AKENTEN APPIAH-MENKA UNIVERSITY OF SKILLS TRAINING AND ENTREPRENEURIAL DEVELOPMENT

EFFECT OF REPLACING MAIZE WITH SORGHUM ON THE GROWTH PERFORMANCE, CARCASS CHARACTERISTICS, GASTROINTESTINAL pH, BONE TRAITS, AND PROFIT MARGINS OF COBB 500 BROILER CHICKEN PRODUCTION

MATHEW LOGOYONA AZUWIA

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BY

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SEPTEMBER, 2024

DECLARATION

STUDENT'S DECLARATION

I hereby declare that this thesis, with the exception of quotations and references contained in published works which have been duly acknowledged; is the result of my own original work and that no part of it has been presented for another degree at this university or elsewhere.

MATHEW LOGOYONA AZUWIA

………………………………… ……………………………………….

SIGNATURE **DATE**

SUPERVISOR'S DECLARATION

I hereby declare that the preparation and presentation of this work were supervised in accordance with guidelines for the supervision of theses as laid down by the Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development Mampong-Ashanti

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SIGNATURE

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DR. HOLY KWABLA ZANU **DATE**

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DEDICATION

I dedicate this thesis to the entire Azuwia family.

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DEFINITION OF ABBREVIATIONS

ANF	Antinutritional Factor
BC	Before Christ
BW	Body Weight
CF	Crude Fibre
CP	Crude Protein
CRD	Completely Randomized Design
DM	Dry Matter
EE	Ether Extract
EFSA	European Food Safety Authority
FAO	Food and Agriculture Organization
FAOstat	Food and Agriculture Statistics
FCR	Feed Conversion Ratio
FCRc	Corrected Feed Conversion Ratio
FE	Fermented
GF	Grower-Finisher
GS	Grain Sorghum
HT	Hydrolyzable Tannins
LAB	Lactic Acid Bacteria
NFE	Nitrogen-Free Extract
PEI	Production Efficiency Index
PER	Protein Efficiency Ratio
UN	Unfermented

ABSTRACT

The cost of feed in poultry production constitutes about 70 to 80 percent of total production cost and out of this, about 95 percent is meant for meeting the energy and protein requirements of the diet. Therefore, these necessitate the need for cheaper and always available cereal ingredients that can meet the energy requirement of the birds which constitute over 40 percent of the feed composition. Sorghum was identified as the major crop that can easily replace maize because of its similarity in composition with maize. The study examined the impact of replacing maize with sorghum in Cobb 500 broiler chicken diets on growth performance, carcass traits, bone characteristics, gastrointestinal pH, and production economics. The experiment involved randomized treatments, with maize-based diets showing the highest mean, unfermented sorghum-based diets second and fermented sorghum-based diets third. Again, feed cost at the end of the trial showed significant difference among treatments (P=0.039). The maize-based diet recorded the highest total feed cost as shown in table 4.12 followed by treatment fermented sorghum-based diet which recorded a total feed cost similar to that of the unfermented sorghum-based diet. The study found that replacing maize with processed sorghum in Cobb 500 broiler chickens' diets leads to significant profitability differences, with the highest profit observed when comparing maize-based and unfermented sorghum-based diets.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the study

Sorghum (*Sorghum bicolor*) is a grain that is frequently utilized as an energy source in chicken feed in several nations in addition to maize (Mabelebele et al., 2018). According to Rumler et al. (2022), sorghum possesses nutritional characteristics similar to those of maize. According to Wang. (2018), sorghum has a larger protein content when compared to maize, but maize has a substantially higher calorie and fat content than sorghum. The amino acid profile of sorghum is similar to that of maize.

According to research done by Ari Akin et al. (2022), sorghum and maize have comparable lysine digestibilities. Several studies have shown that using sorghum as a substitute for maize has varied effects, some being positive regarding performance, while other experiments produced negative results (McCuistion et al., 2019). Sorghum plants can grow under dry and hot climatic conditions (Borrell et al., 2021). In response to global warming, sorghum was identified as a plant that can be adaptive to future climate change, so it is necessary to maximize its use, including using it as a feed ingredient (Raza et al., 2019).

The utilization of sorghum in poultry diets is reported to have some limitations because sorghum contains anti-nutritional compounds, such as tannin, kafirin, and phytate (Liu et al., 2021). Tannins bind nutrients to form complex compounds, making them resistant to breakdown in poultry's digestive tract (Hassan et al., 2021). In addition, tannins have been reported to bind to protein and starch, thereby causing low protein and starch digestibility (Cirkovic Velickovic & Stanic-Vucinic, 2018). Bouajila et al. (2020) reported that most of the Phosphorus in sorghum is in the form of Phytate-P (81–83%).

Phytate can bind proteins and minerals so that they cannot be digested in the intestinal tract of poultry (Dersjant-Li et al., 2021). Kafirin is one form of protein in sorghum, with studies showing that the composition in sorghum protein is in the range of 49–54% (Soto & Pritzkow, 2018). Kafirin is low in the amino acids; lysine, histidine, and arginine (de Souza et al., 2019).

Experiments including sorghum in a broiler chicken diet have produced varied results caused by many factors, including the inclusion level of sorghum in the chicken feed, the experimental methodology, the type and quality of sorghum, the age of the broiler chickens and feeding patterns (Crisol-Martínez et al., 2017). Such variation in experimental results makes it challenging to reach firm conclusions regarding the effects of dietary sorghum inclusion in a broiler chicken diet, so meta-analysis methodology is an alternative option (Hidayat et al., 2019). Meta-analysis research uses data from existing studies that have been carried out systematically and quantitatively to obtain accurate conclusions (Sjofjan et al., 2019). Accordingly, the current study aimed to evaluate the effects of sorghum utilization in a broiler chicken diet on growth performance, carcass traits, tibia and femur characteristics (weight and breaking strength), gut pH and the cost-benefit analysis.

The issue of climate change and global warming has led to erratic rainfall patterns mostly in tropical Africa, Ghana inclusive. This, coupled with an increase in the prices of maize due to competition with humans has led to the scarcity of maize (Grote et al., 2021). It has also necessitated the search for an alternative to maize in poultry feed formulation. The high cost of maize in Ghanaian markets has affected the profitability of poultry production negatively and thus, resulted in inadequate protein intake among Ghanaian households.

1.2 Problem Statement

The cost of feed in poultry production constitutes about 70 to 80 percent of total production cost and out of this, about 95 percent is meant for meeting the energy and protein requirements of the diet (Mallick et al., 2020). These necessitate the need for other cereal ingredients that can be used alongside maize to meet the energy requirement of the poultry which constitute over 40 percent of the feed composition (Ahiwe et al., 2018). Sorghum was identified as the major crop that can easily replace maize because of its similarity in composition with maize (Dabija et al., 2021a). Sorghum has the potential to precipitate and pose adverse effects on the productivity of poultry. These precipitates could be found in the foliage and/or seeds used in practical feeding (Ebeid et al., 2020). These compounds are often called anti-nutritional factors. Anti-nutritional factors are also those generated in natural feedstuff by the normal metabolism of the species from original materials and by different mechanisms that exert effects contrary to optimum nutrition (Adebo et al., 2022).

Despite reports of anti-nutritional factors in sorghum, several techniques are available for treating sorghum to reduce the effect of these anti-nutritional factors. Although there are advantages to using sorghum as an energy source in broiler diets, not much research has been done on the use of fermented sorghum in particular. The industry's capacity to take advantage of the potential benefits that fermented sorghum could provide in terms of enhanced nutrient utilisation, feed efficiency, and overall performance of broiler chickens is hampered by the absence of thorough studies.

Fermentation of sorghum is likely to have several positive effects on its usability as a feed for broiler chickens. Firstly, the fermentation process can help break down complex carbohydrates, making the nutrients more accessible to the chickens during digestion.

This could potentially improve the overall digestibility of the sorghum. Additionally, fermentation may also help in reducing the anti-nutritional factors present in sorghum, which can have negative effects on the chickens' health and performance. Furthermore, fermented sorghum might have a more appealing taste and odour, which could potentially increase the acceptance and consumption of the feed by the broiler chickens. Overall, the fermentation process is expected to enhance the nutritional value and palatability of sorghum, making it a more effective energy source for broiler chickens.

1.3 Hypothesis

Cobb 500 broiler chickens fed an unfermented or a fermented sorghum-based diet will not perform differently from those fed on a maize-based diet. This hypothesis is based on the fact that sorghum is reported to contain a nutrient composition similar to that of maize. Fermentation of the sorghum is also expected to reduce the anti-nutritional factors and improve its digestibility for the birds.

1.4 Objectives of the study

The study was to evaluate the effect of dietary replacement of maize with either unfermented or fermented sorghum in the diet of Cobb 500 broiler chickens, on their general performance**.**

1.5 Specific Objectives

The study was conducted to specifically assess the effect of diets containing sorghum as an energy source on:

1. Phytochemical properties of sorghum
2. Growth performance of broilers
3. Carcass traits of broilers
4. Gut pH of broilers

5. Bone characteristics of broilers
6. Cost-benefit analysis

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Sorghum

According to Ingle et al. (2018), Sorghum (Sorghum bicolour L.) belongs to the Andropogoneae tribe and the Gramineae family. Guinea maize is the name given to it in West Africa (Sufiyana et al., 2020). Like wheat, maize, and oats, sorghum is a grain that is grown all over the world, but in warmer regions of Africa, it is especially valued as a staple food.

Sorghum is mostly made up of carbohydrates, while it also contains protein, lipids, tannins, and polyphenols (Da Silva, 2016). The sorghum grain has several sections and is spherical in shape. With an annual production of over 57 million tonnes, sorghum is the fifth most important crop in the world after maize, rice, wheat and barley. It was domesticated approximately 5,000 years ago in northeastern Africa (Winchell et al., 2018). With an annual production of 6.9 million tonnes, Nigeria is the nation's biggest producer of the crop, making it the most significant cereal grain (Ahmad Yahaya et al., 2022). Nigeria and other Sub-Saharan African (SSA) nations have not been able to fully exploit the crop's economic potential because of a number of production and productivity limitations.

Factors contributing to the low production and development of sorghum include the absence of high-yield varieties, declining soil fertility, drought conditions, Striga infestation, and limited access to financing, credit, and production resources (Ahmad et al., 2022). In Nigeria, research initiatives focused on sorghum have played a key role in creating and introducing varieties suitable for industrial purposes, designed for different agro-ecological regions (Ajeigbe et al., 2018). Nonetheless, due to desirable characteristics such as good taste, adaptability, resistance to insect pests, and low input requirements, small-scale farmers—who account for over 90% of sorghum production—tend to prefer using their saved seeds from native, unimproved varieties (Ahmad Yahaya et al., 2022).

2.2 Types of sorghum

Several varieties of sorghum exist across the whole world. Some of them include the following.

Grain Sorghum: Grain sorghum comes in various shapes and sizes, from tight-headed, round panicles to open, droopy panicles. It can be short or tall. Grain sorghum varieties include red, orange, bronze, tan, white, and black (Kawuyo et al., 2022). Red, orange, or bronze sorghum are versatile and used in various segments of the sorghum industry (Thao, 2018). Tan, cream, and white varieties are typically made into flour for the food industry.

Forage Sorghum: Forage sorghum is primarily grown for grazing pasture, hay production, silage, and green-chop. It typically grows 8-15 feet tall and is popular for use as silage to feed livestock.

Biomass sorghum is an exciting crop with promising potential for addressing environmental and energy challenges. Hybrids of bioenergy sorghum are essential for replenishing soil carbon. The chemical molecules that sustain life on Earth require carbon. The deep root systems of these hybrids improve their capacity to fix carbon in the soil. They thus, increase the fertility and water-holding capacity of the soil. According to de Almeida et al. (2019), biomass sorghum reaches a height of up to 20 feet in a normal growing season.

Sweet Sorghum: Unlike grain sorghum, sweet sorghum is harvested for its stalks rather than the grain. It is crushed, similar to sugarcane or beets, to produce sorghum syrup. Sweet sorghum was once a predominant table sweetener in the U.S

Broomcorn sorghum is used in making brooms and brushes. It’s cultivated specifically for its long, stiff bristles. It is known as “broomcorn” due to its use in broom-making.

2.3 Origin and Distribution of Sorghum

The earliest evidence of using wild sorghum as food is from the Sahara, around 7500 BC, where hunter-gatherers lived (Venkateswaran et al., 2019). Similarly, a recent study by Winchell et al. (2017), has shown that the earliest domesticated sorghums are found in Neolithic populations of Sudan around the fourth millennium BC. There is disagreement over the precise origin and location of sorghum domestication. Nonetheless, archaeological data suggests domestication in eastern Sudan circa 3000 BC, contrary to Venkateswaran et al. (2019). Some studies suggest that there may have been more than one domestication event, potentially explaining the origin of the group *guinea-margaritiferum* of the genus *Sorghum*, which was domesticated more recently (Upadhyaya et al., 2019).

2.4 Sorghum Production

Globally, sorghum plantings have grown by more than 60% in recent years, while yields have improved by 23% (Visarada & Aruna, 2019). Sorghum is one of the most significant grains in terms of output, with an annual total production of 40–45 million tonnes from about 40 million hectares (Behling et al., 2017). The advent of high-yielding crop varieties is responsible for these higher yields. One of the most significant staple crops in the world is sorghum (Sorghum bicolour (L.) Moench). Because of its short lifespan, rapid growth, and great yield, it is cultivated in semi-arid areas that are prone to drought.

According to Madukwe et al. (2023), it is very adaptable to a wide range of agroclimatic conditions. Some notable producers of sorghum in the world are shown in the table below:

Table 2.1: Important producers of sorghum

Countries	Volume of production (million tonnes)	Area cultivated (million ha)
United States	17.0	4.0
India	11.0	12.5
Nigeria	6.0	5.7
China	4.5	1.5
Mexico	3.5	1.3
Sudan	3.0	5.0

Source (Behling et al., 2017)

2.5. Processing of sorghum

Originating in Africa and India, sorghum is one of the oldest grains and is used in a wide variety of modern cuisines. It is widely used in products all around the world, such as tortillas, bread, cookies, oats, and commercially extruded foods. Grain quality is typically improved through processing, which transforms the grain into an edible form (Yoganandan et al., 2021).

