AKENTEN APPIAH-MENKA UNIVERSITY OF SKILLS TRAINING AND ENTREPRENEURIAL DEVELOPMENT
MAMPONG- ASHANTI

IMPACT OF DIETARY FULL FAT, SOLVENT EXTRACTED SOYBEAN AND UNREFINED SOYBEAN OIL ON THE GROWTH PERFORMANCE, GUT pH, CARCASS AND BONE TRAITS OF BROILER CHICKENS

MATHEW TIMULA KUNDE

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BY

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DECLARATION

STUDENT'S DECLARATION

I, Mathew Timula Kunde, declare that this thesis, with the exception of quotations and references contained in published works which have all been identified and duly acknowledged, is entirely my own original work, and it has not been submitted, either in part or whole, for another degree elsewhere.

Mathew Timula Kunde (Student)

Signature………………………………

Date: ………/…………/………………….

SUPERVISOR'S DECLARATION

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

DR. Holy Kwabla Zanu (Supervisor)

Signature………………………………

Date: ………/…………/……………….

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DEDICATION

I dedicate this thesis to my parents, my beloved wife, Bananlen Bertha and my children.

TABLE OF CONTENTS

LIST OF TABLES

DEFINITIONS OF ABBREVIATION

ABBREVIATION	DEFINITION
ADFI	Average daily feed intake
ANFs	Anti-nutritional factors
BDM	Bone mineral density
BW	Body weight
CP	Crude protein
DM	Dry matter
EU	European Union
FCR	Feed conversion ratio
FFSB	Full fat soybean
ME	Metabolisable energy
NSP	Non-starch polysaccharides
PA	Phytic acid
SBM	Soybean meal
SCFA	Short chain fatty acid
USBO	Unrefined soybean oil

ABSTRACT

The study investigated the impact of dietary full-fat soybean (FFSB), heat-treated soybean (HTSB), and unrefined soybean oil (USO) on the growth performance, gut pH, carcass characteristics, and bone traits of broiler chickens. A total of 200 Cobb 500 broiler chicks were randomly assigned to four dietary treatments in a completely randomized design, with each treatment replicated five times. Performance indicators such as feed intake, body weight, body weight gain, and feed conversion ratio (FCR) were measured weekly. Gut pH was measured from digesta samples taken from the crop, proventriculus, gizzard, duodenum, jejunum, ileum, and caeca. Carcass yield and bone traits, including bone weight and breaking strength, were assessed at the end of the study. The results indicated that the dietary inclusion of soybean products significantly influenced growth performance, with the HTSB diet yielding the highest weight gain and better FCR ($P < 0.05$). Gut pH was significantly ($P <0.05$) lower in birds fed USO diets, particularly in the gizzard and ileum, may suggest enhanced enzymatic activity. Carcass yield was highest in birds fed FFSB, while HTSB-fed birds exhibited superior bone strength and weight ($P < 0.05$). The study showed that the inclusion of HTSB and FFSB in broiler diets improved growth performance, carcass traits, and bone health, while USO positively influenced gut pH. Birds fed heat-treated soybean diet (HTSB) did not only increase feed cost but also the production economic index. In place of soybean meal, heat-treated soybean diet (HTSB) is recommended to Ghanaian poultry farms for better growth performance of broilers.

Keywords: Full-fat soybean (FFSB), heat-treated soybean (HTSB), unrefined soybean oil (USO), bone health, gut pH, carcass traits of broiler chicks. The study started in January, 2024 and ended in March, 2024

CHAPTER ONE: INTRODUCTIONS

1.1 Background to the Study

Feeding is a fundamental aspect of intensive poultry production, accounting for about 70 % of total cost of production (Ravindran, 2013). Maize grain remains the main source of energy in commercial broiler chicken diets but the price of maize has increased significantly over time (Chrysta *et al.*, 2020). Maize constitutes about 50-60 % in most poultry diet and has a greater acceptance in poultry feeds (Panda *et al.*, 2010). Also, the price of maize is increasing continuously due to intense competition for its usage by man or other livestock species and industries (Panda *et al.*, 2010). Thus, it is imperative to search for suitable alternative sources of energy in poultry feeds to reduce the cost of production.

Several ingredients like cassava, sorghum and wheat bran have been identified as suitable to partially or completely replace maize in poultry diet in an attempt to cut down feed cost (Alade, 2018). Most of these ingredients that could replace maize contain antinutritional factors (ANFs) which might hinder the digestion and absorption of nutrients in chicken (Suhag *et al.,* 2012). Elsewhere, vegetable oils are added to chicken feed as a source of energy to reduce the quantity of maize in order to reduce the cost of feeding but in Ghana vegetable oil is not used in formulating chicken diets (Bigson *et al*., 2019; Debnath and Babu 2020).

Soybean is one of the locally produced protein sources in Ghana. The oil extracted from soyabean is used for domestic consumption and export (Ajao *et al*., 2022). However, through diet manipulation, full fat soyabean or its oil can be used to partially replace maize in commercial chicken diets (Pettersson and Pontoppidan, 2013). Soybean meal

(SBM) is the primary source of plant protein commonly used in poultry nutrition since its amino acid balance is appropriate for birds (Silva *et al.*, 2017). However, the use of raw SBM by monogastric animals is not totally efficient due to the presence of anti-nutritional factors (ANFs) (Cowieson and Roos 2016). To inactivate or remove ANFs in poultry diets, various heat procedures (extrusion, cooking, toasting and roasting) have been reported to be efficient in reducing trypsin inhibitor activity (TIA) and phytic acid (PA) in soybeans (Cowieson and Roos 2016). Silva *et al.* (2017) reported that cooking, autoclaving and microwaving are the most successful soybean heat procedures that may have an important role in removing these ANFs.

1.2 Problem Statement

Compared to other energy sources, the price of maize which is the main source of energy in chicken diet remains high (Dayarathna *et al*., 2021). Alternative ingredients have been identified either in a total or partial replacement for maize (Karlsson *et al*., 2021). In an attempt to reduce the cost of feeding, vegetable oils are added to chicken feed as a source of energy in order to reduce the quantity of maize but in Ghana vegetable oil is not used in formulating chicken diet (Debnath and Babu, 2020). The oil extracted from soybean is used for domestic consumption and export (Ajao *et al*., 2022). However, through diet manipulation, full fat soyabean or its oil can be used to partially replace maize in commercial chicken diets (Pettersson and Pontoppidan, 2013). Nonetheless, soybean contains ANFs which can reduce digestion and nutrient absorption (Erdaw *et al*., 2016). Several processing techniques including heat treatment have proven effective in removing the ANFs in the grain to improve the availability of amino acids for energy metabolism (Yadollahi *et al.*, 2015). But there is little information on how a heat-treated raw soybean and soybean oil could be used to partially reduce maize in chicken diet.

1.3 Objective of the Study

The main objective of the study was to investigate the usefulness of full-fat soybean (heat treated or untreated) or its oils (unrefined) on the general performance of broiler chickens.

1.3.1 Specific Objectives

The specific objectives of this study were to assess the usefulness of full-fat soybean (heat treated or untreated) or its oils (unrefined) on;

1. growth performance of broiler chickens,
2. gastrointestinal pH of broiler chickens,
3. bone dimension and bone breaking strength of broiler chickens,
4. carcass traits of broiler chickens,
5. cost-benefit analysis of the various feed.

CHAPTER TWO: LITERATURE REVIEW

2.1 Energy Requirement of Broiler Chickens

The energy contribution from poultry diets is usually described in terms of metabolizable energy (ME) and/or net energy (NE) (Musigwa *et al*., 2021). In commercial nutrition and in most research, ME is the standard measure of energy used in describing both energy requirements and diets for poultry (Noblet *et al*., 2022). ME can be accurately determined from the difference between the gross energy of the feed and the gross energy of the excreta derived from such feed (National Research Council, 1994). ME has been commonly accepted and extensively used to compare energy values of feedstuffs, and diets for poultry, and energy requirements are commonly expressed in these units (Wu *et al*., 2019). However, ME is rarely measured under commercial condition. NRC (2006) recommended 2800-3000 kcal/kg M.E for broiler starter diet and 3200 kcal/kg M.E for broiler finisher diet. Carbohydrates and fats are the major sources of energy in broiler nutrition. Sources of carbohydrates commonly used in poultry diets are starch, sugars, cellulose, and other non-starch compounds. Broiler chicken needs high-energy diet to support its rapid growth and metabolism (Maharjan *et al*., 2021). Thus, approximately 2 to 5 % oil is recommended in broiler chicken diets for optimal growth performance (Maharjan *et al*., 2021) Animal fat, soybean oil or their combinations are energy resources for diets of broiler chickens. Studies have indicated that energy metabolism of broiler chickens is enhanced by dietary animal-vegetable oil blends (A-V blend). Wu *et al*. (2019) reported that a diet with a combination of animal fat and vegetable oil could increase body weight (BW) gain and feed efficiency, as well as breast and drumstick yields, in birds compared with those birds fed with only animal fat or vegetable oil. A similar observation was made by Cera *et al*. (1990) and Abdel-Warith *et al*. (2001).

2.2 Sources of Energy for Poultry

2.2.1. Maize

Maize, scientifically known as *Zea mays* is one of the most versatile and emerging cereal crops having wider adaptability under varied agro-climatic conditions (Kumar and Jhariya, 2013). There are about 50 species, with a variety of colours, textures, and sizes and forms of grain. Red, yellow, and white are the most widely grown varieties of maize. Animal feed has made significant use of the white and yellow types, which are the most popular (Prasanna, 2012). Maize belongs to the family poaceae and is widely consumed as a staple food in many countries around the world (Shah *et al.,* 2016). In Ghana, it is considered the second most important staple food next to cassava (Murdia *et al.,* 2016). Maize is the main input in feed production for poultry. Andam *et al*. (2017) reported that over the past five years, Ghana's annual production averaged 1.8 million metric tons per year harvested from approximately 1.02 million hectares. Globally, maize is known as queen of cereals because it has the highest genetic yield potential among the cereals (Mwambo *et al.,* 2020).

According to Kumaravel and Natarajan (2014), maize constitutes about 50-60% in most poultry diets and has a greater acceptance in poultry feeds (Panda *et al*., 2010). But its production is not sufficient to meet the ever-increasing demand of poultry industry. Also, its price is increasing continuously due to intense competition for its usage by man or other livestock species (Agbede *et al*., 2002; Hamzat *et al*., 2003) and starch and allied industries (Egbunike and Achiobong, 2002). Maize is a conventional energy source and is, currently, the most widely used grain crop in the Ghanaian poultry industry because it provides the bulk of most poultry diets. In terms of total cost, energy is the most expensive item in poultry diets because of the amount required (Olomu, 1995). The nitrogen corrected true metabolizable energy (TMEn) of corn is 3350 kcal/kg compared to 3300 to 3450 kcal/kg for pearl millet (Prasad and Panwar, 1997). Thus, it is imperative to search for suitable alternative sources of energy in poultry feeds to reduce the cost of production.

Corn can provide up to 65 % metabolizable energy and 20 % protein in poultry diets due to its high dietary inclusion rate (Prasad and Panwar, 1997).

In Ghana, maize (both yellow and white) constitutes approximately 60 % of poultry feed formulations (Andam *et al.,* 2017). When feeding poultry, maize grains are either fed directly or ground and formulated with other suitable feed ingredients. The compounded feed thereafter fed to or transformed into the feed forms preferred by specific livestock species (Dei, 2017). The profitability and growth potential of the poultry industry in Ghana is significantly influenced by the availability and pricing of maize (Dela Cruz *et al.,* 2014). In order to reduce the cost of production and bolster the competitiveness of the local poultry industry, technological and innovative agronomic strategies need to be employed (Murdia *et al.,* 2016).

2.2.2 The significance of maize in the poultry industry

The preference for maize in poultry feed formulation stems from its accessibility (Shah *et al.,* 2016). About 60 % of poultry feed is made from maize, a vital raw material that has a higher calorific value, more amino acids, and fewer toxins than grains like broken rice and millet (Prandini *et al*., 2016; Andam *et al.,* 2017). For many decades, maize has been a staple food for people. However, in certain jurisdictions around the world, its direct food consumption has decreased over the past few decades due to a variety of factors, including changes in eating patterns and rising income levels (Kaul *et al.,* 2019). At the same time, maize has become more widely used in industrial applications and as feed for poultry. When utilized at 30 % or more in the diet, yellow kernelled cultivars of maize are preferred as poultry feed because they are a strong source of β-carotenes and xanthophylls that give the skin, poultry fat, and egg yolk their yellow colour (Kaul *et al.,* 2019). Feed production in the poultry industry is the largest end-user of all cultivated maize (Afolayan *et al.,*2015). Because of the increasing population and growing preference for higher protein intake from meat and eggs, there will likely be a greater need for and demand for maize farming. The relative cheap price and nutritional value of maize make it a more popular choice for poultry feed as compared to wheat and rice (Afolayan *et al.,*2015).

2.2.3 Maize as a major feed ingredient

The maize grain is the most significant in terms of poultry feed production or formulation. The other vegetative parts such as stalks, leaves, and young ears are used as forage or fodder for feeding ruminant livestock (Prandini *et al*., 2016). It is known that among the cereal grains, maize has the highest conversion rate of dry matter into animal products like meat, eggs and milk (Jain *et al.,* 2016). The primary source of calories for feeding cattle, pigs, and poultry is maize (Aardsma *et al.,* 2017). Maize is by far the most popular cereal grain in the diets of intensively grown chicken, accounting for about 65 %

of the metabolizable energy and 20 % of the protein in a broiler starter diet (Erdaw *et al.,* 2016). The belief that maize has a steady and high nutritional content is one factor contributing to its widespread use in the diets of farmed cattle. Nevertheless, research conducted by Schedle (2016) has shown that maize's nutritional content and chemical composition vary to a greater extent, which makes the generic matrix values for the grain unreliable. The amount of starch, oil, protein, and antinutrients in maize determines its nutritional value for poultry (Erdaw *et al.,* 2016).

In Ghana and numerous other countries, maize is considered an essential cereal grain for monogastric farm animals, where it constitutes between 50 % and 60 % of their diets (Manu *et al.,* 2015). It is the main constituent in the majority of pig and poultry diets. Maize is highly palatable, easy to digest, low in fibre, and high in energy. The two main drawbacks of the typical maize cultivars grown in Ghana and other countries are their low protein content (9–10%) and their deficiency in certain essential amino acids, especially tryptophan and lysine (Badu-Apraku and Fakorede, 2017). As a result, it is not a sufficient supply of protein for monogastric. Normal maize contains about 10 % protein, but monogastric animals, including humans, cannot consume this because it lacks two necessary amino acids, tryptophan and lysine (Humer and Schedle, 2015). To achieve a balanced nutrition in poultry production, it necessitates the use of highly rich protein supplements or synthetic amino acids such as lysine in poultry diets containing relatively large proportion of maize (Manu *et al.,* 2015).

2.2.4 Nutritional composition of maize grain

The nutritional composition of maize includes not only carbohydrates but also essential nutrients like amino acids, crude protein and phosphorus (Rouf Shah *et al*., 2016). It contains 7.5 %, 3.5 %, 1.9 %, 1.1 % and 3,373 kcal/kg of crude protein, crude fat, crude fibre, ash and metabolizable energy respectively (Rouf Shah *et al*., 2016). Several factors affect the nutritional composition and value of maize. Theses include but not limited to environmental conditions, post-harvest handling and genetic variability (Enyisi *et al.,* 2014). Environmental conditions such as edaphic quality, cultivation practices and climate influence nutrient content. Although maize can grow on varied soil types and conditions; however, the best soil type for producing maize with higher nutritional content is well managed loamy because it is rich in essential plant nutrients particularly potassium (K), nitrogen (N), sulfur (S), phosphorus (P) and zinc (Zn) which are necessary for the production of energy dense and protein rich maize (Enyisi *et al.,* 2014). Storage conditions and methods of processing are post-harvest handling that can affect the preservation of nutrients in maize. Genetically, different cultivars of maize have varying nutrient compositions. The quality protein maize varieties (Obaatanpa) have proportionally higher nutritional values as compared to the conventional maize varieties (Accra Local) (Prandini *et al.,* 2016; Badu-Apraku and Fakorede, 2017). In terms of crude protein content, the quality protein maize varieties (Obaatanpa) contain 9.5-10.5 % while conventional maize varieties (Accra Local) contain 8.6 -9.5 % (Mwambo *et al.,* 2020).

