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EFFECTS OF DIET DILUTION, FEED TEXTURE AND FARM FORMULATED DIETS ON BROILER PERFORMANCE, METABOLIC DISORDERS, GASTRO-INTESTINAL TRACT DEVELOPMENT AND COST BENEFITS

By Nchele Peter Kuleile

A DISSERTATION

Presented to the Department of
Animal Nutrition
program at Selinus University

Faculty of Life & Earth Science
in fulfillment of the requirements
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Supervised by
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THESIS APPROVAL

NAME: Nchele Peter Kuleile

DEGREE: Doctor of Philosophy (Animal Nutrition)

TITLE: Effects of Diet Dilution, Feed Texture and Farm Formulated Diets on Broiler Performance, Metabolic Disorders, Gastro-Intestinal Tract Development and Cost Benefits

EXAMINING COMMITTEE: CHAIR: ______________________________

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SUPERVISIOR: Professor Fava Salvatore

DATE DEFENDED/APPROVED ____________________________

DECLARATION

I hereby declare that the dissertation titled "**Effects of Diet Dilution, Feed Texture and Farm Formulated Diets on Broiler Performance, Metabolic Disorders, Gastro-intestinal Tract Development and Cost Benefits**" is my original work and the dissertation has not formed the basis for the award of any degree, associateship, fellowship or any other. The material borrowed from similar titles other sources and incorporated in the dissertation has been duly acknowledged. I understand that I myself could be held responsible and accountable for plagiarism, if any, detected later on. The research papers published based on the research conducted out of the course of the study are also based on the study and not borrowed from other sources.

Signature of the student;  Date; 14 February 2024

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LIST OF ACRONYMS AND ABBREVIATION

AA	Amino Acid
ACC	Acetyl-CoA carboxylase
ADFI	Average Daily Feed Intake
ADG	Average Daily Gain
AF	Aflatoxins
AI	Atherogenic index
AIA	Acid Insoluble Ash
AIBP	Agro-Industrial By-Products
ALP	Alkaline Phosphatase
ALT	Alanine Transaminase
AM	Amylose
AMEn	Apparent Metabolisable Energy
ANFs	Anti-Nutritional Factors
ANOVA	Analysis of Variance
AOAC	Association of Official Analytical Chemist,
AP	Amylopectin
AP	Animal Proteins
APM	Akasya Pod Meal
AR	Apparent retention
AST	Aspartate Transaminase
BHT	Butylated Hydroxytoluene
BOS	Bureau of Statistics
BSFL	Black Soldier Fly Larvae
BV	Biological Value
BW	Body Weight
Ca	Calcium
CD	Crypt Depth
CDM	Cold Dress Mass
CF	Crude Fibre

CIAD	Coefficients of Ileal Apparent Digestibility
CNS	Central Nervous System
CoA	Co-enzyme A
COS	Chitoligosaccharide
CP	Crude Protein
CRD	Completely Randomized Design
Cu	Copper
CV	Coefficient of variation
DBG	Dried Brewers Grain
DF	Dietary Fibre
DL-Met	DL-Methionine
dLys	Digestible Lysine
DMG	Dimethylglycine
DNA	Deoxyribonucleic Acid
DON	Deoxynivalenol
EAA	Essential Amino Acids
EBI	European Broiler Index
EST	Egg Shell Temperature
FAO	Food and Agriculture Organisation
FAS	Fatty acid synthase
FCR	Feed Conversion Ratio
FE	Feed Efficiency
Fe	Iron
FI	Feed Intake
FOS	Fructooligosaccharides
FUM	Fumonisins
GDP	Gross Domestic Product
GE	Gross Energy
GIT	Gastro Intestinal Tract
Gly	Glycine serine
GNP	Groundnut Pod
H_20	Water
H_2O_2	Hydrogen peroxide

H_2SO_4	Sulphuric acid
HCL	Hydrochloric Acid
$HClO_4$	Hypochloric acid
HDL	High-density lipoprotein
HNO_3	Nitric acid
HP	Heat Production
IDF	Insoluble Dietary Fibre
IMO	isomalto-oligosaccharide
IU	International Unit
K	Potassium
Kcal	Kilocalories
Kg	Kilograms
KH_2PO_4	Potassium dihydrogen phosphate
La_2O_3	Lanthium oxide
LC	Lignocellulose
L-Met	L-Methionine
LP	Low Protein
LSD	Least Significance Difference
MDH	Malate dehydrogenase
ME	Metabolisable Energy
MEI	Metabolisable Energy Intake
Mg	Magnesium
Mn	Manganese
MOS	Mannooligosaccharides
MUFA	Monounsaturated Fatty Acids
N	Nitrogen
Na	Sodium
NDC	Non-Digestible Carbohydrates
NEp	Net Energy Production
NFE	Nitrogen Free Extract
NH_4	Ammonium
NRC	National Research Council
NSDP	National Strategic Development Plan

NSP	Non-Starch Polysaccharides
OCM	Olive Cake Meal
OCN	Osteocalcin
OTA	Ochratoxin A
p	Probability value
PDH	Pyruvate dehydrogenase
PI	Performance index
PKM	Palm Kernel Meal
PNM	Peanut Meal
PP	Plant Proteins
PUFA	Polyunsaturated Fatty Acids
RBDG	Re-Fermented Brewery Dried Grain
RDS	Rapidly Digestible Starch
RFI	Residual Feed Intake
RFO	Raffinose oligosaccharide
RNA	Ribonucleic Acid
RS	Resistant Starch
SAM-e	S-Adenosyl Methionine
SBP	Sugar Beet Pulp
SCFA	Short-Chain Fatty Acids
SDS	Sudden Death Syndrome
Se	Selenium
Ser	Serine
SFAs	Saturated Fatty Acids
SFH	Sunflower Hulls
SH	Soyabean Hulls
SHMT	Serine hydroxymethyltransferase
TD	Tibial Dyschondroplasia
TI	Thrombogenic index
TiO_2	Titanium dioxide
TSAA	Total Sulphur Amino Acid
UV	Ultraviolet
VFA	Volatile Fatty Acids

VH	Villus Height
WD	Water Depletion
WI	Water Intake
WR	Water Restriction
WR	Water Restriction
ZEN	Zearalenone
Zn	Zinc
ß	beta

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LIST OF PUBLICATIONS

This thesis is based on the work described in the following published papers underlisted below. The research work was carried out between 2017/18 and 2018/19 academic years at the National University of Lesotho

Kuleile NP, Macheli T, Kamoho S, Jobo T and Ncheche K (2020). The effects of feed forms on broiler metabolic and skeletal disorders. International Journal of Research Publication 52(1). http://ijrp.org/paper-detail/1117

Kuleile NP, Adoko G and Nkheche M (2019). The influence of dried brewery grain in broiler diets on production performance. Online Journal of Animal and Feed Research.9(3):134-138, ISSN 2228-7701

Kuleile NP and Molapo SM (2019). The influence of feed form on broiler production and gastrointestinal tract development. Online Journal of Animal and Feed Research. 9(1):38-43.ISSN 2228-7701

Kuleile NP, Ncheche K, Macheli T and Ntsoana M (2019). The influence of broiler feed form on the metabolic and skeletal disorders. In; PanaAfrica Poultry Congress Proceedings. Lome, Togo. 14–16 May 2019. http://www.cersa-togo.org. pp 16.

Kuleile NP (2018). The comparison of farm formulated and commercial diets on broiler production performance and carcass yield. Abstract ID: 536. In the proceedings for the XVth European Poultry Conference Dubrovnik, Croatia 17th to 21th September 2018, World's Poultry Science Journal. ISBN/EAN: 978-90-829157-0-9.pp 422

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ABSTRACT

The high broiler feed costs, high mortality of chicks and high fat content in broiler carcass had prompted this study. The study was undertaken in Lesotho in the form of four feeding experiments. The seven objectives of the study were to investigate the influence broiler feed texture on broiler performance, carcass quality and gastrointestinal tract development, to study the effects of non-starch polysaccharide inclusion in broiler diets performance, carcass quality and gastrointestinal tract development, to assess the influence of non-starch polysaccharides on broiler metabolic disorders and skeletal disorders, to evaluate the impact of non starch polysaccharides on broiler feed passage rate and utilization, to consider the benefits of broiler diet dilution on feed costs reduction and to compare the effects of farm formulate and commercial diets on broiler performance and feed cost reduction.

All broiler feeding experiments were carried out using Completely Randomised Design (CRD) in a well-ventilated housing structures. Birds were managed intensively under a deep litter system. Feed and water were supplied ad-libitum. Routine management practices including vaccination and drug administration when necessary were observed.Farm formulated diets were compiled with aid of AFOS feed formulation software and they were formulated to meet the nutritional requirements of growing and finishing broilers according to NRC, 1994. The chemical analysis of experimental diets were done using standard methods according to AOAC (1990) as outlined below for determination of the following parameters; dry matter determination, crude protein, energy, crude fibre (ADF & NDF), ether extract, minerals (calcium and phosphorus) and nitrogen free extract.

In the feed texture trial, data collection was done on weekly basis for production parameters such as feed intake, feed conversion ratio, live weight and growth rate while the number of dead birds (mortality), signs of ascites, lameness and SDS data were collected daily. All dead birds were examined for the signs of ascites by presence or accumulation of fluids in the abdominal cavity. Feed utilization trial was conducted during the last week of growing and finishing phases using indicator method. During each phase, two birds were taken from each replicate with six birds per treatment making a grant total of twenty-four birds per each phase. Carcass parameters were collected at the end of finishing phase on carcass weight, dressing percentage, gizzard and intestinal weight and length. Broiler feed passage rate and digestibility trial was conducted during

the last week of growing and finishing phases using indicator method. During each phase, two birds were taken from each replicate with six birds per treatment making a grant total of twenty-four birds per each phase. The diet dilution feeding experiment using NSP lasted for four weeks. Nutrient utilization was determined using both internal and external markers substances according to Sakomura and Rostagno (2007) procedure with modification. Acid Insoluble Ash (AIA) was used as internal marker, which contain mainly silica treated with hydrochloric acid with Celite™ which is an external marker substance to improve the recovery of the markers. Nutrient retention and utilization were calculated.

The findings of the current study on feed texture trial indicated that dietary treatment had a significant ($P<0.05$) influence on all production parameters such as feed intake, live weight, growth rate, feed conversion ratio, mortality rate and all carcass parameters such as carcass yield, weight, dressing percentage and abdominal fat. Gastrointestinal tract development results indicated that dietary treatment had a significant effect on intestinal length ($P=0.015$) whereby birds that consumed diet in a mash form had superior intestinal length. The intestinal and gizzard weight parameters were not significantly ($P>0.05$) influenced by the dietary treatment. The dietary treatment also had a significant effect on incidences of ascites and lameness in broiler chickens whereby birds offered diet in the form of pellets had better production performance and higher incidences of the ascites, lameness and mortality than birds fed diet in mash form. On the other hand the dietary treatments did not have a significant ($P>0.05$) effect on SDS. However, there were more incidences of SDS in birds offered pelleted diets than mash diet. Birds fed mash diet had fewer incidences because they were experiencing moderate growth rates compared to birds fed pelleted diet with fast growth rates.

Broiler chickens that consumed pelleted diet utilized energy and proteins better than those fed mash diet form in all parameters such as apparent metabolisable energy (AME), metabolisable energy intake (MEI), net energy for production (NEp), protein retention and efficiency of utilization for energy and proteins. Birds offered mash spend more time consuming their feed compare to birds fed pellets and therefore, expend more energy in this process resulting in lower feed conversion efficiency. It was evident from the results that diet in mash form can be used to control the incidences of metabolic disorder by reducing growth rates of broilers.

The inclusion of NSP in broiler diets treatments had a significant ($P<0.05$) effect on average feed intake, growth rate, body weight, feed conversion ratio, carcass weight, dressing percentage, gizzard and intestinal weights whereby broilers under control and 25% NSP had similar and better performance than animals in other treatments except for gizzard and intestinal weight which were higher in 75% NSP. The higher fibre content of NSP was found to be the limiting factor in the utilization by broiler especially at inclusion rate beyond 25% which was characterized by low digestibility of dry matter, NDF and protein. Cost benefit analysis indicated that there was a 21% reduction in feed costs when using 25% NSP in broiler diets. It was concluded that 25% NSP inclusion rate is the one giving similar production performance and carcass yield to the commercial feeds except for the visceral parts. Therefore farmers can include the NSP up to 25% in broiler feeds for optimum performance and carcass yield between growing and finishing stages and save 21% in feed costs.

The on-farm feed formulation experiment assessed the influence of two dietery treatments being control in the form of commercial feed and the treatment in the form of farm formulated mixture on broiler production, carcass quality and feed costs. The findings revealed that dietary treatments did not have significant effect on feed intake (P= 0.304), body weight (P= 0.751), feed conversion ratio (P= 0.080), carcass weight (P = 0.06), dressing percentage (P = 0.160) and visceral organs; heart (P = 0.061), liver (P = 0.331), gizzard (P = 0.012) and intestinal weight (P = 0.022). On the other hand the dietary treatments had a significant influence on cost of feed/50kg (P= 0.003) and cost reduction in % (P= 0.002) whereby farm formulated diet was relatively cheaper than commercial diet as per cost of 50kg feed and with respect to cost reduction, farm formulated diet was reduced significantly at about 6% .

It can be concluded that broiler feed texture plays an important role in the production of broiler but both small and large particle size feeds each has its own advantages and disadvantages. For optimum meat yield and fast growth rates pelleted and crumble feeds are recommended because of their significantly high efficiency of utilization and retention rates of energy and protein needed for broiler growth. On the other hand large particle size feeds such as pellets and crumbles enticed high incidences of metabolic disorder. Mash diet is highly recommended where farmers who want to reduce high mortality due to metabolic disorders and to obtain a high quality carcass with low fat content but it will also attract extra feeding costs of two weeks after normal maturity period of six weeks in order to make up for the lower body weight at six weeks. The findings of the study were the clear testimony that mash diet form reduced metabolic and skeletal disorders as well as SDS. The mash diet form also influenced the gastrointestinal development better than other feed forms.

The results of the study confirmed that broiler qualitative feed restriction using NSP at 25% inclusion level gave similar performance to control diet in the following parameters; production performance, carcass characteristics, gastrointestinal tract development, NSP utilization and feed costs. The implication of these findings are that the inclusion of NSP at 25% in broiler diets is able to reduce feeds, growth rate, carcass weight, gastrointestinal tract development, NSP utilization and feed costs though the reduction was statistically different from the control group. Farmers can utilize NSP at 25% rate in order to reduce feed costs, broiler fast growth rates associated with poor quality carcass and high mortality in the form of metabolic disorders. Majority of farmers in Lesotho have access to NSP sources from cereal by products and industrial waste like brewery grain. The nutrients utilization results indicated that broiler chickens utilized nitrogen, starch better than NDF, and concluded that NDF digestibility proved that broiler chickens are not efficient in the digestibility and utilization of high feed ingredients with more twenty-five percent NSP.

According to the findings there were no significant ($p>0.05$) difference between broilers fed commercial and farm formulated feeds on, feed intake, body weight, feed conversion ratio, carcass weight, dressing percentage, heart and the liver. On the other hand there were significant ($p<0.05$) difference between broilers fed commercial and farm formulated feeds on, gizzard weight and intestinal weight whereby birds fed farm formulated had higher weights than those fed commercial diets. Economic analysis results revealed that there were significant differences between commercial and farm formulated diet in respect to cost per 50kg bag and cost reduction whereby the use of farm-formulated diets reduced the feed cost by 6%. The implications of these findings suggest that farm formulated diet can be used to obtain same production performance and carcass yields as commercial diet. Farm formulated diets were relatively cheaper to produce than the commercial, resulting in a more economic production of broiler. It is recommended that poultry farmers could consider formulating their own feeds provided that they have necessary skills or can source out professionals to assist them.

CHAPTER ONE
1.0 INTRODUCTION

1.1 Background

The Kingdom of Lesotho is a small, landlocked country of about 2.2 million people, 65 per cent of whom are rural. Lesotho's climate is generally classified as temperate with alpine characteristics. It is divided into four agro-ecological zones based on climate and elevation: Lowlands, Senqu River Valley, Foothills and Mountains (Cauley, 1986). The country experiences hot summers and relatively very cold winters. Temperatures tend to be lower than in other countries at similar latitudes mainly due to the higher elevations. Four distinct seasons are recognized, with large fluctuations in temperature and very erratic rainfall. Its location exposes the country to the influences of both the Indian and the Atlantic Oceans, with wide differences in temperature. The rainy season is in summer from October to April when about 83 percent of rainfall occurs (Ministry of Agriculture, 1995). In the lowlands and foothills, this period is frost free, with cool nights and warm days. January is the hottest month. In winter, May to July night temperatures are below 0ºC and it is generally cold in Lesotho even at daytime. In the mountains, winter precipitation falls mainly as snow (Ministry of Agriculture, 1995). High winds of up to 20 meters per second can sometimes be received during summer thunderstorms (Climate Change Knowledge Portal, 2021). The relative humidity varies from 45 to 85 percent and is lowest in the month of August and September.

Agriculture is a relatively small part of Lesotho's economy, contributing an average of four per cent to the national gross domestic product (National Statistical System of Lesotho, 2022). During the second quarter of 2021, agriculture GDP grew by 6.9% (BOS, 2021). Livestock production share of the country GDP accounted for 62% of total agriculture contribution. In order to proof their commitment to financing agricultural activities, Malabo Declaration of 2014 stipulated that member countries should target 6% annual growth in agriculture and should contribute 10 percent of their national budget to agriculture for which 3% to be allocated to livestock. The growth in agriculture is a key factor for overall performance of the economy and poverty reduction (Poulton and Kanyinga, 2014).

Despite its low contribution to GDP, agriculture is an important means of livelihood for the majority of rural Basotho (FAO, 2019). Lesotho is faced with chronic food insecurity and malnutrition, primarily affecting women, children, and vulnerable groups from poor households (Lesotho Food Systems, 2021). National Strategic Development Plan 2018/19 – 2022/23 (NSDP II) outlines that in 2017/18, an estimated 15% of the population was food insecure, of which 78% resides in rural areas. This is despite implementation of agricultural support programs, including crop production input subsidy and share cropping initiatives by the Government of Lesotho. Poultry production plays an important role in the food security of Basotho who reside in both rural and township area. Poultry provide a good source and affordable animal protein source. NSDP II has identified poultry production as the priority area for investment in Lesotho. A number of Non-governmental organization has made good progress in the improvement and replication of family poultry in the rural areas of Lesotho aimed at improving food security and livelihood.

Poultry production started during the colonial rule in Lesotho before 1941, and indigenous breeds dominated it. The Department of Agriculture introduced improved breeds scheme for farmers between 1941 and 1952. Poultry plant was built in Maseru between 1953 and 1962, which produced improved chickens, which were sold to farmers. Between 1963 and 1972, Lesotho established applied nutrition programme to address issues of food insecurity and the egg marketing co-operatives to improve the marketing of eggs. The period between 1973 and 1994 saw the regulation of egg marketing system, which was changed to free market system after 1994 because poultry farmer's appealed to the Ministry of Agriculture to be allowed to sell eggs directly to wholesalers, retailers and consumer.

The most common species of poultry in Lesotho is chicken (Gallus Gallus Domesticus). The total number of chickens in Lesotho was estimated at 372 584 according to Livestock Report of 2020 published by the Bureau of Statistic Lesotho (BOS). According to BOS (2022), the most dominant type of production is indigenous poultry that account for 75.3% of the total chickens in Lesotho while improved chickens are dominant by layers and broilers which accounted for 14.7% and 8.4% respectively. The highest number of improved breeds was observed in Leribe district while the highest number of indigenous chickens were recorded in Leribe and Berea (BOS, 2022). Figure 1 below depicts the distribution of chickens types in Lesotho between 2015-2016 financial year and 2019-2020.

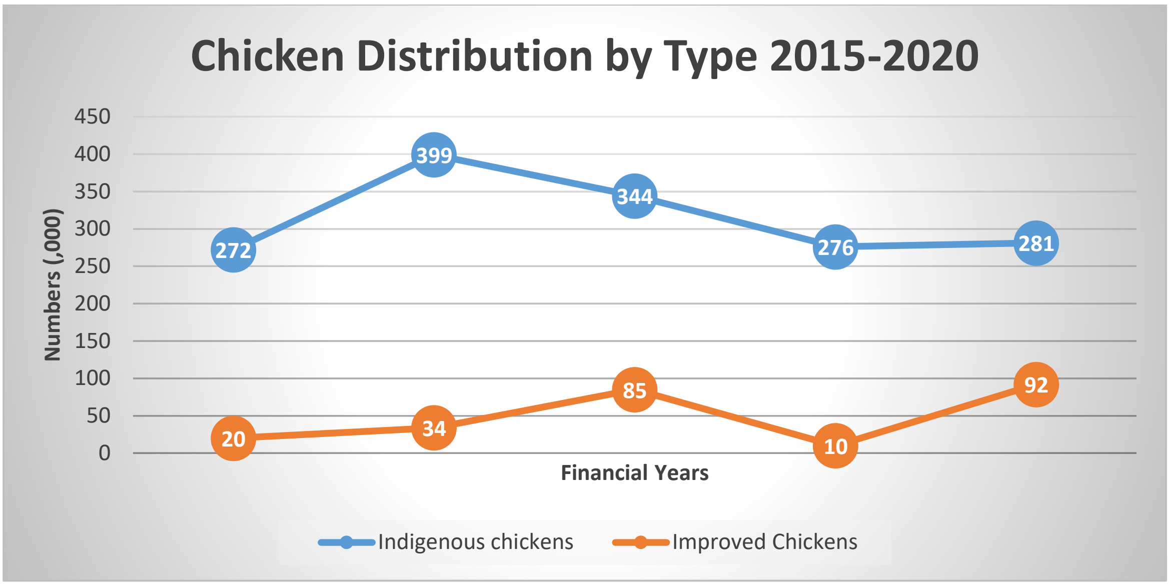

Figure 1: Chicken distribution by type financial year 2015-2016 to 2019-2020

The development of poultry value chain has been earmarked as one of the strategic investment area for the country according NSDP II. The country has secured funding to that effect from US Department of Agriculture. There are many untapped business opportunity in poultry value chain such as broiler and layer parent stock, hatchery, animal feeds production, equipment, medication, packaging materials and value addition processing such slaughter houses and butcheries.

The slow growth of improved breeds in Lesotho could be because of Lesotho dependency on the neighbouring republic of South Africa for supply of poultry products such as meat and eggs as well as inputs such as day-old chicks and layer replacement stock. According to the Department of Marketing, in the calendar year 2019 Lesotho imported broiler products worth of M954 249 136.88 which increased to M15 452 665 443.40 in the calendar year 2021. These products included; breasts, livers, mixed portion, soup pack, thighs, wings, quarter leg, drumsticks, heads and feet, hearts, intestines, neck and whole chicken. The most imported broiler item was thighs which increased from 13 916 297kg in 2019 to 43 658 655 kg in 2021.

Seasonal changes and the altitude affect broiler production and productivity (Khajali, 2022). High-altitude environments such as mountainous districts of Mokhotlong, Thaba Tseka and QachasNek impose several challenges to broiler chickens, including hypobaric hypoxia, dehydration and cold (Parr et al., 2019). Extraordinary growth rate of a broiler chicken turns a 40 g broiler chick at hatch into a 4000 g chicken at 56 days of age (Khajali and Wideman, 2016). As a result, the growth rate of skeletal muscles outpaced the growth rate of the heart and lungs. Therefore, a mismatch has been evolved between oxygen-demanding organs (i.e., muscles) and oxygen-supplying organs (i.e., heart and lungs), which triggers hypoxemia and potentially predispose broilers to ascites syndrome (Decuypere et al., 2000). Lesotho has four seasons with cold winter and hot summers. Cool temperatures are the primary triggers for ascites in broiler production (Wideman, 2001). The incidence of ascites is higher in the colder environmental temperatures (Wideman, 1988; Shlosberg et al., 1992; Yahav et al., 1997), because cold ambient temperatures increase the oxygen requirement, cardiac output, and blood flow and may result in increased pulmonary arterial pressure overload on the right ventricle (Julian et al., 1989).

Due to high costs of heating broiler houses particularly during winter season and high mortality caused by ascites, the majority of farmers do not produce broiler during this season and hence why broiler production in Lesotho is characterised as seasonal production. Tsiouris et al. (2015) reported that fuel cost for heating of poultry houses is a major economic factor for the poultry industry and affects significantly the profit for the producer. The researchers added that this cost makes cold one of the main barriers limiting the development of the poultry husbandry in cold regions of the world. As temperature drop, birds need more calories of energy to maintain their body temperature (Patel, 2022). Therefore, bird consumes more feed to compensate heat loss from body which led to poor feed efficiency. The major constraint associated with poultry feeding is consistent increases in prices of various feedstuffs (Kuleile, 2019) thus as a consequence cheaper and non-conventional feed ingredients have to be used which contain higher percentage of Non-Starch Polysaccharides(NSP) along with starch complexed with them.

Feeding strategy in growing broiler chickens should be to produce animals with maximum lean body mass, highest feed conversion ratio and maximum body weight. Broiler chickens have the genetic potential for significant weight gain over a very short period. Weighing just 42 grama at hatch, broilers can achieve a weight of 2,800 grams within the next 42 days, which is an average daily growth rate of 66 grams (Kenyon, 2019). This growth rate is particular significant within the first seven days, as the bird has the potential to increase its bodyweight by 450 percent from day zero to day seven (Kenyon, 2019). However, these dramatic increases in growth rate and muscle size have ensued some undesirable selection responses, such as high mortality (Chen et al. 2012, Xu et al. 2017, Karaarslan et al., 2023),, increased body fat deposition (Chen et al. 2012,Poltowicz et al.

2015, Xu et al. 2017), a higher incidence of metabolic disorders (Chen et al., 2012, Poltowicz et al. 2015, Xu et al. 2017), a higher incidence of leg problems (Lippens et al.2000, 2002, Rezaei et al. 2006, Dibner et al. 2007, Chodova et al. 2021) and quality issues in breast muscle (Petracci and Cavani 2012, Poltowicz et al. 2015, Huang and Ahn 2018).

Feed restriction has been commonly used to optimize lean carcass tissue, reduce metabolic disorders, control body weight, and reduce reproductive problems in both meat-type and egg-type chickens and excessive fat deposition (Gobane et al., 2021). Fat is an undesirable product that not only increases the occurrence of metabolic diseases and skeletal deformities, but also causes problems in feed efficiency, difficulties in meat processing, and rejection of meat by consumers for health reasons. It is a proven fact that broilers with heavy deposits of abdominal fat indicate poor finishing (Team Pashudhan Praharee, 2023). Feed restriction programs have also shown the potential to reduce the incidence of ascites (Urdaneta-Rincon and Leeson, 2002) and sudden death syndrome (SDS) (Gonzales et al., 1998). These conditions are more commonly observed in fast growing broilers that are fully fed. Broiler chickens fed ad libitum likely consume energy at two or three times greater than their maintenance needs (Urdaneta-Rincon and Leeson, 2002), and so fat deposition is increased. To produce a leaner bird and reduce the unfavourable effects of fat on human health, there is interest in the poultry industry to reduce fat deposition in broiler carcasses. The incidence of heart diseases have increased in humans in the past years and has been associated to high fat consumption, especially saturated fat. Consequently, the consumption of meat containing lower levels of saturated fat (white meat), such as poultry, has increased. Qualitative and/or quantitative feed restriction of broilers might reduce the amount of fat or abdominal fat in carcasses (Cornejo et al. 2007.) Jahanpour (2015) reported that the feed-restricted broilers had lower levels of triglycerides and abdominal fat at the finishing age.

Feed restriction is divided into two main groups namely quantitative and qualitative restriction. Quantitative feed restriction involve the reduction in the amount or quantity of feed offered while qualitative feed restriction is the denial of birds to certain nutrients by mixing the compounded feed with inert fibres sources. Qualitative feed restriction requires changing the nutritional value of the diet or incorporation of chemical drugs (Alkhair, 2021). It is performed by using diets with low energy or protein content or both, this is accomplished by adding non-digestible ingredients and addition of appetite suppression drugs. Many researchers have used diet dilution because of the advantage of attaining a more consistent growth pattern within a flock (Urdaneta-Rincon and Leeson, 2002). The use of diluted diets relies upon the fact that broiler chicks eat close to their physical intake capacity (Gobane, 2014). Diet dilution is accomplished by lowering the level of either protein or energy or both. When broilers fed with low nutrient dense diets they will increase their feed intake in an attempt to maintain nutrient intake.

Non-starch polysaccharides (NSP) constitute a major part of the dietary fibre component in plant-based feed ingredients, accounting for approximately 10% of the nutrients in a poultry diet (Nguyen et al., 2022). The majority of the NSP are composed of arabinoxylans, cellulose and b-glucans. They can also be divided into water-soluble and water-insoluble fractions (Morgan et al., 2022; William et al., 1997). Soluble NSP has a high water holding capacity, causing increased digesta viscosity, which led to increased excreta moisture content (Morgan et al., 2018). Insoluble NSP on the other hand act as a nutrient diluent and physical barrier to digestive enzymes (Hetland et al., 2004). It can also stimulate gizzard and proventriculus function, increasing grinding of feed and peptic digestion in the gizzard, and maintains motility and digesta flow in the gastrointestinal tract through absorbing water and increasing digesta bulk (Yokhana et al*.,* 2016). Dietary NSP directly and indirectly affects nutritive value of the diet, as well as digestive function and metabolic processes, through its impact on development and morphology of the gastrointestinal tract (Nguyen et al., 2022) and on microbiota population and composition (Mahmood and Guo, 2020). Consequently, there is increasing interest in the positive effects of feeding dietary NSP to poultry, including supplementing diets directly with sources of fibre (Nguyen et al., 2022). Most of the NSP present in cereal by-products are insoluble and therefore do not raise digesta viscosity and will not form a highly viscous gel (Choct, 2015). Knudsen (2014) evaluated the NSP content of common cereals used in broiler diet and reported that oats, maize, sorghum and wheat bran had 23%, 38%, 5% and 36% NSP respectively.

Dietary fiber has been considered a nutrient concentration diluent and an antinutritional factor affecting poultry performance (Gonzalez-Alvarado et al., 2008; Mateos et al., 2012; Sadeghi et al., 2015). The main reason was that insoluble dietary fiber had been used as a nutrient diluent due to the lack of enzymes to digest β 1-4, β 1-3 and β 1-6 linkages of non-starch polysaccharides (Raza et al., 2019), which would impair growth performance when the content was high (Heywang, 1950) As a consequence, commercial diets generally contain 2–3% crude fiber (CF) (Choct, 2015). However, CF is also a functional component of normal digestive organ function (Cao et al., 2003; Hetland et al., 2004; Jimenez-Moreno et al., 2009). Moderate dietary fiber could promote the development of digestive organs, increase digestive enzyme activity and nutrient digestibility, improve health status and enhance growth performance in poultry (Tejeda and Kim, 2021; Sklan et al., 2003; Sigleo et al., 1984). Dietary fiber has been associated with changes in growth performance, nutrient digestibility, intestinal morphology and gastrointestinal regulation, which are generally ignored in animal diets, especially in poultry diets.

When bird consumes more feed it will also increase intake of protein and other nutrient through this feed. Protein and other nutrient use for energy production they become waste. To avoid this wastage the ration should be altered in such a way that energy content of ration is increase by using energy rich sources like oil, fat, etc and reduce protein and other nutrient content of ration by keeping energy at same level. In winter number of feeders should be increased as compared to summer. Feed should be available to the bird whole of the day. For proper growth of broiler during summer, diet containing 23% protein and 3100 Kcal ME/kg diet is needed. While in winter 3400 Kcal/kg ME and 23% protein is needed. Therefore there is a need to improve feeding strategies for broiler in order to reduce production costs, metabolic disorders and improve the quality of meat.

Broiler nutrition in recent time have been focused in research on the use of agro-industrial wastes in monogastric feeds. In fact, many feeds that can be fed alternatively at cheaper cost to monogastric livestock are based on the use of agro-industrial waste that are of no food value to humans (Iyayi and Fayoyin, 2005). Onwuka, et al.(1997) stated that a major strategy to develop the livestock industry in developing countries could be the use of agricultural by-products like pineapple waste, corn cobs and brewers dry grain.

1.2 Problem statement

Broiler farmers in Lesotho are facing a number of challenges such as high mortality, poor quality carcass with high fat content and high feed costs, which increases their production cost. Feed costs are estimated at 70% of broiler production. The high feed costs are influenced by high costs of maize and soyabean, which are the chief ingredients in broiler diets. The other challenge is related broiler fast growth rates, which manifest itself in the form of metabolic disorders and condemnation of carcass with high fat content. Farm formulated feeds aimed at reducing feed costs are blended with locally available feed ingredients which are dominated by high fibre content which are poorly utilized by broilers.

1.3 Objectives of the study

1) To investigate the influence broiler feed texture on broiler performance, carcass quality and gastrointestinal tract development
2) To study the effects of non-starch polysaccharide inclusion in broiler diets performance, carcass quality and gastrointestinal tract development.
3) To assess the influence of non-starch polysaccharides on broiler metabolic disorders and skeletal disorders.
4) To evaluate the impact of non starch polysaccharides on broiler feed passage rate and utilization
5) To consider the benefits of broiler diet dilution on feed costs reduction
6) To compare the effects of farm formulate and commercial diets on broiler performance and feed cost reduction

1.4 Impact of the expected results

The finding of the study will be of high benefit to broiler producers, research institution and consumers because it will provide solutions to reduce high mortality rate of chicks and chickens during the finishing stage due to metabolic disorders, address the problematic area of high fat content broiler meat and to resolve the problem of high feed costs. The readily available solution will be sorted in the form of non-conventional feeds inclusion in broiler diets to reduce feed costs as well as the use of qualitative feed restrictions to regulate broiler growth, which will reduce incidence of metabolic disorders and improve carcass quality. The study will also provide important information on the choice of appropriate feed texture suitable for the age of broiler chickens. The study will also justify the benefits of farm feed formulation and qualitative feed restriction on carcass quality and feed costs reduction.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Feeding of broiler

A broiler is any chicken that is bred and raised specifically for meat production. Most commercial broilers reach slaughter weight between four and six weeks of age. Proper animal nutrition is key to successful livestock production. Nutrition is critical to efficient poultry farming. Whether raising chickens for commercial egg or meat production, each flock requires certain poultry nutrition considerations depending on its end use. The same diet does not suit all types of birds through every stage of growth (Anderson International Corp, 2023). The modern broiler is fast-growing and feed-efficient and the first seven days of a broiler's life represent approximately 22% of the growing cycle for a 2kg broiler (Sacranie,2023).There is, therefore, a narrow window of opportunity to provide appropriate management and nutrition in order to maximise performance. Good nutrition can increase feed efficiency and the rate of gain in animals. Animals must be fed diets that meet their needs. If their needs are not properly met, the animals won't grow, reproduce and they could possibly die.

Broiler feeding programme is more emphasized on live weight gain and feed conversion ratio and profitability of farmers. The growth of broilers depends upon the level of balanced protein in their diet along with other nutrients. In absence of optimum level of protein and amino acids the growth is restricted and birds need longer time to reach the marketable weight. The biggest challenge in poultry farming is to provide proper nutrition that is perfectly adapted both to the performance potential and physiological requirements of each category of poultry (Wilhelmsson et al., 2019), while ensuring the financial profitability; hence, 70–75% of production costs are generated by feeding (Pires Filho et al., 2021). Among the dietary ingredients, the most expensive are those providing the desired level of protein (Usturoi et al., 2023).

Any delay in initial feed intake may suppress gastrointestinal development and cause early malnutrition, suppress thyroid activity and inhibit satellite cell proliferation and muscle growth potential (Hussein and Jawad, 2023). These are the lasting effects of early nutrition and feeding on subsequent performance (Sacranie, 2023). Feed deprivation in the first 36 hours of hatching significantly reduces villi height, thus affecting the enterocyte population and subsequent intestinal lymphatic tissue and the immune system

(Hollemans et al., 2018). Allowing chicks to eat and drink as soon as they are placed will provide them with much-needed nutrients, electrolytes and energy to get the digestive system functioning and developing along with other internal organs, allowing the chicks to actively utilise the nutrients and antibodies they absorbed from the yolk for their overall development (Sacranie, 2023). Licuicel Complex is one of the most promising strategies for feeding chicks directly in the hatchery. This product can be administered together with gel and specialized dispensing machines since it contains an innovative formulation that includes several nutrients, vitamins, minerals, highly digestible amino acids, and prebiotics that promote the stimulation of gastrointestinal development and functioning, in addition to positively influencing growth and productive performance, thus favoring the well-being of the birds.

2.2 Dietary nutrients for broiler

Nutrients are the chemical substances found in feed materials that can be used, and are necessary, for the maintenance, growth, production, and health of the bird. The nutrient needs of poultry are complex and vary by species, breed, age and sex of the bird (Damron and Sloan, 1998). More than 40 specific chemical compounds or elements are nutrients that need to be present in the diet of the bird to support life. These materials are divided into six classifications: water, protein, carbohydrates, fats, vitamins, and minerals. A good diet must include all six of these nutrients in proper amounts. If any are insufficient then growth, reproduction, eggshell quality, egg production, egg size and other factors may be affected. Dietary energy is among the most essential among feed nutrients, because it influences the use of other nutrients by its capability to regulate a high degree of feed intake (Seth and Mishra, 2018).

2.2.1 Water

Water is a critical nutrient in bird metabolism and nutrition. From a physiology perspective, water consumed by the bird is used for nutrient transportation, enzymatic and chemical reactions in the body, body temperature regulation and lubrication of joints and organs (Tabler et al., 2023). Water is often not thought of as a nutrient, but it is an important nutrient because it regulates body temperature, transports other nutrients, and takes part in numerous chemical reactions in the body. Therefore, water should be available to the birds at all times.

Poultry require a consistent and sufficient supply of water to meet their physiological needs, such as hydration, thermoregulation, digestion, and waste excretion. Water plays a vital role in multiple metabolic and physiological processes that occur throughout the body. Water aids in the transportation of nutrients; glucose, amino acids, vitamins and minerals. It conducts gases, in particular oxygen and carbon dioxide. Water carries waste products to the liver and kidneys for elimination. It is responsible for maintaining mineral homeostasis (McCreery, 2015). Water aids in the transportation of hormones from their source to the target organ. It is responsible for the adjustment of body temperature. Finally, it aids in the excretion of end-products of digestion (particularly urea), anti-nutritional factors ingested with the diet, drugs and drug residues (McCreery, 2015).

The water intake of poultry can vary depending on several factors, including their age, breed, sex, size, feed intake, environmental conditions, and production stage (Attanti, 2023). Water cools the bird's body through evaporation. Birds do not have sweat glands so a major portion of their evaporative heat loss happens in the air sacs and lungs due to rapid respiration. If medications are to be given to poultry, it is generally through the water. Both the compound and water quantities should be carefully and accurately measured before giving them to the birds.

The normal water consumption for chickens ranges from 1.6 to 2.0 times that of feed intake (Fairchild and Ritz, 2009). Drinking behavior is closely associated with feed intake, such that factors affecting feed consumption will indirectly influence water intake. Several factors affect the daily water requirement for poultry: e.g., housing conditions (temperature, light regimen and intensity, etc.), performance level, and feeding-related factors like type and ingredients (El Sabry et al., 2023).

Numerous factors, including hardness, pH, and total dissolved solids, affect water consumption in chicken farms. Minerals and salts at high concentrations in animal drinking water produce physiological abnormalities in broilers, resulting in loss of the broilers' health, growth, feed intake, and immune status. Water pH might affect palatability and taste, as well as causes problems with regular absorption and digestion. Low pH reduces the performance and decreases shell quality while making water unpalatable and corroding metal components of the watering system (Ravindran and Abdollahi, 2021). The pH range for well water is typically between 6.5 and 7.5 (Saleh et al., 2023).

Water pH is a crucial factor where the ideal pH range for drinking water is between 5 and 7, and if the pH falls below 5, less water will be consumed, which might result in parasitic infections. In contrast, the higher pH levels may imply potential salt contamination (such as sodium bicarbonate), which would lead to reduced absorption of dietary elements, including calcium, phosphorus, potassium, and magnesium (Vermeulen et al.,2002).Also, broilers that were given acidic drinking water performed better, but broilers given alkaline drinking water performed poorly (Veermani et al., 2003). Bobinienė et al (2018) compared the quality of water on broiler performance learned that water treated with electromagnetic vibrations had a positive impact on the chemical composition of meat and carcass of meat. In the trial group, the amount of dry matter and protein in broiler chickens' meat was larger. The water treated with electromagnetic vibrations had a positive effect on broiler chicken carcass yield, the weight of edible parts and muscle weight.

Chikumba and Chimonyo (2014) examined the impact of water restriction on poultry performance found the following results water restriction also affected the weight of birds at 16 wk of age. The BW of the birds at 16 wk of age declined proportionally as the magnitude of water restriction increased. The ADG was also influenced by water restriction level such that birds on 40% of ad libitum water intake had the lowest gains (9.6±0.55 g/bird/d) followed by those that received 70% of ad libitum (13.8±0.55 g/bird/d) while those on ad libitum (19.0±0.55 g/bird/d) water intake had the highest ADG.

Water deprivation resulted in a negative linear relationship on ADFI. As the level of water deprivation increased, ADFI decreased at an increasing rate (Mhmoud et al., 2023). Water restriction had a profound influence on ADFI. Birds subjected to ad libitum water intake had the highest ADFI (81.9±3.04 g/bird/d), followed by those on 70% of ad libitum (70.7±3.04 g/bird/d) and 40% of ad libitum (65.9±3.04 g/bird/d) water intake, which were not significantly different (Chikumba and Chimonyo ,2014). Water restriction level had a significant effect on the FCR. Birds on 40% of ad libitum water intake had the highest FCR of 7.2±0.41 g/g, followed by those on 70% of ad libitum water intake with 5.2±0.41 g/g, while those on ad libitum water intake with 4.4±0.41 g/g had the lowest. In contrary, Offiong et al. (2003) observed no difference in FCR between control and treated group, which was subjected to partial water deprivation.

Mhmoud et al. (2023) conducted an enquiry on the responses of broiler chickens to incremental levels of water deprivation and realized linear increases in the relative weight of gizzard, spleen, heart, lungs, liver, and gastrointestinal tract with an increase in water deprivation levels. The relationship between water deprivation and cold dress mass (CDM) was quadratic. As the duration of water deprivation increased, there was a decrease in CDM. On a similar study Chikumba and Chimonyo (2014) determined that birds on the 40% of ad libitum water intake had the lowest (824±47.7 g/bird) dressed weights compared to those on 70% of ad libitum (991±47.7 g/bird) and ad libitum water intake (1,017±47.7 g/bird), which were not significantly different. Heart weight was significantly lower in birds on the 40% of ad libitum water intake (8±0.4 g/bird) than those on the 70% of ad libitum (10±0.4 g/bird) and ad libitum water intake (10±0.4 g/bird), which were also similar. The highest liver weights were recorded in birds on ad libitum (35±1.9 g/bird) followed by those on 70% of ad libitum (30±1.9 g/bird) and 40% of ad libitum (27±1.9 g/bird), in that order.

Chikumba et al. (2013) and Iheukwumere and Herbert (2003) reported that water restriction(WR) could change the blood constituent profile, e.g., triglycerides, cholesterol, total protein, albumin, and globulin concentrations in the serum of water-restricted chicks. Tissue and organ depletion because of water restriction in broilers was associated with elevated enzyme activities of alkaline phosphatase (ALP), alanine transaminase (ALT) and aspartate transaminase (AST) (Fasina et al., 1999). Chikumba et al. (2014) and Ndlela et al. (2019) reported that severe WR (40% and 70% WR of ad libitum WI) or WD (6–12–18 24 h) decreased muscle fat content and thickness of breast meat cuts. These alterations can be due to the depletion of glycogen reserves and a high rate of catabolism of fat (El Sabry et al., 2023).

Kaya and Dereli Fidan (2023) explored the effect of drinking water temperature on broiler and resolved that management practices such as drinking water temperature in broilers could reduce the detrimental effects of high ambient temperature on growth performance, meat quality traits, and behaviour.

2.2.1.1 Sources of water

The animal obtains water from three sources; drinking water, water in feed and metabolic water (McCreery, 2015).

Drinking water

Drinking water constitutes the greatest source of water to poultry and it is made available in drinkers (Amaral,2004). It is of great concern to poultry producers due to its great variability in quality and potential for contamination.

