickens. However, a higher dietary CF level of 5.1 % optimized nitrogen retention in male Venda chickens aged 35 to 42 days. Thus, male Venda chickens had a higher dietary CF level for optimal nitrogen retention compared to male Ross 308 broiler chickens. There is need, therefore, to determine the biological reasons for the differences.

In the present study, NDF digestibility was affected by dietary CF level in both male Ross 308 broiler and Venda chickens aged 35 to 42 days. However, there were different dietary CF levels for optimal NDF digestibility values, 3.7 and 4.9 % for male Ross 308 broiler and Venda chickens, respectively. Male Venda chickens may have had a higher dietary CF level for optimal NDF digestibility, possibly, because of the presence of specific cellulose degrading bacteria in their gut and, therefore, advantaged these chickens when challenged with diets high in CF.

Metabolizable energy intake was not affected by dietary CF level in male Ross 308 broiler and Venda chickens aged 35 to 42 days. Jorgensen *et al.* (1996) and Hetland *et al.* (2003) reported contrary results when pea, oat and wheat bran were added to the diets of broiler chickens. Hetland *et al.* (2005) and Jimenez-Moreno *et al.* (2011) found that the inclusion of oat hulls in the diet of broiler chickens increased bile acids concentration in the chyme which may improve lipid digestibility, ultimately resulting in increased metabolizable energy intake. This premise was not confirmed by the results of the current study as no effects were found on metabolizable energy intake of the chickens.

The results of the present study indicated that the Ross 308 broiler chicken breed had higher DM digestibility and nitrogen retention than indigenous Venda chickens. This, possibly, enabled broiler chickens to be able to meet their requirements for fast growth (NRC, 1994). Borin *et al.* (2006) reported that DM digestibility was similar between chicken breeds. However, results of the current study indicated that CP, NDF and ADF digestibility values as well as metabolizable energy intake were not affected by the different chicken breeds. These findings confirm the results of Jackson and Diamond (1996) and Proudman *et al.* (1970) in comparing jungle fowl and broiler chickens fed similar diets. Kras *et al.* (2013) reported contrary findings to those of the present study, where ADF digestibility of the Label Rouge breed, a slow-growing chicken was higher compared to the Cobb 500 at 41 days of age. Also, Sekgobela (2018) reported that male Venda chickens had higher NDF and ADF digestibility values when compared to Ross 308 broiler chickens.

3.6.5 Gut organ weight

In the present study, dietary CF level had effect on GIT weight of male Ross 308 broiler and Venda chickens aged 42 days. The weight of the GIT of chicken tends to increase with higher dietary CF level (Sacraine *et al.,* 2012). Similarly, Jorgensen *et al.* (1996) found that increased dietary inclusion of pea hulls resulted in heavier GIT weights of broiler chickens. A dietary CF level of 4.1 % optimized GIT weights in male Ross 308 broiler chickens. Jimenez-Moreno *et al.* (2011) reported that broiler chickens offered diets containing CF levels of between 3.5 and 4.5 % resulted in improved GIT weights. A higher GIT weight is associated with better digestion efficiency. In male Venda chickens, a higher dietary CF level of 6.3 % CF optimized GIT weights in male Venda chickens. Kassim and Tanganyika (2018) reported that 6.6 % dietary CF optimized GIT weights in scavenging chickens. The overall weight of GIT of Ross 308 broiler chickens was higher than that of indigenous Venda chickens. These results support the findings by Mabelebele *et al.* (2017) who compared internal organs of Ross 308 broiler and Venda chickens.

The crop weights of male Ross 308 broiler and Venda chickens were not affected by dietary CF level. Studies conducted on the use of various forms of physical feeds (pellets, coarsely ground, fine) for broiler chickens, did not show differences in crop content weight due to dietary CF level (Sacraine *et al.,* 2012).

Gizzard weights of both male Ross 308 broiler and Venda chickens were affected by dietary CF levels used in the current study. Increased dietary CF level resulted in higher gizzard weights of male Ross 308 broiler chickens. Kheravii *et al.* (2018) reported results similar to those of the current study in broiler chickens fed diets containing oat hulls. Gizzard development is stimulated by structural material in the diet and large particles (Sadeghi *et al.,* 2015). The gizzard grinds the digesta until it is thoroughly ground to a particular size before being expelled to the next digestive organs (Rezaei *et al.*, 2011). The muscles of the gizzard adapt by increasing in weight as a response to the higher demand for grinding action (Mateos *et al.*, 2012). A strong and positive relationship between dietary CF level and gizzard weights. These results support the findings of Deniz *et al.* (2007) in broiler chickens fed rice bran in their diets. Hence, increasing dietary CF levels from 3 to 7 % resulted in heavier gizzard weights in male Ross 308 broiler and Venda chickens. However, Amerah *et al.* (2015) and Sarbaz *et al.* (2018) found that diets containing 5.3 and 6.5 % CF, respectively, optimized gizzard weights of broiler chickens. In the present study, a dietary CF level of 5.9 % resulted in optimal gizzard weights of indigenous Venda chickens aged 42 days. The overall gizzard weight of indigenous Venda chickens was higher than that of Ross 308 broiler chickens. Mabelebele *et al.* (2014) reported similar findings when gizzard weights of the two breeds were compared. Singh and Pathak (2018), also, reported that the Cobb-400 broiler chickens had lower gizzard weights than Indian native chickens.

There were strong and negative relationships between dietary CF level and small intestine weights of Ross 308 broiler chickens. Thus, small intestine weights of male Ross 308 broiler chickens tended to decrease when dietary CF level increased from 3 to 7 %. Sarikhan *et al.* (2010) reported similar findings in broiler chickens. Sadeghi *et al.* (2015) and Noy and Sklan (2002) also confirmed that increased dietary CF level resulted in decreased weights of the small intestines. However, Santos *et al.* (2019) reported contrary results. These authors reported no effect of dietary CF level on small intestines of broiler chickens. Dietary CF level did not improve small intestine weights of male Venda chickens. There was no literature available on the effects of dietary CF level on intestine length of indigenous chickens. The Ross 308 broiler breed had heavier small intestine weights compared to indigenous Venda chickens. Yang *et al.* (2013) and Raphulu *et al.* (2015) reported similar findings and associated the differences with the body weights of the breeds. Therefore, larger bodied chickens such as broiler chickens have heavier intestines in order to support better digestion efficiency (Jorgensen *et al.*, 1996).

The caeca in chickens are responsible for providing a site for hind-gut fermentation of fibre components in the diet (Yu *et al.,* 1998). Higher dietary CF levels may result in increased capacity and functionality of this organ and, thus, cause increased caecum weight (Jorgensen *et al.*, 1996). Dietary CF level affected caecum weight in male Venda chickens aged 42 days. A dietary CF level of 8.0 % CF optimized caecum weights. However, caecum weights of male Ross 308 broiler chickens were not influenced by dietary CF levels used in the study. Ross 308 broiler chickens had heavier caecum weights than Venda chickens. This supports findings of Mabelebele *et al.* (2014).Ross 308 broiler and Venda chickens had similar proventriculus weights. Mabelebele *et al.* (2014) reported similar findings.

3.6.6 Gut organ lengths

Dietary CF level alters the morphological condition of the GIT of chickens (Mateos *et al.,* 2012). Intake of diets high CF causes expansion of the GIT resulting in increased lengths due by hypertrophy of gut tissues (Jorgensen *et al.,* 1996). The length of the small intestines may be in proportion with the available surface area for nutrient digestion and absorption (Noy and Sklan, 2002). The present study indicated that dietary CF level increased GIT and small intestine lengths of male Ross 308 broiler chickens. Similar dietary CF levels of 5.6 and 5.5 % optimized GIT and small intestine lengths, respectively. Sarbaz *et al.* (2018) reported that a dietary CF level of 6.5 % optimized intestinal lengths of broiler chickens. Dietary CF levels used in this study did not affect GIT, small intestine, caecum and large intestine lengths of male Venda chickens. Studies on the effect of dietary CF level on the length of gut organs of Venda chickens are limited. Sekgobela (2018) reported that increasing dietary CF level increased the GIT and duodenum lengths of Venda chickens; however, small intestines and caeca lengths were not affected.

There were no breed differences in lengths of gut organs between Ross 308 broiler and Venda chickens. This is contrary to reports of De Verdal *et al.* (2010) who found that broiler chickens had longer digestive organs than slow growing chickens.

3.6.7 Gut organ digesta pH values

Results of the current study indicated that dietary CF level did not affect the digesta pH of the crop, small intestines, caeca and large intestines of male Ross 308 broiler and Venda chickens. Svihus (2014) reported similar results on the digesta pH of the crop of broiler chickens. These authors found that there are little variations of digesta pH values in the crop. Hence, the digesta pH was similar to that of the feed. However, a prolonged retention time in the crop may be associated with considerable fermentation activities, which produce organic acids and ultimately reduce the pH values (Abbas-Hilmi *et al.*, 2007). The proventriculus and gizzard digesta pH of male Ross 308 broiler and Venda chickens aged 42 days were affected by dietary CF level. The proventriculus and gizzard are digestive organs responsible for the secretion of hydrochloric acid and pepsinogens, and also the mechanical breakdown of the ingested food material (McDonald *et al.*, 2010). The digesta is moved through peristaltic muscle contractions between the two organs (Svihus, 2014). In male Ross 308 broiler chickens, dietary CF levels of 5.5 and 7.4 % optimized proventriculus and gizzard digesta pH values, respectively. Sarbaz *et al.*, (2018) reported increased digesta pH in the crop and proventriculus of chickens when diets had higher CF levels. However, in Venda chickens lower dietary CF levels of 4.2 and 4.3 % optimized proventriculus and gizzard digesta pH, respectively. Thus, digesta pH values of the proventriculus and gizzard of male Ross 308 broiler chickens were optimized at higher dietary CF levels.

The results of the current study indicate that there were no breed differences in all the organ digesta pH values with the exception of the small intestines of Ross 308 broiler and Venda chickens. The digesta pH of the small intestines from Venda chickens was higher than those of Ross 308 broiler chickens. The present findings are contrary to those of Mabelebele *et al.* (2017) who reported that indigenous chickens had higher organ digesta pH values, particularly the crop, proventriculus, gizzard and small intestines.

3.7 Conclusion

Dietary CF level affected feed intake, growth rate and live weight in male Ross 308 broiler and Venda chickens aged 1 to 21 days. A dietary CF level of 3.9 % optimized feed intake; while a single dietary CF level of 4.5 % optimized both growth rates and live weights of male Ross 308 broiler chickens. Feed intake, growth rate, FCR and live weight of male Venda chickens aged 1 to 21 days were optimized by different dietary CF levels of 4.4, 4.8, 5.0 and 4.7 %, respectively.

Higher dietary CF levels adversely affected CP, ADF and NDF digestibility values in male Ross 308 broiler chickens. Dry matter digestibility, ME intake and nitrogen retention were optimized at different dietary CF levels of 3.8, 3.7 and 4.1 % in male Ross broiler chickens, respectively. In male Venda chickens DM and CP digestibility values, ME intake and nitrogen retention were optimized at different dietary CF levels of 3.5, 3.7, 3.3 and 4.1 %, respectively. Also, there were strong and negative relationships between dietary CF level and NDF and ADF digestibility values of male Venda chickens. Hence, dietary CF level adversely affected NDF and ADF digestibility values of both male Ross 308 broiler and Venda chickens aged one to 21 days.

Dietary CF level affected feed intake, growth rate, FCR and live weight of both male Ross 308 broiler and Venda chickens aged 22 to 42 days. Feed intake of male Ross 308 broiler was optimized at a dietary CF level of 6.4 %. Increased dietary CF level resulted in poorer growth rates, FCR and live weights of male Ross 308 broiler chickens. Different dietary CF levels of 4.5, 5.8, 6.4 and 5.7 % optimized feed intake, growth rate, FCR and live weight of Venda chickens, respectively. These dietary CF levels for optimal production performance in chickens aged 22 to 42 days were higher than those of chickens aged 1 to 21 days.

Dietary CF level had effect on nutrient digestibility and nitrogen retention in both chicken breeds. Dry matter, CP and NDF digestibility values, and nitrogen retention were optimized at dietary CF levels of 3.4, 4.4, 3.7 and 4.4 % in male Ross 308 broiler chickens. Thus, CP digestibility and nitrogen retention were optimized at similar dietary CF levels. However, in male Venda chickens, DM, CP and NDF digestibility values and nitrogen retention were optimized at different dietary CF levels of 5.1, 5.5, 4.9 and 5.1 %, respectively. Also, dietary CF levels for optimal nutrient digestibility and nitrogen retention were higher in male Venda chickens than in male Ross 308 broiler chickens. Therefore, responses in production performance and nutrient digestibility to varying levels of dietary CF depended on breed, age of chickens and the performance parameter of interest. This indicated that higher dietary CF level resulted in decreased fibre digestion with in both broiler and Venda chickens aged 1 to 21 days.

The weights of the GIT, gizzards and small intestines of male Ross 308 broiler chickens aged 42 days were affected by dietary CF level. The GIT weight was optimized at a dietary CF level of 4.1 %. There were positive and negative relationships between dietary CF level and gizzard and small intestine weights, respectively. Thus, increasing dietary CF level resulted in higher gizzard weights and lower small intestine weights in male Ross 308 broiler chickens. In male Venda chickens, different dietary CF levels of 6.3, 5.9 and 8.0 % optimized GIT, gizzard and caecum weights, respectively. Hence, dietary CF levels for optimal digestive organ weights depended on the digestive organ. Ross 308 broiler chickens had heavier GIT, gizzard, small intestine and caecum weights than Venda chickens. However, crop, proventriculus and large intestine weights were similar in male Ross 308 broiler and Venda chickens.

The GIT and small intestine lengths of male Ross 308 broiler chickens were affected by dietary CF levels used in the present study. Dietary CF levels of 5.6 and 5.5 % optimized GIT and small intestine lengths, respectively. However, in male Venda chickens, the lengths of the GIT and digestive organs were not affected by dietary CF levels used in the present study.

Different dietary CF levels of 5.5 and 7.4 % optimized the proventriculus and gizzard digesta pH in male Ross 308 broiler chickens, respectively. Thus, dietary CF level for optimal proventriculus and gizzard digesta pH may depend on the digestive organ of interest in male Ross 308 broiler chickens aged 42 days. However, almost similar dietary CF levels of 4.2 and 4.3 % optimized the proventriculus and gizzard digesta pH values in male Venda chickens, respectively. Therefore, dietary CF levels for optimal proventriculus and gizzard digesta pH were higher in male Ross 308 broiler chickens than in male Venda chickens. Thus, dietary CF levels for optimal organ digesta pH is dependent on the organ and breed of chicken. Manipulation of the gut pH might result in differences in the utilization of dietary CF in chickens depending on the level and breed. This needs to be examined with the case of increasing the gut pH through the use of buffers such as sodium bicarbonate.

CHAPTER 4

EFFECT OF DIETARY SODIUM BICARBONATE SUPPLEMENTATION IN THE DRINKING WATER OF CHICKENS ON PRODUCTIVITY AND GUT MORPHOLOGY

Abstract

The study was conducted to determine the effect of sodium bicarbonate supplementation level in the drinking water on feed intake, digestibility, feed conversion ratio (FCR), growth rate, gut organ weight, length and digesta pH of male Ross 308 broiler and Venda chickens aged 22 to 42 days. The study, also, determined the effect of sodium bicarbonate supplementation level in drinking water on types of bacterial species in crop and gizzard digesta of male Ross 308 broiler and indigenous Venda chickens. Increased sodium bicarbonate supplementation level resulted in increased ($P<0.05$) drinking water pH values. Supplementation levels of 8.9, 2.04, 2.97 and 2.97 g of sodium bicarbonate per litre of drinking water optimized water intake, feed intake, growth rate and live weight of male Ross 308 broiler chickens, respectively. There was a strong and positive relationship ($P<0.05$) between sodium bicarbonate supplementation and water intake of male Venda chickens. A single supplementation level of 3.8 g of sodium bicarbonate per litre of drinking water optimized growth rate and live weight of male Venda chickens. Supplementation levels of 2.63, 6.67 and 7.0 g of sodium bicarbonate per litre of drinking water optimized DM and CP digestibility values, and nitrogen retention, respectively, in male Ross 308 broiler chickens. Higher sodium bicarbonate supplementation level resulted in decreased NDF digestibility in male Ross 308 broiler chickens. Supplementation levels of 3.2 and 4.52 g of sodium bicarbonate per litre of drinking water optimized DM and NDF digestibility values, respectively, in male Venda chickens. There were negative relationships between sodium bicarbonate supplementation level in the drinking water and CP digestibility and nitrogen retention of male Venda chickens. Supplementation levels ranging from 2.2 to 9.2 g of sodium bicarbonate per litre of drinking water optimized the Proventriculus weight, gizzard weight, small intestines weight, GIT length, small intestines length, proventriculus digesta pH and gizzard digesta pH of male Ross 308 broiler and Venda chickens aged 42 days. Sodium bicarbonate supplementation level for optimal gut morphological traits depended on the parameters of interest.

