

Effect of Processed Cowpeas-Based Diets (*Vigna Unguiculata*) on Feed Intake and Growth Performance, Protein Digestibility and Ammonia Emission in Broiler Chickens

Edmore Bumhira^{1*}, James Madzimure², Irvine D T Mpofu¹

¹Chinhoyi University of Technology, P. Bag 7724 Chinhoyi, Zimbabwe

²Africa University, 1 Fairview Road Old Mutare, Zimbabwe

***Corresponding Author:** Edmore Bumhira, Chinhoyi University of Technology, P. Bag 7724 Chinhoyi, Zimbabwe.

Abstract

This research sought to assess the effect of diets made from processed cowpeas on feed consumption and growth performance, protein digestibility, and ammonia emission in broiler chickens. Dehulling, roasting, boiling, dehulling-roasting and dehulling-boiling techniques were used to process the cowpea grains. Broiler diets were formulated using soybean, white maize and cowpea meal as ingredients for broiler starter and finisher diets. Cowpea meal was added to the broiler starter and finisher diets at inclusion levels of 10% and 15%, respectively. The diets plans were designed to be iso-proteinous and iso-energetic. Two hundred and ten (210) 1-day-old Cobb 500 broiler chicks were randomly assigned into seven dietary groups using a perfectly randomized design. Each dietary treatment was replicated three times with ten birds per replicate. The dietary treatments included maize-soybean meal (MS), maize-soybean-dehulled-boiled cowpea meal (MSDBC), maize-soybean-dehulled-roasted cowpea meal (MSDRC), maize-soybean-dehulled-cowpea meal (MSDC), maize-soybean-boiled cowpea meal (MSBC), maize-soybean-roasted cowpea meal (MSRC) and maize-soybean-raw cowpea meal (MSUC). Weekly measurements were taken for average feed intake, weight gain, and ammonia emissions. The feed conversion ratio was determined on a weekly basis. At the conclusion of the experiment, the economic efficiency of each dietary treatment was assessed. Processing improved the nutrient composition of cowpeas. Processing increased crude protein but crude fibre and crude fat were reduced compared to the untreated cowpeas ($P < 0.05$). Feed intake decreased in the MSBC treatment diet, although feed intake from the other treatments was similar to the control diet. There was no difference across all the dietary treatments on body weight gain and feed conversion ratio. The economic efficiency for broilers fed processed cowpea-based diets was higher and ranged from 0.80 to 0.86% and the economic efficiency of broilers fed the control diet was 0.76%. The broilers fed the raw cowpea-based diet had the lowest profit margins (US\$0.70 per US\$1.00 invested). Processed cowpeas-based diets had no ($P > 0.05$) effect on the digestibility of proteins. The digestibility coefficients of proteins in diets containing processed cowpeas ranged from 54.1 to 65.2% compared to 51.0% of the diet containing raw cowpeas. Processed cowpeas-based diets caused no effect on the amount of ammonia emitted from broiler excreta across all the dietary treatments. Therefore, adding processed cowpeas at inclusion rates of 10% for broiler starter diets and 15% for finisher diets has no effect on feed consumption and growth performance. This practice can enhance protein digestibility, reduce environmental pollution, and support climate-smart agriculture by lowering ammonia emissions from poultry facilities.

Keywords: Alternative protein, Cowpeas, Anti-nutrients, Growth performance indices, Nutrient digestion, Nitrogen excretion, Chickens.

1. INTRODUCTION

1.1. Background

Cowpeas are a very important, carbohydrate, dietary fiber and protein-rich crop commonly grown in Africa (Wakibia, 2015). Both human food and animal feed can be made from it. Antinutrients, such as phytates, protease inhibitors, lectins and tannins, however, limit its use in livestock feed manufacture, particularly for broiler feed (Abbas and Ahmad, 2018). The

problem is further compounded by technical limitations including the lack of research and the need for processing technologies aimed at improving their utilisation as a broiler feed ingredient (Omenna *et al.*, 2016). According to Koivunen *et al.* (2016), the majority of the protein in broiler feeds now comes from soybean meal, with minor percentages coming from animal sources such as blood meal, meal derived from flesh and bones, and meal derived from fish. The popularity and use of the latter has been

reduced and, in some countries, abolished in livestock feed formulations due to their association with zoonotic diseases e.g salmonellosis. In developing and underdeveloped countries, their use is limited by high cost and unavailability (Omenna *et al.*, 2016).

Direct competition between humans and livestock for soybeans (Katumo, 2018) has driven increased demand for the commodity, leading to increased prices on the market. Due to low productivity brought on by recurrent droughts, inadequate irrigation systems, costly supplies, a lack of funding, price controls, unfavourable contract systems, unbankable land tenure, and low technical farmer skill, there is a scarcity of soybeans in Zimbabwe (Nyoni, 2021). As a major ingredient in feed making, high prices of soybean meal (US\$780 per ton) mean high feed costs, which reduce the viability of poultry production. The high cost of soybeans makes it important to look for alternatives as well as practical ways to combine other protein sources for making chicken feed (Gadzirayi *et al.*, 2021). In Zimbabwe, cowpeas are a versatile and locally accessible source of plant protein. Cowpeas have greater drought tolerance compared to the conventional soybeans. Cowpeas are an underutilized legume and are not utilized in commercial poultry feed formulation, yet they have good nutritional profiles for potential combination with conventional protein sources for poultry feeds (Katumo, 2018).

Besides its beneficial effects in terms of drought tolerance and good nutritional profile, cowpeas contain some anti-nutritional factors (Abbas and Ahmad, 2018) that are known to have the substantial effect of reducing the digestion of proteins in the gut of monogastric animals. Tannins precipitate with proteins to form insoluble complexes which make proteins indigestible to enzymes (Omenna *et al.*, 2016). Phytates precipitate with minerals and make them indigestible and not absorbable in small intestines (Koivunen, 2016). Katumo (2018) reported that Protease inhibitors inactivate chymotrypsin, trypsin, and α -amylase and render them unable to digest proteins.