Water in feed

This is the water available in the feed. However, feeding of wet mashes to poultry has not been recommended for use in large-scale commercial poultry production, on the basis that it does not offer any nutritional advantage and is difficult to apply (Forbes, 2003). Water contained in or on the feed is extremely variable. It may range from a low of 5 percent in dry grains to about 90 percent in young, fast-growing grasses. In addition, the amount of dew or precipitation on the grass at the time of grazing is subject to wide fluctuations. In the case of poultry, diets are blended from dry ingredients and intake of water in a feed accounts for about 10 percent of the total feed intake (NRC, 1981).

Metabolic water

Metabolic water refers to water created inside a living organism through their metabolism, by oxidizing energy-containing substances in their feed (Li et al., 2016). The catabolism of 1 kg of fat, carbohydrate, or protein produces 1190, 560, or 450 g of water, respectively (NRC, 1981). Metabolic water is important to all animals, particularly those residing in dry environments, such as the kangaroo rat (Church et al., 1974). Metabolic water also depends on the type of nutrient catabolized. Oxidation of fat produces the greatest amount of metabolic water. However, overall contribution of metabolic water to daily water needs is less than 5% to 10% in most animals.Birds excrete uric acid and can have a net gain of water from the metabolism of protein (Alagawany et al., 2016). Migratory birds have been reported to rely exclusively on metabolic water production while making non-stop flights. About 70% of metabolic water is located in the cells, with the remaining 30% making up the extracellular space and the blood. The water content of the body is related to its protein content. As an animal ages, it's body fat percentage increases and protein content decreases. As this occurs, the body water content, as a percentage of body weight, decreases (McCreery, 2015).

2.2.2 Proteins

Proteins (Greek proteios, primary or of first importance) are biochemical molecules consisting of polypeptides joined by peptide bonds between the amino and carboxyl groups of amino acid residues. Proteins perform a number of vital functions such as ;structural unit of protoplasm; primary source of amino acids the building block of cellular proteins; biological catalysts known as enzymes are proteins ;hormones, that regulates of chemical reactions; antibodies; transport of water, inorganic ions, organic compounds and oxygen (Fernandez, 2017).

2.2.2.1 Types of Protein Based on Origin

There are two major sources of proteins, animal and plant proteins (Abro et al., 2012).

2.2.2.1.1 Animal Proteins (AP)

These are proteins of animal origin characterized by a better quality protein than vegetable proteins. They have high biological value meaning high profile of essential amino acids. They are called "complete" protein. They are costly (high price), not affected by seasonal variations, available all year round. Lack of or limited antinutritional factors. Require little or no processing before incorporation in human or animal feed/food. Included in small quantities in animal feeds. Chemical composition is relatively standardized. Crude protein greater than 65% CP. The commonly available animal proteins are fishmeal containing 60% of protein. Protein sources of animal origin are generally expensive and its use in animal feed is blood meal, bone meal, meat meal, feather meal, dicalcium phosphate.It is a major source of protein for poultry birds(Abro et al., 2012). Animal protein sources administration in the broiler feed is a beneficial up to 50:50 % inclusion rate.

Animal proteins are well balanced in terms of essential amino acids that are necessary for body growth and development, but they are expensive for commercial broiler production. Therefore, they are usually used to complement the amino acid balance in the diets rather than as the main protein source. Also the concern associated with disease transmission from products of animal origin is also taken into consideration. In general, the quality of animal protein sources is dependent on the composition of the raw material used. Animal protein supplements are derived from poultry and poultry processing; meat packing and rendering operations; fish and fish processing, and milk and dairy processing (Denton et al., 2005).

The administration of animal protein source in broiler ration below 50:50% did not have economical effect on net profit of the flock. The results of the present investigation are further supported by the observation of Memon et al., (2005) who also had similar experience regarding economics and they reported that the net profit was higher in broiler fed rations containing 50:50 % ratio of AP % PP as compared to the other groups. These results are further supported by finding of Ibrahim, (2002) who concluded that better economic efficiency was obtained in chicken given local poultry slaughterhouse by-product meat meal, blood meal, bone meal, feather meal in feed and obtained high net profit due to better feed efficiency

2.2.2.1.2 Plant Proteins (PP)

These are proteins of plant origin, often termed "incomplete" proteins. Characterized by low biological value (BV) compared to animal proteins meaning lower profile of essential amino acids (EAA) (Olsen and Johnson, 2023). Plant protein is included in higher percentages in animal feed, percentage constituent crude protein of plant protein is between 20-45% CP. Its use is affected by seasonal availability. The main source of plant protein used is soybean meal, sunflower cake, cottonseed cake and groundnut cake. Poultry diets are composed of natural feedstuffs, and can therefore be supplemented with small amounts of synthetic amino acids to meet the bird's requirements for the most limiting amino acids(Abro et al., 2012). Not available all year round. It contains antinutritional factors especially in the raw state, proximate composition or chemical composition is not standardized i.e. variable. Plant proteins are usually cheaper than animal proteins; however, there is a limitation to their use because of their content of anti-nutritional factors (ANFs)(Beski et al., 2015). In general, vegetable (plant) protein sources are nutritionally unbalanced and poor in certain EAA and this decreases their biological value as they may not furnish the required limiting amino acids needed by birds for egg and meat production (Beski et al., 2015).

Plant protein requires a lot of processing before incorporation in animal feed. Deficient in one or more essential amino acids and the quality is lower compared to animal proteins (Brennan, 2021). Beskie et al. (2015) reiterated that plant proteins contain some anti-nutritional components that naturally exist within their structures, which can adversely affect the quality of the protein and limit its value in animal nutrition. ANFs are substances produced in natural feedstuffs as byproducts of the different metabolic processes of species (for example, inhibition or activation of nutrients, reduction in the digestive or metabolic utilization of feed) that detract from the nutritive value of the feed (Akande et al., 2010).

The nutritional value of peanut meal (PNM) as one of PP sources has been well clarified, with 40.1–50.9% crude protein, 0.7–6.0% fat and 5.8–12.6% fiber, as well as a rich array of vitamins, minerals and antioxidant components. Furthermore, it also contains some active components, such as resveratrol and peanut lectin (Arrutia et al., 2020).However, there are many limitations when PNM is used as a poultry feed ingredient, including the imbalanced amino acid profiles, anti-nutritional factors (the phytate content is about 1.5%), and vulnerability to contamination by mycotoxins and pathogenic bacteria (Batal et al., 2005; Li et al., 2023).These factors seriously limit the use of PNM as a high-quality protein raw material in poultry feed.

2.2.2.2 Amino Acids

All proteins are polymers containing chains of amino acids chemically bound by amide (peptide) bonds. Most organisms use 20 naturally occurring amino acids to build proteins. The linear sequence of the amino acids in a protein is dictated by the sequence of the nucleotides in an organisms' genetic code. These amino acids are called alpha (a)-amino acids because the amino group is attached to the first carbon in the chain connected to the carboxyl carbon.

In poultry, 22 amino acids are needed to form body protein, some of which can be synthesized by the bird (non-essential), whereas others cannot be made at all or in sufficient quantities to meet metabolic needs (essential)(Alagawany et al., 2020). Essential amino acids must be supplied by the diet, and a sufficient amount of non-essential amino acids must be supplied to prevent the conversion of essential amino acids into non-essential amino acid. Additionally, if the amino acids supplied are not in the proper, or ideal, ratio in relation to the needs of the animal, then amino acids in excess of the least limiting amino acid will be deaminated and likely used as a source of energy rather than towards body protein synthesis(Applegate and Angel, 2008). This breakdown of amino acids will also result in higher nitrogenous excretions (Applegate and Angel, 2008).

Nutraceuticals are the nutrients or constituents of animal diet that have nutritional and pharmaceutical importance by preventing various diseases, possessing immunomodulatory potential, providing health benefits and consequently increasing productivity (Helal et al. 2019; Waheed Janabi et al. 2020). They include nutrients and non-nutrients, like amino acids, minerals, vitamins, fatty acids, enzymes, prebiotics, probiotics, synbiotics, pigments, medicinal herbs, herbal extracts, antioxidants, organic acids, flavouring agents, etc. (Alagawany et al. 2018; Elgeddawy et al. 2020). Besides the role of amino acids as protein and peptide components, some amino acids such as glutamine, cysteine, leucine, arginine, tryptophan, and proline are involved in the regulation of metabolic pathways, thereby affecting growth, protein accumulation, maintenance, immunity, and health (Qaid and Al-Garadi, 2021). Amino acid transport relies on sodium-dependent symporters, proton-motive forces, antiporters, and the gradient of other amino acids. The metabolic fate of absorbed amino acids mainly depends on nutrient availability (Selle and Liu, 2019). Amino acids moving through catabolic pathways ultimately serve as precursors of gluconeogenesis (Ma et al., 2021) and contribute to 40% of the total amino acids loss in fasted animals. Proteins are synthesized from free aminoacids, which become available either from dietary (the end product of digestion) or from metabolic origins as the result of amino acid biosynthesis within the body. These amino acids, either circulating via the blood or accumulating within tissues, form pools. The amino acids concentrations within these pools are based on the equilibrium between gains and losses (Dublecz, 2011).

Excessive amino acids (nitrogen) undergo catabolism, presumably from the degradation of imbalanced amino acids, and can accumulate ammonia (Stern and Mozdziak, 2019). Ospina-Rojas et al. (2014) reported that reducing crude protein (CP) from (220 g/kg to 190 g/kg) increased plasma ammonia by 59.4% (7.27 vs. 4.56 mg/dL) and negatively impacted performance. Ammonia detoxification occurs through its reaction with glutamate to form Glutamine. Glutamine enters the Krebs cycle which produces uric acid and nitrogen waste (Salway, 2018). Glycine (Gly), serine (Ser), and glutamic acid are also needed for uric acid production, and the former can be limiting in low CP diets. It has been suggested that a minimum Gly + Ser value should be set between 2% to 2.5% (Kidd et al., 2021). An imbalance of amino acids resulting in inadequate ammonia detoxification could result in ammonia toxicity and reduced performance (Stern and Mozdziak, 2019). Moreover, bird performance could be further reduced due to increased litter nitrogen resulting in footpad lesions. For example, Ross 308 broilers fed reduced CP at 22 g/kg to 23 g/kg had reduced litter nitrogen and footpad lesions, with no adverse effects on performance or yields (Kidd et al., 2021).

Dietary amino acids are used to build protein for muscle growth, membrane glycoproteins, and enzymes involved in numerous biochemical processes, and act as precursors for the synthesis of DNA/RNA (Wu, 2013). Dietary supplementation with one or a mixture of functional amino acids (glutamine, leucine, proline, arginine, cysteine, and tryptophan) is possibly beneficial for improving or optimizing the efficiency of metabolic transformations to boost muscle development, meat quality and reducing adiposity by inhibiting excess fat deposition (Wu, 2013). Heavy broilers are raised primarily for breast meat, and dietary AA density has a substantial effect on performance and carcass yield. Increased breast meat yield have been reported widely when broilers are fed diets with high AA density

(Johnson et al., 2020). In addition, breast meat yield in current commercial broiler strains is optimized at a higher digestible lysine (dLys) level than that required for growth Kerr et al., 1999). The increased sensitivity of the pectoralis major to dietary lysine relative to other skeletal muscles is an effect of the higher rate of protein metabolism and concentration of lysine in the tissue(Johnson et al., 2020). Furthermore, increasing dietary AA density also reduces fat pad yield(Johnson et al., 2020). This effect has been attributed to changes in gene expression, hormone production, and metabolite formation in response to increased AA intake, which reduce lipogenesis.

Corrent and Bartelt (2011) postulated that to reduce dietary crude protein levels in broiler feed, it is necessary to know which indispensable amino acids become limiting in diets and what the requirement of broilers is. The usage of feed amino acids (methionine sources, L-Lysine sources, L-Threonine) in broiler feed is well established. Depending on the requirement assumed for each amino acid, Valine, Isoleucine, Tryptophan and Arginine are generally considered as the next limiting amino acids in broiler feed. Indeed, the amino acid composition of protein differs between feedstuffs and can impact the order in which amino acids become limiting in diets. Typically, methionine is the first limiting acid in diets for broiler chickens (Bunchasak, 2009) and, consequently, inclusions of synthetic methionine in broiler diets were commercially adopted in the 1960s as they became increasingly cost-effective (Kidd et al., 2013).

Teng et al. (2023) assessed the effects of methionine inclusion in broiler diets on broiler performance and realised that birds fed the diet without Met (60% Met) had significantly lower body weight (BW), body weight gain (BWG), and feed intake (FI), and higher feed conversion ratio (FCR) than the other treatments. L-Met supplementation of total sulfur amino acid (TSAA) requirement (80 and 100% L-Met) increased BW and BWG of birds compared to DL-Met supplementation (80 and 100% DL-Met). Moreover, birds fed L-Met had lower FCR than the DL-Met groups. There was no significant difference for FCR among 80% L-Met, 100% DL-Met, and 100% L-Met, whereas the 100% L-Met had significantly lower FCR than the 80% DL-Met group. Birds fed 100% Met regardless of the isoform had lower FCR compared to those fed 80%.

2.2.3 Carbohydrates

Carbohydrates are very diverse molecules that chemically can be classified according to their molecular size as sugars, oligosaccharides and polysaccharides with the latter consisting of starches and non-starch polysaccharides (NSP) and glycosidic bonds (Cummings and Stephen 2007). Based on the chemical classification, it is possible to group the carbohydrates nutritionally: digestible carbohydrates represent the carbohydrates that can be digested by the host's enzymes and absorbed in the small intestine (monosaccharides, disaccharides and most starches) while non-digestible carbohydrates (NDC) are the carbohydrates that cannot be degraded by the host's endogenous enzymes, but potentially can be degraded by microbial fermentation (Bach Knudsen and Lærke, 2023).

Carbohydrates make up the largest portion of a poultry diet. They appear in greatest supply in plants in the form of sugars, starches or cellulose. Starch is the form in which most plants store energy and it is the only complex carbohydrate, which chickens can readily digest. Chickens cannot digest cellulose. Carbohydrates are the major energy source for poultry but only ingredients containing starch, sucrose or simple sugars are efficient energy providers. Carbohydrates are not present as pure chemical entities as described above. In feed, they are present as a mix of sugars, oligosaccharides and polysaccharides. Furthermore, polysaccharides are mostly linked to other biopolymers such as proteins and lignin.

2.2.3.1 Sugars

Sugars (DP 1-2) are water-soluble components composed of monosaccharides and disaccharides. Sucrose, a disaccharide composed of glucose and fructose, is the most abundant sugar in plant products. Lactose, consisting of glucose and galactose, is the main carbohydrate component in milk, while maltose, made up of two glucose units, is found in sprouted cereals, but not in non-germinated cereals. In most feedstuffs, however, monosaccharides are present in low concentrations (Bach Knudsen and Lærke, 2023). Glucose and sucrose are simple sugars with less complex structures compared with starch. Newly hatched chicks can use both of these simple carbohydrates efficiently (Wang et al., 2018)) have demonstrated that incorporation of glucose or sucrose into broiler diets results in heavier birds compared with starch-based diets. Al-Rabadi et al. (2018) stated that glucose has an amino acid-sparing effect, which results in increased nitrogen retention in the animal body. In addition, glucose may reduce amino acid oxidation, which further enhances retention (Weurding et al., 2003). Glucose can be derived from various sources, such as sucrose. Sucrose is a disaccharide carbohydrate that can be easily utilized by poultry (Wang, 2014) and has been reported to possess a higher AMEn than glucose (3330 kcal/kg vs. 3750 kcal/kg) (Leeson and Summers, 2001). Sucrose has to be broken down into glucose and fructose by sucrase before it can be absorbed (Wang, 2014). Sugar (sucrose) has been accepted as a better energy source than starch and has been reported as a dietary energy source that could, at least partially, replace fat in poultry diets (Hussein et al., 2016). Hussein et al. (2018) indicated that sugar syrup, a high-quality molasses with 76% sugar, composed of major monosaccharides sugars like glucose, fructose and sucrose. Sugar syrup obtained as a byproduct of molasses from refineries. In comparison to starch, sugar is a prominent energy reservoir and the total metabolizable energy of sugar syrup is 15.6 MJ/kg.

Al-Rabadi et al. (2018) investigated the effects of sucrose-based high-lysine diet on blood chemistry, growth performance, and gastrointestinal morphology of broiler chickens during the growing stage and found that carcass weight and breast relative weight was lower in chickens on sucrose-lysine– based diet than in animals on oil-based diet. However, gizzard, liver, and heart relative weights were higher in the sucrose–lysine diet group.No differences were found in relative weights of other organs (thigh, proventriculus, spleen, small intestine, large intestine, and abdominal fat).

2.2.3.2. Oligosaccharides

Oligosaccharides are carbohydrates and composed of short chains of monosaccharides; they improve the performance of poultry, enhance growth of beneficial microbiota in the gut, and stimulate immune ability (Rezaei et al., 2015). In addition, several studies have been carried out to evaluate the feeding of oligosaccharides as prebiotics to poultry. Oligosaccharides can improve feed efficiency due to the enhancement of the intestinal morphology. Chang et al (2022) stated that functional oligosaccharides, which are natural, versatile, non-toxic, and non-resistant compounds, are considered as new feed additives that can replace antibiotics environmental-friendly under certain conditions. Studies have shown that oligosaccharides could improve animal performance, intestinal microflora, immune regulation, antioxidant, antimicrobial, anti-inflammatory, and cholesterol reduction (Camacho et al., 2019; Maochen et al., 2020).The most commonly present oligosaccharides in feedstuffs are raffinose oligosaccharides and fructo oligosaccharides. Raffinose oligosaccharides are a homologous series consisting of 1-4 galactose β-linked units linked to sucrose. They are present in a wide variety of plant materials. Fructo oligosaccharides are a homologous series that consist of 1-7 fructose β-linked with a terminal sucrose unit primarily found in roots of chicory and tubers of Jerusalem artichoke. Other types of oligosaccharides, such as xylo oligosaccharides and transgalacto oligosaccharides, are occasionally used as ingredients. The nutritional effects of oligosaccharides depend strongly on their chemical structure. Oligosaccharides possess several attributes, including an ability to withthstand high temperatures during feed pelleting and the physical and chemical conditions along the gastrointestinal tract (Iji and Tivey, 1998).

Blanch et al. (2022) examined the effects of soy stachyose and raffinose on broiler performance and reported that chickens can use, via fermentation in the caeca and large intestine, galacto-oligosaccharides to a certain extent (up to 1.25% in the diet), generating short-chain fatty acids and consequently energy, which is used for growth. In this sense, low levels of galacto-oligosaccharides could play a role as prebiotics. However, from 1.25% of soy galactosides (GOS) in the diet, chickens cannot ferment higher amounts, so growth is no longer improved. At levels of 1.8% GOS in the feed, body weight gain remains the same as at 1.25%, and the feed conversion rate remains stable.Chang et al (2022) compared three sources of oligosaccharides on broiler performance and intestinal morphology and found that supplemented chitooligosaccharide (COS) in the diet improved the production performance, breast meat quality, and regulation of intestinal microflora in broilers. Small dose of isomalto-oligosaccharide (IMO) (0.1 or 0.2%) improved the performance of laying hens (Wu et al.,2011).Raffinose oligosaccharide (RFO) supplementation significantly increased ADG, but decreased feed efficiency in yellow-feather broilers. It is worth mentioning that during the whole rearing period, the RFO group showed improved ADG by 8%, and feed efficiency was significantly decreased by 2.6%, as compared with the control group(Chang et al., 2022). Birds supplemented with mannooligosaccharides (MOS) and fructooligosaccharides (FOS) and Zn-bacitracin significantly improved BW at both day 21 and day 35, compared with the negative control (Ao and Choct,2013). Birds given MOS and FOS had improved feed conversion ratio (FCR) at day 21. This effect on FCR became less apparent as the birds got older, but still maintained a numerical difference.

2.2.3.3. Starch

Starch is mainly composed of α-glucans in the form of amylose and amylopectin. Amylose is considered to be a linear polysaccharide composed of α-*D*-glucose units linked by α-1,4-glycosidic bonds with less than 0.5% α-1,6-branching points(Ai and Jane, 2018). Amylopectin is a larger, more branched molecule composed of α-*D*-glucose units linked by 95% α-1,4-glycosidic bonds and 5% α-1,6-glycosidic bonds. Amylose/amylopectin ratio is the main factor affecting starch digestion(Tan et al., 2021).Due to its molecular configuration and structure, amylose is not easy to digest in the small intestine, while amylopectin is easy to digest, which may lead to a rapid increase in postprandial blood glucose and insulin levels.

Poultry flocks have a high energy requirement, which they derive from dietary starch, lipid, and protein. In the majority of poultry diets, starch in cereal grains is the most important energy source for which poultry have a high digestive capacity (Herwig et al., 2019). However, feed ingredients vary in starch characteristics that affect the rate and extent of digestion. Among the factors affecting digestion are starch granule size, amylose:amylopectin ratio, and the degree of encapsulation and crystallinity (Parada and Aguilera, 2011). Luo et al. (2023) mentioned that starch is divided into two main components: amylose (AM) and amylopectin (AP). Previous reports have demonstrated that AP is easier to digest than AM, and starches with a higher ratio of AP may lead to a sharp rise in blood glucose and insulin levels (Gao et al., 2020). Additionally, researchers found that the digestion kinetics of starch and amino acids are interdependent, with the properties of starch digestion affecting the metabolic pathways of amino acids (Selle and Liu, 2019). When rapidly digestible starch (RDS, a low AM/AP starch) is consumed, glucose is rapidly released in the small intestine, a process that may not be able to continuously meet the normal energy requirements of broilers. In such cases, more amino acids may be oxidized to provide the energy needed by the body, resulting in a decrease in amino acid utilization (Yin et al., 2019).
It was shown that cereals, the main starch source for birds, affect pH and colour of meat probably through the glycogen metabolism. In spite of the fact that Garcia et al. (2005) show that the replacement of 500 g.kg-1 of maize by sorghum lowered the pH of poultry meat. del Puerto et al. (2016) evaluated the effect on the animal response to different starch sources in diet prior to slaughter for a period and learned that there were no significant effects observed due to the source of starch on weight gain, feed conversion and mortality. Liu et al. (2020) evaluated the performance of broilers fed maize resistant starch (RS) and concluded that feeding broilers with diets containing higher concentrations of RS impaired the development of small intestine, which resulted in lower apparent total tract retention of nutrients and poorer body weight gain, feed efficiency and carcass traits of broiler chickens.

2.2.3.4 Non-starch polysaccharides

NSPs consist of a range of soluble and insoluble polysaccharides predominantly present in primary and secondary plant cell walls (Carpita and Gibeaut,1993). It is by far the most complex part of the carbohydrate fraction because of a large number of different building blocks and a great diversity in linkages to different hydroxyl groups and orientations. The building blocks of NSP are the pentoses arabinose and xylose, the hexoses glucose, the galactose and mannose, the 6-deoxyhexoses rhamnose and fucose and the uronic acids glucuronic and galacturonic acids (or their 4-O-methyl ethers). Therefore, when compared to sugars, oligosaccharides and starch, there are more different building blocks (10 common monosaccharides) that can exist in two ring forms (pyranose and furanose), and these residues can be linked through glycosidic bonds at any one of their 3, 4 or 5 hydroxyl groups available and in 2 (α or β) orientations. As a result, NSP can adopt a huge number of three-dimensional shapes and thereby offer a vast range of functional surfaces. NSP make up the major part of the cell walls where they typically represent 90-95% (Iji and Tivey, 1998).

Dietary fiber has been considered a nutrient concentration diluent and an antinutritional factor affecting poultry performance (Mateos et al., 2012). The main reason was that insoluble dietary fiber had been used as a nutrient diluent due to the lack of enzymes to digest β 1-4, β 1-3 and β 1-6 linkages of non-starch polysaccharides (Raza et al., 2019), which would impair growth performance when the content was high. Consequently, commercial diets generally contain 2–3% crude fiber (Choct, 2015). However, CF is also a functional component of normal digestive organ function. Moderate dietary fiber could promote the development of digestive organs, increase digestive enzyme activity and nutrient digestibility, improve health status and enhance growth performance in poultry (Mateos et al., 2012). Dietary fiber has been associated with changes in growth performance, intestinal morphology and gastrointestinal regulation, which are generally ignored in animal diets, especially in poultry diets (Tejeda and Kim, 2020).

Dietary fiber (DF) is defined as the edible parts of plants or analogous carbohydrates that are resistant to digestion and absorption in the monogastric animals and human small intestine with complete or partial fermentation in the large intestine. It includes mainly non-starch polysaccharides, oligosaccharides, resistant starch, and lignins (Guo et al., 2018). DFs from plant origins may include phenolic compounds, waxes, saponins, phytates, cutin, phytosterols, etc., and/or compounds associated with celluloses, hemicelluloses, and polysaccharides (Dhingra. Et al., 2012). The definition of DF also includes oligosaccharides such as inulin, and fructo-oligosaccharides that are three to nine monomeric units (Dai and Chau, 2016).

Singh and Kim (2021) outlined the chemical of structural fibre like cellulose, hemicellulose, pectins and resistant starch and substantiated that cellulose is the major component of the plant cell wall and consists of a linear chain of up to 10,000 glucose monomer units per molecule linked by ß (1→4) glycosidic bonds. Hemicellulose refers to a heterogeneous group of chemicals that also include both linear and branched chain of monomers other than glucose. Pectins are gel-forming polysaccharides that are mostly found in the outer skin of rind of fruits and vegetables and consists of polymers of galacturonic acids interspersed with rhamnose and branched chain of pentoses and hexoses (Lara-Espinoza et al, 2018). ß-glucans are polysaccharides of variable sizes that consist of glucose polymer linked via ß-(1→3) and ß-(1→6) or via ß-(1→4) and ß-(1→3) glycosidic bonds (Du et al., 2019). Tan et al. (2021) described resistant starch as a homopolysaccharide of glucose that is resistant to digestion by endogenous enzymes and is categorized into various types based on its physical inaccessibility, granular form, retrogradation, and chemical modification.

Tejeda and Kim (2021) suggested a simpler definition of fiber as the sum of soluble and insoluble non-starchpolysaccharides(NSP) and lignin.Notwithstanding their composition, soluble fibers are avoided when formulating broiler diets since these are the type of fibers that increase intestinal viscosity, reducing the passage rate of the digesta through the gastrointestinal tract, which can create hypoxic conditions in the intestinal tract that favour pathogenic bacteria growth. In general, the term of DF refers to any carbohydrate that is not broken down and passes into the large intestine (colon) where it is partially or fully fermented by enteric microorganisms into short chain fatty acids (Ibrahim and Menkovska, 2022). These short chain fatty acids as well as enteric microorganisms cell particles and metabolites promote healthy physiological effects for both human and animals (Ríos-Covián et al., 2016).

Feeding moderate amounts of fibers in diets of poultry has been considered as one of the alternatives proposed to improve nutrient digestibility and growth performance due to their role in the development of the GIT and to modify the characteristics of the intestinal contents (Jha and Mishra, 2021). Pan and Yu (2014) confirmed that the GIT of poultry is particularly different from other species as it is much shorter and lighter. However, it is relatively much longer (i.e., cm/kg body weight) and heavier (i.e., g/kg body weight) in poultry compared to other livestock (Wickramasuriya et al., 2022). The GIT system's function includes digestion, absorption, and protection, and the structure of the gut is well adapted to perform these functions. As the site of digestion, GIT maximizes nutrient utilization to reduce substrate for bacteria and support epithelial cell growth and differentiation.

When the gizzard is well-developed, an improvement in gut motility is also observed, which may reduce the risk of gut pathogens colonizing the lower segments of the GIT, thus reducing the risk of gut diseases, including salmonellosis and coccidiosis (Celi et al., 2017). Jha and Mishra (2021) reported that the coarse fiber particles are selectively retained in the gizzard that ensures a complete grinding and a well-regulated feed flow and secretion of digestive juices. Jiménez-Moreno and Mateos (2013) verified that the inclusion of 3% SBP or oat hulls increased gizzard weight in broilers fed similar types of diets.

The inclusion of fermentable DF in the poultry feed supports the growth and establishment of beneficial microbes and probiotic bacteria by providing them substrates for extracting energy and fuelling their metabolism and it can also provide energy for microbial protein synthesis and prevents the fermentation of undigested protein into ammonia (Singh and Kim, 2021). The dietary inclusion of coarse insoluble fiber sources like oat hulls in moderate amounts (between 2% and 3%) usually improves the growth performance of broilers fed low-fiber diets (Mateos et al., 2012). Pettersson and Razdan (1993) observed that feed intake in 18 day-old chicks was reduced when the level of SBP of the diet was increased from 2.3% to 9.2%. Similarly, Jiménez-Moreno et al.(2011) reported that an increase in the level of the fiber sources from 2.5% to 7.5% linearly reduced average daily weight gain from 1 to 12 days. Sittiya et al. (2019) verified that dietary fiber decreases nutrient digestibility and chicken performance. Santos et al. (2019) also found decreased body weight gain when diets with 2.5% SH were fed to broilers from 1 to 21 days of age. Similarly, Sklan et al. (2003) found that the inclusion of up to 3% soybean hulls in diets decreased body weight gain in turkeys (1 to 4 wk of age). However, turkeys at 14 weeks of age fed 6 or 9% soybean hulls had more body weight gain than those fed 3% soybean hulls. Shahin and Abdelazim (2005) found that high fiber inclusion in broiler diets decreased carcass weight. Mateos et al. (2012) reported that dietary fiber decreased the intestinal length and weight of the organs of birds. Consequently, these changes might reduce carcass yield (Jørgensen et al., 1996).

The presence of insoluble dietary fiber such as cellulose, lignin, and arabinoxylans can also modulate the size of the small intestine, pancreas, and ceca, which can result in improvements of the total tract apparent retention of nutrients and feed efficiency as described by different researchers (Gonzalez-Alvarado et al., 2007). The normal retention of feed in the gizzard has been shown to be between half an hour to one hour, which can increase up to two hours when structural (i.e., fiber) components are added to the diets. In an experiment (Amerah et ai., 2009), it was reported that inclusion of 6% wood shavings increased the size of the proventriculus and gizzard while reducing the relative empty weight of the small intestine and increasing feed efficiency by 4.7%. Similarly, studies using oat hulls and soyhulls at 3% in the diet have been shown to result in increased proventriculus and gizzard size as well as in improved feed conversion (Gonzalez-Alvarado et al., 2007.

The strategical benefit of dietary fiber at low to moderate inclusion level may be due to a decrease in digesta passage rate at upper part of the GIT, thus enhancing digestibility and nutrients' utilisation (Sekh and Karki, 2022). Furthermore, dietary fibre can improve fermentation process at the distal GIT, and can positively modify microbiota maintaining or even enhancing intestinal health and immunity. Dietary fibre can also positively regulate poultry behavior by reducing the risk of vices like cannibalism and over-preening (Sekh and Karki, 2022).

In order to improve utilization of fibrous feeds in poultry Józefiak et al. (2005) proposed that exogenous feed enzymes can reduce the bacterial colonization in the ileum by reducing the nutrients available for fermentation. Bedford and Apajalahti (2001) added that feed enzymes can provide benefits to the birds by releasing more nutrients for utilization by the host while providing degraded products such as oligomers of polysaccharide substrates for utilization by the cecal microbes for the production of short-chain fatty acids (SCFA). Teitge et al.(1991) supported that there are limited processing techniques in use in poultry feed production to improve the utilization of DF but pelleting and micronizing have been reported to increase the action of pentosanase on fibrous diet. Exogenous NSPase, phytase, and xylanase can increase the bioavailability of several nutrients affected by high-fiber content in feed and concurrently provide degraded fiber fragments and oligosaccharides for utilization by the gut microbiome (Teitge et al.,1991). These NSPase enzymes can decrease digesta viscosity and alleviate the deleterious effect of viscous fiber on the intestinal mucosa in poultry (Singh and Kim,2021).

2.2.4 Fats/Lipids

Fats are an important energy source because they contain twice as much energy as any other feed ingredient because of this trait, fats play an important role in starting and growing diets. Fats make up more than 40% of the dry egg contents and 17% of the dry weight of a market broiler. Fats are also important in the diet because they help in the absorption of certain vitamins. They also provide essential fatty acids. Essential fatty acids aid in membrane integrity, hormone synthesis, fertility, and hatchability. The inclusion of fat and oil is a common practice in modern poultry production to increase the energy content of diet. In addition, dietary fat reduced passage rate of the digesta through the gastrointestinal trait, allowing for better nutrient absorption and utilization (Latshaw, 2008). The addition of fat to diet, besides supplying energy, improves the absorption of fat-soluble vitamins, diminishes the pulverulence, increases the palatability of the rations(Poorghasemi et al., 2013).

Fat inclusion in broiler diets affects carcass fat quality because dietary fatty acids are incorporated with little change into the bird body fats (Scaife et al., 1994). 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 (Yau et al., 1991; Pinchasov and Nir, 1992; Saenz et al., 1999). All fats and oils from animal, and vegetable sources, contain mixtures of both saturated and unsaturated fatty acids. Saturated fatty acids (SFAs) contain only single carbon-to-carbon bonds, are quite stable, and are the least reactive chemically. Unsaturated fatty acids contain one (monounsaturated fatty acids [MUFAs]) or more (polyunsaturated fatty acids [PUFAs]) carbon to-carbon double bonds in the cis configuration (Dawood, 2015). The chemical reactivity increases as the number of double bonds increase. Trans fatty acids are unsaturated fatty acids that contain at least one double bond in the trans configuration (Dawood, 2015). Fat is mainly composed of triglycerides and, although fats are not water-soluble, its digestion takes place in an aqueous environment of the gastrointestinal tract, where it is hydrolyzed by lipase into fatty acids and mono- and diglycerides

Ferrini et al. (2008) observed that the replacement of tallow by vegetable fats rich in polyunsaturated fatty acids like sunflower oil, soybean oil, or linseed oil resulted in a decrease of abdominal fat deposition in broilers. On the other hand, Shahryar et al. (2011)

found that the addition of 6% animal fat in broiler diet led to an increase of abdominal fat and gizzard weight in comparison with those of birds fed unsupplemented diets. Seyedalmoosavi et al.(2023) reported that using up to 20% full-fat black soldier fly larvae (BSFL) in the diet did not influence key meat characteristics and broiler performance. Similarly, Cullere et al. (2019) reported that breast and leg physical meat quality and nutritional composition remained substantially unaffected in broilers that received diets in which 50% or 100% of the soybean oil was replaced with BSFL fat. However, Murawska et al. (2021) found that replacement of soybean meal with high levels (75 or 100%) of full-fat BSFL meal in broiler diets compromised growth performance and carcass traits (lower juiciness and taste intensity).

2.2.5 Minerals

Minerals are often classified as macro or trace minerals in reference to the concentrations required(Pal, 2017). Macro-minerals such as calcium and phosphorus are generally required in larger quantities than trace minerals like iron, copper and iodine. In some cases, the ratio of one mineral to another is important. Calcium to phosphorus ratios are a primary example. Minerals are important for structural components such as bones and physiological processes. Minerals complete many important functions in the poultry body. It is most important in the formation of bones. Laying hens also require calcium for eggshell formation. Minerals are needed for the formation of blood cells, blood clotting, enzyme activation, energy metabolism and muscle function. Grains are low in minerals, so all poultry feeds contain supplemental sources. Calcium, phosphorus and salt are needed in the greatest amounts. Micro minerals like iron, copper, zinc, manganese and iodine are supplied through trace mineral mixes.

Essential vitamins and minerals are not always found in sufficient quantities and/or available forms in the feedstuffs used for poultry. Therefore, they are supplemented in diets by using vitamin and mineral premixes. Premixes are formulated specifically for each species, as well as the stage of growth and/or production. Vitamins and minerals are found in commercial feeds at adequate amounts. If mixing ingredients with a supplement or concentrate on farm, instructions can be obtained from the feed tag or by consulting with the feed company’s nutritionist. An excess or deficiency in vitamins and minerals fed to poultry may lead to sickness or disease.

Inadequate mineral supplementation during the growth phase of birds results in an imbalance in mineral homeostasis and improper development of bones, i.e., abnormal bone calcification (Faria et al., 2020). However, excess calcium (Ca) may act as an antagonist, making it difficult to absorb trace minerals such as iron (Fe), copper (Cu), zinc (Zn) and other minerals such as magnesium (Mg), sodium (Na) and potassium (K) (Smith and Kabaija, 1985; Waldroup, 1996).

Faria et al. (2020) supported that trace minerals such as selenium (Se), Cu, Fe, manganese (Mn) and Zn are essential to chicken development because they are active in several metabolic pathways. These minerals are involved in physiological functions that are essential to the maintenance of life, including reproduction, growth, immune system function, bone formation and energy metabolism (Dibner et al., 2007).

Mineral imbalance, particularly of calcium(Ca) is one of the problems responsible foreconomic losses to poultry industry. Maintenance of calcium and phosphorus (P)ratio at 1.0:0.5 is essential for performing various functions in the body (Angel et al.,2005). Calcium is important for bone development, blood-clot formation, muscle contraction and eggshell quality (Talpur et al., 2012). Dietary Ca and P have no effect on weight gain and feed efficiency but increased bone ash Ca level at third week of age (Scheideler et al., 2008).

The calcium level of 10 grams kg–1 combined with micro mineral supplementation level of 0.82 grams per kg results in greater weight gain, higher deposition of the macrominerals calcium and phosphorus in bone tissue and of the microminerals Manganese, Zinc, iron, copper and selenium in the liver and breast and lower excretion of these microminerals in the litter (Faria et al., 2020). Trace minerals such as iron, manganese, zinc, copper and selenium play many significant roles as enzyme cofactors and as constituents of metalloenzymes, either individually or in combination, in supporting growth, production and maintenance of the structural integrity of tissues (Saber et al., 2020). The availability of minerals from feed materials of plant origin, as well as from traditional inorganic sources, i.e., oxides, sulphates, or carbonates, is relatively low, while the requirements of modern, high-producing lines of laying hens and broiler chickens for microelements are very high(Saber et al., 2020).

2.2.6 Vitamins

There are 13 vitamins required by poultry that are classified as fat or water soluble. Fat soluble vitamins are A, D, E and K. Water soluble vitamins are thiamin, riboflavin, nicotinic acid, folic acid, biotin, pantothenic acid, pyridoxine, Vitamin B12and choline (Mitchell, 2015). Vitamins are nutrients required in small amounts (milligrams or micrograms) which may or may not be synthesized by the animal´s organism. They are classified according to their physiological functions in the body and how they contribute to the maintenance of health. Vitamins are essential for the different development phases of a bird, and their absence in the diet, or low absorption, may induce signs of metabolic deficiency (Barroeta et al., 2012). Fat-soluble vitamins (A, D, E and K) have a primary role in the bird´s metabolism. These vitamins are digested and absorbed through the same pathway as fats because they are associated with food lipids and are stored in tissues like the liver and adipose tissue (Barroeta et al., 2012).

The recommended fat-soluble vitamin supplementation levels to ensure satisfactory performance are 7500 IU of vitamin A, 2000 IU of vitamin D3, 10 IU of vitamin E and 1.8 mg of vitamin K per kilogram of diet. However, the National Research Council (NRC, 1994) recommends supplementing 2500 IU, 250 IU, 4 IU and 0.4 mg of vitamins A, D3 , E and K3 per kilogram of diet (Rostagno et al., 2011), Inclusion levels vary considerably between recommendation tables, line manuals and companies' recommendations.

2.2.6.1 Vitamin A

Vitamin A is required for normal growth, reproduction and maintenance of epithelial cells in good condition (skin and the linings of the digestive, reproductive, and respiratory tracts). Deficiency causes nutritional roup, characterised by conjunctivitis, oculo-nasal discharge, and eyelids stuck together with thick exudates. In advanced cases necrosis and keratinisation of mucosa of alimentary and respiratory tract occurs (Khan et al., 2023). Fish liver oil and greens are rich sources of vitamin A (Castaneda et al., 2005).

2.2.6.2 Vitamin D3

Vitamin D, also known as calciferol, is the inactive form of vitamin D that can be ingested through diet or be generated endogenously in the skin when exposed to UV light. Vitamin D is converted into its active form 1,25-dihydroxycholecalciferol (1,25-(OH)2 D3), following a two-step hydroxylation process mediated by two key enzymes, 25-hydroxylase and 1α-hydroxylase (Vinayak ingredients,2022). Vitamin D3 is required for proper absorption and utilisation of calcium and phosphorous, which are required for normal growth, bone development, and eggshell formation (Warren and Livingston, 2021). Vitamin D can be produced when sunlight hits the bird's skin. The poultry industry is interested in reducing tibial dyschondroplasia (TD) in fast-growing broilers. TD occurs in fast-growing avian species and is a lesion in which the growth plate of the tibia head is avascular and is not mineralized causing bowing of the tibiotarsus and lameness of the bird (133, 134). Increasing dietary vitamin D_3 with increased dietary Ca has been observed to reduce the incidence and severity of TD in young broilers (Edwards,1990). Deficiency leads to rickets. Birds produce thin shelled eggs with reduced hatchability, show leg weakness and penguin like sitting posture. The beak, claws and ribs become very pliable. Characteristic feature is the bending of sternum and spinal column. Fish liver oils are rich sources of vitamin D.

2.2.6.3 Vitamin E

Tocopherol is a biological antioxidant that could contribute to improved growth, physiological, and immunological performance in broiler chickens because of its ability to neutralize free radicals and reduce lipid peroxidation in both the plasma and skeletal muscle (Gao et al., 2010, Selim et al., 2013). Oxidative stress has been regarded as one of the major factors negatively affecting the performance of birds in the poultry industry (Xiao et al., 2011; Voljc et al., 2011). Deficiency leads to encephalomalacia/crazy chick disease, exudative diathesis in young birds, muscular dystrophy seen more frequently in older and mature birds.

The main effects of vitamin E sources and inclusion levels and their interaction did not have significant influence on BWG, FI, FE and the relative weights of the liver, spleen, thymus, and bursa of fabricius (Pitargue et al., 2019). Higher carcass yield was observed in chickens from the experimental group. Zdanowska-Sąsiadek (2016) observed no significant difference in the percentage of breast and leg muscle between experimental diets. The researchers added that experimental group chickens had a higher percentage of heart and gizzard of the body weight but a lower percentage of liver. The addition of vitamin E affected a decrease of abdominal fat in birds from the experimental group.

2.2.6.4 Vitamin K

Vitamin K is essential for synthesis of prothrombin, thus it plays an important role in clotting mechanisms and it is also a coenzyme for γ-carboxylase, plays an important role in bone formation and mineralization (Hamidi et al., 2013). Osteocalcin (OCN) is produced by osteoblasts during bone formation, and the carboxylation of OCN relies on vitamin K. Vitamin K deficiency leads to the synthesis of undercarboxylated OCN, which had a poor affinity for hydroxyapatite and a low biological activity leading to a poor bone mineralization (Hamidi et al., 2013).

In laying hens O'Sullivan et al. (2020) discovered that there was no significant difference across the four vitamin K_3 dietary treatment groups in hen final body weight, feed intake, or FCR. Likewise, there was no significant difference across the four treatment groups in total egg weight or average egg weight. There was a nonsignificant trend of a treatment effect on total number of eggs per pen, total eggs per hen, and percentage egg production, with the highest vitamin K_3 treatment group.

Deficiency of vitamin K may cause an increase of blood spots in eggs, haemorrhages in the legs and breast and a failure of blood clotting. Wheat germ oil, fish liver oil, alfalfa meal, greens, germinated pulses, soybean oil, grains and fish meals are rich source of Vitamin A, D3, E and K.

The B vitamins include vitamin thiamin, riboflavin, niacin, pantothenic acid, pyridoxine, biotin, folic acid, and cyanocobalamin. The B vitamins are involved in many metabolic functions, including energy metabolism. A vitamin premix is typically used to compensate for the fluctuating levels of vitamins found naturally in food and to assure adequate levels of all vitamins.

2.2.6.5. Vitamin B1

Thiamine (Vitamin B1) is necessary for proper carbohydrate metabolism. Avian species are unable to produce thiamine (vitamin B1; water soluble vitamin) (Weber, 2009). Thus, in birds, diet is the main source of thiamine. Thiamine is a component of thiamine pyrophosphate, which participates in oxidative decarboxylation of pyruvic acid and α-ketoglutaric acid. These reactions generate acetyl- coenzyme A (CoA) and succinyl-CoA, which are involved in carbohydrates, proteins, and lipids metabolism (Chen et al., 2018). The deficient birds show anorexia, loss of weight, ruffled feathers, dropping of wings and paralysis of muscles. The birds sit on flexed legs and draw back the head in a 'star-gazing' position. Feeding diet deficient in thiamine to birds leads to loss of appetite, low hatchability, low carcass yield, impaired carbohydrates, proteins and lipids metabolism and high mortality rate (Weber, 2009). Thiamine is found in abundance in rice polish, wheat bran and cereal grains.