2.5.1 Primary processing of sorghum for food

Grading: First, sorghum goes through a number of processing steps, including packaging and grading. Grading is essential in primary processing because it ensures that the sorghum grains meet certain requirements for quality. Sorghum grading involves cleaning huge farm grains with a cleaner-cum-grading machine. According to their size, this machine separates them into three groups: larger, medium, and relatively little. The equipment additionally removes unwanted particles from the grains to ensure that only pure sorghum grains are collected.

This grading process ensures that the sorghum grains are consistently of a consistent size and quality, which benefits both farmers and customers. By separating the grains into different sizes, grading helps farmers get the greatest price for their sorghum based on its quality. Grading makes packing easier. After being graded, the grains are promptly placed in gunny bags. The grains are protected from external contaminants and maintain their quality during storage and transportation thanks to this packing technique (Song et al., 2022).

Destoning: Destoning is a crucial step in the processing of sorghum grain, which involves removing any debris, stones, and glumes from the grain. This process is required to increase the storage capacity and customer acceptance of sorghum grains. By eliminating unwanted components, destoning raises the grain's quality and worth. It aids in preventing damage to milling and processing equipment by removing any extraneous objects that can cause disruptions or malfunctions. Destoning sorghum grains has been found to improve the efficiency of decortication and other processing steps.

Decortication: This means removing the uppermost layer, or pericarp, of the grain. It was thought that decortication may greatly improve the digestibility and apparent protein quality of sorghum. It was shown that using a decorticator-degerminator instead of traditional roller milling techniques resulted in a better starch recovery while processing sorghum. These results suggest that a critical step in getting the grain ready for additional processing is decortication, which is made possible by destoning.
Since many African dishes call for decorticated grain, sorghum grains must be decorticated in order to be utilised in them. Destoning makes it easier to remove the outer

layers during decortication, which gets rid of non-fermentable components like fibres and improves protein quality and digestibility (Wahyuningsih et al., 2019).

Dehulling or pearling of grain sorghum: Grain polishing and pearling are two effects of dehulling sorghum that can greatly enhance the grain's appearance and market value. The pericarp, or outer coating, of the grain is removed by the abrasive dehulling process, also known as pearling. By reducing the amount of dirt, germs, and insoluble fibre on the bare grain, this process not only removes the pericarp's bitterness but also improves the final product's appearance. Dehulling also helps with blackening issues that may occur in grain sorghum grown during the Kharif season. Despite the higher yield, grain sorghum grown during wet seasons may turn black due to fungal and mould infestations. Dehulling or pearling can mitigate this issue by eliminating the discoloured outer layer, enhancing the item's overall appearance and potentially increasing its market value. Dehulling has been proven to have a considerable impact on the nutritional value and functional properties of sorghum grains. For example, decortication of sorghum lowers the total phenol concentration in the flour since most phenolic compounds are found in the pericarp and aleuronic layer (Salazar-López et al., 2018).

2.5.2 Secondary processing

Grain must be processed into a form analogous to flour or any other usable ingredient before it can be utilised to make any type of food product. Grain is processed by a variety of equipment to create flour, flakes, pops, and fine and coarse rawa. After sorghum is processed in a pulveriser, the flour is sieved to the proper consistency. Roti and fine flour are used to make cakes and biscuits. The particle sizes of the two types of sorghum semolina are fine (0.6 mm) and coarse (1.18 mm). Both types of sorghum semolina may be sold commercially on the open market. While the endosperm is the only ingredient required to manufacture rawa in a Brabender semolina machine, the pericarp is separated and utilised to make bran (Ratnavathi et al., 2016).

Sorghum flour: Sorghum has gained attention in the present hunt for healthy and sustainable food sources because to their high nutritional value. Although they are not yet often consumed, sorghum is a beneficial addition to diets. In an effort to increase the utility of sorghum and its incorporation into conventional food production, one strategy that has been studied is combining refined sorghum flours with commercial wheat flour. This technique blends the nutritional benefits of sorghum with the well-known characteristics and versatility of wheat flour.

Determining the maximum amount of sorghum flour that can be added without compromising the quality of the baked goods is the aim of study on the effects of combining sorghum flour with wheat flour. The study found that millet flour can be used in place of 10% to 20% of wheat flour. Thus, a significant amount of wheat flour can be substituted with sorghum flour. Without sacrificing baked goods' quality, this modification can increase their nutritious content (Ratnavathi, 2019).

2.5 Nutritional value of sorghum

Sorghum's nutritional makeup has been thoroughly studied in (Hossain et al., 2022). According to Onogwu et al. (2018), the whole grain of sorghum has roughly 89–90% dry matter (DM), 8.9–15% crude protein (CP), 2.8% ether extract (EE), 1.5–1.7% ash, 2.1–2.3% crude fibre (CF), and 71.7–72.3% nitrogen-free extract (NFE).

A summary of the nutrient composition of whole-grain sorghum and maize is presented in Table 2.2.

Table 2.2: Nutrient composition of maize and sorghum (%)

Component	Maize[c]	Maize[a]	Maize[b] (Decan 103)	Sorghum[c] (Nigerian local)	Sorghum[b] (Indian local)	Sorghum[d] (Brown coat)	Sorghum (ICSV112)
Dry matter	90.10	91.80	-	93.31	92.50	88.94	-
Organic matter	90.53	-	-	93.06	-	-	-
Crude protein	9.65	8.8	9.8	10.48	9.50	14.89	8.9
Ether extract(fat)	3.98	4.10	52	2.97	2.50	3.30	3.7
Crude fibre	1.99	2.10	1.4	2.01	2.70	3.01	1.2
Ash	9.47	1.00	1.3	6.94	1.20	2.59	1.7
NFE	73.46	75.80	73.10	61.24	76.60	65.16	73.50
Gross Energy (Kalkg)			4140				4120

Sources: Etuk *et al.,* (2012)

2.6. Antinutritional Factors (ANFs)

According to Thakur et al. (2019), anti-nutritional factors are biological compounds found in food that decrease the utilisation or uptake of nutrients, resulting in impaired gastrointestinal functioning and metabolic performance. Examples of these compounds found in plants include lectins, tannins, β-glucans, saponins, and protease inhibitors. These substances can be categorised based on their mode of action as follows:

- Substances that depress protein digestion or metabolic utilisation, such as protease inhibitors, lectins (haemagglutinins), saponins, and polyphenolic compounds
- Substances that reduce or interfere with the utilisation of mineral elements, such as phytotic acid, oxalic acids, glucosinolates, and gossypol

- Substances that deactivate or increase the need for specific vitamins, such as cyanocobalamin, pyridoxine, nicotinic acid, anti-thiamin, and anti-vitamins A, D, E, and K.

Two significant anti-nutritional components of sorghum are the cyanogenic glycoside dhurrin, which is mostly found in the aerial shoot and sprouted seeds, and tannin, a polyphenolic molecule found in the grain (Rodríguez-España et al., 2022). Gelatin and other proteins can be precipitated out of aqueous solutions by tannins, which are water-soluble polyphenolic heterogeneous compounds with a molecular weight more than 5000 Daltons (Kavitha & Kandasubramanian, 2020). Tannins are widely thought to be composed of two types of polyphenolic systems: the hydrolysable tannins (HT) (pyrogallol class), which contain glucose esters and acids like ellagic and chebulic.

2.6.1 Kafrins in sorghum

Sorghum contains kafirin, a prolamin storage protein that has been utilised to create microparticles. Da Silva (2016) has created a new method for the extraction and subsequent creation of kafirin microparticles. Additionally, Tapia-Hernández et al. (2019) shown that these kafirin microparticles had a special porosity property that may be used to encapsulate chemicals within the microparticles. According to Rodríguez-Félix et al. (2022), kafirin encapsulating microparticles (KEMS) are of interest for the production of biodegradable biofilms and may prove to be a useful product.

2.6.2 Tannins in sorghum

Tannins are water-soluble polyphenolic heterogeneous compounds having molecular weight of over 5000 Daltons and the ability to precipitate gelatin and other proteins from an aqueous solution. Tannins are the most significant anti-nutritional factor which may lower the nutritional value and utilization of energy and protein in sorghum. The concentration of these compounds varies in different sorghum genotypes and production environments(Nazari et al., 2021).

The pericarps of sorghum grains can be pigmented or non-pigmented and can be white, red, brown, or black. According to Montes et al. (2017), the colour of the pericarp is determined by the expression of the B1 and B2 genes, both of which are necessary for the presence of tannins. According to Hariprasanna et al. (2015), tannins are the most significant anti-nutritional element that could lower sorghum's nutritional value as well as its ability to use protein and energy. These compounds' contents vary depending on the sorghum genotype and production environment.

Tannins are generally thought to be composed of two types of polyphenolic systems: the condensed tannins (CT) (catechol tannins), which are based on leu-co-anthocyanidin and similar substances, and the hydrolysable tannins (HT) (pyrogallol class), which have esters of glucose and acids like chebulic, ellagic, gallic, and m-digallic. Acids, bases, and enzymes can easily hydrolyse the pyrogallol tannins. One well-known gallotannin in the category is tannic acid, which has 8–10 moles of gallic acid for every mole of glucose. Despite containing a variety of similar molecules, the chemical formula for commercial tannic acid is C76H52O46. Another member of the HT group is Ellagitannins (Zhou et al, 2020). HT is not found in monocotyledons but is prevalent in dicotyledon leaves, fruits, pods, and galls (Getachew et al 2016).

Condensed tannins (CT) are not hydrolysable and widespread, typically producing anthocyanidins on acid degradation. Condensed Tannins contain the familiar flavonoid skeleton, epicatechin and catechin linked together (Fig. 2). Flavan-3-ols and Flavan-3-4-diols linkages are commonly recognized (Whiting., 2001).

The pH affects the complex formation of tannin and protein. Condensed Tannins can react and form complexes by H-bonding with carbohydrates and proteins but at neutral pH they form stronger bonds with proteins (Quan et al., 2019). Condensed tannins in protein complex are stable and insoluble in the pH range of 3.5 – 7.0 but unstable and release protein at pH of < 3.0 and >8.0 (Dai et al., 2020). Condensed Tannins are widespread in legume forages and sorghum (Kelln et al., 2021). The chemical structure of tannic acid, one of the types of tannin is illustrated in figure 2.1 below.

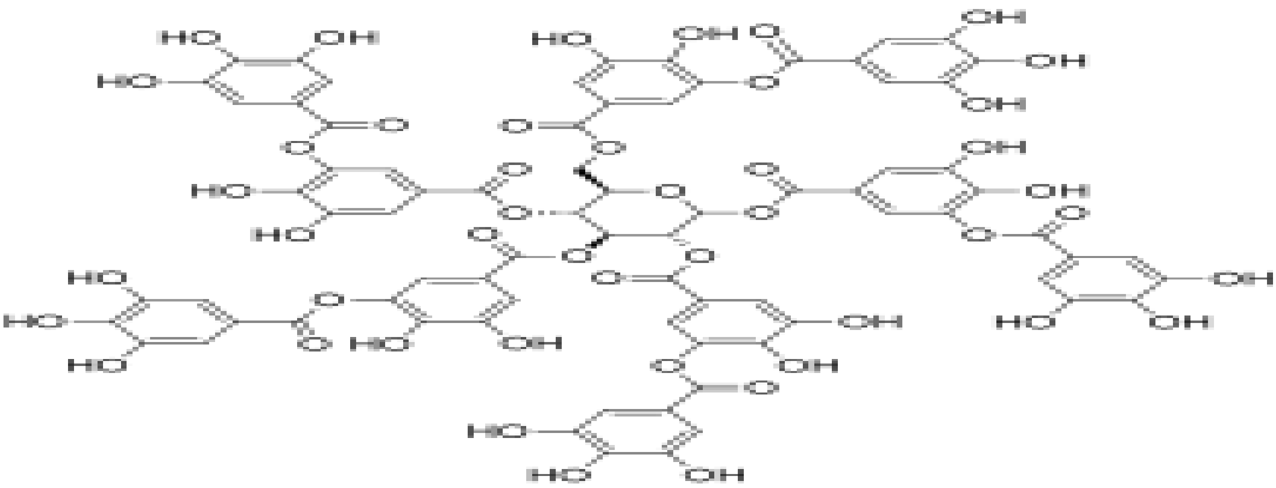

Figure 2.1 Representative chemical structure of a tannic acid, a type of tannin (Kaczmarek, 2020)

The main anti-nutritional effects of tannins include: a reduction in voluntary feed intake due to reduced palatability, diminished digestibility and utilization of nutrients, and adverse effects on metabolism and toxicity (Addisu., 2016). According to Addisu. (2016) these effects may be achieved via several mechanisms. Tannins exert an inhibitory effect on a broad spectrum of digestive enzymes at several sites in the digestive tracts of poultry.

Audu. (2018) reported that the ideal digestibility of energy, protein, arginine and leucine was reduced as dietary tannin levels rose to 20g/kg diet and beyond while methionine and phenylalanine were only negatively affected at tannin levels of 25g/kg diet. Protein efficiency ratio (PER) and net protein ratio are negatively correlated with tannic acid (Hafeez et al., 2019). Feed conversion efficiency increased with increasing levels of tannin up to 15g/kg diet while pancreatic and jejunal enzyme activities were not affected. This suggests that a wider range of factors may be involved in regulating the effect of tannins on poultry (Mahmoudi et al., 2022).

