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Processed Pigeon Pea Meal Partially Replaces Soybean Meal in Sasso Chicken Diets: Growth, Feed Efficiency, Carcass Traits, Economic Outcomes

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Abstract

The rising cost and limited supply of soybean meal (SBM) have increased interest in locally available protein alternatives for poultry production. This study assessed the effects of partially replacing SBM with processed pigeon pea meal (PPM) on growth performance, feed efficiency, carcass traits, and economic returns of Sasso chickens under Ethiopian smallholder conditions. A total of 135 day-old Sasso chicks were assigned to three dietary treatments in a completely randomized design with three replicate pens of 15 birds each. PPM was included at 0%, 24%, and 32% in starter diets and 0%, 22%, and 29% in finisher diets. Over an eight-week trial, growth performance, feed intake, feed conversion ratio (FCR), carcass characteristics, and economic outcomes were evaluated. Results showed that PPM inclusion did not significantly affect ($P > 0.05$) feed intake, body weight gain, or most carcass traits. However, birds fed the highest inclusion level exhibited a significantly poorer FCR ($P < 0.05$), indicating reduced feed efficiency. Economic analysis revealed that all treatments generated negative net returns under prevailing market conditions, though PPM inclusion reduced the magnitude of losses. The marginal rate of return was positive for both PPM treatments (100.4% for T2 and 102.1% for T3) relative to the control, but these values must be interpreted cautiously given the overall unprofitability. Key limitations include the absence of direct quantification of anti-nutritional factors, amino acid profiling, and nutrient digestibility measurements, as well as limited replication ($n = 3$ pens per treatment) that reduced statistical power. Processed pigeon pea meal can partially replace soybean meal in Sasso chicken diets under smallholder systems, but its use requires careful economic evaluation and should be accompanied by amino acid supplementation strategies. Future research should address the identified knowledge gaps through comprehensive laboratory analyses and appropriately powered experimental designs.

1. Introduction

The increasing global demand for animal-source foods, driven by rapid population growth, urbanization, and rising incomes, has intensified the need for efficient and sustainable poultry production systems (FAO, 2023). Poultry meat is widely recognized as one of the most efficient sources of high-quality animal protein because of its rapid growth rate, high feed conversion efficiency, relatively low greenhouse gas emissions, and short production cycle (Scanes, 2015). Consequently, poultry production plays a critical role in improving food and nutritional security, particularly in developing countries.

Feed represents approximately 60–70% of the total cost of poultry production, with protein ingredients accounting for a substantial proportion of feed costs (Ravindran, 2013; Alagawany et al., 2021). In Ethiopia, smallholder poultry production systems face particular challenges related to feed costs, with limited access to affordable protein sources (FAO, 2023). While the 60–70% figure is generally accepted in the international literature, it should be noted that this ratio may vary among small-scale poultry operations in Ethiopia depending on local market conditions, season, and production system. Region-specific data on feed cost shares in Ethiopian smallholder poultry systems are limited, representing a gap in the literature that future research should address.

Soybean meal (SBM) remains the predominant plant protein source in poultry diets because of its high crude protein concentration (typically 44–48%), balanced amino acid profile, excellent digestibility, and consistent feeding value (Heuzé et al., 2015). However, increasing prices, competition with human food and industrial uses, climate-related production challenges, and dependence on imported soybean products have stimulated the search for locally available and economically sustainable alternative protein sources (Mottet and Tempio, 2017; FAO, 2023).

Grain legumes have received considerable attention as alternative protein ingredients because they are widely adapted to tropical environments and contribute to sustainable crop-livestock production systems through biological nitrogen fixation and reduced dependence on imported feed resources (Siddhuraju et al., 2005). Among these legumes, pigeon pea (*Cajanus cajan*) is particularly attractive because of its drought tolerance, adaptability to marginal environments, moderate protein content (approximately 18–22%), and relatively low production cost. In Ethiopia, pigeon pea is increasingly cultivated in several parts of the southern region, where it represents a potentially valuable but underutilized protein source for livestock feeding.

However, the economic rationale for using pigeon pea as a feed ingredient requires careful examination. While pigeon pea may have lower production costs than soybean, market price data comparing these ingredients in Ethiopian local markets are limited. The price gap between PPM and SBM in local markets varies seasonally and regionally, and this variability has significant implications for small-scale producers who must make feed purchasing decisions based on current market conditions. Furthermore, the processing requirements for pigeon pea (soaking, boiling, drying, and grinding) entail additional labor and energy costs that must be factored into any economic comparison. These processing costs are absent in soybean meal-based diets, making direct cost comparisons between the two protein sources potentially misleading if processing costs are excluded (Upton, 1979; Ouma et al., 2022).

Despite its nutritional potential, the utilization of pigeon pea in poultry diets is constrained by the presence of anti-nutritional compounds, including trypsin inhibitors, tannins, phytates, and polyphenolic compounds, which may reduce nutrient digestibility, amino acid availability, and overall feed utilization in monogastric animals (Apata and Ologhobo, 1997; D'Mello, 1995). Previous studies have shown that processing methods such as soaking, boiling, dehulling, fermentation, and extrusion can substantially reduce these anti-nutritional factors and improve the feeding value of pigeon pea for poultry (Amaefule and Obioha, 2001; Arif et al., 2017). However, the extent of anti-nutritional factor reduction depends on the processing conditions and should ideally be confirmed through direct chemical analysis.

Several investigations have evaluated processed pigeon pea meal as a partial substitute for soybean meal in broiler diets and generally reported satisfactory growth performance at moderate inclusion levels (Amaefule and Obioha, 2001; Olayemi et al., 2018; Chowdhury et al., 2020; Ojediran and Emiola, 2021). However, responses have varied according to bird genotype, dietary inclusion level, processing method, and overall diet formulation. Moreover, information on the utilization of processed pigeon pea meal in Sasso chickens under Ethiopian production conditions remains limited. Most previous studies

have primarily focused on growth performance, while comparatively fewer have simultaneously evaluated feed efficiency, carcass characteristics, and economic returns under smallholder production systems.

Furthermore, few studies have critically examined the trade-offs between feed cost reduction and feed efficiency decline when using alternative protein sources in small-scale poultry operations. Previous economic analyses of alternative feed ingredients have often failed to account for processing costs, seasonal price fluctuations, or the biological trade-offs associated with reduced nutrient digestibility (Ouma et al., 2022; Mutua et al., 2021). For example, Ouma et al. (2022) demonstrated that partial budget analyses in smallholder systems frequently omit labor and fuel costs associated with feed processing, leading to overly optimistic economic conclusions. Similarly, Mutua et al. (2021) found that seasonal price variability can substantially alter the economic ranking of alternative feed ingredients, yet few studies incorporate sensitivity analyses. This gap in the literature limits the practical utility of research findings for smallholder producers who must make informed decisions about feed ingredient choices.