The undigested protein is excreted from the avian digestive tract as uric acid in urine and protein in faeces (Ritz *et al.*, 2004). Because of its volatility, uric acid can be readily hydrolyzed, mineralized, and volatilized to produce ammonia (Ritz *et al.*, 2004; Gerber *et al.*, 2010; Ershadi, 2020). Ammonia is produced when bacteria,

specifically *Bacillus pastures*, break down undigested protein and uric acid in poultry litter (Such *et al.*, 2021). According to published data, ammonia concentrations above 25 ppm reduce broiler feed intake, feed efficiency, and immunity to disease as well as cause conjunctivitis in the eyes (Ali, 2021). According to Ali (2021), ammonia contaminates the land, water, and air. When ammonia is released into the atmosphere, it combines with acidic substances like nitric acid and sulfuric acid to create ammonium nitrate and sulphate, which can be left behind on soil, vegetation, and water surfaces (Gerber *et al.*, 2010). These acidic deposits can cause eutrophication in open water bodies and abundant vegetation growth leading to the replacement of slow-growing species with fast – growing species thereby affecting both aquatic and terrestrial ecosystems (Ritz *et al.*, 2004).

It is well established that when poultry are fed on raw legume grain, several nutritional disorders ensue. Therefore, to lessen the anti-nutritional elements in legume grains, a variety of processing techniques have been employed, including roasting, dehulling, soaking, and boiling (Nalle, 2010; Koivunen, 2016). Dehulling removes tannins and structural fibers that are located in the seed hulls but do not alter the composition of protease inhibitors, lectins, and phytates which are located in the seed cotyledon (Cho *et al.*, 2019). Boiling can reduce or completely eradicate all anti-nutrients in legume grains but inadvertently reduce nutrient concentrations through leaching (Chisowa, 2022). Roasting removes anti-nutritional factors in the grains but over-heating and underheating can negatively affect the chemical composition of grain legumes (Bumhira and Madzimure, 2022). Under-heating fails to remove anti-nutrients and overheating can cause soluble sugars to react with an amino – group to form insoluble nutrient complexes (Maillard reactions) that are not digestible.

There hasn't been much research done on the effects of feeding raw and processed cowpea grain on nutritional digestibility and broiler performance (Usubharatana and Phunggrassani, 2016), and the findings of the few studies that have been done have been inconsistent. Furthermore, not much is known regarding the impact of feeding cowpea meal to broiler diets on the atmospheric ammonia output. Therefore, more research is needed to understand how partially substituting cowpea meal for soybean

meal in broiler diets affects feed intake, nutritional digestibility, and ammonia emission.

1.2. Problem Statement

There is a shortage of soybeans to use in the manufacture of livestock feed in Zimbabwe. Chigumira *et al.* (2017) reported that the area planted under soybeans in Zimbabwe declined from 61000ha in the year 2001 to 42000ha in the year 2016 and as a result, the national soybean yield declined from 140763 metric tonnes (MT) to 47755 MT in the year 2001 and year 2016, respectively. During the 2021–2022 growing season, Zimbabwe harvested 71300 MT of soybeans, significantly less than the country's needs of 240000 MT for industrial oil pressing and production of animal feed (Nyoni, 2021; Gatsi, 2024). Prices for both soybeans and chicken feed have increased as a result of the local soybean shortage.

Cowpeas have a lot of potential to replace soybean meal in broiler diets. According to Chiduku (2022), cowpeas are grown on roughly 14.5 million hectares worldwide and 13 million hectares in Africa, respectively. A yearly harvest of 6 million tonnes of cowpeas is made worldwide. Africa produces 83.4% of the world's total output (Kebede *et al.*, 2020). According to Chiduku (2022), despite Zimbabwe's favorable climate and suitable soils for cowpea production, not much is known about the country's trends in cowpea production. To ensure that farmers can harvest enough grains for their own use and the feed of their livestock, several awareness programs are needed to educate farmers about the advantages of producing drought-tolerant crops, such as cowpeas. However, cowpea usage is limited by the presence of anti-nutritional factors (ANF), primarily lectins, phytates, tannins, and enzyme inhibitors (Manole *et al.*, 2024). These products are anti-physiological, anti-metabolic, and unpalatable to monogastric animals (Abbas and Ahmad, 2018). In addition to increasing the quantity of ammonia released into the atmosphere from broiler houses and having a detrimental impact on the productivity, meat quality, and carcass characteristics of broiler chickens, the ANF also reduces the nutritional quality, digestibility, absorption, and utilization of nutrients from diets based on cowpeas.

1.3. Justification of the Study

Zimbabwean smallholder farmers who produce two-thirds of broiler meat (Zimbabwe Poultry

Association, 2021) might benefit from this research because they will be able to tap on the underutilized cowpea grain which is locally available and cheap to make broiler feed. Cowpea grain costs US\$390 per MT and soybean costs US\$620 per MT (Gatsi, 2024; Shambare, 2024)

This might improve nutrition at the household level and the nation at large since most people will be able to consume meat protein from cheaply produced broiler meat. Farmers might be able to use cheap and effective processing methods to remove anti-nutrients from cowpeas to formulate their broiler feed. The use of processed cowpea grains in broiler diets might directly empower women and improve their economic status since 60% of poultry producers in Zimbabwe are women (Mupanedemo, 2021). Utilization of cowpea grains in poultry diet formulation might also provide small-scale farmers with a good market for this dry land crop.