2.6.3 β-glucans in sorghum

A polysaccharide called β-glucan is naturally present in the cell walls of bacteria, fungi, yeasts, seaweeds, and cereals. Depending on where it comes from, β-glucan has very different physicochemical, functional, and technological properties. The domains of professional sports, fitness, cosmetics, and therapy all use this polysaccharide. The potent immunostimulant, prebiotic, and dietary fibre properties of β-glucan have sparked interest in it. The food industry is interested in using β-glucan because of its positive effects on consumers' health as well as its functional and technological properties, which greatly enhance the consumer attributes of food products (Khorshidian et al., 2018).

The use of oat β-glucan in the food industry became possible when the European Food Safety Authority (EFSA) confirmed in 2010 that the daily consumption of oat β-glucan in the amount of 3 g can reduce the risk of coronary diseases and have a positive effect on the cardiovascular system, provided that a diet with low saturated fat content is followed. β-glucan made from yeast has been recognized as a novel ingredient and authorized for release since 2011.

The β-glucan, a polysaccharide composed solely of glucose monomers, is adaptable and multipurpose, but research on its properties which are heavily influenced by the plant from which it originated is still lacking, particularly when it comes to how the various ingredients of the recipe interact with one another (Singh & Bhardwaj, 2023). Although β-glucan shows great potential as a technologically functional ingredient for the food industry, the information about its properties needs to be arranged and dispersed more in the scientific literature before it can be of any use to food professionals. Because β-glucan can form gels and increase the viscosity of products during technological processing, it has a high structuring ability and is studied specifically for its rheological properties. This information can be useful when studying low-fat food systems. The consistent effects of molecular weight, pH, temperature, shear rate, and the length of time it takes to break spatial bonds on the thixotropy and structuring ability of food systems containing β-glucan are still up for debate and need more research (Hamad et al., 2019).

2.6.4 Lectins in sorghum

Lectins are a diverse class of proteins that may attach to the carbohydrate moieties of simple or complex glycans with varying avidities and affinities while maintaining their molecular structures. Lectins were formerly thought to be extracellular compartment-localized defensive molecules that were only expressed in reaction to a foreign organism (Osman et al., 2023).

Nonetheless, data indicates that they can interact with cellular compartments located in the nucleus and cytoplasm that have endogenous glycan receptors. It thus performs a plethora of physiological roles. Plants are unable to escape adverse weather conditions and hostile environments because of their limited mobility. They must thus adjust to these circumstances by altering numerous physiological and molecular reactions in addition to controlling their metabolic pathways. Aside from its involvement in numerous physiological aspects of plants, like defence against predators, storage protein, in-cell sugar transport, etc., research on plant lectin's function as a stress adapter in various cellular locations across a range of crops has also been conducted (Marothia et al., 2023). For instance, it was intriguingly demonstrated that, depending on the stressor, oil seed flax lectin has distinct sugar specificities. Furthermore, a significant variation in the lectin coefficient activity (1/lectin activity) was observed according to the kind of stress and the lectin organ of localization. The scientists relate these variations in lectin activity and sugar specificity to lectin's ability to modulate stress. Five lectin genes are expressed at the transcriptomics level in rice (Oryza sativa): OsEULS2, OsEULS3, OsEUL1a, OsEUL1b, and OsEUL2D. Different EUL transcripts with varying degrees of expression are found when the plant is treated with different types of stress, whether biotic or abiotic. The majority of them were found in the vascular tissues of the seeds, root tips, and shoots. The transgenic *Arabidopsis thaliana* plant harbouring Nictaba-Like Lectin genes from *Glycine max* exhibits enhanced tolerability against bacterial infection compared to the wild-type plant. These outcomes indicated the involvement of *G. max* lectin in the biotic stress tolerance.

2.6.5 Saponins in sorghum

Saponins are high molecular weight glycosides which can form foam in aqueous solution. They are credited with several pharmacological and biological activities like hypocholesterolemic, anti-carcinogenic, anti-microbial, anti-inflammatory, anti-oxidant and immunomodulatory effects on both poultry and animals (Chaudhary et al., 2018). Saponins are contained in various parts of plants such as seed, stem, root, pericarp, shell and bark. The optimum level of saponin is being used as a feed supplement in poultry and monogastric animal nutrition and has shown many beneficial effects. In the present review, an attempt was made to summarize these promising effects of saponins in poultry and monogastric animal nutrition. However, saponins are bitter and reduce the feed intake of livestock, including poultry. High levels of saponins in poultry diets result in decreased performance and growth rate (Ramteke et al., 2019).

2.6.6 Procession of sorghum to reduce anti-nutritional factors

Sorghum grains (SGs) and sorghum flour (SF) are rich sources of macronutrients, micronutrients, and bioactive compounds (Rashwan et al., 2021). It is a meal that shows promise in lowering the risk of diet-related illnesses including diabetes and obesity in human beings. Besides, sorghum proteins do not bring about autoimmune allergy responses. Thus, consumption of sorghum is recommended as safe for people with celiac disease (Simnadis et al., 2016).

However, consumption of SGs as human food especially pigmented grains has some challenges due to the presence of multiple anti-nutritional components e.g., tannins, phytic acid, trypsin inhibitor, and protein cross-linker, etc. that have negative effects (Tripathi & Shrivastava, 2019). These anti-nutritional factors further reduce the feed efficiency to animals and human. Numerous technical processing techniques, including germination, fermentation, heating, soaking, steaming, and others, can reduce the anti-nutritional components. Furthermore, bread, cakes, porridges, starches, and other items made from sorghum grains can have their quality enhanced by these scientific procedures. Furthermore, the usage of SGs and their derivatives as food additives is aided by these processing procedures (Jafari et al., 2017; Mo et al., 2019; Palavecino et al., 2019; Xiong et al., 2019).

Germination: Singh et al. (2017) reported that germination of sorghum was earlier widely studied for change in their physicochemical and nutritional properties. According to Singh et al. (2017), germination is a cheap and efficient method of enhancing cereal quality. It can lead to structural modification and the synthesis of new compounds with high biological activity, increased nutrition value, and grain stability. These grains and their flour can be used to make speciality foods and value-added products (Singh et al., 2017). Since various anti-nutritional factors like tannins, phytates, and protease inhibitors were reduced or eliminated during germination, resulting in better nutrient digestibility, vitamin, and mineral availability, germinated sorghum was carefully considered to be much healthier than native sorghum.

The work of (Singh et al., 2017) revealed that germination of sorghum increased the gel consistency while paste clarity was decreased as compared to native flour. Proteins were modified by the action of enzymes during higher germination time and temperature conditions, which resulted in significantly higher protein solubility of germinated sorghum flour, which also resulted in enhancing the foaming and emulsifying properties of the flour. Germination can be used as a low-cost natural bio-processing technique for the preparation of modified flour with enhanced function properties without chemical modification or genetic engineering.

Fermentation: Fermentation is an age-old practice by a human being, to induce favourable biochemical reactions caused by microorganisms in the targeted food. Fermentation brings a change in flavour, texture and nutritive value of the food. Traditionally, lactic acid bacteria (LAB) have fermented rice, black grams, sorghum, millet, and other grains to produce a variety of foods and drinks. Yeast fermentation is important for making bread and other specialty meals for human consumption. Numerous benefits result from LAB fermentation, such as the inhibition of enter pathogenic bacteria, enhanced palatability and acceptability due to changes in texture, flavour, and colour, reduction of anti-nutritional factors like phytic acid and tannins, enrichment of nutrients through a microbial synthesis of vitamins, enhanced protein and starch digestibility, increased oil-binding capacity, emulsifying capacity, and emulsifying stability, and decreased water-binding capacity (Mohapatra et al., 2017).

Fermentation causes structural changes in the sorghum storage proteins like prolamins and glutelins so that they are more susceptible to digestion by the pepsin enzyme (Duressa et al., 2018). The improvement in protein digestion through fermentation is attributed to the degradation of tannins according to (He et al., 2020). Mohapatra et al. (2017) observed that natural LAB fermentation of whole ground sorghum increased available amino acids like lysine/leucine, isoleucine, methionine, and vitamins like niacin, riboflavin, and thiamine. Moreover, the protein quality increased significantly as a result of fermentation. When compared to raw sorghum, fermentation is a suitable alternative for boosting the availability of minerals, decreasing anti-nutritional components such as phytic acid and tannin, and increasing the digestibility of sorghum proteins (Mohapatra et al., 2017).

Fermentation has proven to be better at reducing the phytate level than the malting process of grain sorghum (Ojha et al., 2018). (Mohapatra et al., 2017) reported a reduction of tannin content by 92 % in high tannin content variety during 14 h fermentation of grain sorghum and the phytate content in the raw sorghum flour (12.1 μmol/g) was significantly reduced after) and fermentation (7.4 μmol/g). The reduction in phytic acid level was reported to be about 57-80 % of different varieties of sorghum after 12 h of fermentation. They also observed that malting reduces the phytic acid content by 68-83 %, whereas cooking reduces the phytic acid content only by 17.9-37.5 % and soaking for 12 h the reduction was in the tune of 8.2-14.4 % and that level increased to 57-60 % when the soaking time increased up to 24 h.

Soaking: Sorghum grains often are soaked before further processing. According to Li et al. (2022), soaking for a certain time can lead to the physical and chemical changes of seeds. During soaking, water enters the kernel, leads to rupture of the grain cells, swells and softens the physical structure, and releases the water-soluble compounds. Li et al. (2022) again opined that soaking significantly decreased total phenols, total flavonoids, tannins, phenolic acids compounds, flavonoid components, vitamin E, β-carotene, antioxidant activity, α-glucosidase, and α-amylase inhibitory activities of sorghum grains. However, Xiong et al. (2019) showed that soaking increased the total flavonoid content in sorghum, while total phenolic content, condensed tannin content, and antioxidant activity were not affected; this may be related to the slight increase of total phenolic content, which might be due to the release of some bound phenolic compounds and the minor loss of total phenolic content, and condensed tannin content might be too negligible to cause statistically significant differences. In brief, soaking can reduce water-soluble compounds in sorghum.

Soaking improved mineral bioavailability and digestibility by reducing anti-nutrients after soaking in other seeds of cereal crops (Soni et al., 2022). There has been no report on the effect of soaking on mineral bioavailability and protein digestibility. To fully understand how soaking affects nutrient content, food utilization, digestibility, and absorption from sorghum, more research is required.

Enzymatic treatment: Another technique for processing sorghum is enzymatic treatment. Enzymatic treatment is an environmentally friendly technique. Recently, polyphenol oxidase, tannase, and phytase were used to reduce antinutritional compounds, such as tannins and phytate, in sorghum products (Li et al., 2022). They reported that there are many enzymes that can be used in the treatment of sorghum. For example, some cell wall degrading enzymes could be used to break down the cell wall and release the phenolic compounds. Hence, more researches are expected to study the effects of kinds of enzymatic treatments on bioactive compounds and potential human health benefits.

2.7 Effects of replacing maize with sorghum on the growth performance of Cobb 500 broiler chickens

As part of the efforts to find a suitable replacement for dietary maize, a study (Daramola et al., 2019) was carried out to evaluate the effects of feeding four varieties of Sorghum bicolor on the growth performance of broiler chickens in Zaria, Kaduna state, Nigeria. The effects of feeding four varieties of raw sorghum (Samsorg-14, Samsorg-40, Samsorg17 and KSV-15) in total replacement of maize on the performance of broiler chickens were reported as follows; The results showed significant ($P<0.05$) differences in final weight, average daily weight gain, feed intake, cost /kg gain and feed conversion ratio for broiler chickens fed four varieties of sorghum in this study compared to birds fed the maize diet. Birds fed the maize diet had the best growth performance, although birds fed Samsorg-14 (T2) statistically showed no significant ($P>0.05$) difference from birds fed the control diet (T1-100 % maize inclusion) in terms of final weight and daily weight gain and in addition had the least cost / Kg gain. (Daramola et al., 2019).

2.8 Effects of replacing maize with sorghum on the carcass traits of Cobb 500 broiler chickens

Several attempts have been made to see if sorghum could be used to replace maize either partially or totally in the diet of broiler chickens. One such attempt is the work of (Gebeyew et al., 2015) which sought to replace maize partially with sorghum. Results of their research revealed that the mean slaughter weight of broiler chickens fed a diet containing 45 % sorghum was significantly higher ($P<0.01$) than the other treatments and there was no difference between broiler chickens fed a full maize diet, broiler chickens fed a diet containing a 15 % sorghum and those fed diet containing 30 % sorghum. Except for shank; abdominal fat, head, skin and cloaca, there were significant (P<0.05) differences among treatments for carcass and organ measurements. The dressed weight and percentage of T4 broiler chicks were significantly higher (P<0.01) than other treatments and there was no difference between the full maize diet, 15 % sorghum diet and 30 % sorghum diet treatments. Reported significant differences for Hubbard classic chicks. In contrast to their results, Hassan et al. (2021) reported dressing percentage with no significant difference among the treatments. The eviscerated weight of broilers in their experiment showed a significant (P<0.05) difference among the treatments. This result is supported by El-Faham et al. (2017) who reported higher eviscerated weight for Hubbard Classic broilers. The breast meat of birds 45 % sorghum diet showed a significantly higher (P<0.01) value. This result agrees with Hassan et al. (2021) who reported significant differences in breast meat. The 45 % sorghum diet and 30 % sorghum diet showed significantly higher (P< 0.01) than 15 % sorghum and full maize diet and the latter treatments showed no significant difference between each other. Broilers with better-developed breast meat were considered superior finishers. Statistical analysis revealed that drumstick and thigh showed differences among the treatments. The 45 % sorghum diet was higher as compared to the 15 % sorghum diet and full maize diet, but similar to the 30 % sorghum diet which is in agreement with the results of Moses et al. (2022) who reported significant difference (P<0.01) in drumstick and thigh of Ross 308 broiler chickens fed malted sorghum-based diets.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Location and duration of the research

The experiment was conducted at the poultry section of the Department of Animal ScienceEducation, College of Agricultural Science Education of Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development- Ashanti Mampong campus. The research started on 10th April, 2023 and ended on 5th June, 2023 (lasting for 56 days).