Therefore, this study was conducted as a preliminary evaluation of the effects of partially replacing soybean meal with processed pigeon pea meal on the growth performance, feed efficiency, carcass characteristics, and economic returns of Sasso chickens under Ethiopian smallholder conditions. The study aimed to determine whether processed pigeon pea meal could serve as a practical and economically viable alternative protein source while identifying potential limitations associated with higher dietary inclusion levels. The study was designed as an applied performance evaluation rather than a mechanistic investigation. Consequently, anti-nutritional compounds, amino acid digestibility, blood biochemical indices, intestinal morphology, and other physiological responses were not measured. The findings are interpreted primarily on the basis of production performance and economic outcomes, providing a foundation for future mechanistic investigations.

2. Materials and Methods

2.1 Study Area

The feeding trial was conducted from January to March 2024 in Melokoza District, Gofa Zone, southern Ethiopia, approximately 906 km southwest of Addis Ababa. The area is characterized by a mixed crop-livestock production system in which pigeon pea (*Cajanus cajan*) is increasingly cultivated because of its adaptability to the local agroecology and its potential as a livestock feed resource. The experiment was carried out under standard poultry management conditions at a smallholder production unit.

2.2 Collection and Processing of Pigeon Pea Seeds

Mature pigeon pea seeds were obtained from local farmers in the study area in December 2023. Foreign materials, damaged seeds, and impurities were manually removed before processing. The seeds were soaked in clean water for 24 hours and subsequently boiled for 30 minutes following procedures

described by Amaefule and Obioha (2001) and Arif et al. (2017). After boiling, the seeds were sun-dried to a constant moisture level and ground using a hammer mill to produce pigeon pea meal (PPM).

Processing Cost Documentation

The processing of pigeon pea seeds involved the following labor and energy inputs, which were recorded to enable economic analysis

- Soaking (24 hours): Labor for setup and monitoring = 0.5 person-hours per 10 kg seeds
- Boiling (30 minutes): Fuel (firewood) = 2 kg per 10 kg seeds; Labor = 1.0 person-hour per 10 kg seeds
- Sun-drying (48–72 hours): Labor for spreading and collection = 0.5 person-hours per 10 kg seeds
- Grinding: Mechanical grinding cost = 50 Birr per 100 kg (local mill rate)

Total processing cost was calculated as 2.50 Birr per kg of processed PPM, based on local labor rates (25 Birr/day for 8 hours) and fuel costs at the time of the study.

Important Limitation

Anti-nutritional compounds (trypsin inhibitors, tannins, phytates) were not directly quantified before or after processing in the present study. The soaking and boiling procedures were employed based on published literature indicating their effectiveness in reducing these compounds (Amaefule and Obioha, 2001; Arif et al., 2017; Locali-Pereira et al., 2024). However, the actual reduction achieved in this study cannot be verified, and statements regarding the effectiveness of processing remain assumptions. This represents a significant limitation of the present study that must be considered when interpreting the results.

2.3 Experimental Diets and Dietary Treatments

Three experimental diets were formulated separately for the starter (0–4 weeks) and finisher (5–8 weeks) phases. Processed pigeon pea meal was incorporated as a partial replacement for soybean meal on an ingredient inclusion basis. Dietary inclusion levels were:

Starter Phase (0–4 weeks):

- T1 (Control): 0% PPM
- T2 (Low PPM): 24% PPM
- T3 (High PPM): 32% PPM

Finisher Phase (5–8 weeks):

- T1 (Control): 0% PPM
- T2 (Low PPM): 22% PPM

- T3 (High PPM): 29% PPM

Soybean Meal Replacement Calculation:

In the finisher phase, the control diet contained approximately 30% soybean meal. The replacement of soybean meal with PPM represented:

- T2 (22% PPM): Soybean meal reduced from 30% to approximately 19% (36.7% reduction in soybean meal protein)
- T3 (29% PPM): Soybean meal reduced from 30% to approximately 15.5% (48.3% reduction in soybean meal protein)

These calculations assume similar protein digestibility between ingredients. The diets were formulated to satisfy the nutrient requirements of broiler chickens according to NRC (1994), using the analyzed nutrient composition of the feed ingredients.

2.4 Chemical Analysis

Representative samples of pigeon pea meal, soybean meal, maize, wheat, and the experimental diets were analyzed for dry matter (DM), crude protein (CP), crude fibre (CF), and ash according to the Official Methods of Analysis of the Association of Official Analytical Chemists (AOAC International, 2019). Laboratory analyses were conducted at the Animal Nutrition Laboratory of Arba Minch University.

2.5 Experimental Birds and Management

A total of 135 day-old Sasso chicks were used in the experiment. Before allocation to dietary treatments, chicks were brooded under standard commercial management conditions and fed a commercial starter ration during a one-week adaptation period. After adaptation, birds were randomly assigned to one of three dietary treatments using a completely randomized design (CRD). Each treatment consisted of three replicate pens with 15 birds per replicate, resulting in 45 birds per treatment.

2.6 Experimental Measurements

Daily feed intake was determined as the difference between feed offered and feed refused. Birds were individually weighed at the beginning of the experiment and subsequently at weekly intervals. Body weight gain was calculated as the difference between final and initial body weight, while average daily gain (ADG) was obtained by dividing total weight gain by the number of experimental days. Feed conversion ratio (FCR) was calculated as:

FCR = Total feed intake (g) ÷ Total body weight gain (g)

At the end of the feeding trial, two birds were randomly selected from each replicate for carcass evaluation. Birds were fasted for approximately 12 hours before slaughter. Dressing weight, dressing percentage, breast weight, thigh weight, liver, heart, gizzard, and eviscerated carcass weight were

recorded following standard carcass evaluation procedures (Jensen, 1984). Carcass traits were calculated as both absolute values and percentages of live weight.

2.7 Economic Analysis

A partial budget analysis was performed following the procedures described by Upton (1979) and updated methodological guidelines from recent agricultural economics literature (Ouma et al., 2022; Mutua et al., 2021). The analysis compared the costs and returns of each treatment relative to the control.

Cost Calculations:

Total variable costs included: **Feed cost**: Calculated using prevailing local market prices of feed ingredients (collected from Melokoza District markets in January 2024) and the total feed consumed during the experiment. **PPM processing cost**: Calculated as 2.50 Birr per kg of processed PPM, based on documented labor and fuel inputs (Section 2.2). This cost was applied only to T2 and T3, as the control diet contained no PPM.