Considerable research has not been carried out to quantify ammonia concentrations emitted from livestock facilities including poultry facilities in Sub-Saharan African countries (Omotoso *et al.*, 2024). Determining the amount of ammonia emitted from excreta of broilers fed with processed cowpea-based diets may help poultry farmers to know whether cowpeas will contaminate or not contaminate the environment with excessive ammonia emissions and enable Zimbabwe to come up with national regulations that stipulate the permissible amount of ammonia to be emitted from poultry facilities.

1.4. Objectives of the Study

1.4.1. General objective

The general objective of this study was to increase knowledge on the effectiveness of processed cowpeas as a soybean supplement in broiler diets. The main goal was to improve domestic self-sufficiency in supplementary protein in poultry diets and lowering imports of soybeans.

1.4.2. Specific objectives

The specific objectives of this study were to:

- Determine the effects of processed cowpea grain on feed intake and broiler chicken growth performance.
- Determine the effect of cowpea grain processing techniques on the broiler chicken's nutrient digestibility and ammonia emissions.

1.5. Alternate Hypotheses

The following hypotheses were tested:

- Processing cowpea grains improves feed intake and growth performance of broilers.
- Processing cowpea grains improves digestibility of nutrients in poultry cowpea-based diets and reduces ammonia emissions from the excreta.

2. MATERIALS AND METHODS

The experimental procedures were approved by the National Animal Research Ethics Committee (NAREC) SI 246 of 2021.

2.1. Study Site

This experiment was conducted at the Kadoma premises of the Cold Storage Company, which is situated in the Kadoma District of Mashonaland West Province at 18° 20' 24" S 29° 54' 00" E. It receives 739 mm of rain on average per year, with minimum and highest temperatures of 14°C and 28°C, respectively. The study site is 1183 meters above sea level. The Agri-analysis (Aglabs) laboratory in Harare performed the digestibility tests and chemical analysis of the excreta samples obtained from the seven dietary treatments.

2.1.1. Cowpeas Grain and Preparation

The cowpea grains (CBC5 variety) utilized in this experiment were bought in a Kadoma neighbourhood market. To get rid of bad grains, the cowpea grains were sorted. While some of the

sorted cowpea grains were left untreated, others were roasted in a metal box roaster for 15 minutes at 120°C. Cowpea grains were mixed with an equal amount of sand and then roasted. The sand was used to evenly distribute the heat and ensure even roasting of cowpea grains. The roasted cowpea grains were, afterwards, separated from the cowpeas-sand mixture using a 2mm sieve. Another sample was dehulled and boiled at 120°C for 15 minutes. The last sample consisted of dehulled cowpea grains which were boiled at 120°C for 15 minutes. The cowpeas in the six groups were ground so they could fit through a 1.5 mm sieve.

2.1.2. Chemical analyses of samples from differently processed cowpea grain

Representative 500g samples of the above-mentioned differently processed cowpea grain were extracted using official standard techniques recommended by Afolabi *et al.* (2021) and sent to the laboratory of Agri-analysis Centre Pvt Ltd (Aglabs) in Harare to ascertain their chemical compositions and gross energy.

2.1.2.1. Moisture Content

The AOAC method proposed by Vakili *et al.* (2023) was employed to ascertain the moisture content. The moisture content was determined using the five-gram samples. Feed samples weighing five-gram each were oven-dried at 105°C and cooled for seventy-two hours with desiccators. The amount of moisture in each sample was determined using the formula below:

$$\text{Moisture (\%)} = \frac{(W_1 - W_2)100}{W_1}$$

Where;

W_1 = weight (g) of wet sample

W_2 = weight (g) of dry sample

2.1.2.2. Content of Proteins

The AOAC (2023) recommended feed analytical methodologies were used to calculate the protein content. Ten milliliters of pure H₂SO₄ and one Kjeldahl catalyst tablet were added to the micro-Kjeldahl flask along with five-gram samples. The digestion process was carried out for a duration of four hours.

The resultant digest was then transferred and contained within a 100- milliliter volumetric

flask. For the Kjeldahl analysis, a 5 milliliter aliquot of the digest was pipetted into the Kjeldahl apparatus. Then, 5 milliliters of a 40% (w/v) sodium hydroxide (NaOH) solution was added to the sample. The mixture was then steam distilled, and the resulting ammonia collected into a 50 milliliter conical flask containing 10 milliliters of boric acid and a methyl red-methylene blue indicator mixture. The green-colored solution was subsequently titrated using a 0.01 N hydrochloric acid (HCl) solution.

The %N is equal to (Titre × nitrogen atomic mass × HCl utilized normalcy × 4) to calculate the protein, the percentage of nitrogen was multiplied by a constant 6.25.

2.1.2.3. Ether Extract

According to the AOAC feed analytical methodology described by Vakili *et al.* (2015), the fat content was determined using the Soxhlet extraction system. For this analysis, five-gram samples were placed into a fat-free extraction thimble, which was then gently packed with

cotton wool. The pre-dried, cooled, and weighed 250 ml Soxhlet flask and the reflux condenser were then connected to the thimble, which was placed inside the Soxhlet extractor. Petroleum ether was added to the soxhlet flask until it reached a quarter of its capacity, and the extractor and condenser were ready to be mounted on the heater. The heater was left running with the water running from the tap for six hours in order to promote ether vapor condensation. The percentage fat content was computed using the formula below:

$$\text{Fat (\%)} = \frac{(W_1 - W_0)100}{\text{Weight of sample}}$$

Where; W_1 is the weight of fat plus empty flask

W_0 is the weight of empty flask

2.1.2.4. Percentage Ash content

The ash content was containing a 5 g feed sample to 550°C for eight determined using the standard Association of Official Analytical Chemists Method (2023). Five-gram samples were

weighed and put into a ceramic crucible with a known weight. A muffle furnace was used to heat the crucible hours. It was cold, in a desiccator. The following formula was used to calculate ash content:

$$\text{Ash (\%)} = \frac{(P_2 - P_1)100}{P_0}$$

Where,

P_0 is the sample weight before drying, P_1 is the empty weight of the porcelain, and P_2 is the combined weight of the sample and porcelain after drying for eight hours at 550°C in the furnace.