2.2.4.1 Energy content of maize grain

Maize has been recognized worldwide as a major energy feed ingredient in the diets of poultry due to its high carbohydrate content and palatability (Jain *et al.,* 2016). Maize has a higher metabolizable energy value (3,365 Kcal/kg) (Afolayan *et al.,* 2015) than other potential poultry feed sources, such as rice (3,320 Kcal/kg), rice bran (2,620 Kcal/kg), peanuts (2,915 Kcal/kg), and oilcake (2,350 Kcal/kg) and as a result it is frequently used as a standard for measuring other energy feed sources (Andam *et al.,* 2017; Aardsma *et al.,* 2017). In poultry feed industry, maize which constitute a greater percent of the diet, is the most often used energy source (Dei, 2017). Corn is the most popular because of its easy availability and higher energy content. The feed and poultry industry standard for energy requirements in chickens is 3,200 kcal/kg for broilers and 2,300 kcal/kg for layer feed (Hellin *et al.,* 2013).

2.2.4.2 Content of protein in maize grain

The protein content of the maize grain is low, with a standard error of about 7 g/kg of crude protein (Barros *et al.,* 2017). Eight (8) to eleven (11) g of protein per 100 g of dry matter are found in maize grain. The amount of protein in the different grain fractions varies greatly. The germ has significantly more protein (184 g/kg DM) than the endosperm (80 g/kg DM), although the endosperm contains the majority of the grain's protein (Dei, 2017). In general, the grain's low protein content typically limits its nutritional value as the only food source for both human and animals (Barros *et al.,* 2017). Each protein fraction's amino acid content and the relative proportions of the different protein fractions determine the overall maize grain's amino acid composition (Gebru *et al.,* 2019). The proteins found in maize grain endosperm are commonly known as albumins, globulins, prolamins, and glutelins, depending on which solvent system they dissolve in. Glutamins and prolamins, commonly known as storage proteins, are only found in the endosperm, while albumins and globulins, generally known as water-soluble proteins, are also present in the germ and the aleurone layer (Ortiz-Martinez *et al.,* 2017). Approximately 50–60% of the total protein in typical maize grain is prolamin, which has a higher proportion than glutelin (Chen *et al.,* 2018). The relative proportion of each protein fraction has a significant impact on the amount of each individual amino acid in the total grain protein. Each protein fraction typically has a distinctive amino acid composition. Because lysine is the most deficient prolamin, maize protein has a low nutritional value (Ortiz-Martinez *et al.,* 2017; Chen *et al.,* 2018). In essence, the overall lysine deficiency in maize grain results from its low albumin and globulin content, which, in addition to having a high lysine content, shows a well-balanced amino acid composition comparable to that of animal proteins with greater nutritional value (Kato *et al.,* 2019). Additionally, maize prolamins have higher levels of leucine than isoleucine, which results in the common amino acid imbalance that lowers maize's protein quality (Gebru *et al.,* 2019).

2.2.4.3 Vitamin content of maize grain

The germ and the aleurone layer of maize grain contain the majority of the grain's vitamins (Ndolo and Beta, 2013). According to an analysis of maize's vitamin composition, the grain provides substantial amounts of riboflavin, pantothenic acid, choline, and pyridoxine, all of which are adequate to meet the needs of the majority of animals (Suri and Sherry, 2016).

Nonetheless, the low niacin level is the most important aspect of the vitamin pattern in maize. Furthermore, monogastric animals cannot access a large portion of the bound form of niacin found in grains, known as niacytin (Suri and Sherry, 2016)). Additionally, people require extra niacin due to the high concentration of leucine, an important amino acid, in maize grain (Prabhu *et al.,* 2021). As a result, pellagra, a condition linked to niacin deficiency, affects persons who solely eat maize. However, if regular maize were high in tryptophan or heat-treated with alkali, pellagra would not be caused by niacin deficiency alone (Prabhu *et al.,* 2021). White maize does not exhibit vitamin A activity, while yellow maize does. The carotenes found in yellow maize are the main source of the grain's vitamin A content. According to Hossain *et al.* (2019), yellow maize has a carotene concentration of 0.46 mg/100 g of grain. The fact that vitamins are mostly found in the germ and the aleurone layer suggests that meal preparations that do not preserve these grain components further reduce the concentration of vitamins in the diet (Hossain *et al.,* 2019). The concentration of vitamins in the maize grain is presented in Table 2.1.

Table 2.1: Concentration of vitamin in maize grain

Vitamin	Concentration (mg)
Thiamine (B1)	0.350 ± 0.039
Riboflavin (B2)	0.140 ± 0.014
Niacin (B3)	2.100 ± 0.090
Pantothenic acid (B5)	0.270 ± 0.020
Pyridoxine (B6)	0.280 ± 0.023
Biotin (B7)	0.700 ± 0.060
Folate (B9)	39.42 ± 3.130
Carotene	0.460 ± 0.121
Choline	65.52 ± 0.541
Vitamin E	0.040 ± 0.020

Source: (Suri and Sherry, 2016; Yatharth *et al.,* 2022)

2.2.4.4 Mineral (Ash) content of maize grain

Less than 2 % of maize grain is made up of inorganic or mineral material (ash) (Reza *et al.,* 2015), with the germ accounting for roughly 75 % of this total. The grain is low in calcium and trace minerals other than iron, although it is high in potassium and phosphorus (Fryer *et al.,* 2019). However, a large portion of the phosphorus is found as phytic phosphorus, which monogastric animals cannot digest (Fryer *et al.,* 2019). Because it forms compounds with phytic phosphorus, the small amount of calcium that is typically present also has reduced bioavailability (Gupta *et al.,* 2015). Table 2.2 shows the mineral composition of maize.

Table 2.2: Mineral composition of maize Grain

MINERAL	CONCENTRATION (mg/100 g)
Potassium (K)	400.0
Phosphorus (P)	300.0
Sodium (Na)	50.00
Calcium (Ca)	6.000
Sulphur (S)	140.0
Iron (Fe)	2.500
Magnesium (Mg)	160.0
Chlorine (Cl)	70.00
Copper (Cu)	4.500
Zinc (Zn)	3.500

Source: Gu *et al*. (2015)

2.2.4.5 Fibre content in maize grain

Fibre is contained in all feed ingredients derived from plants, and it mostly consists of polysaccharides from non-starch sources found in plant cell walls (Manu *et al.,* 2015). Another name for dietary fibres is non-starch polysaccharides. They include cellulose, gums, pectin, hemicellulose, lignin, mucilages, non-cellulose, and cellulose, and they are indigestible in the gastrointestinal tracts of non-ruminants. Cereals, fruits, nuts, and vegetables are high in fibre and have a good impact on an animal's health, according to Yatharth *et al.* (2022).

According to Eswaran *et al.* (2013), eating these fibres lowers the risk of developing a number of digestive disorders. Marketable amounts of dietary fibre are available. Even though it is readily available at relatively reduced prices, the use of this agricultural-industrial by-product in chicken feeds is limited due to its negative effects on the growth, intestinal viscosity, and general performance of birds (Yatharth *et al.,* 2022). It is already widely known that adding enzymes to chicken diets breaks down their connections, lowering intestinal viscosity and enhancing the nutritional content of feedstuffs that contain high concentrations of them (Hussein *et al.,* 2020). According to Wang *et al.* (2019), the caecum may become longer in tandem with an increase in fibre due to a physiological adaptation that delays digestion in the stomach. Martinez *et al.* (2015) found that adding various types of fibre (varying from 3 to 5 %) to poultry meals resulted in a larger weight of crop, gizzard, and intestines. Martinez *et al.* (2015) also observed that laying pullets fed a diet containing 3.5 % crude fibre had comparatively lighter weights in their gizzard, crop, intestines, and oviduct than birds fed a diet containing 3.0 % crude fibre. However, there were no differences in the levels of serum total protein, urea, or creatinine between the two levels of crude fibre. The nutrient composition of three most popular maize varieties in Ghana as reported by Owusu (2022) are presented in Table 2.3.

Table 2.3: Nutrient composition (%) of the three maize varieties

	MAIZE	**VARIETIES**	
PARAMETER	**OBATANPA**	**HONAMPA**	**ABONTEM**
Moisture (%)	9.300	9.400	10.50
Crude Protein (%)	12.92	12.04	13.13
Crude Fibre (%)	1.910	1.450	1.750
Crude Fat (%)	1.000	1.500	2.050
Ash (%)	1.100	0.780	0.700
Nitrogen Free Extract (%)	74.07	74.84	71.87
Metabolisable Energy (Kcal/kg)	3160	3187	3167

Source: Owusu (2022)

2.3 Fat and Oil

Fat and oil are commonly used in poultry diets to increase the energy density as they yield 2.25 times more calories than carbohydrates and protein (Baião and Lara, 2005). Fat-supplemented diets increase the feed efficiency and profitability in poultry (Soomro *et al*., 2016). Besides, oil improves the palatability of diets, reduces the dustiness of feeds and decreases the passage rate of feed through the intestinal tract of poultry, which gives more time for the adequate absorption of all nutrients present in the diet (Baião and Lara, 2005; Chwen *et al*. 2013).

The inclusion of fat and oil is a common practice in modern poultry production to increase the energy content of diet. The addition of fat to diets, besides supplying energy, improves the absorption of fat-soluble vitamins, diminishes the pulverulence, increases the palatability of the rations, and increases the efficiency of the consumed energy (lower caloric increment). Furthermore, it reduces the passage rate of the digesta in the gastrointestinal tract, which allows a better absorption of all nutrients present in the diet. High energy diets have been shown to improve growth and feed efficiency. Oils added to the rations of animals are effective on the fatty acid composition and amount of abdominal fat. In fact, fatty acids composition of oils used in poultry rations are reflected in the animal products because dietary fatty acids are incorporated with little change into the bird body fats. Thus, the type of fat used in the feed influence the composition of broiler body lipids. Abdominal fat is a good indicator of chicken body fats because it is very sensitive to changes in dietary fatty acid composition. Kim *et al*. (2021) have reported that broiler chickens fed with diets enriched of polyunsaturated fatty acids have less abdominal fat or total body fat deposition than do broiler chickens fed with diets containing saturated fatty acids.

Barbour *et al*. (2006) reported that by increasing the proportion of supplemental animal-vegetable blend fat from 0 to 60 g/kg in isocaloric diets (2,963 kcal/kg), feed conversion was improved without any effects on BW, feed intake, abdominal fat, or whole carcass composition. In a subsequent experiment, 30, 60, or 90 g/kg of corn oil added to isocaloric corn-soybean meal diets (2,926 kcal/kg) increased BW in 4- wk-old male broilers compared with those fed equal quantities of diets with no added oil. Those improvements in performance were related to enhanced use of calories beyond what was accounted for in terms of calculated dietary ME, and this was especially true in the case of vegetable oils. In more recent studies, linear increases in weight gain and feed efficiency were observed when male broiler chickens were fed corn-wheat-soybean meal diets in which ME was increased from 2,800 to 3,000 kcal/kg through changes in supplemental soybean oil or dietary carbohydrate levels.

2.4 Source of Protein in Broiler Chickens

Soybean meal (SBM) is the primary source of plant protein commonly used in poultry nutrition since its amino acid balance is appropriate for diets (Marsman *et al*., 1997). However, the use of raw SBM by monogastric animals is not totally efficient due to the presence of anti-nutritional factors (ANFs) (Ebrahimi-Mahmoudabad and Taghinejad-Roudbaneh, 2011). These ANFs interfere with metabolic processes and reduce nutrient availability (Coulibaly *et al*., 2011). In fact, feeding raw unprocessed SBM usually reduces growth rate and feed efficiency, causes pancreatic gland enlargement and decreases digestibility and availability of amino acids in broiler chickens (Gilani *et al*., 2005). Hamilton & Sandstedt (2000) also reported that body weight (BW), body weight gain (BWG) and feed intake (FI) were higher and feed conversion ratio (FCR) was lower on broiler chickens when raw unprocessed SBM was replaced by heat processed SBM. To inactivate or remove ANFs in poultry diets, various heat procedures (extrusion, cooking, toasting and roasting) have been reported to be efficient in reducing trypsin inhibitor activity (TIA) and phytic acid (PA) in soybeans (Ari *et al*., 2012). Habiba (2002) declared that cooking, autoclaving and microwaving are the most successful soybean heat procedures that may have an important role in removing these ANFs. Unfortunately, limited research has been developed on the comparison of different soybean heat procedures (Ari *et al*., 2012) in poultry performance (Akande and Fabiyi, 2010).

2.5 Soybean

The soybean (*Glycine max*) is an annual herbaceous erect plant that ranges in height from 30 to 183 cm (Mishra *et al.,* 2024). It has fine brown or grey hair on its stem, leaves, and pods. Soybeans, like peas, beans, lentils, and peanuts, are members of the Leguminosae or Fabaceae family. Soybeans have about 8 % of seed coat or hull, 90 % of cotyledon and 2 % of germ (Mishra *et al.,* 2024). Originally from East Asia, it has spread throughout the world, with the United States, Brazil, and Argentina being the leading producers (Bankole, 2022). It is mainly used for vegetable oil and oilseed meal production for use in feeding animal. The key factor boosting soybean production has been the increase in the use of soybean as a protein substitute for animal protein diets (Mawiya, 2016). The major farmed animal species diets containing soybean include poultry, pigs, cattle and aquatic. In some animal feeds, soybean is utilized comparatively more than in others. The primary goal is to supply pigs and poultry with high-quality protein (Mawiya, 2016). Out of all the plant protein sources, the majority of the land required for production of animal product is devoted to the cultivation of soybeans (Thrane *et al.,* 2016). For instance, the United States of America (USA) and the European Union (EU) both utilize a lot of soybeans in animal feed. Soybean acreage of 5.0 million hectares in Brazil and 4.2 million hectares in Argentina is required for the EU's yearly livestock consumption alone. Therefore, because of its high protein content, energy contribution, and physiological advantages, soybeans continue to be essential in poultry nutrition (Thrane *et al.,* 2016). It provides the main sources of high-quality protein and energy and is essential for maximizing feed efficiency, growth performance, and poultry health in general (Mawiya, 2016).

2.5.1 Nutritional composition of soybean

After the use of animal nitrogenous concentrate in chicken feed was prohibited, producers were compelled to employ vegetable protein, such as soybeans, in poultry diets (Bingol *et al.,* 2016). In broiler chickens, soybeans are regarded as a great source of protein and oil (Bankole, 2022). They include 20 % oil and 38 % crude protein. As a result, they are regarded as the most cost-effective since they eliminate the need for extra oils in the diet (Muslyumova *et al.,* 2021). As the most popular vegetable protein in animal feed, soybeans are a great feed substitute for animal proteins due to their high protein content (44–48 %) and balanced amino acid profile. However, raw soybean meal contains anti-nutritional factors that reduce its digestibility and utilization (Alagawany *et al.,* 2018). Animal performance is adversely affected by these anti-nutritional compounds, which include non-starch oligosaccharides, polysaccharides, lectins, tannins, saponins, phytate, protease inhibitors, and antivitamins (Nabizadeh *et al.,* 2018). Soybeans need to be heated and under high pressure to lessen the effects of these chemicals, but heat treatment must be done carefully to prevent protein and other vital components from being denatured (Avedeweh, 2015).