Feed cost per kg of diet was calculated as: Feed cost (Birr/kg) = Σ (Ingredient inclusion rate × Ingredient price) + Processing cost

Revenue Calculations

Revenue was calculated based on actual final body weights of birds in each treatment multiplied by the local market price for live Sasso chickens at 8 weeks of age (60 Birr/kg, based on January 2024 market survey).

Net Return

NR = Total Revenue - Total Variable Cost

Marginal Rate of Return (MRR)

The MRR was calculated using the standard formula

MRR = (Δ Net Return / Δ Total Variable Cost) × 100

Where, Δ represents the change in value between treatments.

Sensitivity Analysis

A sensitivity analysis was conducted to assess the robustness of the economic results to changes in key parameters

1. PPM price: ±20% variation
2. SBM price: ±20% variation

3. Live chicken price: ±20% variation

2.8 Statistical Analysis

All experimental data were analyzed using one-way analysis of variance (ANOVA) under a completely randomized design using SAS software version 9.4 (SAS Institute Inc., Cary, NC, USA). The statistical model used was:

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

Where Y_{ij} is the observed response variable, μ is the overall mean, T_i is the fixed effect of dietary treatment, and ε_{ij} is the random experimental error.

When treatment effects were significant ($P < 0.05$), means were separated using Duncan's Multiple Range Test (Duncan, 1955). Results are presented as treatment means with their corresponding standard error of the mean (SEM).

3. Results

3.1 Chemical Composition of Feed Ingredients

The proximate composition of the feed ingredients used in the experimental diets is presented in Table 1. Significant differences ($P < 0.05$) were observed among ingredients for crude protein (CP), ash, and crude fibre (CF) contents. Soybean meal contained the highest crude protein concentration (37.57% DM), confirming its role as a high-quality protein source in poultry diets. In contrast, processed pigeon pea meal (PPM) contained 19.33% crude protein, indicating that although it provides a substantial amount of protein, its protein concentration is considerably lower than that of soybean meal.

The dry matter content of all ingredients exceeded 93%, demonstrating their suitability for storage and feed formulation, with no significant differences ($P > 0.05$) among ingredients. Processed pigeon pea meal contained moderate crude fibre (3.42%) compared with maize (0.87%) but lower fibre than soybean meal (5.30%). The relatively higher fibre content of pigeon pea compared with cereal grains is characteristic of grain legumes and may influence nutrient utilization when incorporated at higher dietary levels.

The chemical composition obtained in the present study is generally consistent with published values for processed pigeon pea meal, although some variation among studies is expected because of differences in cultivar, growing environment, maturity stage, and processing methods (Heuzé et al., 2017; Arif et al., 2017). Overall, the nutrient composition indicates that processed pigeon pea meal has potential as a locally available alternative protein ingredient, provided diets are carefully formulated to satisfy the nutrient requirements of poultry.

Table 1. Chemical composition of feed ingredients used in formulating the experimental diets

Nutrient (% DM basis)	Pigeon Pea Meal	Soybean Meal	Maize (Corn) Meal	Wheat Meal	SEM	P-value
Dry matter (DM, %)	93.15	95.02	94.57	93.81	0.42	0.075
Crude protein (CP)	19.33	37.57	8.11	11.72	6.31	<0.001
Ash (%)	1.55	5.50	2.16	1.32	0.99	<0.001
Crude fiber (CF)	3.42	5.30	0.87	1.37	0.98	<0.001

DM = dry matter; CP = crude protein; CF = crude fibre; SEM = standard error of mean. Different superscripts within a row indicate significant differences (P < 0.05). Dry matter showed no significant differences (P > 0.05); therefore, superscripts were omitted.

3.2 Anti-Nutritional Factors: Literature Context and Processing Effects

This section provides literature context only. No anti-nutritional factor measurements were made in the present study, and the values cited below are from published sources, not from this experiment. This information is provided to help interpret the study findings but should not be construed as data from this research. The anti-nutritional factor (ANF) content of raw and processed pigeon pea has been extensively quantified in the literature. Table 2 presents a synthesis of laboratory-measured values for key ANFs, including trypsin inhibitors, tannins, phytates, oxalates, saponins, and total phenolics, along with the reported effects of processing methods.

Table 2. Anti-nutritional factors in raw and processed pigeon pea: compiled literature values from laboratory analyses

Anti-nutritional factor	Raw pigeon pea	Processed pigeon pea	Processing method(s)	Reference
Trypsin inhibitor	23.89–35.43 TIU/mg protein; 1.01–13.11% inhibition	0.59 mg/g (soaking); 95% reduction after soaking and boiling	Soaking, boiling, roasting	Amaefule & Obioha (2001); Arif et al. (2017); Locali-Pereira et al. (2024)
Tannins	0.14–0.97 mg/g; 3.55%	0.25–1.47%; 0.88–1.38%	Boiling, soaking, toasting	Apata & Ologhobo (1997); Naka et al. (2025)
Phytic acid	6.21–11.31 mg/g; 10.71 mg/g	0.46–9.02 mg/g; 1.06–2.24 mg/g	Soaking, boiling, roasting	Chowdhury et al. (2020); Naka et al. (2025)
Oxalate	2.22 mg/g	0.85–1.87 mg/g; 0.75–1.44 mg/g	Soaking, boiling, roasting	Naka et al. (2025)
Saponins	24.72 mg/g; 2,015–3,055 mg/100 g	0.78–2.66 mg/g; 0.88–1.76 mg/g	Soaking, boiling	Naka et al. (2025)
Total phenolics	7.75 mg GAE/g; 4.44–26.15 mg/g	2.91 mg GAE/g	Soaking, boiling, dehulling	Siddhuraju et al. (2005); Goswami et al. (2024)
Lectins/haemagglutinins	Present (qualitative)	Reduced following heat treatment	Cooking, autoclaving	Onwuka (2006)

Abbreviations: ANF, anti-nutritional factor; GAE, gallic acid equivalents; TIU, trypsin inhibitor units.

Processing methods such as soaking, boiling, dehulling, fermentation, and extrusion can substantially reduce these anti-nutritional factors (Table 2). Locali-Pereira et al. (2024) demonstrated that soaked-boiled pre-treatment reduced trypsin inhibitor activity by 95%, providing strong evidence that the soaking and boiling procedures employed in the present study could have substantially reduced this ANF. Naka et al. (2025) reported that roasting reduced oxalate to 33.867 mg/100 g and phytate to 4.512 mg/100 g, while germination significantly decreased ANFs. Abd El-Hack et al. (2018) confirmed that pigeon pea contains ANFs that negatively affect feed efficiency, and that processing methods such as fermentation, boiling, milling, soaking, and roasting can minimize these harmful effects.

However, Goswami et al. (2024) demonstrated that genotype significantly influences ANF reduction, with autoclaving achieving higher in vitro protein digestibility in low-polyphenol genotypes (90.4%) compared to high-polyphenol genotypes (84.3%). This genotype-dependent response underscores the critical importance of direct ANF quantification for the specific cultivar and processing method used - a limitation acknowledged in the present study.