Sodium bicarbonate supplementation level affected bacterial species found in the crop and gizzard digesta of chickens. There were different bacterial species found in the crop and gizzard digesta of male Ross 308 broiler and Venda chickens. Results of the study indicate that meat colour (L*, a* and b*) of the breast and thigh meat of both

breeds of chickens were not affected (P>0.05) by sodium bicarbonate supplementation. However, the redness (a*) of the breast meat of indigenous Venda chickens was higher (P<0.05) than a* values of Ross 308 broiler chickens. Sodium bicarbonate supplementation level did not improve (P>0.05) breast meat tenderness, juiciness, flavour, overall acceptability and meat pH of Ross 308 broiler chickens. Supplementation levels of 3.6, 3.2 and 4.7 g of sodium bicarbonate per litre of drinking water optimized meat juiciness, flavour and shear force of male Venda chickens, respectively.

It was concluded that sodium bicarbonate supplementation in the drinking water affected (P<0.05) growth, NDF digestibility and bacterial species composition of male Ross and Venda chickens. Sodium bicarbonate supplementation level for optimal response in chickens depended on production variables of interest and breed of the chicken.

4.1 Introduction

Poultry diets contain varied levels of crude fibre (CF). Crude fibre is naturally present in all plant-based feed ingredients (Sadeghi *et al.*, 2015). These ingredients are important because they are used to provide energy, protein and other minerals in poultry diets (FAO, 2013). Ingredients high in CF include oil-seed meals such as canola, soya beans, cotton and sunflower, cereals (maize, rice, barley, and oats) and leaf meals.

Moderate levels of dietary CF are important for the growth and development of the gastrointestinal tract and ultimately growth and health of chickens (Sarikhan *et al.*, 2010; Mateos *et al.*, 2012; Inchareon, 2013). However, the chickens' ability to cope with varied levels of CF is rather limited. This is primarily because of the lack of digestive enzymes to degrade fibre in the of gut birds (Bedford and Schulze, 1998; Mateos *et al.*, 2012). Thus, diets with high CF levels limit the utilization of energy and other nutrients.

Better crude fibre digestion is important for chickens under extensive or intensive production systems. This ensures the utilization of feed ingredients that would otherwise be disposed of. Broiler chickens have CF digestibility coefficients ranging from 16 to 24.1% (Gopinger *et al.*, 2014); while in indigenous Venda chickens, dietary CF digestibility coefficients range from 26.8 to 41 % (Mwalusanya *et al.*, 2002). Thus, indigenous chickens digest CF better than broiler chickens. The breakdown of plant cell walls by digestive processes facilitates the accessibility to potentially indigestible nutrients. Reasons for higher CF digestibility in indigenous chickens are not clear. Mabelebele *et al.* (2014) reported that indigenous Venda chickens had higher gut pH values than Ross 308 broiler chickens. This, therefore, suggests that gut pH may explain the tolerance of high dietary CF levels by indigenous Venda chickens.

Gut pH is an important factor which affects the composition of microbiota, digestibility and absorption of most nutrients (Shang *et al.*, 2018). Lower gut digesta pH values are associated with improved immune system and sanitized gut environment (reduces fungal contamination) (Dittoe, 2018). Gut digesta pH values affect nutrient absorption (Dittoe, 2018; Hajati, 2018). However, the effect of increased gut digesta pH on crude fibre digestion in broiler and indigenous Venda chickens has not been extensively examined. This is important because it is a critical factor that may influence the presence and activity of cellulose degrading bacteria in the gut (Hussain *et al.*, 2017). Thus, affecting CF digestibility. However, its effect on CF digestibility in chickens has not been determined.

Sodium bicarbonate is an ingredient capable of increasing the water pH (Branton *et al.*, 1997). This is important because it is a critical factor that may influence the presence and activity of cellulose-degrading bacteria in the gut (Hussain, *et al.,* 2017), thus, affecting CF digestibility. However, its effect on CF digestibility in chickens has not been extensively determined.

Sodium bicarbonate is used in poultry diets as a source of sodium (Na) and supplies beneficial bicarbonate (Mongin, 1968; Leeson and Summers, 2005). It is the major cation in the extracellular fluid and is closely associated with chloride and bicarbonate (HCO_3) in the management of acid-base balance (Seifer and Chang, 2017). It is commonly added in the drinking water in order to control the effects of heat stress by boosting electrolyte balance in animals (Borges *et al.,* 2007). Damron *et al.* (1986) showed that sodium in sodium bicarbonate was equally bioavailable to that in salt for broiler chickens. Studies show that addition of electrolytes to broiler diets improves retention of fluids in the carcass, thus, preventing dehydration (Borges, 1997) and hence, meat properties such as colour, juiciness and flavour may be affected. There are no other studies that investigated the effect of the supplementation of sodium bicarbonate in the drinking water of chickens. Information on levels for optimal sodium bicarbonate supplementation in the drinking water on gut digesta pH, fibre digestibility, productive performance, gastrointestinal morphology, bacterial presence and meat quality of chickens is, therefore, limited.

4.2 Objectives

The objectives of this study were to determine:

a. the effect of sodium bicarbonate supplementation level in drinking water on feed intake, digestibility, feed conversion ratio and growth rate of male Ross 308 broiler and Venda chickens aged 22 to 42 days.
b. the effect of sodium bicarbonate supplementation level in drinking water on gut organ weight, length and digesta pH of male Ross 308 broiler and Venda chickens aged 42 days.
c. the effect of sodium bicarbonate supplementation level in drinking water on types of bacterial species in crops and gizzard digesta of male Ross 308 broiler and Venda chickens aged 42 days.

4.3 Hypotheses

The hypotheses of the study were as follows:

a. Sodium bicarbonate supplementation level in drinking water has no effect on feed intake, digestibility, feed conversion ratio and growth rate of Ross 308 broiler and indigenous Venda chickens aged 22 to 42 days.
b. There is no effect of sodium bicarbonate supplementation level in drinking water on gut organ weight and length, and digesta pH of Ross 308 broiler and indigenous Venda chickens aged 42 days.
c. Sodium bicarbonate supplementation level in drinking water has no effect on the type of bacterial species in crop and gizzard digesta of Ross 308 broiler and indigenous Venda chickens aged 42 days.

4.4 Materials and methods

4.4.1 Study site

The study was conducted at the University of Limpopo Livestock Unit. The study site was as described in Section 3.4.1

4.4.2 Experimental treatments, design and procedures

A total of 120 male chickens (60 Ross 308 and 60 Venda) were used in this study. Male chickens were used because they grow faster than their female counterparts (Benyi *et al.,* 2015). The broiler and indigenous Venda chickens were 22 days old at the commencement of the study. Prior to the commencement of the experiment, chickens were offered a commercial starter diet (Table 4.1) and during the experimental period, they were offered a grower diet to meet their nutrient requirements (Table 4.2). The experimental period was 3 weeks wherein chickens were housed in an open-sided poultry house that had 24 partitions (pens). Each pen measured about 1 m^2. Chickens had access to feed and treated water *ad libitum.* The experiment had four treatment levels of 0, 2.5, 5.0 and 7.5 g sodium bicarbonate per litre of drinking water, which were replicated 3 times. A 2 (breed) X 4 (sodium bicarbonate level) factorial arrangement in a completely randomised design was used.

Water containing sodium bicarbonate was prepared in the mornings daily, throughout the experimental period. Lighting was provided 24 hours per day.

Table 4.1 Nutrient composition of the starter diet fed to Ross 308 broiler and Venda chickens before the start of the trial

Nutrient	Starter
Dry matter (g/Kg)	880
Crude protein (g/kg DM)	233.0
Energy (MJ/kg DM)	12.0
Crude fibre (g/kg DM)	60
Crude fat (g/kg DM)	25
Calcium (g/kg DM)	12
Phosphorus (g/kg DM)	6.0
Potassium (g/kg DM)	9.2
Magnesium (g/kg DM)	1.9
Sodium (g/kg DM)	1.5
Lysine (g/kg DM)	11.0

4.4.3 Data collection

Ambient weather temperature was observed daily throughout the experimental period. Water intake was determined by subtracting the amount of water remaining from the amount given. The remaining water was measured using a measuring cylinder at 08.00 am every morning.

All chickens were weighed at the beginning of the experimental trial using an electronic sensitive weighing balance (Radwag, PS 4500/C/2) thereafter, weekly measurements were taken to determine growth rates. Feed intake was determined by subtracting the weight of the feed refusals from the weight of total feed given. Feed conversion ratio was calculated by dividing feed intake by the growth rate for a specified period. Mortality was observed per pen throughout the study period.

4.4.3.2 Nutrient digestibility

The nutrient digestibility trail was done when the chickens were aged 35 to 42 days. The procedure for nutrient digestibility determination was as described in Section 3.4.3.

4.4.3.3 Digesta pH measurement

The digesta pH was measured at each segment of the GIT using a digital pH meter (Crison, Basic 20 pH meter) prior to the emptying of the digesta. The segments of the GIT measured included: the crop, proventriculus, gizzard, small intestines (at the Meckel’s diverticulum), caecum and large intestines. Measurements were performed by inserting the pH meter probe into each segment of the GIT.

4.4.3.4 Digestive organ weight and length measurements

At the termination of this trial, one chicken per replicate was sacrificed for measurements of digestive organ weights and lengths. The crop, proventriculus, gizzard, small intestines, caeca and large intestines were flushed with distilled water to clean the digesta and then weighed. The carcass weights were, also, measured. For length measurements, the whole GIT, small intestines, caeca and large intestines were taken.

Table 4.2 Nutrient composition of the grower diet fed to Ross 308 broiler and Venda chickens

Nutrient	Grower
Dry matter (g/Kg)	880
Crude protein (g/kg DM)	198.8
Energy (MJ/kg DM)	12.5
Crude fibre (g/kg DM)	60.5
Crude fat (g/kg DM)	10
Calcium (g/kg DM)	10
Phosphorus (g/kg DM)	5.5
Potassium (g/kg DM)	9.7
Magnesium (g/kg DM)	2.0
Sodium (g/kg DM)	1.6
Lysine (g/kg DM)	11.5

4.4.3.5 Digesta sample collection for microbial analysis

The crop and gizzard digesta contents were sampled from Ross 308 broiler and indigenous Venda chickens. One chicken per replicate was selected for the determination of cellulolytic bacteria. Chickens were slaughtered by neck dislocation (Sparrey *et al.*, 2014). The whole gastrointestinal tract was removed from the abdominal cavity of chickens. The crop and gizzard were sterilized externally by 70 % ethyl alcohol. The digestive organ cavity was aseptically opened using a sterile blade. Samples of the content were transferred into labelled centrifuge tube and transported to the laboratory at Biotechnology Unit (University of Limpopo) for further analysis.

Isolation of microbial organisms

In the laboratory, 1 g of the digesta was added to 100 mL of peptone water (1.5 % peptone, 10 g NaCl /L) contained in stomacher bags and these were incubated at 37 ºC for 2 hours (Rohde *et al.*, 2015).

After incubation, 2.5 µL was pipetted behind the filter side with no particles from the sample and inoculated onto M9 minimal media plates containing microcrystalline cellulose (Avicel©, a carbon source). The plates were then incubated for 72 hours.

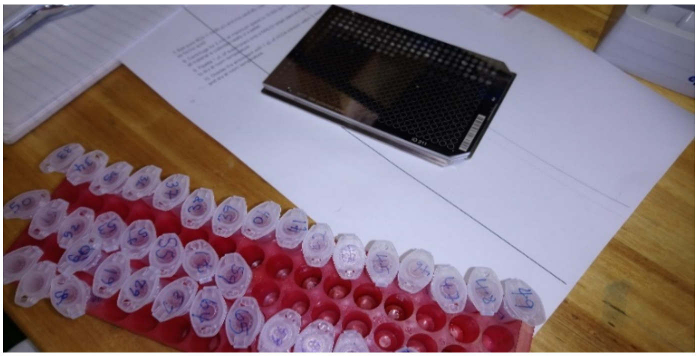
Thereafter, colonies that had grown were marked and picked for sub-culturing onto nutrient agar plates which were incubated for 24 hours at 37 ºC.

Identification of isolates

Sub-cultured isolates were identified using matrix assisted laser desorption ionization time of flight mass spectrophotometer (MALDI-TOF MS). Bacterial isolates were prepared for identification using the formic acid extraction method (Matsuda *et al.*, 2012). Isolates were transferred into 1.5 ml Eppendorf tubes containing 300 µL of deionized water and were vortexed thoroughly. Ethyl ethanol (900 µL) was then added and also mixed thoroughly by vortexing. The Eppendorf tubes were centrifuged at ≥13000 rpm for 2 minutes. The supernatant was decanted without disturbing the pellet, and the tubes were left to dry at room temperature for about 5 minutes.

After drying, 5 µL of 70 % formic acid was added to Eppendorf tubes containing the pellet and mixed by vortexing. Then 5 µL of acetonitrile (ACN) was also added followed by thorough vortexing. Eppendorf tubes with all the contents were thereafter centrifuged at 13 000 rpm for 2 minutes. The supernatant was pipetted (1 µL) onto a MALDI target plate and allowed to dry at room temperature. After drying, an overlay with 1 µL of α-cyano-4-hydroxycinnamic acid (HCCA) was applied on the entire spot and allowed to dry. Then the plate was inserted into the ionization chamber of the MicroFlex LT bench top mass spectrometer (Bruker Daltonics, Maldi Biotyper, Bremen, Germany) which is shown in Insert 4.2. The software for the control of the spectrometer was FlexControl 3.3 and Maldi Biotyper 3.1 (Bruker Daltonics) was used for the analysis of the spectra and comparison with the database.

Escherichia coli DH5α was used as a quality control as recommended by the manufacturer on each experiment.



Insert 4.1 A photo showing the MALDI target plate after spotting the supernatant from Eppendorf tubes

Insert 4.2 A photo of the MicroFlex LT bench top mass spectrometer (Bruker Daltonics, Maldi Biotyper, Bremen, Germany) at the Biotechnology Unit, University of Limpopo

4.4.3.6 Meat quality of chickens

Meat pH: The thigh and breast muscles were used. After 45 minutes post-mortem, pH measurements were taken using a pH meter (Crison, Basic 20 pH meter). An electron probe was inserted into an incision made on the thigh and breast muscles and the values were recorded. Before measurements were taken, the pH electrode was calibrated, using 3 buffers with pH values of 4.01, 7.00, and 9.01. The observed pH value was an average of 3 replicate measurements on the same muscle samples (Rammouz *et al.*, 2004).

Meat colour: A well calibrated portable colorimeter was used to determine the colour of the meat. The colour meter was placed flat against the surface of the muscle (Petrolli *et al.*, 2016). For each reading, 3 measurements were performed, and the final value for each sample is the average of those readings. The meat colour was expressed in the Commission Internationale d'Eclairage L*a*b* dimensions whereby L* for lightness, lower values indicate a darker colour), a* for redness, higher positive values indicate a higher contribution of redness and b* for yellowness, higher values indicate a higher contribution of yellowness) values. The meat colour evaluation was performed before the samples were frozen at −20°C.

Meat tenderness: The Warner-Bratzler shear force test was used to determine the tenderness of chicken breast meat. The Instron Universal Testing Machine™ was used to measure the maximum force required to shear strips of samples of meat (Dar and Light, 2014). Strips [1.0 cm (width) × 0.5 cm (thickness) × 2.5 cm (length)] parallel to the muscle fibre were prepared from the medial portion of the meat and sheared once vertically and perpendicularly for the muscle fibres (Molette *et al.*, 2003). The crosshead was affixed with the Warner-Bratzler apparatus for the shearing and speed was 250 mm/min.

Meat sensory evaluation: A total of 20 Semi-trained panellists were used to evaluate the meat. The breast meat from different treatments was grilled using an oven at a temperature of 105 ^{0}C for 50 minutes. The panellists judged the eating qualities such as flavour, tenderness and overall acceptability of the meat on the 5-point scale indicated on Table 4.3.

4.4.4 Chemical analysis

The procedures for the determination of dry matter, organic matter, crude protein, neutral detergent fibre, acid detergent fibre and ash contents were as described in Section 3.4.4.

Table 4.3 Evaluation scores that were used for sensory evaluation

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

Source: Motsepe *et al.* (2016)

4.4.5 Statistical analysis

All data on production performance, nutrient digestibility and carcass characteristics of the chickens were analysed using the General Linear Model procedures of SAS (2010).

The following model was used:

$$Y = \mu + W_0 + Brd + SB + (Brd \times SB) + e$$

Where Y = observation; μ = overall mean; W_0 = Initial bird weight (covariate); Brd = breed effect; SB = sodium bicarbonate level; Brd X SB level interaction effect and e = random error.

Fisher's least significant difference (LSD) test was applied for mean separation where there were significant differences ($P<0.05$). The responses in optimal productivity, nutrient digestibility, organ digesta pH, organ weight and length, meat tenderness and juiciness of the chickens to the level of sodium bicarbonate supplementation were modelled using the following quadratic equation:

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

Where Y = productivity, nutrient digestibility, organ digesta pH, organ weight and length; a = intercept; b_1 and b_2 = coefficients of the quadratic equation; x = level of sodium bicarbonate supplementation; e = random error and $-b_1/2b_2$ = x value for optimal response. The quadratic model was used because it gave the best fit.