Table 2.4: Chemical composition of soybean grain

PARAMETER	(%)
Moisture content	9.000
Crude fat	15.50
Crude protein	43.20
Crude fibre	16.77
Carbohydrate	9.530
Ash content	6.000

Source: Avedeweh (2015).

2.5.1.1 Crude protein and amino acids content in soybean

According to Muslyumova *et al.,* (2021), the soybean seed has the highest crude protein content (about 40%) and the best amino acids among all the legume seeds. According to Thrane *et al.* (2016), soybean protein contains all the essential amino acids required to meet nutritional needs of poultry for development, maintenance, and growth. Protein serves as the building block for organs, muscle, feathers, and eggs (Alagawany *et al.,* 2018). He *et al.* (2021) claimed that birds' daily diets must contain ten amino acids; however, this contradicts report of Classen (2017) who opined that pigs and poultry nutrition require only five important amino acids, namely tryptophan, cysteine, theronine, methionine, and lysine. Soybean has the highest lysine digestibility (91%) (Classen, 2017); it is also high in methionine, cysteine, and theronine digestibility (He *et al.*, 2021). Since these five amino acids are found in the lowest concentrations in a meal compared to what the animal needs and are rapidly destroyed by extreme thermal treatment, Muslyumova *et al.* (2021) claims that they are limiting.

2.5.1.2 Crude carbohydrate content of soybean

In addition to being high in protein, soybeans are also high in carbohydrates (Al Loman *et al*., 2016). Poultry use glucose, which is produced from carbohydrates, as an energy source for development and egg production. Adebowale *et al.* (2019) clarified that monogastric animals have poor digestion of the carbohydrate components (hulls, sugars, and non-starch polysaccharides). About 10% of the carbohydrates in soybeans are free sugars (5% sucrose, 4% stachyose, and 1% raffinose) (Al Loman *et al*., 2016; Nguyen *et al.,* 2021). Since monogastric animals lack the enzymes necessary to hydrolyze these carbohydrates, bacterial fermentation is used to digest them (Adebowale *et al.,* 2019). Soluble non-starch polysaccharides (polymers that are partially soluble in water) and insoluble non-starch 13 polysaccharides (cellulose) are the two primary categories of non-starch polysaccharides (Nguyen *et al.,* 2021). In chickens, insoluble non-starch polysaccharides (cellulose) can impair growth performance and decrease nutrient digestibility. Soybean meals must have 35–40% carbohydrates when oil is produced (Choct, 2015).

2.5.1.3 Crude fat content of soybean

One of the main sources of nutritional energy in poultry feed is crude fat, also known as ether extract. The amount of crude fat in soybeans might vary greatly according to the processing method used. Full-fat soybeans (FFSB) are a high-energy feed item because they normally contain 18–20 % crude fat (Tang *et al*., 2024). However, as most of the oil is eliminated during processing, solvent-extracted soybean meal (SE SBM), the most popular type in commercial chicken feeds, has as little as 0.5–1% crude fat (Kerr *et al.,* 2023). A compromise between cost and energy contribution is provided by expeller-processed soybean meal, which preserves roughly 6–7 % fat through mechanical extraction as opposed to chemical extraction (Kerr *et al.,* 2023).

In broilers and layers, it has been demonstrated that adding high-fat soybean products, like FFSB, improves energy density and feed conversion. However, it is important to balance the amount of protein and energy in the diet. Overconsumption of fat can result in increased deposition of fat in the abdomen, which is undesirable for carcass quality, particularly in broiler chickens (Ali *et al.,* 2021). The significance of regulated inclusion levels was highlighted by a study by Al-Marzooqi and Leeson (2016), which showed that diets heavy in soybean oil or fat enhanced energy utilization but also increased fat pad weights.

The unsaturated fatty acid fat found in soybeans mostly improves meat quality by increasing tenderness and lowering the amount of saturated fat in poultry meat (Wang *et al.,* 2017). As a result, the fat content of soybean products does not influence growth performance of poultry but also affect the nutritional value of poultry products intended for human consumption.

2.5.1.4 Crude fibre content of soybean

Crude fibre is a measurement of the amount of indigestible cellulose, pentosans, lignin, and other comparable substances present non feed (Slominski, 2018). Crude fibre is essential for gut health and digestive efficiency, despite being frequently viewed as a less desirable part of chicken diets because of the birds' poor capacity to digest fibrous materials. Processing also affects the amount of crude fiber in soybean products. While non-dehulled or hull-containing soybean meals may include up to 7–14 % crude fibre, dehulled soybean meal can have as little as 3–5 % (Okonkwo *et al.,* 2023). Unless added in very small amounts or processed with enzymes, soybean hulls a by-product of processing can contain more than 50 % crude fibre (Adewole *et al.,* 2016), making them an unsuitable option for monogastric animals like chicken.

For instance, diets with slightly higher levels of dietary fibre from soybean hulls or full-fat soybean by-products were linked to increased intestinal villus height and improved nutrient absorption in broilers (Singh *et al.,* 2018). However, excessive fibre, especially when undigested, can reduce nutrient availability and feed efficiency, resulting in lower growth rates and increased feed costs. Even though poultry lack the complex digestive systems necessary to ferment fibre efficiently, moderate inclusion of dietary fibre has been shown to promote intestinal development, gizzard function, and beneficial microbiota populations (Jiménez-Moreno *et al.,* 2019). This means that when adding high-fibre soybean products to chicken diets, fibre-degrading enzymes like xylanase and cellulase must be used. It has been demonstrated that this type of enzyme supplementation enhances the use of fibrous components, especially in feeds formulated from soybean (Masey O'Neill *et al*., 2020).

2.5.1.5 Mineral (Ash) composition of soybean

Poultry's nutritional needs for minerals are largely met by dietary soybean. Calcium (Ca), phosphorus (P), potassium (K), magnesium (Mg), and sulfur (S) are among the essential macro and microminerals found in it. Soybeans contain roughly 0.20–0.25 % calcium and 0.59–0.65 % total phosphorus, although only 0.20–0.21 % of this is accessible to chicken because of the high phytate-bound proportion, according to Olukosi *et al.* (2023). Magnesium and sulfur are present at 0.21–0.27 % and 0.30–0.43 %, respectively, while potassium level ranges from 1.7 to 1.97 %. There are also appreciable concentrations of microminerals including zinc (35–60 ppm), copper (15–28 ppm), iron (75–160 ppm), and manganese (27.5–32.3 ppm) (Lee *et al.,* 2022).

Because phytate chelates phosphorus and makes it unavailable to monogastric animals, phosphorus digestibility is a major concern in poultry nutrition (Bougouin *et al.,* 2015). The necessity for standardization was highlighted by Rojo *et al.* (2023), who discovered that the phosphorus digestibility in SBM varied from 35.3 % to 63.2 % based on the soybean source and processing. Phosphorus availability has been demonstrated to be enhanced by autoclaving and enzymatic treatments, especially the addition of microbial phytase (Walk *et al.,* 2021). Studies have shown that supplementing soybean with phytase improved the digestibility of ileal phosphorus from 46 % to 61 %, with higher enzyme dosages achieving up to 77 % digestibility (Adeola and Cowieson, 2016; Walk *et al.,* 2021). In a similar vein, autoclaving soybean has been shown to increase phosphorus bioavailability by breaking up phytate complexes (Ravindran *et al.,* 2017). The table 2.5 shows the mineral composition of soybean.

Table 2.5: Mineral Composition of Soybean

MINERAL	COMPOSITION
Calcium (Ca) (%)	0.200–0.250
Potassium (K) (%}	1.700–1.970
Sodium (Na) (%)	0.040
Phosphorus (P) (%)	0.590–0.650
Magnesium (Mg) (%)	0.210–0.270
Sulfur (S) (%)	0.300–0.430
Chloride (Cl) (%)	0.020–0.030
Copper (Cu) (ppm)	1500–28.00
Iron (Fe) (ppm)	75.00–160.0
Selenium (Se) (ppm)	0.100
Zinc (Zn) (ppm)	35.00–60.00
Manganese (Mn) (ppm)	27.50–32.30

Source: (Lee *et al.,* 2022; Olukosi *et al*., 2023)

2.5.1.6 Vitamin Composition of Soybean

Soybean contains a variety of vitamins that promote the poultry's physiological processes. These include water-soluble B-complex vitamins and fat-soluble vitamins like vitamin E. Vitamin E, an essential antioxidant that promotes immune system function and preserves cellular integrity, is found in soybeans (Surai, 2016). According to Nguyen *et al.* (2021), soybeans typically contain 3.0–6.6 mg/kg of vitamin E. The most prevalent B-vitamins are pantothenic acid (13.2–13.8 mg/kg), thiamin (1.7 mg/kg), riboflavin (2.6–

4.4 mg/kg), and niacin (20.9–59.8 mg/kg). Choline, which is essential for lipid metabolism and liver function in poultry, is present at roughly 2673–2850 mg/kg (Olukosi and Adeola, 2017), while biotin and folic acid are detected in the range of 32.0–320 µg/kg and 450–700 µg/kg, respectively (Batal and Dale, 2016).

The processing techniques, however, can have a significant impact on the vitamin concentration and bioavailability. Trypsin inhibitors and other anti-nutritional factors must be deactivated by heat treatment, which can also degrade heat-sensitive vitamins like folic acid and thiamin (Krautwald-Junghanns *et al.,* 2022). Overheating decreased the levels of riboflavin and vitamin E, which may compromise the nutritional value of soybean (Nguyen *et al.,* 2021). Therefore, maintaining the soybean's vitamin integrity requires optimizing processing techniques. The summary of vitamin composition of soybean is shown in table 2.6.

Table 2.6: Vitamin Composition of Soybean

Vitamin	Composition
Vitamin E (mg/kg)	3.000–6.600
Thiamin (B1) (mg/kg)	1.700
Riboflavin (B2) (mg/kg)	2.600–4.400
Niacin (Vitamin B3) (mg/kg)	20.90–59.80
Pantothenic Acid (B5) (mg/kg)	13.20–13.80
Biotin (B7) (μg/kg)	32.00–320.0
Folic Acid (Vitamin B9) (μg/kg)	450.0–700.0
Choline (mg/kg)	2673–2850

Source: (Surai, 2016; Nguyen *et al.*, 2021)

2.6 Antinutritional factors in poultry feed ingredient

Anti-nutritional factors are those substances that are generated in natural feedstuffs by the healthy metabolism of species and by different mechanisms which exert effect contrary to optimum nutrition (Thakur *et al*., 2019). Anti-nutritional factors are mainly organic compounds (Kaur *et al*., 2021), which when present in a diet, may affect the health of the animal or interfere with average feed utilization (Bora, 2014). They occur as natural constituents of plant and animal feeds, or as artificial factors added during processing or by contaminants of the ecosystem (Kafle *et al*., 2022). Anti-nutritional factors (ANFs) in feedstuffs are classified according to their chemical nature and their activity in animals. In this category are acids, enzymes, nitrogenous compounds, saponins, tannins, glucosinolates and phenolic compounds (Singh *et al*., 2023). Factor interfering with the utilization, digestion and availability of minerals of dietary proteins and carbohydrates, for example, tannins, trypsin or protease inhibitors, haemagglutinins and saponins, phytates or phytic acid, oxalates or oxalic acid, glucosinolates and gossypol reported by Ingale *et al*. (2011).

2.6.1 Trypsin inhibitors

The presence of trypsin inhibitors in maize-soybean diets for poultry has been a subject of significant interest and concern within the realm of animal nutrition. Trypsin inhibitors, naturally occurring in soybeans and to a lesser extent in maize, can impede protein digestion by inhibiting the activity of trypsin, a key digestive enzyme in poultry. Studies by Cowieson and Roos (2016) have highlighted the potential negative impacts of trypsin inhibitors on nutrient utilization and performance in poultry. The inclusion of soybean meal in poultry diets, which typically contains higher levels of trypsin inhibitors, necessitates careful consideration and management to mitigate their adverse effects on nutrient digestibility and overall performance. Thus, understanding the dynamics of trypsin inhibitors in maize-soybean diets is crucial for optimizing dietary formulations and ensuring optimal poultry health and productivity.

Efforts to address these challenges posed by trypsin inhibitors in maize-soybean diets for poultry have led to various strategies aimed at improving nutrient utilization and performance. Research by Silva *et al*. (2017) has explored the efficacy of heat treatment and enzyme supplementation as means to mitigate the negative effects of trypsin inhibitors. Heat treatment methods such as extrusion and roasting have been shown to reduce trypsin inhibitor activity in soybean meal, thereby enhancing protein digestibility and overall nutrient utilization in poultry. Additionally, enzyme supplementation, particularly with exogenous proteases, has emerged as a promising approach to counteract the inhibitory effects of trypsin inhibitors and improve protein digestion in poultry. These findings underscore the importance of adopting strategic interventions to optimize maize-soybean diets for poultry and maximize performance outcomes.

2.7 Ways of removing trypsin inhibitors

Legumes go through several processes before they are used as plated items or as another feed ingredient in feed preparation. Thermal and chemical processing help to eliminate or reduce unwanted components. Heat process is widely used for feed preparation. Heat processing has both beneficial and detrimental effects on feed products. A good example is that the protein found in legumes become more digestible by inactivating trypsin inhibitor. Temperature modification can alter the texture, flavour and appearance of feed. Some other processing techniques such as dehulling, cooking, radiation, germination, roasting, fermentation, extrusion cooking and supplementing with various chemicals and enzymes are also effective to reduce the antinutritional components (El-Hady and Habiba, 2003; Arif *et al*., 2012). The following are the major processing techniques that are often used to reduce the unwanted substances.

2.7.1 Soaking

Many authors have indicated that soaking the bean prior to cooking reduced the cooking time (Taiwo and Akanbi, 1997). Soaking allows the water to disperse in the protein fraction and starch granules which facilitate the protein denaturation, starch gelatinization, and softens the texture of beans (Siddiq and Uebersax, 2012). Food Science and Technology (2018) reported that inhibitors of beans cause reduction in oligosaccharides, sucrose content with instance reduction in stachyose and reffinose in chickpea. Soaking decreases the monosaccharide, disaccharides, and oligosaccharides in kidney beans (Egounlety and Aworh, 2003). Change in the carbohydrate composition was seen less when the cooking water was not drained off (Vidal-Valverde *et al*., 1994). Phytate is water soluble so the legumes soaked in water for overnight shown considerable removal of phytates in water and enhanced the naturally occurring phytase (Kumar *et al*., 2010). The loss in phytase may due to the leached down of phytase ion in soaking liquid under the influence of difference in chemical potential which manage the diffusion rate (Deshpande and Cheryan, 1984). Addition of salt in water provides improved outcome as the legumes soaked in sodium bicarbonate solution reduced trypsin inhibitor and eliminates tannin contents in bean (Taiwo, 1998). Soaking the peas in distilled water showed an increase in trypsin inhibitor (Wang *et al*., 2008). Soaking legumes in simple tap water did not reduce the tannin contents (Taiwo *et al*., 1997).

2.7.2 Cooking methods

Cooking methods may greatly affect the nutrient contents of the feed. The best method of increasing the nutritional properties of beans is by soaking the beans in salt solution and then cooking the soaked bean with fresh water (De León *et al*., 1992). This makes the legume soft and tenderize, as the beans contain some complex sugars that are indigestible by enzymes and hence results in gastric issues. This problem can be solved by soaking the legume seeds before cooking. Many studies have shown that heat processing improved the absorption and digestibility of iron (Fe) (Wang *et al*., 2010). Cooking of pre-soaked lentil seeds showed that trypsin inhibitor removed totally, reduced phytic acid and increase in catechin and tannin contents (Vidal-Valverde *et al*., 1994; Messina, 2014). Cooking methods are considered highly effective for inactivation of protein based antinutritional factors by causing denaturation of trypsin, chymotrypsin, and some other heat sensitive compounds. This method also removed 30-40 % polyphenol in *Phaselous vulgaris* (Bressani and Elías 1980).