3.2 Experimental design and dietary treatments

The Cobb 500 broiler day-old chicks were randomly allotted the three dietary treatment groups following a completely randomized design (CRD). Each treatment group had five replicates with 10 birds per replicate. The broilers were randomly distributed to replicate groups to give near-uniform initial weights for all the groups. The treatment groups included control diet/Treatment 1(T_1)- maize-based diet, Treatment 2(T_2)- Unfermented Sorghum-based diet, and Treatment 3(T_3)- Fermented Sorghum-based diet.

3.3 Processing of the sorghum

The sorghum procured from the Ejura market was soaked in water for three days. It was then sun-dried properly. The dried sorghum grains were then ground in a corn mill to moderate texture and used to formulate the diet. The soaking or fermentation was aimed at reducing the anti-nutritional factors in sorghum.

3.3.1 Proximate analysis protocol

A proximate analysis was conducted in the Nutrition Laboratory of the Department of Animal Science, Faculty of Agriculture of Kwame Nkrumah University of Science and

Technology. The various analysis protocols that were followed to determine the proximate composition of the sorghum are outlined as follows.

Moisture Content

Moisture content was determined by the method of the Association of Official Analytic Chemists' (AOAC, 1984)- by drying the sample in an oven until a constant weight was obtained. Two grams of the sample was accurately weighed into a previously cleaned, dried and weighed glass crucible. The crucible with its content was put into a drying oven (Gallenkamp, model OV 880 England) at 105 ˚C for 3.5 hours. The sample was then cooled in a desiccator and weighed. The process was repeated until a constant weight was obtained. The loss in weight expressed as a percentage of the initial weight of sample gave the percent moisture content using the formula:

$$\%\ Moisture = \frac{(weight\ of\ wet\ sample - weight\ of\ dry\ sample)}{Weight\ of\ wet\ sample}\ x\ 100$$

Crude Protein Content

Crude protein was determined by the method of the Association of Official Analytical Chemists' (AOAC, 1990). Two grams (2.0 g) of the sample was weighed into a digestion flask and 0.5 g of selenium catalyst (or copper capsules/tablets) was added.

Twenty-five milliliters (25 ml) of concentrated H_2SO_4_was added and the flask was shaken to mix the contents. The flask was then placed on a digestion burner for 8 hours and heated until the solution turned green and clear. The sample solution was then transferred into a 100 ml volumetric flask and made up to the mark with distilled water. 25 ml of 2 % boric acid was pipetted into a 250 ml conical flask and 2 drops of mixed indicator (20 ml of bromocresol green and 4ml of methyl red) solution added. Into the decomposition chamber of the distillation apparatus was added 15 ml of 40% NaOH solution. 10 ml of the digested sample solution was then introduced into a Kjedahl flask. The condenser tip of the distillation apparatus was then dipped into the boric acid contained in the conical flask. The ammonia in the sample solution was then distilled into the boric acid until it changed completely to bluish green. The distillate was then titrated with 0.1 N HCl solution until it became colourless. The percent total nitrogen and crude protein were calculated using the equation:

$$\% \, Total\ Nitrogen = \frac{(100 \text{ x } (\text{VA} - \text{VB}) \text{ x N x } 0.01401)}{10 \text{ W}} \ x \ 100$$

Where, *VA = Volume (ml) of HCl used in the sample titration*

VB = Volume (ml) of HCl used in the blank titration

N = Normality of HCl

W = Weight of sample (g)

% Crude Protein = % Nitrogen x 6.25

Crude Fat Content

Crude fat was determined based on the Sohxlet Extraction Method of AOAC (1990).

A 250 ml quickfit round bottom flask was washed and dried in an oven (Gallenkamp, model OV 880, England) at 105 ˚C for 25 minutes and allowed to cool to room temperature before it was weighed. Two grams (2.0 g) of the sample was weighed into a muslin thimble. This was inserted into the extraction column with the condenser connected. 200 ml of the extraction solvent (petroleum ether, boiling point 40-60 ˚C) was poured into the round bottom flask and fitted into the extraction unit. The flask was then heated with the aid of electrothermal heater at 60 ˚C for 2 hours. Losses of solvent due to heating were checked with the aid of the condenser so that it cooled and refluxed the evaporated solvent. After extraction, the thimble was removed and the solvent salvaged by distillation. The flask containing the fat and residual solvent was placed on a water bath to evaporate the solvent followed by a further drying in an oven (Gallenkamp, model OV 880, England) at 105 ˚C for 30 minutes to completely evaporate the solvent. It was then cooled in a desiccator and weighed. The fat obtained was expressed as a percentage of the initial weight of the sample using the formula:

$$\% \, Crude \, Fat = \frac{weight \, of \, fat}{\text{weight of sample}} \, x \, 100$$

Crude Fibre Content

Crude fibre was determined by the method of the Association of Official Analytical Chemists' (AOAC, 1990). The defatted sample (from crude fat determination) was transferred into a 750 ml Erlenmeyer flask and 0.5 g of asbestos was added. 200 ml of boiling 1.25 % H_2SO_4 was added and the flask was immediately set on a hot plate and condenser connected to it. The content was brought to boil within 1 minute and the sample was digested for 30 minutes. At the end of the 30 minutes, the flask was removed and the content was filtered through a linen cloth in a funnel and subsequently washed with boiling water until the washings were no longer acidic [test acidity with Methyl Orange indicator- -Red-to-Colorless]. The sample was washed back into the flask with 200 ml boiling 1.25 % NaOH solution. The condenser was again connected to the flask and the content of the flask was boiled for 30 minutes. It was then filtered through the linen cloth and thoroughly washed with boiling water until the washings were no longer alkaline [test alkalinity with Phenolpthalein indicator- -Pink-to-Colorless]. The residue was transferred to a clean crucible with a spatula and the remaining particles washed off with 15 ml ethanol into the crucible. The crucible with its content was then dried in an oven (Gallenkamp, Model OV 880, England) at 105 ˚C overnight and cooled in a desiccator and weighed. The crucible with its content was then ignited in a furnace (Muffle furnace size 2, England) at 600 ˚C for 30 minutes, cooled and reweighed. The loss in weight gave the crude fibre content and was expressed as a percentage of the initial weight of the sample using the formula.

$$\% \, Crude\ Fibre = \frac{(\text{weight of crucible + sample before ignition}) - (weight\ of\ crucible + ash)}{\text{Weight of Fresh Sample}}\ x\ 100$$

Ash Content

Ash was determined using the method of the Association of Official Analytical Chemists cited by Kalagatur et al. (2018). A 2.0 g sample was weighed into a previously dried and weighed porcelain crucible. The crucible with its content was placed in a Muffle furnace (Muffle furnace size 2, England) preheated to 600 ˚C for 2 hours. After this period the crucible with its content was removed and cooled in a desiccator. The crucible with its content was then weighed. The weight of the ash was expressed as a percentage of the initial weight of the sample using the formula.

$$Ash\ \% = \frac{\text{Weight of Ash}}{\text{Weight of Sample}}\ x\ 100$$

Carbohydrate Content / Nitrogen Free Extract

Total percentage carbohydrate was determined by the difference method as reported by Sharma & Giri. (2022). This method involves adding the total values of crude protein, crude fat, crude fibre, moisture and ash constituents of the sample and subtracting it from 100. The value obtained is the percentage carbohydrate constituent of the sample.

Carbohydrate (%) = 100 – (Protein % + Fat % + Fibre % + Moisture % + Ash %)

Energy (kCal/100 g) = 4 x Protein % + 4 x Carbohydrate % + 9 x Fat %.

3.4 Experimental birds and management

One hundred and fifty day-old Cobb 500 chicks were procured from an Ivorian firm by the name Fuani Farms. On the first day (day 0), 10 of the day-old chicks of similar weight were weighed together and randomly placed in each of the 15 experimental pens. The birds were reared in open-sided deep litter housing with wire mesh dividing pens. Each experimental pen had an average area of 2.24 m^2. Fresh disinfected wood shavings were used as bedding materials. The birds were provided feed and water *ad libitum* throughout the 56-day duration of the experiment. Pen weight (weight of all birds in a pen) was taken weekly. All prophylaxes were administered under the strict supervision of the veterinary technician at the university farm. Feed was also weighed before it was given to the birds all the time.

3.5 Experimental diets

Three separate experimental diets were formulated taking into consideration the ingredient requirements of broiler chickens. The first diet was a maize-based diet, diet 2 an unfermented sorghum-based diet and diet 3 was a fermented sorghum-based diet.

The birds were provided starter diets from day 0 up to day 30 and grower-finisher diets continued from day 31 to the end of the research.

Table 3.1: Ingredients and feed composition of starter diets

Ingredient	Maize-based diet	Unfermented sorghum-based diet	Fermented sorghum-based diet
Maize %	63	0	0
Wheat bran %	1	1	1
Sorghum %	0	63	63
Soyabean meal %	24	24	24
Fish meal %	9	9	9
Oyster shell %	1.5	1.5	1.5
Dicalcium phosphate %	0.5	0.5	0.5
Mineral premix %	0.5	0.5	0.5
Salt %	0.5	0.5	0.5
Total	100	100	100
Calculated Composition			
Crude Protein	23.23	23.04	23.13
Fat	3.55	4.00	3.97
Fiber	3.08	3.10	3.11
Calcium	0.9	0.92	0.9
Av. Phosphorus	0.4	0.4	0.4
ME, Kcal	3100	3100	3070

Vitamin A, 8,000,000 IU; Vitamin B1, 1300 mg, Vitamin B2, 2500 mg, Vitamin D3, 3000 IU; Vitamin E, 10,000 IU; Vitamin K3, 1,500 mg; Vitamin B6, 1,000 mg; Vitamin B12, 6 mg, Nicotinic Acid, 5,000 mg,Pantothenic Acid, 4000 mg; Choline Chloride, 8000 mg; Copper, 2,500 mg; Cobalt, 700 mg; Iron, 4,500 mg; Zinc, 55, 000 mg; Methionine, 50,000 mg; Lysine, 200,000 mg; Selenium (1%), 1,300 mg; Iodine, 2,000 mg; Manganese, 60, 000 mg; Antioxidant, 625 mg.

Table 3.2: Ingredients and feed composition of grower/finisher diets

Ingredient	Maize-based diet	Unfermented sorghum-based diet	Fermented sorghum-based diet
Maize %	74	0	0
Wheat bran %	0	0	0
Sorghum %	0	74	74
Soyabean meal %	12.8	12.8	12.8
Fish meal %	11.2	11.2	11.2
Oyster shell %	0.7	0.7	0.7
Dicalcium phosphate %	0.4	0.4	0.4
Mineral premix %	0.5	0.5	0.5
Salt %	0.5	0.5	0.5
Total	100	100	100
Calculated Composition			
Crude Protein	21.65	21.19	21.13
Fat	3.99	3.67	3.47
Fiber	2.82	2.25	2.11
Calcium	0.6	0.61	0.62
Av. Phosphorus	0.3	0.3	0.3
ME, Kcal	3210	3290	3290

Vitamin A, 8,000,000 IU; Vitamin B1, 1300 mg, Vitamin B2, 2500 mg, Vitamin D3, 3000 IU; Vitamin E, 10,000 IU; Vitamin K3, 1,500 mg; Vitamin B6, 1,000 mg; Vitamin B12, 6 mg, Nicotinic Acid, 5,000 mg,Pantothenic Acid, 4000 mg; Choline Chloride, 8000 mg; Copper, 2,500 mg; Cobalt, 700 mg; Iron, 4,500 mg; Zinc, 55, 000 mg; Methionine, 50,000 mg; Lysine, 200,000 mg; Selenium (1%), 1,300 mg; Iodine, 2,000 mg; Manganese, 60, 000 mg; Antioxidant, 625 mg.

3.5.0 Data collected

3.5.1 Growth performance

Data collected during the research included the following: body weight, weight gain, feed consumption, feed conversion ratio and livability. These data were calculated every week. Feed consumption was calculated by subtracting the leftover feed from the feed supplied. Body weight was also calculated by simply dividing the pen weight by the number of birds in the pen. Again, weight gain was calculated as the difference between the current body weight and the initial body weight. The feed conversion ratio was calculated by dividing the difference between the current pen weight and the sum of the initial body weight and all mortality weights by the current feed consumption. Livability was calculated by dividing the current number of birds in a pen by the initial number of birds put in the pen and multiplying by 100 %.

3.5.2 Gastrointestinal pH

Two birds were sampled randomly from each replicate pen and weighed together after which they were taken through a cervical neck dislocation procedure. The birds were then dissected immediately and the Crop, Pro-ventricular, Gizzard, Doudenal, Jejunal, Ileal and caecal pH for each bird was taken using a pH meter (the Hannah Instrument, UK) according to the description by Zanu et al. (2020). The average pH of the two birds per pen was calculated.

3.5.3 Bone characteristics

The procedure for determining bone traits from the tibia and femur involves several steps. Firstly, the bones are carefully removed from the body, ensuring minimal damage or alteration. Once removed, the bones are cleaned to remove any soft tissue and then allowed to dry completely. After the bones are prepared, various dimensions such as length, width, and density can be taken using specialized tools such as callipers and osteometric boards. These measurements are essential for understanding the physical characteristics and traits of the bones, which can provide valuable information for anthropological, medical, or forensic purposes, (tibia and femur) traits determination.

The determination of bone breaking strength involves the use of a machine called a biomechanical testing system. This machine is designed to apply controlled mechanical loads to bone samples in order to measure their strength and structural properties. The bone sample is secured within the machine, and force is gradually applied until the bone fractures. By measuring the force applied and the displacement, the breaking strength and other mechanical properties of the bone can be determined. This information is valuable for understanding bone health, evaluating the effects of diseases such as osteoporosis, and assessing the success of medical interventions such as implants or bone grafts.