2.2.6.6. Vitamin B2

Riboflavin (Vitamin B2) is part of enzyme systems so plays a vital role in metabolism and is an important co-factor for multiple flavin enzymes (Lambertz et al.,2020). The deficiency causes diarrhoea and "curled toe paralysis in birds between the first and second week of age (Johnson and Storts, 1988). The affected birds walk upon their hocks with the aid of their wings. Further relevant symptoms in birds lacking riboflavin are nervous malformations (Cai et al., 2006) and footpad dermatitis (Shepherd and Fairchild, 2010). In adult birds, decreased egg production, increased embryonic mortality and dead in shell chicks, with dwarfing and clubbing down feathers were seen. Embryo mortality reaches a peak between 18 to 20 days of incubation. Grasses and brewer's yeast are rich source of this vitamin. Lambertz et al. (2020) studied the effects of a riboflavin source suitable for use in organic broiler diets on performance traits and health indicators and discovered that animals receiving the a high diet showed a higher final BW than animals fed either without riboflavin supplementation or with riboflavin from the alternative source at low level while 74.4%, dressing weight was higher in a high compared with all other groups. Breast percentage of low was lower than that of both control groups but did not differ to a high. For the ratio of thigh, wings and carcass, no difference between treatments were found.

2.2.6.7 Vitamin B6

Pyridoxine (Vitamin B6) is necessary for proper metabolism of amino acids. Vitamin B6 and folic acid are two key vitamins utilized as coenzymes in methionine metabolism. Pyridoxal phosphate, an active form of B6, plays a key role as coenzyme for serine hydroxymethyltransferase (SHMT), cystathionine ß-synthase (EC 4.2.1.22, CBS), and C-ase (Finkelstein, 2000). Vitamin B6 has been shown to alter homocysteine metabolism by decreasing SHMT activity and by suppressing homocysteine catabolism via the transsulfuration pathway. Due to deficiency, spasmodic convulsions and jerky movements are seen in sick birds. The bird should be fed cereal grains, yeast and alfalfa meal. Pyridoxine influences the control of feed intake through their roles in neurotransmitter synthesis and regulation in the central nervous system, since it is involved in the hydroxylation and decarboxylation of tryptophan for the synthesis of serotonin (Groff and Gropper, 2000), which is known to control feed intake through the melanocortin pathways and helps to control appetite and ward off eating (Heisler et al., 2003).

2.2.6.8. Vitamin B12

Cyanocobalamin (Vitamin B12) is involved with nucleic acid synthesis, carbohydrate and fat metabolism and methyl synthesis. It also plays a vital role in the nervous system and proper brain functioning, homocysteine metabolism, energy metabolism, normal blood functions, cell division, and in the immune system (Ahmad et al., 2019). Its deficiency shows slowed growth, poor feed utilisation and reduced hatchability. Embryonic mortality reaches peak on the 17th day of incubation. Myotrophy of legs and haemorrhages in the allantois of the embryo may be seen. Fish meal, milk products and animal proteins are sources of vitamin B12. An increased supply for the animals with vitamin B12 induced a higher yield of breast meat byy supplementation of 20 µg B12 and a higher percentage of breast meat and legs when adding on 0.65 mg Cobalt. It was concluded that 20 µg of vitamin B12 per kg feed meet the requirements of growing chickens for fattening (Halle et al., 2011).

2.2.6.9. Choline

The nutrient choline has three essential metabolic functions: it is a component of membrane phospholipids; it participates in lipid liver metabolism, preventing fat accumulation in the liver; and it is a precursor of acetylcholine (Farina et al., 2017). In addition, choline prevents perosis or chondrodystrophy in poultry, and it can be oxidized to betaine to donate methyl groups, sharing this function with methionine, which, according to Zeisel (1990), consumes the most choline in the body. In broiler diets choline is normally supplemented as choline chloride.

It contributes to various metabolic functions including lipid transport, cell signaling, and biosynthesis of methylated compounds (Gregg et al., 2022). The interconnected biosynthesis pathways of choline and the sulfur amino acids Methionine and Cysteine make it difficult to determine dietary choline requirements (Hofmann et al., 2020). The generation of many methylated compounds relies on the S-Adenosyl Methionine (SAM-e) cycle. Methionine is converted to SAM-e, which then acts as a cofactor for many methyl group transfer reactions. Choline enters the cycle upon conversion to betaine, which then donates its methyl groups to a folic acid derivative. This results in the formation of Methionine to regenerate SAM-e (Gregg et al., 2022).

Choline deficiency in birds causes fatty liver syndrome, perosis, and disturbances in liver fat mobilization due to the low availability of carrier lipoproteins (Selvan et al., 2018). In fast-growing broiler strains, choline deficiency also results in growth retardation and bone deformation (Igwe et al., 2015). Affected birds tend to suffer tibial-tarsal rotation, tendon dislocation (gastrocnemius) and more often leg joint thickening; in adult birds, problems such as ascites and cirrhosis can also occur (Selvan et al., 2018).

Hassanien et al. (2012) supplemented broiler with acetyl choline and found that acetyl choline supplementation at 15 mg/kg diet significantly increased BW at 3 weeks of age by 9.56%, and numerically improved FCR by 8.0% during the same period of age compared to those fed unsupplemented control diet, respectively. There was no significant effect of acetyl choline supplementation at 5 or 10 mg/kg feed on BWG, FI and FCR during all experimental period, nor was there a significant impact of either 5 or 10 mg acetyl choline on FCR during 0-3, 3-6 as well as 0-6 weeks of age. It was reported that supplementing the diets of modern broilers with increasing concentrations of choline chloride did not impact feed intake, BW gain, FCR and carcass parts (Gregg et al., 2022).

2.2.7 Energy

Energy is not a nutrient, per se, but a property of energy-yielding nutrients such as carbohydrates, lipids, and protein (Ravindran and Abdollahi, 2021).The energy derived from carbohydrates, lipids, and protein is different, with lipids providing 2.5 times more energy than carbohydrates. These differences may explain part of the contradictory findings on the age effects on energy utilization (Ravindran and Abdollahi, 2021).

Feed is the major source of energy and it provides chemical energy that is present in the nutrients (Priyankarage et al., 2011). Simple carbohydrates, some complex carbohydrates, protein and fat in the feed are the main energy supplying nutrients. Poultry tend to eat to meet their energy needs, provided other essential nutrients are adequate in the diet, especially at thermo neutral zone (Prusty et al., 2022). Animals require energy for growth, maintenance, digestion and reproduction. Most dietary ingredients contain energy released by the breakdown (burning) of fats, carbohydrates and protein(Ravindran and Abdollahi, 2021). The major energy sources in poultry diets are cereal grains, such as wheat and corn, which have a high starch content. Concentrated sources of energy, including fats and oils, are usually provided to obtain optimum growth and performance. Approximately 23.4 MJ of dietary energy is used to produce one kg of poultry meat and the cost of supplying energy from poultry feeds account for half of the total cost of a feed (Priyankarage et al., 2011).

Energy intake is an essential factor in broiler production because of its involvement in growth rate, carcass quality as well as its role in the development of certain metabolic diseases. Dietary energy is supplied in broiler nutrition through different feed resources. Dietary energy content strongly regulates feed consumption, and energy is the most expensive item in poultry diets (Ceylan et al., 2021). Rosa et al. (2007) demonstrated that broiler feed intake increases linearly with decreasing dietary energy level. Albuquerque et al. (2003) on a similar study confirmed feed intake was reduced as a result of higher dietary energy density. In was also attested that broilers fed free-choice on diets with either 2700 or 3300 kcal metabolizable energy/kg presented the same growth rate and constant energy consumption (Leeson et al., 1996). Hu et al. (2019) showed that a diet containing 12.13 MJ/kg AMEn reduced average daily weight gain and increased FCR compared with those having normal (13.38 MJ/kg) or high energy (14.64 MJ/kg) at the end of 21 days.

Reduction in abdominal fat is a current goal in poultry industry so as to improve the efficiency of diets and to provide a less fat-laden meat product for consumers. Different nutritional strategies provide an opportunity to reduce production costs and at the same time, improve carcass quality in broiler chickens. Lowering the dietary energy level has been used to achieve the reduction in abdominal fat deposition (Ahiwe et al., 2018). Abdominal fat depot areas are considered as main location of excessive energy deposition (Summers et al.,1992). With regard to the influence of dietary treatment on abdominal fat weight, it was found that the lowest energy diet (2950 kcal/kg) decreased abdominal fat as compared to the other diets. Leeson et al. (1996) found that an increase in dietary energy level was followed by higher abdominal fat deposition. However, Oliveira Neto et al. (1999) and Albuquerque et al. (2003) did not find significant effect of dietary energy level on abdominal fat deposition in broilers. The comparison of different energy levels on broiler carcass parameters results proved that the treatment had no influence on carcass, breast, and wings yields even though energy consumption was directly related to weight gain (Rosa et al., 2007). A number of researchers [Leeson et al. (1996), Oliveira Neto et al. (1999), Albuquerque et al. (2003), and Sakomura et al. (2004) who confirmed that dietary metabolizable energy level did not affect carcass yield in broilers at slaughter age also supported similar results.

Ataei et al.(2022) assessed the influence of different dietary energy levels in broiler performance and demonstrated that during the growing period, modern broiler chicks consume feed regardless of the energy level of the diet and continue up to physical satiety. Grower dietary energy levels do not affect the average daily feed intake but affect the body weight gain and feed conversion ratio at 11 to 24 days of age. However, at the whole periods (1-42 d) feed intake, weight gain, feed conversion ratio, final live weight, and relative carcass yield do not affect by different dietary energy levels during the growing period.

2.3 Feed sources for broilers

The major ingredients in poultry diets provide energy and protein for poultry to maintain health, growth, and produce eggs. Common energy sources in poultry feeds include cereals and fats. Cereals are grasses that produce edible starchy grains, many of which can be used in poultry diets as an energy source. Barley, maize (also called corn), sorghum, and wheat are cereals often used in poultry diets (Hawkins, 2023).

Fats and oils provide a concentrated source of energy, which include tallow, poultry fat (derived from poultry offals), feed grade animal feed, etc. However, inclusion of fat in poultry diet is not necessary since the cereals and protein supplements used in the diet (Mallick et al., 2020) can cover up fat percentage.

The possible protein sources for poultry feeds include soybean, cottonseed meal, groundnut cake, fishmeal, meat and bone meal, cereal by-products, etc., many cereal grains which are used for human consumption are also used for poultry feed. The grains are cleaned and then either dry or wet milled. Many of the by-products of both wet and dry milling are suitable for inclusion in poultry feeds. Common cereal by-products are grain hulls, bran, middlings, rice polishing, etc.

2.3.1 Energy sources

2.3.1.1 Maize

- Maize is the principal energy source used in poultry diets in most of the countries because of its high-energy value, palatability, presence of pigments and essential fatty acids.
- It contains highest amount of energy (ME 3350 kcal/kg) among cereal grains.
- It has 8-13% of crude protein.
- It has high TDN of 85-90%.
- Maize has low fibre content and is highly palatable.
- Extremely low in calcium and deficient in vitamin B_{12} but fair in phosphorus content.
- Yellow maize provides carotene and xanthophylls pigments for colouration of egg yolk, poultry fat and skin when it is used at 30% and above in the diet.
- Maize is an excellent source of linoleic acid, which contributes for egg size, and maize protein is mainly deficient in tryptophan and lysine.

2.3.1.2 Sorghum

- Sorghum contains slightly lower energy but more protein than maize (ME 3200 kcal/kg; Protein 10%).
- Sorghum protein is deficit in lysine, methionine and arginine.
- Light coloured sorghum varieties can be used as the principal energy source.
- Darker varieties, that are bird resistant, can contain tannins in the seed coat and should be used less.

- Higher levels of tannin in sorghum may reduce the palatability and thereby feed intake. While tannin free sorghum can be used as a sole source of energy in layer diet without affecting egg production, egg weight and energy efficiencies.
- It can be included upto 30% in chicks ration and upto 60% in the grower and layer rations.

2.3.1.3. Wheat

- Wheat is rich in protein and calcium and but low in fat and energy compared to maize.
- Wheat is a good source next to maize and sorghum (ME 3100 kcal/kg).
- Its protein content is highly variable (11-14%).
- Wheat protein is deficient in methionine and threonine.
- Wheat contains indigestible non-starch polysaccharides (arabinoxylans) that reduces the performance of poultry.
- The enzyme, xylanase, may be used when wheat is incorporated in feed at high level.
- It can be included up to 20% in chick ration and up to 30% in grower and layer rations.

2.3.1.4 Pearl millet

- They have 8-12% of crude protein and rich tannin content.
- It can be included up to 30% in chick ration and up to 60% in grower and layer ration.

2.3.1.5 Animal and vegetable fat

- Fat (Vegetable/Animal) provides 2.25% more energy than carbohydrate or protein.
- Oil and fat reduces the dustiness in feed and lessens the wear on feed mixing equipment.
- Vegetable oil like corn oil, Groundnut oil, sunflower oil and animal fat like lard, tallow are extensively used in livestock feeding.
- Animal fat contains saturated as well as unsaturated fatty acids of C20, C22, and C24.
- Vegetable fats contain greater proportion of linoleic acid.
- Higher level of polyunsaturated fatty acids leads to rancidity and therefore anti-oxidants like Butylated hydroxytoluene (BHT) or Ethoxyquin should be included in high fat diet.

2.3.1.6 Molasses

- It is a by-product produced during juice / extract prepared from selected plant material.
- It is a concentrated water solution of sugars, hemicelluloses and minerals.
- Four varieties of molasses are commonly available viz. cane molasses, beet molasses, citrus molasses and wood molasses.
- It is palatable, reduces dustiness and improves pelleting.
- Cane molasses is a product of sugar industry and contains 3% protein with 10% ash.
- Beet molasses is a product during production of beet sugar and has higher protein (6%).

- Citrus molasses is bitter in taste with highest protein (14%) and produced when oranges or grapes are processed for juice.
- Molasses is a good source of energy and an appetiser.
- It reduces dustiness in ration and is very useful as binder in pellet making.
- It can be included up to 2% in the chick ration and 5% in the grower and layer ration.

2.3.2 Protein sources

2.3.2.1 Soya bean

- Soya bean meal contains 47-49% protein and is an excellent source of lysine, tryptophan and threonine but it is deficient in methionine.
- Like other oil seeds, raw soybeans have number of toxic and inhibitory substances.
- These toxic, inhibitory substances and other factors in soya bean like saponins can be inactivated by proper heat treatment during processing.
- It can be included up to 35% in chick ration and up to 25% in grower and layer ration.

2.2.2.2 Sunflower oil cake

- The protein quality of sunflower cake is very good due to its higher availability of lysine and methionine.
- Sunflower oilcake contains 40% of protein.
- It has very short self-life.
- The expeller variety of Sunflower seed meal or cake has high content of polyunsaturated fatty acids.
- It can be included up to 10% in chick ration and up to 20% in grower and layer rations.

2.2.2.3 Fish meal

- Fish is an excellent source of protein, containing adequate concentrations of limiting amino acids like lysine, methionine and threonine.
- It is also rich in available P, Ca, Se, iodine and vitamin B_{12}.
- Fish meal is the one of the best poultry feed stuffs and a good source of animal protein.
- Its composition varies widely depending upon whether it is made from whole bony fish or fish canary scraps.
- The protein content of fish meal is usually around 60% with a digestibility of 93-95%.
- The presence of fish scales reduces its feeding value.
- It can be included up to 10% in the ration.

2.2.2.4 Meat and bone meal

- Besides a good source of high quality protein, it is a good source of calcium and phosphorus.
- The carcasses of unproductive and dead animals and offals from slaughter house waste are sterilized and made into meal.

- The quality of meal is variable depending upon the processing methods and the proportion of gelatin it contains.
- The variable quality, contamination and content of phosphorus limit the use of these meals.
- The sterilized meat and bone meal can be included up to 5% in the poultry ration.

2.3.3 Fibre and Non-Starch Polysaccharides Sources

2.3.3.1 Wheat bran

- Wheat bran is an excellent food with more fiber content.
- It is laxative when mashed with warm water but tends to counter act scouring when it was given dry.
- It can be included upto 5% in the chick ration and 10% in the grower and layer ration.

2.4 Broiler production parameters

2.4.1 Feed intake

Successful broiler development is dependent on optimal feed intake throughout the growing period (Jafarnejad et al., 2010). Feed intake is one of the most critical, and often overlooked, factors that determine nutrient levels in feed. Animals have daily requirements for quantities of nutrients to maintain body processes and support production, including growth and/or milk production. Numerous factors influence feed intake and thus the amount of nutrients consumed. The importance of the control of feed intake is to match food consumption with the required level of production. If voluntary food intake is too low then the rate of production is likely to be depressed, making the requirements of maintenance to become a very large proportion of the metabolisable energy in the food and so giving poor production and poor efficiency of food conversion. If feed intake is too high, there will be excessive fat deposition. The amount of feed consumed is closely associated with growth and production performance. Modern animal breeds will not grow to their full genetic potential unless they consume their full nutritional requirement each and every day. Aside from adequate diet formulation, maintaining maximum feed intake is the single-most important factor that will determine the rate of growth and efficiency of nutrient utilization .Problem of overeating is obesity. Animal normally eat the amount of food to satisfy their energy requirements including continued fat deposition in the adult.

There are some circumstances when insufficient is eaten resulting in body weight loss and decrease in productive process like growth, milk and egg production. Problem of undereating occurs normally when there is short of food or famine. The problem of undereating is at its most critical stage when other abdominal organs are competing for space (uterus, fat) or when energy requirements are very high, as in early lactation. Feed intake may be depressed also when food is deficient in an essential components such as protein, minerals, vitamins or aminoacids. Such deficiencies depress intake due to to a specific effect on the brain or a more general depression of metabolism leading to a decrease in energy output.

The regulation of voluntary food intake in animals and humans is complex and involves central and peripheral regulatory mechanisms (Hu et al., 2019). In the central nervous system (CNS), the hypothalamus is the brain region that regulates food intake and energy homeostasis (Gustavo et al., 2013), and the arcuate nucleus (ARC) of the hypothalamus is believed to play a crucial role in these processes (Sam et al., 2012). Arcuate nucleus contains 2 populations of neurons with opposing effects on food intake (Hu et al., 2019).

2.4.1.1 Dietary factors that influence feed intake

2.4.1.1.1 Dietary energy

Dietary energy content has the most predictable effect on feed intake on meat birds. Energy requirement is dependent on the energy needs for body maintenance and growth or production. Body maintenance requirements, which have a priority over production, are influenced by the bird's health status, its degree of mobility (influenced by stocking density, physical activity, and social interactions), and body heat loss (influenced by ambient temperature, humidity, air speed). Therefore, feed intake will increase as dietary energy content decreases until it is limited by either gut fill or other physiological limitations. Leeson et al. (1996) highlighted that broiler is not normally eating to physical capacity, and have a remarkable ability to control energy intake when offered diets of varying energy content. The researchers suggested that pattern of energy intake observed indicated that broilers were adjusting their feed intake, in response to energy needs, with the same classical precision as seen in Leghorn birds (Payne, 1967).

Maiorka et al. (2008) showed that the regulation of feed intake with dietary energy levels was correlated with the age of the birds. Adult birds are more able to digest and absorb fat and therefore may have a better feed intake adjustment according to these factors, while young chickens are not yet able to adjust their feed intake according to dietary energy levels. Low ambient temperatures (10.47±3.3°C) cause an increase in feed intake. Since low ambient temperature stress causes an increase in feed intake it is difficult to further increase feed intake at the dietary energy level as an index to improve the positive effect of cold stress (Kim et al., 2019).

2.4.1.1.2 Dietary protein

Dietary protein and amino acid content has more of an indirect effect on feed intake than any direct effect. Growth can be very sensitive to daily amino acid intake and changes in food intake may reflect only changes in production rather than being a primary response to protein (Boorman, 1979). Specific amino acid imbalances can modify food intake in chicks very rapidly and this suggests that the ensuing growth depression is not the immediate cause of the response. The mechanism that controls food intake is sensitive to the concentration of certain aminoacids in the blood is shown by acute changes in intake which follows the intravascular injection of amino acids into chicks receiving deficient or imbalanced diets (Tobin and Boorman, 1979). An and Kong (2023) showed that feed intake decreased as dietary CP concentrations increased but the growth rate and feed intake remained unchanged with diets containing less than 21% CP. There was an increase in the feed intake of birds who were fed the high-CP diet (20.0% CP) compared with those who were fed the low-CP diet (6.0% CP), which may be attributed to the decrease in dietary energy concentration from 3,633 to 3,023 kcal/kg (An and Kong, 2023).

Srilatha et al. (2017) showed that the chicks fed higher CP had lower feed intake compared to those fed a low-CP diet. The results were also previously confirmed by several studies of (Aletor et al.,2000, Sklan and Plavnik, 2002). The decreased feed intake with increases in CP was due to depressing effect of CP / amino acids in excess of dietary requirement. At a dietary protein content of 200 grams per kg, the birds tended to consume less feed on the unbalanced diets than on the balanced diets. This effect was significant for the birds on the restricted feed intake, containing 300 and 400 grams CP per kg. Feed intake declined with an increase in dietary protein content for the birds on the balanced diets fed ad libitum or restricted. There was no significant effect of varying crude protein content on feed intake on the unbalance protein diet when fed ad libitum or restricted (Swatson et al., 2002).

2.4.1.1.3 Vitamins and minerals

influence feed intake only when dietary levels are deficient or several fold above requirement. Deficient dietary levels causes metabolic disorders that led to an indirect adverse effect on feed intake. Slight mineral deficiencies may stimulate feed intake as the bird attempts to achieve its intake requirement. In contrast, excessive dietary vitamins and minerals are detected by the bird's sense of taste, resulting in refusal to consume the feed. Mineral excess are also associated with significant increases in water consumption. Excess in dietary salt will depress feed intake and stimulate water consumption. Excess in dietary calcium will have depressed feed intake in growing meat birds. Deficiencies of trace mineral will not affect appetite unless they are prolonged.

2.4.1.1.4 Naturally occurring compounds

Naturall occurring compounds such as protease inhibitors, goitrogens, alkaloids, oxalates, and phytates are innate natural components of particular feed ingredients that can impair the availability of nutrients, depress feed intake, and reduce the growth in animals that consume them. Other antinutritional factors in foods are produced as a result of fungal or microbial metabolism or by the plants themselves as defensive mechanisms against injury or infection. Fortunately, the presence of a toxic factor per se does not preclude the utilization of the material as a feedstuff. Numerous processing methods are available to neutralize or detoxify the deleterious components of by-products and waste materials.

2.4.2 Broiler growth rate

The growth process includes increase in cell number (hyperplasia) and increase in cell size (hypertrophy).The early stages of growth occurs mainly through the process of hyperplasia while the later stages are a result of hypertrophy. Growth of fowl is analogous to growth of mammalian, consisting of three or four cycles, two of these cycles however occurred after hatching. William (2023) decribed animal growth as an increase in body height, length, girth and weight that occurs when a healthy young animal is given adequate food, water and shelter. Live weight is the most important and commonly measured of these features and, if recorded at regular intervals, it may be used to plot a simple growth curve. Animal growth is determined by a complex variety of factors but these can be reduced to three main categories: the animal’s gene pool, the nutrients with which it is supplied, and its environment. The common factor linking and communicating these is the endocrine system (Hafs and Zimbelman, 1994).

The major tissues of the body that undergo growth are bones, which are mainly calcium and phosphorus, muscle which is mainly protein & water and adipose tissue which triglycerides (long chain fatty acids bound to glycerol). Broadly speaking it can be said that any tissue in the body which is not fat or bone is protein. Bone growth dictates mature frame size and hence mature body weight of a bird.

Growth curve functions are the most adequate means for describing the growth pattern of BW or body parts, because they summarize the information into a few parameters that may be interpreted biologically. Several growth functions are available for the description of growth such as Brody's, logistic, Gompertz, von Bertalanfy, and the four-parameter Richards function, which summarizes all the above growth functions into one(Goliomytis et al., 2003).

Diet fat content and composition are powerful tools to modify animal growth and the partition of energy between lean and fat tissues, thus affecting body and tissue composition. Supplementing fats in porcine diets has been evaluated in the context of strategies to improve growth rate and feed efficiency (Amills et al., 2020).

The average gram daily weight gains play an important role in the optimum growth of the birds. Under normal practical conditions, a broiler must gain an average of 65 grams or more per day. The average daily weight gain is not uniform for each week and varies considerably depending on age and sex (Butcher and Nilipour, 2019). The Table 1 below depicts average daily gain in broiler chickens.

Table 1: Average daily weight gain in grams

Days of Age	Gram Average Daily Weight Gain/Week
1-7	25
8-14	33
15-21	42
22-28	51
29-35	59
36-42	65
43-49	70

2.4.3 Feed efficiency

Feed efficiency has been considered as one of the important parameters in assessing the potential of bird strain or feeding program etc. The feed conversion rate (FCR) is a measure of how well a flock converts feed intake into live weight and it also shows how efficiently animals utilize their diet for maintenance and net production (Rahman, 2022). Feed efficiency could also be considered as a homoeostatic process representing the net result between energy intake, which is determined by the voluntary feed intake and the efficacy of digestive processes (eg nutrient digestion and absorption) and energy expenditure, which depends on the maintenance requirements, specific nutrients repartitioning mechanisms and the rate of metabolic processes and intermediary metabolism in tissues and organs (Zampiga et al., 2021).

Feed efficiency is the most important trait in the poultry industry because feed accounts for approximately 70% of the total production cost. In poultry production, feed efficiency is generally defined as the relative ability of an animal to convert feed to product. The most widely used indexes for evaluating feed efficiency are the feed conversion ratio (FCR) and residual feed intake (RFI) (Li et al., 2020). FCR is the mathematical relation obtained by dividing the amount of feed the animal consumed by the production it provided. The FCR is an index for the degree of feed utilization and shows the amount of feed needed by the animal to produce one kg of meat. Ranjhan (1976) noted that feed conversion efficiency in broiler production could be expressed in three different ways; (a) Feed efficiency = weight gain feed in-take (b) Efficiency of feed utilization = feed in-take weight gain (c) Feed conversion = feed in-take body weigh.

Birds considered to have better feed efficiency typically have a lower proportion of feed intaketo body weight gain. Over the past decades feed efficiency has been improved throughchanges in a number of aspects of meat poultry production (Willems et al., 2013). Li et al.(2020) described the digestive efficiency is defined as the proportion of dietary intake minus feces, and metabolizable efficiency is defined as the proportion of dietary intake minus feces and urine. In poultry, metabolizable efficiency is easier to determine and is a more practical measure than digestive efficiency, because feces and urine are voided together via the single channel of the cloaca (Vohra, 1972).

Proudfoot and Hulan (1989) discovered that the crumbled-pelleted dietary regimens resulted in a significant improvement in feed conversion to 2l days of age; however, by 49 day the magnitude of the difference between all-mash and crumbled-pelleted feeds declined. Researchers further indicated that there was no significant overall difference in feed conversion between all-mash diets but coarse versus very coarse mash exhibited a significant difference at 49 days of age.

2.4.3.1 Factors affecting feed efficiency

2.4.3.1.1 Hatchery Management

There is now plenty of evidence to show that conditions during the hatching process have an effect on growth rate and FCR. For example, overheating embryos in the later stages of incubation will have a detrimental effect on gut development and subsequent nutrient digestion and absorption (Ross, 2011). Hulet et al. (2017) observed no significant differences in feed conversion at market age between birds subjected to different embryonic temperature treatments. Researchers added that chicks incubated at the high temperature had significantly poorer feed conversion at 21 days of age than the chicks from the lower or medium groups. Ipek et al. (2015) studied the influence of eggshell temperature (EST) on chicks post hatch performance and found that there were no significant differences in feed conversion ratio between experimental weeks 1 and 2. Feed conversion ratio was similar in both the low and high EST groups at 3, 4, and 5 weeks of age. During the 6-week life span, the low and high EST groups presented significantly worse feed conversion ratio relative to the EST control group.

2.4.3.1.2 Sex

The feed efficiency of female broilers will usually be higher (less efficient) than male birds of corresponding weight, after about 30 days of age. The reason for this is that female birds tend to deposit proportionally more fat in the carcass. Body fat takes 9 times as much feed energy to produce as does muscle. The reasons for this is that fat contains more energy than does protein per unit of weight, and more importantly, muscle is only about 20% protein by weight, the remainder being water. For this reason it is usually uneconomical to grow female broilers much beyond 45d unless special emphasis is placed on reducing fat deposition. Likewise with heavy male birds, feed efficiency is going to be greatly influenced by the growth of fat vs muscle. Da Costa et al. (2017) showed that the BW of males reared as separate sex was negatively impacted from 17 to 32 days, whereas sex separate female birds had higher BW from day 25 to 41 compared to females reared as mixed-sex. England et al. (2023) ascertained that when the females are reared as mixed-sex, the competition for feeder space from males may be higher and could result in the females having a lower feed intake and lighter BW under mixed-sex conditions. Conversely, males reared under mixed-sex conditions can easily exclude smaller birds, such as females, from the feeders allowing them to increase feed intake and grow faster.

It is well known that male and female broilers differ in their growth performance and this has been supported by many studies. Lopez et al. (2011) conducted a trial to evaluate the sex effect on final BW in broilers and found male and female broilers slaughtered at 42 days of age were significantly different with respect to live BW with males being heavier than the females. this results were honoured by the work of (Young et al., 2001; Kidd et al., 2005; Shafey et al., 2013; Benyi et al., 2015; Da Costa et al., 2017; Madilindi et al., 2018) who showed that males were heavier than females at the same time.

2.4.3.1.3 Temperature

Probably the most important non-dietary factor influencing feed conversion is the ambient temperature of the poultry house. Birds are homeothermic, that is, they are warm-blooded animals. This means that they regulate or stabilize their body temperature metabolically irrespective of the environmental temperature. In cold weather, chickens will consume more feed so as to produce more energy, and most of the energy or calories produced would be used to heat up the body and maintain the normal body temperature (Akinbobola, 2023). The energy won't be used to produce meat (or converted to meat). In heat stress, each °C above the optimum range decreases feed intake by 2%. Therefore, the feed needs to be denser to fulfill the requirement, or the animal will lose weight (Heinzl and Caballero, 2021). Social stress also influences animal performance, especially chronic stress situations. Keeping the animals in their thermoneutral zone and mitigating the impact of stressors means more energy can go towards performance.

2.4.3.1.4 Nutrient Density and Digestibility

The management of energy consumption of broilers can reduce production costs and enhance product quality. In general, birds consume to satisfy their energy requirements and stop eating, even when the requirements for other nutrients such as proteins, minerals and vitamins have not been satisfied (Maliwan et al, 2022). To achieve success in chicken meat production, it is necessary to provide adequate energy to support tissue growth and effective tissue and organ physiology (Ahiwe et al., 2018). When the amount of energy consumed exceeds the physiological demand, the excess is deposited as fat in the carcass, which is considered a waste product and thus represents an economic loss for poultry producers (Ahiwe et al., 2018).

Nutrient density is a key factor affecting the growth, carcass quality, and health of broilers, which in turn affects the cost effectiveness of their production (Brickett et al., 2007). High nutrient density may decrease the feed intake (FI) and feed conversion ratio (FCR) of broiler chickens (Delezie et al., 2010). It has also been reported that a balanced energy-to-protein ratio is important to achieve optimum broiler carcass yield and meat quality.

Higher energy content in the diet and better protein digestibility improve FCR. Saldaña et al. (2015) assert that increasing the energy content of a diet led to a linear decrease of the average daily feed intake but improved FCR quadratically. The energy intake by itself remained equal. However, these diet improvements also increased costs. Numerous researchers also attested that the dietary energy level had no significant effect on a feed conversion ratio of broiler chickens at 11-24 days (Heger et al., 2014), 11 to 22 days (Abudabos et al., 2014) and 14 to 35 days of ages (Chrystal et al., 2020).

An interaction was found between nutrient density and feed form for feed efficiency during the 0- to 6-day, 7-to 13-day, and 14- to 20-day time periods. However, as birds aged, there was an increasingly more important effect of nutrient density (Brickett et al., 2007). Diet with 19% crude protein, using only commercially available ingredients, was not adequate because it worsens feed conversion. Abreu et al. (2022) compare the concentration of crude protein in broiler diets on performance and concluded that the diet with 21% crude protein, using only commercially available ingredients, reduces the availability of apparent metabolizable energy and apparent metabolizable energy corrected for nitrogen balance due to high nitrogen excretion, so it should be avoided. The experimental diet 19% crude protein plus synthetic amino acids (19E+Aa) improves the crude protein digestibility coefficient, exhibits low nitrogen excretion, and has feed conversion similar to diets with 21% crude protein (using only commercially available ingredients), 19% crude protein (using experimental ingredients), and 21% crude protein (using experimental ingredients), all with higher oil inclusion.

2.4.3.1.5 Molds and Mycotoxins

Molds reduce the nutrient and energy content of the feed and negatively impact feed efficiency. They are dependent on active water in the feed and feed ingredients. Compared to bacteria, which need about 0.9-0.97 Aw (active water), most molds require only 0.86 Aw (Heinzl and Caballero, 2021). Besides spoiling raw materials and reducing their nutritional value, molds also produce mycotoxins, which negatively impact animal health, including gut health (Escrivá et al., 2015). Mycotoxins are secondary metabolites of low molecular weight produced by a wide range of fungi, principally molds. There are over 200 species of molds that produce mycotoxins. Aflatoxins (AF), zearalenone (ZEN), ochratoxin A (OTA), fumonisins (FUM), trichothecenes such as deoxynivalenol (DON), and T-2 toxin are some of the mycotoxins that can significantly impact the health and productivity of poultry species(Murugesan et al., 2015).

Mycotoxins have been shown to exert detrimental effects on the gastrointestinal tract by altering the normal intestinal functions such as barrier function and nutrient absorption while some mycotoxins also affect the histomorphology of the intestines, thereby affecting nutrient digestibility (Mgbeahuruike et al.,2021). Wache et al.(2009) added that mycotoxins increase the permeability of the intestinal epithelial layer in numerous species, which can result in excessive/uncontrolled leakage of substances into the animal, as well as affecting intestinal cell viability. Mycotoxins can also reduce cell proliferation, thus reducing the intestine's ability to repair and replenish itself. A decreased absorption of glucose was observed following T-2 toxin and DON intoxication in the gastrointestinal tract resulting from suppressed expression of the SGLT1 glucose transporter gene (Grenier and Applegate, 2013).

A recent global survey of mycotoxins in feed indicated that the trichothecene deoxynivalenol (DON) was the most prevalent mycotoxin, with 79% of the samples testing positive at an average concentration of 0.6 mg/kg and a maximum concentration of 8.4 mg/kg (Kosicki et al., 2016). It is well known that DON can alter the intestinal morphology of poultry, impairing nutrient uptake, which can adversely affect energy and nutrient availability and, consequently, reduce growth performance (Wang and Hogan, 2019). Kolawole et al. (2020) observed a strong positive correlation between the FCR and the exposure to different mycotoxins in broilers chickens. Weaver et al. (2020) found that FCR during the first 7 days was reduced in birds consuming mycotoxin contaminanted diet compared with birds consuming control diet. Several trials found that mycotoxins such as ochratoxin A, DON, fusaric acid or zearalenone may not impact the performance of broilers during the starter period (Yunus et al, 2012).

2.4.3.1.6 Oxidation of Fats

Lipids in poultry diets serves as a source and a storage means of energy, they induce better resorption of liposoluble vitamins, slow down food passage through the intestine and, therefore, enable better exploitation of the food (Baltić et al., 2017). They also increase the efficiency of energy consumption, as well as acceptability of the food. The energy value of the fats and oils in food and feed depends on numerous contributors, such as length of the carbon chain, specific organization of saturated and unsaturated fatty acids in the glycerol molecule, structure of free fatty acids, structure of the food/feed, amounts and types of triglycerides added to food/feed, and the intestinal flora, species, sex and age of the animal (Ratnayake and Galli, 2009).

The oxidation of feedstuffs manifests in the rancidity of fats, destruction of the fat-soluble vitamins A, D, and E, carotenoids (pigments), and amino acids, leading to a lower nutritional value of the feed. When lipids are oxidized, the intermediate products (free radicals) and end products (aldehydes, ketones, alcohols, etc.) can subsequently interact with other diet components, such as proteins, vitamins, and pigments, negatively impacting their nutritional properties (Wealleans et al., 2021). The effects of oxidation can substantially reduce feed digestibility and palatability, resulting in decreased feed intake and feed efficiency (Desbruslais and Wealleans, 2022). Halbaut et al.(1997) confirmed that oxidation within the diet results in the rancidity of fats and oils and the degradation or full destruction of vitamins, pigments, and amino acids, resulting in reduced nutritional and energy values of the diet. Subsequently, feed intake and efficiency may be impaired and nutritional deficiencies may occur, leading to reduced performance and potential nutritional deficiencies.

Baião and Lara (2005) attested that the inclusion of lipids in poultry diets improves FCR because lipids reduce gastric movement, slowing the passage of diet in the digestive tract and this, in turn, improves nutrient utilization and increases the feeling of satiety, and thus lipids are known as gastric emptying inhibitors (Abreu et al., 2022).
Lipid oxidation has been shown to have several effects that are detrimental to poultry production.It was well recognized that oxidation reduces the palatability of feed, consequently reducing feed intake and overall performance. Furthermore, the oxidation process has been shown to reduce the nutritional value of the diet due to reactions with lipids, proteins, and/or fat-soluble vitamins within the diet (Desbruslais and Wealleans ,2022). Some oxidation products including, for example, 2-propenal, 2-butenal, 4-Hydroxy-

trans-2-nonenal, 4-Hydroxy-trans-2-hexenal, and α and β unsaturated aldehydes are considered toxic to the animal, causing damage to intestinal enterocytes and the liver (Engberg and Borsting, 1994).

2.4.3.1.7 Anti-Nutritional Factors

Compounds that interfere with the intake, availability, or metabolism of nutrients in the animal are referred to as anti-nutritional factors (ANF). Their biological effects can range from a mild reduction in animal performance to death, even at relatively small intakes. The subject is complicated by the fact that different species and ages react in different ways to the presence of anti-nutritional factors. The ANF negatively affect the nutritive values of the leguminous grains through direct and indirect reactions. They inhibit proteins and carbohydrate digestibilities and they even induce pathological changes in the intestine and liver tissues (Bressani and Sosa, 1990).Thus, ANF affects the metabolism and inhibits a number of enzymes and then bind nutrients, making them unavailable. ANFs are classified based on their chemical structures, they are grouped as: (a) Proteins (protease inhibitors and haemagglutinins (lectins), (b) Glycosides (glucosinolates, cyanogens, saponins and estrogenic factors), (c) Phenol (gossypol, tannins) and (d) Miscellaneous (Mammo and Wude, 2018).

Tannin is one of the anti-nutritional factors common in most cereal grains and legume seeds. Tannins bind proteins, thus impairing protein digestion (Olomu, 1995). The adverse effects of some toxic factors in plants (Phytotoxins) or anti-nutritional factors found in poultry feeds are well known (Medugu et al., 2012). Tannins are responsible for an astringent taste of the feed that induces a lower feed intake due to reduced palatability (Butler et al., 1984). Numerous researchers certified that tannins in poultry diets reduced dry matter intake, body weight gain, feed efficiency and nutrient digestibility [Mohammed and Ali (1988); Gualitieri and Rapaccni (1990); Douglas et al. (1993); Hassan et al. (2003) and Ravindran et al. (2006)]. On the other hand Hidayat et al (2021) observed that the inclusion of of up to 3% dietary tannins in broiler diets improved gut health and digestive performance.

Pertiwi et al. (2023) explored the detrimental effect of tannin on growth performance, visceras weight and blood biochemistry in broiler chickens reared under tropical area and attested that tannin supplementation significantly increased the feed conversion ratio in all phases relative to the control group. Tannin supplementation in the diet significantly reduced daily feed intake during the grower phase, final body weight, carcass weight, intestine weight, liver weight, and total visceral weight, compared to the control group. Tannin had lower levels of aspartate aminotransferase but higher levels of low-density lipoprotein and alanine aminotransferase.

There are various traditional methods and technologies, which can be used to reduce the levels of these anti-nutrient factors. Several processing techniques and methods such as fermentation, germination, debranning, autoclaving, soaking etc. are used to reduce the anti-nutrient contents in foods. By using various methods alone or in combinations, it is possible to reduce the level of anti-nutrients in foods (Samtiya et al., 2020). Soaking and roasting followed by pressure cooking is one of the best treating mechanisms to reduce the harmful effects of ANFs. Supplementation of the feeds with typical microbial enzymes, particularly when they are in a combined state enables also to reduce the negative effects of ANFs(Erdaw, 2023).

2.4.3.1.8. Diseases

The general health of a flock influences feed conversions. Sick broilers do not perform well. Watch closely for early signs of disease and treat broilers quickly and properly. The main reason for this is that feed intake is reduced, and so again proportionally more feed is directed towards maintenance. Freitas et al.(2023) found that coccidiosis disease reduced the daily feed intake, as was evident at the acute phase, with the worst reduction averaging 19%, estimated to be at 5 dpi. The reduction in feed consumption is associated with the production of inflammatory cytokines that produce negative feedback in the central nervous system, reducing the animals' appetite (Johnson, 1997). In the same way, the worst reduction in daily weight gain, averaging 39%, was 5 dpi.

The Eimeria infection induces a worse reduction in ADG due to the lesions in epithelial cells in the gut, which reduces digestibility of nutrients and energy (Amerah and Ravindran, 2014; Kim et al., 2022) and the efficiency of nutrient transport from the intestinal lumen to epithelial cells (Teng et al., 2021) resulting in a higher feed conversion rate and an increase in maintenance to repair tissue damage (Moraes et al., 2019).Eliminate, as early in the grow-out as possible, broilers that have no chance of making it to market. Obviously an unhealthy broiler is likely to have poor feed efficiency. With enteric diseases there can be more subtle changes in feed utilization because various parasites and microbes can reduce the efficiency of digestion and absorption of nutrients.

A broiler with sub-clinical coccidiosis is not likely to absorb nutrients with optimum efficiency, because the oocytes will destroy some of the cells lining the cut. More recently the phenomenon of so-called'feed-passage has been observed in broilers. Undigested feed particles were seen in the excreta, and so consequently feed efficiency was affected. The exact cause of this problem is unknown, but is most likely the consequences of a microbial challenge.

2.4.4 Nutrients digestibility and efficiency of utilization

2.4.4.1 Nutrients digestibility.

The feed ingredients used in poultry diets are mostly of plant origin. Plant materials are rich sources of carbohydrates, i.e. low-molecular-weight sugars, starch and NSP, the latter being resistant to digestive enzymes. These complex NSPs are a heterogeneous group of compounds that include cellulose, pectins, ß-glucans, pentosans, heteroxylans, and xyloglucan, which cannot be hydrolyzed by the endogenous digestive enzymes of humans and monogastric animals (Kumar et al., 2012). NSP are the least digestible constituent of poultry feed, as birds lack endogenous NSP-degrading enzymes (Kim et al., 2022). Microbial fermentation in the hindgut of birds can partially hydrolyse NSP, but only to a very small extent. Although NSP utilisation is limited in poultry, there is strong evidence that intestinal microbiota, gut physiology and nutrient digestibility are directly influenced by dietary NSP, depending on their water solubility (Kim et al., 2022). Nutrient digestibility refers to the notion of bioavailability. It depends on the animal (species, strain, age), the composition of feedstuff, and eventual technological treatments (thermal and / or mechanical). Digestibility is therefore an index of the disappearance of food in the intestine, but not of the efficiency of use of food by animal metabolism. A food can be very digestible without providing enough nutrients to make up needs of animal (Atchadé et al., 2019). According to Rivière (1991), food digestibility can be determined from three groups of methods: (i) In vivo methods;
(ii) in vitro methods (laboratory method) and (iii) Mathematical or prediction methods.
However, the microbial flora permanently colonizing the gastrointestinal (GI) tract can to a certain degree, break down the NSP fraction (Jorgensen et al., 1996). The end-products of the microbial degradation are various gases (H_2, CO, CH,), lactic acid and short-chain fatty acids (SCFA). The SCFA produced are rapidly absorbed from the gut lumen (Rechkemmer et al. 1988. In the chicken, the caecum appears to be the main environment

for microbial degradation of dietary fibre (DF), protein and uric acid, and for absorption of the fermentation products (Thomas & Skadhauge, 1988).