(5g) cowpeas sample without lipid (W) was placed into a conical flask which contained 200 cm³ of 0.3188M H₂SO₄ for 30 minutes and was then washed until all the acid was removed. The remaining product was then mixed with 0.32M NaOH solution and washed again to remove the base. The residue was subjected to elevated oven temperature of 105°C and weighed (X). The dried material was incinerated at a temperature of 550°C for 2 hours and the residue was allowed to cool and then weighed (Z).

2.1.2.5. Unprocessed Fiber

The samples of differently treated cowpea grains were analysed for crude fibre using the method described by Igwemmar *et al.* (2022). Five grams

$$\text{Crude fibre} = \frac{(X - Z) 100}{W}$$

Where W = weight of the sample (g), X = weight of dry residue (g), Z= weight ash sample (g).

2.1.2.6. Chemical Analyses of Broiler Excreta Samples

The freeze-dried excreta samples weighing 100g each collected from the 7 dietary treatments were sent to the Agri-analysis (Aglabs) laboratory in Harare for chemical analysis. The faecal samples were ground so they could pass through a 1.5 mm filter after being dried in an oven at 90°C.

calculate the moisture content, crude protein, ether extracts, crude fiber, and ash in poultry excreta samples.

The AOAC (2006) techniques of analysis, as stated by Vakili *et al.* (2015) were used to

2.2. Treatment Diets

Broiler diets were produced using IDT Feed Formulation Software to be iso-caloric and iso-nitrogenous. In order to test the effects of protein source and processing techniques rather than protein level, the dietary treatments were designed to include the same amounts of energy

and protein. Changing the components will introduce an additional variable into the experiment and alter the diets' quantities of protein and energy.

The feeds for broilers were designed to fulfil their nutritional needs in accordance with Cobb500 (2022). The broiler starter and finisher diets were divided into seven distinct dietary treatments, as shown in Tables 1 and 2, respectively.

2.3. Experimental Design

Two hundred and ten one-day-old unsexed Cobb 500 broiler chicks were randomly allocated into seven dietary treatments using a completely randomised design (CRD). Each dietary treatment was replicated three times with 30 broilers per treatment and 10 birds per replicate.

2.4. Animal Management and Data Collection

Irvine's Day Old Chicks (Pvt) Ltd supplied two hundred and ten (210) one-day-old, unsexed Cobb 500 broiler chicks. The chicks were housed in an open-sided deep litter housing. After being cleaned and disinfected, the broiler house was allowed to rest for two weeks. The floor was covered with 10mm of fresh litter. The birds were raised for two weeks in accordance with Cobb's

(2017) recommendations for the best practices for raising chicks. Weekly weight increase and feed intake records were measured. Mortality was recorded as it occurred. Following the recommendations of Tshovhote *et al.* (2003), all birds from the seven treatment groups were fasted for twenty-four hours at the age of twenty-one. The broilers survived on 50g glucose solution during this fasting period. After fasting, twenty one birds from each dietary treatment were fed with ad libitum feed for a period of 24 hrs. However, to make some corrections for endogenous protein losses, 9 birds from each dietary treatment were fasted for another 24 hrs but were given 50g glucose solution. Following a 24-hour period, 100g excreta samples were obtained from every dietary group, freeze-dried at -20°C, and refrigerated.

Ammonia emitted by faecal matter from the seven dietary treatments was measured using a digital Ammonia Test Meter (NH3 Gas Detector, Model FD-90A, range 0 – 100 ppm, designed in CA, USA and made in China) every week until the broilers reached 6 weeks of age. Ammonia was measured in parts per million (ppm) units at birds' height level.

Table 1. Cowpea-Based Starter Diets for Broilers

Ingredient	Treatment						
	MS (%)	MSUC (%)	MSBC (%)	MSDC (%)	MSDBC (%)	MSDRC (%)	MSRC (%)
Maize	62	57	57	58	58	58	57
SBM	35	30	30	29	29	29	30
CWP	0	10	10	10	10	10	10
Vit-min mix	3	3	3	3	3	3	3
Total	100						
CP %	21	21	21	21	21	21	21
ME (MJ/Kg)	12.23	12.16	12.16	12.23	12.22	12.22	12.18

MS = Maize-Soybean, MSUC = Maize-Soybean Untreated Cowpeas, MSBC = Maize-Soybean-Boiled Cowpeas, MSDC = Maize-Soybean-Dehulled Cowpeas, MSDBC = Maize-Soybean-Dehulled Boiled Cowpeas, MSDRC = Maize-Soybean-Dehulled Roasted Cowpeas, MSRC = Maize-Soybean-Roasted Cowpeas.

Table 2. Cowpea-Based Finisher Diets for Broilers

Ingredient	Treatment						
	MS (%)	MSUC (%)	MSBC (%)	MSDC (%)	MSDBC (%)	MSDRC (%)	MSRC (%)
Maize	67	60	61	61	61	61	60
SBM	30	22	22	21	21	21	22
CWP	0	15	15	15	15	15	15
Vit-min mix	3	3	3	3	3	3	3
Total	100						
CP %	19	19	19	19	19	19	19
ME (MJ/Kg)	12.32	12.32	12.32	12.39	12.38	12.38	12.33

MS = Maize-Soybean, MSUC = Maize-Soybean Untreated Cowpeas, MSBC = Maize-Soybean-Boiled Cowpeas, MSDC = Maize-Soybean-Dehulled Cowpeas, MSDBC = Maize-Soybean-Dehulled Boiled Cowpeas, MSDRC = Maize-Soybean-Dehulled Roasted Cowpeas, MSRC = Maize-Soybean-Roasted Cowpeas. ME (MJ/Kg) = Metabolisable energy in Megajoules per Kilogram.