3.5.4 Relative organ weight

The two birds per pen that were sampled and taken through the head-dislocation procedure, were eviscerated and various parts including the thigh, drumstick, breast meat, empty gizzard, liver, heart and fat pad/abdominal fat were weighed and recorded according to the procedure described by Gebeyew et al. (2015). The weight of each part was expressed as a percentage of the sample weight (also known as live weight) of the bird.

3.6 Phytochemical screening

A phytochemical screening was carried out to determine the presence or absence of selected phytochemical properties of the sorghum before and after fermentation. The screening was done. The various procedures followed in doing the screening for each phytochemical property are outlined as follows.

3.6.1 Test for Anthraquinones

Born Ranger’s test was used to determine the presence or absence of anthraquinones. A small quantity volume of the sample was heated in weak sulphuric acid and allowed to cool. It was then filtered and the filtrate extracted with chloroform and treated with dilute ammonia. The presence of anthraquinones derivatives was confirmed by the layer changing colour from pink to red.

3.6.2 Test for Steroids and Triterpenoids

The Salkowski test was used to determine the presence of steroids and triterpenoids in the sorghum. The sample (extract) of the sorghum was treated in chloroform and a few drops of strong sulfuric acid were added. The mixture was agitated briskly and left to stand for about 3-5 minutes for it to form two layers. The colour of the lower layer was observed to see if there was red color to indicate the presence of steroids and production of yellow colour in the lower layer to confirm the presence of triterpenoids.

3.6.3 Test for Alkaloids

Test 1 was used to determine the presence of alkaloids in the sorghum. A few drops of 30 % dilute HCl and 0.5 ml Wager’s reagent were added to the sorghum sample. [Wagner’s reagent: 2 g Iodine + 6 g Potassium Iodide in 100 ml]. The mixture was observed looking out for a flocculent reddish-brown precipitate which indicates the presence of alkaloids.

3.6.4 Test for Cyanogenic Glycosides

About 250 µL of the sorghum sample or extract and an equal amount of cold, concentrated sulfuric acid were mixed.

Glycosides are present if a bright green, blue, black, or red colour develops.

3.6.5 Test for Cyanogenic Glycosides

About 250 µL of the sample or extract and an equal amount of cold, concentrated sulfuric acid were mixed. Glycosides are present when a bright green, blue, black, or red colour develops.

3.6.6 Test for Flavonoids

Dissolve an amount of the sorghum sample or extract was dissolved in 98 % concentrated H_2SO_4. The formation of intense colour was supposed to indicate the presence of flavonoids.

3.6.7 Test for Terpenoids

A sample or extract of the sorghum was treated with a small volume of chloroform. An equal volume of 98 % concentrated H_2SO_4 was added. A red to purple colour formation in the chloroform-soluble portion was expected to indicate the presence of terpenoids.

3.6.8 Test for Tannins

A portion of the sorghum sample or extract was mixed with a few drops of 0.1 % Ferric Chloride. The mixture was observed for brownish-green coloration which indicates the presence of tannins.

3.6.9 Test for Saponins

About 0.5 ml amount of the sorghum sample or extract was dissolved in 5 ml of distilled water in a test tube. The test tube with the solution was shaken vigorously. A stable persistent froth with a honeycomb structure was expected to confirm the presence of saponins.

3.7 Cost-benefit analysis

3.7.1 Price of Bird

This represents the selling price of each bird under different treatments (Maize-based diet, Unfermented sorghum-based diet and Fermented sorghum-based diet). It was calculated by multiplying the body weight of the bird by the price per kg weight which is derived from market analysis or experimental results related to each diet type. Price of bird= Price per kg weight X Body weight of bird.

3.7.2 Total Feed Cost

This is the total cost incurred for feeding the birds for the duration. It was calculated by summing up the daily feed costs based on the specific diet for the duration the birds were kept.

3.7.3 Profit

Profit was calculated by subtracting the Total Feed Cost from the Price of Bird for each treatment: Profit = {Price of Bird} - {Total Feed Cost}.

3.7.4 Feed Cost : Profit

This is a ratio formed by dividing the Total Feed Cost by the Profit. It shows how much was spent on feed for each unit of profit generated:

Feed Cost: Profit = {Total Feed Cost} /{Profit}.

3.7.5 Performance Efficiency Index (PEI)

This index was calculated as a measure of the overall efficiency of the diet treatments. It usually accounts for weight gain or productivity relative to feed cost, incorporating both feed efficiency and profitability.

3.8 Statistical analysis of data

Data collected were taken through the Box-cos transformation before they were analyzed. Data were analyzed using the one-way ANOVA procedure of the Minitab 21.2 statistical software to assess the effects (of unfermented sorghum and fermented sorghum). Fisher LSD means separation test was used to make pairwise comparisons between treatment means at probability level of 5 % ($P<0.05$).

CHAPTER FOUR

4.0 RESULTS

4.1. Effect of fermentation on phytochemical properties of sorghum

Table 4.1 highlights the impact of fermentation on the phytochemical profile of sorghum, revealing a notable reduction in specific bioactive compounds post-fermentation. In its unfermented state, sorghum was found to contain tannins and flavonoids, both of which are known for their potential health benefits. However, upon fermentation, both tannins and flavonoids were no longer detected in the sorghum samples. The absence of tannins and flavonoids in fermented sorghum may suggest a reduction in its antioxidant capacity post-fermentation, although it could also indicate the formation of other bioactive metabolites. All the other phytochemical properties that were tested for, were already not in the unfermented sorghum.

Table 4.1: Phytochemical properties of sorghum, before and after fermentation

Phytochemical	Unfermented sorghum	Fermented sorghum
Anthraquinones	-	-
Saponins	-	-
Tannins	+	-
Terpenoids	-	-
Flavonoids	+	-
Cyanogenic glycoside	-	-
Alkaloidss	-	-
Triterpenoids	-	-
Streroid	-	-

+, present; -, absent

4.2.1: Proximate analysis of the sorghum fed to the birds

Table 4.2 presents a comparison of the nutritional composition of unfermented and fermented sorghum, along with various parameters expressed in percentages and metabolizable energy in kilocalories per kilogram (Kcal/Kg). Unfermented sorghum has a moisture content of 10.11%, while fermented sorghum shows a slightly higher moisture content at 10.58%. This indicates that fermentation may lead to increased water retention. Both types of sorghum show similar ash content, with unfermented at 1.85% and fermented at 1.84%. This suggests that fermentation does not significantly alter the mineral content proportion. The crude fat content is higher in fermented sorghum (6.65%) compared to unfermented sorghum (5.85%). This difference may indicate that fermentation enhances lipids. Fermented sorghum also has a higher crude fiber content (0.92%) than unfermented (0.78%). Increased fiber can be beneficial for digestive health. Interestingly, crude protein content declines from unfermented (11.38%) to fermented (10.73%). This decrease could be due to protein breakdown during fermentation. Unfermented sorghum has a higher nitrogen-free extract percentage (70.03%) than fermented sorghum (69.28%). This suggests that fermentation may lead to slight reductions in readily available carbohydrates. The metabolizable energy is slightly higher in fermented sorghum (3365.78 Kcal/Kg) compared to unfermented (3350.64 Kcal/Kg), indicating a potential benefit of fermentation for energy availability. Overall, fermentation appears to enhance certain nutritional aspects like fat and fiber while slightly reducing protein and carbohydrate fractions. This could have implications for the use of fermented sorghum in animal feeds or as a food ingredient.

Table 4.2: Proximate analysis of the fed to the birds

Parameter	Unfermented sorghum	Fermented sorghum
Moisture,	10.11	10.58
Ash,	1.85	1.84
Crude Fat,	5.85	6.65
Crude Fibre,	0.78	0.92
Crude Protein,	11.38	10.73
Nitrgen-Free Extract,	70.03	69.28
Metabolizable Energy, kcal/kg	3350.64	3365.78

4.2.2 Proximate analysis of diets fed to the birds

Table 4.3 presents the nutritional composition of two types of diets for poultry: Starter and Grower/Finisher diets. Each diet is analyzed across three different formulations (1, 2, and 3) for both stages. Here's a summary of the key components:

Moisture ranges from 9.20% to 9.55%, showing a relatively consistent moisture content among the formulations. Ash varies between 7.39% and 10.45%, indicating slight differences in mineral content. Crude Fat shows variability, with values from 3.68% to 7.09%. This suggests that different formulations have varying fat content, which can influence energy levels. Crude Fibre ranges from 1.03% to 4.95%. Higher fibre levels in some formulations can impact digestion and overall nutrient absorption. Crude Protein has a notable range, from 16.86% to 22.11%. Protein is crucial for growth, so variations can affect the efficacy of the diet. Nitrogen-Free Extract varies from 49.37% to 55.33%, reflecting the amount of carbohydrates and sugars available for energy. Metabolizable Energy (kcal/kg): The values range from 2918.44 to 3076.90 kcal/kg. This indicates the energy available from the diets, with higher values indicating greater energy content.

Grower/Finisher Diet Analysis: Moisture: Slightly lower than the Starter Diets, ranging from 8.96% to 9.43%. Ash shows similar trends as the Starter Diet, with values between 7.39% and 9.14%. 3. Crude Fat: A more consistent fat level compared to the Starter Diet, varying from 6.35% to 7.09%. Crude Fibre: Higher fibre contents, ranging from 1.03% to 4.95%, potentially to promote gut health. Crude Protein reduced in comparison to Starter Diets, ranging from 16.86% to 18.61%, which is suitable for finisher diets as the protein requirement decreases. Nitrogen-Free Extract shows an upward trend from the starter diets, ranging from 51.9% to 55.33%, which might be beneficial for energy in the later stages of growth. Metabolizable Energy (kcal/kg) ranges from 3058.78 to 3180.31 kcal/kg, indicating a generally higher energy content for grower/finisher diets.

Conclusion: Overall, the data indicates variations in nutritional components between the starter and grower/finisher diets, reflecting the changing dietary needs of poultry at different growth stages. The Starter Diets emphasize higher protein and varying energy sources, while the Grower/Finisher Diets show a gradual shift towards higher energy and slightly reduced protein levels. These formulations are tailored to optimize growth and health in poultry at different life stages.

Table 4.3: Proximate analysis of diets fed to the birds

Parameter	**Starter Diet**			**Grower/Finisher Diet**		
	1	2	3	1	2	3
Moisture, %	9.44	9.55	9.20	8.96	9.43	9.04
Ash, %	9.21	10.45	9.93	9.14	7.39	9.86
Crude Fat, %	6.00	3.68	5.67	7.09	6.80	6.35
Crude Fibre, %	2.65	2.80	4.59	4.95	2.47	1.03
Crude Protein, %	20.80	22.11	21.24	16.86	18.61	18.39
Nitrogen-Free Extract, %	51.90	51.41	49.37	53.00	55.30	55.33
Metabolizable Energykcal/kg	3076.	2918.44	2977.64	3058.78	3180.31	3136.41

4.2.3 Effect of dietary replacement of maize with unfermented or fermented sorghum on growth performance of Cobb 500 broiler chickens, 0-7 days

It was observed on day 7 that treatment effects were not significant for feed intake, feed conversion ratio (FCR), and livability. Cobb 500 broiler chickens fed a maize-based diet recorded the highest treatment mean in each case. However, as shown in table 4.4, body weight and gain showed significant differences statistically. The maize-based diet also recorded the highest body weight followed by the unfermented sorghum-based diet and then the fermented sorghum-based diet. It was discovered that Gain on the day followed the same trend as body weight. Maize-based diet recorded the highest gain which was followed by the unfermented sorghum-based diet and the fermented sorghum-based recorded the least weight gain.

Table 4.4: Effect of dietary replacement of maize with unfermented or fermented sorghum on growth performance of Cobb 500 broiler chickens, 0-7 days

Treatment	BW, g	Gain, g	Intake, g	FCRc	Livability, %
T_1	114.0^a	76.58^a	58.00^a	0.756^a	100^a
T_2	102.0^b	64.57^b	50.00^a	0.776^a	100^a
T_3	88.00^c	50.47^c	46.00^a	0.931^a	100^a
P-Value	0.002	0.001	0.149	0.161	-
SEM	*8.56*	7.88	9.13	0.146	-

Means in the same column that do not have the same superscript are significantly different (P<0.05)

T_1, Maize-Based Diet; T_2, Unfermented Sorghum-Based Diet; T_3, Fermented Sorghum-Based Diet; FCRc, Corrected Feed Conversion Ratio; BW, Body Weight

4.2.4 Effect of dietary replacement of maize with unfermented or fermented sorghum on growth performance of Cobb 500 broiler chickens, 0-14 days

Feed intake and Livability did not show significant treatment effects on day 14. Body weight, weight gain, and feed conversion ratio, on the other hand, were significantly affected ($p<0.05$) by treatment as illustrated in Table 4.5. Maize-based diet recorded the highest body weight on that day. There was no significant difference unfermented sorghum-based diet and fermented sorghum-based diet although the unfermented sorghum-based diet had a slightly higher body weight than the fermented sorghum-based diet. The same trend was observed in weight gain; the maize-based diet recorded the highest gain followed by the unfermented sorghum-based diet and then the fermented sorghum-based diet with treatment means which were not much different from each other.

Again, there was no significant difference between the FCRc of unfermented sorghum-based diet and fermented sorghum-based diet despite that the fermented sorghum-based diet recorded the highest FCRc. The maize-based diet recorded the least FCRc with a value not significantly different from that of the unfermented sorghum-based diet.