In order to ameliorate the anti-nutritive effects of NSP and improve bird performance, non-starch polysaccharide degrading enzymes (NSPase) have been supplemented in poultry diets (Williams et al., 2014). The NSP degrading enzymes (NSPases) are known to increase the digestibility of raw materials for monogastrics and a combination of NSPases, amylases and proteases help digesting feed ingredients, thereby increasing the use of nutrients and the energy available for growth (Oluyinka et al., 2008) and production. Arabinoxylans is most prevalent NSPs (43-47% in broiler) therefore inclusion of high quality Xylanase works by two mechanisms of action one by breaking down the component of cell wall which release encapsulated nutrients (Singh and Kim, 2021). As one of the most important exogenous enzymes, non-starch polysaccharidase (NSPase) is commonly used in poultry diets and plays many essential roles such as breaking down the non-starch polysaccharides, releasing nutrients encapsulated by the cell wall, reducing intestinal viscosity, improving animals' utilization of nutrients, and affecting the composition and metabolic potential of bacterial populations (Walters et al., 2018).

Xylamax is one such commercially available enzyme that is chemically an endo 1,4 beta xylanase that releases 130kcal ME/kg of corn based diet and 150 kcal ME/kg in wheat diet. It is GH11 xylanase that hydrolyses both soluble and insoluble xylans, maximizing release of nutrients from feed grains, it is developed to function at peculiar pH of 5.7-7.0 of poultry's small intestine where major digestion occur. Accelerate digestion by reducing digestion viscosity and increase passage rate. It also improves gut health, lessens pathogen, lessen necrotic lesions, increase villi height, reduced mucosal MDA (indicator of oxidative stress), pre-biotic effect, FCR improved by 4-6 points, Improvement of average bird finished weight and flock uniformity,Thermostable during pelleting at 85 degree celsius. Overall, the supplementation of NSPase enzyme seems to improve ADG in broilers from 20 to 25-days of age by 2.5 g/day and decrease FCR by 6 points compared to fibrous control diet. The improvement in growth performance of broilers in response to exogenous enzymes is based on underlying mechanism of improvement in the digestibility of nutrients (Zhang et al., 2014).

Wyatt et al. (2008) reported that a corn-soy based diet, one will need to use NSP enzymes, such as xylanase, glucanase, that are more effective at targeting and breaking down the insoluble fibre fraction. A direct benefit of feeding these enzyme products is through reducing the variability in birds and improvements in bird uniformity across the different feed batches. Exogenous NSPases break down plant cell wall carbohydrates and reduce chain length producing smaller polymers and oligomers. At some point, the fragments become small enough, i.e. short-chain oligosaccharides, and numerous enough to act as a substrate (pre-biotic) for bacterial fermentation. Xylanases, mannanases and cellulases produce xylo-, manno- or gluco- oligosaccharides, respectively. The benefit of such end products depends upon the type and quantity of the oligosaccharides produced, with different enzymes producing different oligosaccharides. These short chain oligosaccharides travel to the lower gut and become substrates for bacterial fermentation in the ileum and caecum, which can be beneficial with VFA production and altering the bacterial population (Wyatt et al.,2008). Supplementation of compound NSP enzymes (β-mannanase, β-glucanase, xylanase, and cellulase) in the diet can solve the negative effects produced by excessive NSPs and improve the digestion and utilization rate of nutrients (Cheng et al., 2023). This may explain why feeding with a low-metabolizable energy diet supplemented with an NSP enzyme did not affect the production performance of broilers. Furthermore, the apparent utilization rate of dry matter, crude protein, energy and crude fibre appeared to increase significantly in the case of a low-metabolizable energy diet with the addition of 200 mg/kg compound NSP enzymes (Cheng et al., 2023). This result indicates that the compound NSP enzyme effectively enhanced utilization of nutrients in the feedstuff.

2.4.4.2 Efficiency of nutrient utilization

With the high cost of nutrients, efficiency of nutrient utilization for the production of edible protein is equally as important as performance or carcass composition in determining optimum dietary levels. Although the efficiency of energy utilization has been shown to improve with increases in dietary energy or decreases in dietary protein (Jackson et al., 1982). Nutrient metabolism in livestock is complex due to several interacting factors (e.g. rate of growth, environment, genotype, food composition, feed intake, etc). It is crucial to understand the complexity because this will lead to better matching of animal requirement to nutrient supply and consequently, reduced nutrient excretion to the environment(Reis et al., 2018).

Feed passage rate throughout the digestive tract influences nutrient utilization by determining the time available for nutrients contact with digestive enzymes, absorptive surfaces as well as microbial populations (Fuerjiafu, 2016). The rate of feed passage can be expressed as the amount of digesta which passes a point of the digestive tract in a given time (Fuerjiafu, 2016). In other words, it can be indicated as the time, referred to retention time, which takes the digesta of a meal to pass through the gastrointestinal tract and can be measured by adding a marker to the diet (Almirall and Esteve-Garcia 1994; Vergara et al. 1989). The rate at which digesta move through the gastrointestinal tract, the rate of fermentation of the feed, and the amount of dry matter consumed are major factors that determine how much of a nutrient will be digested, absorbed, and utilized in the animal. Alterations in any one of these three generally change the other two (Colucci et al., 1982).

Protein and energy are expensive components of a poultry diet. Moreover, the amount and form of crude protein or synthetic amino acid supply in feed could make the difference between economic gain or loss to producers. In addition, the digestibility of protein or synthetic amino acid source and the amount offered to the animal will have implications for nitrogen excretion to the environment (Donato et al., 2016). Evaluation of amino acid (AA) requirements involves knowledge of efficiency of utilization, which could be determined through nitrogen balance technique, where the amino acids deposition is regressed against consumption (Sakomura et al., 2015).
It is important to estimate precisely the energy value of feedstuffs and diets, either for least-cost formulation or for adapting feed supply to the metabolizable energy requirements of broilers. Unfortunately, such energy is not used with 100% of efficiency for production, because during metabolism, around 15% of the energy is wasted as heat, and this is commonly referred to as heat increment or specific dynamic action (Yaghobfar, 2016). In fact, net energy values vary with bird age, species, and production level; this poses a logistical problem during formulation. Protein sources may also supply a substantial amount of energy and their interaction with the main energy sources has a bearing on the overall energy supply and utilization (Hossain et al., 2012). So it is important to determine the energy value of diets containing plant protein sources. The performance of birds is closely associated with feed nutrients and energy utilization, which is primarily related to availability of more nutrients and energy from the feed ingredients.

Broiler chickens consume 4.702 kg of feed over 42 days with dietary protein contents declining from 230 to 183 g/kg, with a weighted average of 201 g/kg protein. This corresponds to an intake of 945 g protein for an output of 376 g. Therefore, 2.51 kg of dietary protein is required to generate 1.00 kg of protein in a chicken carcass or saleable end product (Macelline et al., 2021).The dietary protein to carcass protein ratio of 2.51 is unmatched by other terrestrial food producing animals (Macelline et al., 2021). The efficiency of protein gain in broiler chickens (33.3%) was estimated to exceed that of pigs (23.3%) and feedlot cattle (12.1%) by clear margins (Macelline et al., 2021).

Feed efficiency has been considered as one of the important parameters in assessing the potential of bird strain or feeding program etc. In North America the value is calculated by dividing feed intake by weight gain, and so values of around 1.9 are common for 42 d old birds. In some European countries, the efficiency is calculated as weight gain divided by feed intake, and a corresponding value would be 0.53 (Omafra, 2022). Whatever system is used, measures of feed efficiency are useful in describing feed intake in relation to growth rate.

The value of a feedstuff depends mostly on the level of nutrients it contains, the amount ingested voluntarily by the animal and the digestibility and, or, degradability of the nutrients consumed(Magalhães et al., 2013). The efficient evaluation of a feedstuff to determine the prediction of the animal response is based on knowing the daily amounts of digestible protein and energy that the animal can obtain from this feed.

The efficiency of utilization of dietary protein and energy is significantly affected by their respective levels of inclusion in broiler diets. Protein utilization decreased with each increment of dietary protein, whereas increases in dietary energy resulted in small increases in protein utilization over the range tested. The efficiency of protein utilization can be accurately predicted from dietary protein level and energy:protein ratio, however the efficiency of energy utilization is more dependent on carcass fat content than on the level of dietary energy or the energy: protein ratio, as shown below.

Protein utilization (%)

$Y = 32.3 - 54X J + .061X2 - 1.0X3$ [10] ($R^2 = .90$)

where Xj = crude protein (%)

X2 = calorie: protein ratio

X3 = sex

Energy utilization (%)

$Y = 17.9 + .047Xi + 1.6X2$ [11] ($R^2 = .38$)

where Xt = calorie:protein ratio

X2 = sex

$Y = 24.3 - .0048XJ + 1.2X2 + 70.8X3$ [12] ($R^2 = .89$)

where Xj = metabolizable energy (kcal/kg)

X2 = sex

X3 = carcass fat (kg)

$Y = 26.2 - .0029X! + .20X2$ [13] ($R^2 = .57$)

where Xj = metabolizable energy (kcal/kg)

X2 = abdominal fat (g)

Efficiency of protein utilization is influenced by the changes in the rates of both synthesis and degradation, but the critical determinant of net protein utilization efficiency is the rate of degradation (Tomas et al., 1988). Degradation rates are increased by amino acid deficiency (Nieto et al., 1995), which is the main reason that amino acid balance must be optimal to maximize both protein utilization efficiency and growth performance (Indarsih and Pym, 2009).

The digestive dynamics of starch and protein has important impacts on the transition of amino acids and glucose across the gut mucosa and their post-enteral availability at sites of protein synthesis. The provision of some slowly digestible starch in broiler diets has been shown to advantage feed efficiency and breast meat yield (Herwig et al., 2019). This could be partially attributable to slowly digestible starch sparing amino acids from catabolism in the gut mucosa (Enting et al., 2005). Chang'a et al (2019) reported that metabolizable energy intake, NE_p and the energy retained as protein were better when pelleted diets were fed than mash diets.

2.4.5 Gastrointestinal Tract (GIT) Development

To meet the needs for growth and maintenance of the rapidly growing chick, the digestive system is required to digest and absorb the exogenous nutrients at a rate adequate to meet its demands. In consequence, the chick places high precedence on intestinal growth to ensure that the nutrient supply functions are met. In addition to the physical architecture of the GIT, a strong barrier function and the immune system must be in optimal condition (Ravindran and Abdollahi, 2021).

El Sabry and Yalcin (2023) indicated that a well-developed digestive system from the embryonic stage to market age plays a significant role in achieving the target performance. Since chicken is precocial, its day-old chick can be independently fed immediately after hatching. Therefore, forming villi–crypt structures and a functional epithelium is a prerequisite prehatch. The morphological, cellular and molecular changes occurring in the digestive system during embryo development are vital for the early post-hatch stage to enhance nutrient utilization and optimize the growth of chicks (Reicher and Uni, 2021). Moreover, the formation and development of the intestine in chicken have a crucial role in the overall health of broilers (Schokker et al., 2011).

Pakiding et al. (2020) investigated the effects of the moment of first feed intake after hatch on intestinal development and growth performance of broiler chickens and verified that the height of villi, depth of the crypt and length of the gastrointestinal tract were significantly affected by treatment. The longer delay in the provision of feed and water in day-old chick were lower height of villi and depth of the crypt, and shorter length of the gastrointestinal tract.

The growth of the digestive tract occurs allometrically, with components of the GIT growing at different rates than the rest of the body. In the days following hatching, weights of proventriculus, gizzard, and small intestine increase more rapidly in relation to body weight than other organs and tissues (Katanbaf, 1988). This growth is maximal between 4 and 8 days of age and thereafter there is a relative decline. The mass of the small intestine increases almost six times within the first 7 days (Uni et al.,1998). Rubio (2018) statd that birds are evolved to have a grinding organ or “the gizzard”, which helps to reduce the particle size of the ingredients, increase the mixing of the digesta with digestive enzymes, increase reverse peristalsis, and maintain feed in the intestine for a longer time (Duke, 1992). Researchers have reported that the mechanical pressure exerted by the gizzard during grinding may exceed 585 kg/cm2 and that the digesta passing from the gizzard into the small intestine is smaller than 40 µm regardless of the original particle size of feed (Cabrera, 1994; Hetland et al., 2002).

The gizzard is the principal physical feed-processing organ in poultry (Amerah et al., 2007). Generally, a well-developed gizzard is associated with powerful contractions of the muscular layers, which not only ensures the complete grinding of the feed, but also increases intestinal refluxes, facilitating the mixing of the digesta with digestive enzymes (Jiménez-Moreno et al., 2019). It has been documented that diet composition is important to the development of the gizzard (Kheravii et al., 2018). The gastrointestinal tract (GIT) is the main site of nutrient digestion and absorption in the body. The mechanisms of fiber functions in the gastrointestinal tract depend on the chemical structure, particle size and concentration (Adibmoradi et al., 2016). The development of the gastrointestinal tract could directly reflect the digestion and absorption function of the body.

Adding fiber ingredients could dilute the diet and may improve gastrointestinal peristalsis (Zhang et al., 2023). Adding 1% insoluble fiber to the diet of broilers could increase the relative weight of the proventriculus, gizzard and liver and improve the proteolytic activity of the pancreas (Yokhana et al., 2016). Broilers fed 3% wheat bran had the increased relative weights of their gizzard and small intestines and enhanced pancreatic amylase and trypsin activity, which was correlated with nutrient digestibility (Shang et al., 2020). Zhang et al. (2023) stated that adding fibrous feedstuffs dilutes the diet and may improve the motility and function of the gastrointestinal tract (GIT). Shakouri et al. (2006) reported that fiber inclusion diet did not compromise growth in broiler chickens. The beneficial effects of fiber were also shown to be related to decreasing gizzard pH, which was accompanied by enhanced nutrient utilization to support and/or increase growth (González-Alvarado et al., 2007). Mingbin et al. (2015) studied effects of feed form, feed particle size on growth performance, carcass characteristics and digestive tract development of broilers, and found that the gizzard weights of crumble-pellet fed birds were significantly lower than mash fed birds measured on day 41. Further to that, the ileum weight decreased progressively with feed particle size, and the ileum length differed between birds fed crumble-pellet and mash diets. Pelleting reduced feed particle size, and small particles are retained in the gizzard for less time than coarse particles, resulting in less mechanical stimulation (Mateos et al., 2012) and reduced organ size. Ramchandar et al. (2022) on the similar observed contrasting results indidcating that the feed particle size did not have any significant effect on gizzard weight. Yan et al. (2015) also supported that, the broiler chicken fed with fine (2 mm screen hole diameter), medium (5 mm screen hole diameter) and coarse (8 mm screen hole diameter) ground mash feed had no significant effect on gizzard development at 41 days of age. Chicks fed pellets diet had significantly the lowest gastrointestinal tract percentage, while those fed mash diet had the highest value, the gizzard percentage was also significantly higher in chicks fed a mash diet than those fed a pellet diet (Amber et al., 2023).

Rezaeipour and Gazani (2014) found that the relative gizzard weight was higher in birds fed mash feeds than in those fed pelleted feeds. Remarkable gizzard relative weight reduction was observed when broiler mash diets were replaced by whole wheat diets or pelleted diets. These findings could mean that pelleting reduced the gizzard's need for grinding, reducing its function to that of transit, and decreasing transit time due to particle size which resulted in reduced organ weight (Amber et al., 2023).

When pelleted diets are fed to chicken, there is increased excreta score and reduced excreta dry matter (DM). He site for the reabsorption and recycling of water in the GIT is the caeca, studies have shown that the length and weight of the caeca is lower in birds fed pelleted diets than those fed mash diets and this might be the reason for the greater loss of water through the excreta in pellet-fed birds (Aguzey et al. 2018). Several study have also reported of lower relative length of the di erent segments of the digestive tract of birds fed pelleted diets compared to those fed mash diets . Although several studies have reported that the length and weight of the segments of the GIT are lowered in pellet-fed birds (Amerah et al.,2007). Zang et al.(2009) reported of an increase in the villus height and crypt depth of birds fed pelleted diets compared with mash diet. Aguzey et al. (2018) concluded that diet form (mash or pelleted), type of grain and level of non-starch polysaccharides have various impacts on the function, shape and overall morphology of the gizzard and the intestines with mash diets being recommended for proper gizzard function and weight.

2.4.6 Carcass quality

Poultry meat is one of the most inexpensive and popular protein sources in the world (Daniel et al., 2011). The current demand for broiler chicken products is not based on high broiler bodyweight alone but has low-fat deposits. The appearance, texture, juiciness, wateriness, firmness, tenderness, odor and flavor are the most important and perceptible meat features that influence the initial and final quality judgment by consumers before and after purchasing a meat product (Cross et al., 1986). Consumers tend to consume food products that are safe for consumption with low fat and cholesterol levels. (Irwani et al., 2022). There is a need for ingredients that can reduce fat levels but are not dangerous if people consume these products. Poultry meat is known to have low fat content and high concentrations of omega-3 fatty acids, which can be beneficial for humans' vascular health (Betti et al., 2009).

There are many definitions of quality, but the most preferred one refers to the composite of those characteristics that differentiate individual units of a product and which have significance in determining the degree of acceptability of that unit to the user" (Groom 1990). However, for meat industry, meat quality is a term used to describe the overall meat characteristics including its physical, chemical, morphological, biochemical, microbial, sensory, technological, hygienic, nutritional and culinary properties (Ingr 1989). Allen et al. (1998) stated that quality in terms of processors, manufacturing and other value adding sectors in addition consider the following as important quality aspects; water holding capacity, shear force, drip loss, cook loss, pH, shelf life, collagen content, protein solubility, cohesiveness, and fat binding capacity are indispensable to acquire excellent functional properties that will ensure a final product of exceptional quality and profitability .

The content of fatty acids and their ratios are important criteria related to the health promoting properties of meat (Mili´cevi´et al., 2014). Poultry meat is a good source of PUFA, especially n-3 PUFA, including eicosapentaenoic acid C20:5 n-3 and docosahexaenoic acid C22:6 n-3, which have a positive effect on the function of the brain and the cardiovascular system (Biesek et al., 2020). Other important criteria are, for example, the omega 6/3 ratio of fatty acids and the atherogenic index (AI) and thrombogenic index (TI), and their values indicate a lower or higher risk of coronary heart disease or cancer (Cartoni Mancinelli et al., 2021). Lower AI and TI values are positively correlated with a lower risk of serious abnormalities in the coronary arteries. In the human diet, the recommended values should be lower than 1 for AI and 0.5 for TI [25]. The sex of birds, in addition to their diet and genotype, is also an important parameter influencing the ratio and concentration of individual fatty acids (Cartoni Mancinelli et al., 2021).

Nutrition of birds has a significant impact on poultry meat quality and safety. The response of a bird to its feed is closely related to the changes in the growth of the skeleton, muscle and fat depot. Feeding of Low-fat and carbohydrate-rich diets to birds do not influence sensory characteristics (Moran 2001), but decrease carcass fat, carcass yield and breast meat yield (Smith et al. 2002). The growth performance of broiler chickens has increased greatly over the last few decades due to improvements in genetics, nutrition and management. However, the fast growth rate of broilers has resulted in health problems, and the higher nutrient supply has led to an increased fat deposition (Tumova and Teimouri, 2010). Novotny et al. (2021)worked on the influence of different feed particle size in broiler diets on the performance parameters and digestive viscosity and confirmed that the diets with a different particle size (coarse, medium, and fine) showed no influence on feed consumption, body weight, and yield of carcass, breast meat and leg meat. Chicks fed pellets diet had significantly the highest values of the liver, giblets, and abdominal fat percentages, while those fed mash diet had the lowest values. Carcass trait values did not influence by enzyme supplementation in the diets (Amber et al., 2023).

2.4.7 Abdominal fat pad

Limiting the feed intake in avian species using various methods, (quantitative or qualitative feed restriction) has successfully addressed many problems that affect poultry farms due to intensive selection, e.g., fatness. The abdominal fat tissue is crucial in poultry because it grows faster compared with other fat tissues (Butterwith, 1989). In avian species, most fatty acids are synthesized in the liver and transported via low-density lipoproteins or chylomicrons for storage in adipose tissues as triglycerides (Hermier, 1997). The abdominal fat pad is a reliable parameter for judging total body fat content because it is linked directly to total body fat content in avian species (Fouad and El-Senousey, 2014). Hood (1982) also supported that there is a significant correlation coefficients between body and abdominal fat and these suggest that the weight of the fat pad could be a useful indicator of body fatness.

The origin of fats in broiler chicken body is by means of exogenous (from the diet) or endogenous (synthesized in the liver) or from skeleton (Haro, 2005). Storage fat is localized as: abdominal fat (including fat surrounding gizzard, proventriculus, bursa of fabricius, cloaca, and adjacent muscles), sartorial fat (subcuticular fat in cranial thigh region), fat located in the neck (subcuticular fat in ventro-caudal neck region) and mesenteric fat, adhered to mesentery, along the intestine from the pylorus to the colon (Tumova and Teimouri, 2010). It has been long recognized that nutrition has a significant effect on fat deposition. Fat deposition happens when there is a positive energy balance and when the nutrients in the feeds are not balanced. In particular, the energy to protein ratio of the feed and the type and amount of dietary fat are the most important factors affecting body fat deposition (Tumova and Teimouri, 2010).

Nutritional factors can regulate body fat deposition. In poultry dietary energy level can be modified to reduce body fat deposition. Kassim and Suwanpradit (1996) showed that reducing the energy level from 3,200 to 3,000 kcal/kg in broiler chickens from 21 to 42 days of age significantly reduced the abdominal fat percentage and total body fat deposition without any negative effects on the average daily gain, feed intake, or dressing percentage. Rabie and Szilagyi (1998) also found that the abdominal fat deposition was reduced significantly by decreasing dietary energy level from 3,227 to 3,059 kcal/kg in broilers from 18 to 53 days of age had no significant impact on the final live weight, carcass yield, or breast meat. In general, it is accepted that inhibiting the absorption of dietary fat and fatty acid synthesis, and/or promoting fatty acid β-oxidation reduces abdominal fat deposition by decreasing the size and/or number of abdominal adipose cells (Fouad and El-Senousey, 2014).

Shahin and Abdelazim (2006) reported that abdominal fat, carcass fat and total body fat yields greatly decreased by feeding birds with high fiber diets and produces less abdominal fat depots. Mourao et al. (2008) also added that birds fed diets containing insoluble fiber (NSP) produced lighter carcasses with lower levels of abdominal fat compared with control.

Protein is the most expensive component of poultry diets. Increasing dietary protein content improves the average daily gain, carcass yield, and carcass quality by increasing protein content while reducing body fat deposition. Jlali et al. (2012) found that increasing dietary CP level from 17% to 23% in fat and lean broiler chickens from 21 to 63 days of age caused a significant reduction in abdominal fat deposition. Therefore, dietary protein content must play a direct or indirect role in the regulation of lipid metabolism. Fouad and El-Senousey (2014) concluded that dietary protein level affected body fat deposition directly. Thus, it is better to meet the protein requirements of birds to produce high quality meat with low fat deposition.

Zhong et al. (1995) found that early feed restriction significantly reduced abdominal fat deposition because of a significant decrease in the number of abdominal adipose cells. Thus, the application of quantitative or qualitative feed restriction in commercial farms could be an effective method for reducing the level of undesirable fat in modern strains of poultry. Santoso et al. (1993) exhibited that quantitative feed restriction for 10 days (beginning on the first day in the second week of age for female broiler chickens) led to a significant decrease in the abdominal fat percentage and total body fat deposition. It is well known that female broiler chickens tend to deposit more fat than male broiler chickens. Moreover, Rezaei et al. (2010) and Wu et al. (2012) established that qualitative feed restriction in modern broiler chickens and meat-type ducks reduced body fat deposition. Rezaei et al. (2010) found that the inclusion of rice hulls in the diet of broiler chickens at a level of 20% for five days starting at 16 days of age significantly reduced the abdominal fat and total body fat deposition.

Numerous research explained that the reduction of abdominal fat weight by feed restriction is possible by inhibiting the activity of the rate limiting enzyme during lipogenesis in the livers of broiler chickens. Tan and Othani (2000) found that quantitative or qualitative feed restriction decreased the activities of the main lipogenic enzymes, including ACC and FAS, in the livers of White Pekin ducks. Wu et al. (2012) confirmed that feed restriction lowered the body fat content by decreasing the hepatic activity of MDH, G-6- PDH, and FAS enzymes.

2.5 Phase feeding

Phase feeding is a nutritional management strategy in which the ingredient and chemical composition of the diet is modified over time, so that the diet more closely meets the nutrient requirements of an animal (Mudhunguyo and Masama, 2015). In practice, broilers are switched from starter to finisher diets at about 28 days of age in a two-stage feeding system and are raised with the sexes combined. However, it is not evident whether changing the diet at different ages for different sexes will affect performance (Diambra and McCartney, 1985). Phase feeding can be used to delay maturity, increase the growing period and reduces costs associated with excess protein or amino acids and improves growth. Phase feeding is also associated with compensatory growth with possible benefits, which include feed savings and high efficiency of feed utilization (Meremikwu and Obikaonu, 2020).

Salem et al. (2023) compared three phase feeding regime on broiler production and revealed that there was a slight difference between the three feeding broiler programs, and while most parameters did not differ considerably, the two phase feeding showed a small improvement in the economic efficiency of about two percent. Hauschild et al. (2015) on the other hand indicated that increasing the number of feeding phases is unfavorable to production logistics. The researchers advised that a solution to these logistical challenges have been provided by the development of feeding systems that mix two diets automatically in real time, allowing the animal’s requirements to be met throughout its growth. Researchers, therefore advised that, ensuring that all requirements are properly met using only two feed formulations poses a problem requiring the use of multiple complex algorithms.

Broiler chicks are commonly fed three diets with increasing energy and decreasing protein content. The three phase feeding program is made up of starter, grower and finishing phase. Some farmers adopt four and five phases to optimize their production. One phase feeding program on the other hand ration meet the nutritional requirements of broiler birds from day old until slaughter. One phase feeding system allows for simplified feed flow management (AFGRI, 2021). It was reported that a multiphase feeding resulted in reduced amino acid use through reduction of nitrogen excretion, fat accumulation on the carcass, production cost (increasing efficiency and decreasing amino acid supplementation), and improving feed efficiency utilization (Dawood Rahoma,2023). Gutierrez, et al.(2008) added that during early age, birds on both continuous multiphase feeding programs had significantly greater cumulative body weight gain and improved feed conversion ratio compared to the 4-phase feeding program.

Tolimir, et al.(2010) concluded that multiphase feeding had an effect on performance especially the level of food utilization. The multiphase program led to improvements in final body weight, in addition to an increase in breast yield. Precisely, the use of the mixing method proposed by Létourneau-Montminy et al. (2005) enhanced performance of broilers, even when compared with traditional four phase programs based on an average level of nutrient requirements for each phase (Hauschild et al., 2015). Anyigor and Etuk (2018) confirmed that birds on the four-phase feeding regimes (T2, T3,and T4) produced significantly higher final body weights and body weight gains, better feed conversion ratio and lower feed cost per kg body weight gain than those in the dual-phase (control (T1)) feeding regime. Birds on T3 produced the best values in most of the parameters measured. It is recommended that the four-phase feeding regime particularly T3 (pre-starter 0-7 days, starter 8-13 days, grower 14-42 days and finisher 43-56 days) be adopted for optimal broiler performance and net income.

Loupe and Emmert (2000) concluded that phase-feeding would not be economically feasible if six or more diets were fed during the grow-out period, because of increased costs associated with diet preparation, transport, and storage. It may be possible to accomplish PF by initially delivering a nutrient-dense starter-type diet and a less dense grower-type diet, which could be blended at a desired rate to achieve gradual decreases in dietary amino acid levels. Percentage abdominal fat pad size was significantly reduced as dietary protein increased and as days of diet change increased. Phase feeding had a greater effect than finisher protein content on percentage abdominal fat pad size. The response of percentage abdominal fat pad size was more dramatic than any other trait measured; this suggests that the rate of fat deposition increases rapidly as the broiler approaches market weight. The starter diet, fed for a longer time, was effective in significantly reducing fat deposition (Diambra and McCartney, 1985).

Hamdeen and El- Amin Mohammed (2015) investigated effects of phase feeding on broiler performance andserum-carcass lipids and reported that phase feeding showed significant decreased final body weight, body weight gain, and feed conversion ratio but showed no significant effect ontotal feed intake. Furthermore there were no significant differences on all carcass parameters except neck weight, which significantly increased between two and three diet phase feeding respectively. The effect of phase feeding on broiler carcass internal organs weight results indicated that phase feeding (one, two, three diets) showed no significant effect on liver, pancreas,spleen, and heart weights, but it showed significant reduction on gizzard and abdominal fat pad weights (Hamdeen and El- Amin Mohammed,2015).

Gutierrez et al.(2008) stated that continuous multiphase feeding programs had significantly greater cumulative BW gain and improved FCR relative to birds on the 4-phase feeding program. Saveewonlop et al. (2019) added that the effects of the different phase-feeding programs with different feed forms on broiler performance for the entire period (1-37 days of age) revealed no significant differences in body weight gain, feed consumption, FCR, or mortality among birds fed the different phase-feeding programs with different feed forms. The effects of the different phase-feeding programs with different feed forms on carcass traits had no significant influence on carcass percentage, percentage of edible internal organs (liver, gizzard and heart) or percentage of cut parts (neck and head, breast, thigh, drum, wing, shank and leg, abdominal fat and skeleton) among treatments (Saveewonlop et al., 2019).

Mudhunguyo and Masama (2015) examined the broiler chicken performance on different phase feeding programs and exhibited that broiler chickens under two phase feeding were significantly lighter at 1789 grams than four phase feeding (1871grams) at day 36. Carcass weights and weights of internal organs were significantly different amongst the feeding phases, with superior weights noted on four phase feeding program. Broilers on four phas feeding had significantly heavier feet weights than those on two and three phase feeding programmes. Three phase feeding had the least feed conversion ratio of 1.34

compared to two phase feeding (1.32) and four phase feeding (1.28). Karan et al. (2020) tested the influence of dietary multiple phase feeding on growth performance of commercial broiler chicken realised that feed conversion ratio of broilers of three phase feeding was significantly better than that of control group during fifth week and also during the overall performance. The multiple phase feeding has not put any adverse effect on percentage mortality of broilers. Furthermore, broilers fed with the multiple phase feeding showed higher net profit per bird and also per kg of body weight as compared to the broilers of control group.

2.5.1 Pre starter phase

The primary aim of a pre-starter diet is to fulfill the specific nutritional needs of the young chick, supporting its transition from eating the yolk sac to the first diet consumed. Pre-starter feed is a special feed given to chicks at the early period (0-5 days) consisting of highly digestible feed materials. For getting sufficient performance with regards to numbers and quality from chicks until the slaughter, the first week after hatching is of paramount importance. Because the early feeding stage, which makes up the first week of the 35 to 42 days of feeding for the chicks is very important for many vital aspects that will affect later stages, such as the development of the digestive, immune and skeletal systems (Durmuş, 2018). The role of early stage feeding practices is significant with regards to the form, digestibility, nutritional content and problem free transition from yolk sac feeding (lipid form) absorbed during the embryonic period to solid feeding (proteins and carbohydrates)Availability of nutrients immediately after hatch is critical for growth and development (Blanch, 2023). A diet fed to broiler chicks for the first four days is often referred to as a pre-starter. As for standard starter diets, highly digestible ingredients are selected, but high-quality, high-value raw materials are used, more than doubling their cost.

The gastrointestinal tract grows four times faster than the rest of the body during the first two weeks of life (Blanch, 2023). This organ is driving body weight gain and as such requires up to 40 percent of the energy and protein that the young bird consumes. High protein content is also necessary in diets for young birds, apart from for growth to help maintain body temperature. Probiotics may added to diets to seed the gut with beneficial bacteria or protect it from pathogens.

Any delay in initial feed intake may suppress gastrointestinal development and cause early malnutrition, suppress thyroid activity and inhibit satellite cell proliferation and muscle growth potential. These are the lasting effects of early nutrition and feeding on subsequent performance (Juul-Madsen et al., 2004). The chicks come out from an embryonic condition in which the energy basis of their nutrition is yolk's fat and egg white's proteins. Immediately after birth, during the first hours of life there is a significant reduction in the endogenous glycogen levels, which need to be replaced preferably by glycogen from the consumption of corn starch or another source of starch (Lamot, 2017). The yolk sac may be sufficient for the first few hours of chicks' survival, all the other requirements fail during the long hours until their arrival to the farm. Willemsen et al. (2010) suggest that the deprivation of feed and water for 72 hours can have long-term negative effects on chicken's welfare and behaviour.

2.5.2 Starter phase

It is the initial feed for broiler chickens and it is given to broiler chicks from age 0 day to 10 days (Brake et al., 1992). The diet must contain maximum quality proteins and energy sources. In starter feed, the crude protein level is high (21-22% CP) and the metabolizable energy level is low (3000 Kcal/kg ME). Crude fiber content is low (4-5% CF) because chicks can't digest fiber very well. The starter feed must contain supplements and essential minerals and vitamins. A quality broiler starter feed supports early growth and physiological development, ensuring that your chickens grow up to be healthy and profitable. A good starter feed should be based on the broiler chicks' needs and not the cost of making it.

The objective of the brooding period (0-10 days of age) is to establish good appetite and maximum early growth in order to meet the seven-day body-weight objective. It is recommended that a broiler starter feed be fed for ten days. The starter represents a small proportion of the total feed cost and decisions on starter formulation should be based primarily on performance and profitability rather than purely on diet cost. The benefit of maximising nutrient intake on early broiler growth and subsequent performance is well established. Feeding broilers the recommended nutrient density will ensure optimal growth is established during this critical period of life. Waldroup, et al.(1992), observed that the carcass dressing percentage of males was reduced significantly when the starter diet reached 29 days; no significant effects on carcass traits. Holsheimer(1980), reported that the starter diet had only a slight effect on the carcass composition of male broilers.

2.5.3 Grower phase

Broiler Grower feed is generally fed for 14- 16 days following the Starter. Starter to Grower transition will involve a change of texture from crumbs/mini-pellets to pellets. Depending on the pellet size produced, it may be necessary to feed the first delivery of Grower as crumbs or mini-pellets. During this time broiler growth continues to be dynamic. It therefore needs to be supported by adequate nutrient intake. For optimum feed intake, growth and FCR, provision of the correct diet nutrient density, especially energy and amino acids, is critical. Grower diet had a pronounced effect on the carcass composition and decreased the dietary lysine content and carcass protein content (Dawood Rahoma,2023). Lundeen (2019) investigated the impact of feed form, on broiler performance by growth stage and learnt that broilers receiving crumbles and 80% intact pellets had increased feed intake and bodyweight in the starter and grower growth phases. Broilers receiving crumbles had a decreased feed conversion ratio by 0.02 in the starter growth phase.

2.5.4 Finishing phase

Broiler Finisher feeds account for the major volume and cost of feeding a broiler. It is therefore important that feeds are designed to maximise financial return for the type of products being produced. Finisher feeds should be given from 25 days until processing. Birds slaughtered later than 42-43 days may need a second Finisher feed specification from 42 days onwards. Benyi and Habi (1998) researched on the effects of food restriction during the finishing period on the performance of broiler chickens and showed that there were no significant differences between the effects of 15% feed restriction and 2-day reduction in feeding time per week on final body weight, growth rate and abdominal fat. Researchers continued that reduction in feeding time by 2 days/week resulted in the same feed efficiency as ad libitum feeding and quantitative feed restriction by 15% and a significantly better feed efficiency than 30% quantitative feed reduction. Reducing feeding time by 2 days/week seemed to have less severe effects on the birds than quantitatively reducing feed supply by 30%.

Vegetable oils in finishing diets (29-42 days) of broiler chickens improved some performance indices as compared to chickens fed diet rich in animal fat. Moreover, lower abdominal fat pad weight was observed in birds fed finishing diet containing vegetable oils compared to birds fed diet containing animal fat. Serum triglyceride and HDL levels were significantly influenced by modification of dietary fat sources 14 days prior to slaughter (Mirghelenj et al., 2016). It was recommended that feeding finishing broilers 10 per cent dietary level of Groundnut Pod (GNP) yielded best carcass, and organ qualities! Hence, poultry farmers are encouraged to incorporate this level of GNP in finishing broiler's diet as it can be used without any negative effects on the carcass characteristics (Ajayi et al., 2020).

2.5.5 Withdrawal periods

Withdrawal periods for drugs will dictate the use of a special withdrawal finisher feed. A Withdrawal feed should be fed for sufficient time prior to slaughter to eliminate the risk of pharmaceutical product residues in the meat. Statutory withdrawal periods for prescribed medicines that are specified in product data sheets must be followed. It is not recommended that extreme dietary nutrient reductions be made during the withdrawal period. Emmert and Baker (1997) reported that phase feeding may support the elimination of some excess dietary crude protein and supplemental amino acids, thereby potentially reducing dietary costs and nitrogen excretion.

Emmert and Baker (1997) reported that phase feeding may support the elimination of some excess dietary crude protein and supplemental amino acids, thereby potentially reducing dietary costs and nitrogen excretion. Pope and Emmert (2001) stated that in comparison phase feeding reduces production costs. Warren and Emmert (2000) reported that the phase feeding program affected feed costs, and income was similarly affected (fewer feed costs). Concluded that phase feeding reduced dietary costs without sacrificing growth performance or carcass yield. Table 2 below is an example of a five phase feeding programme.

Table 2: Five phase feeding program

	Unit	Pre-starter	Starter	Grower	Finisher	Withdrawal
Period of use	Days	0 – 10	11 – 20	21 – 33	34 – 42	> 42
M.E.	Kcal / kg	3,000 – 3,050	3,000 – 3,050	3,050 – 3,100	3,150 – 3,200	3,150 – 3,200
Crude protein	%	22 – 24	22 – 24	20 – 22	19 – 21	17 – 19
Amino acids (crude/digestible)						
Lysine	%	1.40 / 1.23	1.40 / 1.23	1.25 / 1.06	1.15 / 0.98	0.95 / 0.81
Methionine	%	0.60 / 0.54	0.60 / 0.54	0.54 / 0.47	0.49 / 0.42	0.43 / 0.38
Methionine + Cystine	%	1.05 / 0.90	1.05 / 0.90	0.98 / 0.85	0.90 / 0.78	0.78 / 0.68
Threonine	%	0.90 / 0.78	0.90 / 0.78	0.85 / 0.72	0.78 / 0.67	0.67 / 0.57
Tryptophan	%	0.24 / 0.22	0.24 / 0.22	0.22 / 0.19	0.21 / 0.18	0.16 / 0.14
Minerals	%					
Calcium	%	1.00 – 1.05	1.00 – 1.05	1.00 – 1.05	0.90 – 0.95	0.80 – 0.85
Av. phosphorus	%	0.50	0.50	0.45	0.40	0.40
Sodium	%	0.16 – 0.18	0.16 – 0.18	0.16 – 0.18	0.16 – 0.18	0.16 – 0.18
Chloride	%	0.15 – 0.20	0.15 – 0.20	0.15 – 0.20	0.15 – 0.17	0.15 – 0.17
Potassium	%	0.85	0.85	0.80	0.75	0.70
Added trace minerals per kg						
Zinc	mg	80		80		
Copper	mg	10		10		
Iron	mg	60		60		
Manganese	mg	80		80		
Iodine	mg	1.0		1.0		
Selenium	mg	0.2		0.2		
Added vitamins per kg						
Vit. A	I.U.	15,000	12,500		10,000	
Vit. D3	I.U.	3,000	2,500		2,000	
Vit. E (*)	mg	50 – 100	30 – 100		30 – 100	
Menadione K3	mg	3	2		2	
Thiamine B1	mg	3	2		2	
Riboflavin B2	mg	8	6		6	
Pantothenic acid	mg	15	10		10	
Pyridoxine B6	mg	4	3		3	
Niacin PP	mg	60	40		40	
Folic acid	mg	1.5	1.0		1.0	
Vit. B12	mg	0.02	0.01		0.01	
Vit. C	mg	200	200		200	
Biotin	mg	0.2	0.1		0.1	
Choline (Chloride) (***)	mg	(700)	(600)		(600)	
Total choline (**)	mg	1,800	1,600		1,400	

2.6 Nutrient requirements of broiler

Poultry feed is made up of several ingredients so these ingredients are graded as calories (fats, oils, carbohydrates), protein (amino acids), vitamins and minerals. There are six classes of nutrients required by poultry on daily basis and they are; carbohydrates, the major source of energy for poultry. Most of the carbohydrate in poultry diets are provided by cereal grains. Fats; provide energy and essential fatty acids that are required for some bodily processes. Proteins are required for the synthesis of body tissue (particularly muscle), physiological molecules (such as enzymes and hormones), feathers and for egg production. Proteins also provide a small amount of energy.Vitamins are organic chemicals (chemicals containing carbon) which help control body processes and are required in small amounts for normal health and growth. Minerals are inorganic chemicals (chemicals not containing carbon) which help control body processes and are required for normal health and growth and water (Poultry Hub Australia, 2023).

The science of poultry nutrition involves providing a balance of nutrients that best meet the bird's needs for growth and development, maintenance, and production (ARC, 2014). The supply of nutrients should be refined to preclude over and under supply of nutrients while considering economic and environmental implications. It is elusive and expensive to simultaneously supply all nutrients to meet the exact nutrient requirement of the birds. Therefore, an ideal protein concept is generally exercised (ARC, 2014). The ideal protein can be defined as one that provides the exact balance of amino acids needed for optimum performance and maximum growth of chickens. It is essential amino acids in dietary protein that a bird requires and not the protein *per se*. In poultry diets, first and second limiting amino acids include methionine and lysine, respectively. Dietary energy is among the most essential among feed nutrients, because it influences the use of other nutrients by its capability to regulate a high degree of feed intake (Seth and Mishra, 2018).

2.6.1 Nutrient Requirements for maintenance

Maintenance refers to the state in which there is neither gain or loss of a nutrient by the animal body, regardless of the purpose of feeding an animal. A substantial portion of food/feed is used for supporting vital body processes, which are essential for life that portion consisted of the amount of feed needed to keep all the necessary tissues of an animal intact, which is not growing, working, or yielding any product (Gannon, 2019). This demand for food/feed is referred to as the maintenance requirement, and tissue breakdown would occur if this demand is not met. A proportion of food/feed used for maintenance would differ depending on a multitude of factors such as species, age, rate of growth/production, etc. For a large segment of human population, the maintenance requirement may consist of the primary need for food, but this is not true for many farm animals simply because they are usually fed for productive purposes.

The animal getting no feed, doing no external work, and yielding any product is still carrying out vital/essential body processes such as respiration, circulation, maintenance of muscular activities, production of internal secretions, etc. With no feed, the nutrients needed to support those activities must come from the breakdown of body tissues, and this is referred to as fasting catabolism (Noblet,2007). Energy expended in the fasting animal is represented by the fasting heat production and can be measured in the respiration calorimeter (or other method of indirect calorimetry) and this can provide a useful basis of reference for other phases of energy metabolism. By eliminating all the potential factors that may increase heat production, the minimum energy expenditure compatible with the maintenance of life can be obtained, and such a minimum value is called basal metabolism or basal metabolic rate. Heat production is obviously related to body size, and it is commonly accepted that 0.75 to be the power of body weight best related to basal metabolism. Basal metabolism is highest in the newborn and gradually decreases during the growth period, and there are also some species and intraspecies differences, as would be expected.

2.6.1.1 Energy

Feed is the major source of energy and it provides chemical energy that is present in the nutrients (Priyankarage et al.,2011). Simple carbohydrates, some complex carbohydrates, protein and fat in the feed are the main energy supplying nutrients. Poultry tend to eat to meet their energy needs, provided other essential nutrients are adequate in the diet, especially at thermo neutral zone (Prusty et al., 2022). Animals require energy for growth, maintenance, digestion and reproduction. Most dietary ingredients contain energy released by the breakdown (burning) of fats, carbohydrates and protein (Ravindran and Abdollahi, 2021). The major energy sources in poultry diets are cereal grains, such as wheat and corn, which have a high starch content. Concentrated sources of energy, including fats and oils, are usually provided to obtain optimum growth and performance. Approximately 23.4 MJ of dietary energy is used to produce one kg of poultry meat and the cost of supplying energy from poultry feeds account for half of the total cost of a feed (Priyankarage et al., 2011).

The energy requirement of broiler birds is expressed in terms of dietary concentration i.e. kcal (metabolizable energy) ME/kg diet, since there is daily change in body weight of growing birds (Prusty et al., 2022). For commercial white broilers energy requirement (ICAR, 2013) is 3000 kcal ME/ kg from 0-14 days (pre-starter phase), 3050 kcal ME/ kg from 14-21 days (starter phase) and 3100 kcal ME/ kg from 21-42 days (finisher phase). Coloured broilers grow at a slower rate owing to a comparatively lower requirement i.e. 2950 kcal ME/ kg from 0-21 days and 3050 kcal ME/ kg from 21-42 days (ICAR, 2013).