The linear relationships between sodium bicarbonate supplementation level and responses in feed intake, digestibility and body weight changes were modelled using the following linear equation:

$$Y = a + bx + e$$

Where Y = water intake and digestibility; a = intercept; b = coefficient of the linear equation; x = level of sodium bicarbonate supplementation and e = random error.

4.5 Results

4.5.1 Production performance

All chickens were offered a starter diet (Table 4.1) prior to the commencement of the trial and a grower diet (Table 4.2) once the trial had commenced. These diets met nutrient requirements for both broiler and indigenous chickens as recommended by the National Research Council (NRC, 1994). The pH values of the drinking water used in the study are presented in Table 4.4. Supplementation of sodium bicarbonate in the drinking water of chickens resulted in different ($P<0.05$) water pH values. Increasing sodium bicarbonate supplementation level resulted in higher ($P<0.05$) water pH values.

Table 4.4 pH values* of drinking water given to male Ross 308 broiler and indigenous Venda chickens

Sodium bicarbonate concentration (g/L drinking water)	pH value
0.0	$6.73^{a} \pm 0.009$
2.5	$8.22^{b} \pm 0.008$
5.0	$8.36^{c} \pm 0.011$
7.5	$8.42^{d} \pm 0.003$

* : Values presented as mean ± standard error

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

The effects of sodium bicarbonate supplementation level in drinking water on production performance of male Ross 308 broiler and Venda chickens aged 22 to 42 days are presented in Table 4.5. Both sodium bicarbonate supplementation level in the drinking water and breed factors had effects ($P<0.05$) on water intake, feed intake, growth rate and live weight of chickens. However, no effects ($P<0.05$) were observed for feed conversion ratio. Male Ross 308 broiler chickens offered either 5.0 or 7.5 g of sodium bicarbonate per litre of drinking water had higher ($P<0.05$) water intake than those that were given 0 or 2.5 g of sodium bicarbonate per litre of drinking water. Similarly, those that were offered 2.5 g of sodium bicarbonate per litre of drinking water had higher ($P<0.05$) water intake than those on 0 g of sodium bicarbonate per litre of drinking water. However, sodium bicarbonate supplementation levels of either 5.0 or 7.5 g per litre of drinking water resulted similar ($P>0.05$) water intake in male Ross 308 broiler chickens. A sodium bicarbonate supplementation level of 8.9 g per litre of drinking water optimized ($r^2 = 0.995$) water intake in male broiler chickens (Table 4.6). In male Venda chickens, water intake increased ($P<0.05$) as sodium bicarbonate supplementation level in the drinking water was increased. There was a positive and linear relationship ($r = 0.99$) between sodium bicarbonate supplementation level in the drinking water and water intake ($Y = 202.43 + 23.85X$).

Feed intake of male Ross 308 broiler chickens offered 0 or 2.5 g of sodium bicarbonate per litre of drinking water was higher ($P<0.05$) than those of chickens given 7.5 g of sodium bicarbonate per litre of drinking water. However, male Ross 308 broiler chickens given 0, 2.5 or 5 g of sodium bicarbonate per litre of drinking water had the same ($P>0.05$) feed intakes. Similarly, male Ross 308 broiler chickens given 5 or 7.5 g of sodium bicarbonate per litre of drinking water had the same ($P>0.05$) feed intakes.

Table 4.5 Effect of sodium bicarbonate supplementation level in drinking water on performance of male Ross 308 broiler and indigenous Venda chickens aged 22 to 42 days*

Treatment		Variable				
		Water intake (ml/d)	Feed intake (g/d)	Growth (g/d)	FCR	Live weight (g)
	SB (g/L)				`	
Male Ross 308 chickens	0.0	360.1^{d} ± 6.59	114.7^{a} ± 2.53	58.7^{ab} ± 1.75	2.0^{b} ± 0.07	1875^{a} ± 18.9
	2.5	438.8^{b} ± 25.92	117.3^{a} ± 3.31	62.7^{a} ± 10.05	1.9^{b} ± 0.19	1957^{a} ± 25.8
	5.0	509.9^{a} ± 20.34	112.3^{ab} ± 3.89	63.2^{a} ± 9.28	1.8^{b} ± 0.14	1969^{a} ± 11.9
	7.5	531.6^{a} ± 25.94	104.4^{b} ± 3.95	49.3^{b} ± 9.58	2.0^{b} ± 0.18	1676^{b} ± 72.8
Male Venda chickens	0.0	200.8^{g} ± 30.06	80.3^{c} ± 6.664	27.3^{d} ± 2.75	2.9^{a} ± 0.46	938^{d} ± 62.4
	2.5	265.7^{f} ± 8.37	95.2^{c} ± 8.10	34.1^{c} ± 3.38	2.8^{a} ± 0.62	1081^{c} ± 104.6
	5.0	319.3^{e} ± 22.06	94.8^{c} ± 8.61	31.0^{cd} ± 1.77	3.0^{a} ± 0.55	1017^{c} ± 32.5
	7.5	381.7^{c} ± 35.43	85.4^{c} ± 7.90	28.6^{d} ± 0.62	3.0^{a} ± 1.07	966^{cd} ± 35.6
Breed						
Ross 308		460.1^{a} ± 38.77	112.18^{a} ± 4.95	58.5^{a} ± 1.84	1.9^{b} ± 0.04	1869^{a} ± 66.6
Venda		291.9^{b} ± 38.51	88.9^{b} ± 3.65	22.8^{b} ± 0.87	2.9^{a} ± 0.11	1000^{b} ± 31.7
Probabilities						
Sodium bicarbonate level		0.0001	0.0179	0.0418	0.9887	0.0197
Breed		0.0001	0.0001	0.0001	0.0001	0.0001
B. soda X breed interaction		0.8406	0.5347	0.9676	0.9060	0.0637

$^{a, b, c, d, e}$: Means in the same column not sharing a common superscript are significantly different ($P<0.05$)

FCR : Feed conversion ratio

* : Values presented as means ± standard error

SB : Sodium bicarbonate

A sodium bicarbonate supplementation level of 2.0 g per litre of drinking water optimized feed intake (r^2= 0.988) in these chickens (Table 4.6). On the contrary, sodium bicarbonate supplementation levels used in the present study did not affect (P>0.05) feed intake of male Venda chickens aged 22 to 42 days.

Table 4.6 Sodium bicarbonate supplementation levels in drinking water for optimal water intake (l/chicken/day), feed intake (g/chicken/day), growth rate (g/chicken/day) and live weight (g) of male Ross 308 broiler and indigenous Venda chickens aged 22 to 42 days

Variable	Formula	r^2	Optimal B. soda level (g/L)	Optimal Y-response
Male Ross 308 broiler chickens				
Water intake	$Y = 358.01 + 40.52X – 2.28X^2$	0.995	8.89	538.0
Feed intake	$Y = 114.94 + 1.71X – 0.42X^2$	0.988	2.04	116.7
Growth rate	$Y = 58.16 + 4.26X – 0.716X^2$	0.952	2.97	64.5
Live weight	$Y = 1863.25 + 89.1X – 15.0X^2$	0.950	2.97	1995.6
Venda chickens				
Growth rate	$Y = 27.83 + 2.792X – 0.368X^2$	0.790	3.80	33.1
Live weight	$Y = 949.0 + 59.0X – 7.76X^2$	0.796	3.80	1061.1

r^2: Coefficient of determination

Male Ross 308 broiler chickens offered 2.5 or 5.0 g of sodium bicarbonate per litre of drinking water had higher (P<0.05) growth rates than those offered 7.5 g of sodium bicarbonate per litre of drinking water. However, those offered 0, 2.5 or 5.0 g of sodium bicarbonate per litre of drinking water had similar (P>0.05) growth rates. Similarly, male Ross 308 broiler chickens offered 0 or 7.5 g of sodium bicarbonate per litre of drinking water had similar (P>0.05) growth rates. A sodium bicarbonate supplementation level of 2.97 g per litre of drinking water optimized (r^2= 0.952) growth rate of male Ross 308 broiler chickens (Table 4.6)

Male Venda chickens offered 2.5 g of sodium bicarbonate per litre of drinking water had higher (P<0.05) growth rates than those offered 0 or 7.5 g of sodium bicarbonate per litre of drinking water. However, those offered 2.5 or 5.0 g of sodium bicarbonate per litre of drinking water had the same (P>0.05) growth rates. Similarly, male Venda chickens offered 0, 5.0 or 7.5 g of sodium bicarbonate per litre of drinking water had the same (P>0.05) growth rates. A dietary CF level of 3.8 g of sodium bicarbonate per litre drinking water optimized (r^2= 0.790) growth rate in male Venda chickens (Table 4.6).

Male Ross 308 broiler chickens offered sodium bicarbonate levels of 0, 2.5 or 5.0 g per litre of drinking water had higher (P<0.05) live weights than those offered 7.5 g of sodium bicarbonate per litre of drinking water. However, those offered 0, 2.5 or 5.0 g sodium bicarbonate per litre of drinking water had similar (P>0.05) live weights. Live weight was optimized (r^2 = 0.990) at 2.97 g of sodium bicarbonate per litre of drinking water in Ross 308 broiler chickens (Table 4.6). Male Venda chickens offered 2.5 or 5.0 g of sodium bicarbonate per litre of drinking water had higher (P<0.05) live weights than those offered 0 g of sodium bicarbonate per litre of drinking water. Male Venda chickens that were offered 0 or 7.5 g of sodium bicarbonate per litre of drinking water had similar (P>0.05) live weights. Similarly, male Venda chickens offered 2.5, 5.0 or 7.5 g of sodium bicarbonate per litre of drinking water had the same (P>0.05) live weights. A sodium bicarbonate supplementation level of 3.8 g per litre of drinking water optimized (r^2 = 0.796) live weights of male Venda chickens (Table 4.6). Male Ross 308 broiler chickens had higher (P<0.05) water intake, feed intake, growth rate and live weight, and better (P<0.05) feed conversion ratio than male Venda chickens. No interaction effects (P>0.05) were observed between sodium bicarbonate supplementation level and breed of the chickens.

4.5.2 Nutrient digestibility, metabolizable energy intake and nitrogen retention

Results of nutrient digestibility, metabolizable energy intake and nitrogen retention values of male broiler and indigenous Venda chickens offered different levels of sodium bicarbonate in drinking water are presented in Table 4.7. Male broiler chickens given 2.5 g of sodium bicarbonate per litre of drinking water had higher (P<0.05) DM digestibility values than those offered 7.5 g of sodium bicarbonate per litre of drinking water. However, male broiler chickens offered 0, 0.25 or 5.0 g of sodium bicarbonate per litre of drinking water had similar (P>0.05) DM digestibility values. Similarly, male broiler chickens offered 0, 5.0 or 7.5 g of sodium bicarbonate in drinking water had the same (P>0.05) DM digestibility values.

Table 4.7 Effect of sodium bicarbonate supplementation level on nutrient digestibility, metabolizable energy (ME) intake (MJ/kg DM) and nitrogen retention (g/day) in male broiler and indigenous Venda chickens (means ± standard errors) aged 35 to 42 days

Treatment		Digestibility (%)				ME intake	Nitrogen retention
		DM	CP	NDF	ADF		
	SB (g/L)						
Male Ross 308 chickens	0.0	66.3^{ab} ± 2.9	61.5^{a} ± 1.99	59.7^{cd} ± 2.41	43.1^{b} ± 3.57	12.1^{a} ± 1.78	2.65^{a} ± 0.09
	2.5	70.2^{a} ± 3.40	61.0^{a} ± 1.45	61.2^{c} ± 2.45	41.9^{b} ± 1.07	12.4^{a} ± 0.99	2.33^{ab} ± 0.92
	5.0	66.1^{ab}± 0.78	59.1^{ab} ±0.89	54.1^{d} ± 2.97	39.7^{b} ± 2.09	12.3^{a} ± 1.42	2.39^{b} ± 0.20
	7.5	60.9^{b} ± 4.2	59.8^{b} ± 0.42	53.2^{d} ± 1.78	40.1^{b} ± 2.07	12.0^{a} ± 1.67	2.24^{b} ± 0.05
Male Venda chickens	0.0	62.4^{b} ± 0.5	59.0^{b} ± 1.2	64.2^{b} ± 1.12	47.7^{a} ± 2.08	10.7^{a} ± 2.15	1.65^{c} ± 0.24
	2.5	75.7^{a} ± 1.45	55.7^{bc} ± 2.3	68.3^{a} ± 1.02	47.9^{a} ± 2.48	11.8^{a} ± 1.78	1.58^{d} ± 0.11
	5.0	64.0^{ab} ± 1.43	56.2^{bc} ± 1.7	67.6^{a} ± 1.07	46.7^{a} ± 1.7	11.2^{a} ± 1.67	1.54^{d} ± 0.05
	7.5	60.2^{b} ± 1.48	51.4^{c} ± 0.78	66.9^{ab} ± 0.25	47.0^{a} ± 0.76	10.9^{a} ± 1.78	1.47^{d} ± 0.7
Breed							
Ross 308		65.8^{a} ± 0.75	60.4^{a} ± 2.31	57.1^{b}± 3.87	41.2^{b} ± 3.73	12.2^{a} ± 1.07	2.40^{a} ± 1.04
Venda		65.6^{a} ± 2.56	55.6^{b} ± 3.55	66.8^{a}± 2.25	47.3^{a} ± 2.08	11.1^{a} ± 0.87	1.56^{b} ± 2.11
Probabilities							
Sodium bicarbonate level		0.0452	0.0025	0.0178	0.1782	0.2231	0.0492
Breed		0.1105	0.0125	0.0001	0.0012	0.1056	0.0001
B. soda X breed interaction		0.0776	0.0847	0.1745	0.2174	0.3421	0.3214

$^{a, b, c, d}$: Means in the same column not sharing a common superscript are significantly different (P<0.05).
DMD : Dry matter digestibility
CPD : Crude protein digestibility
NDFD : Neutral detergent fibre digestibility
ADFD : Acid detergent fibre digestibility
SB : Sodium bicarbonate

A supplementation level of 2.63 g of sodium bicarbonate per litre of drinking water optimized ($r^2 = 0.946$) DM digestibility (Table 4.8). Male Venda chickens offered 2.5 g of sodium bicarbonate per litre of drinking water had higher DM digestibility values than those offered 7.5 g of sodium bicarbonate per litre of drinking water. However, those on 2.5 or 5.0 g of sodium bicarbonate per litre of drinking water had the same ($P>0.05$) DM digestibility values. Similarly, male Venda chickens offered 0, 5.0 or 7.5 g of sodium bicarbonate per litre of drinking water had the same ($P>0.05$) DM digestibility values. A supplementation level of 3.2 g of sodium bicarbonate per litre of drinking water optimized ($r^2 = 0.624$) DM digestibility in male Venda chickens (Table 4.8).

Table 4.8 Sodium bicarbonate supplementation levels in drinking water for optimal nutrient digestibility (%) and nitrogen retention (g/d/bird) of male Ross 308 broiler and indigenous Venda chickens aged 35 to 42 days

Variable	Formula	r^2	Optimal sodium bicarbonate level (g/L)	Optimal Y-response
Male Ross 308 broiler chickens				
DMD	$Y = 66.65 + 1.918X – 0.364X^2$	0.946	2.63	69.2
CPD	$Y = 61.70 – 0.64X+ 0.048X^2$	0.778	6.67	59.6
N-retention	$Y = 2.62 – 0.098X + 0.007X^2$	0.813	7.0	2.28
Male Venda chickens				
DMD	$Y = 64.05 + 4.4X - 0.68X^2$	0.624	3.20	71.2
NDFD	$Y= 64.44 + 1.736X – 0.192X^2$	0.881	4.52	68.4

r^2 : Coefficient of determination

DMD : Dry matter digestibility

CPD : Crude protein digestibility

NDFD : Neutral detergent fibre digestibility

Male broiler chickens supplemented with 0 or 2.5 g of sodium bicarbonate per litre of drinking water had higher ($P<0.05$) CP digestibility values than those offered 7.5 g of sodium bicarbonate per litre of drinking water. However, male broiler chickens offered sodium bicarbonate levels of 0 or 2.5 g per litre of drinking water had similar ($P>0.05$) CP digestibility values. Similarly, broiler chickens offered 0, 5.0 or 7.5 g of sodium bicarbonate per litre of drinking water had the same CP digestibility values. A supplementation level of 6.67 g of sodium bicarbonate per litre of drinking water optimized ($r^2 = 0.778$) CP digestibility in male broiler chickens (Table 4.8). Male Venda chickens offered 0 g of sodium bicarbonate per litre of drinking water had higher ($P<0.05$) CP digestibility values than those offered 7.5 g of sodium bicarbonate per litre of drinking water. However, male Venda chickens offered 0, 2.5 or 5.0 g of sodium bicarbonate per litre of drinking water had similar ($P>0.05$) CP digestibility values. Venda chickens offered 2.5, 5.0 or 7.5 g of sodium bicarbonate per litre of drinking water, also, had similar ($P>0.05$) CP digestibility values. There was a negative linear relationship ($r = 0.917$) between sodium bicarbonate supplementation level and CP digestibility values of Venda chickens (Table 4.9).