Table 4.5: Effect of dietary replacement of maize with unfermented or fermented sorghum on growth performance of Cobb 500 broiler chickens, 0-14 days

Treatment	BW, g	Gain, g	Intake, g	FCRc	Livability, %
T_1	270.0^a	232.6^a	300.0^a	1.291^b	100.0^a
T_2	220.7^b	183.2^b	263.3^a	1.436^{ab}	98.00^a
T_3	190.0^b	152.5^b	250.0^a	1.671^a	100.0^a
P-Value	0.001	0.001	0.173	0.016	0.397
SEM	*25.94*	25.71	40.57	0.176	2.58

Means in the same column that do not have the same superscript are significantly different (P<0.05)

T_1, Maize-Based Diet; T_2, Unfermented Sorghum-Based Diet; T_3, Fermented Sorghum-Based Diet; FCRc, Corrected Feed Conversion Efficiency; BW, Body Weight

4.2.5 Effect of dietary replacement of maize with unfermented or fermented sorghum on growth performance of Cobb 500 broiler chickens, 0-21 days

Similarly, feed intake and Livability for day 21 did not respond significantly (p>0.05) to treatment whereas body weight, weight gain and corrected feed conversion ratio did respond significantly to treatment as can be observed in Table 4.6 below. The table reveals that a maize-based diet produced the highest body weight on the day. Unfermented sorghum-based diet recorded the second-highest treatment mean and fermented sorghum-based had the least. With weight gain, the data revealed that maize-based still recorded the highest mean with unfermented sorghum-based diet and fermented sorghum-based taking the second and third positions respectively. Coming to FCRc, it was the fermented sorghum-based diet that had the highest treatment mean which was not much different from the one recorded by the unfermented sorghum-based diet with maize-based recording the least value.

Table 4.6: Effect of dietary replacement of maize with unfermented or fermented sorghum on growth performance of Cobb 500 broiler chickens, 0-21 days

Treatment	BW, g	Gain, g	Intake, g	FCRc	Livability, %
T_1	532.9[a]	495.5[a]	714.5[a]	1.450[b]	96[a]
T_2	421.3[b]	383.9[b]	789.8[a]	2.059[ab]	96[a]
T_3	346.0[c]	308.5[c]	664.0[a]	2.254[a]	100[a]
P-Value	0.000	0.000	0.221	0.012	0.300
SEM	*52.94*	52.83	108.1	0.370	4.47

Means in the same column that do not have the same superscript are significantly different (P<0.05)
T_1, Maize-Based Diet; T_2, Unfermented Sorghum-Based Diet; T_3, Fermented Sorghum-Based Diet; FCRc, Corrected Feed Conversion Ratio; BW, Body Weight

4.2.4 Effect of dietary replacement of maize with unfermented or fermented sorghum on growth performance of Cobb 500 broiler chickens, 0-28 days

On day 28, Body weight, Feed weight gain and FCRc showed a significant difference statistically as observed in Table 4.7 below. On the other hand, Feed intake and Livability did not show a significant response to the treatment statistically. Maize-based diet recorded the highest body weight followed by the unfermented sorghum-based diet with the fermented sorghum-based diet showing the least body weight for the day. When it comes to gain, a maize-based diet took the lead. Unfermented sorghum-based diet and fermented sorghum-based diet then followed in that order although, not much different from each other. Looking at FCRc, the fermented sorghum-based diet recorded the highest treatment mean unfermented sorghum-based diet recorded the second highest mean which is not much different from the treatment mean of the fermented sorghum-based diet. The maize-based diet then comes with the least treatment mean.

Table 4.7: Effect of dietary replacement of maize with unfermented or fermented sorghum on growth performance of Cobb 500 broiler chickens, 0-28 days

Treatment	Bw, g	Gain, g	Intake, g	FCRc	Livability, %
T_1	894.7^a	857.2^a	1346^a	1.575^b	96a
T_2	706.7^b	669.2^b	1540^a	2.306^a	94^a
T_3	570.0^c	532.5^b	1254^a	2.447^a	100^a
P-Value	0.001	0.000	0.058	0.003	0.139
SEM	*93.33*	93.20	171.2	0.338	4.47

Means in the same column that have the same superscript are not significantly different (P<0.05); $T_{1,}$ Maize-Based Diet; $T_{2,}$ Unfermented Sorghum-Based Diet; $T_{3,}$ Fermented Sorghum-Based Diet; FCRc, Corrected Feed Conversion Ratio; BW, Body Weight

4.2.5 Effect of dietary replacement of maize with unfermented or fermented sorghum on growth performance of Cobb 500 broiler chickens, 0-35 days

Day 35 saw body weight, weight gain and feed conversion efficiency responding significantly to the treatment while feed intake and livability remained unresponsive to the treatment.

It can be observed that Cobb 500 broiler chickens fed a fermented sorghum-based diet recorded the highest FCRc followed by the unfermented sorghum-based diet and maize-based in that order even though there was no significant difference between them. When it comes to gain, the maize-based diet recorded the highest gain. The unfermented sorghum-based diet and fermented sorghum-based diet did not show signficant difference in their means. The unfermented sorghum-based diet fermented sorghum-based diet showed no significant difference between their treatment means. As shown in table 4.8, body weight for day 35 followed the same trend as weight gain. Maize-based diet recorded the highest body weight followed by the unfermented sorghum-based diet which was not much different from the fermented sorghum-based diet.

Table 4.8: Effect of dietary replacement of maize with unfermented or fermented sorghum on growth performance of Cobb 500 broiler chickens, 0-35 days

Treatment	Bw, g	Gain, g	Intake, g	FCRc	Livability, %
T_1	1276^{a}	1238^{a}	2125^{a}	1.718^{b}	96.00^{a}
T_2	1003^{b}	965.5^{b}	2384^{a}	2.482^{a}	94.00^{a}
T_3	821^{b}	783^{b}	1959^{a}	2.614^{a}	96.00^{a}
P-Value	0.001	0.001	0.066	0.006	0.868
SEM	*142.9*	142.6	268.6	0.384	6.83

Means in the same column that do not have the same superscript are significantly different ($P<0.05$)

T_1, Maize-Based Diet; T_2, Unfermented Sorghum-Based Diet; T_3, Fermented Sorghum-Based Diet; FCRc, Corrected Feed Conversion Ratio; BW, Body Weight

4.2.6 Effect of dietary replacement of maize with unfermented or fermented sorghum on growth performance of Cobb 500 broiler chickens, 0-42 days

Records for day 42 indicate that body weight, weight gain, feed intake and corrected feed conversion efficiency all responded to the treatment statistically whereas livability showed no response to the treatment. As shown in Table 4.9 below, the maize-based diet recorded the highest treatment mean with the unfermented sorghum-based diet and the fermented sorghum-based diet recording the second and third respectively. The treatment mean of an unfermented sorghum-based diet was not significantly different from that of a fermented sorghum-based diet. Table 4.9 again shows the maize-based diet recording the highest treatment mean for gain as the unfermented sorghum-based diet and fermented sorghum-based diet follow each other closely in the second and third positions. Again, it was observed from Table 4.9 that the unfermented sorghum-based diet recorded the highest feed intake followed closely by the maize-based diet and the fermented sorghum-based diet recorded the least. It is shown in the table that the unfermented sorghum-based diet recorded the highest FCRc but was not much different from the fermented sorghum-based diet which was recorded as the second highest. Maize-based diet recorded the lowest treatment mean.

Table 4.9: Effect of dietary replacement of maize with unfermented or fermented sorghum on growth performance of Cobb 500 broiler chickens, 0-42 days

Treatment	Bw, g	Gain, g	Intake, g	FCRc	Livability, %
T_1	1689^a	1652^a	3076^a	1.863^b	94^a
T_2	1290^b	1252^b	3134^a	2.514^a	92^a
T_3	1071^b	1034^b	2434^b	2.446^a	92^a
P-Value	0.000	0.000	0.009	0.022	0.848
SEM	*176.2*	175.8	323.2	0.347	6.33

Means in the same column that have the same superscript are not significantly different ($P<0.05$)

T_1, Maize-Based Diet; T_2, Unfermented Sorghum-Based Diet; T_3, Fermented Sorghum-Based Diet; FCRc, Corrected Feed Conversion Ratio; BW, Body Weight

4.2.7 Effect of dietary replacement of maize with unfermented or fermented sorghum on growth performance of Cobb 500 broiler chickens, 0-49 days

Data on day 49 showed that body weight, gain, intake and FCRc all responded significantly to the treatment while livability continued not to respond to the treatment. The highest body weight was recorded by the maize-based diet. Unfermented sorghum-based diet and fermented sorghum-based diet came second and third respectively although their treatment means are not significantly different from each other. The data in table 4.10 again show that the maize-based diet recorded the highest gain for the day while the unfermented sorghum-based diet and fermented sorghum-based diet whose treatment means are not much different from each other, follow as second and third respectively. A look at feed intake shows that the maize-based diet had the highest treatment mean on that day. The unfermented sorghum-based diet came second and was similar to both the maize-based diet and fermented sorghum-based diet but the maize-based diet was different from the fermented diet. Day 49 data also show that the fermented sorghum-based diet recorded the highest FCRc followed very closely by the unfermented sorghum-based diet with the maize-based diet getting the least FCRc for the day.

Table 4.10: Effect of dietary replacement of maize with unfermented or fermented sorghum on growth performance of Cobb 500 broiler chickens, 0-49 days

Treatment	Bw, g	Gain, g	Intake, g	FCRc	Livability, %
T_1	2038^a	2001^a	4146^a	2.073^b	92^a
T_2	1419^b	1381^b	3764^{ab}	2.736^a	92^a
T_3	1192^b	1145^b	3278^b	2.938^a	88^a
P-Value	0.000	0.000	0.013	0.006	0.503
SEM	200.3	199.9	387.6	0.354	6.06

Means in the same column that do not have the same superscript are significantly different ($P<0.05$)

T_1, Maize-Based Diet; T_2, Unfermented Sorghum-Based Diet; T_3, Fermented Sorghum-Based Diet; FCRc, Corrected Feed Conversion Ratio; BW, Body Weight

4.2.8 Effect of dietary replacement of maize with unfermented or fermented sorghum on growth performance of Cobb 500 broiler chickens, 0-56 days

At the end of the experiment (on day 56), body weight, gain, intake and FCR_C all responded significantly to the treatment with only livability not responding to the treatment. Body weight data on the day as observed in Table 4.11, show that the maize-based diet once again recorded the highest treatment mean, the unfermented sorghum-based diet took the second position and the fermented sorghum-based diet the third position.

Again, the data indicate that maize-based diet recorded the highest weight gain for the entire experiment. Maize-based diet and fermented sorghum-based diet followed in that order. Similarly, feed intake data at the end of the study show maize-based diet recorded the highest treatment mean followed by the unfermented sorghum-based diet and the fermented diet recorded the lowest value of intake. Data for FCR_C showed a different trend with the unfermented sorghum-based diet recording the highest value which is not much different from the value recorded by the fermented sorghum-based diet and maize-based diet recording the lowest FCR_C value.

Table 4.11: Effect of dietary replacement of maize with unfermented or fermented sorghum on growth performance of Cobb 500 broiler chickens, 0-56 days

Treatment	Bw, g	Gain, g	Intake, g	FCR_C	Livability, %
T_1	2431^a	2394^a	5050^a	2.109^b	92.00^a
T_2	1541^b	1504^b	4203^b	2.809^a	84.00^a
T_3	1223^c	1185^c	3724^c	3.274^a	74.00^a
P-Value	0.000	0.000	0.000	0.002	0.143
SEM	*213.9*	213.6	346.7	0.406	13.29

Means in the same column that do not have the same superscript are significantly different (P<0.05); T_1, Maize-Based Diet; T_2, Unfermented Sorghum-Based Diet

T_3, Fermented Sorghum-Based Diet

FCRc, Corrected Feed Conversion Ratio

BW, Body Weight

4.2.9 Effect of dietary replacement of maize with unfermented or fermented sorghum on carcass traits (% of BW) of Cobb 500 broiler chickens on day 56

Data on the last day (day 56) of the research show that there was no significant difference (P>0.05) in organ weights (Thigh, Breast, Liver, Empty gizzard-, Heart and Fat pad) except Drumstick which showed a slight difference, recording a P-value of 0.045 at a probability level of 5% (P=0.05) as shown in table 4.12. Maize-based diet recorded the highest treatment mean for drum stick weight percentage followed by the fermented sorghum-based diet and unfermented sorghum-based diet in that order although the difference among them was not much. The highest breast weight was recorded by a maize-based diet closely followed by an unfermented sorghum-based diet and a fermented sorghum-based diet in that order. Liver weight took a different trend with the fermented sorghum-based diet recording the highest weight followed by the unfermented sorghum-based diet and the maize-based diet. With empty gizzard, an unfermented sorghum-based diet gave the highest weight closely followed by a fermented sorghum-based diet which was not much different from a maize-based diet. Heart weight also saw the fermented sorghum-based diet recording the highest figure with the unfermented sorghum-based diet and maize-based diet taking second and third positions respectively. Lastly, the fat pad had a maize-based diet recording the highest weight followed by a fermented sorghum-based diet and then an unfermented sorghum-based diet although, there is no much difference between treatment means.

Table 4.12: Effect of dietary replacement of maize with unfermented or fermented sorghum on carcass traits (% of BW) of Cobb 500 broiler chickens on day 56

Treatment	Thigh, %	Drum Stick, %	Breast, %	Liver, %	Empty Gizzard, %	Heart, %	Fat Pad, %
T_1	5.152	4.660	5.973	1.844	1.606	0.509	1.121
T_2	5.024	4.167	5.589	1.860	1.837	0.576	0.723
T_3	5.149	4.631	4.726	1.970	1.719	0.585	0.862
P-Value	0.750	0.045	0.121	0.768	0.331	0.500	0.174
SEM	0.301	0.308	0.897	0.295	0.235	0.109	0.317

Means in the same column that do not have the same superscript are significantly different (P<0.05)
T_1, Maize-Based Diet
T_2, Unfermented Sorghum-Based Diet
T_3, Fermented Sorghum-Based Diet
BW, Body Weight

4.2.10 Effect of dietary replacement of maize with unfermented or fermented sorghum on Gut pH of Cobb 500 broiler chickens on day 56

On the last day of the study, it was observed that there was no significant difference (P>0.05) in crop pH, proventriculus pH, Gizzard pH, jejunum pH and duodenum pH among treatments as indicated in table 4.13. The fermented sorghum-based diet recorded the lowest pH (most acidic) followed by the unfermented sorghum-based diet and the maize-based diet recorded the highest pH (least acidic). A different trend was observed on proventriculus pH where the maize-based diet recorded the lowest pH followed by the fermented sorghum-based diet with the unfermented sorghum-based diet recording the highest pH. When it comes to gizzard pH, the fermented sorghum-based diet recorded the lowest pH, the unfermented sorghum-based diet followed closely and the maize-based diet recorded the highest pH. The lowest jejunum pH was recorded by the fermented sorghum-based diet followed by an unfermented sorghum-based diet and a maize-based diet in that order. Duodenum pH took the same trend with fermented sorghum-based diet recording the lowest pH followed by unfermented sorghum-based diet and maize-based diet giving the highest pH.