Based on literature recommendations, soaked and boiled pigeon pea meal can be included in poultry diets at levels of 15-20% in the starter phase and 20-30% in the finisher phase (Olayemi et al., 2018). The inclusion levels used in the present study (24-32% starter; 22-29% finisher) are within or slightly above these recommended ranges. The upper end of these inclusion levels may approach the threshold at which residual anti-nutritional factors begin to negatively affect nutrient utilization.

3.3 Amino Acid Profiling: Literature Context

The following data are compiled from published amino acid analyses of pigeon pea. These values are presented as contextual evidence. They do **not** represent measurements from the present study. The amino acid composition of pigeon pea has been characterized in multiple laboratory studies. Table 3 presents a synthesis of amino acid profiling data, expressed as g/16 gN (grams per 16 grams of nitrogen), which is the standard unit for reporting amino acid composition.

Table 3. Amino acid profile of pigeon pea: compiled literature values (g/16 gN)

Amino Acid	Raw Pigeon Pea	Roasted Pigeon Pea	Soybean Meal (Reference)	Reference
Lysine	6.99–7.79	7.28–7.55	7.50–8.33	Akande et al. (2010)
Methionine	0.28–0.41	0.21–0.44	0.81–0.89	Akande et al. (2010); Cell.com (2025)
Cystine	Low (deficient)	Low (deficient)	0.72–0.78	Akande et al. (2010); Singh & Eggum (1984)
Methionine + Cystine	20.88 mg/g protein	—	1.04–1.44 g/16 gN	Hindawi (2020)
Threonine	2.11–4.22	Increased	4.10–4.36	Akande et al. (2010)
Tryptophan	Deficient	—	1.55–1.66	Singh & Eggum (1984)
Arginine	Lower than SBM	Decreased	7.70–7.91	Muangkeow (1994)
Leucine	80.02 mg/g protein	—	7.50–8.00	Hindawi (2020)
Valine	45.15 mg/g protein	—	5.30–6.00	Hindawi (2020)
Isoleucine	Low	—	4.00–4.50	Singh & Eggum (1984)
Histidine	Higher than SBM	—	2.19–3.11	Muangkeow (1994)
Phenylalanine	Higher than SBM	—	5.0–5.66	Muangkeow (1994)
Glutamic acid	16.02	16.55	—	Akande et al. (2010)

Akande et al. (2010) conducted comprehensive amino acid analysis of raw and roasted pigeon pea seeds and found that lysine was the most concentrated indispensable amino acid (7.79 g/16 gN for raw seeds and 7.55 g/16 gN for roasted seeds), while the seeds were deficient in cystine and methionine. Singh and Eggum (1984) confirmed that among important food legumes, pigeon pea contained the lowest amount of limiting sulfur amino acids (methionine and cystine).

Agboola et al. (2021) evaluated the standardized ileal amino acid digestibility (SIAAD) of red and white pigeon pea varieties in broiler chicks and found that arginine had the lowest SIAAD value in both varieties, while white pigeon pea had higher crude protein and higher digestibility values for several amino acids than red pigeon pea. Muangkeow (1994) reported that pigeon pea seed meal had higher lysine, threonine, phenylalanine, valine, and histidine but lower arginine, tryptophan, isoleucine, and leucine compared to soybean meal.

The deficiency in sulfur-containing amino acids has direct implications for poultry nutrition. Amaefule et al. (2011) noted that a diet containing 30% raw pigeon peas required supplementation with methionine, while a 40% inclusion of raw pigeon peas necessitated supplementation with both lysine and methionine to enhance chick growth. These findings suggest that pigeon peas are deficient in both methionine and lysine, and that supplementation can mitigate these deficiencies.

These documented deficiencies support the hypothesis that the reduction in feed efficiency observed at higher PPM inclusion levels may have been partly attributable to amino acid imbalances, particularly given the absence of synthetic amino acid supplementation in this study. However, because amino acid profiling was not performed in the present study, protein quality differences among treatments cannot be definitively assessed. The literature values in Table 3 provide context but do not substitute for direct measurement.

3.4 Nutrient Digestibility and Metabolizable Energy: Literature Context

Note: The following data are compiled from published digestibility trials. These values are presented as contextual evidence. They do not represent measurements from the present study. Nutrient digestibility and metabolizable energy content of pigeon pea have been evaluated in several laboratory studies. Table 4 presents a synthesis of these data.

Table 4. Nutrient digestibility and metabolizable energy of pigeon pea: compiled literature values

Parameter	Raw Pigeon Pea	Processed Pigeon Pea	Processing Method	Reference
Apparent metabolizable energy (AME)	2175.0 kcal/kg DM; 2286.2 kcal/kg DM	2485.0 kcal/kg DM (boiled); 2465.0 kcal/kg DM (roasted); 2596.0 kcal/kg DM (boiled); 2945.5 kcal/kg (roasted); 3115.9 kcal/kg (cooked)	Boiling, roasting, cooking	Muangkeow (1994); Londoo-Uribe et al. (2019)
True metabolizable energy (TME)	—	2453.0–2596.0 kcal/kg DM (boiled)	Boiling	Muangkeow (1994)
Crude protein digestibility	Lower	Significantly improved ($P < 0.05$)	Boiling, roasting	Onu et al. (2006); Muangkeow (1994)
Apparent ileal nitrogen digestibility	Lower	Improved ($P < 0.05$)	Roasting	Frontiers (2025)
Ether extract digestibility	—	Decreased with higher PPSM inclusion	—	Muangkeow (1994)
Dry matter digestibility	—	Variable	Boiling, roasting	Onu et al. (2006)

Muangkeow (1994) conducted comprehensive digestibility trials and found that the apparent metabolizable energy (AME) and true metabolizable energy (TME) content of pigeon pea seed meal were significantly improved by boiling (2596.0 kcal/kg DM) and roasting (2576.1 kcal/kg DM). However, when energy values were corrected for nitrogen, significant increases were obtained only from boiling, not from roasting.

Onu et al. (2006) conducted a 28-day feeding trial with finisher broilers and found that significant differences ($P < 0.05$) existed among groups in protein digestibility only, with processed pigeon pea seed meal outperforming raw pigeon pea seed meal. Muangkeow (1994) reported that the coefficient of digestibility of crude protein significantly decreased with increased levels of PPM in broiler starter, broiler finisher, and layer diets.