Table 4.9 Relationships between dietary sodium bicarbonate supplementation level in drinking water and neutral detergent fibre and crude protein digestibility and nitrogen retention in male broiler and indigenous Venda chickens aged 35 to 42 days

Variable	Formula	r	Probability
Male Ross 308 broiler chickens			
NDFD	$Y = 61.0 – 1.06X$	-0.861	0.001
Male Venda chickens			
CPD	$Y = 58.9 – 0.89X$	-0.917	0.083
N-retention	$Y = 1.65 – 0.023X$	-0.995	0.005

r : correlation coefficient

NDFD : Neutral detergent fibre digestibility

CPD : Crude protein digestibility

Male broiler chickens offered 2.5 g of sodium bicarbonate per litre of drinking water had higher ($P<0.05$) NDF digestibility values than those offered either 5.0 or 7.5 g of sodium bicarbonate per litre of drinking water. However, broiler chickens given 0.0 or 2.5 g of sodium bicarbonate per litre of drinking water had the same ($P>0.05$) NDF digestibility values. Similarly, broiler chickens given 0, 5 or 7.5 g of sodium bicarbonate per litre of drinking water had the same ($P>0.05$) NDF digestibility values. Increasing sodium bicarbonate level in drinking water linearly ($r = -0.845$) decreased NDF digestibility values in broiler chickens (Table 4.9). Male Venda chickens offered 2.5 or 5.0 g of sodium bicarbonate per litre of drinking water had higher ($P<0.05$) NDF digestibility values than those offered 0 g of sodium bicarbonate per litre of drinking water. Male Venda chickens given 2.5, 5.0 or 7.5 g of sodium bicarbonate per litre of drinking water had similar ($P>0.05$) NDF digestibility values. A sodium bicarbonate supplementation level of 4.52 g per litre of drinking water optimized NDF digestibility values (r^2 = 0.881) of indigenous Venda chickens (Table 4.9).

Nitrogen retention values of male broiler chickens offered 0 g of sodium bicarbonate per litre of drinking water were higher (P<0.05) than those from chickens given 5 or 7.5 g of sodium bicarbonate per litre of drinking water. However, broiler chickens offered 0 or 2.5 g of sodium bicarbonate per litre of drinking water had similar (P>0.05) nitrogen retention values. Similarly, male broiler chickens given 5.0 g of sodium bicarbonate per litre of drinking water had the same (P>0.05) nitrogen retention values as those given 7.5 g of sodium bicarbonate per litre of drinking water. Nitrogen retention in broiler chickens was optimized (r^2 = 0.813) at 7.0 g of sodium bicarbonate per litre of drinking water (Table 4.8). Male Venda chickens offered 0 g of sodium bicarbonate per litre of drinking water had higher (P<0.05) nitrogen retention values than those given 2.5, 5.0 or 7.5 g of sodium bicarbonate per litre of drinking water. However, Venda chickens offered 2.5, 5.0 or 7.5 g of sodium bicarbonate per litre of drinking water had similar (P>0.05) nitrogen retention values. A negative linear relationship (r = 0.994) was observed between sodium bicarbonate supplementation level in drinking water and nitrogen retention in Venda chickens (Table 4.9).

4.5.3 Gut organ digesta pH

Results of the effect of sodium bicarbonate supplementation level in the drinking water on organ digesta pH values in broiler and indigenous Venda chickens are presented in Table 4.10. Inclusion of sodium bicarbonate in the drinking water of Ross 308 broiler and Venda chickens aged 22 to 42 days affected (P<0.05) digesta pH values of the crop, proventriculus and gizzard contents. However, small intestine, caecum and large intestine digesta pH values were not affected (P<0.05) by inclusion of sodium bicarbonate in the drinking water of the chickens.

Male broiler chickens given 7.5 g of sodium bicarbonate per litre of drinking water had crop digesta pH values higher (P<0.05) than those given 0 or 2.5 g of sodium bicarbonate per litre of drinking water. However, chickens given 5.0 or 7.5 g of sodium bicarbonate per litre of drinking water had crop digesta with similar (P>0.05) pH values. Similarly, broiler chickens given 0 g of sodium bicarbonate per litre of drinking water had crop digesta with the same (P>0.05) pH values. There was a linear relationship (r = 0.992) between sodium bicarbonate supplementation level and crop digesta pH values (Table 4.11). Venda chickens given 7.5 g of sodium bicarbonate per litre of drinking water had higher ($P<0.05$) crop digesta pH values than those given 0, 2.5 or 5.0 g of sodium bicarbonate per litre of drinking water. However, male Venda chickens given 0, 2.5 or 5.0 g of sodium bicarbonate per litre of drinking water had crop digesta with the same ($P>0.05$) pH values. Crop digesta pH values were optimized ($r^2 = 0.944$) at a sodium bicarbonate supplementation level of 1.6 g of per litre of drinking water (Table 4.12).

Broiler chickens given 7.5 g of sodium bicarbonate per litre of drinking water had proventriculus digesta with pH values higher ($P<0.05$) than those of male broiler chickens offered 0 g of sodium bicarbonate per litre of drinking water. However, male broiler chickens given 7.5 g of sodium bicarbonate per litre of drinking water had proventriculus digesta with similar ($P>0.05$) pH values to those of chickens given 2.5, or 5 g of sodium bicarbonate per litre of drinking water. Proventriculus digesta pH values of broiler chickens were optimized ($r^2 = 0.944$) at a sodium bicarbonate level of 9.2 g of sodium bicarbonate per litre of drinking water (Table 4.12). Male Venda chickens offered 2.5, 5.0 or 7.5 g sodium bicarbonate per litre of drinking water had higher ($P<0.05$) proventriculus digesta pH than those of 0.0 g sodium bicarbonate per litre of drinking water. Male Venda chickens given 7.5, 5.0 or 2.5 g of sodium bicarbonate per litre of drinking water had similar ($P>0.05$) proventriculus digesta pH values. Proventriculus digesta pH values of chickens given 7.5, 5.0 or 2.5 g of sodium bicarbonate per litre of drinking water were higher ($P<0.05$) than those of male Venda chickens given 0 g of sodium bicarbonate per litre of drinking water. A sodium bicarbonate supplementation level of 5.2 g per litre of drinking water optimized ($r^2 = 0.944$) proventriculus digesta pH values in Venda chickens (Table 4.12).

Male broiler chickens given 7.5 or 5.0 g of sodium bicarbonate per litre of drinking water had higher ($P<0.05$) gizzard digesta pH values than those offered 0 g of sodium bicarbonate per litre of drinking water. However, gizzard digesta pH values of chickens given 2.5, 5.0 or 7.5 g of sodium bicarbonate per litre of drinking water were the same ($P>0.05$). A supplementation level of 8.3 g of sodium bicarbonate per litre of drinking water optimized ($r^2 = 0.983$) gizzard digesta pH values in Ross 308 broiler chickens (Table 4.12). Male Venda chickens given 7.5 g of sodium bicarbonate per litre of drinking water had gizzard digesta pH values that were higher ($P<0.05$) than those offered o g of sodium bicarbonate per litre of drinking water.

Table 4.10 Effect of sodium bicarbonate supplementation level in drinking water on gut organ digesta pH values* of male broiler and indigenous Venda chickens aged 42 days

Treatment		Gut organ					
		Crop	Proventriculus	Gizzard	Small intestines	Caecum	Large intestines
	SB (g/L)						
Male Ross 308 broiler	0.0	3.98^{c} ± 0.292	3.25^{b} ± 0.233	2.42^{b} ± 0.308	6.23^{a} ± 0.088	5.98^{a} ± 0.725	6.53^{a} ± 0.143
	2.5	4.40^{bc} ± 0.304	3.97^{ab} ± 0.356	2.90^{ab} ±0.496	6.13^{a}± 0.205	6.24^{a} ± 0.064	6.20^{a} ± 0.181
	5.0	5.31^{ab} ± 0.433	4.77^{ab} ± 0.505	3.54^{a} ± 0.176	6.12^{a}± 0.162	6.83^{a} ± 0.626	6.30^{a} ± 0.234
	7.5	6.38^{a} ± 0.187	5.07^{a} ± 0.708	3.56^{a} ± 0.569	5.93^{a}± 0.243	6.34^{a} ± 0.133	6.52^{a}± 0.304
Male Venda chickens	0.0	5.37^{b} ± 0.430	3.76^{b} ± 0.136	2.207^{b}± 0.331	6.81^{a}± 0.207	6.55^{a} ± 0.177	5.95^{a} ± 0.467
	2.5	5.52^{b} ± 0.115	5.76^{a} ± 0.610	2.550^{ab}±0.488	6.03^{a} ± 0.420	6.74^{a} ± 0.155	6.36^{a} ± 0.185
	5.0	5.59^{b} ± 0.211	6.25^{a} ± 0.194	3.093^{ab}±0.399	6.79^{a} ± 0.196	6.86^{a} ± 0.113	6.58^{a} ± 0.175
	7.5	6.67^{a}± 0.151	5.88^{a} ± 0.176	3.673^{a}± 0.336	6.02^{a} ± 0.185	6.77^{a} ± 0.121	6.35^{a} ± 0.106
Breed							
Ross 308		5.02^{a} ± 0.535	4.25^{a} ± 0.403	3.11^{a} ± 0.275	6.10^{a} ± 0.063	6.35^{a} ± 0.178	6.38^{a} ± 0.079
Venda		5.79^{a} ± 0.298	5.41^{a} ± 0.561	2.88^{a} ± 0.321	6.41^{a} ± 0.223	6.73^{a} ± 0.065	6.31^{a} ± 0.130
Probability							
SB level		0.0493	0.0034	0.0345	0.1654	0.0953	0.1443
Breed		0.1024	0.0954	0.0843	0.3432	0.1943	0.1643
SB level X Breed interaction		0.2344	0.0932	0.1830	0.0823	0.1290	0.1232

* : Values presented as mean ± standard error

$^{a, b, c}$: Means in the same column not sharing a common superscript are significantly different ($P<0.05$)

SB : Sodium bicarbonate

However, male Venda chickens offered 0, 2.5 or 5.0 g of sodium bicarbonate per litre of drinking water had similar ($P>0.05$) gizzard digesta pH values. There was a positive and linear ($r = 0.994$) relationship between sodium bicarbonate supplementation level in the drinking water and gizzard digesta pH of male Venda chickens (Table 4.11).

There were no ($P>0.05$) breed differences in digesta pH values of the crops, proventriculus, gizzards, small intestines, caeca and large intestines (Table 4.9). There were, also, no interactions between sodium bicarbonate supplementation level in the drinking water and breed of the chickens on digesta pH values.

Table 4.11 Relationships between dietary sodium bicarbonate supplementation level in drinking water and crop and gizzard pH values in male broiler and indigenous Venda chickens aged 42 days

Variable	Formula	r	Probability
Male Ross 308 broiler chickens			
Crop	$Y = 3.801 + 0.324X$	0.992	0.016
Male Venda chickens			
Gizzard	$Y = 2.140 + 0.197X$	0.994	0.006

r: correlation coefficient

Table 4.12 Sodium bicarbonate supplementation levels in drinking water for optimal gut organ digesta pH values in male Ross 308 broiler and indigenous Venda chickens aged 42 days

Variable	Formula	r^2	Sodium bicarbonate level for optimal Y (g/L)	Optimal Y-response
Male Ross 308 broiler chickens				
Proventriculus	$Y = 3.461 + 0.31X – 0.017X^2$	0.559	9.2	4.90
Gizzard	$Y = 2.381 + 0.30X – 0.018X^2$	0.983	8.3	3.63
Male Venda chickens				
Crop	$Y = 5.425 – 0.12X + 0.037X^2$	0.944	1.6	5.20
Proventriculus	$Y = 3.792 + 0.99X – 0.095X^2$	0.994	5.2	6.30

r^2: Coefficient of determination

4.5.4 Gut organ weights

Results of the effect of sodium bicarbonate supplementation level in drinking water on digestive organ weights in male Ross 308 broiler and indigenous Venda chickens are presented in Table 4.13.

Table 4.13 Effect of sodium bicarbonate supplementation level in drinking water on weights (g) of gut organs of male Ross 308 broiler and indigenous Venda chickens aged 42 days*

Treatment		Digestive organ					
		Crop	Proventriculus	Gizzard	Small intestines	Caecum	Large intestines
	SB (g/L)						
Male Ross 308 broiler	0.0	8.5^{a} ± 0.60	9.4^{b} ± 0.58	41.2^{b} ± 2.29	84.3^{b} ± 4.67	7.0^{a} ± 0.72	19.2^{a} ± 1.82
	2.5	10.0^{a} ± 1.14	11.2^{a} ± 0.61	49.2^{a} ± 1.35	110.4^{a} ± 14.10	6.9^{a} ± 0.90	17.0^{a} ± 1.46
	5.0	9.1^{a} ± 0.65	9.7^{b} ± 0.1	37.0^{b} ± 1.77	87.6^{b} ± 6.14	7.4^{a} ± 0.91	14.1^{a} ± 1.11
	7.5	10.1^{a}± 1.01	10.8^{ab} ± 0.53	38.7^{b} ± 2.70	92.2^{ab} ± 3.45	6.5^{a} ± 0.64	16.1^{a} ± 1.85
Male Venda chickens	0.0	7.9^{a} ± 1.72	6.3^{cd} ± 0.62	34.4^{b} ± 3.22	39.4^{c} ± 2.77	7.1^{a} ± 0.917	10.5^{a} ± 1.69
	2.5	8.4^{a} ± 1.51	7.5^{c} ± 0.09	40.1^{b} ± 6.75	45.0^{c} ± 2.24	10.2^{a} ± 0.90	17.8^{a} ± 7.73
	5.0	6.5^{a} ± 1.46	5.8^{d} ± 0.12	38.9^{b} ± 3.72	46.7^{c} ± 4.8	9.2^{a} ± 1.99	11.7^{a} ± 2.97
	7.5	9.1^{a} ± 2.25	5.4^{d} ± 0.35	32.4^{b} ± 1.24	48.6^{c} ± 4.19	10.5^{a} ± 0.95	17.5^{a} ± 0.12
Breed							
Ross 308		9.4^{a} ± 0.43	10.3^{a} ± 0.29	41.6^{a} ± 2.52	93.6^{a}± 4.51	6.9^{a} ± 2.37	16.6^{a} ± 0.85
Venda		8.0^{a} ± 0.81	6.2^{b} ± 0.28	36.5^{a} ± 3.04	44.9^{b}± 1.87	9.2^{a} ± 0.67	14.4^{a} ± 2.06
Probability							
Sodium bicarbonate level		0.9724	0.0165	0.0265	0.0108	0.1954	0.2855
Breed		0.4934	0.0055	0.1802	0.0384	0.4697	0.4621
B. Soda x breed interactions		0.8867	0.1018	0.3544	0.1474	0.1795	0.2934

* : Values presented as mean ± standard error

$^{a, b}$: Means in the same column not sharing a common superscript are significantly different (P<0.05).

SB : Sodium bicarbonate

Sodium bicarbonate supplementation level in drinking water affected ($P<0.05$) proventriculus, gizzard and small intestine weights of Ross 308 broiler chickens. However, the crop, caeca and large intestines of broiler chickens were not affected ($P>0.05$) by sodium bicarbonate supplementation in drinking water.

Male broiler chickens offered 2.5 g of sodium bicarbonate per litre of drinking water had higher ($P<0.05$) proventriculus and small intestine weights than those of male broiler chickens given 0 or 5 g sodium bicarbonate per litre of drinking water. However, broiler chickens offered 0, 5.0 or 7.5 g sodium bicarbonate per litre of drinking water had similar ($P>0.05$) proventriculus and small intestine weights. Similarly, male broiler chickens offered 2.5 or 7.0 g sodium bicarbonate per litre of drinking water had the same ($P>0.05$) proventriculus and small intestine weights. Sodium bicarbonate levels of 5.7 and 3.8 g per litre of drinking water optimized (r^2 = 0.129 and 0.284, respectively) proventriculus and small intestine weights, respectively, of broiler chickens (Table 4.14). Sodium bicarbonate supplementation level affected ($P<0.05$) proventriculus weights of indigenous Venda chickens. Other Venda chicken gut organ weights were not affected ($P>0.05$) by sodium bicarbonate supplementation level. Male Venda chickens offered 2.5 g of sodium bicarbonate per litre of drinking water had higher ($P<0.05$) proventriculus weights than those offered 0 or 5 g of sodium bicarbonate per litre of drinking water. However, male Venda chickens offered 0 or 2.5 g of sodium bicarbonate per litre of drinking water had similar ($P>0.05$) proventriculus weights. Those given 5 or 7.5 g of sodium bicarbonate per litre of drinking water, also, had similar ($P>0.05$) proventriculus weights. A supplementation level of 6.9 g of sodium bicarbonate per litre of drinking water optimized (r^2 = 0.646) proventriculus weight of Venda chickens (Table 4.12).