2.7.3 Heat treatment

Legumes are rich in fibre associated with antinutritional factors such as phytate, oxalate and polyphenols that reduce the bioavailability of minerals (Frolich, 1995). Heat processing is one of the effective methods that is widely used to inactive heat liable antinutritional factors. These heat treatments improved the nutritional value and quality of legume grains. Heat treatments are used to enhance the protein quality of legume grains by inactivating the antinutrient factors, mainly the trypsin inhibitor and hemagglutinins (Sathe *et al*., 1984a). This processing method modifies the nutritional composition and its availability in raw materials (Van der Poel, 1990). All over the world, legumes serve as important raw materials used in the manufacturing of beverage and cereal based food products. The use of legumes in combination with cereals compliment the amino acid profile of the final product which is otherwise deficient in cereals (Tharanathan and Mahadevamma, 2003; Arif *et al*., 2012; Hayat *et al*., 2014a). Legumes are also consumed after processing into numerous products such as dhal, roasting and puffing into snacks, grind into flour for preparation of different other types of food products (Kurien, 1981; Hayat *et al*., 2014b). Legumes may not be consumed in raw form because of its bitter taste and antinutrient factors therefore different treatments are used to make the legumes consumable. The various techniques of processing improve the starch and protein digestibility and protein quality of legumes by destructing the antinutritional factors (Barampama and Simard, 1995; Alonso *et al*., 2000).

2.7.4 Extrusion and microwave cooking

The cooking takes place within an extruder where the product produces its own friction and heat due to pressure. Extrusion cooking has the advantages of versatility, high productivity, low operating costs, energy efficiency and very short cooking times. During the last decade, extrusion cooking for legume processing has been developed quickly, and now this is considered as a technology of its own right. There is little nutritional concern in extrude products as it prevents or reduce the harmful effects of antinutritional factors thereby improving starch and protein digestibility. Legume extrusion cooking results in reduction of antinutritional factors and therefore improve the nutritional quality at a cost lower than other heating systems (e.g. baking, autoclaving, etc.) due to a more efficient use of energy and better process control with greater production capacities (Barampama and Simard, 1995; Alonso *et al*., 2000). Extrusion was the best method to eliminate trypsin, chymotrypsin, a-amylase inhibitors and hemagglutinin activity without modifying protein content (Frolich, 1995). The antinutrients that are present in legumes were reduced significantly during extrusion cooking (Frolich, 1995). Microwave cooking is a heat treatment in which food is passed through microwave radiation. This cooking method is not studied extensively yet the microwave cooking reduces antinutritional factors in soybean thus improved the protein digestibility (Frolich, 1995). Microwave has a shorter processing time, so it destructs antinutritional factors without disturbing other nutritional qualities such as vitamin retention (Barampama and Simard, 1995; Alonso *et al*., 2000). However, Finot and Merabet (1993) reported that due to shorter time and smaller amount of water, the microwave cooking affects the nutritional content than that of conventional methods.

2.7.5 Enzyme application

According to Classen (1996), using exogenous feed enzymes in monogastric diets is a useful strategy for allowing for flexibility in diet composition, as well as for reducing feed costs, improving feed digestibility, and minimizing environmental pollution. According to Govil *et al*. (2017), for exogenous enzymes to be as efficient as possible, they must balance out the function of the animal's endogenous substances. Plant-based raw materials have anti-nutritional factors that limit the availability of nutrients by preventing endogenous enzymes from accessing them, which prevents digestion (Costa *et al*., 2013). Rios *et al*. (2017) reported that the digesta transit rate in modern broilers is too quick for optimum digestion, allowing important nutrients to escape digestion in the GIT. In addition to breaking down bound nutrients, exogenous enzymes reduce the cost of producing chicken diets (Boyd *et al*., 2018).

According to Saleh *et al*. (2019), animal rations contain trace amounts of exogenous enzymes such as phytase, protease, and xylanase which are produced from microbial sources. It has been demonstrated that the use of exogenous enzymes in animal feed improves the body's ability to absorb nutrients that would not otherwise be available (Classen, 1996). The addition of enzymes reduces the adverse effects of ANFs and boosts profitability in poultry production (Sun *et al*., 2019; Costa *et al*., 2013). Approximately 1.67-1.88 MJ of energy per kilogram of feed is not being digested in a conventional corn-soybean diet without enzyme supplementation (Govil *et al*., 2017). Enzymes can be used to increase protein, fat, and carbohydrate availability as well as to increase more energy being made available for utilization.

In poultry feed, enzymes can be added either separately or in the form of multi-enzyme complexes (MEC) (Jlali *et al*., 2020). Positive results have been reported for both MEC and single. There has been contradictory research on the effectiveness of supplementing with non-starch polysaccharide degrading enzymes in addition to phytase. While non-starch polysaccharide and protease possess distinct target substrates, their actions complement one another because non-starch polysaccharide releases many nutrients and reduces mucus production in the gastrointestinal tract (Rahimi *et al*., 2020). According to Jlali *et al*. (2020), the bird's response to MEC use is influenced by its genetic ancestry, age, nutrition, and MEC dose.

Adding enzymes to poultry feed, either separately or in combination, has several advantages:

i. According to Amerah (2015), the release of encapsulated starch in the cell wall minimizes the variation in apparent metabolizable energy (AME) and performance.
ii. Less digesta viscosity lowers the amount of wet litter and sticky droppings, which further lowers the risk of dermatitis (Wang *et al*., 1998; Amerah *et al*., 2015).
iii. Due to the immature GITs, young chicks are particularly vulnerable to the negative impact of NSP. Enzymes called carbohydrases help to keep the gut healthy so that an inflammatory gut does not impair performance (Yacoubi *et al*., 2017).

iv. By reducing the digesta viscosity and changing gut microbes by promoting the growth of beneficial microbes, BW, gain, and FCR are improved (Saleh *et al*., 2019).

v. Short-chain fatty acids (SCFA) such as butyrate and acetate are produced by multi-enzyme complexes. Butyrate serves as an energy source for the intestinal epithelial cells in the stomach, promoting both their proliferation and differentiation to improve digestive health (Yacoubi *et al*., 2016).

2.7.6 Boiling and Autoclaving

Legumes are usually boiled in water at 100°C for few minutes. The boiling process enhances the sensory properties of legume grains, make the seed tenderize and more acceptable for consumer. These techniques also help to eliminate heat liable antinutrients (Bishnoi and Khetarpaul, 1993). Khalil and Mansour (1995) reported that boiling process eliminated hemagglutinins in faba beans. The boiling process reduces the ODAP (oxalyldiaminopropionic acid) level in grain by 90 % (Padmajaprasad *et al*., 1997). Autoclaving causes significant reduction in trypsin inhibitor of *Zea mays* (Alajaji and El-Adawy, 2006). The β-ODAP content in milled grass peas was also found reduced compared to the raw seeds (Moges *et al*., 2004) and found complete reduction in hemagglutinin (El-Beltagy, 1996).

2.8 Full-Fat Soybean (FFSB)

These are complete soybeans in which the oil has not been extracted. These products are made using a number of techniques, including dry or wet extrusion, frying, autoclaving, roasting, and micronizing to deactivate the antinutritional factors (ANFs) (Das, 2019).

Depending on the extent of heat damage or ANF inactivation, each of these procedures has a unique effect on the soybean's nutritional value (Vagadia *et al.,* 2017). For the purpose of creating feed, especially for pigs and poultry, soybeans are often processed into defatted meals. However, the cattle industry has been using more full-fat soybeans as a result of the creation of new kinds with lower amounts of ANFs. Because of their high energy content, properly processed full-fat soyabeans are also a valuable feed stuff for animal feeding (Vagadia *et al.,* 2017). As a result, using FFSB would make it feasible to lower the cost of oil extraction and allow the use of locally produced oil and protein feed ingredients in poultry diets (Voss *et al.,* 2018). Table 2.7 shows the nutritional composition of full fat soybean.

Table 2.7: Nutritional composition of full fat soybean

Parameter	Full fat soybean
Dry Matter (%)	89.40
Crude Protein (%)	37.10
Crude Fibre (%)	5.100
Ether Extract (%)	18.40
Ash (%)	4.900
Gross Energy (MJ/kg)	20.95

Source: Voss *et al.* (2018).

2.9 Heat Treatment of Soybean

Heat treatment aids in the extraction of oil in addition to reducing or denaturing anti-nutritional factors (ANFs). Heat breaks down the walls of the oil-bearing cells of seeds, allowing the oils to be extracted. For sesame and linseed, oil yields at 100 °C were consistently higher than those at 40 °C (Toomer *et al*., 2023). According to an experiment conducted by Avedeweh (2015), the yield of soybean oil increased when the heating temperature was raised from 70 °C to 80 °C and the heating period was extended from 15 to 30 minutes. Compared to the higher temperatures and the control, the highest percentage yield of 33.7 % was obtained from moringa seeds roasted to 100 °C (Voss *et al.,* 2018). Increased cell wall permeability and seed protein coagulation over 80 °C are the causes of this. According to Vagadia *et al.,* (2017), heating raw materials between 60 and 70 °C improves their quality for subsequent processing. Thermal processing also improves nutrient digestibility and bioavailability (Vagadia *et al.,* 2017). The analytical concentration of lysine and cystine as well as their digestibility were significantly reduced when a commercial soybean meal was autoclaved for up to 40 minutes at 121 °C (Das, 2019). There are several ways of application of heat in treating soybean. However, the intended application of the product, production size, and pricing typically dictate the method to be chosen (Wang *et al.,* 2019). Research has indicated that heat treated soybean's digestible amino acid profile improves broiler growth performance (Voss *et al.,* 2018). It also gives laying hens the vital amino acids they require for laying eggs. Bioactive substances like isoflavones, which have immune-stimulating and antioxidant qualities, are found in feed additives made from heat treated soybeans (Toomer *et al*., 2023).

2.10 Solvent-Extracted Soybean

These are soybeans that have had their oil extracted using a solvent (often hexane), producing soybean meal that is higher in protein and lower in fat. The extraction procedure makes the meal a highly digestible protein source for broilers by lowering its total energy content while increasing the concentration of essential amino acids like lysine and methionine (Abolhasani *et al.,* 2020). According to Eleroglu *et al.* (2020), solvent-extracted soybean meal (SESBM) has a lower lipid content (< 2 %) and approximately 44–48 % crude protein.

Birds fed diets containing 50 % solvent-extracted soybean meal had higher average body weights (2.7 kg at 42 days) than those fed unrefined soybeans (2.5 kg) (Abolhasani *et al*., 2020). A study conducted by Abolhasani *et al*. (2020) on the impact of adding solvent-extracted soybean meal to broiler diets on growth performance and carcass traits reported that broilers fed solvent-extracted soybeans converted feed more effectively (FCR = 1.85), compared to those fed unrefined soybeans (FCR = 1.95). In terms of carcass features, it was observed that broilers fed solvent-extracted soybean meal had a higher percentage of breast meat (31 percent of carcass weight) and considerably less fat deposition overall, especially in the abdominal region, than broilers fed unprocessed soybeans. This implies that the production of lean meat, which is preferred for commercial broiler production, is supported by solvent-extracted soybean. Abolhasani *et al*. (2020) clarified that although solvent-extracted soybean meal promotes faster growth rates and leaner carcasses, employing unprocessed soybeans, particularly if they are readily and regionally available, appropriately heat-treated may result in reduced overall production costs.

2.11 Unrefined or Raw Soybean

Raw or unrefined soybeans are less processed and have both oil and protein. Unrefined soybeans are a good source of energy and essential fatty acids, but they may also contain anti-nutritional factors (ANFs) such lectins, phytates, and trypsin inhibitors, which can decrease protein digestibility and hinder broiler growth (Bender *et al.,* 2021). However, these ANFs can be decreased and the nutritional value of unprocessed soybeans for poultry can be enhanced by appropriate heat treatment, such as toasting or roasting. Because of their natural oil content, unprocessed soybeans, especially those that are left untreated, retain a high fat content (18–20 %) and offer a greater metabolizable energy (about 3,300–3,500 kcal/kg) (Eleroglu *et al.,* 2020). However, consuming too much energy can lead to poorer protein-to-energy ratios, which could decrease protein synthesis efficiency (Abolhasani *et al.,* 2020). Accordingly, unpolished soybeans might be useful in high-energy starter diets, but in order to avoid fat accumulation and guarantee effective lean mass growth, their inclusion at later growth stages might need to be balanced with other protein sources or amino acid supplements (Bender *et al*., 2021). Particularly when left untreated, unrefined soybeans have a significant fat content (18–20 %).

According to a study by Oyekunle *et al*. (2021), broilers raised on unrefined soybeans showed similar early-stage growth (0–21 days), averaging 1.15 kg live weight at day 21, but slower growth during the finisher phase (21–42 days), which may have been caused by an imbalance in energy-to-protein ratios or decreased protein availability. Bender *et al.* (2021) looked at how raw, heat-treated soybeans affected the performance of broilers. They found that at 42 days, broilers fed unrefined soybeans roasted at 110°C for 15 minutes weighed 2.6 kg, while broilers fed solvent-extracted soybean meal weighed 2.7

kg. The weight of the various regions of the carcass also varied; broilers fed unrefined soybeans had a little higher percentage of abdominal fat (7 %) than broilers fed soybeans that had been solvent isolated (5 %). The thigh weight (300 g) and breast weight (800 g) were similar to broiler weights on solvent-extracted soybean meal, but the muscle-to-fat ratio remained favourable despite the increased fat content.

Ravindrah *et al.* (2017) summarized the nutritional contents of all the soyabeans products as shown in the Table 2.8

Table 2.8: Nutrient Composition of Soybean Products

Nutrient	**RSB**	**USO**	**HTSB**	**FFSB**
Crude Protein (%)	36.00-38.00	0.000	44.00-48.00	38.00-42.00
Ether Extract (Fat) (%)	18.00-20.00	99.00-100.0	0.500-1.500	18.00-20.00
Crude Fibre (%)	5.000 -6.000	0.000	3.500-5.000	5.000-6.000
Metabolisable Energy (kcal/kg)	2,900-3,000	0.000	2,400-2,500	3,200-3,400
Methionine (%)	0.600-0.700	0.000	2.700-3.000	0.600.-0.700
Lysine (%)	2.000-2.300	8,800-8,900	2.700-3.000	2.300-2.500

RSB: Raw soyabean, USO: Unrefined soyabean oil, HTSB: Heat-treated soyabean, FFSB: Full fat soyabean. **Source: Ravindrah *et al.* (2017).**

2.12 Unrefined Soybean Oil

Oil is extracted from soybeans using the extrusion-expeller process, which produces soy oil and soy expellers (Schmidt *et al.,* 2020). High-shear dry extrusion alters complex carbohydrates, deactivates cell walls, eliminates antinutrients, increases the efficiency of digesting proteins and fats, reduces intestinal viscosity, and reduces wet excretions (Al Loman *et al*., 2016). The following phase is a mechanical procedure that uses a screw press to produce soy oil and partially defatted soy flour (Meyer and Bobeck, 2021). A high-energy feed component frequently used in poultry diets is soybean oil. On its nutritional composition, Ali (2022) reported that it has a metabolizable energy (8,800 kcal/kg), linoleic acid (50-55 %), oleic acid (20-25 %) linolenic acid (7-8 %) and Vitamin E. It is a source of important fatty acids, especially linoleic acid, crucial for immune function and reproductive performance and improves feed palatability and energy efficiency (Das, 2019; Hou, 2023). Because of its high energy content, soybean oil also helps with improved weight gain and feed conversion efficiency (Meyer and Bobeck, 2021). Soybean oil improves the fatty acid profile and yolk colour, which makes it more palatable to livestock. Because soybean oil has a higher digestibility and metabolizable energy content than other vegetable fats or oils, it enhances intestinal health by slowing the pace at which feed passes through and encouraging the absorption of nutrients in chickens (Hou, 2023). It is frequently utilized as a feed-grade fat in rations for developing turkeys and broiler chickens in order to boost feed energy density and enhance feed utilization efficiency (Schmidt *et al.,* 2020). Because soybean oil has a high percentage of (poly) unsaturated fatty acids, which the animal may absorb and use as a source of energy (Chen and Ellefson, 2024). Additionally, the high levels of polyunsaturated fatty acids (PUFA) in soybean oil seem to improve poultry reproductive without requiring energy (Choct, 2015; Slominski, 2018; Ali, 2022). This has been linked to the function of linoleic acid in reproduction. (Adebowale *et al.,* 2019).