2.6.1.2 Crude Protein

Dietary protein is important for animal growth, development and maintenance (Kamran et al., 2004). Protein is composed of amino acids. Since amino acids differ in concentration with each protein source, the quality of protein varies, influencing its nutritional value. Amino acids are either essential or non-essential. Non-essential amino acids can be produced by the birds when necessary, but essential amino acids must be provided in the diets because the birds cannot produce them (Wu, 2009. The balance of dietary amino acids is also important, as birds will not perform well if the ratio of one or more amino acids to the others is not appropriate.

Protein can be found in most feedstuffs, although feeding cereal grains alone does not provide enough of the essential amino acids or a balanced amino acid profile. Therefore, cereal grains must be mixed with other protein-rich ingredients to meet the amino acid requirements of the birds for growth and development. Sources of concentrated protein are soybean meal, canola meal, legumes (peas, lentils), meat meal and fishmeal.
Feeding high amino acid density diets improves feed conversion and increases weight gain and breast meat yield of broiler chickens (Kidd et al., 2004).

Methionine + cystine (total sulfur amino acid, TSSA) perform a number of functions in enzyme reactions and protein synthesis. Methionine is an essential amino acid for poultry and has an important role as a precursor of cystine (Farkhoy et al., 2012). Methionine is usually the first limiting amino acid in most of the practical diets for broiler chicken (Vieira et al., 2004). Lysine is often one of the limiting amino acids in broiler diets. As such, it used as the reference amino acid to which all other essential amino acids are rationed in the ideal amino acid pattern . Therefore, it is crucial to obtain an accurate Lys and Met + Cys requirement to support optimum growth of fast-growing commercial broilers (Farkhoy et al., 2012).

2.6.1.3 Minerals and vitamins

Minerals are often classified as macro or trace minerals in reference to the concentrations required. Macro-minerals such as calcium and phosphorus are generally required in larger quantities than trace minerals like iron, copper and iodine. In some cases, the ratio of one mineral to another is important. Calcium to phosphorus ratios are a primary example. Minerals are important for structural components such as bones and physiological processes. Deficiencies can lead to problems similar to those caused by inadequate amounts of dietary vitamins. An excess or deficiency in vitamins and minerals fed to poultry may lead to sickness or disease.

Vitamins and minerals are required by all animals in order to maintain health and maximize production. Vitamins are organic compounds required in small amounts. Their function is to assist physiological processes, including normal growth, feathering and leg development. Deficiencies of various vitamins may cause problems such as skin lesions, nervous disorders, muscle problems, reduced egg production in layers, reduced growth in meat birds and improper chick development in eggs from breeding birds.

Essential vitamins and minerals are not always found in sufficient quantities and/or available forms in the feedstuffs used for poultry. Therefore, they are supplemented in diets by using vitamin and mineral premixes. Premixes are formulated specifically for each species, as well as the stage of growth and/or production. Vitamins and minerals are found in commercial feeds at adequate amounts. If mixing ingredients with a supplement or concentrate on farm, instructions can be obtained from the feed tag or by consulting with the feed company's nutritionist.

2.6.1.4 Water

Water is not often thought of as a nutrient, but it is an important nutrient because it regulates body temperature, transports other nutrients, and takes part in numerous chemical reactions in the body. Therefore, water should be available to the birds at all times. Water consumption can be affected by feed type, stage of production and growth, disease status and environmental temperature. The volume of water required for poultry is often estimated by multiplying the daily feed consumption by two. For example, if a group of birds is eating 10 kg of feed per day, the estimated daily water consumption is 20 litres (10 kg feed x 2 = 20 kg water. One kg water = one litre of water). Birds can drink up to twice their estimated daily water consumption under hot environmental conditions.

2.6.2 Nutrient requirements for growth

Growth involves an increase in the structural tissues such as muscle and bone and also in organs, but should be distinguished from the increase that results from fat accretion in the reserve tissues. Thus, essentially, growth is characterized primary by an increase in protein, minerals and water, also various vitamins are required. A minute amount of lipid goes into the structure of each cell, but this does not represent a specific dietary requirement (except, essential fatty acids) because of the synthesis of lipid from carbohydrates.

Various nutrients are needed for growth, but the need for energy is by far the largest & primarily determines the total feed required. The maintenance portion of the total energy need during growth increases with body size, but the additional need for the growth depends on the rate and the composition of the tissue being formed. The amount of energy represented by the tissue growth decreases with age, thus reflecting the declining rate of body increase measured on a percentage basis. The amount of energy stored per unit of body increase becomes larger with age because of its lower water content and higher fat content. The true growth tissue contains only a trace of fat, but a certain amount of fat accretion is inevitable consequence of growth. In practice, a considerable amount of fattening is an integral part of growing animals for meat.

2.6.3 Factors affecting poultry nutrient requirements

A large number of factors, including, affects the nutrient requirements of poultry:

Genetics

Different species, breeds or strains of birds have different average body sizes, growth rates and production levels and will absorb and utilise nutrients from feed with different levels of efficiency (Jacob, 2018). Therefore, they will require feed with different nutrient compositions. The genetics of commercial poultry is constantly changing, and as a result, so are their nutrient requirements. Consequently, breeders of commercial poultry provide information on the specific nutrient requirements for the birds they sell.

Age

Nutrient requirements are related to both body weight and the stage of maturity in bird. Sulistiyanto et al. (1999) found that utilization of energy-yielding feedstuffs is age dependent and aded that by 14 days of age, the chick were able to efficiently utilize the energy in the diet. Classen (2013) supported that broilers response to dietary energy has been shown to be affected by bird age, with younger birds seemingly less able to respond appropriately because of physical limits in digestive tract capacity. This could also relate to the reduced digestive ability (Sklan, 2001) and the nature of the diet ingredients and form.

Sex

Prior to sexual maturity, the sexes have only small differences in their nutrient requirements and males and females can usually be fed the same compromise diet to achieve acceptable growth rates. Differences in nutrient requirements are larger following the onset of sexual maturity and significantly different diet formulations are then required for each sex. Wecke and Liebert (2019) compare the utilization of crude protein between male and female and verified that the crude protein composition of the body weight gain remained insignificant between both genders, but the protein partitioning in the feather and feather-free body fraction provided oppositional results. Male chickens yielded higher quantities of protein in the feather-free body and females had relatively more feather protein in the gained bodt weight (Wecke and Liebert, 2019).

Environmental conditions

Environmental factors are generally recognized to have a major impact on the production of meat and eggs from poultry. These include temperature, humidity, light (length of day and intensity), altitude (air pressure and partial pressures of oxygen and carbon dioxide), wind velocity (air movement), solar energy, quality of air and water, and density of population (NRC, 1981). Poultry have increased energy requirements to maintain normal body temperature in cold ambient temperatures and the opposite in hot ambient temperatures. Food digestion processes produce body heat, the amount of which will vary according to the nutrient composition of the diet and this is called the heat increment of the diet. In cold temperatures, it may be desirable to formulate a diet with a higher heat increment and the opposite in hot temperatures.

Housing system

The type of housing system will influence the level of activity of the birds and therefore their energy requirements. The use of shelter to shield poultry from the macroenvironment is an approach to enhance productivity and thus justify such expenditures. The structure creates around the bird a meso- and microenvironment (NRC, 1981) that moderates but does not alleviate environmental impact. In temperature-nutrition studies, it is important to consider the environment in the cage (microenvironment) and to avoid use of measurements taken within the building (mesoenvironment)(NRC, 1981). Housing can therefore reduce the "thermal stress" of animals in both cold and hot conditions and improve their performance. It also allows better control of both the quantity and quality of feed, a reduction in the energy expenditure and improvement in animal comfort and welfare (Close, 2023).

Health status

The diseases that broiler will encounter include respiratory diseases, intestinal diseases, parasitic diseases, liver diseases and various nutritional deficiencies. These diseases will affect the feed intake of laying hens, the digestion and absorption and utilization of nutrients, and affect the conversion of energy, which will eventually lead to a decrease in the energy utilization rate of feed (Polifar group limited, 2023). An immune challenge decreases tissue protein synthesis and increases protein degradation rates in part because of reduced feed intake and an increased need for nitrogen to synthesize immunological products, which may alter specific amino acid needs (Whitney, 2010). The net results of these metabolic adjustments are reduced body growth rate, less efficient utilization of feed for growth, and potentially fatter carcasses (Whitney, 2010).

Production aims

The optimal nutrient composition of the diet will vary according to production aims, such as optimising weight gain or carcass composition, egg numbers or egg size. Poultry that are raised for breeding purposes may need to have their energy intake restricted to ensure that they do not become obese (Jacob, 2018).

2.7 Dietary feed forms and texture

2.7.1 Feed texture

Mash, crumble and pellet are the common feed forms in the poultry industry that directly affects growth performance, nutrient digestion, intestinal health, and productivity of the birds (Amoozmehr et al., 2023). Common feed forms in animal feed are pellets, crumbles or mash. However, in the broiler industry, pellets and crumbles are mainly used. In less intensive areas, mash production for broilers is common too (Kreis, 2019). Mash is form of a complete feed that is finely ground and mixed so that birds cannot easily separate out ingredients and each mouthful provides a well-balanced diet. Mash diets gives greater unification of growth, less death loss and are more economical because pellets and crumbles costs slightly more than the same ration in mash form (Kuleile and Molapo, 2019). However, ground feed is not so palatable and does not retain their nutritive value as well as ungrounded feeds.

In general, processing complete poultry feed into pellets involve preconditioning the total mixed diet which is followed by extrusion of the mash through a pellet mill die. In the recent decade, usage of poultry feed in the form of pellet have a lot of benefits such as; decreased ingredient segregation, less time and energy expended for prehension, destruction of pathogenic organism, thermal modification of starch and protein, improved palatability and high feed intake (Jahan et al., 2006). Crumble diet also is a type of feed prepared at the mill by pelleting of the mixed ingredients and then crushing the pellet to a consistency coarser than mash (Kuleile and Molapo, 2019). Recently this form of a feed is becoming popular in broiler production due to its convenience of feeding.

Broilers fed crumble-pellet diets show improved weight gain, feed intake, and feed conversion ratio compared to birds fed mash (Massuquetto et al., 2020. Azizian and Saki (2020) found a significant increase in the average daily feed intake (ADFI) from the use of large particle size than mash. Hamilton and Proudfoot (1995) supported that the improvement in broiler performance with pelleted diets may be attributable to a greater digestibility of carbohydrates together with increased daily nutrient intake.

The feed particle size influences the feed intake, growth changes, or development of the digestive tract (Novotný et al., 2023). Several studies on broiler chickens observed that feeding with a coarse mixture increases the relative gizzard weight and decreases pH (Novotný et al., 2023). Feed particle size is usually defined as the average particle size distribution of individual components of feed or as the fineness of feed grinding. Wolf et al.(2012) described the specific size as coarse >1.4 mm, medium 0.8–1.4, fine 0.4–0.8, and very fine <0.4 mm. The optimal particle size distribution should correspond to the physiological needs, which enables the optimal use of nutrients and increases the productivity of the animals.

The importance of the physical structure of the diet as a means of improving feed efficiency and live performance has been recognized (Xu et al., 2015). A reduced particle size allows greater interaction of the feed with the digestive enzymes owing to its increased surface area (Chewning et al., 2012). However, a finer particle size could decrease gut peristalsis and increase feed consumption and the rate of passage, thus reducing feed digestibility (Svihus et al., 2002; Pacheco et al., 2013). A coarser feed structure was demonstrated to influence nutrient digestibility and animal live performance positively (Xu et al., 2015). Development of a larger, more functional gizzard, through provision of feed with coarser particles or structural fibre has been shown to improve digestibility and efficiency of nutrient utilisation.

Kreis (2019) observed that coarse particles in the feed stimulate gizzard activity, which results in improved grinding and gizzard development, as well as longer residence times, increased stimulation of digestion and improved body weight gain. In contrast, fine particles cause diverse health issues, such as poor gut motility, swollen proventriculus, poor water and electrolyte reabsorption, increased feather picking or increased susceptibility to enteric pathogens. However, apparent nutrient digestibility values can be positively affected by reduced feed particle size, whereas apparent metabolizable energy was not affected (Kreis, 2019).

Amoozmehr et al (2023) investigated the effect of feed form and nutrient density on growth performance, blood parameters, and intestinal traits in broiler breeder pullets discovered that pullets fed the pellet diet had greater BWG and lesser feed per gain ratio than those who were fed the mash diet and the values for the crumble diet were intermediate of pellet and mash diets at the entire of experiments. Mingbin et al. (2015) found that carcass, breast, and thigh and drumstick yields were not affected by feed form. Jafarnejad et al (2010) reported that maximum weight gain was observed in birds fed on diet containing 23% CP on both crumble-pellet and mash diets in all weeks. Birds fed dietary energy levels of 3200 Kcal ME/kg gained significantly more weight than birds fed 3000 Kcal ME/kg in the mash diets at second and third weeks but no difference in BW was noted for birds fed the pellet diets with the different levels of metabolizable energy in all weeks. Nir etal.(1994) indicated that chicks fed pelleted diets spend less time and energy feeding, they were also less active than mash-fed birds and spend less energy for maintenance.

2.7.2 Farm Formulated diets

Poultry feeding is one of the important branches of poultry industry, since feed cost accounts for 70–80 percent of the total farm expenses (Mallick et al., 2020). Of total feed cost, about 95 percent is used to meet energy and protein requirements, while 3 to 4 percent for major mineral, trace mineral and vitamin requirements, and 1 to 2 percent for various feed additives. Poultry diets are formulated from a mixture of ingredients, including cereal grains, cereal byproducts, fats, plant protein sources, animal byproducts, vitamin and mineral supplements, crystalline amino acids and feed additives. These are assembled on a least-cost basis, taking into consideration their nutrient contents as well as their unit prices. The continuous increase in the cost of poultry feed ingredients (especially energy sources) has forced some farmers as well as feed manufacturers to use poor quality energy feed ingredients. This practice has resulted to poor feed intake, weight gain, FCR and meat quality (Robertson and Perez-Maldonado, 2010). The importance of dietary energy in poultry feeding cannot be over-emphasised because increasing or decreasing the dietary energy has been reported to affect feed intake in addition to promoting or undermining efficient feed utilisation and growth rate (Ahiweet al., 2018).

An alternative more cost effective approach is for a farmer to compound his own feed for the chickens. The exorbitant feed cost of conventional feed ingredients has necessitated to formulate efficient and cost effective broiler ration. This is done by assembling the various feed ingredients in their right proportions and processing them at a miller. However one of the major problems encountered especially by small-scale farmers who wish (or are forced by lack of funds) to formulate their own rations is inadequate knowledge of poultry nutrition. When poultry diets are designed using conventional foodstuffs, they follow a predictable pattern and approximate quantities of the various ingredients. Another handicap for these local small poultry farmers is the inaccessibility of the vitamin and mineral premix and lack of data on the average nutrient content of the many local foodstuffs in the ration (Anthony, 2004).

Feed formulation is the process of quantifying the amounts of feed ingredients that need to be combined to form a single uniform mixture (diet) for poultry that supplies all of their nutrient requirements. Since feed accounts for 70% of total live production costs for most types of poultry throughout the world, a simple mistake in diet formulation can be extremely expensive for a poultry producer. Feed formulation requires a thorough understanding of the nutrient requirements of the class of poultry (e.g., egg layers, meat chickens or breeders; feed ingredients in terms of nutrient composition and constraints in terms of nutrition and processing, and cost and availability of the ingredients (Hawkins, 2023). The nutrients of interest in the formulation of poultry feed as crude protein, metabolizable energy, fat, and calcium and phosphorous as major macro minerals and lysine and methionine as major amino acids of interest (Pond et al., 2005).

Feed formulation often referred to as least cost formulation, is the process of matching the nutrient requirements of a class of animals with the nutrient contents of the available ingredients (raw materials) in an economic manner.

2.7.3 Novel feeds

Due to their high nutrients contents, soybean meal and yellow maize are conventional feedstuffs in poultry feeds. Moreover, these two feed ingredients are also high in demand by other animals (soybean meal) and humans (yellow corn) (Alshelmani et al. 2021). The global consumption of poultry products, such as meat or eggs, appears to be increasing in the developing countries. Therefore, the global demands of the main poultry feedstuffs would increase leading to higher cost of poultry production.

The use of industrial by-products in animal diets can reduce the incorrect disposal of these products into the environment. Their use as an alternative source in animal feed may replace or complement other ingredients of high added value, which are used as food sources in human diets (Parpinelli et al., 2018). When used in broiler diets, these alternative ingredients can reduce production costs, resulting in more economically viable and nutritionally productive feed.

It is known that some developing countries produce a huge amount of alternative feedstuffs, considered as agro waste by–products such as wheat bran, rice bran, cotton seed meal, copra meal and palm kernel cake. However, many of these agro waste by–products are featuring on presence of non-starch polysaccharides (NSPs) such as xylan and mannan as well as anti-nutritional factors (Alshelmani et al., 2016).

Utilization of non-conventional local feeds as substitutes of conventional ones is a popular trend in broiler feeding practices (Buragohain, 2016). Depending on availability and nutritional values, many non-conventional feeds are used in broiler rations to economize the feeding (Maqbool et al., 2021). Denstadli et al. (2010) concluded that in broilers from 12 to 33 days, 10 to 20% inclusion of dried brewers grains supported acceptable growth and feed utilization, and seemed to favour the development of a well-functioning gizzard. Inclusion rates up to 20% did not depress gain or feed conversion during early growth (0 to 8 weeks) and rates up to 30% at 8-12 weeks did not decrease performance (Deltoro López et al., 1981). Increasing the inclusion rate of dried brewers grains in pelleted diets up to 40% without correction for protein and metabolisable energy decreased body weight gain and feed:gain ratio (Denstadli et al., 2010).

2.7.3.1 Brewery grain

The price of feed sources is the determining factors for the profit margins in poultry production. Therefore, utilization of alternative feed resources in poultry ration is a best option for successful poultry production (Gebremedhn et al., 2019). These alternative feed ingredients can be the non-conventional feed sources like brewery-spent grain. There are several by-products that can be obtained from production of beer, such as, brewers grains (wet or dried), brewers dried yeast, etc. These materials are considered to be good sources of un-degradable protein and water soluble vitamins (Oreopoulou and Russ, 2007).

Brewers grains are the solid residue left after the processing of germinated and dried cereal grains (malt) for the production of beer and other malt products (malt extracts and malt vinegar). Though barley is the main grain used for brewing, beers are also made from wheat, maize, rice and sorghum. Brewers grains are collected at the end of the mashing process, once all sugars have been removed from the grain. The remaining product is a concentrate of proteins and fibre that is suitable for animal feeding (Crawshaw, 2004). Adams et al.(2022) reported that brewer's grains is low-cost residues but can be costly to transport due to its perishability and bulkiness when wet. As with many other by-products, the composition and nutritional values of brewer's grains depend on the industrial process, selected cereals, and methods of preservation. According to NRC (1994) brewers' dried grain contain 25.3% protein, 6.3% fat and 2080 kcal/kg metabolizable energy (ME). Brewers' dried grain is rich in essential amino acids: 0.9% lysine, 0.4% methionine, 0.4% tryptophan, 1.3% phenylalanine, 1.3% threonine and 1.6% valine (Yismaw et al., 2019).

2.7.3.2 Wheat bran

Wheat bran has a high fiber and phosphorus content. It can be included in the grain mix up to a level of 25%. Adding wheat bran to animal's diet, with its significant amount of dietary fiber, will help its body to feel satisfied and comfortably full for a longer period. Fiber as feed component in poultry nutrition has traditionally been given little consideration as it has only a low nutritional value from a chemical point of view. However, due to its unique physicochemical properties, several studies showed that insoluble fiber sources may affect digestive tract development and function resulting in improved chicken health and growth performance (Röhe and Zentek, 2021).

Wheat bran, a by-product of the dry milling of common wheat (*Triticum aestivum* L.) into flour, is one of the major agro-industrial by-products used in animal feeding((Heuzé et al., 2015). It consists of the outer layers (cuticle, pericarp and seedcoat) combined with small amounts of starchy endosperm of the wheat kernel. Other wheat processing industries that include a bran removal step may also produce wheat bran as a separate by-product: pasta and semolina production from durum wheat (*Triticum durum* Desf.), starch production and ethanol production.

Wheat bran is a bulky feed that can be used to lighten dense, heavy feed mixtures and is well known for its ability to prevent constipation because of its swelling and water-holding capacities. A main distinctive feature amongst different fiber sources is the solubility (Pietsch, 2022). Vegetable roots and fruits like apple, orange and sugar beet deliver mainly soluble fiber (i.e. pectin) while all kinds of bran deliver more insoluble (i.e. cellulosic) fiber (Pietsch,2022). Insoluble dietary fiber (IDF) has a nonviscous structural component, and recent studies in poultry have demonstrated that moderate amounts (20–30 g/kg) of IDF to be beneficial to nutrient utilization by improving gastrointestinal development and enzyme secretion(Donadelli et al., 2019). Therefore, supplementing insoluble dietary fiber to broiler diets may be a feasible method to improve feed efficiency. J0rgensen et al (1996) studied the influence of dietary fibre (DF) and observed that body-weight gain did not differ significantly between the medium and high (DF) levels for any of the three DF sources tested. The chickens fed on the low-DF control diets had a significantly lower feed intake and consequently lower daily gain than the chickens fed on the other two DF levels. The feed: gain ratio was always highest for the high-DF levels. The chickens fed on the medium-DF level of oat bran had the highest growth rate and the lowest feed conversion ratio.

Pietsch (2022) reported that digestibility of starch is higher and digesta passage rate faster when a moderate level of insoluble fiber is present in the diet. Due to the faster passage rate there is less accumulation of toxic substances in the intestinal tract. The effect of insoluble fiber on gut functions stems from its ability to accumulate in the gizzard, which seems to regulate digesta passage rate and nutrient digestion in the intestine (Pietsch, 2022). Shang et al (2020) indicated that the fiber fraction in the diet is usually retained longer in the gizzard as they are hard to ground to a certain critical size that allows them to pass through the pyloric sphincter, which stimulates mechanically the development of the muscular layers of the gizzard.

The empty body weights of chickens fed on the high-DF diets tended to be lower than for chickens fed on the medium-DF diets. However, chickens on both the medium and the high-DF levels were significantly heavier than chickens fed on the low-DF diets. Digesta in the GI tract (gutfill) was linearly related to the DF level with the DF from pea exerting a significantly greater influence than the other two DF sources (J0rgensen et al., 1996). The empty-body weights of chickens fed on the control diets were in general lower than for the other chckens, making direct comparisons between the other groups difficult. Both the weight and length of the GI tract increased with increasing DF level; in particular the caecum increased considerably (J0rgensen et al., 1996).

The relative weight of proventriculus and small intestine, as well as the relative length of small intestine did not significantly vary with any of the dietary treatments on Day 21 or 42. However, birds fed WB had a greater relative weight of gizzard than those fed control diet on both Day 21 and 42 (Piao, 2023). Regarding intestinal morphology, there was no difference in the villus height, crypt depth, and villus height to crypt depth ratio among treatments in the duodenum. However, in jejunum, compared with control, the wheat bran increased villus height and villus height to crypt depth ratio. A similar pattern was also observed in ileum. The supplementation of wheat bran increased villus height and villus height to crypt depth ratio when compared with control.

Small intestine length can be considered an indicator of good intestinal mucosal development. This has a direct impact on intestinal health and nutrient absorption, since a longer intestine means a larger area of exposure of nutrients to absorptive cells (Guerra, 2018). The duodenum is the portion responsible mainly for the digestion of the nutrients from the feed. It is the site where the action of pancreatic juice and bile containing its digestive enzymes and emulsifying substances occurs. A greater development of this segment increases the time of action and contact of the bolus with digestive enzymes, thus improving digestive processes and providing a greater content of nutrients to be absorbed (Assis et al., 2021)

2.7.3.3 Bakery waste

The use of Agro-industrial by-products (AIBPs) in animal feed holds tremendous potential in alleviating the existing critical situation of high cost and inadequate supply of feed(Epao et al., 2017). Considerable efforts have been made to improve the utilization of these AIBPs in monogastric nutrition. Among AIBs bakery waste has shown promising results as a source of energy (Epao et al., 2017).

Bakery wastes are a combination of different wastes, and their composition is thus highly variable (McGregor, 2000). Bakery wastes are mostly breads removed from the food market as they become unsellable after only 24 hours, but they can consist in any other ingredient like dough, flour, sugar and other edible ingredients, such as icing, burnt or broken product (McGregor, 2000). Bakery wastes may contain ground plastic bags as the bakery wastes are unwrapped mechanically (McGregor, 2000). For better storage, it is useful to dry bread from its usual 63-65% DM to 90%.

In general, bakery meal is rich in starch because wheat flour is the main ingredient in all bakery products. Because this starch is already thermally processed (cooked), it is highly digestible, and thus, of high nutritive value. As such, bakery meal is ideal for the diets of starter broilers. In general, bakery meal contains about 2,981 kcal/kg net energy (NRC-Swine, 2012), which compares very favorably with maize at 2,672 Kcal/kg net energy.

Accordingly, it contains 3,500 kcal/kg metabolizable energy for poultry, when maize is at 3,300 kcal/kg (Mavromichalis, 2013).

Dried bakery waste replaced maize without adverse effects, up to inclusion levels higher than 25% (Heuzé et al., 2018). Total replacement of maize was even possible with the use of extruded bakery waste, used at levels above 50% in young animals and 60% in older broilers (Heuzé et al., 2018).

2.7.3.4 Insects meal

Insects can be used to produce cheap source of protein. It is known that insects are considered as a natural food for birds. Insects are rich in protein (40–76%) and essential amino acids (Kareem et al., 2018), particularly sulfur containing amino acids. Insects meal are usually featuring on high fat content (Kareem et al., 2018).

A wide range of insects is available for use in poultry diets (Elahi et al., 2022). Common houseflies, black soldier flies, yellow mealworms, and blowflies are among the insects that are the potential alternatives for protein sources in poultry diets, as highlighted by (Sajid et al., 2023). Insects have high mineral contents, including zinc (Zn) and iron (Fe), as noted by Sajid et al. (2023), and contain an array of vitamins, including riboflavin, folic acid, cyanocobalamin, thiamine, and retinol traces, as described by Sajid et al.(2023). Insects additionally possess a particular kind of peptide that shows an antioxidant action, which can be beneficial for the health of livestock, according to Schiavone et al. (2018). Insect meal contains a greater amount of essential amino acids compared to conventional feedstuffs. The insects can be used as a live (fresh), dried, and paste form for poultry diets. A dried insect is considered suitable for poultry diet because the water content in fresh or live insect stimulates the degradation, antimicrobial activity, and Millard reaction (Elahi et al., 2022).

One of the other key barriers for incorporating insects in animal feed is the lower number of reared insect species. To address this issue, it is necessary to identify the most appropriate insect species capable of allowing cost-effective protein synthesis on a large scale.

2.7.3.5 Worms meal

Worms are natural nutrient sources for poultry animals. For example, chicken can pick up the earth worms and their larvae in and on the surface of the soil (Köse and Öztürk, 2017). Jacob (2023) stated that the nutritional profile of earthworm meal is comparable to that of other protein sources currently used in poultry feeds, especially that of fish meal.

Earthworms are high in lysine and have a good profile of methionine and cysteine and of phenylalanine and tyrosine. In addition, earthworm meal is high in essential long-chain fatty acids that contain a range of vitamins and are particularly rich in niacin.

Gunya et al. (2019) showed that the addition of 3% of earth worm meal in ration significantly improved live weight of broilers compared to the control group. Nalunga et al. (2021) reported that increasing the earthworms in broiler diets from 0, 1, 3, 5 and 7% did not affect the weights of the cecum, heart, pancreas, proventriculus, and lungs.

2.8 Feed restriction in broiler feeding

The feed restriction programs is one of the main techniques in growth curve manipulation for increasing production efficiency and decreasing the unfavorable effects of fast growth rate in broiler chicken production industry and could be profitable in broiler chickens production efficiency(Nassef et al., 2015). However, restrictive feeding introduces other welfare problems, as it entails that basic behavioral and physiological needs are not met. This often results in abnormal behavior (indicating frustration and hunger) and physiological stress responses (Aarhus University, 2021). Feed restriction strategies are classified into quantitative feed restriction which include quantity-limited of feed or time-limited access to the feeder and qualitative feed restriction which refers to reduction of nutrients density particularly protein, amino acids and energy or diet dilution using fibres' sources(Ebeid et al., 2022).

Quantitative and qualitative feed restriction are procedures that could be applied to manipulate the feeding strategies of poultry in order to decrease growth, and metabolic rate to some extent and so alleviate the incidence of some metabolic disorders as well as improving feed conversion in broiler chickens (Sahraei, 2012). These methods includes: physical feed restriction, limiting the level of consumption of feed in time (skip-a-day feeding) or reducing the time of illumination of feeding, diet dilution, chemical methods of feed restriction and use of low protein or low energy diets (Zubair and Lesson, 1996).

Feed restriction has been adopted in broiler production to avoid rapid growth rate, which is associated with ascites, lameness, mortality, and poor reproductive results (Esmail, 2018; Trocino et al., 2020). In addition, feed restriction in the early stage is beneficial for improving the feed efficiency and decreasing the rearing cost.

The feed-restricted broilers had lower levels of triglycerides and abdominal fat at the finishing age. A similar effect of feed restriction on carcass fat was also reported by Jahanpour et al (2015), who fed only 50 % of the normal feed quantity during the 6th to the 11th day of rearing and showed that this level of restriction reduced carcass fat and abdominal fat. This corroborates other studies that also show that most fat storage develops in the first stage of the rearing period (Yu and Robinson, 1992) and that feed restriction at early postnatal stage produces long-term effects on lipid metabolism (Yang et al., 2010). Feed restriction may induce the digestive-physiological adaptations in the form of increasing the weight of crop, proventriculus, gizzard, duodenum and caecum and length of duodenum and pancreas (Ebeid et al., 2022). Khurshid et al (2019) revealed that body weight and body weight gain decreased with increase in the level of feed restriction whereby a significant effect was observed in the body weight and body weight gain of broiler chicken beyond 5% restriction level when compared with the control group.

Khurshid et al (2019) also observed a profound effect on liveability with highest liveability of 97.77% in 15% feed restricted group as compared to 71.11% in adlib fed group probably affected the overall performance whereby the overall performance in terms of Broiler Farm Economy Index revealed most optimum value of 1.39 for 15% feed restricted group. Urdaneta-Rincon and Leeson (2002) showed that feed restriction of 10% from day 14 to 29 reduced BW at day 35 but not at d 42 or 49. In addition, feed restriction in this period did not affect abdominal fat pad, but the longer the period of feed restriction, the lower the cumulative feed conversion ratio (FCR) at d 42. Anane et al. (2022) researched on effects of feed restriction and early age thermal conditioning on growth performance and carcass characteristics of meat-type chickens and reported that feed restriction reduced feed intake but improved upon the feed conversion ratio in broilers. Feed restriction also reduced the abdominal fat and ether extract in chicken meat whilst increasing the moisture and crude protein levels in the meat.

On the economic side, Makinde, (2012) reported that the revenue declined as the period of feed restriction increased. This ascertains the assumption that the faster the growth rate, the better the utilization of feed, since maintenance nutrient needs are minimised. Melo et al. (2021) compared quantitative and qualitative feed restriction on broilers and testified that broilers submitted to a quantitative restriction of 10% of Ad libitum consumption of control diet between 14 and 28 days presented a lower feed intake, but a similar weight gain and feed conversion ratio compared with birds fed AL between 14 and 42 days. While the groups of broilers submitted to qualitative food restriction programs of 10% of protein and essential amino acids between 14 to 28 days or of 29 to 42 days did not change the feed intake, weight gain and feed conversion ratio in comparison with birds fed AL between 14 to 42 days. The qualitative feed restriction stimulated feed intake, which led to a greater weight gain, and a worse feed conversion ratio compared to broilersfed quantitative feed restriction.

2.8.1 Methods of feed restrictions

2.8.1.1 Diet dilution

Diet dilution is one of the methods used in feed restriction for fat growing broiler chickens. It is characterised by reduction in the nutrient density of most expensive feeds (Melo et al., 2021). The adoption of diluted diets relies upon the fact that broiler chickens eat close to their physical intake capacity (Newcombe and Summers, 1984). Fibrous diets are used to dilute the daily distributed ration, by adding different concentrations of raw material sources of insoluble fiber, might be a useful nutritional strategy to increase daily feed allocation and cleanup time (Asensio et al.,2020). In this way, it might be possible to obtain more uniform flocks and reduce pullets under the standard BW with poor skeletal development and under stress.Qualitative feed restriction, however, is deemed to be a promising method for increasing satiety and improving the behavioral opportunities, hence increasing the welfare of the chickens. The idea of qualitative feed restriction is to reduce the feed quality regarding the energy content by adding diluents such as non-digestible ingredients such as fiber, with reduced nutrient density (Aarhus University, 2021). Dilution of dietary nutrient levels is a common practice in early feed restriction strategies (Moradi et al., 2013). Wood charcoal (Rezaei et al., (2006), rice husks (Rezaei & Hajati, 2010), oat hulls (Qaisrani et al., 2013) and sand (Farjo et al., 1986) have been studied as diluents of poultry diets.

Dietary fiber chemically includes non-starch polysaccharides such as cellulose, arabinoxylans, inulin, chitins, pectins, beta-glucans and phenolic polymer lignin that are present in the cell wall of plants (Bach Knudsen, 2001). Aftab et al. (2018) pointed out that replacement of part of the dietary starch with a slowly digested starch source has been shown to help improve growth performance and FE, perhaps by sparing amino acid catabolism by enterocytes, and/or through more synchronised uptake of glucose and nitrogen by the systemic circulation.

Birds fed diets high in insoluble NSP spent more time feeding and appeared calmer than those fed low NSP diets (Hetland and Choct, 2003). Insoluble NSP accumulates in the gizzard and is retained longer than other nutrients, probably because it has to be ground to a critical particle size before entering the small intestine ((van Krimpen,2008). Such accumulation of NSP in the gizzard may also indicate that increased levels of coarse NSP in the diet might lead to a slower rate of feed passage (van Krimpen,2008).

Pourazadi et al. (2020) concluded that for the entire experimental period, insoluble fibre inclusion in broiler diets improved average daily gain and feed conversion ratio compared to the control group. Broilers fed sunflower hulls, SFH had higher ADG and better FCR than broilers fed sugarcane bagasse. Fibre inclusion increased the relative weight of breast and thigh and decreased relative weight of liver compared to the control group, but coarse grinding of the sugarcane bagasse decreased relative weight of abdominal fat. Mazzuco et al (1999) observed that diet dilution did not influence the incidence of ascites or sudden death syndromes. The researchers indicated that nutritional strategy to reduce the losses by metabolic diseases and the abdominal carcass fat content was accomplished by losses on the performance of the birds.

Röhe et al. (2020) examined the effect of a diluted diet containing 10% lignocellulose (LC) on the gastrointestinal tract, intestinal microbiota, and excreta characteristics of dual purpose laying hens and found that LC-fed hens showed increased relative weights of the gizzard, small intestine and large intestine resulting in a higher weight of the total gastrointestinal organs compared to hens fed control diet. Röhe et al (2020) reminded that it is well known that the feeding of coarsely ground as well as mash diets can increase the relative gizzard weights of broilers and laying hens compared to feeding finer particles and thermally processed diets. However, researchers added that it might be difficult to distinguish between the effect of fiber inclusion and that of the feed particle size. Independent of the particle size, fiber particles are harder to grind and thus accumulate in the gizzard lumen (Hetland et al., 2003), which in turn might stimulate organ development and function (Hetland et al., 2005; Mateos et al., 2012).

Broilers fed diet dilution with beet pulp were significantly had higher dressing, breast, wing, and drumstick percentage compared with wheat bran. Increasing levels of diet dilution reflected in increasing dressing percentage. Using the higher level of diet dilution (5%) reflected in decreased the abdominal fat percentage (Hemat et al, 2021). The interaction between diet dilution and their levels showed significantly different on all carcass parameters except edible parts. The broiler fed beet pulp 4 and wheat bran 5 recorded the highest dressing percentage compared to all treatments. There was significant interaction between diet dilution and levels in intestine length and index and tibia weight percentage (Hemat et al, 2021).

2.8.1.1.1 Effects of Replacing Maize in Broiler Diets

Maize is the primary source of energy in poultry diets. However, the use of maize for livestock feed, human food and industrial raw materials has resulted in a high cost of chicken feed with a concomitant rise in the price of chicken products (Ahiwe et al., 2018). Thus, for the chicken industry to be sustained, there is a need for the exploitation of other energy sources as an alternative to maize (Ogbuewu and Mbajiorgu, 2023).

Recently, the increased use of yellow corn for ethanol production has consumed a significant amount of corn, which has had a large effect on the price of corn. This has had a major impact on poultry production as well. For example, in broiler production, yellow corn constitutes ~60–70% of the poultry diet. A decrease in the availability of corn and an increase in the price of diets have a major effect on broiler production. Therefore, we must find new alternative ingredients that can be used as a substitute for yellow corn partially or totally, and these alternatives must not have a negative effect on the growth performance of broilers (Saleh et al., 2020). One of the approaches is the use of alternative sources of energy such as wheat bran.

Wheat bran is a by-product of the dry milling of common wheat (*Triticum aestivum L.)* into flour, is one of the major agro-industrial by-product used in animal feeding. It consists of the outer layers (cuticle, pericarp and seed coat) combined with small amounts of starchy endosperm of the wheat kernel (Feedipedia, 2012).Wheat bran is a good source of protein, carbohydrates, vitamins and betain (Slavin, 2003). The significant amount of betain, which is known to decrease carcass fat, protect intestinal cells from coccidian infection and improve performance in poultry.

Wheat bran has been considered a palatable feed ingredient and appropriate for feeding livestock (Fuller, 2004), but may not be included in poultry diets in appreciable amounts. Research has shown that wheat bran inclusion in poultry diets is usually kept low, especially in cases where calculations are based on least cost formulation (Walugembe, 2013). However, high inclusion rates could be used in layer molt diets (Soe et al., 2009).

The high fibre level in wheat bran leads to reduction in the fatness of the carcass (Taiwo ,1981). Similarly, dietary protein content, in addition to its effects on weight gain and feed efficiency, has a marked effect on the quality of edible meat and fat content (Poultry World, 2017). The energy component of the diet is also a factor that determines meat quality. Maize is the chief source of energy in diets for monogastric animals (especially poultry) and it constitutes up to 60 per cent of the ration (Afolayan et al., 2012). Abubakar and Ohiaege (2011), Kana et al.(2012) and Adeyemo et al. (2014) stated in their reports that live weight was highest in birds fed diets in which 50 per cent of maize was replaced by cassava flour meal while Oso et al.(2014) and Abu et al. (2015) reported that body weight and live weight reduced significantly with increasing cassava root meal level.

Papadomichelakis et al.(2019) tested the inclusion of Olive cake meal (OCM) in broiler diets and discovered that even a low dietary dried olive pulp content of 50 to 75 g/kg could reduce the BW gain and feed efficiency early in broilers. Thus, the high fiber content and anti-nutritional factors present when high levels of OCM were used can be blamed for the reduction in broiler performance and did not improved nitrogen retention and ether extract digestibility. The researchers recommended that the replacement of 10% of maize with olive cake meal (OCM) is suitable for broiler diets, resulting in improved growth performance, reduced abdominal fat, decreased plasma cholesterol, and increased oleic acid as monounsaturated fatty acids and linolenic acid as polyunsaturated fatty acid contents.

Gebeyew et al. (2015) did a research on the substitution of maize with sorghum on broiler diets and found that the highest cost per kg feed was in the maize-based diet compared to sorghum - based diets. The sorghum based diet was the cheapest. Based on the on their finding dietary treatment four (ration containing 45% sorghum inclusions) can be concluded as profitable ration in broiler production. Irekhore et al. (2018) studied the effects of substituting maize with cassava grits and concluded that replacement of maize with cassava grits in the diets of Arbor Acre Plus and Marshall broiler chickens had no detrimental effects on dressed weight and choice cuts of broiler chickens. The researchers recommended that Cassava grits could therefore be used to replace up to 60 per cent of maize in finishing diets for broiler chickens where carcass characteristics are paramount.

2.8.1.2 Use of low protein or low energy diets

Energy and protein are the two main nutrients that can affect all production limits in broiler chickens (Kamran et al., 2008). Energy and protein are very important nutrients for broilers like other living creatures. Energy is required for body functioning and protein is an essential constituent of all tissues of animal body. Protein having major effect on growth performance of the bird is the most expensive nutrient in broiler diets (Jafarnejad et al., 2010). Dietary protein quality is a critical regulator of poultry growth, reproductive performance, and plays important role in the development of the gastrointestinal tract. Protein-rich components are the most expensive ingredients in broiler diets and the member states of the European Union are dependent on the overseas soybean import

(Such et al., 2021). A major concern for the modern poultry industry is to reduce feed cost and to optimize the protein supply of animals. Feeding low protein (LP) diets with increased crystalline amino acids could be a solution.

Jones (1999) discovered that chicks fed the low energy diet consumed significantly more feed than those fed the high-energy diet. The chicks fed the low energy diet from zero to three weeks of age did not differ significantly in body weight or in abdominal fat pad development from the control birds at four weeks of age. Taylor et al. (2022) observed that chickens could over-eat as much as 34.1 % to compensate for diluted diets. Nideou et al. (2017) testified that low-energy and low-protein diets significantly reduced performance parameters, such as feed efficiency, growth rate, egg production, incubation parameters and hatchling quality. The reduced egg weight and laying rate in the low-energy and low-protein diet groups might be due to nutrient deficiency. Bunchasak et al.(2005) and Novak et al.(2006) reported that birds that received low crude protein had low egg weights compared with birds that received optimum and high crude protein. In addition, Valkonen et al.(2008) reported that hens consuming low energy produce approximately 2% fewer eggs per day compared with birds fed a high-energy diet.

Despite the evidence that there is no genetic correlation between skeletal disorders and body weight, nutritional evidence suggests that dietary strategies that depress growth rate by altering dietary energy and protein levels and offering various feed forms decrease the incidence of skeletal disorders (SCH International, 2018).

Heger et al. (2014) showed that feed intake increased in all periods, including the growth period (11-24 d) by decreasing the density of metabolisable energy in the diet. Ataei et al.(2022) stated that the energy level of the diet during the growth period did not have significant difference on the performance of different carcass components at the end of the 42 day period. Ndazigaruye et al. (2019) and Chodova et al. (2021) found that normal and low protein levels did not affect breast muscle pH in Ross 308 broiler chickens. Hussein et al. (2019) declared that low energy levels in the diet had no significant effect on breast muscle initial and ultimate pH in Ross 308 broiler chickens.

Strifler et al. (2023) investigated the effects of feeding low protein (LP) diets with different energy-to-protein ratios on broiler performance and stated that a greater precision in the formulation of diets with LP level is required in order to ensure a balanced amino acid (AA) profile of dietary protein to meet the amino acid need of the broilers and to optimize growth performance and carcass yield. The 'ideal protein concept' or 'ideal amino acid profile' on a digestible AA basis has been widely used for this purpose (Kidd et al., 2021). The requirement for limiting essential AAs can be satisfied by the use of crystalline AAs. In the case of avian species usually sulfur-containing amino acids are the first limiting, due to feather formation, but in LP diets lysine, threonine, valine, isoleucine, and arginine should be supplemented (Belloir et al., 2015). In this experiment, the daily gain, feed intake, and feed conversion ratio of animals were the same with reduced CP diets. It means that the amino acid content of LP diets covered the requirements of the animals.

The feeding of different diets with low protein contents did not affect the relative carcass weight, the relative thigh weight, and the relative abdominal fat pad ratio. The relative breast meat yield of broilers fed the isocaloric and reduced crude protein diet in low protein treatment one (LP1) was significantly higher than in the control group (Strifler et al., 2023). The researchers also observed that at the end of the finisher phase, the reduction in dietary crude protein without changes of apparent metabolisable energy (AMEn) in (LP1) did not affect the BW of broilers compared to the control diet. However, the reduction in dietary crude protein together with reduced energy content (LP2 and LP3) led to significantly lower BW of broilers in relation to the control treatment. Among the low protein diets, the reduction in dietary AMEn had a negative effect on the BW, and a 3% reduction (treatment LP3) decreased the BW of broilers significantly compared to the LP1 group.

The dietary CP decrease also had significant effects on meat quality traits with an increase in ultimate pH and a decrease of meat lightness and drip loss (Belloir et al., 2017). The drip loss is one of the parameters characterizing the water-holding capacity of meat, which affects its sensory and technological quality. The lower drip loss of breast meat in the LP1 and LP2 groups compared to the control group means lower cooking loss and lower susceptibility to lipid oxidation (Beauclercq et al., 2017). The lower excess of AAs could contribute to the lower drip loss values in the LP1 and LP2 groups in the present experiment as well (Strifler et al., 2023).