Male Ross 308 broiler chickens offered 2.5 g of sodium bicarbonate per litre of drinking water had higher ($P<0.05$) gizzard weights than those offered 0, 5.0 or 7.5 g of sodium bicarbonate per litre of drinking water. However, male Ross 308 broiler chickens offered 0, 5.0 or 7.5 g of sodium bicarbonate per litre drinking water had similar ($P>0.05$) gizzard weights. A supplementation level of 2.2 g of sodium bicarbonate per litre of drinking water optimized (r^2 = 0.335) gizzard weights in male Ross 308 broiler chickens (Table 4.14). Supplementation of drinking water with sodium bicarbonate did not affect ($P>0.05$) gizzard weight of male Venda chickens.

Table 4.14 Sodium bicarbonate supplementation levels for optimal gut organ weights of male Ross 308 broiler and indigenous Venda chickens aged 42 days

Variable	Formula	r^2	Optimal sodium bicarbonate level (g/L)	Optimal Y-response
Ross 308 Broiler chickens				
Proventriculus	$Y = 9.695 + 0.318X - 0.028X^2$	0.129	5.7	10.6
Gizzard	$Y = 42.905 + 1.102X - 0.252X^2$	0.335	2.2	44.1
Small intestine	$Y = 88.115 + 6.486X - 0.860X^2$	0.284	3.8	100.3
Venda chickens				
Proventriculus	$Y = 6.510 + 0.304X - 0.064X^2$	0.646	2.8	6.9

r^2: Coefficient of determination

4.5.5 Gut organ lengths

Results of the effect of sodium bicarbonate level in drinking water of male broiler and indigenous Venda chickens are presented in Table 4.15. Sodium bicarbonate supplementation level in drinking water of male broiler chickens affected ($P<0.05$) the gastrointestinal tract (GIT) and small intestine lengths. However, caeca and large intestine lengths were not affected ($P>0.05$) by sodium bicarbonate supplementation level in the drinking water. Male broiler chickens given 0 or 2.5 g of sodium bicarbonate per litre of drinking water had higher ($P<0.05$) GIT lengths than those given 5.0 g of sodium bicarbonate per litre of drinking water. However, male broiler chickens given 0, 2.5 or 7.5 g of sodium bicarbonate per litre of drinking water had similar ($P>0.05$) GIT lengths. Male broiler chickens given 5 or 7.5 g of sodium bicarbonate per litre of drinking water had the same ($P>0.05$) GIT lengths. A sodium bicarbonate supplementation level of 7.6 g per litre of drinking water optimized ($r^2 = 0.542$) GIT length of Ross 308 broiler chickens (Table 4.16).

Table 4.15 Effect of sodium bicarbonate level on length (cm) of gut organs of male Ross 308 broiler and indigenous Venda chickens (mean ± standard error)

Treatment		GIT	Gut organ		
			Small intestines	Caecum	Large intestines
	SB (g/L)				
Ross 308 broiler chickens	0.0	216.1^{a} ± 7.99	189.5^{ab} ± 8.11	15.1^{a} ±1.88	13.1^{a} ± 0.83
	2.5	223.3^{a} ± 8.19	191.6^{a} ± 17.92	19.1^{a} ±0.98	13.5^{a} ± 1.19
	5.0	188.0^{b} ± 2.69	160.3^{c} ± 2.31	17.4^{a} ±1.11	12.8^{a} ± 1.23
	7.5	204.3^{ab} ± 3.17	173.0^{bc} ± 3.2.74	18.5^{a} ±0.96	13.5^{a} ± 2.18
Venda chickens	0.0	125.8^{c} ± 5.33	103.5^{d} ± 3.82	12.5^{a} ± 0.50	9.7^{a} ± 0.33
	2.5	142.8^{c} ± 6.78	113.5^{d} ± 6.76	13.7^{a} ± 0.73	11.3^{a} ± 1.14
	5.0	123.0^{c} ± 2.78	105.7^{d} ± 9.24	14.3^{a} ± 1.45	10.0^{a} ± 0.01
	7.5	138.0^{c} ± 1.44	114.3^{d} ± 3.17	13.5^{a} ± 0.58	10.5^{a} ± 0.50
Breed					
Ross 308		208.0^{a} ± 7.71	$178.9.5^{a}$ ± 7.40	17.5^{a} ± 5.88	13.2^{a} ±4.18
Venda		132.4^{b} ± 4.76	109.3^{b} ± 2.74	13.5^{a} ± 3.37	10.4^{a} ± 2.35
Probability					
Sodium bicarbonate level		0.0025	0.0257	0.2536	0.8050
Breed		<.0001	<.0001	0.8690	0.2358
Soda level x breed (interactions)		0.2297	0.0784	0.6410	0.9610

$^{a, b, c}$: Means in the same column not sharing a common superscript are significantly different (P<0.05).

SB : Sodium bicarbonate

Male broiler chickens offered 2.5 g of sodium bicarbonate per litre of drinking water had higher ($P<0.05$) small intestine lengths than those given 5.0 g of sodium bicarbonate per litre of drinking water. However, those given 0 or 2.5 g of sodium bicarbonate per litre of drinking water had similar ($P>0.05$) small intestine lengths. Similarly, those given 5 or 7.5 g of sodium bicarbonate per litre of drinking water had the same ($P>0.05$) small intestine lengths. A sodium bicarbonate level of 7.2 g per litre of drinking water optimized ($r^2 = 0.379$) small intestine lengths of Ross 308 broiler chickens (Table 4.16). Lengths of the GIT and digestive organs of male Venda chickens were not affected ($P>0.05$) by sodium bicarbonate supplementation level in the drinking water.

Ross 308 broiler chickens had higher ($P<0.05$) GIT and small intestine lengths than male Venda chickens. However, caeca and large intestine lengths were similar ($P>0.05$). There were no interaction effects ($P>0.05$) between sodium bicarbonate supplementation level and breed digestive organ lengths of chickens.

Table 4.16 Sodium bicarbonate supplementation levels for optimal gut organ lengths (cm) in Ross 308 broiler chickens

Variable	Formula	r^2	Optimal sodium bicarbonate level (%)	Optimal Y-response
GIT	$Y = 220.8 – 5.558X + 0.364X^2$	0.379	7.6	199.6
Small intestine	$Y = 193.4 – 6.412X + 0.424X^2$	0.542	7.2	169.2

r^2: Coefficient of determination

4.5.6 Bacterial species found in the crop and gizzard contents of male Ross 308 broiler and Venda chickens

Crop

Results of the effect of supplementing sodium bicarbonate in the drinking water on bacterial species found in the crop digesta of male Ross 308 broiler and Venda chickens aged 42 days are presented in Table 4.17. Supplementation level of sodium bicarbonate in the drinking water affected the type of bacterial species found in the crops of male Ross 308 broiler chickens. Thus, *Bacillus atrophaeus, Bacillus subtilis* and *Lactobacillus paracasei* were only found in crop digesta of Ross 308 broiler chickens without sodium bicarbonate supplementation in their drinking water. *Proteus mirabilis, Aeromnas cavaie, Lactobacillus gasseri* and *Xanthobacter autotrophicus* were only found in the crop digesta of Ross 308 broiler chickens supplemented with 2.5 g of sodium bicarbonate per litre of drinking water. *Cronobacter sakazakii, Enterobacter aerogenes* and *Klebsiella pneumonia* were only found in the crop digesta of Ross 308 broiler chickens supplemented with 5.0 g of sodium bicarbonate per litre of drinking water. Similarly, *Bacillus safensis, Escherichia coli, Bacillus pumilus* and *Staphylococcus succinus* were only found in the crop digesta of Ross 308 broiler chickens offered 7.5 g of sodium bicarbonate per litre of drinking water. However, *Staphyloccocus epidermis* was found in crop digesta of male Ross 308 broiler chickens offered 5.0 or 7.5 g sodium bicarbonate per litre of drinking water.

Different bacterial species were found in the crop digesta of Venda chickens given different supplementation levels. The crop digesta of Venda chickens not supplemented with sodium bicarbonate in the drinking water had *B. atrophaeus, B. subtilis* and *Bacillus circulans.* Male Venda chickens offered 2.5 g of sodium bicarbonate per litre of drinking water had *P. mirabilis, B. atrophaeus and E. coli in* their crop digesta. Male Venda chickens offered 5.0 g of sodium bicarbonate per litre of drinking water had *Staphylococcus aureus* and *E. Coli* in their crop digesta. Similarly, Venda chickens given 7.5 g of sodium bicarbonate per litre of drinking water had *B. safensis, E. coli and S. epidermidis.* However, male Venda chickens offered 0 or 2.5 g sodium bicarbonate per litre of drinking water had *Bacillus atrophaeus* in their crop digesta. Supplementing drinking water with 2.5, 5.0 or 7.5 g sodium bicarbonate per litre resulted in Venda chickens having *E. coli* in their crop digesta. Also, *Staphylococcus epidermis* was found in crop digesta of Venda chickens offered higher supplementation levels of 5.0 or 7.5 g sodium bicarbonate per litre of drinking water. Some bacterial species were found in both Ross 308 broiler and Venda chicken breeds. When drinking water was without sodium bicarbonate supplementation the crop digesta of both Ross 308 and Venda chickens had *B. atrophaeus* and *B. subtilis.* However, *B. circulans and L. paracasei* were found in male Ross 308 broiler and Venda chickens, respectively.

Table 4.17 Effect of supplementing sodium bicarbonate in the drinking water on bacterial species found in the crop contents of male Ross 308 broiler and Venda chickens aged 42 days

SB level (g/L)	Bacterial species	MALDI-TOF MS Score value	
		Ross 308 broiler chickens	Venda chickens
0	*Bacillus atrophaeus*	1.590	1.842
	Bacillus subtilis	1.488	1.788
	Lactobacillus paracasei	1.404	-
	Bacillus circulans	-	2.21
2.5	*Proteus mirabilis*	1.857	1.979
	Aeromnas cavaie	1.678	-
	Lactobacillus gasseri	1.376	-
	Xanthobacter autotrophicus	1.562	-
	Bacillus atrophaeus	-	1.749
	Escherichia coli	-	2.156
5.0	*Staphylococcus epidermidis*	1.392	1.622
	Cronobacter sakazakii	1.702	-
	Enterobacter aerogenes	1.692	-
	Klebsiella pneumonia	1.914	-
	Escherichia coli	-	2.146
	Staphylococcus aureus	-	1.821
7.5	*Bacillus safensis*	1.402	1.794
	Escherichia coli	1.989	2.002
	Staphylococcus epidermidis	1.062	1.687
	Bacillus pumilus	1.374	-
	Staphylococcus succinus	1.021	-

Proteus marabilis was found in the crop digesta of both Ross 308 broiler and Venda chickens supplemented with 2.5 g of sodium bicarbonate per litre of drinking water. However, *A. cavaie, L. gasseri* and *X. autotrophicus* were only found in the crop digesta of Ross 308 broiler chickens. Similarly, *B. atrophaeus* and *E. coli* were only found in the crop digesta of Venda chickens offered 2.5 g of sodium bicarbonate per litre of drinking water. Ross 308 broiler and Venda chickens offered 5.0 g of sodium bicarbonate per litre of drinking water had *S. epidermidis* in their crop digesta. However, only Ross broiler chickens supplemented with 5.0 g of sodium bicarbonate in the drinking water had *C. sakazakii, E. aerogenes and K. pneumonia.* Also, only Venda chickens supplemented with 5.0 g of sodium bicarbonate in the drinking water had *E. coli* and *S. aureus* in their crop digesta. All the bacterial species (*B. safensis, E. coli and B. pumilus*) found in the crop digesta of Venda chickens supplemented with 7.5 g of sodium bicarbonate per litre of drinking water were, also, found in the crop digesta of Ross 308 broiler chickens supplemented with the same level of sodium bicarbonate in the drinking water.

Gizzard

Results of the effect of supplementing sodium bicarbonate in the drinking water on bacterial species found in the gizzard digesta of male Ross 308 broiler and Venda chickens aged 42 days are presented in Table 4.18. There were bacterial species that were found exclusively in the gizzard digesta of Ross 308 broiler chickens for each supplementation level of sodium bicarbonate in the drinking water. Thus, *Campylobacter jejuni, Cellulomonas gelida* and S*taphylococcus camosus* were found in gizzard digesta of male Ross 308 broiler chickens that were not supplemented with sodium bicarbonate. Similarly, *Bacillus natto* was only found in gizzard digesta of male Venda chickens offered water without sodium bicarbonate supplementation. C*lostridium difficile* was only found in gizzard digesta of male Ross 308 broiler chickens offered 2.5 g of sodium bicarbonate per litre of drinking water. While *staphylococcus lentus* and *staphylococcus sciuri* were only found in gizzard digesta of male Venda chickens offered 2.5 g of sodium bicarbonate per litre of drinking water. *Bacillus cereus, Pseudomonas thivervalensis, Staphylococcus epidermidis* and *Staphylococcus lugdunensis* were found only in male Ross 308 broiler chickens offered 5.0 g of sodium bicarbonate per litre of drinking water. Similarly, *Lysinibacillus fusiformis, Lactobacillus gasseri* and *Pseudomonas plecoglossicida* were found in the gizzard digesta of male Ross 308 broiler chickens offered 7.5 g of sodium bicarbonate per litre of drinking water. While *L. fusiformis* was only found in the gizzard digesta of male Venda chickens offered 7.5 g sodium bicarbonate per litre of drinking water.

Table 4.18 Effect of sodium bicarbonate supplementation level in the drinking water on bacterial species found in gizzard contents of male Ross 308 broiler and Venda chickens aged 42 day

SB level (g/L)	Bacterial species	MALDI-TOF MS Score value	
		Ross 308 broiler chickens	Venda chickens
0	*Escherichia coli*	2.021	1.872
	Bacillus atrophaeus	1.925	-
	Bacillus safensis	1.605	-
	Campylobacter jejuni	1.827	-
	Cellulomonas gelida	1.250	-
	Staphylococcus carnosus	1.246	-
	Bacillus cereus	-	1.96
	Bacillus megaterium	-	1.888
	Bacillus natto	-	1.566
2.5	*Escherichia coli*	1.721	2.317
	Bacillus atrophaeus	1.786	-
	Bacillus safensis	1.895	-
	Clostridium difficile	1.370	-
	Staphylococcus lentus	-	1.567
	Staphylococcus sciuri	-	1.654
5.0	*Bacillus cereus*	1.749	1.737
	Bacillus atrophaeus	1.385	-
	Pseudomonas thivervalensis	1.224	-
	Staphylococcus epidermidis	1.323	-
	Staphylococcus lugdunensis	1.456	-
	Bacillus megaterium	-	1.980
	Corynebacterium confusum	-	1.269
	Escherichia coli	-	2.290
	Lysinibacillus sphaericus	-	1.381
7.5	*Escherichia coli*	1.952	2.130
	Lysinibacillus fusiformis	1.914	1.289
	Lactobacillus gasseri	1.184	-
	Pseudomonas plecoglossicida	1.224	-

While *B. safensis* was found in gizzard digesta of Ross 308 broiler chicken offered 0 or 2.5 g of sodium bicarbonate per litre of drinking water. Similarly, *E. coli* was found in the crop digesta of Ross 308 broiler chickens offered 0, 2.5 or 7.5 g of sodium bicarbonate per litre of drinking water.Ross 308 broiler and Venda and chickens not supplemented with sodium bicarbonate had different bacterial species in their gizzard digesta (Table 4.18). *Bacillus atrophaeus, Bacillus safensis, Campylobacter jejuni* and *Cellulomonas gelida* were found in the gizzard digesta of Ross 308 broiler chickens. Similarly, *Staphylococcus carnosus, Bacillus cereus, Bacillus megaterium* and *Bacillus natto* were found in the gizzard digesta of Venda chickens. However, only *E. coli* was found in the gizzard digest of both Ross 308 broiler and Venda chickens. Ross 308 broiler chickens offered 2.5 g of sodium bicarbonate per litre of drinking water had *B. atrophaeus, B. safensis and C. difficile*; however, Venda chickens offered 2.5 g of sodium bicarbonate per litre of drinking water had *S. lentus* and *S. sciuri* in their gizzard digesta. Both chicken breeds had *E. coli* when offered 2.5 g of sodium bicarbonate per litre of drinking water. Ross 308 broiler chickens offered 5 g of sodium bicarbonate per litre of drinking water had *Pseudomonas thivervalensis, S. epidermidis and Staphylococcus lugdunensis* in their gizzard digesta. Venda chickens offered 5 g of sodium bicarbonate had *B. megaterium, Corynebacterium confusum, E. coli* and *Lysinibacillus sphaericus* in their gizzard digesta. However, *B. cereus* was common in both chicken breeds. Ross 308 broiler chickens offered 7.5 g per litre of drinking water had *Lactobacillus gasseri, E. coli, Lysinibacillus* and *Pseudomonas plecoglossicida* in their gizzard digesta. While *E. coli* and *L. fusiformis* were found in the gizzard digesta of Venda chickens.

4.5.7 Meat colour

Results of the effect of sodium bicarbonate supplementation level in drinking water on breast and thigh meat colour of male Ross 308 broiler and Venda chickens are presented in Table 4.19. Meat colour (L*, a* and b*) of the breasts and thighs of male Ross 308 broiler chickens were not affected ($P>0.05$) by sodium bicarbonate supplementation level in drinking water. Similarly, differences ($P>0.05$) observed between breeds except for the redness ($P<0.05$) of the breast meat. Breast meat from male Venda chickens had higher ($P<0.05$) redness values than those of male Ross 308 broiler chickens.