More recent research by Frontiers (2025) demonstrated that roasting pigeon peas improved apparent ileal nitrogen digestibility, aligning with observed improvements in growth performance. Chicks fed roasted pigeon peas exhibited body weight gain, feed consumption, and crude protein intake similar to those of the control group ($P > 0.05$), and nitrogen digestibility comparable to the conventional maize-soybean control diet. This study also confirmed that raw pigeon peas negatively affect broiler performance and gut morphology due to ANFs, but roasting effectively reduced these compounds, making roasted pigeon peas a promising alternative protein source that can partially replace soybean and maize meal up to 40% of the diet without compromising broiler growth or gut health.

Londoo-Uribe et al. (2019) reported that raw pigeon pea grain presented an AME value of 2286.2 kcal/kg DM, which was lower than roasted grain (2945.5 kcal/kg) and cooked grain (3115.9 kcal/kg), demonstrating that thermal processing substantially improves energy availability.

These findings suggest that the soaking and boiling procedures employed in the present study likely improved nutrient availability relative to raw pigeon pea. However, the genotype-dependent variability in ANF reduction and protein digestibility means that the specific cultivar used in this study may have responded differently than those reported in the literature.

3.5 Calculated Nutrient Composition of Experimental Diets

The calculated nutrient composition of the experimental diets is presented in Table 5. The diets were formulated to provide similar crude protein and metabolizable energy concentrations across treatments in accordance with recommended nutrient requirements for growing chickens. Crude protein content varied only slightly among treatments (20.5%, 20.3%, and 20.1% for T1, T2, and T3, respectively), indicating that replacement of soybean meal with processed pigeon pea meal was achieved without major changes in the overall dietary protein concentration.

Dietary crude fibre increased progressively with increasing pigeon pea meal inclusion (4.1%, 4.8%, and 5.5% for T1, T2, and T3, respectively). This reflects the naturally higher fibre content of pigeon pea compared with soybean meal and cereal ingredients. Increased dietary fibre may influence nutrient digestibility and feed utilization, particularly at higher inclusion levels.

The relatively similar nutrient composition among treatments suggests that differences observed in growth performance and feed efficiency were unlikely to be caused by large differences in crude protein or energy concentrations. Nevertheless, amino acid composition, metabolizable energy, and nutrient digestibility were not directly measured. Therefore, possible differences in amino acid balance and nutrient availability among treatments should be considered when interpreting the biological responses of the birds.

Table 5. Calculated nutrient composition of experimental diets (% DM basis)

Nutrient (% DM basis)	T1 (PPM 0%)	T2 (PPM 22-24%)	T3 (PPM 29-32%)
Dry matter (%)	92.8	92.6	92.5
Crude protein (%)	20.5	20.3	20.1
Crude fibre (%)	4.1	4.8	5.5
Ash (%)	6.2	6.1	6.0
Ether extract (%)	4.3	4.2	4.1
Metabolizable energy (kcal/kg)*	3000	2985	2970

**Calculated from ingredient composition. DM = dry matter; CP = crude protein; CF = crude fibre; PPM = pigeon pea meal; T1 = treatment one; T2 = treatment two; T3 = treatment three.*

3.6 Growth Performance

The effects of partially replacing soybean meal with processed pigeon pea meal (PPM) on the growth performance of Sasso chickens during the starter, finisher, and overall experimental periods are presented in Tables 6, 7, and 8.

3.6.1 Feed Intake

Dietary treatment did not significantly ($P > 0.05$) influence daily feed intake during either the starter or finisher phase (Tables 6 and 7). Birds in all treatment groups consumed comparable quantities of feed throughout the experiment, indicating that inclusion of processed pigeon pea meal did not adversely affect diet acceptability or palatability. Similar observations have been reported by Amaefule and Obioha (2001) and Olayemi et al. (2018), who found that moderate inclusion levels of processed pigeon pea meal did not reduce voluntary feed intake in broiler chickens.

The comparable feed intake observed among treatments suggests that the soaking and boiling procedures used in the present study were sufficient to maintain feed acceptability. However, because anti-nutritional compounds were not quantified before or after processing, the extent of their reduction could not be verified experimentally.

3.6.2 Body Weight and Body Weight Gain

Initial body weights were similar ($P > 0.05$) among treatment groups at the start of the experiment, indicating successful random allocation of birds. During the starter phase, birds fed diets containing processed pigeon pea meal achieved body weight gains comparable to those of birds receiving the soybean meal-based control diet. At the end of the starter phase (4 weeks), body weights were 440 g, 442 g, and 448 g for T1, T2, and T3, respectively, with significant differences among treatments ($P = 0.036$). This indicates that birds in the high PPM group (T3) had slightly but significantly higher body weights at the end of the starter phase compared to the control group.

During the finisher phase, initial body weights (which corresponded to final starter weights) differed significantly among treatments ($P = 0.036$), reflecting the carry-over effect from the starter phase. Final body weights at 8 weeks were 1314 g, 1317 g, and 1345 g for T1, T2, and T3, respectively, with no significant differences among treatments ($P = 0.187$). This indicates that the significant differences observed at 4 weeks were no longer present at 8 weeks, suggesting compensatory growth or convergence in body weight among treatments during the finisher phase. These findings indicate that partial replacement of soybean meal with processed pigeon pea meal supported satisfactory growth under the conditions of the present study. The ability of birds fed processed pigeon pea meal to maintain body weight gain may be attributed to the adequate supply of dietary protein and energy provided by the formulated diets. Similar findings have been reported in previous studies evaluating processed grain

legumes as alternative protein sources in poultry diets (Heuzé et al., 2017; Chowdhury et al., 2020; Ojediran and Emiola, 2021). Nevertheless, because amino acid digestibility and nutrient utilization were not evaluated, the present study cannot determine whether dietary protein quality differed among treatments. The absence of amino acid profiling is a significant limitation, as pigeon pea protein is known to be deficient in sulfur-containing amino acids compared to soybean meal (Akande et al., 2010; Singh and Eggum, 1984).

3.6.3 Feed Conversion Ratio

Feed conversion ratio (FCR) differed significantly ($P < 0.05$) among treatments during the overall experimental period (Table 8). Birds in T2 (1.80) and T3 (1.79) exhibited significantly poorer FCR compared to T1 (1.76), but did not differ significantly from each other. This indicates that inclusion of processed pigeon pea meal at both 22-24% and 29-32% resulted in reduced feed efficiency compared to the soybean meal-based control diet.

Although birds maintained comparable final body weights, higher dietary inclusion of processed pigeon pea meal resulted in poorer feed conversion efficiency, indicating that a greater quantity of feed was required to produce the same unit of body weight gain. The total feed intake was significantly higher in T3 (2153 g) compared to T1 (2066 g) and T2 (2117 g), which contributed to the poorer FCR in the PPM-containing groups.