2.8.1.3 Chemical Methods

The use of chemicals during the early period of growth depress the feed intake of broilers. The following drugs are used to suppress feed intake: Phenylpropanolamine hydrochloride which is known as an anorectic drug, monensin sodium, an ionophore which at low concentrations acts as a coccidiostat, but it causes anorexia at higher doses. Acetic and propionic acids and calcium propionate are also used to depress appetite (Alkhair, 2021). This qualitative method of feed restriction has the benefit of evenly distributing the feed among birds and so reducing the variation in growth that can occur with physical feed restriction programs

Glycolic acid has also been used as a chemical means of restricting feed intake of broilers (Jones, 1999). The feed intake of birds given diets supplemented with 1.5% and 3% glycolic acid was depressed by 17% and 45%, respectively. These reductions in feed intake due to glycolic acid supplementation resulted in growth retardation during the under nutrition period to 71% and 41% respectively, relative to the growth of control birds(SHC international, 2018)1. Male broilers exhibited complete body weight recovery at 49 days of age, with no difference between the birds restricted by the dietary glycolic acid addition or those subjected to physical feed restriction. Due to its natural occurrence, glycolic acid may serve as a safe and useful anorectic compound for restricting feed intake in poultry(SHC international, 2018).

Pinchasov and Jensen (1989) incorporated 1.5 and 3.0 % glycolic acid into broiler starter feed and obtained 22% and 50% reduction, respectively, in feed intake of broilers from seven to 14 days of age. Lacy et al. (1982) significantly decreased feed consumption of broiler chickens with a pharmacological dosage of tryptophan.

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Phenylpropanolamine hydrochloride and monensin sodium were used in the control of growth rate at the rate of 400 and 300 mg per kg of diet, respectively and they significantly decreased body weight of the broiler chickens at 4 weeks of age (Oyawoye and Krueger, 1990). Metzler et al (1987) examined the effects of monensin feeding and withdrawal time on growth and carcass composition in broiler chickens and learned that values for fat pad weight (as a percentage of body weight) and grams of lipid per fat pad of unmedicated birds were not different from those measures in medicated birds after 5 or 7 days of withdrawal. Fat pad weights and lipids per fat pad of birds after 10 days of monensin withdrawal were intermediate between those of unmedicated and monensin-medicated broilers.

Dimethylglycine (DMG) is a naturally occurring glycine derivative, which is useful as additive to broiler diets as it improves nutrient digestibility and reduces the development of broiler ascites syndrome (Kalmar et al., 2014). Prola et al. (2013) theorized that an emulsifying effect of DMG in the intestinal tract, allows non-fat nutrients to be more efficiently absorbed, rendering more nutrients available for utilization. Dietary DMG has also been shown to improve carcass characteristics by decreasing fat deposition and increasing meat yield. These changes are linear in the range between 0 and 1 g Na DMG/kg feed and are more pronounced with increased level of dietary polyunsaturated fatty acids (Kalmar et al., 2011)

2.9 Metabolic and skeletal disorders of broilers

Fiber inclusion in broiler's diets has become an interesting nutritional strategy, due to its potential effects on the gastrointestinal tract development. Positive effects have been shown to be mediated by the increase of gizzard development and nutrient digestibility, as well as the interactions with the gut microenvironment and gut-associated immune system (Mahmood and Guo, 2020; Shang et al., 2020). Finely ground wheat bran increased accessibility for bacterial enzymes, leading to higher butyric and propionic acids concentration in the cecum, and effective control of *Salmonella* infections in broilers (Rybicka et al.,2024). Short-chain-fatty-acids (SCFAs) mainly acetic, propionic and butyric acids, produced from fiber fermentation in the caeca (Iji et al., 2001; Mateos et al., 2012), suppress pathogenic and encourage the multiplication of beneficial bacteria (Abazari et al., 2016; Khan and Iqbal, 2016; Jha et al., 2019)

Modern broiler chicken strains are characterized by very high growth rate and low feed conversion ratio. Unfortunately, this increase in growth rate is associated with high body fat deposition, high mortality and high incidence of metabolic diseases and skeletal disorders (Tumova and Teimouri, 2010). The metabolic disorders of greatest economic importance, at least in broiler production, are skeletal disorders, ascites, and sudden death syndrome. Ascites and sudden death syndrome are both metabolic diseases associated with insufficiencies of the cardiovascular system (Angel, 2007). These negative aspects are of major concern for the farmer and processor, because they can bring about important economic losses.

Broiler feed form had a direct influence on the occurrence of ascites and SDS because it affects growth rates of broilers (Camacho et al., 2004). Kuleile and Molapo (2019) studied the effects of feed form on broiler production and profitability in Lesotho and revealed that feeds in particulate form gave better performance and fast growth rate while feeds in mash form reduced growth rate significantly. Hasani et al. (2018) observed high incidence of ascites, SDS and leg problems on birds fed crumble and pelleted diet than those offered mash. Sanotra (1999) assessed the prevalence of lameness in commercial flocks and found that 30.1% of the birds were suffering from chronic pain and they could not move around to access feeds. Sahraei (2014) reviewed factors affecting metabolic and skeletal disorders in broiler and highlighted that any means that reduce broiler growth rate had a potential to minimize incidence of disorders.

2.9.1 Ascites

Ascites (pulmonary hypertension syndrome, or water belly) is a metabolic disorder, characterized by hypoxaemia, increased workload of the cardiopulmonary system, central venous congestion an excessive accumulation of fluid in body coelomic cavities(Doughman,2021), hypertrophy of the right ventricle and a flaccid heart, and finally death (Guo et al., 2023). Breast muscles turn dark, and up to 300 ml of clear yellow fluid with clots of fibrin was pooled in the distended abdominal cavity (Dosković et al., 2019). The right half of the heart is enlarged, dilated and hypertrophic. The liver is grey and enlarged. The lungs are oedematous. At slaughter, carcasses of these chickens were discarded as unusable (Maslić-Strižak et al., 2012).

In most cases, ascites was diagnosed between 4 and 5 weeks of age. The males of meat lines are more subjected to ascites than the females of the same lines because of their faster growth and better feed conversion ratio (Ezzulddin, 2023). Ascites in meat chickens can be caused by significant dietary parameters, such as high feed concentration, and an increase in feed consumption, in addition, to feed texture. Diets low in calories have been suggested as a way to lower the prevalence of ascites (Ezzulddin, 2023). Singh et al. (2011) supported that there were direct correlation between metabolic rate and ascites and as a result the incidence of ascites were reduced by limiting growth rate through feed restriction programmes using mash diets, feeds low in nutrients, and supplemental antioxidants and omega-3 fatty acids.

Devegowda (2019) reported that birds fed on an ad libitum low-nutrient density regimen (2900 kcal and all amino acids level to energy level from 3-21 day) showed significantly reduced ascites mortality compared with the birds fed ad libitum with a high-nutrient density regimen (3000- 3100 kcal and all amino acids maintained in relation to energy level from 3-21 day). Ozkan et al. (2006) probed the effects of early feed restriction on performance and ascites development in broiler chickens subsequently raised at low ambient temperature and learned that feed restriction treatment reduced the total mortality, mortality from ascites, and over all ascites incidence. Researchers went on further that ascites mortality was first observed 1wk after cold exposure, and all mortality occurred during the fifth and sixth weeks. At slaughter age, ascitic broilers had smaller relative weights of breast muscle and spleen than those of the healthy birds, but the relative weights of lung, heart, and liver and RV:TV ratios were greater in the ascitic ones (Ozkan et al.,2006). Demir et al. (2004) evaluated the effects of early and late feed restriction or feed withdrawal on growth performance, ascites and blood constituents of broiler chickens mortality and verified that death due to ascites and the incidence of leg disorders were unchanged by feeding regimes, although the incidence of ascites in first week to 16 weeks was significantly lower than broilers fed on adlibitum basis.

2.9.2 Sudden Death Syndrome

Sudden death syndrome (SDS) is also known as morte subita, acute death syndrome, heart attack, dead in good condition, lung oedema, and flip -over disease (Saki and Hemati 2011). It is characterized by the sudden death of well-nourished broiler chickens after abrupt and brief flapping of their wings (Saki and Hemati, 2011). This syndrome mostly occurs in heavier males birds when their growth rate is highest. There are short convulsions and frantic wing-beating prior to death, and the weight of internal organs is the same as in healthy chickens (Sosnówka-Czajka and Skomorucha, 2022). Death usually occurs within 1-2 minutes with the birds lying on their backs with outstretched wings.

SDS is associated with acute heart failure, which is induced, among others, by excessive dietary levels of vitamin D3 (Sosnówka-Czajka and Skomorucha, 2022). According to these authors, the high level of vitamin D3 in feed increases the incidence of SDS in broiler chickens almost 2.5-fold from 5 weeks of growth. Probably, vitamin D3 weakens the heart muscle and doubles the frequency of ventricular fibrillation and arrhythmia, which directly contributes to the sudden death syndrome ((Sosnówka-Czajka and Skomorucha, 2022).

In broilers, pelleted feed is extensively used. It has many advantages. It reduces bulkiness, minimizes, wastage, destroys toxin while pelleting and processing and it has higher digestibility as compared to mass. Due to pelleted feed there is faster growth rate hence incidence of SDS and ascites in broilers (Siddiqui et al., 2009). Julian and Lesson (1985) observed that birds feed diet high in glucose are more likely to show SDS and recorded significantly higher blood lactate levels in the birds that died of SDS than survived. Nassef et al. (2015) persued the effect of feed restriction on growth performance, sudden death syndrome and some blood parameters in broiler chickens and observed that 25% feed restriction reduced SDS to 0%, while in ad libitum feeding it was 3.33%.

Numerous studies showed that feeding mash to broiler chickens may significantly slow the growth of birds and lower the incidence of cardiac defects compare d to feeding pelleted or crumbled feed, thus reducing the risk of sudden death syndrome (Azizian and Saki,2020; Kuleile et al.,2020; Meshram and Bijoy,2017). Supplementation of broiler chicken diets with vitamin E and selenium or Bcomplex vitamins or multivitamin electrolytes is relatively effective in controlling the incidence of sudden death syndrome (Shabani et al., 2013). Maddahian et al. (2015) observed that probiotics reduce blood lipid metabolites, which decreases the incidence of metabolic disorders and may indirectly reduce the incidence of SDS.

According to Scott (2002), limiting the nutritive value, in particular the energy level of feed improves the welfare of broiler chickens and protects them against sudden death syndrome. As reported by Karki (2011), SDS mortality in broiler chickens increases beyond 40 days of age and may average up to 9.6%, while restricted feeding and 8–10% lower dietary nutrient concentration significantly reduce mortality caused by SDS.

In 1984, Mollison et al. observed that a lower dietary energy to protein ratio caused the incidence of SDS in a broiler flock to decrease. In turn, Madrigal et al. (2002) compared the effect of feeding low-energy, high-ener-gy and high-fibre diets to broilers in the first period of growth on the incidence of sudden death syndrome but found diet type to have no influence.

2.9.3 Skeletal disorders

Genetic selection for fast growth in broiler chickens has resulted in high feed efficiency and shorter rearing period, but also in more porous and less mineralized leg bones than slower growing broiler chickens (Rayner et al., 2020). Consequently, fast-growing broilers have more leg and locomotion problems than slower growing broilers (Torres and Korver, 2018), expressed a higher risk of lameness and bone breakage (Shim et al., 2012; Güz et al., 2022). Bone disorders are not the only factor involved in leg health. Tendons, ligaments, articulations and nerves can also be affected and it is more difficult to find solutions to problems caused by these components of the skeletal system(Oviedo-Rondón, 2008). Valgus (VVD), crooked toes, tibial dyschondroplasia (TD), vertebral deformities, twisted legs, osteoporosis of the proximal femur, and femoral head necrosis are the most common skeletal pathologies causing leg problems (Oviedo-Rondón, 2008).

Among the most common leg abnormalities affected by nutritional practices are tibial dyschondroplasia, resulting from inadequate vascularisation and ossification of the growth plate resulting in an abnormal mass of cartilage under the growth plate, causing unnatural biomechanical forces, and therefore gait alteration, additional bone abnormalities, and even fractures (Julian, 1998; Farquharson and Jeffries, 2000; Angel, 2007). On the other hand,Osteopenia is a significant disease of the skeleton in mature chickens used for egg production. It characteristically occurs in lines of laying hens with high rates of egg production and wa regarded as a generalised skeletal disorder resulting in bone fractures (Koutoulis, 2017).

Skeletal problems can be as follows: related to nutritional deficiencies; infections of the bone, joints, or both; intestinal diseases that lead to malabsorption; mechanically or trauma-induced; have a genetic component; associated with fast growth rates; and composed of interactions among the above factors (Riddell, 1992). These skeletal disorders observed in broiler birds are associated with lameness due to pain and or biomechanical dysfunction, which results in poor growth, culled birds, increased mortality from starvation, dehydration, increased carcass condemnation and downgrading at slaughter. Excess protein content in feed, especially animal protein, leads to impaired purine metabolism in the body (Liu et al., 2023). This results in the conversion of purines into large amounts of uric acid and urates, which are then deposited in internal organs and joints. This can cause swelling and deformation of the toes and leg joints, leading to lameness(Liu et al., 2023). Birds are also at greater risk of being trampled and killed during loading and transportation for slaughter (Dunkley, 2007).

Slowing the growth rate during the first 1 to 2 weeks by reducing feed intake can reduce the incidence of leg problems in a flock; however, this could lower dress weight at slaughter ((Dunkley, 2007). Broilers that consume pellet feed have frequently been shown to have higher incidences of skeletal disorders than broilers that consume the same diet in mash form (Bolukbasi et al., 2005). Azizian et al.(2018) investigated the effect of feed form (mash, pellet and extrude) on characteristics of litter, quality characteristics of foot and breast and tibia bone indices in broiler chicken showed that there were no significant difference on footpad dermatitis, calcium and phosphorus of bone and tibia bone characteristics, but the higher rate of hock burns, lameness and percentage of the mortality were observed by pellet and extrude diet form compared with mash diet form in broiler chicken. Pelleted diet form have shown negative effects on values of the moisture, nitrogen of litter and percentage of mortality and increased incidence of hock burn and lameness in broilers compared with mash diet form (Azizian et al.,2018).

On the same note Farm Animal Welfare Council (FAWC) stated that their working group found leg problems of varying degrees of severity on nearly every farm visited (FAWC, 1992). The Report stressed that in the worst cases birds were only able to move with great difficulty and such birds were obviously distressed and had problems in reaching food and water. A Danish study in 1999 assessed the prevalence of lameness in a large and representative sample of commercial flocks. This study found that 30.1% of the birds had gait scores of 3, 4 or 5, scores which indicate that they are suffering from chronic pain (Sanotra, 1999). In an attempt to reduce incidences of skeletal and leg disorders Edwards (2000) recommended that feed deprivation for 8 hour per day, every other day or every fourth day was effective in reducing the incidence of tibial dyschondroplasia. This effect of feed deprivation on development of tibial dyschondroplasia was shown to be true in three different commercial broiler strains. Eight hour feed deprivation decreased the incidence and severity of tibial dyschondroplasia when diets contained both adequate and high levels of calcium.

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CHAPTER THREE

3.0 DATA AND METHODOLOGY

3.1 Ethical approval

The scientific and ethics committee of the Faculty of Agriculture, National University of Lesotho approved the study protocol for the four trials.

3.2 Study site

All the four trials were conducted at National University of Lesotho farm between 2017 and 2019 calendar year. The Faculty of Agriculture farm is situated within the main campus, with the total area of 82 hectares. The campus is situated in Roma some 32 kilometers South-East of Maseru the capital city of Lesotho, Southern Africa (29°28'S; 27°44'E); at the altitude of 1650 m a.s.l. The Roma valley is situated between the longitude 29°32'–29°26'S and the latitude 28°42'–28°48'E, at 1500 to 2000m a.s.l. The Roma valley is broad and is surrounded by a barrier of rugged mountains which provide magnificent scenery. The university enjoys a temperate climate with four distinct seasons.

Feeding Trials

3.3 The influence of feed texture on broiler performance, carcass quality and gastrointestinal development.

3.3.1 Experimental design

The study was a complete randomized design with three different dietary forms namely, mash, crumbles and pellets as treatments with three replication. A total of 315, 16-day-old chicks were used in the trial.

3.3.2 Birds housing and management

The mixed sex, day-old Ross 308 broiler chicks were housed in well-ventilated poultry house. The birds were divided into three dietary treatment replicated three times with a total of nine experimental units. Each replicated was made of 35 chicks. Bird were exposed to 23 hours of lighting and 1 hour of darks during the first three days. Upon arrival, birds were offered stress pack followed by feeding of experimental diets, which were offered on adlibitum basis.

3.3.3 Data collection and measurements

3.3.3.1 Broiler Production

Broiler production parameters including feed intake and body weight were measured on weekly basis, while feed conversion ratio and performance index were calculated from the primary data. Body weight was determined by weighing birds on platform scale while feed intake was determined on weekly basis as amount of feed offered minus refusal.

Feed conversion ratio (FCR) is calculated by dividing kilograms of feed by the weight of the chicken.

Performance index (PI) was computated using the formula below;

PI = (Average grams gained/day X % survival rate)/Feed Conversion X 10

3.3.3.2 Carcass quality

At the end of experimental period all birds in each replicate were slaughtered following a 6-hour fasting in order to determine carcass yield. Birds were withdrawn food for 24 hours but given water in order to empty the digestive tract and to avoid meat contamination during slaughtering. Carcass yield was determined as the weight of the eviscerated carcass in relation to live weight after fasting.

3.3.3.3 Gastrointestinal Tract development

Gastrointestinal tract parameters data was collect at six weeks of age on the following parameters; gizzard weight, intestinal weight and intestinal length. Gizzard and intestinal weights were determined by weighing them on the digital weighing scale after the removal of intestinal contents. Intestinal length was measured using a measuring type. Intestine index was calculated by the proportions as follows;

$$\text{Intestine index} = \frac{\text{intestine length (cm)}}{\text{intestine weight (g)}}$$

3.3.4 Statistical Analysis

The response variables were analyzed as one-way ANOVA with three dietary treatments as the main effects using the GENSTAT C statistical package (Genstat Discovery Edition, 2004). Variables showing a significant F-test ($P < 0.05$) from ANOVA were compared to each other's using Tukey studentized range. The statistical model for one-way analysis was as follows;

$Yij= \mu+Ti+eij$

Where:

Yij = Dietary treatments.

μ = Overall mean of Yij.

Ti = Effect of treatment, i = (1,…,9).

eij= Experimental error.

3.4. The influence of feed texture on broiler performance, metabolic and skeletal disorders and efficiency of nutrients utilization

3.4.1 Experimental design

The study followed a Completely Randomized Design (CRD) with two dietary treatments replicated four times. Dietary treatments were made up of two broiler feed texture namely mash and pellets. The experimental diets had similar nutritive value with different textures.

3.4.2 Birds housing and management

A total of 200, one day old mixed-sex Ross 308 chicks were obtained from a Letsatsi (local agro dealer) on the hatching day. The birds were reared in deep litter floor pens. The chicks were allocated into 6 pens and they were 25 birds per replicate. The room was lit 24 hours for the first 42 days. The experimental feeds and water were provided on ad libitum basis during the whole experimental period and all necessary prophylaxis and vaccination requirements for broilers were administered.

3.4.3 Data collection

3.4.3.1 Production parameters

Data on production parameters was collected on weekly basis with exception of mortality rate which was done on daily basis. Data was collected on the following parameters; body weight, feed intake, feed conversion ratio and mortality. Body weights were measured using a platform scale, Feed intake was determined as the difference between quantity of feed offered and quantity left over and feed conversion ratio (FCR) was calculated as feed intake (g) over live weight (g). Feed conversion ratio was calculated as feed intake (kg) divided by live weight (kg). The body weights were measured using platform weighing scale. Growth rates were measured as the final weight minus initial weight divided by number of days. Mortality rate was recorded from week one until week 6 using the following formula.

Mortality % = Number of dead birds in a replication divided by number of initial birds in a replication X 100.

3.4.3.2 Metabolic and skeletal disorders

Data collection started at beginning of the growing phase up to the end of finishing phase (17 to 42 days) because pelleted feeds were too big for consumption by the day-old chicks.

Skeletal Disorders

Birds were observed on daily basis for the sings of lameness, abnormal gait and those sitting down all the time not able to reach waterers and feeders.

United State gait-scoring system was used to measure the prevalence of leg weakness by assessing the walking ability of broilers. Walking ability was scored according to three category as follows;

0	(No obvious signs of problems)
1	(Obvious signs)
2	(Severe signs)

Any skeletal abnormalities were recorded as they were discovered.

Metabolic Disorders

Sudden death syndrome was recorded as birds that die without any symptoms of illness and they usually lie on their back with the feet raised. Dead birds were collected daily, weighed, and necropsied for the presence of water accumulation in the abdomen, which was considered as ascites.

3.4.3.3 Efficiency of nutrients utilization

The apparent metabolisable energy of experimental diets was determined using both internal and external markers substances according to Sakomura & Rostagno (2007) procedure with modification. Acid Insoluble Ash (AIA) was used as internal marker which contain mainly silica treated with hydrochloric acid with Celite™ which is an external marker substance to improve the recovery of the markers. Nutrient retention and utilization were calculated as follows;

$$AME(MJ/kg)=GEi-[GEo\times(AIAi/AIAo)]$$

Where;

GE_i is gross energy (MJ/kg) in feeds;

GE_o is the gross energy (MJ/kg) in excreta,

AIA_i is the Acid Insoluble Ash concentration in the diets; and

AIA_o is the Acid Insoluble Ash concentration in the excreta.

Energy utilization variables including net energy production (NEp), Heat prododuction (HP), energy retention and efficiency of utilization were computed according formulas in Chang'a et al.(2019) procedures.

The net energy production (NE_p) was computed using the following equation.

Initial GE of carcase(kJ)=carcase GE(kJ/g)×body weight of bird(g) (1)

Final contents of carcase(kJ)=carcase GE(kJ/g)×body weight of bird(g) (2)

NEp(kJ)=(2)−(1)

Heat of production (HP), which consists of the heat increment of feeding and fasting HP was calculated as the difference between NE_p and ME intake:

HP(kJ)=MEI−NEp

Where;

ME intake (MEI) was calculated using the following formula:

MEI(kJ)=ME(kJ/g)×feed intake(g)

Energy retention:

Energy retained as fat (RE_f) and as protein (RE_p) were calculated as follows:

REf(kJ)=carcase fat (g)×38.2 kJ/g

REf(kJ)=carcase crude protein content(g)×23.6 kJ/g

The values 38.2 and 23.6 kJ/g are energy values per gram of fat and protein, respectively, as derived by Larbier and Leclercq (1994).

Metabolizable energy efficiencies:

Efficiency of ME use for energy retention (kRE)=NEp/MEI

Efficiency of ME use for lipid retention (kREf)=REf/MEI

Efficiency of ME use for protein retention (kREp)=REp/MEI

3.4.4 Statistical analysis

The influence of two dietary treatments on broiler production performance, metabolic and skeletal disorders and efficiency of nutrients utilization were compared by subjecting data to T Test statistical tool offered by IBM SPSS (version 20.0) using the model below.

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \qquad t = \frac{\bar{x} - \mu}{\frac{s}{\sqrt{n}}}$$

Where;

x̄ = is the observed mean, i.e., the sample's mean value.

μ = is the theoretical or population mean, i.e., the population's mean value.

s = is the standard deviation of the sample.

n = is the sample size, i.e., the number of observations in the sample.

3.5 The effects of diet dilution using Non-Starch Polysaccharides on broiler performance, carcass quality and feed costs

3.5.1 Experimental design

A completely randomized design was used with four dietary treatments replicated three times. Four experimental diets were formulated at the farm in such a way that the control diet contained maize as the chief energy source while the other three diets had Non-Starch Polysaccharides (NSP) in the form of dried brewers grain (DBG) replacing maize at the rate of 25, 50 and 75% in diets 2, 3 and 4 respectively. The NSP in the form of wet brewery grain was collected from Lesotho only brewery company named Maluti Mountain Brewery. Figure 1 below depicts unloading of NSP from the truck.

Figure 1: Procurement of NSP and packaging into small bags

Feed mixing

The experimental diets were formulated to meet the nutritional needs of broilers during growing and finishing phases. Experimental diets were formulated using locally available feed ingredients such as crushed yellow maize, soyabean oilcake, hominy chop, mineral and vitamin premix, sunflower oilcake. Below Figure 2 students evaluating different feed ingredients before feed formulation.

Figure 2: Evaluation of different feed ingredients before feed formulation

Experimental diets were mixed and offered in a mash form as shown below in Figure 3 and 4 respectively.

Figure 3: Mixing of experimental diets

Figure 4: Experimental diet in the mash form

The physical and chemical composition of experimental diets used during the growing phase are shown in Table 3 below.

Table 3: Physical and chemical composition of NSP experimental diets

Ingredients	**Control**	**T1 (25%NSP)**	**T2 (50%NSP)**	**T3(75%NSP)**
Maize	50	38	25	21
Soyabean	17	20	20	20
Fish meal	7	2	2	2
Sunflower	15	10	10	10
Hominy feed	10.5	17.5	17.5	17.5
NSP	0	12	25	29
Salt	0.25	0.25	0.25	0.25
Mineral Premix	0.25	0.25	0.25	0.25
Determined Analysis				
Dry matter	88.05	88.07	88.68	88.87
Crude Protein	19.41	19.86	21.97	22.62
Crude Fat	9.76	7.85	8.41	8.58
Crude Fibre	5.55	7.02	8.58	9.05
[1]NDF	16.43	22.84	28.22	29.87
[2]ADF	6.78	8.95	11.22	11.92
Starch	35.12	29.71	22.25	19.96
Sugars	3.55	4.10	4.03	4.01
[3]DE (MJ/kg)	14.40	13.29	12.79	12.63
[4]ME (MJ/kg)	13.80	12.67	12.11	11.93
Lysine	1.06	0.99	1.06	1.09
Threonine	0.75	0.74	0.80	0.83
Methionine	0.38	0.34	0.36	0.37
Cysteine	0.32	0.35	0.37	0.38
Methionine Cysteine	0.70	0.68	0.73	0.75
Tryptophan	0.22	0.24	0.27	0.27
Isoleucine	0.80	0.80	0.88	0.90
Valine	0.94	0.95	1.05	1.05
Leucine	1.57	1.55	1.65	1.67
Phenylalanine	0.89	0.92	1.01	1.04
Tyrosine	0.65	0.66	0.70	0.72

[1] Neutral Detergent Fibre

[2] Acid Detergent Fibre

[3] Digestible Energy

[4] Metabolisable Energy

3.5.2 Birds housing and management

A total of 180 day-old broilers were used in this study. The birds were randomly divided into 4 treatments of 45 birds each. Each treatment was replicated 3 times with 15 birds per replicate as shown in Figure 5 below. The experiment lasted for six weeks. The birds were reared in deep litter system. Fresh water and treatment diets were supplied ad libitum throughout the period of the experiment. Routine management practices including vaccination and drug administration when necessary was duly observed.

Figure 5: Experimental birds tasting experimental diet

3.5.3 Data collection and measurements

Data was collected on proximate composition of experimental diets and on the following parameters; production, carcass quality, gastrointestinal development, NSP utilization and feed cost.

3.5.3.1 Proximate analysis of formulated diet

The chemical analysis of experimental diets were done using standard methods according to AOAC (1990) as outlined below for determination of the following parameters; dry matter determination, crude protein, energy, crude fibre (ADF and NDF), ether extract, minerals (calcium and phosphorus) and nitrogen free extract.

Moisture Determination

Moisture was determined by the loss in weight that occurs when a sample was dried to a constant weight in an oven. About 2 grams of a feed sample was weighed into a silica dish previously dried and weighed. The sample was then dried in an oven for 650C for 36 hours, cool in a desiccator and weigh. The drying and weighing continues until a constant weight was achieved.

%Moisture = wt of sample + dish before drying- wt of sample+ dish after drying x100
Wt of sample taken

Since the water content of feed varied, very widely, ingredients and feed are usually compared for their nutrient content on moisture free or dry matter (DM) basis.
%DM = 100 - %Moisture.

Ether Extract

The ether extract of a feed represents the fat and oil in the feed. Soxhlet apparatus was the equipment used for the determination of ether extract. It consist of 3 major components

Procedure:

About 150ml of an anhydrous diethyl ether (petroleum ether) of boiling point of 40-600C was placed in the flask. 2-5 grams of the sample was weighed into a thimble and the thimble was plugged with cotton wool. The thimbles with contents were placed into the extractor; the ether in the flask was then heated. As the ether vapour reaches the condenser through the side arm of the extractor, it condenses to liquid form and drop back into the sample in the thimble, the ether soluble substances were dissolved and were carried into solution through the siphon tube back into the flask. The extraction continues for at least 4 hours. The thimbles were removed and most of the solvent was distilled from the flask into the extractor. The flask was then disconnected and placed in an oven at 650C for 4 hours, cool in desiccator and weighed.

%Ether extract = wt of flask + extract – tare wt of flask x100
wt of sample

Crude Fibre

The organic residue left after sequential extraction of feed with ether can be used to determine the crude fibre, however if a fresh sample is used, the fat in it could be extracted by adding petroleumether, stir, allow it to settle and decant. Do this three times. The fat-free material was then transferred into a flask/beaker and 200mls of pre-heated 1.25% H_2SO_4 was added and the solution was gently boiled for about 30mins, maintaining constant volume of acid by the addition of hot water.

The buckner flask funnel fitted with whatman filter was pre-heated by pouring hot water into the funnel. The boiled acid sample mixture was then filtered hot through the funnel under sufficient suction. The residue was then washed several times with boiling water (until the residue was neutral to litmus paper) and transferred back into the beaker. Then 200mls of pre-heated 1.25% Na_2SO_4 was added and boiled for another 30mins. Filter under suction and wash thoroughly with hot water and twice with ethanol. The residue was dried at 650C for about 24hrs and weighed. The residue was transferred into a crucible and placed in muffle furnace (400-6000C) and ashed for 4hours, then cool in desiccator and weighed.

$$\%\text{Crude fibre} = \frac{\text{Dry wt of residue before ashing - wt of residue after ashing x100}}{\text{wt of sample}}$$

Crude Protein

Crude protein was determined by measuring the nitrogen content of the feed and multiplying it by a factor of 6.25. This factor is based on the fact that most protein contains 16% nitrogen. Crude protein was determined by kjeldahl method. The method involves three stages of analysis namely digestion, distillation and titration.

Digestion

2 grams of the sample was weighed into kjeldahl flask and on to it 25mls of concentrated sulphuric acid was added followed by, 0.5 grams of copper sulphate, 5 grams of sodium sulphate and a speck of selenium tablet. Heat was applied in a fume cupboard slowly at first to prevent undue frothing and continued to digest for 45mins until the digesta become clear pale green. The digesta was left until completely cool and rapidly 100mls of distilled water was added. The digestion flask was rinsed 2-3 times and the add the rinsing was added to the bulk.

Distillation:

Markham distillation apparatus was used for distillation. Steam up the distillation apparatus, add about 10mls of the digest into the apparatus via a funnel, and allow it to boil. 10mls of sodium hydroxide was added from the measuring cylinder so that ammonia is not lost. Distil into 50mls of 2% boric acid containing screened methyl red indicator.

Titration: the alkaline ammonium borate formed was titrated directly with 0.1N HCl. The titre value which was the volume of acid used was recorded. The volume of acid used was fitted into the formula which becomes

$$\%N = \frac{14 \text{ x VA x } 0.1 \text{ x w x}100}{1000\text{x}100}$$

VA = volume of acid used

w= weight of sample

%crude protein = %N x 6.25

Ash

Ash is the inorganic residue obtained by burning off the organic matter of feedstuff at 400-6000C in muffle furnace for 4hours. 2 grams of the sample was weighed into a pre-heated crucible. The crucible was placed into muffle furnace at 400-6000C for 4 hours or until whitish-grey ash was obtained. The crucible was then placed in the desiccator and weighed.

$$\%Ash = \frac{\text{wt of crucible+ash} - \text{wt of crucible}}{\text{wt of sample}}$$

Nitrogen Free Extract (NFE)

NFE was determined by mathematical calculation. It was obtained by subtracting the sum of percentages of all the nutrients already determined from 100.

%NFE = 100-(%moisture + %CF + %CP + %EE + %Ash)

NFE represents soluble carbohydrates and other digestible and easily utilizable non-nitrogenous substances in feed.

Neutral Detergent Fibre

About 0.5 to 1.0 grams sample was placed in 600-ml beaker, followed by 100 mL of neutral detergent fiber solution. The mixture was heated to boiling (5 to 10 min). Heat was decreased when the boiling begins and it continued boiling for up to 60 minutes. After 60 min, contents were filtered into preweighed Whatman #541 filter paper under vacuum using low vacuum at first, increasing only as more force was needed. Contents were rinsed with hot water, filtered, and repeated twice then followed by wash with acetone twice. The filter paper with its contents was folded and place in preweighed aluminum pan. Sample was dried overnight in 100°C oven and cooled in the dessicator. Sample was weighed to determine the yield. For samples with a high starch content: 50 µL of heat-stable amylase was added to to the beaker along with NDF solution as in Step 2, and followed the remaining steps. For the most difficult samples, a 1-gram sample was treated with 30 ml of 8 M urea solution plus 50 µL of heat-stable amylase solution. The mixture was heated on a steam bath at 80 to 900 C for 5 minutes, then incubated at room temperature for 4 hours or overnight. After incubation, 100 mL of NDF solution was added and treated as in Step 3 and following. An additional 50 μL of heat-stable amylase was added at this point.

Acid Detergent Fibre

1 gram of air-dried sample was transferd to beaker followed by addition of 100 mL acid detergent solution. The mixture was heated to boil (5 to 10 min), and boiled exactly 60 min. Contents were filtered with light suction into previously tared crucibles. Filtrate was washed with hot water 2 to 3 times and was followed by wash thoroughly with acetone until no further colour was removed. The filtrate was suctioned and oven dried at 100°C for 24 hours. The samples were cooled in dessicator followed by weighing.

Calcium Determination

Lanthium oxide solution preparation

58.65 grams of La_2O_3 was added to 1 litre volumetric flask, and 250 ml of HC1 was added slowly add under the hood and dissolve completely and brought to volume with reagent grade H_20, and capped tightly.

Sample preparation

1 to 2-grams sample were ashed in muffle in duplicate. The ash residue was placed in 250-ml beaker, followed by 50 ml of 1:3 HC1 (1 part HC1 to 3 parts H_20) and several drops of HNO_3 and boiled under hood. Cooled and filtered into 50- or 100-mL volumetric flask that has been rinsed with dilute acid and diluted to volume with reagent grade H_20.

Standard preparation:

1 ml of stock calcium solution (1,000 g/mL) was placed into 100-mL volumetric with Hamilton syringe, and brought to volume with reagent grade H_20. A working solution (10 g/mL) was prepared by placing the following ml; 0, 2.5, 5, 10, 20, and 30 ml into 100-ml volumetrics with acid-rinsed glass pipettes, followed by 20 mL of La_2O_3 solution, brought to volume with reagent grade H_20, and cap (0 serves as blank; others equate to 0.25, 0.5, 1, 2 and 3 g/mL standards).

Preparation of Unknown solution:

8-ml of predetermined aliquot of unknown (ashed sample in solution) was placed into culture tube with syringe, followed by 1 ml of La_2O_3 solution and enough H_20 to bring a total volume of 5 ml, and the tubes were closed with rubber cocks.

The reading of standards and unknowns samples were done on atomic absorption spectrophotometer. Results were expressed in concentration (mg/ml).

Calculations:

Atomic absorption spectrophotometer reading yields g/ml in tube.

Multiply this value by 5 to determine the quantity of calcium in the aliquot.

Divide volume of ash in solution by aliquot taken from that solution:

Example – 100/0.1 = 1,000

Multiply amount of Calcium in aliquot by this factor to determine quantity of Calcium in volumetric flask.

Divide by dry sample weight:

(Total g/g of dry sample x 1g/106 g) x 100 = % Calcium, dry matter basis.

Determination of Phosphorus

Preparation of Molybdovanadate reagent

1) 40 grams of NH_4-molybdate ·$4H_2O$ was dissolved in 400 ml hot H_2O and cooled. 2 grams NH_4-metavanadate was dissolved in 250 ml hot H_2O, cooled, and added 250 ml of 70 % $HClO_4$. Gradually added molybdate solution to vanadate solution with stirring and diluted to 2 litres.

2) Phosphorus standard solutio.

(1) 2 mg P/ml phosphorus stock solution.

8.788 grams KH_2PO_4 was dissolved in 1 litre of H_2O in the volumetric flask and diluted to the mark. (2) working solution 0.1 mg P/mL.

Dilute 50 ml stock solution was diluted in 1litre of volumentric flask with distilled water.

Preparation of Standard Curve

Standard curve was prepared transferring 2, 5, 8, 10, and 15 ml of working solution into 100ml volumetric flask which were equivalent to 0.2, 0.5, 0.8, 1.0, and 1.5 mg phosphorus. Water was used to prepare the blank (i.e., molydovanadate solution and water only).

The researcher ednsure that all glassware had been rinsed with dilute acid before use. Sample solutions containing phosphorus between 0.2 and 1.5milligrams were placed in the 100ml volumetric flask followed by 20 ml of molybdovanadate reagent, diluted to volume with H_2O, and mixed well. The sample solutions were left for 10 minutes after which they were readon the spectrophotometer at 400 nm using H_2O as the blank. Phosphorus concentration was estimated from the standard curve.

3.5.3.2 Production parameters

Live body weight, feed intake, and the number of dead chicks were recorded weekly. Calculations were made for daily weight gain, feed conversion rate, and mortality rate.

Feed intake was determined as the difference between the quantity of feed offered and the leftovers. Platform weighing scale was used to weigh the birds.

3.5.3.3 Carcass parameters

At the end of growing and finishing phases (weeks 28 and 42) five birds from each replicate/15 birds per the treatment were fasted overnight, weighed and slaughtered by serving both of the right and left carotid artery and jugular vein in a single cut and allowed to bled. The carcasses were allowed to bleed freely for 5 minutes, defeathered using warm water and then re-weighed to obtain plucked carcass weight as shown in Figure 6 below. They were then be decapitated, eviscerated and weighed to obtain the dressed weights.

Figure 6: Slaughtering and eviceration of birds

The eviscerated carcass was weighed and manually cut using a knife into different commercial cuts, which were breast, thighs, and wings. The different commercial cuts were weighed to de-termine the weights which was also expressed as the ratio of carcass weight.The carcass dressing weight, fat pad weight and gizzard weight were also measured. Dressing percentage was expressed as dressed carcass weight over live weight, multiplied by 100. An electronic top loading scale with maximum weight of 3kg (sensitive at 0.1g) was used to weigh the bird and the carcasses.

3.5.3.4 Gastrointestinal tract development

At the end of growing and finishing phases (weeks 28 and 42) five birds from each replicate/15 birds per the treatment were fasted overnight, weighed and slaughtered by serving both of the right and left carotid artery and jugular vein in a single cut and allowed to bled.Birds eviscerated weight and cut up parts were recorded. The digestive tract and internal organs were separated. The length of the esophagus and crop, small intestine, both caeca and large intestine were tape-measured. In addition, the following internal organs were separated and weighed; gizzard (without digesta), proventriculus (without digesta), liver (without gallbladder), heart, and spleen. The percentage of gastrointestinal tract organs to carcass weight were determined.

3.5.3.5 Utilization of NSP by broiler chickens

The digestibility trial was conducted during the last week of growing and finishing phases using indicator method. During each phase, two birds were taken from each replicate with six birds per treatment making a grant total of twenty-four birds per each phase. During the total tract digestibility trial birds were transferd to metabolism cages where they were acclimatised to the treatment diets and environment for three days before the actual data collection started. The four dietary treatments were mixed with Titanium dioxide (TiO2) which is the common marker substance used in indicator method at rate of 5 grams/kg. Faecal samples were then collected for five consecutive days. Samples were air-dried and cleaned to remove feathers and other contaminants. Faeces collected from each treatment were homogenized, ground to pass through a 0.5 mm sieve and stored in airtight plastic containerds at 4°C. Excreta samples were analyzed for DM, Neutral detergent fibre(NDF) and nitrogen (N). The degradability test of NSP was analysed by quantifying TiO2 concentration in both feed and faecal samples using UV-spectroscopy.

The UV-spectroscopy assay was based on that of Short et al. (1996) as follows; triplicate aliquots (approximately 0.3 grams) of each digesta sample and five replicates of each of the feed samples were ashed in porcelain crucibles for 16 hours at 650°C. Once cooled, 10ml H_2SO_4 (7.4 M) was added to each crucible and the samples were heated for approximately 1 hour until completely dissolved. The contents were then transferred quantitatively into 100ml volumetric flasks via filter papers (Whatman 541) using distilled water. 10ml of 30% H_2O_2 was then added to each flask and the flasks made to volume with distilled water. Solutions were thoroughly mixed prior to reading on a spectrophotometer set at 410nm. Sample analysis was repeated if the Z-value between the same samples exceeded 5%. The calibration curve was prepared using 250mg titanium dioxide dissolved in 100ml of 7.4M sulphuric acid (H_2SO_4) and diluted to 500ml with distilled water to produce a standard titanium solution of 0.5mg/ml.

Apparent digestibilty was estimated using the formulas below;

Digestibility (%) = 100 – (100 x (marker concentration in feedstuff / marker concentration in feces) x (nutrient concentration in feces / nutrient concentration in feedstuff)).

Digestibility (%) = $1 - [1 \times (TiO_{2,\%\ diet}/TiO_{2,\%\ digesta/excreta}) \times (nutrient_{\%\ digesta/excreta}/nutrient_{\%\ diet})] \times 100$,

3.5.3.6 Cost benefit analysis

The cost per kg of the diet was calculated by multiplying the percentage composition of the feedstuffs with the price per kg of each feedstuff and summing all. Total feed intake x cost per kg feed gave total feed cost. Feed cost per kg weight gain was calculated as FCR x cost per kg of diet.

3.5.4 Statistical Analysis

The response variables were analysed using one-way ANOVA with four dietary treatments as the main effects using the Social Science Statistical Tool (IBM SPSS version 20, 2011). When F test indicated overall significant difference, post-hoc multiple comparison procedure was carried out using Least Significance Difference (LSD). The statistical model for one-way analysis was as follows;

$Y_{ij} = \mu + T_i + e_{ij}$

Where:

Y_{ij} = Dietary treatments.

μ = Overall mean of Y_{ij}.

T_i = Effect of treatment, i = (1,…,9).

e_{ij} = Experimental error.

3.6 Comparison of commercial and on-farm formulated diets on broiler performance, carcass quality and cost benefit

3.6.1 Experimental design

The experimental design was Completely Randomized Design with two dietary treatments and replicated three times. Dietary treatments were made up of control (commercial diet) and the treated group (farm-formulated diet). The sample of experimental diets were subjected to proximate analysis according to methods prescribed by AOAC (2002) which were carried out at the National University of Lesotho, Department of Animal Science Nutrition laboratory. The physical compositions of farm-formulated diet are displayed in the table below.

Table 4: Physical and Chemical Composition of on-farm formulated diets.

Ingredients	**Inclusion rate (%)**	
	Finisher	**Grower**
Maize	39.75	30
Wheat bran	15	20
Lucerne	14	16
Hominy feed	12	15
Sunflower	10	12
Fish meal	7	5
Sodium chloride	1.25	1
Vitamin and mineral premix	1.0	1
Calculated Chemical Composition	**Percentages**	
Dry matter	83.55	100
Crude Protein	17.02	19.02
Crude Fat	4.13	4.52
Crude Fibre	8.27	10.78
Ash	5.21	5.91
NFE [1]	51.98	57.76
ME [2]	11.62	8.46
DE [3]	12.14	13.19
TDN [4]	68.55	75.58
Calcium	0.93	0.95
Total Phosphorus	0.73	0.81
Lysine	0.78	0.83
Methionine	0.38	0.41
Methionine Cysteine	0.61	0.68
Threonine	0.65	0.72
Tryptophan	0.20	0.23
Isoleucine	0.69	0.76
Leucine	1.40	1.51
Phenylalanine	075	0.83
Valine	0.86	0.97
Selenium	0.39	0.42 (mg/kg)
Vitamin A	2848.31	2860.21 (IU/kg
Vitamin D3	1000	1000 (IU/kg)
Vitamin E	27.04	27.3 (mg/kg)
Vitamin B12	10.53	8.18 (mg/kg)

[1] Nitrogen Free Extract
[2] Metabolisable Energy
[3] Digestible Energy
[4] Total Digestible Nutrients

3.6.2 Birds housing and management

A total of 90, one day old mixed-sex Ross 308 chicks were obtained from Letsatsi Farm Feed Supplier. The birds were reared in deep litter floor pens in a well-ventilated rearing house. The chicks were allocated into 6 pens and they were 15 per replicate. The room was lit 23 hours for the first 3 days. Feed and water were be provided ad libitum during the whole trial and while necessary prophylaxis and vaccination were administered. The experimental diet was formulated to meet the nutritional needs of a growing broiler chickens as stipulated by National Research Council of 1994. The least cost raw materials were used in order to optimise feed costs.