Measurement of Production traits (Average weight gain and FCR)

At six weeks, nine birds were randomly selected from each treatment group and weighed to determine the live weight per bird, average weight gain, and FCR;

$$\begin{aligned} \text{Voluntary feed intake (VFI)} &= \text{Feed offered} - \text{feed refused} \\ \text{Weekly weight gain (WWG)} &= \text{Weight}_{\text{week (n)}} - \text{weight}_{\text{week (n-1)}} \\ \text{Week 6 weight gain (WWG)} &= \text{Weight}_{\text{week (6)}} - \text{weight}_{\text{week (1)}} \\ \text{Feed Conversion Ratio (FCR)} &= \frac{\text{Voluntary feed intake (g)}}{\text{Average weight gain (g)}} \end{aligned}$$

The following approach was used to calculate **Economic Efficiency** in accordance with Abou El-Fadel *et al.* (2019) guideline;

Economic Efficiency = Net revenue per bird divided by total feed cost per bird

$$\% \text{True Protein Digestibility (\%TPD)} = \frac{(\text{FC} \times \text{DP}) - (\text{EC} \times \text{ECP}) - (\text{EL} \times \text{ELP})}{\text{FC} \times \text{DP}}$$

Where **FC** represents total feed consumed, **DP** represents crude protein of diet, **EC** represents excreta, **ECP** represents crude protein of excreta, **EL** represents endogenous losses, and **ELP** represents crude protein in endogenous losses.

2.5 Statistical analyses

For the data analysis, the researchers utilized the General Linear Model Procedure (PROC GLM)

$$Y_{ijkl} = \mu + R_i + T_j + \text{Rep}_i \times T_j + W_k + e_{ijkl}$$

Where:

- Y_{ijkl} = response variable (AWFI, AWWG, AWFCR)
- μ = the overall mean
- R_i = effect of the i^{th} replicate
- T_j = the effect of the j^{th} treatment
- $\text{Rep}_i \times T_j$ = Effect of replication by treatment interaction
- W_k = the effect of the k^{th} week (K = I, 2, 3, 4, 5, 6)
- e_{ijkl} = the experimental random error
- $Y_{ijk} = \mu + R_i + T_j + \text{Rep}_i \times T_j + e_{ijk}$

Where;

- Y_{ijk} = response variable (TPD)
- μ = mean common to all observations
- R_i = effect of the i^{th} replicate
- T_j = the effect of j^{th} treatment (j = MS, MSDBC, MSDRC, MSDC, MSBC, MSRC, MSUC)
- $\text{Rep}_i \times T_j$ = Effect of replication by treatment interaction
- e_{ijk} = the random error term.

The week effect was not included since TPD was only done when the birds were 21-days-old, meaning that it was not conducted on a weekly basis.

$$Y_{ijkl} = \mu + R_i + T_j + \text{Rep}_i \times T_j + W_k + e_{ijkl}$$

Calculation of True Protein Digestibility

The following formula described by Borin *et al.* (2002) was used to calculate protein digestibility coefficients of the 7 dietary group:

in the Statistical Analysis System (SAS) ver. 9.3 (SAS Institute Inc., 2010).

Significant differences between the means were determined using the adjusted Tukey's method for mean comparisons, with differences considered significant at the $P < 0.05$ level.

The following models were used in the study:

Where;

Y_{ijkl} = response variable (Ammonia emission)

R_i = effect of the i^{th} replicate

T_j = effect of the j^{th} treatment (j = MS, MSDBC, MSDRC, MSDC, MSBC, MSRC, MSUC)

$Rep_i \times T_j$ = Effect of replication by treatment interaction

e_{ijkl} = the random error term

3. RESULTS

3.1. Chemical Composition of Cowpea Grains

The proximate composition results of differently processed cowpea grains (unanalysed) are shown in Table 3 below. Removal of seed coats (dehulling) from cowpea grains increased both the crude protein content and metabolisable energy but reduced the crude fibre content of cowpea grains. Dehulled-boiled cowpeas had the highest CP content of 30.2% and raw cowpeas had the lowest CP content of 28.1%. Dehulled cowpeas had the highest metabolisable energy (ME) of 11.79MJ/Kg and raw cowpeas had the lowest ME of 11.50MJ/Kg.

3.2. Average Feed Intake

The average weekly feed consumption (AWFI) results per bird across all the seven dietary treatments are presented in Table 4 below. The broilers that were fed with Maize-Soybean-Boiled Cowpea (MSBC) meal consumed the least ($P < 0.05$) amount of feed (643.3g) but the feed consumed by broilers from the remaining dietary treatments did not differ ($P > 0.05$). Replication had no effect on average weekly feed intake ($P = 0.06$). Only week had a significant effect on AWFI ($P < 0.05$). Replication \times Treatment had no effect on average feed intake.

Table 3. Chemical Composition of Differently Processed Cowpea Grains

Parameter	Dry Matter (%)	Crude Protein (%)	Fat (%)	Crude Fibre (%)	Ash (%)	ME (MJ/kg)
UC	89.3	28.1	2.15	8.44	5.7	11.50
BC	90.8	28.2	0.46	6.12	5.6	11.51
DC	93.6	29.8	1.55	3.62	5.4	11.79
DBC	84.5	30.2	1.62	4.07	4.8	11.74
DRC	96.6	29.9	1.71	4.19	5.8	11.73
RC	93.6	28.2	1.72	5.21	5.7	11.61

UC = Untreated Cowpeas, BC = Boiled Cowpeas, DC = Dehulled Cowpeas, DBC = Dehulled Boiled Cowpeas, DRC = Dehulled Roasted Cowpeas, RC = Roasted Cowpeas.