Table 4.19 Effect of sodium bicarbonate in drinking water on the colour* of breast and thigh meat of Ross 308 broiler and indigenous Venda chickens aged 42 days

Treatment		Breast			Thigh		
		Lightness (L*)	Redness (a*)	Yellowness (b*)	Lightness (L*)	Redness (a*)	Yellowness (b*)
	SB (g/L)						
Ross 308 broiler chickens	0.0	$46.8^{a} \pm 3.23$	$3.4^{b} \pm 1.23$	$12.9^{a} \pm 1.34$	$51.0^{a} \pm 1.09$	$7.9^{a} \pm 0.76$	$13.1^{a} \pm 0.97$
	2.5	$49.7^{a} \pm 2.45$	$2.9^{b} \pm 2.07$	$13.2^{a} \pm 1.79$	$49.9^{a} \pm 1.68$	$9.1^{a} \pm 0.97$	$12.7^{a} \pm 0.87$
	5.0	$48.7^{a} \pm 1.38$	$3.1^{b} \pm 0.95$	$14.1^{a} \pm 1.06$	$48.3^{a} \pm 1.62$	$8.5^{a} \pm 1.23$	$14.0^{a} \pm 1.3$
	7.5	$47.1^{a} \pm 2.93$	$2.3^{b} \pm 0.23$	$13.1^{a} \pm 1.65$	$50.1^{a} \pm 1.43$	$9.1^{a} \pm 1.5$	$13.2^{a} \pm 0.87$
Venda chickens	0.0	$52.8^{a} \pm 1.71$	$3.5^{a} \pm 0.63$	$11.0^{a} \pm 0.74$	$50.4^{a} \pm 1.94$	$8.0^{a} \pm 0.66$	$12.9^{a} \pm 1.45$
	2.5	$51.5^{a} \pm 2.12$	$3.4^{a} \pm 0.34$	$8.6^{a} \pm 0.65$	$48.7^{a} \pm 1.56$	$8.2^{a} \pm 0.80$	$12.1^{a} \pm 0.50$
	5.0	$48.8^{a} \pm 3.18$	$5.9^{a} \pm 0.58$	$11.9^{a} \pm 2.85$	$48.9^{a} \pm 1.70$	$8.9^{a} \pm 0.58$	$12.6^{a} \pm 0.98$
	7.5	$52.4^{a} \pm 2.03$	$5.0^{a} \pm 1.24$	$11.7^{a} \pm 0.98$	$49.9^{a} \pm 1.19$	$8.8^{a} \pm 0.83$	$12.4^{a} \pm 2.17$
Breed							
Ross 308		$48.1^{a} \pm 2.1$	$2.9^{b} \pm 1.6$	$13.3^{a} \pm 2.45$	$49.8^{a} \pm 0.56$	$8.7^{a} \pm 0.48$	$13.2^{a} \pm 1.50$
Venda		$51.4^{a} \pm 1.2$	$4.5^{a} \pm 1.83$	$10.8^{a} \pm 0.94$	$49.5^{a} \pm 0.18$	$8.5^{a} \pm 0.73$	$12.5^{a} \pm 1.39$
Probability							
Sodium bicarbonate level		0.1324	0.3002	0.0905	0.0913	0.1954	0.2855
Breed		0.2934	0.0487	0.3702	0.3046	0.4697	0.4621
B. Soda x breed interactions		0.0667	0.4182	0.3944	0.5447	0.2795	0.2934

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

[a] : Means in the same column not sharing a common superscript are significantly different ($P<0.05$)

SB : Sodium bicarbonate

4.5.8 Meat sensory evaluation, shear force and pH

Results of the effect of sodium bicarbonate supplementation level in drinking water on breast meat sensory evaluation, shear force and meat pH of male Ross 308 broiler and Venda chickens are presented in Table 4.20. Sodium bicarbonate supplementation in drinking water did not influence ($P>0.05$) meat tenderness, juiciness, flavour, overall acceptability and meat pH of male Ross 308 chickens. Similarly, male Venda chicken meat tenderness, overall acceptability and pH were not affected ($P>0.05$) by sodium bicarbonate supplementation in the drinking water. However, juiciness and flavour of meat from Venda chickens were affected ($P<0.05$). Breast meat of male Venda chickens given 5 g of sodium bicarbonate per litre of drinking water had a higher score of juiciness compared to that of breast meat from those given 7.5 g of sodium bicarbonate per litre of drinking water. However, those given 0, 2.5 or 5.0 g of sodium bicarbonate per litre of drinking water had breast meat with similar ($P>0.05$) juiciness scores. Similarly, male Venda chickens given 0, 2.5 or 7.5 g of sodium bicarbonate per litre of drinking water had the same ($P>0.05$) juiciness scores. A sodium supplementation level of 3.6 g per litre drinking water optimized ($r^2 = 0.953$) juiciness of meat of male Venda chickens (Table 4.21).

Male Venda chickens offered 2.5 g of sodium bicarbonate per litre of drinking water had a higher ($P<0.05$) meat flavour score than meat from Venda chickens offered 7.5 g of sodium bicarbonate per litre of drinking water. Male Venda chickens offered 0, 2.5 or 5.0 g of sodium bicarbonate per litre drinking water had similar ($P>0.05$) meat flavour scores. Similarly, male Venda chickens offered 0, 5.0 or 7.5 g of sodium bicarbonate per litre of drinking water had the same ($P>0.05$) meat flavour scores. A supplementation level of 3.2 g of sodium bicarbonate per litre of drinking water optimized ($r^2 = 0.581$) meat flavour of male Venda chickens (Table 4.21).

Male Venda chickens offered 0 g of sodium bicarbonate per litre of drinking water had breast meat with a higher ($P<0.05$) shear force value than those of Venda chickens offered 5.0 g of sodium bicarbonate per litre drinking water. However, male Venda chickens offered 0, 2.5 or 7.5 g of sodium bicarbonate per litre of drinking water had similar ($P>0.05$) breast meat shear force values. Similarly, male Venda chickens offered 2.5, 5.0 or 7.5 g of sodium bicarbonate per litre of drinking water had the same ($P>0.05$) breast meat shear force values.

Table 4.20 Meat sensory attributes, shear force and pH of breast meat from chickens supplemented with sodium bicarbonate in drinking water

Treatment		Meat sensory evaluation				Shear force (N)	Meat pH
		Tenderness	Juiciness	Flavour	Overall acceptability		
	SB (g/L)						
Ross 308 chickens	0.0	$3.7^{a} \pm 0.44$	$3.6^{a} \pm 0.75$	$2.8^{b} \pm 0.63$	$3.8^{a} \pm 0.45$	$30.9^{a} \pm 6.19$	$5.8^{a} \pm 0.04$
	2.5	$3.9^{a} \pm 0.18$	$3.4^{a} \pm 0.64$	$3.1^{b} \pm 1.34$	$3.6^{a} \pm 0.16$	$31.0^{a} \pm 3.27$	$5.9^{a} \pm 0.02$
	5.0	$4.0^{a} \pm 0.11$	3.5 ± 0.95	$3.1^{b} \pm 1.27$	$3.0^{a} \pm 0.54$	$31.3^{a} \pm 5.81$	$6.1^{a} \pm 0.12$
	7.5	$3.7^{a} \pm 0.33$	$3.5^{a} \pm 1.07$	$2.5^{b} \pm 1.76$	$3.5^{a} \pm 0.87$	$32.1^{a} \pm 4.20$	$5.8^{a} \pm 0.17$
Venda chickens	0.0	$3.6^{b} \pm 0.44$	$3.0^{bc} \pm 0.14$	$3.3^{ab} \pm 0.13$	$3.6^{a} \pm 0.12$	$34.3^{a} \pm 2.94$	$5.7^{a} \pm 0.04$
	2.5	$3.8^{b} \pm 0.24$	$3.3^{bc} \pm 0.12$	$4.6^{a} \pm 0.14$	$3.9^{a} \pm 0.29$	$28.3^{ab} \pm 2.79$	$5.7^{a} \pm 0.03$
	5.0	$3.8^{b} \pm 0.82$	$3.4^{b} \pm 0.12$	$3.4^{ab} \pm 0.13$	$3.7^{a} \pm 0.60$	$26.2^{b} \pm 3.53$	$6.4^{a} \pm 0.30$
	7.5	$3.8^{b} \pm 1.13$	$2.9^{c} \pm 0.14$	$2.9^{b} \pm 0.12$	$3.6^{a} \pm 0.15$	$30.9^{ab} \pm 1.67$	$6.6^{a} \pm 0.30$
Breed							
Ross 308		$3.8^{a} \pm 0.12$	$3.5^{a} \pm 0.32$	$2.9^{b} \pm 1.1$	$3.2^{a} \pm 0.52$	$31.3^{a} \pm 2.09$	$5.9^{a} \pm 0.81$
Venda		$3.5^{b} \pm 0.05$	$3.1^{a} \pm 0.19$	$3.6^{a} \pm 0.2$	$3.7^{a} \pm 0.31$	$30.6^{a} \pm 3.16$	$5.6^{a} \pm 0.12$
Probabilities							
Sodium bicarbonate level		0.1032	0.0132	0.0088	0.9887	0.0197	0.0678
Breed		0.0318	0.2103	0.0101	0.1121	0.1082	0.1203
B. soda X breed interaction		0.8406	0.5347	0.9676	0.9060	0.0637	0.9878

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

$^{a, b}$: Means in the same column not sharing a common superscript are significantly different ($P<0.05$)

SB: Sodium bicarbonate

A supplementation level of 4.7 g of sodium bicarbonate per litre of drinking water optimized ($r^2 = 0.789$) breast meat shear force values of male Venda chickens (Table 4.21).

Meat from male Ross 308 broiler chickens had higher ($P<0.05$) tenderness values than that from male Venda chickens; however, meat from male Venda chickens had a higher ($P<0.05$) flavour score than that from male Ross 308 broiler chickens. The two breeds had similar ($P>0.05$) juiciness, overall acceptability, shear force and meat pH values.

Table 4.21 Sodium bicarbonate supplementation levels in drinking water for optimal meat juiciness, flavour and shear force of male indigenous Venda chickens aged 42 days

Variable	Formula	r^2	Optimal sodium bicarbonate level (g/L)	Optimal Y-response
Juiciness	$Y = 2.980 + 0.232X - 0.032X^2$	0.953	3.6	3.4
Flavour	$Y = 3.470 + 0.408X - 0.064X^2$	0.581	3.2	4.1
Shear force	$Y = 34.895 - 2.922X + 0.308X^2$	0.789	4.7	28.0

r^2: Coefficient of determination

4.6 Discussion

4.6.1 Production performance

The results of the present study indicated that adding sodium bicarbonate in drinking water resulted in increased water pH. Adding sodium bicarbonate in water raised the pH to around 8.4 and this is similar to other findings (McDonald *et al.*, 2010). It, therefore, has a strong capacity for increasing the pH of drinking water provided to chickens. Other antacids such as calcium carbonate have been reported to have a similar effect on water pH (Shafey, 1999; Walk *et al.*, 2012). Shafey (1999) suggested that chickens adapt to a wide variety of dietary conditions without significant changes in digestive tract pH.

Sodium bicarbonate supplementation levels used in this study ranged from 0 to 7.5 g per litre of drinking water. Results indicated that water intake was affected by sodium bicarbonate supplementation level in both chicken breeds. This is consistent with other studies (Hayat *et al.*, 1999; Zakaria *et al.*, 2009; Osman *et al.*, 2015). Sodium bicarbonate contributes to high water intake by providing dietary sodium ions (Na^+) (Borges *et al.*, 2003; Mushtaq *et al.*, 2014). Sodium, potassium and chloride are strong ions responsible for the acid-base equilibrium and the pH of blood and tissues (Borges *et al.*, 2003). A higher amount of such electrolytes, therefore, induced a higher demand for hydration, thus resulting in higher water intake in the present study (Dai *et al.,* 2009). A supplementation level of 8 g sodium bicarbonate per litre of drinking water optimized water intake in male Ross 308 broiler chickens. Damron *et al.* (1986) reported a sodium bicarbonate supplementation level of 1.44 g/kg DM of feed for optimal water intake. However, in indigenous male Venda chickens, results of the present study indicated that water intake increased linearly with increases in sodium bicarbonate supplementation level. Thus, increases in sodium bicarbonate supplementation in the drinking water resulted in increased water intake. No studies on the effect of sodium bicarbonate supplementation on water intake indigenous chickens were found.

Ross 308 broiler chickens consumed more water than indigenous Venda chickens. Tabler (2003) and Lott *et al.* (2003) found that water intake is, also, correlated to feed consumption and is, therefore, an indicator for flock performance. In the current study, the feed intake and body weights of male Ross 308 broiler chickens were higher than those of indigenous male Venda chickens. It is possible, therefore, that male Ross 308 broiler chickens require more water in order to enhance feed intake. Chikumba and Chimonyo (2014) reported that indigenous chickens have a low requirement for drinking water and have a higher dependence on metabolic water. Hence, in the present study male Venda chickens drank less water than male broiler chickens.

Feed intake was affected by sodium bicarbonate supplementation in the drinking water of male Ross 308 broiler chickens. Peng *et al.* (2015) reported contrary findings that sodium bicarbonate supplementation in drinking water did not affect feed intake in broiler chickens aged 22 to 42 days. The lack of response in their study may have been due to the low levels of sodium bicarbonate used in their experiments. In the present study, feed intakes of male Ross 308 broiler chickens were optimized at a sodium bicarbonate supplementation level of 2.04 g per litre of drinking water. Other studies reported that sodium bicarbonate supplementation levels of <1 g per litre of drinking water optimized feed intakes (Zakaria *et al.*, 2009). Feed intake was not affected by sodium bicarbonate supplementation levels used in this study in the drinking water of male Venda chickens aged 22 to 42 days. Reasons for this are not clear.

Growth rates and live weights were affected by sodium bicarbonate supplementation level in the drinking water in both male Ross 308 broiler and Venda chickens. Zakariah *et al.* (2009) reported similar findings when sodium bicarbonate was supplemented in the feed of broiler chickens and Egyptian Balady chickens. A sodium bicarbonate supplementation level of 2.97 g per litre of drinking water optimized both growth rates and live weights in male Ross 308 broiler chickens. Peng *et al.* (2013) reported an inclusion level of 4 % sodium bicarbonate for optimal growth rates and live weights in broiler chickens. However, a higher sodium bicarbonate supplementation level of 3.8 g per litre of drinking water optimized growth rates and live weights in male Venda chickens. This may indicate that male indigenous Venda chickens tolerate higher dietary sodium bicarbonate supplementation levels for growth rate and live weight compared to male Ross 308 broiler chickens. Feed conversion ratio was not affected by sodium bicarbonate supplementation levels used in this study for both male Ross 308 broiler and Venda chickens. Zakariah *et al.* (2009) and Peng *et al.* (2015) also reported no effects of sodium bicarbonate supplementation on FCR broiler and Egyptian Balady chickens. It is concluded that water intake, feed intake and growth rate of male Ross 308 broiler and Venda chickens were optimized at different sodium bicarbonate supplementation levels. This has implications on ration formulations.

Results of the present study indicate that feed intake, growth rate, FCR and live weight of male Ross 308 broiler chickens were better than those of indigenous male Venda chickens. Such differences are genetically based (Schmidt *et al.,* 2009). Broiler chickens are selected for higher production performance (Leeson and Summers, 2005; Padhi, 2016). Venda chickens, however, are slow-growing chickens (Mbajiorgu *et al.*, 2011; Mabelebele *et al.*, 2017). Thus, male broiler chickens were expected to perform better than male Venda chickens.

4.6.2 Nutrient digestibility

Sodium bicarbonate supplementation levels in drinking water used in the present study affected feed DM digestibility in male Ross 308 broiler and Venda chickens. Akter *et al.* (2019) indicated that the effect on DM digestibility of diets may be attributed to the increased water intake. Dry matter digestibility of male Ross 308 broiler chickens was optimized at a supplementation level of 2.63 g sodium bicarbonate per litre drinking water. However, in male Venda chickens, sodium bicarbonate supplementation in the drinking water improved DM digestibility. A supplementation level of 3.2 g sodium bicarbonate per litre of drinking water optimized DM digestibility in male Venda chickens.

Supplementation of sodium bicarbonate in drinking water affected CP digestibility in both male Ross 308 broiler and indigenous Venda chickens. Crude protein digestibility, in broiler chickens was optimized at 6.67 g of sodium bicarbonate per litre of drinking water. Recoules *et al.* (2017) found adverse effects of sodium bicarbonate inclusion and associated the poor CP digestibility with higher pH values in the digestive tract segments. The gut pH is a critical factor that influences endogenous proteases activities and protein solubility in the proventriculus and gizzard (Recoules *et al.*, 2017). Bryan *et al.* (2018) showed that pepsinogens require low pH values of 1.8 – 3. Thus, in the present study sodium bicarbonate supplementation in drinking water resulted in increased digesta pH, resulting in poor CP digestibility and, also, nitrogen retention values.