Nutrient analysis

The proximate analysis of experimental diet was done according to AOAC (1990) procedure outlined below for determination of dry matter, ash, crude protein, crude fibre, crude fat, neutral detergent fibre, acid detergent fibre and mineral composition.

3.6.3 Data collection and measurements

3.6.3.1 Production performance

Data was collected on the following parameters; body weight, feed intake, feed conversion ratio and mortality on weekly basis. Body weight was measured using a platform scale, Feed intake was determined by difference between quantity offered and left over and FCR was calculated as feed intake (g) over live weight (g).

3.6.3.2 Carcass and viceral parameters

At the end of finishing phase, ten birds were randomly selected from each replicate as representatives of the two dietary treatments. A total of 60 broilers were sampled for carcass evaluation. The broilers were tagged and starved for 12 hours prior to slaughter. Water was offered on adlibitum basis to birds in order to ensure that carcass will not be contaminated by faecal matter. Broilers were slaughtered by severing the jugular vein. The slaughtered broilers were dipped in hot water at a temperature of 70°c to pluck the feathers and then evisceration. The carcass and visceral weights were recorded. Dressing percentage was expressed as dressed carcass weight over live weight, multiplied by 100 (Kleczek et al., 2007). An electronic top loading scale with maximum weight of 3kg (sensitive at 0.1g) was used to weigh the birds, the carcasses and the visceral organs.

3.6.3.3 Cost-benefit

The cost per kg of the diet was calculated by multiplying the percentage composition of the ingredients with the price per kg of each feedstuff and summing all the ingredients costs. Total feed intake x cost per kg feed gave total feed cost. Feed cost per kg weight gain was calculated as FCR x cost per kg of diet.

3.6.4 Statistical Analysis

Data collected on production parameters, carcass quality, visceral traits and cost benefit were entered into Microsoft excel and later transferred to SPSS software (Version 16). Data was later subjected to T-Test analysis using the formula below.

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \qquad t = \frac{\bar{x} - \mu}{\frac{s}{\sqrt{n}}}$$

Where;

x̄ = is the observed mean, i.e., the sample's mean value.
μ = is the theoretical or population mean, i.e., the population's mean value.
s = is the standard deviation of the sample.
n = is the sample size, i.e., the number of observations in the sample.

CHAPTER FOUR

4.0 CONTENTS AND RESULTS

4.1 Results

4.1.1 The influence of feed texture on broiler performance, carcass quality and gastrointestinal development

4.1.1.1 Broiler performance

The results of the average performance during the entire experimental period (Table 4.1) indicated that the dietary treatments had a distinctive effect on feed intake (P =0.001), growth rate per day (P =0.006), body weight (P=0.013), mortality rate (P =0.023) and performance index (P=0.040). The findings also revealed that mash feed texture gave the lowest performance in all parameters measured while crumbled diet gave superior performance in feed intake, FCR and body weight. The pelleted diet gave superior production in performance index with the highest mortality rate. The body weight and performance index of broilers increased as the feed particle size increased from mash to pelleted diets. Birds fed pelleted diets were the most efficient because the consumed less feed than birds fed crumbled diet but had a higher body weight. The mean comparison test indicated there were no significant difference between birds fed crumble and pelleted diets while they were significantly different from birds on mash diet. Birds fed mash diet had lowest performance index while those fed pelleted diet had highest performance index. The increase in particle size size between small particle (mash) and large particle (pellet) led to increased performance. The findings of the current study also revealed birds that had better performance in all production parameter such as feed intake, FCR, and body weight had the highest performance index. The mortality rate between crumble and pelleted diets were also not statistical different from each other according to Least significant Difference test.

Table 4.1: The effect of broiler feed texture on production performance

Parameters	Feed Forms			Significance	
	Mash	Crumbles	Pellets	P[1]	CV[2]
Feed intake (kg)	0.769±0.82[a]	1.107±1.17[b]	0.952±1.01[a]	0.001	20.2
FCR[3](kg/kg)	2.3±1.06	2.2±1.04	2.2±0.90	0.182	22.8
Growth rate (grams/day)	61±1.13	75±1.23	77±1.16	0.006	6.78
Body weight (kg)	1932±0.74[a]	2531±1.13[b]	2883±1.13[b]	0.013	34.6
Mortality rate (%)	0.8±0.02[a]	7.2±0.45[b]	8.3±0.32[b]	0.023	17.6
Performance index	263±0.68[a]	316±1.05[b]	320±1.26[b]	0.040	54.0

a, b Means in rows with different superscripts differ significantly ($p<0.05$)
[1] ($p<0.05$) = non significant
[2] Coefficient of variation
[3] Feed Conversion Ratio

4.1.1.2 Carcass parameters

The effects of broiler feed texture on broiler carcass quality results are shown in Table 4.2 below. The carcass and abdominal weights at the end of the growing phase had responded well to the dietary treatments where birds fed crumbled diet had significant higher weight than birds fed mash form diet. Carcass yield was however not meaningfully ($P>0.05$) affected by the dietary treatment. Carcass yield results however, despite non-significant effect followed a similar trend observed in other carcass parameters where crumbled diet was leading. The results of the current study clearly highlighted that crumbled diet feed form is the most effective feed texture that support high yields broiler yields. The mash feed texture on the other hand representing small particulate feed size performed poorly in comparison with the medium and large particle feed textures. On the other hand small particle size texture such as mash yielded the desired outcomes of low fat carcass as indicated by low abdominal fat content.

Table 4.2: The effect of feed texture on broiler carcass parameters

Parameters	**Feed Texture**			**Significance**	
	Mash	**Crumbles**	**Pellets**	**P[1]**	**CV[2]**
Abdominal fat Wt (g)	18.18±0.02[a]	25.33±1.06[b]	24±0.1.11[b]	0.010	45.2
Carcass weight (kg)	1.052±0.68[a]	1.845±1.19[b]	1.751±1.13[b]	0.001	8.0
Carcass yield (%)	71.67±4.17	74.97±0.89	73.21±2.63	0.777	6.9

a, b Means in rows with different superscripts differ significantly (p<0.05)
[1] (p<0.05) = non significant
[2] Coefficient of variation

4.1.1.3 Gastrointestinal tract development

The effects of feed texture on broiler gastrointestinal tract parameters results are shown in Table 4.3. According to these results dietary treatments had a major (P<0.05) effect on intestinal length while gizzard weight and intestinal weight were not affected by the dietary treatment. It was also observed that the increase in feed particle size from mash to pellet were negatively correlated with intestinal length, gizzard weight and intestinal weight of birds. The mean comparison test indicated that there were no substantial differences between intestinal length f crumble and pelleted diets.

Table 4.3: The influence of broiler feed texture on gastrointestinal development

Parameters	**Feed Texture**			**Significance**	
	Mash	**Crumbles**	**Pellets**	**P[1]**	**CV[2]**
Gizzard Wt (g)	30.82±0.02	20.67±0.06	20.33±0.08	0.495	21.2
Intestinal Wt (g)	82.73±0.03	67±0.08	63.33±0.11	0.408	25.2
Intestinal Length (cm)	148.64±4.2[b]	126.53±2.1[a]	118.27±3.9[a]	0.015	15.1
Intestine index (cm/g)	1.79±0.01	1.89±0.01	1.88±0.01	0.061	11.02

a, b Means in rows with different superscripts differ significantly (p<0.05)
[1] (p<0.05) = non significant
[2] Coefficient of variation

4.1.2 The influence of feed texture on broiler performance, metabolic and skeletal disorders and efficiency of nutrients utilization

4.1.2.1 Production Parameters

The influence of broiler feed texture on production performance results are shown in Table 5.1. According to the results the broiler feed texture treatment had considerable (P<0.05) effect on all production parameters tested. Birds that had access to diet in pelleted feed form had significantly (P<0.05) higher feed intake, growth rate, feed conversion ratio, live weight and mortality rate than birds offered diet in a mash form. The lower feed intake observed in mash diet could be due to difficult in picking mash diet. The difference in live weight between the two treatments was so big that warrants birds under mash diet continue up to eight weeks of age. On the other hand the mortality rate in broilers fed pelleted diet was too high to affect the economic gain of the farmers.

Table 5.1: The influence of broiler feed texture on production performance

Parameters	**Feed texture**		**Significance**	
	Mash	**Pellet**	**P^1**	**CV^2**
Feed intake (gram/week)	769	951	0.033	9.26
Growth rate (gram/day)	59	84	0.019	8.34
Feed conversion ratio (gram/gram)	2.2	2.6	0.024	11.23
Live weight (gram)	1689	2470	0.001	6.91
Mortality rate (percentage)	0.7	7.5	0.002	0.21

(P<0.05) = Means differed significantly
P^{i}= Probability at 5%
CV^2= Coefficient of variation

4.1.2.2 Metabolic and skeletal disorders

The influence of different broiler feed textures on metabolic and skeletal disorders results are shown in Table 5.2. The results indicated that the dietary treatment had substantial (P<0.05) impact on ascites and skeletal disorders incidence while there were no significant (P>0.05) differences on sudden death between the two broiler feed textures. The incidence of ascites and skeletal disorders were significantly higher in broilers fed pelleted diet than birds fed mash diet. Similar trend in results were observed for sudden death syndrome where more incidence were observed in birds offered diet in form of pellets. Of the three metabolic disorders investigated in the current study, ascites and skeletal disorders recorded the highest number of incidences than SDS. The observed results are a clear testimony that broiler diets in mash form has the potential to control or lower the metabolic disorders and reduce the overall mortality.

Table 5.2: The influence of broiler feed texture on incidences of metabolic disorders				
Parameters	**Feed texture**		**Significance**	
	Mash	**Pellet**	**P[1]**	**CV[2]**
Ascites (percentage)	0.75	6.25	0.033	11.26
Sudden death syndrome (percentage)	0.00	1.30	0.356	19.26
Skeletal disorders (percentages)	0.75	5.75	0.001	8.91

(P<0.05) = Means differed significantly
P[i]= Probability at 5%
CV[2]= Coefficient of variation

4.1.2.3 Efficiency of utilization for feed textures

The findings in Table 5.3 below portrays that feed texture had a major (P<0.05) impact on nutrient utilization by broiler chickens. Broiler chickens that consumed pelleted diet utilized energy and proteins better than those fed mash diet in all parameters such as apparent metabolisable energy (AME), metabolisable energy intake (MEI), net energy for production (NEp), protein retention and efficiency of utilization for energy and proteins. Broiler fed mash diet had lower energy and protein efficiency of 56% and 33% against 73% and 39% respectively. The broiler maintained on pellets diet retained more protein for body growth than those on mash diet.

Table 5.3: The influence of broiler feed texture on nutrients utilization				
Parameters	**Feed texture**		**Significance**	
	Mash	**Pellet**	**P[1]**	**CV[2]**
AME[3] (kcal)	2653	2916	0.012	1.11
MEI[4] (kcal)	184	206	0.001	1.02
Nep[5] (kcal)	104	120	0.011	3.01
kRE[6] (percentage)	0.56	0.73	0.005	0.98
kREp7 (percentage)	0.31	0.39	0.001	0.22
Protein retention (kcal)	55	63	0.001	1.46

(P<0.05) = Means differed significantly
[I] Probability at 5%
[2] Coefficient of variation
[3] Apparent Metabolisable Energy
[4] Metabolisable Energy Intake
[5] Net Energy Production
[6] Efficiency of ME for energy retention
[7] Efficiency of ME for protein retention

4.1.3 The effects of diet dilution using Non-Starch Polysaccharides (NSP) on broiler performance, carcass quality, GIT development, NSP utilization and feed costs

4.1.3.1 Production Parameters

The influence of NSP inclusion in broiler diets results on production parameter are shown in Table 6.1. It is evident from these results that NSP inclusion had a noticeable (P<0.05) influence on feed intake, daily weight gain, feed conversion ratio (FCR) and final body weight, whereby birds that consumed control diet without NSP inclusion performed significantly better than all birds in other treatments. It was also observed that the incremental inclusion of NSP resulted in an inverse relationship in all production parameters. Least significant difference result on the other hand revealed that there was no significant (P>0.05) difference in all production parameters between the control and 25% inclusion rate of NSP. The 75% inclusion rate of NSP gave very poor performance in all production parameters observed where live weight was reduced by 66% in comparison with control animals. The poor performance in highest NSP inclusion rate could be due to higher fibre content, which is poorly utilized by broiler chickens.

Table 6.1: The influence of NSP inclusion in broiler diets on production performance

Parameters	NSP inclusion rate				Significance	
	Control	25%	50%	75%	P[1]	CV[2]
Feed intake (g/week)	710.00^{a}	643.00^{b}	577.33^{c}	510.00^{d}	0.001	19.69
Daily weight gain (grams)	91.41^{a}	90.26^{a}	81.99^{b}	73.36^{c}	0.002	26.32
FCR (gram/grams)	2.48a	2.47a	2.37b	1.91c	0.019	16.94
Live weight (grams)	2325.67^{a}	2230.00^{a}	1943.53^{b}	1400.20^{c}	0.001	15.89

a, b,c Means in rows with different superscripts differ significantly (P<0.05)
[1] (P> 0.05) = non-significant
[2] Coefficient of Variation
[3] Feed Conversion Ratio (kg feed/kg weight gain)

4.1.3.2 Carcass parameters

The influence of broiler diet dilution with NSP on carcass production results (Table 6.2) pointed out that dietary treatment had a striking influence on carcass weight (P =0.001), dressing percentage(P =0.010), thigh (P =0.003), wing (P =0.010), breast muscle (P =0.001) and abdominal fat (P =0.001). The carcass parameters had an inverse relationship with increase in NSP inclusion rate. The mean comparison test indicated that carcass parameters between control and 25% NSP groups were not statistically different however, there was substantial difference between control and 50 and 75%NSP. The weight of thighs, wings and breast muscle followed similar trend. The dressing percentage results on the other hand indicated that there were no significant difference between control, 25% and 50%NSP inclusion with the exceptions of 75% NSP inclusion rate that produced significantly low dressing percentage. The highest inclusion rate of NSP in the current study produced the least carcass and meat cuts than all other treatments while undiluted diet performed better than all the treatments in terms of carcass traits.

Table 6.2: The influence of NSP inclusion in broiler diets on carcass characteristics

Parameters	**NSP inclusion rate**				**Significance**	
	Control	**25%**	**50%**	**75%**	**P[1]**	**CV[2]**
Carcass weight (grams)	1795^{a}	1729^{a}	1450^{b}	1010^{b}	0.001	6.45
Dressing percentage (%)	77.4^{a}	77.2^{a}	75.0^{b}	72.4^{b}	0.010	2.2
Thigh (grams)	305^{a}	292^{a}	247^{b}	172^{b}	0.003	1.1
Wing (grams)	233^{a}	224^{a}	189^{b}	131^{c}	0.010	1.07
Breast muscle (grams)	574^{a}	550^{a}	463^{b}	323^{c}	0.001	1.2
Abdominal fat (grams)	28.6^{a}	24.8^{ab}	21.2^{b}	18.7^{c}	0.001	1.11

a, b,c Means in rows with different superscripts differ significantly (P<0.05)
[1] (P> 0.05) = non-significant
[2] Coefficient of Variation

4.1.3.3. Gastrointestinal development of broilers

Effects of broiler diet dilution on gastrointestinal development of broilers at the end of feeding trial (42 days) are shown in Table 6.3. The visceral weight (P =0.031), liver weight (P =0.001), heart weight (P =0.001), gizzard weight (P =0.001) and intestinal length (P=0.016) were significantly affected by the dietary treatment whereby the control diet (undiluted) had performed better than all the treatments while 75% NSP inclusion being the least. The diluted diets had an inverse relation with increase in the inclusion rate of NSP in all the GIT parameters. Diet dilution decreased the weight of viscera, liver, heart and gizzard and at the same time reduced the length of intestines. The mean comparison test on the other hand indicated there were no significant differences between the control diet and 25%NSP dilution. The implication are that the 25%NSP dilution gave similar performance to the control diet.

Table 6.3: The influence of NSP inclusion in broiler diets on gastrointestinal tract Development						
Parameters	**NSP inclusion rate**				**Significance**	
	Control	**25%**	**50%**	**75%**	**P[1]**	**CV[2]**
Visceral weight (grams)	321.67[a]	313.33[a]	275.00[b]	246.00[b]	0.031	11.4
Liver weight (grams)	50.00[a]	47.67[a]	39.67[b]	36.33[b]	0.001	2.3
Heart weight (grams)	11.33[a]	10.67[a]	9.33[a]	6.67[b]	0.001	3.6
Gizzard weight (grams)	94.00[a]	92.33[a]	89.33[a]	78.33[b]	0.001	1.7
Intestinal length (cm)	268[a]	264[a]	252[b]	246[b]	0.016	0.87

a, b,c Means in rows with different superscripts differ significantly (P<0.05)
[1] (P> 0.05) = non-significant
[2] Coefficient of Variation

4.1.3.4 NSP utilization by broiler

The effects of broiler diet dilution with NSP on broiler nutrients utilization results are depicted on Table 6.4. According to the findings broiler diets dilution with NSP had a significant effects on dry matter digestibility (P=0.001), starch digestibility (P=0.010), nitrogen digestibility (P=0.023) and NDF digestibility (P= 0.011). It was observed that the nutrients digestibility had an inverse relationship with NSP inclusion rate in broiler diets. The Least Significance Difference test indicated that for dry matter digestibility there were no signicant (P>0.05) between control and 25%NSP and the similar trend was observed for starch and nitrogen digestibility. On the other hand NDF digestibility results showed that there were no signicant (P>0.05) differences between control, 25%NSP and 50%NSP which differs from 75%NSP diet. The nutrients utilization results indicated that broiler chickens utilized nitrogen and starch better than NDF. From the Table 6.4 below it starch utilization was the highest with more than eighty-five percent digestibility across all the treatments. The results for NDF digestibility proved that broiler chickens are not efficient in the digestibility and utilization of high fibre feed ingredients.

Table 6.4: The influence of NSP inclusion in broiler diets on nutrients utilization						
Parameters	**NSP inclusion rate**				**Significance**	
	Control	**25%**	**50%**	**75%**	**P[1]**	**CV[2]**
Dry matter (%)	74.2[a]	70.4[a]	65.5[b]	63.3[b]	0.001	6.45
Starch (%)	96.6[a]	94.3[a]	89.2[b]	86.1[b]	0.010	10.2
Crude protein (%)	79.1[a]	74.4[a]	68.4[a]	65.5[b]	0.023	3.21
NDF[3] (%)	33.3[a]	32.8[a]	31.2[a]	26.7[b]	0.011	1.02

a, b,c Means in rows with different superscripts differ significantly (P<0.05)
[1] (P> 0.05) = non-significant
[2] Coefficient of Variation
[3] Neutral detergent fibre

4.1.3.5 Cost benefit analysis

The cost benefits analysis for farm formulated and commercial diets results (Table 6.5) indicated that the dietary treatments had a substantial (P<0.05) influence on the cost benefit parameters. The increase in the inclusion rate of NSP had an inverse relationship on the cost parameters. The cost of 50kg feed were reduced from M250 to M180 between 25% NSP and 75% inclusion rated. Similarly, the cost per kg weight gain and kg feed were reduced by 48% and 28% respectively. However, cost of 50kg feeds were not statistically different between control and 25%NSP treatment but cost of 25%NSP were lower by 10.00 units of local currency, which is good saving for the farmer.

Table 6.5: The influence of NSP inclusion in broiler diets on feed costs

Parameters	**NSP inclusion rate**				**Significance**	
	Control	**25%**	**50%**	**75%**	**P[1]**	**CV[2]**
Cost of feed/50kg (M)[3]	260.00^{a}	250.00^{a}	220.00^{b}	180.00^{b}	0.003	2.12
Cost/kg weight gain (M)[3]	12.92^{a}	12.35^{a}	10.3^{b}	6.88^{b}	0.001	5.47
Cost/kg feed (M)[3]	5.21^{a}	5.00^{a}	4.40^{a}	3.60^{b}	0.001	1.96

a, b,c Means in rows with different superscripts differ significantly (P<0.05)
[1] (P> 0.05) = non-significant
[2] Coefficient of Variation
[3] Maloti

4.1.4 Comparison of commercial and on-farm formulated diets on broiler performance, carcass quality and cost benefit

4.1.4.1 Production parameters

The comparison of commercial and own-farm formulated diets on broiler production results are shown in Table 7.1. The broiler production results indicated that dietary treatment had no major influence on feed intake (P=0.304), average daily gain (P=0.462), FCR (P=0.080) and body weight (0.751). However, the commercial diet had higher production performance values than farm-formulated diet in all the observed parameters. The lack of statistical difference in production performance is a clear testimony that the farm formulated diet gave similar performance to the commercial diet. The implications are that the formulation and mix of feed ingredients for farm-formulated feed were correct hence similar production performance.

Table 7.1: The influence of farm formulated diets on broiler production performance				
Parameters	**Broiler Feeds**		**Significance**	
	Commercial	**Farm formulated**	**P[1]**	**CV[2]**
Feed intake (gram/week)	647.24	634.93	0.304	4.13
Average daily gain (gram/week)	55.00	51.27	0.462	19.4
Feed conversion ratio (gram/gram)	1.9	1.7	0.080	1.27
Live weight (gram)	2382	2203	0.751	10.5
(P<0.05) = Means differed significantly P[i]= Probability at 5% CV[2]= Coefficient of variation				

4.1.4.2 Carcass characteristics

The comparison of commercial and on farm formulated diets on carcass characteristics results (Table 7.2) below showed that the treatments did not have a notable (P>0.05) effect on carcass parameters. However, birds fed commercial diet displayed high body weight, carcass and dress percentage in comparison to birds fed farm formulated diet. The non-significant differences results between the two diets means that the farm formulated diet was able to give similar production performance to commercial diet. The farm-formulated diets if blended very well can replace the commercial feeds according to the findings of the current study.

Table 7.2: The influence of farm formulated diets on broiler carcass parameters				
Parameters	**Broiler Feeds**		**Significance**	
	Commercial	**Farm Formulated**	**P[1]**	**CV[2]**
Live weight (grams)	2275	2203	0.481	12.33
Carcass weight (grams)	1772	1666	0.067	12.93
Dressing percentage (%)	76.13	74.13	0.160	0.052
(P<0.05) = Means differed significantly P[i]= Probability at 5% CV[2]= Coefficient of variation				

4.1.4.3 Visceral characteristics

The results on comparison of on farm formulated and commercial diets on broiler visceral organs parameters are depicted on Table 7.3 below. The results indicated that both the on farm formulated and commercial diet did not have a remarkable (P>0.05) influence on visceral components such as heart, liver, gizzard and intestinal length. According these results the farm-formulated diet had performed better than commercial diet on all visceral components measured. This results a clear testimony that farmers under the proper guidance of animal nutritionist can prepare their own feeds using locally available materials.

Table 7.3: The influence of farm formulated diets on broiler visceral parameters				
Parameters	**Broiler Feeds**		**Significance**	
	Commercial	**Farm Formulated**	**P[1]**	**CV[2]**
Heart weight (grams)	8.33	11.33	0.061	0.34
Liver weight (grams)	47.0	50.67	0.331	0.21
Gizzardweight (grams)	72.67	94.0	0.012	0.17
Intestinal weight (grams)	140	166	0.022	0.56
(P<0.05) = Means differed significantly P[i]= Probability at 5% CV[2]= Coefficient of variation				

4.1.4.4 Cost benefit

The results on the comparison of on farm formulated and commercial diets on cost benefit results are depicted in Table 7.4. According to the results there was a major (P<0.05) effect of dietary treatment on cost benefits whereby farm formulated feeds were cheaper and economical than commercial feeds. The cost of feed per 50kg bag (P=0.0030) and feed cost reduction percentage (P=0.002) for farm formulated feeds were signicantly lower than the commercial feeds. In the case of feed per kilogram, cost of feed per daily gain and total feed costs were not statistically different from each other. The results also highlighted that farm-formulated diet costs were slightly economical than the commercial diet in terms of cost of feed per kg, cost of feed per daily gain, cost of 50kg feed, total feed costs and feed cost reduction. The use of farm formulated reduced the overall costs of feeds by 6%, which is a significant saving for the farmer.

Table 7.4: The influence of farm formulated diets on broiler visceral parameters				
Parameters	**Broiler Feeds**		**Significance**	
	Commercial	**Farm Formulated**	**P[1]**	**CV[2]**
Cost of feed per kg (M)	4.70	4.44	0.072	4.1
Cost of feed/daily gain (M)	26	24	0.421	11.5
Cost of feed per 50kg bag	235.20	222.00	0.003	9.34
Total feed cost per bird (M)	12.17	11.27	0.332	3.56
Cost reduction (%)	0	6	0.002	2.76
(P<0.05) = Means differed significantly P[i]= Probability at 5% CV[2]= Coefficient of variation				

CHAPTER FIVE
5.0 DISCUSSIONS

5.1.1 The influence of feed texture on broiler performance, carcass quality and gastrointestinal development

5.1.1.1 Broiler performance

Feed intake, feed conversion ratio and growth rates results obtained by the current study are in agreement with the findings of [Adegbenro et al., 2023; Kuleile and Molapo, 2019; Hasani et al., 2018; Hosseini et al., 2017; Naderinejad et al., 2017; Mingbin et al., 2015; Chehraghi et al., 2013; Chewning et al., 2012;Dozier et al., 2010;Amerah et al., 2007] who indicated that feeding pelleted diets during growing and finishing phases increased broiler feed efficiency significantly. Massuquetto et al (2019) studied the effect of pelleting on growth performance, carcass yield and nutrient digestibility in broiler chickens and found that birds fed the pelleted diet ad libitum had a higher FI (11%) than those fed the mash diet ad libitum, resulting in a 17% higher weight gain, a 6% improvement in FCR and a 183kcal reduction in caloric conversion. By adjusting FCR to a 2.3kg weight, there was an 11% increase when compared to the mash feed.

Contrary to these findings Fasuyi and Odunayo (2015) indicated that mash diet resulted in higher feed intake and feed conversion ratio than birds fed pelleted diet. Broiler mortality rate results are in accordance with the findings of [Bricket et al., 2007 and Van Biljon, 2006] who recorded significantly higher mortality in chickens fed the crumble-pellet regimen (6,57% at 42 days), compared to chickens on the ground crumbles and pellets (4,03% at 42 days) and all-mash regimen (2,85% at 42 days). They also indicated that feeding mash reduced the overall mortality as well as the mortality in every time period, starting at 14 d of age, in comparison with feeding pellet diets. On the other hand[Al-Nasrawi 2016, Moayyedian et al., 2011, Dozier et al., 2010, Norollahi, 2008, Scott 2002, Engberg et al. 2002, Nir et al. 1995] stated that different broiler feed forms did not have a significant influence on mortality rate. Ommati et al., (2013) also reported no differences in mortality rate but however, they observed that mortality was highest in pellets fed broilers with 12.7% while mash fed birds group had 9%. The differences in mortality observed by Scott (2002) were possibly because the mash diet was fed for only 12 days during the starter phase. Bennette et al (2000) observed that feeding of the mash feed on the other hand have been reported to slow down growth rate but reduced mortality caused by sudden death syndrome and ascites.

Chauhan et al (2020) assessed the performance index, glucose and cholesterol level in broiler chickens fed diets containing different supplements and observed enhancement in performance index and HDL cholesterol and significant decline in the glucose, total cholesterol, LDL cholesterol and triglyceride in broilers under supplementary groups as compared to control groups. Susanti (2023) stated that a good IP for raising broiler chickens is above 300. According to the findings of this study broiler fed crumble and pelleted diets had high IP of more than 300. The higher the IP value are indicator for the better success full broiler chicken production (Susanti, 2023). Kryeziu et al. (2018) working on European performance indicators evaluated European Broiler Index (EBI) and European Production Efficiency Factor (EPEF) on broiler chickens covering, daily weight gain and survival percentage and indicated that higher values of these indicators indicated that the birds body weight gain was uniform and the flock was in good health. Farhadi and Hosseini (2014) observed that the chickens grown in the environmentally controlled condition modern house, although raised at higher stocking density (20 vs. 16 Birds/m2) than conventional house, had numerically lower mortality rate and greater production efficiency index probably due to improved environmental conditions trough proper ventilation applied in environmentally controlled condition modern house than conventional house. Many factors affect IP values in broiler chickens: the average body weight of broiler chickens at harvest, the percentage of livestock mortality and feed conversion. Important factors are mortality and reject rates in livestock or the percentage of mortality and depletion.

The observed results on production parameters clearly revealed the superiority of pelleted diets to optimize broiler production during growing and finishing phase items of feed intake, growth and high feed efficiency. Pelleted diet offers a complete nutrient package for broilers because it reduces nutrient segregation and feed wastage as compared to mash diet (Ghazi et al., 2012). Broilers fed pelleted diet had high feed intake than birds fed mash diet because pelleted diet poses larger particle size than mash and therefore it is consumed relatively faster than diet in mash form (Sogunle et al., 2013). Birds consuming diet in mash spent a lot of time and energy in the act of eating and hence why low feed conversion efficiency. (Moran, 1987 and Flemming et al., 2002). Skinner-Noble et al. (2005) indicated that pellet rations increased available dietary energy for BW gain, which improved feed efficiency by reducing the time spent eating and increasing the time spent resting. The benefits of pellet feeding on broiler performance have been extensively reported and the current work confirms the benefits in terms of higher feed intake, weight gain and feed efficiency but prone to high incidences of metabolic disorders. Marx et al. (2021) reported that pelleting also hinders the selection of feed particles, causes less feed waste, decreases the segregation and microbial load of feeds, increases the amount of dietary energy available for production as less time is required for the intake of pelleted feeds, and increases the digestibility of dietary fractions, such as starch and protein.

5.1.1.2 Carcass quality

The observed high performance of broiler fed crumble diet are inline with their highest feed intake.The results of the current study are in corroboration with the findings of Mingbin et al. (2015) who observed that feed texture did not affect broiler carcass yield but had a remarkable influence on abdominal fat weight. Ramchandar et al. (2022) conducted a similar study and found contrasting results where the carsss yield was influenced by feed texture while abdominal fat was not responsive and the source of variation could be due to different particle size of feeds within a particular feed texture. Novotny et al. (2021) found contrasting results on carcass quality traits, where fine or small particle diet performed better than large particle diet on carcass weight and slaughter weight than in the current study where crumble feed texture or medium particle size had the highest carcass weight and yield. Abu et al. (2023) observed that pelleted feed produced a more consistent feed intake and reduced selective feeding in broilers than the mash form of feed. Similarly, improved feed intake, body weight and feed conversion ratio (FCR) were reported for birds fed pelleted feed compared with mash feed. Rubio,(2018) challenged the effects of corn particle size and feed form on growth performance and carcass characteristics of broilers atested that carcass weight was lower in birds fed mash diets compared with those fed crumbles, 3.3 mm micro pellets and 4.4 mm pellets and also observed that breast and carcass meat weight, appeared to be one of the carcass traits most sensitive to feed form.

Corzo et al. (2011) added that birds fed pelleted diet showed higher carcass weight, back-half fat, abdominal fat and higher breast meat yield compared with those fed mash diet. Amber et al. (2023) confirmed the similar trend to the current study where pelleted diets produced better carcass components than mash. The improved performance of pelleted feeds observed in the current study, could be attributed to the fact that chickens fed pellets diet had higher villus height (VH) and crypt depth (CD) in the small intestine, as well as a higher ratio of villus height to crypt depth (VCR) in the duodenum, as compared to those fed mash diet (Wan et al.,2021). The longer VH could be linked with improved surface area and consequently greater absorption of nutrients. Adegbenro et al. (2023) postulated that feeding broiler pellets against mash diets have attributed the improved performance to decreased ingredient segregation, decreased time, and energy spent during prehension and increased palatability and digestibility of feed.

5.1.1.3 Gastrointestinal development

The findings of the effects of broiler feed texture on gastrointestinal development are in agreement with the results of Adegbenro et al. (2023) and Amerah et al (2007) who reported significant greater gastrointestinal tract components in birds fed mash diet. Ramchandar et al. (2022) studied the influence of feed particle size on broiler carcass and concluded that dietary treatment had no significant influence on gizzard weight which is similar to the findings of the current study. Röhe et al. (2014) supported that investigated gastrointestinal organs were influenced by the feed texture whereby birds fed with mash diets had higher proventriculus, gizzard and pancreas weights compared with birds fed the expandate diets. Frikha et al (2009) working with layer pullets observed significant ($P<0.05$) long intestinal length in birds fed mash diet. However intestinal and gizzard weights were not significantly influenced by dietary treatment.

Intestinal and gizzard weight results are in agreement with Amerah et al (2007) and Senkoylu et al.(2009) and partly conform with results of Gabriel et al.(2008) and Mirghelenj & Golian (2009) who confirmed that different feed form did not influence the weight of intestinal components of birds but found that gizzard weight was significantly influenced by dietary treatment. Researchers added that gizzard and caeca weights expressed as a percentage of the body weights were heavier in birds fed mash diets than in those fed pellets. Abdel Magied et al. (2021) revealed that intestinal length and index were not affected by the inclusion of NSP sources as diluents in broiler diets. Xu et al. (2015) confirmed that dietary structural material on intestinal morphology may be due to greater digesta retention time, which enhanced nutrient availability and facilitated greater contact between nutrients and intestinal villi. Kheravii et al. (2017b) discovered that inclusion of coarse particles in diet has been shown to increase digesta retention time in the upper part of the gastrointestinal tract (GIT) (i.e., from crop to gizzard), stimulate gizzard function and increase the secretion of HCl in the proventriculus in broilers. The researcher added that low pH in the upper GIT improves solubility and absorption of mineral salts and pepsin activity. Therefore, feed modulations by use of coarse textured feeds may be beneficial to growth performance of the broiler chickens. The reduced gastrointestinal components observed in the current study could mean that pelleting reduced the gizzard's need for grinding, reducing its function to that of transit, and decreasing transit time due to particle size (Mateos et al., 2012) which resulted in reduced organ weight (Svihus, 2011).

Razaeipour and Gezani (2014) reported that the relative weight of the gizzard was greater in birds fed mash feed than in birds fed pellets. The reduced weight of the gizzard in broilers fed pelleted diets may be an indication that pelleting decreases the grinding requirements of the gizzard thereby reducing its function to merely that of transit, hence its reduced weight. The post-pellet inclusion of whole wheat in broiler diets had greater impacts compared to pre- pellet inclusions. Relative to ground grain control diet, post-pellet whole wheat inclusion increased relative gizzard weight, reduced gizzard digesta pH and reduced incidence of dilated proventriculus (Ali et al., 2021).

5.1.2 The influence of feed texture on broiler performance, metabolic and skeletal disorders and nutrient utilization

5.1.2.1 Production parameters

Feed intake and feed conversion ratio and growth rates results are in agreement with the findings of [Kuleile and Molapo, 2019,Hasani et al.,2018,Hosseini et al.,2017, Naderinejad et al., 2017 Chehraghi et al., 2013, Dozier et al., 2010, Amerah et al., 2007] who indicated that feeding pelleted diets during growing and finishing phases increased broiler feed efficiency significantly. Contrary to these findings Fasuyi and Odunayo (2015) indicated that mash diet resulted in higher feed intake and feed conversion ratio than birds fed pelleted diet. Broiler mortality rate results are in accordance with the findings of [Bricket et al., 2007 and Van Biljon, 2006] who recorded significantly ($P<0.05$) higher mortality in chickens fed the crumble-pellet regimen (6,57% at 42 days), compared to chickens on the ground crumbles and pellets (4,03% at 42 days) and all-mash regimen (2,85% at 42 days). They also indicated that feeding mash reduced the overall mortality as well as the mortality in every time period, starting at 14 days of age, in comparison with feeding pellet diets. On the other hand[Al-Nasrawi 2016, Moayyedian et al., 2011, Dozier et al., 2010, Norollahi, 2008, Scott 2002, Engberg et al. 2002, Nir et al. 1995] stated that different broiler feed forms did not have a significant influence on mortality rate. Ommati et al. (2013) also reported no differences in mortality rate but they observed that mortality was highest in pellets fed broilers with 12.7% while mash fed birds group had 9%. The differences in mortality observed by Scott (2002) were possibly because the mash diet was fed for only 12 days during the starter phase. Massuquetto et al (2020) studied the effects of feed form and energy levels on growth performance, carcass yield and nutrient digestibility in broilers and indicated that high mortality in pelleted fed birds was caused by high metabolizable energy in diets as a results show that broilers fed pellet don't require same energy compared to fed mash, thus more metabolizable energy in diet have revers effect on normal body physiology and health or may pellet feed decrease intestine PH, then infected by E. coli infection after causes ascites.

The observed results on production parameters clearly revealed the superiority of pelleted diets to optimize broiler production during growing and finishing phase items of feed intake, growth and high feed efficiency. Pelleted diet offers ac complete nutrient package for broilers because it reduces nutrient segregation and feed wastage as compared to mash diet (Ghazi et al., 2012). Broilers fed pelleted diet had high feed intake than birds fed mash diet because pelleted diet has a high particle size than mash and therefore it is consumed relatively faster than diet in mash form. Bhuiyan et al.(2021) assessed the use of high fibre diets on energy cost of production and abdominal fat of broiler chickens and found that birds fed on low fibre content diet had higher body weight than birds fed on higher fibre content diets. The body weights of birds were not significantly impacted by medium dietary fibre and high dietary fibre.

Birds consuming diet in mash spent a lot of time and energy in the act of eating and hence why low feed conversion efficiency. (Moran, 1987 and Flemming et al., 2002). Skinner-Noble et al. (2005) indicated that pellet rations increased available dietary energy for BW gain, which improved feed efficiency by reducing the time spent eating and increasing the time spent resting. The benefits of pellet feeding on broiler performance have been extensively reported and the current work confirms the benefits in terms of higher feed intake, weight gain and feed efficiency but prone to high incidences of metabolic disorders.

5.1.2.2 Metabolic Disorders Parameters

Van Biljon (2006) results concurred with the findings of the current study on incidences of ascites and skeletal disorders where the researcher reported significantly higher mortality mainly caused by ascites (11%) and SDS (39%) in crumble-pellet treatment than in all mash diets. Skeletal disorders incidences were higher in grounded crumble-pellet treatment than in group fed all mash diet. A number of researchers also confirmed the findings of the present study that feeding pellets to broilers lead to fast growth rates that in turn resulted in high incidences of ascites and SDS [Hasani et al., 2018, Meshram and Bijoy 2017,Ghazi et al., 2012, Arce-Menocal et al.,2009,Sarvestani et al., (2006), Bolukbasi et al., 2005, Arce et al., 1985]. Arce et al., (1985) observed 15% incidence of ascites in pellets compared to 4% in mash diets. In the current study broilers fed pellets diet grew significantly faster than birds fed mash and hence the high incidence of ascites and skeletal disorders in these group of birds.

Zohair et al (2012) reported that birds in the mash feed groups had a significantly lower mortality rate due to ascites than birds in the pellet feed groups. Malan et al (2003) postulated that the result of higher ascites incidence in fast growing chickens with a high feed efficiency was explained by concomitant and a thyroid hormone deficiency. Decuypere et al (2000) on the other hand suggested that the relationship between susceptibility for ascites and high feed efficiency accompanied with hypothyroidism was responsible for the insufficient supply of oxygen, which resulted in anoxia, hypoxemia and hypoxia. Maslić-Strižak et al. (2012) recommended feeding diets in the mash form for fast-growing hybrids to control the incidences of metabolic diseases. It was also suggested that mash feed slows down the intake of feed and, thus, helps slow down growth rate and reduces the development of ascites syndrome (Urdaneta-Rincon and Leeson, 2002).

Variation in observed results amongst researchers could be as a result of combination of feed form treatment with cold induced treatment, different altitudes, lighting programme, stocking density in rearing house as well as the use of bioenzymes. Researchers also reiterated that skeletal disorders, ascites and SDS are the common cause of economic losses due to mortality and downgrades in fast-growing broiler strains. According to Sosnówka-Czajka and Skomorucha (2022), limiting the nutritive value, in particular the energy level of feed improves the welfare of broiler chickens and protects them against sudden death syndrome. As reported by Karki (2011), SDS mortality in broiler chickens increases beyond 40 days of age and may average up to 9.6%, while restricted feeding and 8–10% lower dietary nutrient concentration significantly reduce mortality caused by SDS.

5.1.2.3 Efficiency of nutrients utilization by broiler

The evaluation of the energy content of feed for monogastric animals has been most commonly based on the digestible energy (DE) or metabolisable energy (ME) contents. However, the closest estimate of the 'true' energy value of a feed should be the net energy (NE) content, which accounts for differences in metabolic utilization of ME of nutrients for maintenance and production (Noblet et al, 2010). In addition, NE is the only system in which energy requirements and diet energy values are expressed on a basis that is theoretically independent of the feed characteristics. With the high cost of nutrients, efficiency of nutrient utilization for the production of edible protein is equally as important as performance or carcass composition in determining optimum dietary levels(Jackson et al., 1982).

The metabolisable energy for maintanance (Mem) is not a constant value and varies with ambient temperature. The MEm of different bird strains increased with decreasing environmental temperature (Sakomura, 2004). The MEm of broilers was negatively correlated by the quadratic effect of ambient temperature (Sakomura et al., 2005). Birds must produce heat when they are housed below the thermoneutral zone and when temperatures exceed thermoneutral zone, birds must expend energy to dissipate heat in order to maintain body temperature(Leeson and Summers,1997). The MEm requirements vary with body feather coverage, for similar reasons. Layers housed at the thermoneutral zone with 0% feather coverage required 38% more MEm than their peers housed at the thermoneutral zone with 100% feather coverage (Peguri and Coon, 1993). Accordingly, birds with poor plumage were found to be more resistant to heat stress than birds with normal feather coverage as the former is able to dissipate heat more easily (Balnave, 2004).

Changa et al. (2023) conducted a similar study on the utilization and nutrient digestibility of mash and pellet diets. The researchers discovered that broiler chicken consumed less energy and retained low protein in mash diet in comparison to pellets diet. These improvements in pellet-fed birds could be because pelleting diets reduces feed wastage and particle selection during consumption. Furthermore, birds use less energy when eating pelleted diets, thus conserving more energy, some of which could be lost when fed mash diets (Serrano et al., 2012). Pellet processing conditions, including pressing, heating, and addition of moisture, might deactivate anti-nutritive factors (ANF) and improve the palatability of diets, leading to an improvement in nutrient availability, particularly energy, for the birds (Abdollahi et al., 2013). These results support the findings of Greenwood et al. (2004), who reported that pelleting diets proportionally increases dietary energy and hence makes more energy available to birds, thereby achieving maximum utilization and retention. Musigwa et al. (2023) stated the inclusion of lipids in diets for growing animals can improve the utilisation efficiency of energy intake, as heat increment (HIf) is lower in fat-rich diets, because fatty acids are deposited in the body with minimal metabolism. The researchers added that, lipids can provide twice as much energy (approximately 9.4 kcal/ g) as the energy provided by digestible carbohydrates or protein (about 4.1 kcal/g each). Svihus (2001) stated that pellet diets may even decrease nutrient utilization and starch digestibility of broilers under some conditions. The researcher further suggested that mash diets were reported to improve the feed conversion ratio, enhance starch digestibility and improve intestinal glucose uptake of broilers compared to those fed pellet diets

On the other hand ME system values do not fully reflect the energy utilised by birds for production or maintenance (Musigwa et al., 2023). It has been reported that 15%, 22% and 32% of ME from fat, carbohydrate and protein, respectively, are lost as HIf in growing chicks (Carré et al. 2014; Wu et al. 2019). The findings of the current study showed that the dietary treatments energy provision were within the minimum requirements of broilers as reported by Barzegar et al. (2019) who suggested that metabolisable energy for maintenance (Mem) of broilers were reported to be 594 to 618 kJ/BW 0.75 per day. Fasting heat production (FHP) values obtained in broilers were 410 to 460 kJ/BW 0.70per day (Noblet et al., 2015) and 386 to 404 kJ/BW 0.75per day (Liu et al., 2017). Massuquetto et al (2020) reported contrary results to the current study where the researchers reported that pelleted diets resulted in lower digestibility of all evaluated parameters compared with mash. Researchers further indicated that mash diets, CIAD of DM, available starch and total starch improved as dietary ME levels increased, whereas in pelleted diets, there was a linear increase in CIAD of DM.