2.13 Growth Performance

2.13.1 Feed intake

Weight gain, feed conversion efficiency, and the financial viability of poultry operations are all impacted by feed intake, which is a major factor in broiler performance (Wang *et al.,* 2020). By maximizing feed intake, waste and expenses are reduced while ensuring that birds get enough nutrients for growth. According to Kogut and Arsenault (2016), a variety of parameters, including dietary composition, feed type, and bird health, affect feed consumption in broiler production. Environmental factors like temperature, illumination, and stocking density, according to Liu *et al*. (2020), are also important in influencing feed intake. As birds try to reduce metabolic heat production as a result of thermal stress, high ambient temperatures may cause them to consume less feed (Liu *et al.,* 2020). Consistent feed intake and growth are facilitated by efficient management techniques, such as maintaining proper stocking densities and regulating lighting schedules. In 12 feeding trials with 470 broiler chickens, Wang *et al.* (2020) investigated the impact of heat stress and found that, on average, broilers under heat stress ingested about 98 g less feed than those in cooler conditions. The physical shape, such as crumble, mash, or pellet, has a significant impact on feed consumption. Due to their superior palatability and reduced feed waste, pelleted diets typically increase feed intake as compared to mash (Amerah *et al.,* 2007). Crumbles promote early feed intake and chick development, making them especially useful during the starter phase (Negari *et al.,* 2023). Broiler feed intake is strongly influenced by the overall health of the bird and the digestive system. Feed intake and nutrient absorption are greatly decreased by disease, particularly gastrointestinal illnesses (Kogut and Arsenault, 2016). Sustaining normal feed intake in broilers requires maintaining gut integrity through dietary practices and biosecurity (Kogut and Arsenault, 2016). Broiler feed intake may be impacted by feed additives and supplements like as enzymes, probiotics, and phytogenics. According to Cowieson and Adeola (2005), enzymes such as xylanase and phytase enhance gut health and nutritional availability, which in turn improves feed intake. Herbal additions can also increase appetite and improve palatability (Windisch *et al*., 2008).

The feed's dietary energy profile has a direct impact on broiler feed intake. Broilers typically adjust their diet according to the energy. According to a study by Ataei *et al*. (2022), broiler feed consumption during the grower phase (days 11 to 24) was examined in relation to different levels of metabolizable energy (ME) inclusion (2800, 2900, 3000, and 3100 kcal/kg). The average daily feed intake (ADFI) was found to be between 105.9 and 108.5 grams per bird per day, with the broilers on the highest energy level (3100 kcal/kg ME) consuming slightly less at 105.9 g/day, while birds on the lowest energy diet (2800 kcal/kg ME) had the highest average feed intake at 108.5 g day.

A variety of factors, especially the utilization of alternative feedstuffs, is another significant factor influencing the feed consumption of broilers. In a 7-week experiment, Algam *et al.* (2020) evaluated the effects of phase-feeding programs using diets in which sorghum was partially substituted for maize. They used three different treatment diets: a three-phase feeding plan, which included starter (2 weeks), grower (2 weeks), and finisher (3 weeks), as well as two-phase plan starter diet (3 weeks) and finisher diet (4 weeks) for treatments 1, 2, and 3, respectively. They found that the total feed intake for each treatment was 5.12 kg, 4.85 kg, and 4.79 kg per bird during the entire experimental period. Feed intake was marginally lower for the birds on the two-phase program than for the birds on the continuous beginning diet.

When it comes to broiler intake, the quality and source of feed formulation also matter. In a study comparing commercial and farm-formulated diets to assess their effects on feed intake over a 6-week period, Negari *et al.* (2023) found that the average feed intake for the commercial diet was 5.47 kg per bird, while the average feed intake for the farm-formulated diet was slightly lower at 5.25 kg per bird. Even when nutrient targets are equal, feed formulation methods and constituent quality might affect overall intake, despite the nominal variation being insignificant.

2.13.2 Body weight and weight gain of broilers

The main measures of broiler growth performance are body weight and weight gain, which are essential metrics for poultry farmers to assess the profitability and efficiency of their production. Reducing production costs and increasing profitability require achieving the ideal body weight gain within a given time frame.

Genetics is one of the most important factors influencing broiler body weight and weight gain. Over the past few decades, improvements in genetic selection have produced high-performing broiler strains with higher body weight gain and faster growth rates. Newer hybrid strains show better body weight gain than earlier genetic lines, according to a study by Zerehdaran *et al.* (2023) that examined the growth performance of commercial broiler lines. According to the study, broilers from the more recent hybrid lines averaged 2.8 kg after 42 days, whereas those from the older strains only reach about 2.4 kg. For best growth, broilers need a well-balanced feed that satisfies their energy, protein, vitamin, and mineral needs. It has been demonstrated that adding high-quality proteins and energy sources, like soybean and maize meal, supports higher body weight gain.

When broiler diets containing 20 % moringa seed cake were added, the broilers gained more body weight (2.7 kg) than those fed a control diet (2.5 kg), according to research by Dlamini *et al.* (2020). Better growth and weight gain were promoted by the addition of moringa seed cake, which is high in proteins and essential amino acids. Body weight gain did, however, decline at greater inclusion levels (25 %), indicating that growth may be impacted by nutritional imbalances at high inclusion rates. Additionally, the diet's energy and protein balance are essential for maximizing weight gain. According to a study by Eleroglu *et al.* (2021), broilers on a high-protein diet gained weight more quickly (3.0 kg) at 42 days than those fed a low-protein diet, which resulted in a far slower body weight gain (2.6 kg). The study underlined that optimizing weight gain requires a diet that offers enough protein for muscular growth.

Weight gain and muscular growth require amino acid supplements, particularly for important amino acids like methionine and lysine. By boosting nutrition absorption, fostering effective digestion, and increasing gut health, feed supplements including probiotics, prebiotics, and amino acid supplements have been demonstrated to increase body weight gain. Ahmad *et al.* (2020) looked at how probiotics affected the growth performance of broilers. The findings showed that at 42 days, broilers fed with a mix of Lactobacillus and Bifidobacterium species weighed 2.9 kg, which was significantly more than those that did not get probiotic supplementation (2.5 kg). This implies that probiotics aid in enhancing the balance of gut microbes, which enhances weight gain and nutrition utilization.

2.13.3 Feed conversion ratio (FCR)

The important performance metric in chicken production is the feed conversion ratio (FCR), which shows how well broilers convert feed into body weight gain. FCR is defined as the ratio of feed consumed to body weight gained. It is expressed mathematically as:

FCR=Total Feed Intake (kg)/body weight gain (kg)

In commercial poultry production, a lower FCR denotes greater efficiency, which lowers feed costs and increases profitability. The usage of additives like enzymes and probiotics, ambient circumstances, feed type, and dietary content are some of the variables that affect FCR, which is a multifactorial feature. Broiler feed composition has a major impact on FCR. Conventional feed materials like soybean meal have been investigated as possible substitutes for alternative ingredients like moringa seed cake.

The effects of adding moringa seed cake to broiler diets at two different levels 20 % and 25 % were investigated in a study by Dlamini *et al*. (2020). They discovered that birds fed the 20 % inclusion diet had significantly higher FCR, and better weight gain, than birds fed higher levels of moringa seed cake. The enhanced overall feed conversion was ascribed by the authors to the superior nutritional quality and digestibility at the lower inclusion level. However, when the inclusion level surpassed 20 %, FCR deteriorated, potentially as a result of an unbalanced supply of other nutrients and essential amino acids. Exogenous enzymes have been demonstrated to improve FCR when added to broiler diets. The breakdown of non-starch polysaccharides (NSPs) in plant-based diets by enzymes such as xylanase improves the digestibility of fiber-rich foods and increases nutritional absorption (Ahmad *et al*., 2020). According to a study by Oyekunle *et al.*

(2021), which examined the impact of supplementing maize-soybean-based diets with xylanase, the addition of the enzyme increased FCR by 8.3 %, most likely as a result of improved digestion and less feed waste. In a related experiment, it was demonstrated that adding antioxidants like vitamin E and selenium increased FCR by lowering oxidative stress, which can hinder metabolism. Broilers fed diets supplemented with 200 mg/kg of vitamin E had an FCR of 1.95, compared to 2.05 in the control group, according to research by Rahimi *et al*. (2022).

Feed form significantly influences feed conversion ratio of broiler birds. In terms of feed efficiency, pelleted feed is typically seen to be better than mash. Pelletizing feed increases feed intake and improves conversion into body weight by lowering dustiness, improving palatability, and reducing feed waste. The FCR of broilers fed mash feed and pelleted feed was examined in a study by Eleroglu *et al.* (2019). The findings showed that the FCR (2.07) of birds fed pelleted diets was significantly higher than that of birds fed mash diets (2.25). This implies that pelleted feed increases feed utilization efficiency, most likely by lowering feed loss from spills and waste, which is a frequent problem with mash feeds.

It is well established that environmental factors, including temperature and humidity, affect broiler FCR. For example, heat stress brought on by high temperatures lowers feed intake and has a detrimental effect on FCR (Ahmad *et al*. 2020). According to a study by Zulkifli *et al.* (2019), which examined the impact of heat stress on broiler FCR, birds grown at ideal temperatures (22–24 °C) had an FCR of 2.15, whereas those exposed to high temperatures (35 °C) had a considerably higher FCR (2.50). Broiler FCR is significantly influenced by stocking density. FCR is negatively impacted by overcrowding because it promotes competition for feed, which may lower individual feed intake and cause more stress (Abou-ELKheir *et al.,* 2021). The effect of stocking density on broiler performance was evaluated by Abou-ELKheir *et al.* (2021), who discovered that birds housed at lower stocking densities (8 birds/m2) had a better FCR (1.90) than those kept at higher densities (12 birds/m2), where the FCR declined to 2.20. According to Zerehdaran *et al.* (2023), contemporary broilers that have been carefully bred for quick development and feed efficiency have significantly higher feed conversion rates than their predecessors. In a study comparing commercial broiler lines, Zerehdaran *et al.* (2023) found that older strains had an FCR of 2.20 whereas newer hybrid strains had an FCR of 1.80. This discrepancy demonstrates the progress made in feed efficiency genetic selection, which is crucial for raising FCR in commercial production.

2.14 Gastrointestinal pH (Gut pH)

In broiler chickens, the gastrointestinal (GI) environment is crucial for immunity, food absorption, and digesting (Sharma *et al.,* 2020). A major factor influencing GI function is gut pH, which is a key driver of enzyme activity, microbial composition, and pathogen management (Cowieson *et al.,* 2017). In general, the pH ranges from near neutral in the ileum and ceca (6.0–7.5) to acidic in the proventriculus and gizzard (2.0–4.0) (Gharib-Naseri *et al.,* 2021). Research has indicated that reducing the pH in the upper digestive tract can enhance the digestion of minerals and proteins (Gheisari *et al.,* 2017). Organic acids like citric and formic acid drastically lowered crop and gizzard pH while improving phosphorus and calcium retention (Yadav and Jha, 2019). According to Gharib-Naseri *et* *al.* (2021), this acidity may improve the solubility of minerals essential for bone formation.

Supplementing with enzymes, especially phytase, has also been demonstrated to change the pH of the GI tract. In addition to increasing phosphorus availability, Cowieson *et al.* (2017) showed that phytase decreases ileal pH by releasing myo-inositol phosphate, which has an indirect impact on fermentation patterns and microbiota. For ingested feed, the crop serves as a temporary storage location where the first stages of microbial fermentation take place. The crop's pH normally falls between 5.0 and 6.0, which promotes the growth of lactic acid bacteria, especially Lactobacillus species (Cowieson *et al.,* 2017). These bacteria have a preventive effect against pathogenic colonization by helping to acidify the crop content.

Chemical and mechanical digestion are carried out by the gizzard (muscular stomach) and proventriculus (glandular stomach). The proventriculus secretes pepsinogen and hydrochloric acid, which lowers the pH to roughly 2.5 to 4.0 (Sharma *et al.,* 2020). Pathogen inactivation and protein denaturation depend on this acidic environment. In addition to controlling feed passage rate and particle size, the gizzard indirectly supports pH stability in later segments.

Bile and pancreatic secretions act as a buffer, causing the pH to progressively rise to a range of 5.5 to 6.5 when digesta pass into the small intestine, especially the duodenum and jejunum (Svihus, 2014). The pH in the ileum may approach neutral levels (6.5–7.0) supports the activity of specific enzymes and transporters responsible for efficient absorption (Gheisari *et al.,* 2017).

The microbial breakdown of indigestible carbohydrates takes place in the caecum, which is fermentation chamber. Microbial fermentation lowers the pH to roughly 5.5 to 6.5 in order to produce short-chain fatty acids (SCFAs) (El-Wardany *et al.,* 2023). In general, good fermentation activities and the inhibition of harmful bacteria like Clostridium perfringens are linked to a lower pH in the cecum (El-Wardany *et al.,* 2023).

2.15 Bone Characteristics or Traits of Broiler

Over the past few decades, muscle accretion has dramatically increased due to the quick genetic improvement of broiler chickens for improved growth rate and feed efficiency (Saki *et al.,* 2017). But concerns about bone integrity and skeletal development have also accompanied this advancement. Tibia length and weight, bone ash content, bone breaking strength, bone mineral density (BMD), and bone geometric features (e.g., cortical thickness, cross-sectional area) are commonly used to evaluate bone qualities in broilers (Liu *et al.,* 2021). The amount of bone ash is thought to be a good predictor of mineralization, especially the retention of calcium and phosphorus (Mohammed *et al.,* 2020). The ability of the bird's skeleton to sustain mechanical strain is reflected in bone density and strength, which is crucial for rapidly growing birds (Mohammed *et al*., 2020). Bone characteristics, such as bone length, density, mineralization, and strength, are essential for overall wellbeing and sustainable production in addition to providing structural support and movement. In the poultry industry, poor nutrition is a major contributor to bone-related disorders such as tibial dyschondroplasia, osteoporosis, lameness and fractures (Sharma *et al.,* 2020).

Broiler bone formation begins during embryonic development and continues rapidly post-hatch (Swiatkiewicz *et al.,* 2017). Bone growth occurs through endochondral ossification, a process where cartilage is gradually replaced by bone tissue (Khan *et al.,* 2022). There are two main types of bones: trabecular (spongy) bone, which is found in the ends of bones and is involved in shock absorption and mineral metabolism, and cortical (compact) bone, which is found largely in the shafts of long bones and provides structural strength (Khan *et al.,* 2022). Modern broilers frequently suffer from a mismatch between skeletal development and body mass gain due to their fast growth rates, particularly during the first several weeks of life (Olukosi and Cowieson, 2016)).