Table 4. Average Weekly Feed Intake, Weight Gain and Feed Conversion Ratio of Broilers Fed on Processed Cowpea-Based Diets

Treatment	AWFI (g / Bird)	AWWG (g /bird)	AWFCR
MSUC	699.2 \pm 20.85 ^a	353.4 \pm 34.98 ^a	1.8 \pm 0.15 ^a
MS	691.8 \pm 20.43 ^a	375.6 \pm 34.98 ^a	1.7 \pm 0.15 ^a
MSDBC	675.3 \pm 20.43 ^a	343.1 \pm 34.98 ^a	1.8 \pm 0.15 ^a
MSDRC	672.5 \pm 20.43 ^a	364.2 \pm 34.98 ^a	1.8 \pm 0.15 ^a
MSRC	668.9 \pm 20.43 ^a	363.1 \pm 34.98 ^a	1.7 \pm 0.15 ^a
MSDC	663.3 \pm 20.43 ^a	373.6 \pm 34.61 ^a	1.7 \pm 0.15 ^a
MSBC	643.0 \pm 20.43 ^b	356.9 \pm 34.98 ^a	1.8 \pm 0.15 ^a

MS = Maize-Soybean, MSUC = Maize-Soybean Untreated Cowpeas, MSBC = Maize-Soybean-Boiled Cowpeas, MSDC = Maize-Soybean-Dehulled Cowpeas, MSDBC = Maize-Soybean-Dehulled Boiled Cowpeas, MSDRC = Maize-Soybean-Dehulled Roasted Cowpeas, MSRC = Maize-Soybean-Roasted Cowpeas. ^{a-b}Means with different superscripts in the same column are significantly different ($P < 0.05$)

3.3. Average Weight Gain (G/Bird) Per Week

The average weekly weight gains (AWWG) for all the seven experimental groups are shown in

Table 4. The dietary groups did not show any difference ($P = 0.66$) in terms of weight gain. Replication had no significant effect on AWWG

(P=012). Only week significantly influenced AWWG (P<0.0001). Replication × Treatment had no effect on average weight gain per week.

3.4. Average Feed Conversion Ratio (Fer)

The Average feed conversion ratios (AFCRs) of broilers fed diets containing differently processed cowpeas are presented in Table 3.4. Feed conversion ratio was not affected (P=0.36) by dietary treatments. The FCR ranged from 1.70 in birds fed the Maize-Soybean diet to 1.80 in broilers fed the Maize-Soybean-Boiled Cowpeas diet. Replication had no significant effect on AWFCR (P=0.15). Only week significantly influenced AWFCR (P<0.0001). Replication × Treatment had no effect on FCR.

3.5. Dietary Intervention’s Impact on Economic Efficiency

The economic efficiency values of feeding broilers with diets containing differently processed cowpeas are shown in Table 5. Feeding broilers with diets containing untreated cowpea meal decreased the economic efficiency (US\$0.70 per every US\$1.00 invested) compared to an economic efficiency of U\$0.76 per every US\$1.00 invested in broilers fed the Maize-Soybean (control) diet. Feeding broilers with diets containing processed cowpeas improved (P<0.05) the economic efficiency values (US\$0.80 to US\$0.86 per every dollar invested).

Table 5. Impact of Cowpea-based diets on Economic Efficiency of Broilers

	MS	MSDBC	MSDRC	MSDC	MSBC	MSRC	MSUC
Price (US\$) / kg diet	0.49	0.47	0.47	0.47	0.47	0.47	0.47
Total feed intake/broiler (g)	4151	3829	4035	4052	4009	3858	4195
Total feed cost (US\$) / broiler	2.05	1.81	1.9	1.89	1.87	1.81	1.99
Chick cost (US\$)	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Labor cost (US\$) / bird	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Other costs (US\$) / bird	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Total variable costs (US\$)/ bird	3.35	3.11	3.2	3.19	3.17	3.11	3.29
Total weight (g) / bird	2360	2290	2350	2305	2284	2315	2235
Feed cost (US\$) / kg gain	1.41	1.36	1.36	1.38	1.39	1.34	1.47
Total revenue (US\$) / broiler	5.9	5.73	5.88	5.76	5.71	5.79	5.59
Net revenue (US\$) / broiler	2.55	2.62	2.68	2.57	2.54	2.68	2.3
Economic efficiency	0.76^b	0.84^a	0.84^a	0.81^a	0.8^a	0.86^a	0.7^b

MS = Maize-Soybean, MSUC = Maize-Soybean Untreated Cowpeas, MSBC = Maize-Soybean-Boiled Cowpeas, MSDC = Maize-Soybean-Dehulled Cowpeas, MSDBC = Maize-Soybean-Dehulled Boiled Cowpeas, MSDRC = Maize-Soybean-Dehulled Roasted Cowpeas, MSRC = Maize-Soybean-Roasted Cowpeas.

3.6. True Protein Digestibility (TPD) Coefficients

The digestibility coefficients of proteins in broiler starter diets made with variously processed cowpeas at 10% inclusion levels are shown in Table 6 below. The protein digestibility (PD) coefficients of diets containing variously processed cowpeas were not different and ranged from 54.6 to 65.2% which, was higher than 51.0% (P<0.05) of the diet which contained raw cowpea meal. Processing cowpeas, therefore, improved the digestion of proteins in starter diets containing cowpea meal. Replication had no effect on TPD (P=0.68). Replication × Treatment had no effect on TPD.

3.7. Amount of Ammonia Emitted from Faecal Material

Table 6 displays the weekly average ammonia (ppm) levels released by the excreta of broilers fed diets formulated using processed and raw cowpeas. It was found that processing had no effect on ammonia emission across all dietary treatments.

The amount of ammonia emitted from the dietary treatments ranged from 1.2 to 1.5 ppm. Replication did not affect ammonia emission (P=0.75) also. Only week significantly influenced ammonia emission (P<0.0001). Replication × Treatment did not affect ammonia emission.