Explanation of Apparent Contradiction: The observation that birds in T2 and T3 maintained similar body weight gain but exhibited significantly poorer FCR can be explained by compensatory feed intake. Birds in the high PPM group consumed more feed (2153 g vs. 2066 g in control), which compensated for reduced nutrient digestibility and allowed comparable weight gain to be achieved at the expense of feed efficiency. This pattern is consistent with the response to dietary dilution, where birds increase feed intake to meet their nutrient requirements when dietary nutrient density is reduced. The higher crude fibre content of PPM-containing diets (5.5% vs. 4.1% in control) likely contributed to reduced nutrient density and energy concentration, necessitating higher feed intake.

The observed reduction in feed efficiency at higher PPM inclusion levels may be attributed to one or more of the following factors, although these remain speculative without direct measurements:

1. **Residual trypsin inhibitors:** These compounds inhibit proteolytic enzymes, reducing protein digestibility and amino acid availability. Even after processing, residual trypsin inhibitors may have reduced the efficiency of protein utilization.
2. **Phytate content:** Phytates can chelate minerals and form complexes with proteins, reducing nutrient availability. The higher fibre content of PPM diets (5.5% vs. 4.1% in control) may have exacerbated these effects.
3. **Tannins:** These compounds bind to proteins and can reduce feed intake and nutrient digestibility, particularly at higher inclusion levels.

4. **Amino acid imbalances:** Pigeon pea protein is deficient in sulfur-containing amino acids (methionine and cysteine) compared to soybean meal (Akande et al., 2010; Singh and Eggum, 1984). Without amino acid supplementation, this may have contributed to reduced protein utilization efficiency.

Table 6. Effects of dietary inclusion of processed pigeon pea meal (PPM) on starter-phase (0-4 weeks) growth performance of Sasso chickens

Variable	PPM 0%	PPM 24%	PPM 32%	SEM	P-value
Initial body weight (g/bird)	138.90	139.00	139.00	0.04	0.195
Final body weight (g/bird)	440□	442□	448□	3.50	0.036
Average daily gain (g/bird/day)	10.75□	10.82□	11.04□	0.13	0.036
Total feed intake (g/bird)	889□	913□	931□	12.30	0.042
Daily feed intake (g/bird/day)	31.75	32.60	33.25	0.44	0.056
Feed conversion ratio (g feed/g gain)	2.95	3.01	3.01	0.06	0.585

a,b Means within a row bearing different superscripts differ significantly (P < 0.05). PPM = processed pigeon pea meal; SEM = standard error of the mean.

Table 7. Effects of dietary inclusion of processed pigeon pea meal (PPM) on finisher-phase (5-8 weeks) growth performance of Sasso chickens

Variable	PPM 0%	PPM 22%	PPM 29%	SEM	P-value
Initial body weight (g/bird)	440□	442□	448□	3.50	0.036
Final body weight (g/bird)	1314	1317	1345	10.00	0.187
Average daily gain (g/bird/day)	31.21	31.25	32.04	0.30	0.187
Total feed intake (g/bird)	1177□	1204□	1222□	13.50	0.040
Daily feed intake (g/bird/day)	42.05	43.00	43.65	0.48	0.063
Feed conversion ratio (g feed/g gain)	1.35	1.38	1.36	0.02	0.604

a,b Means within a row bearing different superscripts differ significantly (P < 0.05). PPM = processed pigeon pea meal; SEM = standard error of the mean.

Table 8. Overall growth performance (0-8 weeks) of Sasso chickens fed diets containing different levels of processed pigeon pea meal (PPM)

Variable	PPM 0%	PPM 22-24%	PPM 29-32%	SEM	P-value
Initial body weight (g/bird)	138.90	139.00	139.00	0.04	0.195
Final body weight (g/bird)	1314	1317	1345	10.00	0.187
Average daily gain (g/bird/day)	20.98	21.04	21.54	0.17	0.187
Total feed intake (g/bird)	2066	2117	2153	25.80	0.041
Daily feed intake (g/bird/day)	36.89	37.80	38.45	0.46	0.041
Feed conversion ratio (g feed/g gain)	1.76	1.80	1.79	0.04	0.049

[a,b]Means within a row bearing different superscripts differ significantly (P < 0.05). Note: Data in Table 8 represent the overall (0-8 weeks) performance. PPM = processed pigeon pea meal; SEM = standard error of the mean.

3.7 Carcass Characteristics

Most carcass characteristics were not significantly influenced by dietary treatment, indicating that partial replacement of soybean meal with processed pigeon pea meal did not adversely affect carcass development (Table 9). The similarity in dressing percentage and major carcass components among treatments suggests that nutrient partitioning toward muscle deposition was maintained despite differences in dietary protein source.

Dressing percentage ranged from 87.42% to 87.64%, with values comparable to those reported for broiler chickens under similar production conditions. Breast weight showed a slight increase in the high PPM group, which may reflect the higher feed intake and slightly greater body weight in this treatment group.

The absence of substantial changes in carcass yield agrees with previous studies reporting comparable carcass performance in broiler chickens fed processed pigeon pea meal (Palaje and Banguilan, 2020; Serebe et al., 2022; Ojediran and Emiola, 2021). These findings support the potential use of processed pigeon pea meal as an alternative protein source in poultry diets when appropriately formulated.

Nevertheless, because amino acid digestibility and nutrient utilization were not directly evaluated, further research is required to determine whether subtle changes in carcass composition may occur at higher inclusion levels.

Table 9. Effects of dietary inclusion of processed pigeon pea meal (PPM) on carcass characteristics of Sasso chickens at 8 weeks of age

Carcass trait	PPM 0%	PPM 22%	PPM 29%	SEM	P-value
Live weight (g)	1314	1317	1345	10.00	0.187
Dressing weight (g)	1152	1152	1176	8.76	0.030
Dressing percentage (%)	87.64	87.44	87.42	0.06	0.013
Eviscerated carcass weight (g)	1009	1008	1028	7.66	0.068
Eviscerated carcass (%)	76.79	76.54	76.43	0.58	0.068
Breast weight (g)	138.0	139.0	142.0	2.08	0.043
Breast weight (% of live weight)	10.50	10.55	10.56	0.16	0.043
Thigh weight (g)*	484.0	484.0	493.0	0.30	0.055
Thigh weight (% of live weight)	36.83	36.75	36.65	0.23	0.055

*[a,b]Means within a row bearing different superscripts differ significantly (P < 0.05). PPM = processed pigeon pea meal; SEM = standard error of the mean. *Thigh weight represents the combined weight of both thighs measured after slaughter.*

3.8 Economic Evaluation

The economic analysis demonstrated a reduction in feed cost with increasing levels of PPM inclusion, reflecting the lower market price of pigeon pea compared to soybean meal (Table 10). However, when processing costs were included, the cost advantage of PPM was partially offset.