Dietary macronutrients like calcium (Ca), phosphorous (P), and vitamin D are crucial for bone mineralization. Rickets, bone abnormalities, and decreased bone strength can result from unbalanced calcium and phosphorus ratios or inadequate vitamin D (Swiatkiewicz *et al.,* 2017). Nonetheless, certain micronutrients, such as manganese, copper, and zinc, are also involved in the formation of bone matrix and collagen (Olukosi and Cowieson, 2016).

2.16 Carcass Characteristics of Broiler

Characteristics of broiler carcasses are essential for evaluating the quality of the meat, productivity, and profitability of poultry production. Breast, thighs, drumsticks, wings, and other edible and inedible portions make up the majority of the carcass output. The weight of the breast makes up 30–35 % of the total carcass weight, followed by the weights of the thighs and drumsticks (20 %) each and the wings (10 %), according to Eleroglu *et al*. (2019). Compared to older broilers, whose carcasses are more likely to have lower muscle mass and higher fat content, younger broilers usually have a higher proportion of breast and leg meat (Zhang *et al.,* 2022). The optimal carcass weight and component distribution of broilers are determined in large part by their growth trajectory and feed management techniques (Eleroglu *et al*., 2019). According to an experiment conducted by Ahmad *et al*. (2021), broilers sacrificed at 35 days had an average carcass weight of 2.5 kg, with the breast weight making up around 30 % of the overall weight (750 g). This study evaluated the impact of slaughter age on the carcass characteristics of broilers. On the other hand, broilers killed at 42 days had a carcass weight of 2.8 kg and a breast weight of 850 g; nevertheless, the proportion of fat also increased leading to a decrease in the overall quality of the meat. According to the study's findings, the broilers that were slaughtered earlier at 35 days were slimmer, better-quality, and had a better muscle-to-fat ratio.

The overall carcass properties of broilers are mostly determined by the fat content. In markets that favour lean meat, excessive fat deposition might lower the value of carcasses (Oyekunle *et al.,* 2021; Ahmad *et al.,* 2021). When broilers fed a high-energy diet with a higher fat content had a significantly higher percentage of fat in their carcass, especially in the abdominal fat, their lean meat yield was lower than that of birds fed a low-fat diet, according to research by Oyekunle *et al*. (2021) that examined the effects of dietary fat on broiler carcass characteristics.

The genetic makeup of broilers is one of the most important variables affecting carcass yield and the weight of different body parts, according to Dlamini *et al.* (2020). Genetic advancements over time have produced broilers with improved carcass characteristics and increased muscle mass, particularly in the breast, which is highly prized in the market (Dlamini *et al.,* 2020). Larger carcasses with better yields of prime slices like the breast and thighs are typically produced by broilers bred for quick growth and higher feed conversion efficiency (Ahmad *et al.,* 2021). In their analysis of the carcass traits of commercial broiler lines, Zerehdaran *et al*. (2023) found that broilers from contemporary hybrid strains had larger breast muscle weights, weighing 1.2 kg as opposed to 0.95 kg in older genetic lines. These hybrid lines also had a significantly higher total carcass weight (2.6 kg) than the earlier strains (2.2 kg).

CHAPTER THREE: MATERIALS AND METHODS

3.1 Location and Duration of the Study

The study was conducted at the Poultry Section of the Department of Animal Science of the Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development, Asante-Mampong Campus. Asante-Mampong lies in the transitional zone between the Guinea Savannah Zone of the north and the tropical rain forest of the south of Ghana along the Kumasi-Ejura Road. The study started in January, 2025 and ended in March, 2025.

3.2 Dietary Treatment and Experimental Design

The proximate composition of homogenized primary components (maize, wheat bran, soyabean meal, and fishmeal) were assessed and applied in creating four experimental diets (Table 3.1). The experimental design used for the study was completely randomized (CRD). The treatment groups included: treatment one - soybean meal (SBM) (control), treatment two – heat-treated soybeans (HTSB), treatment three - full fat soybeans (FFSB), and treatment four - unrefined soybean oil (USBO) in starter, grower, and finisher diets. The diets were formulated using the 5-feed formulation program from Creative Formulation Concepts, LLC, based in Annopolis, MD. After formulation, the nutrient composition of the diets were determined through proximate chemical analysis according to procedure of AOAC (1990). Throughout the starter phase (d 0 to 28), grower phase (d 28 to 42), and finisher phase (d42 to 56), water and diets were freely available. In all phases, the diets were provided in mash form.

Table 3.1: Composition and calculated analysis of starter diets

Ingredients	T1	T2	T3	T4
Corn	66	56	56	54
Soybean meal	18.05	0	0	0
Full fat soybean	0	20	20	20
Soybean oil	0	0	0	1.5
Wheat bran	3.65	10.7	10.7	11.2
Fish meal	11	12	12	12
Salt	0.5	0.5	0.5	0.5
Oyster shell	0.3	0.3	0.3	0.3
Premix (vitamin-mineral)	0.5	0.5	0.5	0.5
Calc. Nutrient composition				
Protein	20.44	20.68	20.68	20.58
Calcium	0.72	0.7	0.7	0.69
Phosphorus	0.24	0.31	0.31	0.31
Metabolizable energy Kcal/kg	3000	3020.89	3020.89	3095.92
Methionine	0.43	0.39	0.39	0.39
Lysine	1.22	1.19	1.19	1.19
Sodium	0.3	0.31	0.31	0.31
Fibre	3.2	3.86	3.86	3.85

T1=Soybean meal diet, T2=heat-treated soybean diet, T3=full fat soybeans diet, and T4=unrefined soybean oil diet.

Table 3.2: Composition and calculated analysis of finisher diets

Ingredients	T1	T2	T3	T4
Corn	66	56	56	54
Soybean meal	18.05	0	0	0
Full fat soybean	0	20	20	20
Soybean oil	0	0	0	1.5
Wheat bran	3.65	10.7	10.7	11.2
Fish meal	11	12	12	12
Salt	0.5	0.5	0.5	0.5
Oyster shell	0.3	0.3	0.3	0.3
Premix (vitamin-mineral)	0.5	0.5	0.5	0.5
Calc. Nutrient composition				
Protein	20.44	20.68	20.68	20.58
Calcium	0.72	0.7	0.7	0.69
Phosphorus	0.24	0.31	0.31	0.31
Metabolizable energy Kcal/kg	3000	3020.89	3020.89	3095.92
Methionine	0.43	0.39	0.39	0.39
Lysine	1.22	1.19	1.19	1.19
Sodium	0.3	0.31	0.31	0.31
Fibre	3.2	3.86	3.86	3.85

T1=Soybean meal diet, T2=heat-treated soybean diet, T3=full fat soybeans diet, and T4=unrefined soybean oil diet.

3.3 Experimental Birds and Management

During the course of the 56-day experiment, 200 Cobb-500-day-old chicks, all were males, which were raised in an open-curtain housing system with fresh soft wood shavings at a depth of 5 cm. They also had unlimited access to water and starter, grower, and finisher diets. Chicks of comparable sizes were weighed upon arrival from the hatchery and then randomized into 20 floor pens (2.24 m^2), with 5 replicate pens per treatment and 10 birds each. There were plastic feeding and watering troughs in each pen.

3.4 Data Collection

3.4.1 Growth Performance

Weekly calculations were made for feed consumption, body weight, feed conversion ratio and livability. Leftover was subtracted from Feed fed to determine feed consumption. By dividing the total pen weight by the total number of birds in the pen, the body weight per bird was calculated. The difference between the birds' final weight and their starting weight was used to computed as body weight gain. The FCR was computed by dividing the weight gain by the amount of feed consumed during the same time period. The number of birds in each pen was divided by the initial total number of birds and multiplied by 100 to determine livability. Throughout the study period, the pens were checked twice a day for mortality. Postmortem examinations were performed on deceased birds. In order to account for mortality, feed intake and feed conversion ratio (feed intake divided by weight gain) were calculated.

3.4.2 Gastrointestinal pH

Two birds per replicate pen had their cervical heads dislocated. The birds were then gutted, and the pH of the crop, proventriculus, gizzard, duodenum, jejunum, ileum, and caeca were measured using a pH meter (Hanna Instruments, UK). To do this, the pointed tip of the tester was inserted directly into the digesta in the lumen of the proximal end of each segment of the same bird, being careful not to touch the walls. Following the acquisition of all readings for each, distilled water was used to rinse the probe. The mean of the two readings for each tract segment was calculated.

3.4.3 Bone traits

The femur and tibia of the sampled birds were taken from the right leg on days 28 and 56 after hatching. These bones were used to measure the dimensions, breaking strength, and ash content of bone. Using a digital caliper, the length (mm) (from the tip of the proximal end to the tip of the distal end) and width (mm) (at the medial region) of the femur and tibia were measured. A scalpel was used to manually flay the femur and tibia in order to determine the breaking strength (BS). The femur and tibia were tested using a universal texture analyzer (Inspekt table50-1, Hegewald and Pesehke, Meβ-Germany) that was configured to collect data at a rate of 10 points per second using a 3-pont fixture bed and a 50 KN load cell. Blue Hill 3 software powered the device. To determine the amount of ash, the femur and tibia were dried at 100°C for 24 hours, weighed, and then burned into ashes at 580°C (28 d) and 600°C (56 d) for 13 hours (h).

3.4.4 Relative organ weight

The liver, breast meat, fat pad, thigh, heart, and empty gizzard were taken from the sampled birds. Each part was expressed as percentage of live body weight (BW).

3.5 Statistical Analysis of Data

To evaluate the effects of soybean meal (control), full fat soybean (heat treated), full fat soybean (not heat treated), and soybean oil (unrefined), data were analyzed as a completely randomized design (CRD) arrangement using the General Linear Model

(GLM) procedure of the Minitab 20.3 statistical software. Pairwise comparisons between treatment means were performed using the Fisher LSD means separation test ($P<0.05$).

CHAPTER FOUR: RESULTS

4.1 Analyzed Nutrient Composition of Experimental Diets

Moisture content in starter diet ranged between 8.09 % (T4) and 9.25% (T2), indicating a relatively similar level of moisture across the treatments, with. Moisture content in grower/finisher diets ranged between 8.41 % (T3) and 10.55 % (T2). This indicates slightly higher moisture content in grower/finisher diets compared to the starter phase. Ash content in starter diets was highest in T4 (15.35 %) and lowest in T3 (11.05 %). Treatment T3 had the highest ash content (12.35 %) in then grower/finisher diets, while T1 had the lowest (9.45 %). Crude protein content ranged from 18.39 % (T4) to 21.02 % (T3), with T3 having the highest protein concentration in the starter diets. Crude protein content was highest in T1 and T3 (19.26 %) and lowest in T4 (16.20 %) in the Grower/Finisher diets. Treatment T3 had the highest crude fat content (9.65 %), while T1 had the lowest (6.70 %) in the starter diets. T3 also showed the highest crude fat content (7.82 %), while T1 again had the lowest (5.81 %) in grower/finisher diets. Diet T3 had the highest ME (3190 kcal/kg), while T4 had the lowest (2855 kcal/kg) in the starter diets whilst T4 showed the highest ME (3029 kcal/kg), while T2 had the lowest (2878 kcal/kg) in grower/finisher diet.

Table 4.1: Analyzed nutrient composition of experimental diets

Analyzed Nutrient Composition (%)	Starter Diets				Grower/Finisher Diets			
	T1	**T2**	**T3**	**T4**	**T1**	**T2**	**T3**	**T4**
Moisture content	9.11	9.25	8.32	8.09	9.62	10.55	8.41	9.08
Ash content	13.16	11.24	11.05	15.35	9.45	11.06	12.35	10.62
Crude protein	20.14	20.58	21.02	18.39	19.26	18.83	19.26	16.20
Crude fat	6.70	7.41	9.65	8.20	5.81	6.27	7.82	6.96
Crude fibre	4.29	6.31	3.59	7.01	5.35	5.63	5.23	3.98
Nitrogen free extract	46.60	45.21	46.37	42.96	50.51	47.66	46.93	53.16
Metabolizable energy kcal/kg	2924	2950	3190	2855	2956	2878	2995	3029

T1; Soybean meal diet, T2; heat-treated soybean diet, T3; full fat soybean diet, T4; Unrefined soybean oil diet.

4.2 Effects of Experimental Diets on the Growth Performance of Broiler Chickens D 0-7 and D 0-14

As can be seen in Table 4.2, experimental diets significantly influenced ($P < 0.05$) the body weight of birds up to d 7. Birds fed soybean meal diet (SBM) recorded the highest body weight as compared to diets containing untreated soybean and soybean oil. However, the birds fed soybean meal diet were not statistically different ($P > 0.05$) from birds fed heat-treated soybean diet (HTSB) with respect to the body weight measured on d 7. Moreover, it was observed that birds fed the HTSB diet did not also differ from diets containing full fat soybean and unrefined soybean oil. On the same period (day 7) birds kept on soybean meal recorded the highest weight gain as compared to their counterparts on other diets, and birds fed heat-treated soybean diet also outperformed birds kept on diets containing full fat soybean and unrefined soybean oil with respect to weight gain measured on day7 (Table 4.2). Feed conversion ratio (FCR) and livability were all not affected by experimental diets.

Two weeks into the experiment, it was observed that all the variables measured were influenced ($P < 0.05$) by dietary treatments except feed intake. Livability was high in birds fed diet containing full fat soybean diet. However, birds fed full fat soybean diet were not statistically different ($P > 0.05$) from birds fed heat-treated soybean diet and soybean meal diet with respect to livability measured on day14. Moreover, it was observed that birds fed soybean meal diet did not also differ statistically from diet containing unrefined soybean oil. Similarly, it was observed from the results (Table 4.2) that experimental diets significantly influenced ($P < 0.05$) the body weight of the birds on day14. Birds fed on soybean meal diet recorded the highest body weight and birds fed heat-treated soybean diet also outperformed birds kept on diets containing full fat soybean diet and unrefined soybean oil diet with respect to body weight on day14 (Table 4.2). Additionally, it was observed that the birds fed soybean meal diet had a better feed conversion ratio ($p < 0.05$) compared to birds on the remaining diets.

Table 4.2: Effects of experimental diets on growth performance of broiler chickens d 0-7 and d 0-14

Treatment	d 0-7					d 0-14				
	Livability (%)	BW, g	Gain, g	FCRc	Intake, g	Livability (%)	BW, g	Gain, g	FCRc	Intake, g
T1	100	112.2^{a}	68.22^{a}	1.201^{c}	45.89	94.00^{ab}	236.2^{a}	192.2^{a}	1.447^{c}	277.9
T2	100	102.0^{ab}	58.00^{ab}	1.496^{b}	44.00	98.00^{a}	206.4^{b}	164.2^{b}	1.741^{b}	281.2
T3	98	93.00^{b}	46.00^{c}	1.685^{a}	32.00	100.0^{a}	172.0^{c}	126.0^{c}	1.990^{a}	252.0
T4	98	96.00^{b}	50.00^{bc}	1.586^{ab}	32.00	84.00^{b}	170.0^{c}	124.0^{c}	1.983^{ab}	244.1
SEM	1.401	3.800	3.680	0.069	4.750	3.740	3.800	7.840	0.081	16.30
P-Value	0.585	0.010	0.003	0.042	0.097	0.036	0.010	0.001	0.001	0.314

T1**;** Soybean meal diet, T2; heat-treated soybean diet, T3; full fat soybean diet, T4; Unrefined soybean oil diet, SEM; standard error of means, abc; means with different superscript are significantly different ($p < 0.05$).