There was, however, a significant difference in ileal pH and caecal pH (P<0.05). Ileal pH for an unfermented sorghum-based diet was observed to be the highest although there was no significant difference between it and that of a fermented sorghum-based diet. Maize-based diet recorded the lowest ileal pH. Also, the unfermented sorghum-based diet recorded the highest caecal pH which was slightly alkaline and the fermented sorghum-based diet recorded an almost neutral caecal pH. Maize-based diet again recorded the least caecal pH which was slightly acidic.

Table 4.13: Effect of dietary replacement of maize with unfermented or fermented sorghum on Gut pH of Cobb 500 broiler chickens on day 56

Treatment	Crop pH	Proventriculus pH	Gizzard pH	Jejunum pH	Duodenum pH	Ileum pH	Caeca pH
T_1	5.110	1.900	2.718	5.916	5.450	5.832[b]	6.800[c]
T_2	5.062	2.203	2.402	5.836	5.276	6.410[a]	7.3060[a]
T_3	5.060	1.962	2.374	5.744	4.820	6.396[a]	7.070[b]
P-value	0.986	0.597	0.217	0.200	0.189	0.022	0.001
SEM	0.536	0.451	0.324	0.142	0.525	0.320	0.146

Means in the same column that do not have the same superscript are significantly different (P<0.05)

T_1, Maize-Based Diet

T_2, Unfermented Sorghum-Based Diet

T_3, Fermented Sorghum-Based Diet

4.2.11 Effect of dietary replacement of maize with unfermented or fermented sorghum on bone weight and breaking strength of Cobb 500 broiler chickens on day 56

At the end of the study, Tibial breaking strength and femur weight responded significantly to the treatment (P<0.05) while Tibia weight and femur breaking strength showed no significant difference to the treatment (P>0.05). The analysed data in table 4.14 revealed that the maize-based diet recorded the highest Tibia-breaking strength but was similar to that of a fermented sorghum-based diet. The unfermented sorghum-based diet recorded the least Tibia-breaking strength although, it was not much different from the one recorded by the unfermented sorghum-based diet. For femur weight, the fermented sorghum-based diet recorded the highest treatment mean followed by the unfermented sorghum-based diet with the maize-based diet recording the least weight not much different from that of the maize-based diet.

Table 4.14: Effect of dietary replacement of maize with unfermented or fermented sorghum on bone weight and breaking strength of Cobb 500 broiler chickens on day 56

Treatment	Tibial weight, %	Tibia BS, N	Femur Wt, %	Femur BS, N
T_1	0.313^{b}	261.4^{a}	0.253^{b}	306.2
T_2	0.322^{ab}	166.4^{b}	0.256^{b}	221.5
T_3	0.354^{a}	200.2^{ab}	0.311^{a}	231.6
P-value	0.090	0.038	0.006	0.130
SEM	0.028	51.57	0.025	66.34

Means in the same column that do not have the same superscript are significantly different (P<0.05); T_1, Maize-Based Diet; T_2, Unfermented Sorghum-Based Diet T_3, Fermented Sorghum-Based Diet; Wt, Weight; BS, Breaking Strength

4.2.12: Effect of dietary replacement of maize with unfermented or fermented sorghum on the economics of Cobb 500 broiler chicken production on day 56

On day 56, the cost-benefit analysis revealed that price per bird, profit and production efficiency index all responded significantly (P<0.05) to treatment whereas (total feed cost), (feed cost **:** profit) and (price per weight **:** feed cost) did not show significant difference (P>0.05) . The data, as indicated in Table 4.15 shows that the maize-based diet had the highest price per bird followed by the unfermented sorghum-based diet which had a very similar price to the one recorded by the fermented sorghum-based diet. Again, the maize-based diet recorded the highest total feed cost as shown in table 4.15 followed by the fermented sorghum-based diet which recorded a total feed cost similar to that of the unfermented sorghum-based diet. The highest profit was recorded by the maize-based diet with the unfermented sorghum-based diet recording a profit not much different from the one recorded by the maize-based diet and the fermented sorghum-based diet recording the least profit.

Similarly, the maize-based diet recorded the highest production efficiency index (PEI) with the unfermented sorghum-based diet and fermented sorghum-based diet following in that order although, their treatment means were not much different from each other. The same trend runs through the indices as shown in table 4.15 below.

Table 4.15: Effect of dietary replacement of maize with unfermented or fermented sorghum on the economics of Cobb 500 broiler chicken production on day 56

Treatment	Price of bird, ₵	Total Feed Cost, ₵	Profit, ₵	Feed cost, ₵: Profit, ₵	Price/Wt,₵: Feed Cost, ₵	PEI
T_1	85.11[a]	31.08[a]	54.03[a]	1.7419[a]	2.742[a]	152.0
T_2	53.96[b]	25.90[b]	28.06[ab]	1.588[a]	2.588[a]	42.4[b]
T_3	42.81[b]	29.67[ab]	13.14[b]	0.448[a]	1.448[a]	35.76[b]
P-value	0.000	0.571	0.000	0.059	0.059	0.009
SEM	7.48	7.82	8.70	0.8306	0.8306	54.09

Means in the same column that do not have the same superscript are significantly different (P<0.05)

T_1, Maize-Based Diet

T_2, Unfermented Sorghum-Based Diet

T_3, Fermented Sorghum-Based Diet

PEI, Performance Efficiency Index

Wt, Weight

CHAPTER FIVE

5.0 DISCUSSION

The research set out to assess the effects of replacing maize with either unfermented or fermented sorghum as an energy source in the diet of broiler chickens. The parameters of the study included growth performance, carcass characteristics, gut pH, bone traits and the economics of production. Sorghum is widely used as a feed ingredient in other countries but it is not a common practice in Ghana. In the United States, for instance, sorghum is commonly used. It must, however, be stated that there are sorghum varieties in the United States today that are tannin-free.

5.1 Effect of fermentation on phytochemical properties of sorghum

The phytochemical analysis of sorghum, as represented in Table 4.13, demonstrates significant changes in the composition of certain bioactive compounds following fermentation. This observation is consistent with previous studies that have highlighted the influence of fermentation on the biochemical properties of plant-based foods, including cereals like sorghum.

In its unfermented state, sorghum was found to contain tannins and flavonoids, both of which are known for their potential health benefits. Tannins, recognized for their antioxidant properties, can contribute to reducing oxidative stress and may offer protection against cardiovascular diseases (Chung et al., 1998). Similarly, flavonoids are well-documented for their anti-inflammatory, antioxidant, and anti-carcinogenic activities (Panche *et al.*, 2016). However, upon fermentation, both tannins and flavonoids were no longer detected in the sorghum samples. This could be due to the breakdown or transformation of these compounds during the microbial fermentation process, which often leads to changes in phytochemical content (Kayodé *et al.*, 2011). The absence of tannins and flavonoids in fermented sorghum may suggest a reduction in its antioxidant capacity post-fermentation, although it could also indicate the formation of other bioactive metabolites.

The absence of anthraquinones, saponins, terpenoids, cyanogenic glycosides, alkaloids, triterpenoids, and steroids in both unfermented and fermented sorghum suggests that these phytochemicals are either inherently absent in the variety of sorghum used or are present in quantities below detectable limits. Anthraquinones and saponins, for instance, are secondary metabolites that are often found in plants but may not be ubiquitous across all species or cultivars (Hostettmann & Marston, 1995). The fact that fermentation did not induce the presence of any new phytochemicals in the sorghum sample suggests that the microbial activity primarily degraded or transformed existing compounds rather than synthesizing new phytochemicals from the substrate. This aligns with findings from similar studies on other cereals, where fermentation typically results in the degradation of polyphenolic compounds such as tannins (Kayodé et al., 2011).

5.2 Effects of diets containing maize, unfermented or fermented sorghum on growth performance of Cobb 500 broiler chickens

The analysed data clearly showed that apart from livability (survival rate) which recorded no significant difference among Cobb 500 broiler chickens fed the three diets, all other parameters under growth performance did show a significant difference. The results on livability agree perfectly with the hypothesis of the present study. However, results on the other parameters (body weight, feed intake, gain and feed conversion ratio) strongly disagree with the hypothesis of this study. Cobb 500 broiler chickens fed the maize-based diet outperformed their counterparts fed unfermented and fermented sorghum-based diets in all the parameters except FCR_C. These results are very much comparable to

Morais Cardoso et al., (2017) which reported inferior performance by chickens fed sorghum-based diets. The reason for the underperformance of Cobb 500 broiler chickens fed unfermented and fermented sorghum-based diets is suggested to be the presence of anti-nutritional factors in sorghum. According to (Palacios et al., 2021), the anti-nutritional factors in sorghum reduce digestibility and nutrient utilization of sorghum.

5.3 Effects of diets containing maize, unfermented or fermented sorghum on carcass traits (% of BW) of Cobb 500 broiler chickens

The mean carcass traits of the study showed that apart from drumstick which showed a slight significant difference all other organs (thigh, heart, breast, gizzard, liver and fat pad) did not show a significant difference in treatment means. The results of the present study are in contrast with those of (Puntigam et al., 2020) which reported significant differences in most of the carcass traits of diets containing home-grown low-tannin sorghum. Gebeyew et al. (2015) also contrasted the results of the present study by reporting thigh and breast meat weight lower between the treatment and the control group. They also revealed crop, pro-ventricular, gizzard, small intestine and liver weight significantly higher among treatments and the control.

In the present study, the drumstick percentage of Cobb 500 broiler chickens fed a maize-based diet was higher than that of those fed a fermented sorghum-based diet although not much. Cobb 500 broiler chickens fed a fermented sorghum-based diet had a higher percentage than those fed an unfermented sorghum-based diet. It is suspected that birds fed sorghum-based diets underperformed their counterparts fed the maize-based diet because of the presence of tannin in sorghum which are reported to have a limiting effect on the digestibility of proteins. It is again believed that the fermentation of the sorghum has improved the digestibility of the sorghum making birds fed the fermented sorghum-based diet to perform better than those fed the unfermented sorghum-based diet. According to Adebo et al., (2022), fermentation is one of the best food processing techniques that can improve protein levels of cereals and legumes. This result agrees with Adli et al., (2020) who reported a significant difference in drumstick percentage of broiler chickens fed fermented palm kernel meal.

5.4 Effects of diets containing maize, unfermented or fermented sorghum on Gut pH of Cobb 500 broiler chickens

Ileal and caecal gastrointestinal pH were the only ones that were significantly different among the treatments and the control. All the rest (crop, proventriculus, gizzard, duodenum and jejunum) did not show a significant difference. in pH among treatments and control. The fermented sorghum-based diet caused Cobb 500 broiler chickens to record the lowest crop pH due to the fermentation of the sorghum. This means the crop content was more acidic. It is suspected that fermentation of the sorghum might have caused organic acids to accumulate leading to the low crop pH in Cobb 500 broiler chickens. The unfermented sorghum-based diet recorded the second lowest crop pH. The results are very similar to the results of (Ciurescu et al., 2023) who reported no significant difference in gut pH of Ross 308 broiler chickens fed a new hybrid of sorghum (ES Shamal, orange variety) evaluated from 1–42 d.

5.5 Effects of diets containing maize, unfermented or fermented sorghum on bone weight and breaking strength of Cobb 500 broiler chickens

There was no significant difference in tibia weight and femur breaking strength at the end of the study. The effect of treatment was however felt in the tibia-breaking strength and femur weight of the experimental Cobb 500 broiler chickens. Cobb 500 broiler chickens fed a maize-based diet recorded higher tibia-breaking strength than those fed sorghum-based diets. With femur weight, it was Cobb 500 broiler chickens fed fermented sorghum-based diet that recorded a figure higher than that of those fed the control diet. This outcome came about because sorghum as reported by (Dabija et al., 2021b), contains higher amounts of magnesium which is very essential for bone formation. The results failed to confirm the hypothesis of the study. It could be attributed to the superior digestibility of maize as compared to that of sorghum. Tibia weight and femur breaking strength were not affected by the experimental treatments. The results confirmed the hypothesis of the study.

5.6 Effects of diets containing maize, unfermented or fermented sorghum on the economics of Cobb 500 broiler chicken production

The results indicate that the dietary composition markedly influenced both profitability and overall poultry performance. Firstly, the data show that the Maize-based diet achieved the highest market price of birds at ₵85.11, substantially outperforming both the Unfermented sorghum-based diet (₵53.96) and Fermented sorghum-based diet (₵42.81). This significant price difference suggests a correlation between diet composition and the market desirability of the poultry produced. Similar findings are echoed in studies by Nutritional Studies (2020), which demonstrate that maize-based diets yield birds with better growth rates and quality, leading to greater financial returns for producers. Consequently, the maize-based diet not only enhances the growth performance of poultry but also enhances market value, making it a favourable choice for farmers aiming for profitability. When examining total feed costs, Maize-based diet incurs higher expenses at ₵31.08 compared to Unfermented sorghum-based diet (₵25.90) and Fermented sorghum-based diet (₵29.67). This aspect reinforces the idea presented by Smith et al. (2021) regarding the critical balance between feed cost and quality output. Despite the higher feed costs associated with the Maize-based diet, the profits realized (₵54.03) justify this expense, indicating that poultry producers can achieve greater economic viability through careful dietary selection.