Sodium bicarbonate supplementation level in the drinking water had effect on NDF digestibility of male Ross 308 broiler and Venda chickens. The NDF digestibility values in male Ross 308 broiler chickens decreased linearly with increased sodium bicarbonate supplementation in the drinking water. It is possible that sodium bicarbonate influenced digesta pH. Hence, gut microbes responsible for producing enzymes for the digestion of fibrous material were affected (Choct, 2015; Pan and Yu, 2014). However, in male Venda chickens, a supplementation level of 4.52 g of sodium bicarbonate per litre of drinking water optimized NDF digestibility. This implies that sodium bicarbonate supplementation level changed gut pH which might have favoured fibre digesting microbes (Jones *et al.*, 2018).

Sodium bicarbonate supplementation level in the drinking water did not affect ADF digestibility of male Ross 308 broiler and Venda chickens aged 35 to 42 days. The type of bacterial species present might not be those for digesting ADF (Mustafa and Baurhoo, 2016). Thus, ADF digestibility remained unaffected by sodium bicarbonate supplementation level. Metabolizable energy intake was also not affected by sodium bicarbonate supplementation level. Davidson and Wideman (1992) reported similar findings in broiler chickens.

Nitrogen retention was affected by sodium bicarbonate supplementation level in the drinking water of both male Ross 308 broiler and Venda chickens. Changes in gut pH have a significant effect on nitrogen retention (Recoules *et al.,* 2017). Sodium bicarbonate supplementation in drinking water buffers the pH in the proventriculus and gizzard which then limit the conversion of pepsinogens to pepsin required for protein digestion (Olukosi and Dono, 2014; Gallardo *et al.*, 2018). Thus, nitrogenous compounds escape digestion. A sodium bicarbonate level of 7.0 g per litre of drinking water optimized nitrogen retention in male Ross 308 broiler chickens. Koreleski *et al.* (2011) reported no effects of sodium bicarbonate in the drinking water of broiler chickens on nitrogen retention. In the present study there was a negative relationship between sodium bicarbonate supplementation level and nitrogen retention in male Venda chickens. No studies on the effect of sodium bicarbonate supplementation in the drinking water of indigenous Venda chickens on nitrogen retention were available.

Male Ross 308 broiler chickens had higher CP digestibility and nitrogen retention than indigenous Venda chickens. This may be a genotypic factor gained through selection and breeding for higher performance in broiler chickens. However, NDF and ADF digestibility values were higher in indigenous Venda chickens than in broiler chickens. Mabelebele *et al.* (2014) suggested that indigenous chickens have physiological adaptations to fibrous diets, thus enabling them to maintain high CF digestibility values. No breed differences were observed in DMD and metabolizable energy intakes.

4.6.3 Gut organ digesta pH

Sodium bicarbonate supplementation in drinking water affected crop, proventriculus and gizzard digesta pH values of both chicken breeds. Svihus (2014) reported that the digesta pH in the gut of chickens vary depending on the dietary components. Thus, increase sodium bicarbonate supplementation which had higher pH resulted in the changes in crop, proventriculus and gizzard digesta pH. The proventriculus and gizzard are the true stomach compartments of birds, where hydrochloric acid and pepsinogen are secreted which effectively lowers the digesta pH values (Gonzalez-Alvarado *et al.*, 2010). In the current study, the pH values of the contents of these organs may have had higher pH values as a result of the acid and base reaction. Sodium bicarbonate is base which upon reaction with hydrochloric acid produces carbon dioxide and water as well as salt (Fordtran, *et al.*, 1984). This reaction, therefore, results in lowered concentration of hydrogen ions, thus, increasing the pH of the digesta in the organs. Similar results were reported by Gordon and Roland (1997) when calcium carbonate was supplemented in the diet of layers.

The pH values of contents of small intestines, caecum and large intestines from both chicken breeds were not affected by sodium bicarbonate supplementation in the drinking water. Koreleski *et al.* (2011) and Zdunczyk *et al.* (2014) reported similar findings in broiler chickens when sodium bicarbonate was incorporated in the feed. The increased pH values by sodium bicarbonate supplementation in drinking water of male Ross 308 broiler chickens might have been buffered by the secretion and reaction with hydrochloric acid of the proventriculus, and also the bile, duodenal and pancreatic enzymes of the small intestines which have pH values of 7.1 to 8.5 (Melamed and Melamed, 2014). Hence, no effects of sodium bicarbonate supplementation in drinking water were observed.

Contrary to reports by Mabelebele *et al.* (2014) and Mabelebele *et al.* (2017) the results of the present study indicate that there were no significant breed differences in pH values of gut organs digesta. These authors found that Ross 308 broiler chickens had lower gut pH values when compared to indigenous Venda chickens.

4.6.4 Gut organ weights

Proventriculus, gizzard and small intestine weights of Ross 308 broiler chickens were affected by sodium bicarbonate supplementation level. Proventriculus, gizzard and small intestine weights were optimized at different supplementation levels of 5.7, 2.2 and 3.8 g sodium bicarbonate per litre of drinking water. Mushtag *et al.* (2014) reported a lower sodium bicarbonate supplementation level of 1.32 % for optimum gizzard weights of broiler chickens aged 42 days. Zdunczyk *et al.* (2014) reported no effects of sodium bicarbonate on weight of intestinal organs of broiler chickens. The results of the current study, also, indicate that weights of the crop, caeca and large intestines of Ross 308 chickens were not affected by sodium bicarbonate supplementation. However, in male Venda chickens, supplementation with sodium bicarbonate affected proventriculus weights. The proventriculus weight was optimised at a supplementation level of 2.8 g of sodium bicarbonate per litre of drinking water. The crop, gizzard, small intestines, caecum and large intestines of Venda chickens were not influenced by sodium bicarbonate supplementation. This is consistent with results of Mushtaq *et al.* (2014) in broiler chickens.

Overall, weights of the proventriculus and small intestines of Ross 308 broiler chickens were higher than those of indigenous Venda chickens. However, the crop, gizzard, caecum and large intestines weights were similar when compared between breeds. Mabelebele *et al.* (2014) reported that crop, gizzard and large intestine weights of indigenous chickens were higher than those of Ross broiler chickens. Jamroz (2002) reported that slow growing chickens had higher proventriculus and gizzard weights than broiler chickens. These authors suggested that the differences in weights are functions of genetic adaptation to fibrous diets by slow-growing chickens. Goromela *et al.* (2006) associated the slow growing chickens with high fibrous feeds which require higher efficiency in grinding food particles into smaller particles during digestion.

4.6.5 Gut organ Lengths

A longer intestinal tract of chickens provides for better digestion and nutrient absorption (Noy and Sklan, 2002). Sodium bicarbonate supplementation had effects on lengths of the GIT and small intestines of male Ross 308 broiler chickens. Supplementation levels of 7.6 and 7.2 g sodium bicarbonate per litre of drinking water optimized the length of the GIT and small intestines, respectively. De Araujo *et al.* (2011) reported different findings when fine calcium carbonate (a buffer) was increased in the diet of broiler chickens. They found that calcium carbonate supplementation did not affect the length of the GIT and small intestines of broiler chickens. In the present study, lengths of the caecum and large intestines of Ross 308 broiler chickens were not affected by sodium bicarbonate supplementation. Similarly, intestinal length of digestive organs was not affected by sodium bicarbonate supplementation level in the drinking water of male Venda chickens. This is consistent with the findings of de Araujo *et al.* (2011) who supplemented calcium carbonate in drinking water of broiler chickens.

Results of the current study indicate that Ross 308 broiler chickens had longer GIT and small intestines than indigenous Venda chickens. However, the caecum and large intestines of the two breeds were of similar lengths. Similar results were reported by Mabelebele *et al.* (2014) between Ross broiler chickens and indigenous Venda chickens. An increase in the length of the GIT of chickens may indicate higher efficiency in digestion and nutrient absorption (Bertechini, 2006). The small intestines are the sites for most digestion and absorption of nutrients. Hence, the longer the intestines, the more the surface area for nutrient digestion and absorption (Svihus, 2014).

4.6.6 Bacterial species found in the crop and gizzard contents of male Ross 308 broiler and Venda chickens

Bacteria found in the crops

Bacterial colonies grown on a cellulose media were isolated and identified. Results of the present study indicate that there were different bacterial species capable of degrading cellulose found in the crop digesta of male Ross 308 broiler and Venda chickens with each sodium bicarbonate supplementation level. A shift to either acidic or alkaline in external pH is stressful for bacteria, which may influence survival and growth (Padan *et al.,* 2005). Changes in the bacterial species composition may have been a result of the increasing crop pH as sodium bicarbonate was increased (Rahmani *et al.*, 2005; Dittoe *et al.*, 2018). Dobey *et al.* (2018), also, found that sodium bicarbonate does not have any direct antibacterial effect, and supported that increases the pH in the gut environment and prevents acidophilic bacteria overgrowth. *Bacillus* and *Lactobacillus* spp known to produce cellulose degrading enzymes, were found in the crops of chickens not supplemented with sodium bicarbonate in their drinking water (Manhar *et al.*, 2017). Increased sodium bicarbonate supplementation may have resulted in the presence of not only cellulose degrading bacteria but, also, those that are pathogenic as well. This might further have implications on NDF digestibility potential of the chickens offered varying levels of sodium bicarbonate in their drinking water. However, *B. atrophaeus, S. epidermis* and *E. coli* were found in crop digesta of chickens offered different supplementation levels of sodium bicarbonate in the drinking water. These may be tolerant to a wider range in pH changes (Pang *et al.,* 2017). Thus, they were found even in crop digesta of Ross chickens offered higher sodium bicarbonate supplementation levels.

Different cellulolytic bacteria were exclusively found in the crop digesta of male Ross 308 broiler chickens and also in male Venda chickens. Bacterial species including *L. paracasei, A. cavaie, L. gasseri, X. autotrophicus, C. sakazakii, E. aerogenes, K. pneumonia, B. pumulis* and *S. succinus* were only found in the crop digesta of Ross 308 broiler chickens. Similarly, *B. circulans* and *S. aureus* were found only in indigenous Venda chickens. Sources of variation in the composition of bacterial species between Ross 308 broiler and Venda chickens may include the breed of hens that laid the eggs, hatching and transporting conditions (Stanley *et al.*, 2013). This also impacts fibre degradation, hence in Venda chickens had higher NDF digestibility compared to Ross 308 broiler chickens.

Bacteria found in the Gizzard

Results of the current study indicate that sodium bicarbonate supplementation level in the drinking water of male Ross 308 broiler chickens resulted in different cellulolytic bacterial occurring in the gizzard digesta. This is may be associated with changes in digesta pH of the gizzard with sodium bicarbonate supplementation. Changes in the gizzard pH affects the composition of bacteria (Smith and Berrang, 2006; Pang *et al.*, 2017). The supplementation of sodium bicarbonate in the drinking water resulted in increased gizzard digesta pH in Ross 308 broiler and Venda chickens.

The results indicated that different bacteria were found in the gizzard digesta of Ross 308 broiler and Venda chickens. These have implications on the NDF digestibility in the host chickens. In the present study, the NDF digestibility of Venda chickens was higher than that of Ross 308 broiler chickens. However, *E. coli* and *B. safensis* were found in the gizzard digesta of both Ross 308 broiler and Venda chickens.

4.6.7 Meat colour

Results of the study indicate that meat colour (L*, a* and b*) from the breast and thigh meat of both male Ross 308 broiler and Venda chickens were not affected by sodium bicarbonate supplementation levels used in the present study. Petrolli *et al.* (2016) found similar results when sodium bicarbonate was administered in the drinking water prior to slaughtering of broiler chickens aged 42 days. Similarly, Jonkowski *et al.* (2011) reported no effect of sodium bicarbonate supplementation on the breast meat colour in broiler chickens. Thus, sodium bicarbonate supplementation level had no effect on meat colour of chickens. Similarly, the L* and b* of the breast meat of both breeds were not different. However, the redness (a*) of the breast meat of indigenous Venda chickens was higher than a* values of Ross 308 broiler chickens. This may be due to genetic differences (Lopez *et al.*, 2011).

The thigh meat from male Ross 308 broiler and indigenous Venda chickens were similar in terms of L*, a* and b*. Joubert (2013) reported similar a* values for broiler Potchefstroom koekoek chickens. However, the L* and b* from broiler chicken thigh meat were higher than those of indigenous Potchefstroom koekoek chickens. The redness (a*) parameter is used to assess myoglobin oxidation, with high redness values indicating high myoglobin oxidation. Wattanachant (2004) and Fanatico *et al.* (2007) associated the higher redness value with the breeds' higher physical activities. Wattanachant *et al.* (2004) reported that Thai indigenous chickens had higher L*, a* and b* in the thigh muscles (biceps femoris) compared to broiler chickens. They suggested that this was probably related to significant differences in muscle pH between the breeds. Although in the current study, meat pH differences were not found.

4.6.8 Meat sensory evaluation, shear force and pH

Results of the present study indicate that sodium bicarbonate supplementation level did not improve breast meat tenderness, juiciness, flavour and overall acceptability of Ross 308 broiler chickens. Petrolli *et al.* (2016) found similar results when supplementing broiler chicken with sodium bicarbonate for broiler chickens prior to slaughtering. Similarly, in the present study, breast meat tenderness and overall acceptability were not affected by sodium bicarbonate supplementation in drinking water of indigenous Venda chickens. However, juiciness, flavour and shear force values of breast meat of indigenous Venda chickens were decreased by sodium bicarbonate supplementation. These results are similar to those of Jankowski *et al.* (2011) for young turkeys when dietary sodium was increased. Literature on indigenous chickens is limited.

Meat pH values of male Ross 308 broiler and Venda chickens were not affected by sodium bicarbonate supplementation. This was not anticipated because sodium bicarbonate supplementation level increases blood pH in chickens (David and Wideman, 1992; Squires and Julian, 2001). Blood alkalosis is known to mitigate the effects of lactic acid accumulation during rigor mortis resulting in higher meat pH. However, results of the present study did not confirm this.

Juiciness and overall acceptability of meat from the two breeds were similar. Joubert (2013) reported similar findings between broiler and indigenous *Potchefstroom koekoek* chickens. Satheeskumar *et al.* (2013), also, found no differences in juiciness and overall acceptability between Indian native and broiler chickens. Similarly, the shear force determined by Warner-Bratzler test showed that meat from the breast meat of both breeds were similar in tenderness. This is contrary to results given by the meat consumers. They determined that Ross 308 broiler chickens had tenderer breast meat than indigenous Venda chickens. Lorenzen *et al.* (2003) and Muchenje *et al.* (2008) reported that a correlation between Warner-Bratzler shear force values and meat sensory panel ratings exist in beef, higher shear force values were consistent with hard (less tender) meat.

4.7 Conclusion

Supplementation with sodium bicarbonate in drinking water resulted in increased pH of drinking water and, thus, affected production parameters of male Ross 308 broiler and Venda chickens aged 22 to 42 days. Water intake and feed intake were optimized at sodium bicarbonate supplementation levels of 8.89 and 2.04 g per litre of drinking water, respectively, in male Ross 308 broiler chickens. Growth rate and live weight were optimized at a similar sodium bicarbonate supplementation level of 2.97 g per litre of drinking water. However, in male Venda chickens, water intake was increased linearly with sodium bicarbonate supplementation level. Growth rate and live weight were optimized at a similar sodium bicarbonate supplementation level of 3.8 g per litre of drinking water. Thus, the supplementation level for optimal growth and live weight were higher in male Venda chickens than in male Ross 308 broiler chickens.

Sodium bicarbonate supplementation level in the drinking water decreased DM, CP and NDF digestibility values and nitrogen retention in male Ross 308 broiler chickens aged 35 to 45 days. The DM, CP digestibility values and nitrogen retention were optimized at sodium bicarbonate supplementation levels of 2.6, 6.7 and 7.0 g per litre of drinking water, respectively, in Ross 308 broiler chickens. Then NDF digestibility decreased linearly with increases in sodium bicarbonate supplementation level in the drinking water of Ross 308 broiler chickens. The DM and NDF digestibility values were optimized by supplementation levels of 3.2 and 4.52 g per litre of drinking water in male Venda chickens. Crude protein digestibility and nitrogen retention linearly decreased with higher sodium bicarbonate supplementation levels in male Venda chickens.

Sodium bicarbonate supplementation in the drinking water affected digesta pH values of the crop, proventriculus and gizzard of chickens of both breeds. The digesta pH of the crop of Ross 308 broiler chickens increased linearly with sodium bicarbonate supplementation in the drinking water. However, the digesta pH of the proventriculus and gizzard were optimized at different sodium bicarbonate supplementation levels of 9.2 and 8.3 g per litre of drinking water, respectively in male Ross 308 broiler chickens. In male indigenous Venda chickens, the crop and proventriculus digest pH values were optimized at different sodium bicarbonate supplementation levels of 1.6 and 5.2 g per litre of drinking water, respectively. While gizzard digesta pH values increased linearly with sodium bicarbonate supplementation in male Venda chickens. Thus, higher sodium bicarbonate supplementation levels optimized the proventriculus and gizzard digesta pH of Ross 308 broiler chickens than male Venda chickens.