Feed Cost Calculation:

Feed cost per kg was calculated as follows:

- **T1 (Control):** Σ (Ingredient inclusion × Price) = 7.92 Birr/kg
- **T2 (22% PPM):** Σ (Ingredient inclusion × Price) + PPM processing cost = 6.61 Birr/kg
- **T3 (29% PPM):** Σ (Ingredient inclusion × Price) + PPM processing cost = 5.42 Birr/kg

Table 10. Economic evaluation of substituting processed pigeon pea meal for soybean meal in Sasso chickens

Variable	T1 (PPM 0%)	T2 (PPM 22%)	T3 (PPM 29%)	SEM	P-value
Total feed consumed per bird (kg)	2.066	2.117	2.153	0.026	0.041
Feed cost (Birr/kg)*	7.92	6.61	5.42	-	-
Total feed cost per bird (Birr)	306	256	216	26.07	0.0001
Average final body weight (kg)	1.314	1.317	1.345	0.010	0.187
Live weight value (Birr/kg)**	60	60	60	-	-
Revenue per bird (Birr)	78.84	79.02	80.70	0.60	0.187
Total revenue (45 birds) (Birr)	3548	3556	3632	26.90	0.187
Total variable cost (feed cost, Birr)	13770	11520	9720	1173	0.0001
Net return (Birr)	-10222	-7964	-6088	-	-
MRR vs. control (%)	-	100.4	102.1	-	-

**Feed cost includes PPM processing cost of 2.50 Birr/kg for T2 and T3. **Live weight value based on January 2024 market survey.*

Marginal Rate of Return Calculation:

T2 vs. T1:

- Δ Net Return = -7964 - (-10222) = 2258 Birr
- Δ Total Variable Cost = 11520 - 13770 = -2250 Birr
- MRR = (2258 / 2250) × 100 = 100.4%

T3 vs. T1:

- Δ Net Return = -6088 - (-10222) = 4134 Birr
- Δ Total Variable Cost = 9720 - 13770 = -4050 Birr
- MRR = (4134 / 4050) × 100 = 102.1%

Note on MRR Interpretation: The MRR values indicate the additional net return obtained per unit of cost reduction when moving from the control to PPM-containing diets. Because all treatments resulted in negative net returns, the MRR in this context represents the rate at which losses are reduced, not profits generated. This distinction is critical for correct interpretation. A positive MRR does not indicate

profitability; it indicates that the PPM treatments reduced losses more efficiently than they reduced costs.

Important Economic Interpretation: It must be emphasized that all treatments resulted in negative net returns (-10,222, -7,964, and -6,088 Birr for T1, T2, and T3, respectively). This reflects the high cost of feed relative to the market price of live chickens in the study area. Under these conditions, no treatment was profitable, and the "economic advantage" of PPM inclusion refers only to the reduction in losses, not to the generation of positive returns.

The key finding is that PPM inclusion substantially reduced the magnitude of these losses, with T3 losing 4,134 Birr less than the control group (a 40% reduction in economic losses). However, a smallholder producer cannot sustain production with a net return of -6,088 Birr, and the practical significance of loss reduction must be evaluated within the broader context of farm viability. Reducing losses and increasing profitability are distinct economic phenomena, and addressing these two concepts without distinguishing between them may give readers a misleading impression.

Sensitivity Analysis: A sensitivity analysis was conducted to assess the robustness of the economic results to changes in key parameters (Table 11).

Table 11. Sensitivity analysis of net return (Birr) to changes in key parameters

Parameter	Change	T1	T2	T3
Base case	-	-10222	-7964	-6088
PPM price	+20%	-10222	-8448	-6876
PPM price	-20%	-10222	-7480	-5300
SBM price	+20%	-10974	-7964	-6088
SBM price	-20%	-9470	-7964	-6088
Chicken price	+20%	-9495	-7237	-5361
Chicken price	-20%	-10949	-8691	-6815

The sensitivity analysis shows that:

1. Changes in PPM price affect only T2 and T3, with a ±20% change altering net returns by approximately ±500-800 Birr.
2. Changes in SBM price affect only T1 (control), as SBM is not used in PPM-containing diets.
3. Changes in chicken price affect all treatments proportionally, with a 20% increase in chicken price reducing losses by approximately 700-750 Birr across all treatments.
4. Under no scenario did any treatment achieve positive net returns, indicating that the unprofitability of the system is robust to reasonable price variations.

Interpretation:

The economic benefits observed in the present study support the use of locally available pigeon pea as a partial substitute for soybean meal, particularly in smallholder poultry systems where feed cost is a major production constraint (Ani and Okeke, 2011; Amaefule et al., 2011). However, the persistent negative net returns across all treatments indicate that feed cost reduction alone is insufficient to ensure profitability under current market conditions. Additional interventions, such as improved bird genetics, better market access, or higher chicken prices, may be necessary to achieve economic viability.

These findings are consistent with previous studies showing that incorporation of alternative protein sources can reduce production costs without compromising overall productivity (Arif et al., 2017; Ojediran and Emiola, 2021). However, the economic analysis in the present study highlights the importance of considering processing costs and the overall profitability context when evaluating alternative feed ingredients.

4. Discussion

The present study demonstrates that processed pigeon pea meal (PPM) can partially replace soybean meal in diets of Sasso chickens without significant adverse effects on growth performance or carcass characteristics, while reducing feed costs. These findings support the potential use of locally available pigeon pea as an alternative plant-protein source in poultry diets, particularly where soybean meal is expensive or difficult to obtain. Nevertheless, the reduction in feed efficiency observed at higher PPM inclusion levels indicates that the nutritional benefits of this ingredient may depend on inclusion level, processing efficiency, dietary formulation and the economic conditions under which poultry are produced.

4.1. Feed efficiency and possible nutritional constraints at higher PPM inclusion levels

The poorer feed conversion ratio observed at the higher PPM inclusion levels warrants consideration. Because nutrient digestibility, amino acid availability and residual anti-nutritional factors (ANFs) were not directly measured in the present study, the mechanisms responsible for this response cannot be established definitively. Nevertheless, several nutritional factors may plausibly contribute.

First, crude fibre increased from 4.1% in the control diet to 5.5% in the diet containing the highest PPM level. An increase in dietary fibre may reduce nutrient density and, depending on its composition, limit the efficiency with which dietary nutrients are utilized. Consequently, birds may need to consume more feed to obtain sufficient metabolizable energy and nutrients, potentially increasing feed conversion ratio.

Second, differences in protein quality between pigeon pea and soybean meal may have contributed to the observed response. Pigeon pea is relatively limited in sulfur-containing amino acids, particularly

methionine and cysteine, compared with soybean meal (Akande et al., 2010; Singh and Eggum, 1984). In the absence of targeted synthetic amino-acid supplementation, increasing the proportion of pigeon pea protein could therefore alter the amino-acid balance of the diet and reduce protein utilization efficiency. However, this explanation remains tentative because amino-acid concentrations and digestibility were not determined in the present experiment.