Table 6. True Protein Digestibility (TPD) Coefficients and Ammonia Emission of Broilers fed on Cowpea-based Diets

Treatment	TPD (%)	WAE (ppm)
MSBC	65.2 ± 0.74 ^a	1.2 ± 0.12 ^a
MS	64.9 ± 0.74 ^a	1.3 ± 0.12 ^a
MSDRC	62.7 ± 0.74 ^a	1.2 ± 0.12 ^a
MSRC	61.7 ± 0.74 ^a	1.3 ± 0.12 ^a

MSDC	55.2 ± 0.74 ^a	1.2 ± 0.12 ^a
MSDBC	54.6 ± 0.74 ^a	1.3 ± 0.12 ^a
MSUC	51.0 ± 0.74 ^b	1.5 ± 0.12 ^a

MS = Maize-Soybean, *MSUC* = Maize-Soybean Untreated Cowpeas, *MSBC* = Maize-Soybean-Boiled Cowpeas, *MSDC* = Maize-Soybean-Dehulled Cowpeas, *MSDBC* = Maize-Soybean-Dehulled Boiled Cowpeas, *MSDRC* = Maize-Soybean-Dehulled Roasted Cowpeas, *MSRC* = Maize-Soybean-Roasted Cowpeas. ^{a-b}Means with different superscripts in the same column are significantly different ($P < 0.05$).

4. DISCUSSION

4.1. The Proximate Composition

The findings of this study indicated that processing positively affected the proximate composition of cowpea grains. All processing techniques that involved removal of the cowpea seed hulls caused a reduction of crude fibre (CF) in processed cowpeas. The results of the study align with Bumhira and Madzimure (2022) and Choi *et al.* (2023) who reported that dehulling increased the protein and fat contents but reduced the crude fibre in faba beans. The reduction in crude fibre in cowpea grains whose seed hulls had been removed can be attributed to the elimination of cellulolytic material and lignin that are generally found in the seed coats of legume seeds. However, roasting and boiling caused a slight increase in the CP content of cowpeas in the current research, which, is consistent with the findings of Anjos *et al.* (2016), who reported that roasting had a minimal impact on the CP content of cowpeas. Rafiee-Yarandi *et al.* (2016) claimed that roasting caused an inevitable loss of heat-sensitive amino acids such as lysine to volatilisation.

Processing resulted in a considerable increase in metabolizable energy of cowpea grains. These results are in support of the findings of Nalle *et al.* (2010) who observed that dehulling resulted in a significant increase in metabolizable energy of cowpeas. This can be due to the removal of non-starch polysaccharides and tannins from the hulls of the cowpea grains. The metabolizable energy (ME) of feed ingredients used in the design of chicken diet is crucial since it affects feed intake (Noblet *et al.*, 2022).

According to Massuquetto *et al.* (2020), broilers on a low-energy diet eat more feed in order to make up for any energy deficit. High dietary energy allows proteins to synthesize muscular tissues rather than focusing on generating energy (Jiang, 2007; Abdollahi *et al.*, 2021). Formulating broiler feeds basing on book value ME without taking into consideration the actual ME values of the ingredients used, results in variations in ME of complete feeds produced

(Abdollahi *et al.*, 2021). Jiang (2007) claimed that a deviation in ME of feed by more than 50kcal/kg affects the cost of feed by US\$2.20 to US\$2.90 per tonne. Variations in metabolisable energy, according to the same author, have an impact on growth performance, carcass quality, and eventually profitability. However, in the current study, diets were made to be iso-energetic.

4.2. Average Weekly Feed Intake

The results of this study showed that both thermal treatment and dehulling caused no differences on feed intake with the exception of a reduced feed intake by broilers fed the boiled cowpea diet.

These results are consistent with the findings of Belal *et al.* (2011) and Ciurescu *et al.* (2023) who observed that feeding broilers with diets containing dehulled cowpeas did not cause any significant effect on feed consumption. However, Akanji *et al.* (2016) claimed that giving broiler chicks meals that included 20% dehulled cowpeas reduced the growth performance indices (feed consumption, growth rate, protein efficiency ratio, and feed conversion ratio). These contradicting results can be attributed to the assumption that Akanji *et al.* (2016) might have used a particular cowpea cultivar that had significant concentrations of protease inhibitors and lectins since dehulling only removes tannins that are contained in seed coats leaving lectins and protease inhibitors unaffected. Bumhira and Madzimure (2022) reviewed that thermal treatment of grain legumes at 120°C for 30 minutes cannot cause any significant effect on feed intake. Similar results were reported by Balaiel (2011), who found no difference in the amount of feed consumed by broilers fed finisher diets containing 20% boiled velvet (*Mucuna utilis*).

4.3. Average Weekly Weight Gain

Dietary treatments did not affect the weekly weight gains of the broiler chickens. The findings are consistent with those of Ciurescu *et al.* (2022) who reported that partial replacement of soybean meal with processed cowpeas in broiler feeds at inclusion levels not exceeding 20% did not affect

broiler weight gain. Embaye *et al.* (2018) and Akure *et al.* (2021) obtained similar results by feeding broilers with 20% boiled cowpeas and 20% *Mucuna utilis* beans, respectively. Abdullahi *et al.* (2023) also observed that broiler growth performance was not affected by feeding them with diets containing 25% roasted Kidney beans (*Phaseolus vulgaris*).

These outcomes might stem from the presumption that cowpea processing successfully eliminated anti-nutrients. This might have enabled the broilers to fully utilise the nutrients for optimal performance.