The weights the proventriculus, gizzards and small intestines of male Ross 308 broiler chickens were affected by sodium bicarbonate supplementation. Proventriculus, gizzards, and small intestine weights were optimized at supplementation levels of 5.7, 2.2 and 3.8 g sodium bicarbonate per litre of drinking water, respectively. Only the proventriculus weight of indigenous Venda chickens was affected by sodium bicarbonate supplementation level in the drinking water. A supplementation level of 2.8 g sodium bicarbonate per litre of drinking water optimized the proventriculus weights.

The GIT and small intestine lengths were affected by sodium bicarbonate supplementation level in Ross 308 broiler chickens. Supplementation levels of 7.6 and 7.2 g sodium bicarbonate per litre of drinking water optimized GIT and small intestine lengths of male Ross 308 broiler chickens. However, no effects of sodium bicarbonate supplementation in drinking water on the length of the GIT and digestive organs were found in indigenous Venda chickens.

Meat colour of breasts and thighs of Ross 308 broiler and indigenous Venda chickens were not affected by sodium bicarbonate supplementation. However, breast meat of

Venda chickens had higher the a* than that of Ross 308 broiler chickens. Meat juiciness, flavour and shear force were affected by sodium bicarbonate supplementation level was increased in the drinking water. Supplementation levels of 3.6, 3.2 and 4.7 g of sodium bicarbonate per litre of drinking water optimized meat juiciness, flavour and shear force of male Venda chickens, respectively. The Ross 308 broiler chicken breast meat was tenderer than that of indigenous Venda chickens. Whilst meat from indigenous chickens had more flavour than broiler chicken meat.

Supplementation level of sodium bicarbonate in the drinking water affected the type of bacterial species found in the crops of male Ross 308 broiler and indigenous Venda chickens aged 42 days. There were bacterial species found in the crop and gizzard digesta of male Ross 308 broiler and Venda chickens that were found only at each sodium bicarbonate supplementation level probably due to its effects on the digesta pH. Thus, supplementation level affected bacterial species found in the digesta. Hence, this may explain differences in NDF digestibility potentials of chickens supplemented with sodium bicarbonate.

CHAPTER 5

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 General discussion

Crude fibre is naturally present in all plant-based feed ingredients and makes up a small but significant proportion of poultry diets (Dhingra *et al.*, 2012). Thus, high dietary CF levels lead to low digestibility and intake of diets. However, digestibility coefficients vary significantly between avian species and, also, within breeds (Goromela *et al.*, 2006; Mabelebele *et al.*, 2014; Varastegani and Dahlan, 2014). The South African poultry industry is comprised of exotic commercial broiler chickens (Ross, Cobb, Hybro, Habbard and Arbor acres broiler chickens) and also has several indigenous chicken breeds that are commonly kept in extensive production systems (DAFF, 2017). Indigenous chickens include Venda, Naked neck, Ovambo, Natal game, Zulu and Nguni chickens (Grobbelaar *et al.*, 2010). The chickens are known to be resilient, well adapted to the tropical environment and being resistant to diseases (Roothaert *et al.*, 2011). Indigenous chickens have high CF levels in their diets. This may suggest that there are mechanisms by which they are able to use to prosper when faced with such dietary complexities. Investigating this may yield information that is critical for improving broiler chicken production. The aim of the study was, therefore, to determine optimal production responses to different dietary CF levels and sodium bicarbonate supplementation levels in Ross 308 broiler and indigenous Venda chickens.

The first objective of the first study was to determine the effect of dietary CF level on feed intake, digestibility, growth rate, FCR, live weight and carcass characteristics of male Ross 308 broiler and Venda chickens aged one to 21 days. There were strong and negative relationships between dietary CF level and diet NDF and ADF digestibility values in both chicken breeds (Table 5.1). This is similar to the observations made by NRC (1994) and Mbajiorgu *et al.* (2011). These negative relationships, in the present study, affected feed intakes, growth rates and live weights of male Ross 308 broiler and Venda chickens. Feed intakes, growth rates and live weights of Ross 308 broiler chickens were optimized at different dietary CF levels of 3.9, 4.5 and 4.5 %, respectively. Jimenez-Moreno *et al.* (2013) indicated that dietary CF levels of 2 - 4 % optimized growth rate in broiler chickens. NRC (1994) and Sekgobela (2018) indicated that dietary CF levels for optimal feed intake, growth rate and live weight of Ross 308 broiler and indigenous slow-growing chickens were different.

Table 5.1 Dietary CF levels for optimal production performance of male Ross 308 broiler and Venda chickens

Age (day)	Variable	CF level for optimal productivity (%)		Correlation coefficient (r)	
		Ross 308 broiler	Venda	Ross 308 broiler	Venda
1 to 21	Feed intake	3.9	4.4	-	-
	Growth rate	4.5	4.8	-	-
	FCR	-	5.9	-	-
	Live weight	4.5	4.7	-	-
	DMD	3.8	3.5	-	-
	CPD	-	3.7	-0.984	
	NDFD	-	-	-0.934	-0.837
	ADFD	-	-	-0.925	-0.987
	ME intake	3.7	3.3	-	-
	N-retention	4.1	4.1	-	-
22 to 42	Feed intake	6.4	4.5	-	-
	Growth rate	-	5.8	-0.647	-
	FCR	-	6.4	0.922	-
	Live weight	-	5.7	-0.647	-
	DMD	3.4	5.1	-	-
	CPD	4.4	5.3	-	-
	NDFD	3.7	4.9	-	-
	ADFD	-	10.1	-	-
	ME intake	-	-	-	-
	N-retention	4.4	5.1	-	-
42	GIT weight	4.1	6.3	-	-
	Gizzard weight	-	5.9	0.998	
	Small intestine weight	-	-	-0.842	-
	Caecum weight	-	8.0	-	-
	GIT length	5.6	-	-	-
	Small intestine length	5.5	-	-	-
	Proventriculus pH	5.5	4.2	-	-
	Gizzard pH	7.4	4.3	-	-

The authors suggested that the reasons for this were genetic and, also, related to adaptation. Indigenous chicken breeds feed on more fibrous feeds and, hence, over the years they become adapted to diets high in CF contents. In the present study, nitrogen retention and ME intake of male Ross 308 broiler chickens aged one to 21 days were optimized at dietary CF levels of 3.7 and 4.1 %, respectively; while ME intake and nitrogen retention of male Venda chickens aged one to 21 days were optimized at dietary CF levels of 3.3 and 4.1 %, respectively. It is concluded that dietary CF level was negatively correlated to NDF and ADF digestibility values in chickens. This affected feed intake, growth rate and live weight of male Ross 308 broiler and Venda chickens aged one to 21 days. However, these production variables were optimized at different dietary CF levels, ranging from 3.3 to 5.9 %. Dietary CF levels for optimal productivity tended to be higher in male Venda chickens, indicating that male Venda chickens tolerate more fibrous diets than male Ross 308 broiler chickens. The implication of these results is that dietary CF levels for optimal productivity will depend on the particular variable in question and breed of chicken. These findings have a lot of implications on ration formulation for broiler and slow-growing chickens.

Growth rate, FCR and live weight of Ross 308 broiler chickens aged 22 to 42 days were adversely affected by dietary CF level (Table 5.1). Thus, feed intake, NDF and nitrogen retention of male Ross 308 broiler chickens were optimized at different dietary CF levels of 6.4, 3.7 and 4.4 %, respectively. Feed intake, growth rates, nitrogen retention and live weights of male Venda chickens aged 22 to 42 days were optimized at different dietary CF levels of 4.5, 5.8, 5.1 and 5.7 %, respectively. These CF levels for optimal productivity of male Venda chickens aged 22 to 42 days are higher than those that optimized productivity of male Venda chickens aged one to 21 days, possibly, indicating that older chickens are more tolerant to fibrous diets than younger ones (NRC, 1994; Mbajiorgu *et al.*, 2011). Different dietary CF levels, ranging from 4.1 to 8.0 %, optimized the GIT weights, gizzard weights, caecum weights, GIT length, small intestines length, proventriculus pH and gizzard pH of male Ross 308 broiler and Venda chickens aged 42 days. Mbajiorgu *et al.* (2011) indicated similar results in broiler chickens and slow-growing chickens. It is noted in the present study that there was a positive relationship between dietary CF level and gizzard weight of male Ross 308 broiler chickens, possibly, indicating heavier gizzards for the grinding of fibrous feeds (Mateos *et al.*, 2012). However, there was a negative relationship between dietary CF level and small intestine length of male broiler chickens aged 42 days. This is contrary to the observations of Jimenez-Moreno *et al.* (2013) that chickens on poor diets will tend to have longer and heavier small intestines in order to increase surface area for nutrient digestion and absorption.

The second part of the study determined the effect of sodium bicarbonate supplementation level in the drinking water on production performance, digestibility, gut pH and morphology, and meat quality of male Ross 308 broiler and Venda chickens. It, also, determined the effect of sodium bicarbonate supplementation level in the drinking water on cellulose degrading bacteria present in the crops and gizzards of male Ross 308 broiler and Venda chickens aged 22 to 42 days. Supplementation with sodium bicarbonate in the drinking water resulted in a linear increase in pH of drinking water provided for male Ross 308 broiler and Venda chickens aged 22 to 42 days. This affected diet digestibility of the chicken breeds. Gallardo *et al.* (2018) reported similar effects of sodium bicarbonate supplementation on nutrient digestibility. Supplementation levels of 2.63 and 3.20 g of sodium bicarbonate per litre of drinking water optimized DM digestibility values in male Ross 308 broiler and Venda chickens, respectively (Table 5.2). The sodium requirement for indigenous chickens is not known (NRC, 1994). It is possible that indigenous chickens may have a higher sodium requirement than broiler chickens, thus, the DM digestibility in male Venda chickens was optimized at a higher supplementation level than male Ross 308 broiler chickens. Crude protein digestibility and nitrogen retention in male Ross 308 broiler chickens were optimized at almost similar sodium bicarbonate supplementation levels of 6.67 and 7.0 g per litre of drinking water. This high sodium bicarbonate supplementation level for optimal CP digestibility and nitrogen retention could not be ascertained since contrary reports have shown that excess sodium bicarbonate supplementation in broiler chicken diets adversely affects diet digestibility (Roussan *et al.*, 2008). Studies are required to ascertain these effects. However, the CP digestibility of male Venda chickens decreased with higher sodium bicarbonate supplementation level. The NDF digestibility of male Ross 308 broiler chickens decreased with higher sodium bicarbonate supplementation level. This indicates that sodium bicarbonate supplementation adversely affected NDF digestibility in male Ross 308 broiler chickens. However, in male Venda chickens, 4.52 g of sodium bicarbonate supplementation per litre of drinking water optimized NDF digestibility. Thus, NDF digestibility in male Venda chickens depended on sodium bicarbonate supplementation level. Productivity of the chicken breeds was, therefore, affected by sodium bicarbonate supplementation level. This is consistent with reports by Hayat *et al.* (1999), Zakaria *et al.* (2009) and Osman *et al.* (2015) on the effect of sodium bicarbonate supplementation in broiler chickens.

Table 5.2 Sodium bicarbonate supplementation levels for optimal production performance of male Ross 308 broiler and Venda chickens aged 22 to 42 days

Age (day)	Variable	Sodium bicarbonate supplementation level for optimal productivity (g/L)		Correlation coefficient (r)	
		Ross 308 broiler	Venda	Ross 308 broiler	Venda
22 to 42	Water intake	8.89	-	-	0.999
	Feed intake	2.04	-	-	-
	Growth rate	2.97	3.8	-	-
	Live weight	2.97	3.8	-	-
	DMD	2.63	3.20	-	-
	CPD	6.67	-	-	-0.917
	NDFD	-	4.52	-0.861	-
	ADFD	-	-	-	-
	N-retention	7.0	-	-	-
42	Proventriculus weight	5.7	2.8	-	-
	Gizzard weight	2.2	-	-	-
	Small intestines weight	3.8	-	-	-
	GIT length	7.6	-	-	-
	Small intestine length	7.2	-	-	-
	Crop pH	-	1.6	0.992	-
	Proventriculus pH	9.2	5.2	-	-
	Gizzard pH	8.3	-	-	0.994
	Meat juiciness	-	3.6	-	-
	Flavour	-	3.2	-	-
	Shear force	-	4.7	-	-

Water intake, feed intake, growth rate and live weight of male Ross 308 broiler chickens were optimized at different sodium bicarbonate supplementation levels of 8.89, 2.04, 2.97 and 2.97 g per litre of drinking water, respectively. This indicates that sodium bicarbonate supplementation level depended on production variables. However, a higher sodium bicarbonate supplementation level of 3.8 g per litre of drinking water optimized both growth rate and live weight of male Venda chickens. Thus, a higher sodium bicarbonate supplementation level optimized growth rate and live weight of male Venda chickens compared to those for broiler chickens. Sodium bicarbonate supplementation level affected the digesta pH of the crop, proventriculus and gizzard of both chicken breeds. Zdunczyk *et al.* (2012) reported similar findings. Supplementation levels ranging from 1.6 to 8.3 g of sodium bicarbonate per litre of drinking water optimized the crop, proventriculus and gizzard digesta pH of male Ross 308 broiler and Venda chickens. The study, also, indicated that digesta pH of the crop of male Ross 308 broiler chickens and gizzard pH of male Venda chickens increased linearly with higher sodium bicarbonate supplementation levels. Thus, digesta pH of male Ross 308 broiler chickens and Venda chickens are dependent on the sodium bicarbonate level.

Different sodium bicarbonate supplementation levels, ranging from 2.2 to 7.6 g per litre of drinking water, optimized proventriculus, gizzard and small intestine weights, and GIT and small intestine lengths of male Ross 308 broiler chickens aged 42 days. In male Venda chickens, the proventriculus weight was optimized at a sodium bicarbonate supplementation level of 2.8 g per litre of drinking water. Other digestive organ weights and, also, lengths were not affected by sodium bicarbonate supplementation level.

Results of the present study indicated that sodium bicarbonate supplementation level in the drinking water affected gut bacteria composition. This was, possible, due to changes in gut pH as sodium bicarbonate supplementation increased (Rahmani *et al.*, 2005; Dittoe *et al.*, 2018). *Bacillus* species were predominately found in the crop of Ross 308 broiler and Venda chickens not supplemented with sodium bicarbonate in the drinking water. Increased sodium bicarbonate supplementation resulted in different bacterial species composition which had different potentials in the digestion of NDF in the feeds.

Different sodium bicarbonate supplementation levels of 3.6, 3.2 and 4.7 g per litre of drinking water optimized meat juiciness, flavour and shear force of breast meat from male Venda chickens aged 42 days. Hence, this has implications on diet formulations for indigenous chickens. However, male Ross 308 broiler chickens were not affected by sodium bicarbonate supplementation level.

5.2 Conclusions and recommendations

It is concluded that dietary CF level was negatively correlated to NDF and ADF digestibility values in chickens. This affected feed intake, growth rate and live weight of male Ross 308 broiler and Venda chickens aged one to 21 days. However, these production variables were optimized at different dietary CF levels, ranging from 3.3 to 5.9 %. Dietary CF levels for optimal productivity tended to be higher in male Venda chickens, indicating that male Venda chickens tolerate more fibrous diets than male Ross 308 broiler chickens.

Growth rate, FCR and live weight of Ross 308 broiler chickens aged 22 to 42 days were adversely affected by dietary CF level. Thus, feed intake, NDF and nitrogen retention of male Ross 308 broiler chickens were optimized at different dietary CF levels of 6.4, 3.7 and 4.4 %, respectively. Feed intake, growth rates, nitrogen retention and live weights of male Venda chickens aged 22 to 42 days were optimized at different dietary CF levels of 4.5, 5.8, 5.1 and 5.7 %, respectively. These CF levels for optimal productivity of male Venda chickens aged 22 to 42 days are higher than those that optimized productivity of male Venda chickens aged one to 21 days, possibly, indicating that older chickens are more tolerant to fibrous diets than younger ones. Different dietary CF levels, ranging from 4.1 to 8.0 %, optimized the GIT weights, gizzard weights, caecum weights, GIT length, small intestines length, proventriculus pH and gizzard pH of male Ross 308 broiler and Venda chickens aged 42 days. There was a positive relationship between dietary CF level and gizzard weight of male Ross 308 broiler chickens, possibly, indicating heavier gizzards for the grinding of fibrous feeds.

Results of the present study indicated that sodium bicarbonate supplementation level in the drinking water affected gut bacteria composition. This was, possibly, due to changes in gut pH as sodium bicarbonate supplementation increased. Increased sodium bicarbonate supplementation resulted in different bacterial species composition which had different potentials in the digestion of crude fibre in the feeds. Bacteria such as the *Bacillus species* identified in the crop and gizzard of Ross 308 broiler chickens need to be thoroughly investigated in order to be used in the production of probiotics as feed additives that have the potential of affecting the digestibility of the fibre fraction in diets. Sodium bicarbonate supplementation level had implications on the meat quality of indigenous Venda chickens. Sodium bicarbonate levels of 3.6, 3.2 and 4.7 g per litre of drinking water optimized meat juiciness, flavour and shear force of breast meat from male Venda chickens aged 42 days. This is important information for farmers and chicken meat customers. Thus, it is suggested that more studies on the subject be done to ascertain the present findings.

CHAPTER 6

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APPENDIX A

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