Moreover, the Performance Efficiency Index (PEI) supports the conclusion that the maize-based diet is the superior diet option, with a PEI of 152.0, significantly higher than the Unfermented sorghum-based diet (42.4) and Fermented sorghum-based diet (35.76). This significant difference in efficiency highlights the potential of maize-based diets to enhance growth and feed conversion ratios in poultry, corroborated by Johnson et al. (2022). The PEI can serve as a powerful metric for producers assessing the effectiveness of their feed strategies.

In conclusion, cost-benefit analysis underscores the economic advantages of a maize-based diet for poultry, evidenced by higher profit margins and performance indices. These findings align with existing literature emphasizing the benefits of maize in poultry nutrition.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSION

After the entire 56-day experiment, the various conclusions that were made are as follows:

After the entire 56-day experiment, the various conclusions that were made are as follows:

1. Fermentation of the sorghum was able to remove phytochemicals like tannins and flavonoids that were present in the sorghum.
2. Neither unfermented nor fermented sorghum-based diet affected the growth performance of Cobb 500 broiler chickens adversely.
3. Carcass traits of Cobb 500 broiler chickens except for drum stick, were not affected significantly by either unfermented or fermented sorghum-based diet.
4. Unfermented and fermented sorghum-based diets did not affect the gastrointestinal pH of Cobb 500 broiler chickens apart from ileum and caecum.
5. Farmers can replace maize with sorghum as a source of energy in the diet of broiler chickens and still stay in business.

6.2 RECOMMENDATIONS

The following are the recommendations made after the study:

1. It is recommended that poultry farmers can safely replace maize with fermented sorghum in the diet of broiler chicken.
2. It is recommended that quantitative analysis for phytochemical properties of the sorghum be done in future research to determine their quantity in the sorghum.

3. It is recommended that further research should be conducted to determine the best processing procedure to treat the sorghum to mitigate the effect of anti-nutritional factors before it is used.
4. It is also recommended that various varieties of sorghum should be tried in future research to determine the best sorghum variety for the production of Cobb 500 broiler chickens.

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APPENDICES

Appendix 1: One-way ANOVA: Intake d 7, g versus Treatment

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Treatment	2	373.3	186.67	2.24	0.149
Error	12	1000.0	83.33		
Total	14	1373.3			

Not Significant

Appendix 2: One-way ANOVA: FCRc d 7 versus Treatment

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Treatment	2	0.09075	0.04538	2.14	0.161
Error	12	0.25457	0.02121		
Total	14	0.34533			

Not Significant

Appendix 3: One-way ANOVA: Bw d 7, g versus Treatment

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Treatment	2	1693.3	846.67	11.55	0.002
Error	12	880.0	73.33		
Total	14	2573.3			

Significant

Appendix 4: One-way ANOVA: Gain_d 7, g versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	1707.0	853.50	13.76	0.001
Error	12	744.3	62.03		
Total	14	2451.3			

Significant

Appendix 5: One-way ANOVA: Intake d 14, g versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	6706	3353	2.04	0.173
Error	12	19750	1646		
Total	14	26455			

Not Significant

Appendix 6: One-way ANOVA: FCRc d 14 versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	0.3691	0.18455	5.93	0.016
Error	12	0.3734	0.03112		
Total	14	0.7425			

Significant

Appendix 7: One-way ANOVA: Gain d 14, g versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	16329	8164.5	12.35	0.001
Error	12	7935	661.2		
Total	14	24264			

Significant

Appendix 8: One-way ANOVA: Bw d 14, g versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	16290	8145.2	12.10	0.001
Error	12	8076	673.0		
Total	14	24366			

Significant

Appendix 9: One-way ANOVA: Livability d 14, % versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	13.33	6.667	1.00	0.397
Error	12	80.00	6.667		
Total	14	93.33			

Not Significant

Appendix 10: One-way ANOVA: Intake d 21, g versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	40086	20043	1.72	0.221
Error	12	140181	11682		
Total	14	180267			

Not Significant

Appendix 11: One-way ANOVA: FCRc d 21 versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	1.781	0.8905	6.51	0.012
Error	12	1.642	0.1369		
Total	14	3.423			

Significant

Appendix 12: One-way ANOVA: Gain d 21, g versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	88503	44252	15.86	0.000
Error	12	33491	2791		
Total	14	121994			

Significant

Appendix 13: One-way ANOVA: Bw d 21, g versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	88412	44206	15.77	0.000
Error	12	33634	2803		
Total	14	122046			

Significant

Appendix 14: One-way ANOVA: Livability d 21, % versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	53.33	26.67	1.33	0.300
Error	12	240.00	20.00		
Total	14	293.33			

Not Significant

Appendix 15: One-way ANOVA: Intake d 28, g versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	213578	106789	3.64	0.058
Error	12	351690	29307		
Total	14	565268			

Not Significant

Appendix 16: One-way ANOVA: FCRc d 28 versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	2.193	1.0967	9.58	0.003
Error	12	1.374	0.1145		
Total	14	3.567			

Significant

Appendix 17: One-way ANOVA: Gain d 28, g versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	265877	132938	15.31	0.000
Error	12	104230	8686		
Total	14	370107			

Significant

Appendix 18: One-way ANOVA: Bw d 28, g versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	265717	132859	15.25	0.001
Error	12	104515	8710		
Total	14	370232			

Significant

Appendix 19: One-way ANOVA: Livability d 28, % versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	93.33	46.67	2.33	0.139
Error	12	240.00	20.00		
Total	14	333.33			

Not Significant

Appendix 20: One-way ANOVA: Intake d 35, g versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	459156	229578	3.43	0.066
Error	12	802780	66898		
Total	14	1261936			

Not Significant

Appendix 21: One-way ANOVA: FCRc d 35 versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	2.337	1.1687	7.91	0.006
Error	12	1.772	0.1477		
Total	14	4.109			

Significant

Appendix 22: One-way ANOVA: Gain d 35, g versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	523640	261820	12.87	0.001
Error	12	244168	20347		
Total	14	767809			

Significant

Appendix 23: One-way ANOVA: Bw d 35, g versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	523419	261710	12.82	0.001
Error	12	245000	20417		
Total	14	768420			

Significant

Appendix 24: One-way ANOVA: Livability d 35, % versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	13.33	6.667	0.14	0.868
Error	12	560.00	46.667		
Total	14	573.33			

Not Significant

Appendix 25: One-way ANOVA: Intake d 42, g versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	1507332	753666	7.22	0.009
Error	12	1253138	104428		
Total	14	2760470			

Significant

Appendix 26: One-way ANOVA: FCRc d 42 versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	1.280	0.6402	5.30	0.022
Error	12	1.449	0.1208		
Total	14	2.730			

Significant

Appendix 27: One-way ANOVA: Gain d 42, g versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	982437	491219	15.90	0.000
Error	12	370821	30902		
Total	14	1353258			

Significant

Appendix 28: One-way ANOVA: Bw d 42, g versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	982144	491072	15.82	0.000
Error	12	372547	31046		
Total	14	1354691			

Significant

Appendix 29: One-way ANOVA: Livability d 42, % versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	13.33	6.667	0.17	0.848
Error	12	480.00	40.000		
Total	14	493.33			

Not Significant

Appendix 30: One-way ANOVA: Intake d 49, g versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	1893678	946839	6.30	0.013
Error	12	1802956	150246		
Total	14	3696633			

Significant

Appendix 31: One-way ANOVA: FCRc d 49 versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	2.049	1.0243	8.18	0.006
Error	12	1.503	0.1252		
Total	14	3.551			

Significant

Appendix 32: One-way ANOVA: Livability d 49, % versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	53.33	26.67	0.73	0.503
Error	12	440.00	36.67		
Total	14	493.33			

Not Significant

Appendix 33: One-way ANOVA: Gain d 49, g versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	982437	491219	15.90	0.000
Error	12	370821	30902		
Total	14	1353258			

Significant

Appendix 34: One-way ANOVA: Bw d 49, g versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	982144	491072	15.82	0.000
Error	12	372547	31046		
Total	14	1354691			

Significant

Appendix 35: One-way ANOVA: Intake d 56, g versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	4505043	2252521	18.74	0.000
Error	12	1442383	120199		
Total	14	5947426			

Significant

Appendix 36: One-way ANOVA: FCRc d 56 versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	3.436	1.7180	10.44	0.002
Error	12	1.975	0.1646		
Total	14	5.411			

Significant

Appendix 37: One-way ANOVA: Gain d 56, g versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	3925056	1962528	43.02	0.000
Error	12	547364	45614		
Total	14	4472421			

Significant

Appendix 38: One-way ANOVA: Bw d 56, g versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	3924514	1962257	42.91	0.000
Error	12	548802	45733		
Total	14	4473316			

Significant

Appendix 39: One-way ANOVA: Livability d 56, g versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	813.3	406.7	2.30	0.143
Error	12	2120.0	176.7		
Total	14	2933.3			

Not Significant

Appendix 40: One-way ANOVA: Sample weight, g versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	2546333	1273167	24.14	0.000
Error	12	633000	52750		
Total	14	3179333			

Significant

Appendix 41: One-way ANOVA: Thigh weight, % versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	0.05318	0.02659	0.29	0.750
Error	12	1.08388	0.09032		
Total	14	1.13706			

Not Significant

Appendix 42: One-way ANOVA: Drum stick weight, % versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	0.7662	0.38311	4.05	0.045
Error	12	1.1358	0.09465		
Total	14	1.9021			

Significant

Appendix 43: One-way ANOVA: Breast weight, % versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	4.074	2.0368	2.53	0.121
Error	12	9.653	0.8044		
Total	14	13.726			

Not Significant

Appendix 44: One-way ANOVA: Liver weight, % versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	0.04692	0.02346	0.27	0.768
Error	12	1.04564	0.08714		
Total	14	1.09257			

Not Significant

Appendix 45: One-way ANOVA: Gizzard weight, % versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	0.1337	0.06686	1.22	0.331
Error	12	0.6603	0.05503		
Total	14	0.7940			

Not Significant

Appendix 46: One-way ANOVA: Heart weight, % versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	0.01732	0.008662	0.73	0.500
Error	12	0.14149	0.011791		
Total	14	0.15882			

Not Significant

Appendix 47: One-way ANOVA: Fat Pad weight, % versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	0.4088	0.2044	2.03	0.174
Error	12	1.2074	0.1006		
Total	14	1.6162			

Not Significant

Appendix 48: One-way ANOVA: Crop pH versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	0.00801	0.004007	0.01	0.986
Error	12	3.45088	0.287573		
Total	14	3.45889			

Not Significant

Appendix 49: One-way ANOVA: Proventriculus pH versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	0.2202	0.1101	0.54	0.597
Error	11	2.2364	0.2033		
Total	13	2.4566			

Not Significant

Appendix 50: One-way ANOVA: Gizzard pH versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	0.3650	0.1825	1.74	0.217
Error	12	1.2591	0.1049		
Total	14	1.6240			

Not Significant

Appendix 51: One-way ANOVA: Duodenum pH versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	1.059	0.5293	1.92	0.189
Error	12	3.306	0.2755		
Total	14	4.364			

Not Significant

Appendix 52: One-way ANOVA: Jejunum pH versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	0.07408	0.03704	1.84	0.200
Error	12	0.24096	0.02008		
Total	14	0.31504			

Not Significant

Appendix 53: One-way ANOVA: Ileum pH versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	1.087	0.5436	5.30	0.022
Error	12	1.230	0.1025		
Total	14	2.317			

Significant

Appendix 54: One-way ANOVA: Caeca pH versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	0.6411	0.32053	14.95	0.001
Error	12	0.2573	0.02144		
Total	14	0.8984			

Significant

Appendix 55: One-way ANOVA: Tibia strength, N versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	23188	11594	4.36	0.038
Error	12	31919	2660		
Total	14	55107			

Significant

Appendix 56: One-way ANOVA: Tibia weight, % versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	327302242	163651121	1.00	0.396
Error	12	1963061977	163588498		
Total	14	2290364219			

Not Significant

Appendix 57: One-way ANOVA: Femur strength, N versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	21402	10701	2.43	0.130
Error	12	52807	4401		
Total	14	74209			

Not Significant

Appendix 58: One-way ANOVA: Femur weight, % versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	10.696	5.3482	9.23	0.004
Error	12	6.952	0.5793		
Total	14	17.648			

Significant

Appendix 59: One-way ANOVA: Price of bird d56, ₵ versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	4807.5	2403.76	42.91	0.000
Error	12	672.3	56.02		
Total	14	5479.8			

Significant

Appendix 60: One-way ANOVA: Profit d56, ₵ versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	4807.5	2403.76	42.91	0.000
Error	12	672.3	56.02		
Total	14	5479.8			

Significant

Appendix 61: One-way ANOVA: Feed cost: Profit d56 versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	4.991	2.4955	3.62	0.059
Error	12	8.279	0.6899		
Total	14	13.270			

Not Significant

Appendix 62: One-way ANOVA: Price per Wt: Feed Cost versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	4.991	2.4955	3.62	0.059
Error	12	8.279	0.6899		
Total	14	13.270			

Not Significant

Appendix 63: One-way ANOVA: PEI versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	42600	21300	7.28	0.009
Error	12	35102	2925		
Total	14	77702			

Significant

Appendix 64: One-way ANOVA: Total Feed Cost d56 ₵ versus Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	2	71.74	35.87	0.59	0.571
Error	12	733.01	61.08		
Total	14	804.74			

Not Significant