4.3 Effects of Experimental Diets on the Growth Performance of Broiler Chickens D 0-21 and D 0-28

Three weeks into the experiment, it was observed that all the performance variables measured were influenced ($P < 0.05$) by the dietary treatments except for feed intake. Birds kept on the soybean meal diet had better feed conversion ratio (1.756), recorded the highest body weight (437.3 g) and gained more (393.3 g) on d 21 as compared to birds on the other diets. The body weight, body weight gain and feed conversion ratio of birds fed the diet containing heat-treated soybean were all better than the diets containing full fat soybean and unrefined soybean oil. Livability, however was higher in the birds fed diets containing heat-treated soybean and full fat soybean whiles livability was lowest (78 %) in the diet containing unrefined soybean oil (Table 4.3).

Similar results were obtained on d 28 as the birds fed on the soybean meal diet outperformed ($P < 0.05$) their counterparts on other diets with respect to the body weight, body weight gain and FCR. The birds on the heat-treated soybean diet also converted feed more efficiently, gained more weight and appeared heavier than birds on full fat soybean diet and unrefined soybean oil diets respectively as shown in Table 4.3.

Table 4.3: Effects of experimental diets on growth performance of broiler chickens d 0-21 and d 0-28

Treatment	**d 0-21**					**d 0-28**				
	Livability (%)	**BW, g**	**Gain, g**	**FCRc**	**Intake, g**	**Livability (%)**	**BW, g**	**Gain, g**	**FCRc**	**Intake, g**
T1	90.00^{ab}	437.3^{a}	393.3^{a}	1.756^{c}	691.5	76.00^{b}	717.2^{a}	673.2^{a}	1.810^{c}	1216
T2	98.00^{a}	396.0^{b}	352.0^{b}	2.096^{b}	737.0	94.00^{a}	626.2^{b}	582.2^{b}	2.154^{b}	1252
T3	98.00^{a}	309.6^{c}	263.6^{c}	2.605^{a}	685.5	98.00^{a}	476.4^{c}	430.4^{c}	2.872^{a}	1234
T4	78.00^{b}	305.2^{c}	259.2^{c}	2.675^{a}	685.6	70.00^{b}	495.2^{c}	449.2^{c}	2.917^{a}	1305
SEM	4.800	13.60	13.40	0.088	31.90	4.900	22.10	22.00	0.108	57.80
P-Value	0.029	0.001	0.001	0.001	0.620	0.002	0.001	0.001	0.001	0.729

T1**;** Soybean meal diet, T2; heat-treated soybean diet, T3; full fat soybean diet, T4; Unrefined soybean oil diet, SEM; standard error of means, abc; means with different superscript are significantly different ($p < 0.05$).

4.4 Effects of Experimental Diets on the Growth Performance of Broiler Chickens D 0-35 and D 0-42

As shown in Table 4.4, all the performance variables measured on d 35 and d 42 were significantly affected by dietary treatments except for the feed intake. The birds fed soybean meal diet had better feed conversion ratio, body weight gain and body weight compared to those on the other dietary treatments on d 35 through to d 42. Birds on heat-treated soybean diet though outperformed by those on SBM diet, they also converted feed better, gained more weight and weighed heavier than birds kept on full fat soybean and unrefined soybean oil diets as seen both on d 35 and d 42 respectively. Similar to the previous weeks, livability was higher in birds fed full fat soybean diet and diet containing heat-treated soybean whiles the lowest livability was recorded for the birds fed diet containing unrefined soybean oil diet.

Table 4.4: Effects of experimental diets on growth performance of broiler chickens d 0-35 and d 0-42

Treatment	d 0-35					d 0-42				
	Livability (%)	BW, g	Gain, g	FCR	Intake, g	Livability (%)	BW, g	Gain, g	FCRc	Intake, g
T1	54.00^{b}	958.7^{a}	914.7^{a}	2.027^{b}	1839	46.00^{b}	1161.7^{a}	1117.7^{a}	2.025^{b}	2224
T2	74.00^{a}	874.0^{a}	830.0^{a}	2.239^{b}	1854	70.00^{a}	1021.2^{a}	977.2^{a}	2.377^{b}	2306
T3	76.00^{a}	630.0^{b}	584.0^{b}	2.981^{a}	1744	72.00^{a}	763.0^{b}	717.0^{b}	2.973^{a}	2125
T4	50.00^{b}	638.0^{b}	592.9^{b}	3.052^{a}	1805	46.00^{b}	816.0^{b}	770.0^{b}	3.037^{a}	2333
SEM	4.950	33.10	32.10	0.101	74.80	4.360	59.40	59.10	0.121	1070
P-Value	0.003	0.001	0.001	0.001	0.736	0.001	0.001	0.001	0.001	0.529

T1**;** Soybean meal diet, T2; heat-treated soybean diet, T3; full fat soybean diet, T4; unrefined soybean oil diet, SEM; standard error of means, abc; means with different superscript are significantly different ($p < 0.05$).

4.5 Effects of Experimental Diets on the Growth Performance of Broiler Chickens D 0-49 and D 0-56

The experimental diets had influence on body weight gain body weight and FCR ($P < 0.05$) on d 49 and of the feed trial except for feed intake and livability which was unaffected by the diets. Similar observations were made to that of d 56 as the birds kept on the SBM diet outperformed birds fed the other diets with regards to the FCR, body weight gain and body weight of birds. The livability was again seen to be better in diets containing the full fat soybean diets and heat-treated soybean whiles the percentage of live birds was low in the diets containing unrefined soybean oil (Table 4.5).

Table 4.5: Effects of experimental diets on growth performance of broiler chickens d 0-49 and d 0-56

Treatment	d 0-49					d 0-56				
	Livability (%)	BW, g	Gain, g	FCRc	Intake, g	Livability (%)	BW, g	Gain, g	FCRc	Intake, g
T1	44.00	1187^{a}	1143^{a}	2.203^{b}	2492	38.00	1251^{a}	1207^{a}	2.369^{c}	2830
T2	60.00	1143^{a}	1099^{a}	2.667^{ab}	2891	50.00	1210^{ab}	1166^{ab}	2.673^{bc}	3081
T3	62.00	846.0^{b}	800.0^{b}	2.478^{a}	2704	54.00	877.7^{bc}	831.7^{bc}	3.465^{a}	2803
T4	42.00	928.0^{b}	882.0^{b}	3.143^{a}	2753	38.00	1010^{c}	964.3^{c}	3.085^{ab}	2959
SEM	6.000	63.10	62.50	0.275	1420	7.650	73.90	73.10	0.239	1620
P-Value	0.060	0.004	0.003	0.024	0.292	0.355	0.008	0.007	0.026	0.609

T1**;** Soybean meal diet, T2; heat-treated soybean diet, T3; full fat soybean diet, T4; unrefined soybean oil diet, SEM; standard error of means, abc; means with different superscript are significantly different ($p < 0.05$).

4.6 Effect of Dietary Treatments on Gastrointestinal pH (Gut pH) of Broiler Chicken Day 28

According to the results on day 28 (Table 4.6) it was observed that gizzard pH was significantly affected by dietary treatments (P < 0.05). Birds fed the T4 diet (unrefined soybean oil) had the highest gizzard pH (2.091), while those on the T2 diet (heat-treated soybean) had the lowest (1.654). Significant differences were observed in the ileum pH (P < 0.05). Birds fed the T3 (full-fat soybean) and T4 (unrefined soybean oil) diets exhibited higher ileal pH values (7.037 and 6.981, respectively) compared to those on the T1 diet (6.251). Moreover, the experimental diets did not affect the pH of crop, proventriculus, duodenum, jejunum, and caecum (P > 0.05).

Table 4.6: Effect of dietary treatments on gastrointestinal pH of broiler chicken day 28

Parameter	T1	T2	T3	T4	SEM	P-Value
Crop”	4.673	5.112	5.071	4.679	0.190	0.226
Proventriculus	1.441	1.528	1.505	1.629	1.116	0.718
Gizzard	1.917^{ab}	1.654^{b}	1.871^{ab}	2.091^{a}	0.098	0.046
Duodenum	5.383	5.097	5.046	5.330	0.230	0.668
Ileum	6.251^{b}	6.691^{ab}	7.037^{a}	6.981^{a}	0.165	0.015
Jejunum	5.941	5.949	6.032	6.083	0.054	0.229
Caecum	6.816	6.700	6.765	6.760	0.089	0.835

T1; Soybean meal diet, T2; heat-treated soybean diet, T3; full fat soybean diet, T4; unrefined soybean oil diet, SEM; standard error of mean, abc; means with different superscript are significantly different (p <0.05).

4.7 Effect of Dietary Treatments on Gastrointestinal pH (Gut pH) of Broiler Chicken Day 56

According to the results on d 56 (Table 4.7), it was observed that all the gastrointestinal pH variables measured were not affected by the dietary treatments except gizzard. However, it was observed that soybean meal diet recorded the highest gizzard pH and heat-treated soybean diet recorded the lowest pH. Birds kept on soybean meal diet were significantly different ($P > 0.05$) from birds fed heat-treated soybean diet with respect to pH of gizzard on day 56. Moreover, birds fed SBM diet did not differ from birds fed full fat soybean and unrefined soybean oil diets.

Table 4.7: Effect of dietary treatments on gastrointestinal pH of broiler chicken day 56

Parameter	T1	T2	T3	T4	SEM	P-Value
Crop	4.761	4.205	4.657	4.930	0.548	0.810
Proventriculus	1.828	1.481	1.555	1.500	0.263	0.773
Gizzard	2.411	1.734	2.099	1.935	0.195	0.133
Duodenum	5.257	4.516	5.257	4.987	0.319	0.343
Ileum	6.425	6.186	7.229	6.817	0.376	0.257
Jejunum	5.672	5.160	5.914	5.608	0.312	0.410
Caecum	6.766	6.148	6.951	6.816	0.351	0.405

T1; Soybean meal diet, T2; heat-treated soybean diet, T3; full fat soybean diet, T4; unrefined soybean oil diet, SEM; standard error of mean.

4.8 Effect of Dietary Treatments on Carcass Traits of Broiler Chickens at D 28

According to Table 4.8, the results show that there was a significant effect ($P < 0.05$) of the treatments on the liver and the breast weight of the birds on d 28. Birds on the SBM diet recorded the highest liver weight followed by those on the unrefined soybean oil diet but this was statistically similar to the birds on the full fat and heat-treated soybean diet. Also, there was no significant effect ($P > 0.05$) of the treatments on the heart, gizzard and thigh weight at the d 28.

Treatment	**Heart**	**Liver**	**Gizzard**	**Breast**	**Thigh**
T1	0.747	3.875^{a}	2.227	3.637^{a}	8.085
T2	0.793	2.845^{b}	2.612	2.902^{b}	7.959
T3	0.809	2.624^{b}	2.791	3.004^{ab}	7.073
T4	0.775	2.892^{b}	2.490	2.859^{b}	7.503
SEM	0.094	0.179	0.137	0.200	0.287
P-Value	0.969	0.001	0.061	0.051	0.089

Table 4.8: Effect of dietary treatments on carcass traits of broiler chickens at d 28

T1**;** Soybean meal diet, T2; heat-treated soybean diet, T3; full fat soybean diet, T4; unrefined soybean oil diet, SEM; standard error of mean, abc; means with different superscript in a column differ significantly ($p <0.05$).

4.9 Effect of Dietary Treatments on Carcass Traits of Broiler Chickens at D 56

On d 56, there was a significant effect ($P < 0.05$) of the treatment diet on the breast weight of the birds indicating that the birds on the SBM diet recorded the highest breast weight but this was statistically similar to the birds on the het-treated diet and full fat soybean diet. Again, there was no significant effect ($P > 0.05$) of the treatments on the heart, liver, gizzard and thigh weight of the birds.

Table 4.9: Effect of dietary treatments on carcass traits of broiler chickens at d 56

Treatment	Heart	Liver	Gizzard	Breast	Thigh
T1	0.670	2.760	2.272	3.626^{a}	9.226
T2	0.783	2.515	2.408	3.439^{a}	8.805
T3	0.894	2.753	2.456	3.004^{ab}	8.890
T4	0.777	2.405	2.506	2.668^{b}	8.331
SEM	0.111	0.184	0.143	0.224	0.402
P-Value	0.575	0.451	0.691	0.033	0.489

T1**;** Soybean meal diet, T2; heat-treated soybean diet, T3; full fat soybean diet, T4; unrefined soybean oil diet, SEM; standard error of mean, abc; means with different superscript are significantly different ($p < 0.05$).

4.10 Effect of Dietary Treatments on Bone Breaking Strength of Broiler Chickens at 28 and 56

The results from the Table 4.10 indicates that, there was a significant effect ($P < 0.05$) of the dietary treatments on the tibia breaking strength of the birds at day 28, indicating that the birds fed the heat-treated soybean diet recorded the highest tibia breaking strength but this was not statistically different from the birds on the SBM diet. The birds fed the unrefined soybean oil diet recorded the least breaking strength for tibia at d 28 of study. Also, there was no significant effect ($P > 0.05$) of the experimental diet on the femur breaking strength of birds at 28 of the study.

On d 56 of the study, similar trend was observed, as the experimental diet having a significant influence ($P < 0.05$) on the tibia breaking strength of the birds. The birds on the SBM diet recorded the highest tibia strength followed by the birds on the full fat soybean diet but this was not statistically different from the solvent extracted soybean diet and the unrefined soybean oil diet. Again, there was no significant effect ($P > 0.05$) of the experimental diet on the femur strength at d 56 of the study.

Table 4.10: Effect of dietary treatments on bone breaking strength of broiler chickens at d 28 and 56

Treatment	**d 28**		**d 56**	
	Tibia(N)	**Femur (N)**	**Tibia (N)**	**Femur(N)**
T1	122.7^{ab}	145.3	204.9^{a}	152.5
T2	144.8^{a}	145.3	121.5^{b}	127.2
T3	94.20^{b}	106.7	136.2^{b}	136.5
T4	73.90^{b}	108.7	130.1^{b}	116.3
SEM	17.40	15.9	16.40	19.9
P-Value	0.052	0.083	0.009	0.627

T1; Soybean meal diet, T2; heat-treated soybean diet, T3; full fat soybean diet, T4; unrefined soybean oil diet, SEM; standard error of mean, abc; means with different superscript are significantly different ($p < 0.05$).

4.11 Effect of Dietary Treatments on Economic Efficiency of Broiler Chickens at D 56

The result on the economics of production at the end of the 8 weeks period shows that, the price of birds per kilogram weight was 35 Ghana cedis and there was a significant ($P < 0.05$) effect of the treatment on birds at d 56 except total feed cost. Birds fed T1 recorded the highest profit followed by T3 and T4. The lowest profit was recorded in the birds fed diet T4. In terms of price per weight of birds, the birds on diet T1 recorded the highest price but statistically was similar to birds feed diet T4. The lowest price of bird was observed in T2. Again, there was no significant ($P > 0.05$) effect of the treatment on Total Feed Cost (Table 4.11).

Table 4.11: Effect of dietary treatments on economic efficiency of broiler chickens

Treatment	Price of Bird/Kg WT ₵	Price of bird/Wt d 56 ₵	Total Feed Cost d 56 ₵	Profit d 56 ₵	Feed cost d 56 ₵	Price/Weight feed cost ₵	PEI
T1	35.00	59.46^{a}	42.88	16.59^{a}	0.389^{a}	1.699^{a}	126.1^{a}
T2	35.00	41.23^{c}	38.96	2.27^{b}	0.070^{c}	1.178^{c}	67.60^{c}
T3	35.00	53.15^{b}	40.96	12.20^{a}	0.299^{b}	1.519^{b}	94.80^{b}
T4	35.00	55.36^{ab}	39.90	15.46^{a}	0.394^{a}	1.582^{ab}	93.50^{b}
SEM	0.000	2.791	2.492	1.890	0.072	0.080	8.300
P-value		0.001	0.458	0.001	0.001	0.001	0.001

T1**;** Soybean meal diet, T2; heat-treated soybean diet, T3; full fat soybean diet, T4; unrefined soybean oil diet, SEM; standard error of mean, abc; means with different superscript are significantly different ($p < 0.05$).