4.4. Average Weekly Feed Conversion Ratio (FCR)

This research shows that dietary treatments did not affect the amount of feed converted into meat (FCR of the broilers). The FCR results of this investigation are similar to those of Embaye *et al.* (2018) and Belal *et al.* (2011) who found that broilers fed diets containing 20% dehulled, dehulled-roasted, and raw cowpeas had similar FCR results. In addition, Mussa (1998) also reported that the inclusion of dehulled cowpeas in broiler diets did not result in any significant difference in the feed conversion ratio between the broilers fed the maize-soy diet and those fed diets containing varying levels of decorticated (dehulled) cowpeas. The similar FCR results obtained might be attributed to the fact that cowpeas' processing effectively eliminated anti-nutritional factors in cowpeas allowing optimal performance.

4.5. Economic Efficiency

In this study, the processing of cowpeas greatly improved the economic efficiency (profit obtained per every dollar invested) of feeding broilers. Birds fed with diets that include roasted cowpeas had the greatest economic efficiency followed by birds fed with dehulled-roasted, dehulled-boiled, and dehulled cowpea-based diets. These outcomes concur with those of Abou El-Fadel *et al.* (2019). Adino *et al.* (2018) also emphasised that the cost of rearing broilers can be reduced by incorporating processed cowpeas into diets. The diet consisting solely of raw cowpeas exhibited the least economic efficiency, which is likely caused by the broilers' inability to absorb and utilise nutrients due to the presence of anti-nutritional factors (tannins, protease inhibitors, lectins and non-starch polysaccharides) in unprocessed cowpeas (Korant *et al.*, 2023).

4.6. True Protein Digestibility (TPD) Coefficients

Processing increased cowpea proteins' digestibility and this is consistent with data published by Abu El-Fadel *et al.* (2019) and Lewis *et al.* (2019). However, the current digestibility coefficients are not as high as results obtained by other authors (Kalpanadevi and Mohan 2013; Oghbaei *et al.*, 2016; Dos Anjos *et al.*, 2016; Oba *et al.*, 2023). Differences in the age and sex of the birds employed as well as variances in the digestibility studies' methodologies may account for the discrepancy between the current study's findings and those of previous investigations. Adult birds, that are better able to digest feed nutrients than the younger birds employed in this experiment, have been used in the majority of nutrient digestibility investigations.

Furthermore, cecectomized cockles were employed by Kim *et al.* (2011) and Oba *et al.* (2023) to evaluate the digestibility of protein. To eliminate hind gut microbial fermentation, which breaks down protein that escapes the proximal gut undigested and converts it into ammonia and other toxic compounds, two modern techniques are used: cecectomy and ileostomy. This procedure causes an underestimation of protein lost through faecal material and an Overestimation of protein retained (Borin *et al.*, 2002). The *in-vivo* method of total tract excreta measurement also overestimates the quantity of protein lost through feces because feathers, scales, and spilled meal can occasionally adulterate the faecal material. *In vitro* digestibility trials such as the pepsin nitrogen digestibility assay are ineffective because they typically use a single proteolytic enzyme (pepsin) in an unnatural setting, whereas the gastrointestinal tract of intact birds contains a wide variety of digestive enzymes (Lewis *et al.*, 2019).

The improved TPDs' obtained from feeding broilers with processed cowpea-based diets are very important in broiler production because proteins in feed are not wasted through excretion but are effectively utilised for building of muscles. Efficient utilisation of proteins is very economical and environmentally friendly since it reduces contamination of the air, water and soil with nitrogen (Sheikh *et al.*, 2018).

4.7. Ammonia Emission

The quantity of ammonia released from the faeces of broilers fed diets comprising differently processed cowpeas was not significantly affected

by the method of processing cowpeas. These results are consistent with published literature which indicated that supplementing soybeans with processed vegetable proteins reduces the amount of ammonia emitted from poultry litter (Lokaewmanee, 2020; Sugiharto, 2022). Processing promotes protein retention in chickens, lowers anti-nutrients (tannins, protease inhibitors, and non-soluble polysaccharides) from grains and legumes, and eventually lowers the quantity of nitrogen or ammonia released through chicken excrement (Mattila *et al.*, 2018). According to Jimenez-Moreno *et al.* (2019), insoluble fibers found in vegetable proteins can alter gut architecture and increase the microbiota in the small intestine, both of which enhance nutrient digestion and retention. According to Sitiya *et al.* (2019), insoluble fibre from vegetable protein sources aids in reducing the pH of the small intestine, which is advantageous for microbes and proteolytic enzymes involved in food digestion.

Poultry litter produced by broilers fed processed cowpea-based diets emits low levels of ammonia, which is environmentally beneficial as it helps prevent soil, water, and air pollution caused by ammonia from poultry production. The presence of excess ammonia can lead to eutrophication of open water bodies and a decrease in dissolved oxygen as dead aquatic plants decompose (Bumhira and Madzimure, 2023). Suffocation and mass fish deaths can occur as a result of this (Sheikh *et al.*, 2018). When ammonia reacts with acidic compounds in the air, it produces particulate matter 2.5 (PM_{2.5}), which can lead to respiratory illnesses in humans. Utilizing processed cowpea-based diets aids in safeguarding the environment from ammonia contamination, thus supporting Sustainable Development Goals 3 (Good Health and Well-being), 14 (Life below water), and 15 (Life on Land).

5. CONCLUSION

The nutritional value of processed cowpeas can be enhanced through roasting, boiling, dehulling, or a combination of dehulling with either roasting or boiling. The incorporation of processed cowpeas in broiler starter and finisher diets improves growth performance, feed intake, FCR and feed efficiency of broilers. The processing of cowpea grains considerably improved protein digestibility and lowered the quantity of ammonia released into the environment when cowpeas are added to broiler diets. To guarantee sustainable chicken farming, it is advised that

cowpeas that are used to partially replace soybeans in broiler diets be processed using either roasting, boiling, dehulling, or a combination of dehulling and roasting techniques.

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