5.1.3 The **effects of diet dilution using Non-Starch Polysaccharides (NSP)on broiler performance, carcass quality, GIT development, NSP utilization and feed costs**

5.1.3.1 Production performance

Production performance results are in agreement with the findings of Anyanwu et al. (2008) who reported similar trends on final body weights and daily weight gains. Aghabeigi et al. (2013) observed similar trends for feed intake between day eleven and forty-two. On the other Swain et al., (2012) reported that inclusion of NSP at 20% did not influence body weight of broilers but had a significant effect on feed intake and FCR whereby birds fed diets with NSP had higher feed intake and FCR than the control group.

Anjola et al. (2016) used 0, 5, 8, 11 and 14% NSP inclusion in broiler diets and reported that there were no significant differences in feed intake, weight gain and FCR amongst the dietary treatments. The lower production parameters characterized by T2 and T3 in the present study could be a result of high fibre content associated with feeding of NSP which means that for inclusion level of 25% NSP, the diet was equally acceptable to the birds as they ate the same quantity feeds as the control group. Denstadli et al. (2010) observed that the inclusion rate of NSP in diets up to 40% decreased body weight gain and FCR, and this is in agreement with the current study for decreased feed intake in T2 and T3 diets that may be attributed to bulkiness and probably poor acceptability of the feed. The researchers also concluded that birds cannot cope with the increased bulkiness of the diet when the inclusion rate of NSP is more than 40%. It was also observd that growth rate generally decreased progressively with increasing levels of DBG in White Leghorn chicks, and thus, DBG could be incorporated in chick rations up to 18% without an adverse effect on growth performance to increase economic efficiency(Wondifraw and Tamir, 2014).

On the other hand, Adama et al (2007) incorporated four levels of sorghum DBG up to 40% to replace maize and groundnut cake in broiler chicken diets, and reported that the growth rate remained similar up to 20%, and then decreased. Dried brewery grain contains a high concentration of NSP and tannins, which have been shown to interfere with the efficiency of feed utilization in monogastric organisms, thus inhibiting the absorption of essential nutrients and digestive enzymes, and hence decreasing feed utilization (Ashour et al., 2021). Gulilat et al (2021) studied the effects of least cost homemade ration on growth performance of Sasso and Indigenous breeds of chicks and found that the depression in growth performance of the groups fed on the farm formulated rations in which 75 and100% of the commercial starters ration was substituted by homemade ration were attributed to high fiber content and low nutritive value of the homemade ration.

Zhang et al (2023) suggested that supplementation with 1% or 2% lignocellulose or 3% sunflower hulls had no effect on the growth performance of broilers. Adding insoluble fiber, such as oat hulls, wood shavings and soybean hulls, could increase feed efficiency by 3–5% and increase body weight between 2–5% when included at 3–5% in broiler diets (Guzman et al., 2015). Taylor et al.(2021) found that the average daily feed intake (ADFI) and feed conversion ratio (FCR) were linearly increased in the broilers fed the 15%, 30% and 45% oat hulls diets compared to control group. Jelveh et al. (2020) diluted broiler diet with cracked maize and recognized that increasing structural components in the diet, namely through including coarse grain particles, has been shown to improve gut health, feed utilization and production efficiency. This is primarily because structural components physically stimulate the activity in the fore gut (Kheravii et al., 2018).

Jangiaghdam et al.(2022) scrutinized the influence of different dietary fibre source on broiler performance and detected that the dilution of the control diet with processed wheat straw increased FI and BWG from 1 to 10 d of age. Dietary insoluble fiber had no effect on FI and BWG from 11 to 24 days and 25 to 42 days of age, but the F: G ratio tended to be better for the control than for the soyabean hulls diet. Salarinia et al. (2018) reported that broilers fed 60 g/kg Rice Hull had higher BWG, Feed intake and lower feed: gain than the control group. Masoudi and Bajarpour (2020) reported that soybean hulls can be used up to 50 g/kg in broiler diets due to the positive impact on conversion ratio and production efficiency factor. Jha and Mishra (2021) reported that increasing fiber content of diets resulted in reduced metabolizable energy which negatively affects the birds' BWG and feed to gain ratio. Guzmán et al (2015) supported that the 4% inclusion of cereal straw or sugar beet pulp as an insoluble fiber source decreased the BWG of the egg layer pullets from 0 to 17 wk of age.

Ndams (2008) investigated the effects of re-fermented brewery dried grain (RBDG) on broiler production and concluded that supplementation of 30% RBDG broiler starter and finisher diets with lysine, enzyme or the combination of lysine, methionine and enzyme (Allzyme) enhanced metabolism of dry matter, ash, ether extract and crude fibre. It also improved apparent crude protein and apparent gross energy metabolism. Birds on combined amino acids and enzyme supplemented diet exhibited superior performance over those on un-supplemented diet (30% RBDG) during both starter and finisher periods. The conflicting results on the influence of NSP on broiler production could be due to varying sources of DBG and experiment conditions.

5.1.3.2 Carcass quality

The inclusion of NSP in broiler diet results are in line with the work of Pandey et al. (2023) who did a similar study on NSP using dried brewery grain in broiler diets. The researcher established that experimental diet had profound influence on carcass weight, dressing percentage and gizzard weight. The highest carcass and liver weights were observed in 20%NSP inclusion while gizzard weight was observed in 25%NSP. Jelveh et al. (2020) showed that carcass yield and final weight achieved by the addition of whole maize grains may be related to physical and functional benefits of whole grains in terms of larger, stronger and functional gizzard and the better matching of daily requirements through self-selection of the birds. Ashour et al. (2021) noticed that the various DBG levels did not have an effect on carcass and giblet percentages, apart from dressing percentage and abdominal fat relative weights. Boostani et al. (2010) and Shabani et al. (2015) observed differences in abdominal fat yield among broilers fed with restriction or ad libitum. Jalal and Zakaria (2012) and Mirshamsollahi (2013) who determined that feed restriction reduced abdominal fat yield, the activity of lipogenic enzymes are depressed during the feed restriction period, peaking during the first week of re-feeding, and gradually reducing in the subsequent weeks. Dressing and abdominal fat percentages decreased gradually with the increasing DBG level in the diets from 6% to 12% while DBG inclusion level of 20% or more was resulted in a reduction in abdominal fat pads and meat tissue. On the contrary, Abdel Magied et al. (2021) explained that increasing levels of dietary dilution (DD) reflected on increasing dressing percent, the broiler fed 4 and 5 % recorded the higher percent 76.35 and 75.64 %, respectively compared with 2 and 3 % (73.16 and 70.78 %, respectively). Fouad and El-Senousey (2014) stated that in avian species, most fatty acids are synthesized in the liver and transported via low-density lipoproteins or chylomicrons for storage in adipose tissues as triglycerides. The abdominal fat tissue is crucial in poultry because it grows faster compared with other fat tissues (Butterwith, 1989). The abdominal fat pad is a reliable parameter for judging total body fat content because it is linked directly to total body fat content in avian species.

Okpanachi et al (2014) used a mixture of DBG and cassava tubers in broiler diets and observed that the incremental inclusion of DBG up to 45% reduced carcass weight, dressing percentage and gizzard weight. Hassanien (2011), Tesfaye et al. (2011), Jalal and Zakaria (2012) and Melo et al. (2021) confirmed that there were noticeable effects of feed restriction on carcass and noble cuts yields compared to chickens fed on ad libitum basis. According to their findings both forms of feed restriction provided a low breast yield compared to broilers fed ad libitum. Weights and yields of edible organs are similar among broilers with and without feed restriction, regardless of the restriction methodology applied. Broiler quality specifications are high meat yield in the carcass and low abdominal fat (Indumathi et al., 2019). A superior carcass is characterized by a desirable composition: maximum proportion of muscle, minimum proportion of bone and optimum proportion of fat indicated by specific trade preference. Also, superior carcass must contain high proportion of most valuable muscles (i.e. breast and thigh muscles) (Indumathi et al., 2019). The results of this study are in agreement with Hassanien (2011), Tesfaye et al. (2011), Jalal and Zakaria (2012) and Van der Klein et al. (2017). It appears that the organs of the gastrointestinal tract were spared from the effects of food restriction depending on animal age and duration of the restriction period (Ferraris et al., 2001).

Contrary to observed results Swain et al. (2012) using maximum of 20% DBG in broiler diets reported significantly high meat yield and gizzard weight in broilers fed diets containing DBG than in control group. The results of the current study imply that DBG should not be included in broiler diets by more than 25% inclusion rate for optimum carcass yield. Bhuiyan et al. (2021) studied the influence of high diets in broiler on carcass quality and reported that the dietary fibre had significant impact on the abdominal fat whereby the birds with medium (and high) fibre content diet deposited less abdominal fat than birds with low fibre content diet. Furthermore, breast yield was significantly higher on high fibre content diet than other two diets. Breast yield did not have significant differences between birds fed on low fibre content diet and birds fed on medium fibre content diet. The other characteristics were not affected by dietary fibre content.

It is probable that the reduction in breast yield of birds with restricted feed may be due to a decreased amino acid intake. The results suggest that the growth rate of broilers is related to nutrient intake, which supports the statement of O'sullivan et al.(1992), for whom the improvement in the body weight of birds is correlated to feed consumption. Radulovic et al. (2021) suggested that during feed restriction period, individuals mobilize body fat faster to provide the necessary energy supply. It has been shown that early feed restriction results in lower hepatic acetyl-CoA carboxylase activity,a rate-limiting enzyme for fatty acid synthesis. This can limit hepatic triglyceride synthesis, causing lower serum triglyceride concentration, and therefore, it partly contributes to reduce fat accumulation.

In order to manage the abdominal deposition it was indicated that reducing dietary protein level from 23% to 20% crude protein (CP) during the starter phase, and from 20% to 18% CP during the finisher phase, significant increase in the abdominal fat content (Kassim and Suwanpradit, 1996). In a comparison of low-protein and normal-protein diets in broiler chickens, Collin et al. (2003) found that low-protein diets caused a significant increase in the abdominal fat content percentage. Yalçin et al. (2010) also found that feeding broiler chickens diets containing 19.2%, 16.6%, and 15.5% CP (low protein) led to an increase in total carcass fat deposition compared with chickens fed diets containing 22.9%, 19.9%, and 18.2% CP (the standard recommended by NRC [1994]) in the starter, grower, and finisher phases, respectively. Increasing dietary protein level in the diets of broiler chickens to 26.6%, 23.5%, and 20.7% in the starter, grower, and finisher phases led to a reduction in total carcass fat deposition compared with diets formulated according to NRC (1994) (Yalçin et al., 2010).

5.1.3.3 Gastrointestinal Tract Development

Enhanced organ development and functionality can result in increased nutrient digestibility within the GIT. Dietary fibre has been seen to have a positive effect on gizzard development (Svihus et al., 2004). The well-developed gizzard is linked with improvements of the digestive organs' mucosal surface within the GIT, leading to improved nutrient digestibility and absorption. The mechanisms by which DF functions in the gastrointestinal tract depend on the chemical structure, particle size, and amount being used (Tejeda and Kim, 2021). Across poultry species, a rapid and relatively consistent intestinal response to changes in DF resulting in modification of intestinal length, villus height, crypt depth as well as the passage rate and size through different segments of the intestines has been reported(Chiou et al., 1996). The use of diets high in fiber, especially insoluble fiber, may reduce the incidence of cannibalism. Therefore, it may be used as an alternative to beak trimming in some production systems (Hartini et al., 2002). It can also improve poultry digestive organ development, especially gizzard activity, increase bile acids and enzyme secretion, and change intestinal microflora. In addition, fibers in poultry diets may positively affect gut health by preventing the adhesion of specific pathogen bacterial populations to the epithelial mucosa. Jha and Mishra (2021) on the utilization of dietary fibre by broiler chickens stipulated that dietary fiber affects the length and weight of the GIT and they observed that the digestibility of all nutrients also decreased with increasing fiber levels. Adaptation to increased inclusion of DF levels increases the size of the GIT, with pea fiber exerting a more substantial impact than wheat bran or oat bran. The length of the intestine, particularly the length and weight of the cecum, increased with the fiber level.

Zhang et al. (2023) working on the the effects of dietary CF level on the gastrointestinal development of broilers revealed that the relative lengths of the ileum and cecum in the 8% CF group were significantly higher than those in the other groups ($p < 0.05$). There were no significant differences in the other gastrointestinal tract development indexes ($p > 0.05$). Davoodi-Omam et al. (2019) found that feed restricted broiler showed a reduction in the diameter of the jejunum and ileum, and of the relative weight of the ileum, and of the length of the duodenum and ileum in comparison with the adlibitum fed broilers. Duarte et al (2014) also supported that a 30% feed restriction of ad libitum intake from 7 to 14 d of age reduced the weight of the small intestine. Kimiaeitalab et al (2018) observed that all the organs of the GIT were heavier and the small intestine and cecum were longer in broilers than in pullets when feeding with same high fiber containing sunflower hulls (SFH) meal compared to sugar beet pulp (SBM), consistent with the greater GIT capacity and average daily FI of broilers. An increase in the weight of GIT is important to pancreatic enzymes secretion to achieve better growth in birds during the early stage of life. Jangiaghdam et al.(2022) inspected the influence of different dietary fibre source on broiler performance and reported that no effects of fiber inclusion were detected for any of the organs studied but the small intestine length was lower in sunflower hulls and soyabean hulls than in processed wheat straw at 42 days of age. Amerah et al. (2009) reported that the relative length of the small intestines was reduced with the inclusion of cellulose or wood shavings as compared to the control diet. The shorter small intestine may be explained by the lower nutrient density, which decreases the surface area needed for absorption. Nursiam et al (2021) investigated the effects of fiber source on growth performance and gastrointestinal tract in broiler chicken and showed that the addition of fiber did not increase the proventriculus capacity as a temporary storage organ during the digestion process. The researchers further reiterated that adding fiber source in broiler feed increased relative weight of the gizzard. The relative weight of the liver was not affected by the addition of fiber in the feed; this indicated that the addition of fiber did not affect the metabolic processes in the body. Shang et al., (2020) observed that replacing 30 g WB/kg diet enhanced nutrient digestibility by improving antioxidant status, gizzard development, intestinal digestive enzyme activities and morphology of broilers and concluded that moderate amounts of insoluble dietary fiber can improve nutrient utilization by positively influencing the physiology of the gastrointestinal tract.

Zhao et al (1996) stated that feeding excessive amounts of fibrous materials to broiler chickens can lead to distension of the GIT and consequently elevated the maintenance energy requirement of the birds. Therefore, the deteriorated growth performance of fiber fed broilers may be attributed to their FI reduction and increased maintenance requirement (Saadatmand et al., 2021). Moreover improved FCR in finishing period of chicks fed fibrous material was confirmed by the fact that immature GIT of the birds at hatch develop and obtain its maturity from 15 to 21 days of age (Sklan, 2001). Hence, birds might be able to digest more fiber with their age and obtained their BWG with lower FI. Dietary fiber increased the relative length of the small intestine. The longer relative length of the small intestine in the fiber groups might be due to the increased effort of this organ to adapt to improve feed consumption and nutrient uptake (Mourão et al., 2008). Mateos et al. (2012) reported that dietary fiber decreased the intestinal length and weight of the organs of birds. Consequently, these changes might reduce carcass yield.

Zhang et al. (2023) found that the relative length of the ileum and cecum of broilers in the 8% crude fibre group was significantly higher than that in the other groups, and the relative length of cecum in broilers was the largest at the crude fibre level of 8.00%, according to the quadratic regression analysis. It was observed that dietary fiber had the function of promoting gastrointestinal development within a certain range. The 8% crude fibre diet was able to stimulate the development of the gastrointestinal tract in broilers aged 22–42 days and was beneficial to the digestion and absorption of nutrients, which promoted the healthy growth of broilers. Diarra et al. (2023) diluted commercial broiler feed with copra meal (CM), palm kernel meal (PKM) and cassava leaf meal (CLM) and recorded heavier liver, gizzard and intestine on the test diets. The researchers suggested that commercial feed dilution with CM, CLM and PKM at 100 g/kg for starter and 200 g/kg for finisher would be a viable option for smallholder broiler production for economic reasons.

5.1.3.4. NSP digestibility and utilization by broiler chickens

Dietary fiber has been reported to reduce feed intake and nutrient digestibility in poultry, but the extent of reduction depends on the type and content of fiber source (Mtei et al., 2019)). The optimum dietary fiber inclusion level for different type of chickens is not well characterized. The difference in how soluble and insoluble fiber affect intestinal passage rate relies on the site of action of each fiber type. When insoluble fiber is fed as particles bigger than 1.5 mm, it can accumulate in the upper part of the gastrointestinal tract (i.e., gizzard and duodenum loop), where most of the bolus mixes with enzymes and where mechanical grinding takes place in the gizzard (Ferrando et al., 1987). While small (3–5%) additions of insoluble fibers can improve nutrient digestibility, extreme supplementation can interrupt normal digestion metabolism by the formation of coating structures that reduce the accessibility of digestive enzymes to nutrients (Tejeda and Kim, 2021).

Nutrient digestibility estimates can vary depending on assay methodology, bird factors (bird type, strain, age, and gender), and dietary factors (e.g., type and content of fiber and antinutritional factors) (Ravindran et al., 1999; Ravindran et al., 2017). Walugembe et al.(2014) stated that bird type influence the responses in the digestibility of nutrients to dietary fiber.The researchers continued that the inclusion of corn distillers dried grains with solubles and wheat bran (60 to 80 g/kg) improved the nutrient digestibility in layer chicks compared to broiler chicks. These differences might suggest an improved capability of digestive tract in layers, compared to broilers, which efficiently utilize nutrients in the presence of fibrous materials, possibly due to the physical characteristics of the fiber source. The relationship between feeding level and digestibility of nutrients appears to depend on the characteristic of the feed (Liu et al., 2019). Dietary fiber is one of the main components in the diet which affects digestibility because higher dietary fiber is inefficiently degradative and makes digesta rapidly pass through the gastrointestinal tract (Noblet and Perez, 1993).

Zhang et al. (2023) studied the influence of dietary fibre in broiler diets on nutrients digestibility and found that digestibility of CP, EE, CF, ADF and NDF in the 8% CF group was significantly higher than that in the other groups ($P<0.05$), and the digestibility of CP, EE, CF, ADF and NDF in each group was significantly quadratically correlated with the CF level ($P < 0.05$). The optimum CF levels for CP, EE, CF, ADF and NDF digestibility in broilers were 8.61%, 8.66%, 9.13%, 7.50% and 6.29%, respectively. In the current study birds fed on 50%NSP and 75%NSP had the lowest digestibilities of NDF and dry matter while starch and crude protein were better digested. However, excessive dietary fiber would form a coating structure that reduce the accessibility of digestive enzymes to nutrients, thus interrupting the normal digestion (Jha et al., 2019). This was the case in the current study because the dietary treatment were included at the rate between25 and 75%NSP which is deemed higher level than in the study of Zhang et al. (2023). Jimenez-Moreno et al. (2013) and GonzalezAlvarado et al. (2010) who noted an improvement in the AMEn of the diet by the inclusion of 25 and 30 g/kg oat hulls in the diet, respectively. The beneficial effects of dietary fiber on nutrient retention depend on basal diet composition, source, and level of fiber (Mateos et al., 2012). Kalmendal et al. (2011) studied the effects of high fibre on intestinal digestion of broilers and found that broilers fed diets containing 0, 10, 20 and 30 g/kg high-fiber sunflower meal showed reductions in DM digestibility, from 0.77 to 0.70, 0.66 and 0.61, respectively. Increasing the inclusion of oat bran from 187 to 375 g/kg in broiler diets reduced the starch digestibility from 0.97 to 0.94 (Jorgensen et al., 1996).

The lower NSP digestibility observed during growing phase of birds fed the high NSP level, compared to the low NSP level, may be a consequence of young birds possessing microbiota that is not yet adapted to digesting complex NSP molecules. The suggestion is that the microbiota will preferentially ferment soluble NSP over insoluble NSP, and as a result, overwhelming a naïve microbiota with sNSP can compromise its ability, and indeed need, to ferment insoluble NSP (Nguyen et al., 2022). However, exposure to these dietary polymers, or ideally oligosaccharides derived from them, in young birds can prime the microbiota to become more adept at utilising more complex NSP later in life (Sadeghi et al., 2015). Adama et al. (2007) incorporated four levels of sorghum DBG, up to 40%, in broiler chickens, which replaced maize and groundnut cake in the diet, and reported that the digestibility of all nutrients (crude protein, ether extract, nitrogen free extract, and ash) decreased with increasing levels of DBG, but was not generally affected dramatically up to 20% levels of DBG.

Nutrient utilization is a very complex process through sophisticated digestive system. Moreover, there are evidences of negative effect of DF on nutrient utilization when the inclusion level gets excess, i.e. higher than usual low to moderate level. This effect may be attributed to abrasive effect of DF on gut mucosa mainly insoluble fiber leading to several nutrients loss like protein, amino acid, mineral, & vitamin (Röhe etb al., 2020. Furthermore, the adverse impact of DF can be greater in younger birds than their older counterparts which likely to happen due to their immature digestive system, and immunity. Besides, certain non-starch polysaccharides (NSP) can bind bile acid, cholesterol or fat that can eventually lower the apparent metabolizable energy (AME) value of poultry feed and thus, poultry performance can get affected (Sekh and Karki, 2022). Singh et al.(2019) looked at NSP utilization in both low and high fiber diets while supplemented with protease, amylase, xylanase, and three species of Bacillus as probiotics. They found that the treatments increased nutrient utilization regardless of dietary fibre level. Another study by Li et al.(2017) showed that the low-fiber diets underutilized energy and crude protein compared with higher fiber diets. Later, they also reported that low fiber diets impacted the cecal microbiota of birds by decreasing microbiota diversity and relative abundance (Li et al., 2017).

Swain et al (2012) studied the effect of feeding brewers' dried grain on the performance and carcass characteristics of Vanarajachicks on nutrient utilization and digestibility and found that the apparent illeal digestibility values of protein and energy were significantly reduced by NSP inclusion at various levels such as 10 and 40% replacing wheat andsoy. The fat retention decreased significantly in chicks fed dietsincorporated with 10 and 20% NSP in lieu of maize, soya bean meal and deoiled rice bran. In contrast, digestibility of ether extract did not differ among broiler finishers fed maize sorghum based NSP at 15 to 30% level (Esonu et al. 1999). Broilers fed diets containing high-fiber sunflower meal showed reductions in DM digestibility, from 0.77 to 0.61 with increasing sunflower meal inclusions (Kalmendal et al., 2011). Increasing the inclusion of oat bran from 187 to 375 g/kg in broiler diets reduced the starch digestibility from 0.97 to 0.94 (Jorgensen et al., 1996).

Faryadi et al (2023) specified that it is well known that an increase in the availability of fermentable fiber in the hindgut of broiler chicken can result in increased excretion of nitrogen (N) via feces at the expense of the excretion via urine, and that N that is excreted via urine is generally more volatile than N that is excreted via feces. Thus, a relatively higher proportion of N that is excreted via urine can be lost during sample processing (e.g., drying) and analysis (Morris et al., 2019), leading to overstimulation of apparent retention(AR) of N and hence AR of DM and GE for diets with less fermentable fiber content. However, the AR of N for the SBP did not differ from that of the control diet. It thus appears that fiber and other components of SBP that escape digestion in the small intestine are less fermentable in the hindgut of broilers than fiber and other components of corn and soybean meal that escape digestion in the small intestine; or dietary SBP increases excretion of N and other energy-yielding components via urine, leading to reduced AR of GE and CP.

Nutrient digestibility and AMEn were lower in layers fed the low fiber diet, but most of these reductions were restored in the diet with fibrous sources (Mtei et al., 2019). Nutrient digestibility responses to dietary fiber content were greater in layers than in broilers and pullets, which may be a reflection of sensitivity of layers to fiber and better development of upper digestive tract. Overall, these findings indicate that laying hens require higher dietary fiber contents to efficiently digest and utilize the nutrients and energy (Mtei et al., 2019). The interactions observed between the fiber content and bird type also suggest that the data on the dietary inclusion level of fiber sources and nutrient digestibility for one type of bird may not be applicable to other bird types. Moreover, broilers showed higher nutrient digestibility and energy utilization than layers, with pronounced differences in the low fiber diet (Mtei et al., 2019).

5.1.3.5 Feed costs efficiency

These findings are in agreement with the work of Swain et al., (2013) who found that the incremental inclusion of DBG reduced the cost per kg feeds. Fasuyi et al., (2018) added that the cost of feed was reduced as the inclusion levels of DBG in the diets increased. The researcher further indicated the control diet had the highest cost while 30%DBG inclusion had the lowest cost. The broilers that provided the highest profitability were subjected to a quantitative restriction of 10% consumption of ad libitum obetween 14 and 28 days of age (Melo et al., 2021). Ndams (2008) found contrasting results with regard to cost per kg weight gain and cost per kg feed. Gulilat et al. (2021) compared the economic efficiency of using commercial and least cost farm formulated diets and determined that there were significant differences among treatments in the cost of gross income, total return, and net return but no difference in chick's cost, feed cost, and total variable cost. Chicks fed 75 and 100% least-cost diet had significantly lower costs of net income than birds on a control diet. Commercial diet increased costs of feed at both breeds as compared to least-cost diet inclusion levels but had good body weight gain. The observed increase in feed cost per kg weight was ascribed to an increase in ADFI but poor feed conversion efficiency and utilization, and poor growth rate of chicks that consumed diets containing high levels of least-cost diet. Nevertheless, a commercial diet significantly reduced feed cost per kg weight gain (Gulilat et al., 2021). Bhuiyan et al. (2021) evaluated the effect of high fibre diets broiler feed costs and attested that the feed costs on meat gained was higher on high fibre content diet than a low fibre content diet. Karaarslan et al. (2023) studied the effects of qualitative feed restriction (QFR) on diet cost analysis in broiler chickens and revealed that the total cost of feed consumed by broiler chickens in the QFR treatment was lower.

The average cost of broiler feed with a quantitative restriction of 10% of consumption ad libitum was lower than that of other feeding programs. This is justified by a low feed intake(Melo et al., 2021). The similarity in the gross income of broilers subjected to quantitative feed restriction between 14 and 28 days with that of broilers subjected to consumption ad libitum was due to weight gain. It resulted in an at least similar gross margin between feed programs. The broilers that provided the highest profitability were subjected to a quantitative restriction of 10% consumption of ad libitum between 14 and 28 days of age ($P<0.05$). Because of a lower cost of feed, they yielded 5% more than birds subjected to consumption ad libitum. The relative profitability index and the productive efficiency index presented results similar to those of broilers fed with a quantitative restriction of 10% of consumption ad libitum of 14 to 28 days and broilers fed at will. Novel et al. (2009) and Hassanien (2011) reported that the level of food restriction provided an economic advantage over broilers fed ad libitum, mainly by an efficient nutrient use. This denotes the possibility of applying a restriction plan in the intermediate phase of production,reducing costs and avoiding bone and metabolic problems (Melo et al., 2021).

Moss et al. (2021) hypothesised that poultry diets are typically formulated to a linear least-cost basis in order to reduce the cost of inputs. It is implied that formulating diets to least-cost will therefore generate the best profits for the business, but this is not necessarily the case. The formulation of diets to maximise profits over the enterprise via the inclusion of meat yield, bird performance and economic data generates a more profitable outcome in an integrated operation. Wongnaa et al. (2023) studied the adoption of farm formulated diets in Ghana and observed that 77% of the farmers used farmers' prepared feed while 23% used commercial feed. Production capacity is the only factor that proved to be significant for use of each type of feed, viz. farmers' own prepared feed and commercially prepared feed. Its significance for both commercial and farmers' own feed, however, is in opposite direction. That is, it is negatively significant for use of commercial feed (5%) and positively significant for use of farmers' own feed (5%). This means that farmers with large production capacity are more likely to use their own prepared feed vis-à-vis commercial feed. The reason can be that farmers with large production capacity have machines and equipment as well as personnel that help them to easily prepare their own feed, and as their capacities tend to be large, preparing their own feed can help them reduce their unit cost of feed, making them enjoy economies of scale.

5.1.4 Comparison of commercial and on-farm formulated diets on broiler performance, carcass quality and cost benefit

5.1.4.1 Production parameters

The effects of farm formulated diets on broiler production parameters findings are in agreement with the findings of Dieumou et al., (2009) and Amouzmehr et al., (2013) who are observed no significant (P>0.05) effect of own-farm formulated diet on the feed intake of broiler chicks. These results are in accordance with the reports of Amouzmehr et al., (2013) who found no significant (P>0.05) differences in weight gain of chick fed with own-farm formulated diet compared to the control group. Botsoglu, (2004) also reported non-significant effect of own-farm formulated diet on weight gain of broiler chicks.

Reyes et al. (2018) deployed Akasya pods meal in broiler diets in an effort to lower feed cost and noticed that the level of crude fiber in the diet increased as the level of Akasya pod meal (APM) was increased. Body weight and body weight gains after 42 days were greater in broilers fed 0%, 0.5%, and 1% APM wherein broilers fed 0% had the greatest body weight and weight gain. Broilers fed 2.5% and 5.0% APM had lower body weights and weight gains. Broilers fed 5.0% APM had the lowest body weight and weight gain after 42 days. Moreover, feed consumption, feed conversion ratio, and percent liveability of broilers were not affected by feeding different levels of APM.

However, the result are in contrast with the work of Sanusi et al. (2015) and Doma et al. (2001) who found that comparison of birds fed farm formulated diet and commercial diets were differing substantially during the finishing on the following parameters; average daily feed intake (DFI), daily weight gain (DWG), and feed conversion ratio (FCR). According Sanusi et al. (2015) farm formulated diet performed better than the other three commercial feeds brands while it was comparable to one of the best feed manufacturer. Dieumou et al. (2012) found that own-farm formulated diet significantly ($P<0.05$) improved the feed intake of broiler chicks.

The observed reduction of BW gains in broilers fed NSP could be attributed to the decreased feed intake and the inefficient utilization of dietary nutrients caused by either the presence of anti-nutritional factors or high fiber in the diet (Reyes et al., 2018).
Loar et al. (2010) observed that broilers fed high concentration of fibrous ingredients had decreased body weight gain and also attributed the lower gains of broiler to high fiber diets. the diet formulated on apparent metabolizable energy and digestible amino acid level (T2) promoted significantly better FI, body weight, PER, and EER results in 42-d-old broilers. Compared with Arian broilers, Ross birds displayed a significantly higher FI and BW. The formulation of diets based on AMEn or TMEn did not influence EER, PER, or the ratio of ME intake per BWG and BW0.75 (Yaghobfar. 2016). Protein and energy efficiencies were reduced between the starter (21 days) and the finisher (42 days) periods. Energy is not used 100% efficiently for production in poultry because, during metabolism, around 15% of the energy is wasted as heat increment or specific dynamic action (Yaghobfar. 2016).

5.1.4.2 Carcass quality

The comparison of farm formulated and commercial feeds on the carcass parameters results were agreeable with a number of researchers who confirmed that the experimental diets have no noticeable influence. Diarra et al. (2013) witnessed that live weight showed no statistical differences ($P>0.05$) between the on-farm and the commercial diets. These results are also in similar with the findings of Sanusi et al. (2015) who observed no major differences ($P >0.05$) on final live weight in broilers fed self-formulated diet compared to those on commercial diets. The results agree with Hassan et al (2011) who observed no related difference (P>0.05) in the mean live weight for both on-farm formulated feed and commercial feed user groups. Patra et al. (2002) revealed that birds fed the commercial diet had slightly higher carcass yields than the on-farm diet value, though not statistically different. The findings are also consistent with the report of Charurat and Niwat (2011) who observed that the yield of hot carcass was not significantly affected by addition of palm kernel meal (70.14 %) or fermented palm kernel meal (69.11 %) compared to those fed commercial diet (69.95 %). Yagoub and Babiker (2008) confirmed that there were non-big difference (P>0.05) in dressing percentage among different treatments. Ullah et al. (2012) discovered similar results on dressing percentage between birds that consumed commercial and farm formulated feeds. Sanusi et al (2015) added that the feeding of on-farm formulated feed did not significantly influence (P>0.05) dressing percentage when compared to commercial group.

On the other hand the outcomes of the study are in disagreement with the study of Hamdu et al. (2022) who portrait that the dietary treatment had a notable impact on the all carcass parameters such as carcass weight, dressing percentage and live weight where-by on farm formulated diet had better live weight and carcass weight than other commercial feeds. Doma et al. (2001) observed a noticeably (P < 0.01) better final live weight in broilers fed on farm-formulated diet compared to those on commercial diets.

The idea behind the commercial treatment body weights being a little bit above the on farm formulated diet treatment might be due to high feed intake of the commercial diet by broilers. The low feed intake of the on farm-formulated treatment might be a resultant of lack of milling or processing of the on farm diet resulting in poor pecking by broilers. On the other hand, the high fibre content of the on-farm diet which must have resulted in increased digesta retention time in the gastro-intestinal tract may be a reason for the lower feed intake observed in the present experiment in respect to the on-farm group. The lower dressing percentage for on farm group may be due to high fiber contents in the on farm formulated diet which results in more developed digestive organs thereby decreasing dressing percentage. Tjetjoo et al.(2022) observed improvement in the carcass yield which was attributed to the higher content of amino acids in millet compared to maize, especially sulfur amino acids which are essential for optimum muscle accretion. Rao et al. (2003) supported that breast and thigh muscle were significantly influenced by replacing maize with millet in broiler diets.

5.1.4.3 Visceral characteristics

The comparison of commercial and farm formulated diets on broiler visceral characteristics results are aligned with findings of Hooshmand (2006) who observed non-significant (P>0.05) differences on giblet weights (except for liver) due to different feeding programs for broilers. Safa et al. (2012) reported no significant difference in the average weight of both the experimental and control groups on gizzard, liver, heart, small and large intestines. This is also in agreement with the work of Siegel. (1984) when studying factors influencing excessive fat deposition in meat poultry concluded that the increase in the size of the gizzard in the on farm group may not be unconnected with the level of fibre in the diets. Khalil et al. (2023) investigated the effects of replacing maize by proso millet on performance of broiler chickens and indicated that millet-based diets decreased liver sizes significantly, probably because millet has a low incidence of mycotoxins compared to other cereals such as wheat and maize. Meanwhile, (Rao et al., 2004) show that the total replacement of yellow maize by millet did not influence the relative weight of the liver of broiler chickens at day 42 of age.

Omenka and Anyasor (2010) researched on inclusion of vegetable-based ingredients in broiler diets and encountered that there were no statistically significant difference in organ weights (head, gizzard, liver, heart, lungs, small intestine, large intestine, upper limbs and lower limbs) between experimental and control groups. The researchers recommended that the addition of vegetable-based products in poultry feed formula would serve as a cheap source of amino acids, antioxidants, vitamins and bioactive metabolites, that are necessary for the growth and development of broiler birds.

González-alvarado et al. (2007), Amerah et al.(2009), Mateos et al. (2012) and Varastegani and Dahlan (2014) reported that feeding high fiber diets enhanced relative length and weight of intestine, caeca and sizes of various digestive components and increased gizzard volume with increasing structural components in the diet. Zhang et al. (2023) postulated that the development of the gastrointestinal tract could directly reflect the digestion and absorption function of the body. Adding fiber ingredients could dilute the diet and may improve gastrointestinal peristalsis. Chickens fed 3% wheat bran have increased relative gizzard weights and increased small intestine activity, which is correlated with nutrient digestibility (Shang et al., 2020). Bhuiyan et al.(2021) worked on the effects of higher fibre diets on broiler visceral organs and discovered that the fibre level had a significant impact on visceral organs whereby the small intestine was significantly larger ($P < 0.019$) on the high fibre diet than a low fibre diet. However, small intestinal weight was not significantly different between birds with low fibre content diet and medium fibre content diet, and between birds with high fibre content diet and medium fibre content diet (Bhuiyan et al., 2021). Meanwhile, the fibre content had the same impact on liver weight. The liver weight was higher ($P < 0.056$) on the high fibre diet than a low fibre diet, but no difference between high (or low) fibre content diet and medium fibre content diet. The weight of the other visceral organs was not impacted by dietary fibre content (Bhuiyan et al., 2021).

5.1.4.4 Feed costs benefit

Most diets used globally to feed chickens are composed of maize and soybean meal. Maize has been recognized as a source of energy. However, the increasing demand and competition between humans and animals and the diversity of its industrial uses for biofuel production raised the prices of maize especially in the drier regions (Khalil et al., 2023). The effects of farm formulated diets on feed cost benefits in the current study are comparable to the work of Adebayo et al. (2002), Afolayan et al. (2009) and Ayewole et al., (2014) who observed that on-farm formulated diets were cheaper than commercial feed. The results are also consistent with the findings of Apantaku et al. (2006) who compiled cost evaluation between commercial and farm formulated diets and revealed that the self-formulated diet was cheaper than compound feeds and had least cost per kg feed. The findings are similar to report by Adeshinwa et al. (1996) who stated that poultry farmers prefer and use self-formulated feeds instead of commercially compounded feeds, which is perceived to be of higher quality and lower cost. Sanusi et al.(2015) concluded that commercial feeds could be successfully substituted by self-formulated feed at the finisher stage. The researchers continued that using self-formulated feed at finisher stage will be cheaper and may attract more profit to the farmer as compared to the commercial feeds.

Catolico and Ampode (2019) prepared home-made feeds for broiler using locally available feed components like palm kernel meal (PKM) and discovered that the addition of PKM in broiler ration had no significant effect on the growth performance of broiler. However, the inclusion of PKM in the homemade ration gave a higher return of investment in raising broilers. In light of the findings, the researchers recommends the incorporation of PKM in the diet of broilers to obtain higher profit. The relative profitability index and the productive efficiency index presented results similar to those of broilers fed with a quantitative restriction of 10% of consumption ad libitum of 14 to 28 days and broilers fed at will. Novel et al. (2009) and Hassanien (2011) reported that the level of food restriction provided an economic advantage over broilers fed ad libitum, mainly by an efficient nutrient use. This denotes the possibility of applying a restriction plan in the intermediate phase of production, reducing costs and avoiding bone and metabolic problems.

Bhuiyan et al. (2021) compare the use of low and high fibre diets on broiler feed costs and observed that the overall feed cost on birds was significantly higher with high fibre content diet than a low fibre content diet. The medium fibre content would have no significant difference with high fibre content or low fibre content diet. Furthermore, the researchers found that, the total feed cost on meat gain would be higher with high fibre content diet than low fibre content diet, but no significant difference with medium fibre content diet.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 The influence of feed texture on broiler performance carcass quality and gastrointestinal tract development

It was concluded that the use of different feed textures in broiler production had a substantial influence on production, carcass quality and development of gastrointestinal tract. Small particle size diet had pronounced influence on the development of gastrointestinal tract and resulted in the heavier and longer intestines. Broiler diets in mash form also had a significantly lower mortality than all the dietary treatments and hence why it is popular amongst the farmers because of the highest number of broilers processed as carcass at the end of growing phase. Pelleted diets on the other hand had the highest mortality. The medium feed texture (crumbles) had pronounced influence on carcass parameter, which resulted in highest carcass yield and weight than any other feed texture. Large particle size texture (pellets) had the overall influence on production parameters such as FCR, body weight and performance index. Broiler diets in mash form despite its relatively cheaper cost and lowest mortality rate resulted in significant lower production performance, low-grade carcass quality and higher production of inedible parts (viscera). The reduced weight of the visceral components such as gizzard in broilers fed pelleted diets may be an indication that pelleting decreases the grinding requirements of the gizzard thereby reducing its function to merely that of transit, hence its reduced weight.

The improvement in performance of broilers fed pelleted diets was attributed to a greater digestibility of carbohydrates together with increased daily nutrient intake. Pelleting broiler diets hinders the selection of feed particles, causes less feed waste, decreases the segregation and microbial load of feeds, increases the amount of dietary energy available for production as less time is required for the intake of pelleted feeds, and increases the digestibility of dietary fractions, such as starch and protein.

Therefore, the choice of the form of feed to be adopted by the farmers depends on the production objectives and the prevailing economic conditions. For the farmers who want to reach the market weight at six weeks of age with heavier carcass, the use of large particle size such as crumbled diet is highly recommended. For those farmers considering economies of scale through lowest mortality and a relatively economical feed price should consider mash feed form.

6.2 The influence of feed texture on broiler performance, metabolic and skeletal disorders and efficiency of nutrients utilization

The findings of the current study revealed that broiler feed forms had a profound influence on the occurrences of ascites, sudden death syndrome and skeletal disorders whereby feed in the form of mash significantly reduced metabolic disorders in broilers compared to feed in the form of pellets which resulted in significantly high incidences. However, broiler mash diet gave significantly poor growth rates, feed conversion ratio and final live weight. The findings on nutrients utilization confirmed that pelleted diets were better utilized by broiler chicken which resulted in high energy and protein retention for optimum meat production and reduction of digestible energy. It was observed that pelleting diets proportionally increases dietary energy and hence makes more energy available to birds, thereby achieving maximum utilization and retention.

It was detected that pelleted feeds improved growth rate and feed conversion ratio, albeit inducing metabolic disorders in broilers. Pelleted diets resulted in a significant higher mortlity rate in the form of ascites and skeletal disorders that reduced the number of animals to be slaughter at the end of growing phase and thus an economic concern for the farmer. It is recommended that farmers in Lesotho should consider feeding their broilers diet in the form of mash during the period of high susceptibility such as wintertime and those farmers in the highlands of Lesotho. It has been suggested that relationship between susceptibility of ascites and high feed efficiency accompanied by hypothyroidism was responsible for the insufficient supply of oxygen, which resulted in anoxia, hypoxemia and hypoxia. Farmers in the highlands should feed their broilers diet in the form of mash coupled with improved management practices that are known to influence metabolic disorders such as temperature control, oxygen, dust percentage in air, microorganism toxins, nitric oxide metabolism, vitamin E and selenium supplementation.

6.3 The effects of diet dilution using NSP on broiler performance, carcass quality, GIT development, NSP utilization and feed costs

The findings of the study discovered that the use of diet dilution in broiler production is of benefit to farmers. It was witnessed that diet dilution with NSP at 25% gave similar results in production, carcass quality, gastrointestinal tract development, NSP utilization and economic benefits in comparison to the control or undiluted diet. The 25%NSP gave good quality carcass with reduced abdominal fat pad attained with relatively low feed intake than the control group thus, it provided good quality on economical basis. It also provided superior carcass with high proportion of most valuable muscles like breast, wings and thigh. With regard to GIT it was found that the increase in the NSP inclusion led to reduced development of GIT organs. The findings also stipulated that feeding excessive amounts of fibrous materials to broiler chickens can lead to distension of the GIT and consequently elevated the maintenance energy requirement of the birds. As a result the deteriorated growth performance of fiber fed broilers may be attributed to their low feed intake and increased maintenance requirement. With regard to utilization of NSP the study provided a comparative information between layers and broilers on NSP utilization that the dietary inclusion level of fiber sources and nutrient digestibility for one type of bird may not be applicable to other bird types. Moreover, broilers showed higher nutrient digestibility and energy utilization than layers, with pronounced differences in the low fiber diet. The study also proved that the digestibility of all nutrients also decreased with increasing fiber levels. Interms of feed costs reduction the diluted diet cost of 50kg feeds were not statistically different between control and 25%NSP treatment but cost of 25%NSP was lower by 10.00 units of local currency, which is good saving for the farmer.

It is therefore recommended that farmers can dilute their broiler feeds during growing and finishing phases by 25% NSP or any high fibre dietary ingredients in order to ensure good quality carcass with low fat content and reducing costs of feed.

Based on observed results on proximate analysis of NSP, production and carcass parameters as well as cost benefit analysis, it is obvious that the use of NSP in broiler diets at rate of 25% during growing and finishing phases can give similar production performance to broiler fed diets containing convention feedstuffs such as soyabean, sunflower, fish meal and maize which are the main factors that push the price of feeds to its limit. The proximate analysis results also proved beyond doubt that NSP can be used in broiler diets to substitute some conventional proteins sources used in broiler diets.

6.4 Comparison of commercial and on-farm formulated diets on broiler performance, carcass quality and cost benefit

It was erudite that there were no significant differences between commercial and farm formulated feeds on production, carcass traits, gastrointestinal tract development and cost benefits. However, commercial feeds had higher mean values than control in production and carcass parameters while farm formulated diet performed better in gastrointestinal development and feed costs. The implications of these findings suggest that on-farm formulated diet could be used to obtain comparable production and carcass quality similar to commercial diet at an economical level. It is therefore recommended that farm should consider mixing their own feeds under the guidance of animal nutritionist in order reduce high feeds costs.

CHAPTER SEVEN

7.0 BIBLIOGRAPHY

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