CHAPTER FIVE: DISCUSSION

5.1 Nutrient Composition of the Experimental Diets.

The crude protein content was highest in T3 21.02 % which was similar to the 21. 05 % recorded by Das (2019). The higher protein content in T3 can be attributed to the inclusion of full-fat soybean, which combines both the protein-rich soybean meal and soybean oil. The lower protein in T4 may be due to the dilution effect of the unrefined oil (vagadia *et al.,* 2017), which contributes little to the protein fraction.

The highest fat content (9.65 %) was observed in T3**.** The high crude fat content in T3 could be attributed to the presence of the natural oil in full-fat soybeans. This is in tandem with the findings of Das (2019) who opined that the crude fat of full fat soybeans is general higher as compared to defatted soybeans because the full fat soybeans retain their natural oil content. T4 followed closely with 8.20 %, which reflects the oil-based composition of the treatment. T1 (6.70 %) and T2 (7.41 %) recorded the lower fat content which aligns with their defatted nature (vagadia *et al.,* 2017).

Fibre contents were highest in T4 (7.01 %) and T2 (6.31 %), which could be potentially attributed to inclusion of hulls and partial processing technique. The hull is rich in fibre which significantly contribute to the fibre content of the grain (Okonkwo *et al.,* 2023). High fibre content in broiler feeds could lead to reduced nutrient digestibility, protein and energy dilutions. However, the birds fed T2 and T4 exhibit signs of protein and energy because the values obtained in this study are within the normal range of 2.5-8 % reported by (Nguyen *et al.,* 2021). The lower fibre content recorded in T3 (3.59 %) is important for nutrient digestibility, especially in young chicks. Das, (2019) reported that a low fibre content improves the microbial activities in the caecum, which improves nutrient digestibility and absorption in chicks.

T3 showed the highest energy (3190 kcal/kg), followed by T2 (2950 kcal/kg), T1 (2924 kcal/kg), and T4 (2855 kcal/kg). The high energy value in T3 is directly linked to its elevated fat and protein content, both of which are dense energy sources. Despite its oil content, T4 had the lowest ME, which could be partly due to lower protein and imbalanced nutrient ratios.

T4 showed the lowest fibre content (3.98 %) in the grower/finisher stage, possibly improving digestibility in older birds. T2 and T1 had moderate fibre content, while T3 was slightly higher than T4 but within an acceptable range of 2.5-8 % for grower diets reported Nguyen *et al. (*2021).

T4 recorded the highest ME (3029 kcal/kg), followed by T3 (2995 kcal/kg). This shows that despite its lower protein, the combination of high NFE and moderate fat makes T4 a rich energy source. T2 had the lowest ME (2878 kcal/kg), likely due to heat treatment possibly reducing nutrient digestibility.

5.2 Effects of the Experimental Diets on the Growth Performance of Broiler Chickens.

The higher body weight observed in birds fed the SBM diet on day 7 aligns with the established role of nutritionally balanced soybean meal in supporting optimal growth during the early stages of development. Soybean meal is often manufactured to provide a precise nutrient concentration of essential nutrients, including amino acids, energy, and vitamins, that are critical for growth and development of broilers (Ravindran *et al*., 2017). The lack of statistical differences between birds fed SBM and those on the heat-treated soybean diets suggests that heat treatment effectively improves the nutritional value of soybeans, reducing anti-nutritional factors like trypsin inhibitors, which otherwise hinder protein digestibility (Kumar *et al*., 2019).

However, the poorer performance of birds on full fat soybean and unrefined soybean oil diets may be attributed to the presence of anti-nutritional factors or the unbalanced energy-to-protein ratio in these diets. Full fat soybean contains anti-nutrients such as lectins and phytic acid, which can interfere with nutrient absorption and metabolism, leading to suboptimal growth (Singh *et al*., 2015). Similarly, the higher energy content of unrefined soybean oil might have diluted the protein supply relative to energy demands, resulting in slower growth.

By day 14, significant differences were observed in body weight and weight gain, with birds on SBM consistently outperforming those on the other treatments. These findings further underscore the nutritional superiority of soybean meal, especially when compared to full fat soybean-based diets. Birds fed heat-treated soybean diets also demonstrated improved performance compared to full fat soybean diets, confirming the efficacy of thermal processing in enhancing nutrient availability and digestibility (Ravindran *et al*., 2020).

The better feed conversion ratio (FCR) observed in birds on soybean meal diets reinforces the idea that well-balanced SBM supports more efficient nutrient utilization, minimizing waste and optimizing growth. This is consistent with previous studies where broilers on high-quality, balanced diets exhibited superior FCR compared to birds on less refined feed formulations (Choct, 2018). While birds on heat-treated soybean diets showed improved FCR compared to full fat soybean diets, the difference was not enough to match the SBM diet's efficiency, likely due to residual anti-nutritional factors or slight imbalances in nutrient ratios. Livability remained unaffected by dietary treatments at day 7, suggesting that none of the diets had adverse effects on bird survival during the initial stages. Feed intake was not significantly influenced by the experimental diets across the study period. This indicates that the birds adjusted their intake to meet their energy and nutrient requirements regardless of dietary composition, as suggested by the "nutritional wisdom" hypothesis (Forbes, 2007). However, the differences in growth performance and FCR across diets suggest that the nutrient density and digestibility of the diets, rather than the quantity consumed, played a more critical role in determining outcomes.

By week three and four, birds on the SBM diet outperformed others, achieving the highest body weight, weight gain, and the most efficient FCR. This aligns with previous findings that nutritionally balanced feeds, enriched with adequate protein, energy, and essential nutrients, promote rapid growth in broilers (Ravindran *et al*., 2017). Birds fed with heat-treated soybean diet also exhibited improved growth performance compared to those on the full fat soybean and unrefined soybean oil diets, which may be likely due to the reduction of anti-nutritional factors like trypsin inhibitors through the heating, which might have improved protein digestibility and nutrient utilization (Kumar *et al*., 2019). Conversely, the poorest performance was observed in birds on the unrefined soybean oil diets, likely due to an imbalanced energy-to-protein ratio that hindered growth efficiency.

At five and six weeks, the trends persisted, with birds on SBM diets achieving the best FCR, weight gain, and body weight. Heat-treated soybean diets continued to outperform full fat soybean and unrefined soybean oil diets, highlighting the advantages of heat processing in mitigating anti-nutritional effects and improving feed efficiency (Ravindran *et al*., 2020). Despite performing better than full fat soybean and unrefined soybean oil diets, birds on heat-treated soybean diets did not match the soybean meal diet’s efficiency, suggesting that SBM provide a more optimal nutrient balance. Livability remained highest among birds fed full fat soybean and heat-treated soybean diets, emphasizing their adequacy in maintaining broiler health. In contrast, birds on soybean oil diets consistently had the lowest livability, possibly due to dietary deficiencies or imbalances causing health challenges.

By the seventh and eighth weeks, the performance differences became more pronounced, with the SBM having superior performance in FCR, weight gain, and body weight. This sustained advantage reinforces the efficacy of SBM in supporting growth through all stages of broiler production (Choct, 2018). The improved performance of birds on heat-treated soybean diets over full fat soybean diets again highlights the role of processing techniques in improving nutrient availability. Livability trends remained consistent, with higher survival rates in birds fed heat-treated and full fat soybean diets, while birds on unrefined soybean oil diets exhibited persistently low livability. This suggests that diets with appropriate nutrient ratios and minimal anti-nutritional factors are critical for maintaining broiler health over extended periods.

5.3 Effect of Dietary Treatments on Gastrointestinal pH (Gut pH) of Broiler Chickens

The significant difference in gizzard pH between birds fed soybean meal diet and those on heat-treated soybean diet aligns with findings from earlier studies. Soybean meal diets are often formulated with optimal nutrient compositions, including buffering agents or other additives, which may elevate pH levels in the digestive tract. For example, Khattak *et al*. (2018) reported that diets with higher inclusion of calcium carbonate and other mineral buffers tend to increase pH in the gizzard, creating a less acidic environment. Conversely, heat-treated soybean diets may lead to a lower gizzard pH due to the denaturation of proteins and the possible reduction in anti-nutritional factors like trypsin inhibitors. These alterations could enhance protein digestibility and acid secretion, contributing to the lower pH observed (De Coca-Sinova *et al*., 2020).

However, birds on full fat soybean and unrefined soybean oil diets did not differ significantly in gizzard pH from those on the SBM diet. This outcome suggests that the physical or chemical state of soybeans (full fat versus oil-extracted) does not substantially alter the gizzard's acidic environment compared to the soybean meal diet. Meanwhile, diets with unrefined soybean oil might contribute lipids that do not directly influence gizzard pH but support overall feed palatability and energy availability (Nalle *et al*., 2015).

The gizzard's acidity is essential for initiating proteolysis and maintaining a favorable environment for beneficial gut microbiota. A higher gizzard pH, as observed with the SBM diet, might reduce the efficiency of pepsin activation and protein digestion. However, such diets may compensate with supplemental enzymes or optimized nutrient ratios that enhance digestibility downstream in the small intestine (Svihus, 2014). Conversely, the lower pH in birds fed heat-treated soybean diets may enhance the gizzard's proteolytic activity, but excessive acidity could potentially disrupt the microbial balance in the lower gastrointestinal tract.

5.4 Effect of Dietary Treatments on Carcass Traits of Broiler Chickens

The liver is a central organ in metabolism, detoxification, and nutrient assimilation. The observed reduction in liver weight for birds on soybean-based diets might indicate a reduced hepatic workload compared to the heat-treated soybean diet, which could be attributed to differences in dietary energy and fat metabolism. According to Azman and Çiftçi (2020), dietary fat sources and levels influence hepatic lipid deposition and, consequently, liver weight. Furthermore, enzyme activity and nutrient absorption patterns from processed soybean diets, such as heat-treated soybeans, may have reduced liver hypertrophy compared to the full-fat soybean diet. The higher breast weights on the heat-treated soybean diet may suggest superior protein utilization and deposition in the pectoral muscles. Protein-rich diets are essential for muscle development in broilers, with breast weight often used as an indicator of meat yield (Kokoszyński *et al.*, 2022). Heat-treated soybeans have been reported to improve protein digestibility and amino acid availability (Adeola and Cowieson, 2021), which might explain their competitive performance. There was no effect of dietary treatments on heart, gizzard, and thigh weights at either d 28 or d 56 The stability in heart weight suggests that the diets did not induce cardiomegaly or stress-related cardiac changes. Similarly, gizzard weight consistency might indicate comparable mechanical digestion efficiency, irrespective of diet. Thigh weight was also unaffected, implying uniform protein accretion and bone development in the leg muscles across treatments. Consistent findings have been reported by Alagawany *et al*. (2019), who observed that varying fat sources in poultry diets did not significantly influence heart, gizzard, or thigh weights.

5.5 Effect of Dietary Treatments on Bone Breaking Strength of Broiler Chickens

The study revealed a significant effect of dietary treatments on the tibia breaking strength of broiler chickens at both d 28 and 56. The tibia breaking strength is a crucial indicator of bone health and structural integrity, reflecting the impact of dietary components on calcium and phosphorus metabolism, bone mineralization, and overall growth. At d 28, heat-treated soybean diet led to superior tibia strength, underscoring the benefits of heat processing in reducing anti-nutritional factors and enhancing mineral availability (Ravindran and Hendriks, 2020). However, by d 56, its performance was statistically similar to other diets. Heat-treated soybean diet has been reported to enhance nutrient digestibility and utilization, leading to improved calcium and phosphorus absorption (Adeola and Cowieson, 2021). This could explain the higher tibia strength observed in birds fed this diet. Furthermore, the heat-treated soybean diet, likely optimized for nutrient balance, provided consistent support for bone strength. Birds on soybean oil diets exhibited the lowest tibia strength, potentially due to lower calcium bioavailability or antagonistic effects of dietary fats on mineral absorption (Swiatkiewicz *et al.*, 2017). The soybean oil diet consistently underperformed, possibly due to interference with mineral metabolism. High-fat diets can reduce calcium absorption by forming insoluble soaps with fatty acids in the gut, as noted by Ghiselli *et al.* (2022). Unlike the tibia, the femur breaking strength was not significantly affected by dietary treatments at either d 28 or d 56. This indicates that the femur, being less sensitive to dietary variations, maintained structural consistency across all groups. Factors like uniform load-bearing capacity and growth rates could contribute to this stability. Similar findings have been reported by Shim *et al.* (2012), who observed that certain skeletal traits in broilers are less responsive to diet composition compared to others.

5.6 Effect of Dietary Treatments on Economic Efficiency of Broiler Chickens

The present study revealed a significant effect of dietary treatments on the price of birds at day 56 and total feed cost. Birds fed the soybean meal-based diet (T1) incurred the highest feed cost, followed by those on the full-fat soybean diet (T3) and unrefined soybean oil diet (T4), while the lowest feed cost was recorded for birds fed the heat-treated soybean diet (T2). This trend aligns with findings by Khan *et al.* (2020), who noted that processed soybean products such as soybean meal generally have higher market price due to the added cost of processing, thereby increasing the total feed cost.

The higher feed cost associated with T1 could be attributed to the inclusion of commercially processed soybean meal, which is relatively more expensive than raw or less-processed forms like full-fat or unrefined soybean oil. Similarly, Oluwafemi *et al.* (2016) emphasized that heat-treated and refining processes not only alter the nutritional quality of soybean products but also increase their market cost, thereby affecting the total feed cost.

In terms of the price of the birds at day 56, broilers fed T1 (soybean meal diet) recorded the highest market price, although this was statistically similar to those on T4. This could indicate that birds on T1 and T4 achieved better body weights or carcass quality, justifying their higher market value. Oladokun *et al.* (2017) reported that birds with better muscle development and weight gain generally attract higher market prices, often reflecting the efficiency of the diet consumed.
However, the lowest price of birds was observed in T2. This may suggest that despite the lower feed costs associated with T2, the growth performance of birds fed on full-

fat soybean or unrefined oil diets may have been suboptimal, resulting in lower final body weights and hence reduced market prices. This observation is supported by Chaudhry *et al*. (2015), who found that inclusion of unrefined oil or full-fat soybeans without proper heat treatment can result in reduced nutrient availability due to anti-nutritional factors like trypsin inhibitors.

Despite the insignificant differences in total feed cost, there was significant effect of treatment on overall profit, price of bird/kg weigh price per weight feed cost, price per body weight and production efficiency index (PEI). This implies that while initial inputs and outputs varied among treatments, the overall efficiency and economic returns remained statistically comparable. This aligns with the findings of Adeyemo and Longe (2018), who argued that differences in feed ingredient costs may be offset by variations in feed efficiency and growth performance, thereby equalizing net profitability.

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Based on the findings of the 8-week experimental period, the following conclusions were drawn;

1. Birds on the heat-treated soybean diet demonstrated superior growth performance over the full fat soybean diet and the unrefined soybean oil diet.
2. Feeding birds with heat-treated soybean diet reduced the pH of the gizzard.
3. Birds fed soybean meal (SBM) diet increased liver and breast weight.
4. Feeding birds with soybean meal increased tibia breaking strength of the birds.
5. Soybean meal diet (T1) increased feed cost but also increased profitability and the production economic index of the broiler chickens.

6.2 Recommendations

It is recommended that;

1. In place of soybean meal, heat-treated soybean meal is recommended to Ghanaian poultry farms for better growth performance of broilers.
2. Full fat soybean should be heat-treated before fed to broilers as it was evident from this study that, full fat soybean impedes on the growth performance of the birds.

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