Third, residual ANFs may have contributed to the reduced feed efficiency at higher inclusion levels. Soaking and boiling were used to process the pigeon pea, but the concentrations of trypsin inhibitors, tannins, phytate or other relevant compounds were not quantified before or after processing. Therefore, the extent to which processing reduced these compounds cannot be established. Previous studies have shown that the effectiveness of pigeon pea processing varies according to cultivar, processing method and processing conditions (Onu et al., 2006; Abd El-Hack et al., 2018; Goswami et al., 2024). Residual ANFs could potentially interfere with protein digestion and nutrient utilization and thereby contribute to poorer feed efficiency at high inclusion levels.

Overall, the present results demonstrate an association between higher PPM inclusion and reduced feed efficiency but do not establish a specific physiological or nutritional mechanism. The observed response may reflect the combined effects of dietary fibre, protein quality, residual ANFs and nutrient availability. Direct assessment of these factors is therefore required before a causal explanation can be made.

4.2. Practical and economic implications

The potential economic advantage of PPM is particularly relevant to smallholder poultry production, where feed constitutes a major component of production costs and dependence on conventional protein sources can constrain profitability. The lower cost of pigeon pea relative to soybean meal provides a potential economic incentive for incorporating processed PPM into poultry diets.

However, the economic value of PPM substitution should not be assessed solely on the basis of ingredient price. Feed conversion efficiency, processing costs, bird performance, market prices and the value of poultry products must also be considered. Thus, an inexpensive protein ingredient may not necessarily provide an economic advantage if its inclusion substantially increases feed required per unit of weight gain.

The present economic analysis indicated that PPM-containing diets reduced production losses under the market conditions considered. Nevertheless, all treatments were economically unprofitable under the prevailing prices. This finding is important because it indicates that biological acceptability of an alternative feed ingredient does not necessarily translate into overall farm profitability. Economic recommendations should therefore be interpreted within the specific market context of the study rather than generalized to all production systems.

The observed performance responses suggest that PPM can be considered as a partial replacement for soybean meal within the tested dietary range. However, recommendations concerning inclusion levels of

approximately 29–32% should be regarded as conditional rather than universal. The appropriate inclusion level will depend on pigeon pea cultivar, processing method, nutrient composition, genotype of the chicken, availability and price of soybean meal and pigeon pea, and the performance objectives of the production system.

4.3. Contribution to the existing literature

Although pigeon pea has previously been evaluated as a poultry feed ingredient, the present study provides additional evidence from Sasso chickens under Ethiopian production conditions. The study is particularly relevant because locally available alternative protein resources may contribute to reducing dependence on conventional feed ingredients and improving the flexibility of poultry feeding systems.

A further contribution is the integration of biological performance and economic evaluation. Assessing feed cost alongside growth and carcass responses provides a more practical basis for evaluating alternative protein sources than performance measurements alone. The findings also highlight an important trade-off: increasing PPM inclusion may reduce dietary cost while potentially compromising feed efficiency at higher inclusion levels.

The study therefore provides useful preliminary evidence for the utilization of processed pigeon pea in Sasso chicken diets while identifying specific nutritional questions that require further investigation. In particular, understanding the relationships among processing, ANF reduction, amino-acid availability, nutrient digestibility and feed efficiency would strengthen the nutritional basis for recommending PPM inclusion levels.

4.4. Study limitations

Several limitations should be considered when interpreting the findings. First, ANFs were not quantified before or after processing. Consequently, the effectiveness of soaking and boiling in reducing specific ANFs cannot be verified. This is important because the magnitude of ANF reduction depends on cultivar and processing conditions (Onu et al., 2006; Abd El-Hack et al., 2018; Goswami et al., 2024).

Second, amino-acid composition and amino-acid digestibility were not determined. Although pigeon pea has been reported to have relatively low concentrations of sulfur-containing amino acids (Akande et al., 2010; Singh and Eggum, 1984), the contribution of amino-acid imbalance to the observed feed conversion response cannot be established without dietary amino-acid profiling and digestibility measurements.

Third, nutrient digestibility and nutrient utilization were not directly assessed. Consequently, it is not possible to determine whether the reduction in feed efficiency resulted from changes in protein digestibility, energy availability, amino-acid utilization or other nutritional factors.

Fourth, physiological indicators such as blood metabolites, digestive enzyme activity and intestinal morphology were not evaluated. These measurements could have provided additional evidence concerning the biological responses to increasing PPM inclusion.

Fifth, the experimental diets were not supplemented specifically to correct potentially limiting amino acids. Consequently, the effect of PPM under a nutritionally amino-acid-balanced formulation remains uncertain. Previous research has indicated that methionine and lysine supplementation can improve performance when pigeon pea is included at higher levels (Amaefule et al., 2011).

Finally, the experiment was conducted during a single production cycle with three replicates per treatment. The relatively small number of experimental units reduces statistical power and may limit the ability to detect smaller treatment effects. In addition, the findings were obtained under specific environmental, management and market conditions and should therefore be extrapolated to other production systems with caution.

4.5. Implications for future research

Further research should focus on defining the nutritional mechanisms underlying the response to processed PPM. Direct quantification of major ANFs before and after processing would establish the effectiveness of the processing procedure and permit identification of residual concentrations associated with changes in bird performance. Comparative evaluation of soaking, boiling, autoclaving, roasting, fermentation and extrusion would also help identify processing strategies that maximize nutrient availability while minimizing processing costs. Previous studies indicate that processing effectiveness varies substantially among pigeon pea genotypes and methods (Onu et al., 2006; Abd El-Hack et al., 2018; Goswami et al., 2024).

Future studies should also characterize the amino-acid composition and standardized ileal amino-acid digestibility of processed PPM and complete experimental diets. Such information would allow identification of limiting amino acids and facilitate formulation of diets based on digestible amino-acid requirements rather than crude protein alone. This is particularly relevant because differences in amino-acid composition and digestibility may influence the response of chickens to increasing PPM inclusion.

Digestibility trials incorporating measurements of crude protein, energy and amino-acid utilization would further clarify whether the poorer feed efficiency at higher inclusion levels is associated with reduced nutrient availability. In parallel, measurements of blood biochemical indicators, digestive enzyme activity and intestinal morphology could help identify physiological mechanisms underlying the observed performance responses.

Research should additionally evaluate amino-acid supplementation strategies, particularly methionine and lysine, to determine whether balancing potentially limiting amino acids can improve feed efficiency at higher PPM inclusion levels. Longer-term studies involving larger numbers of experimental units are also needed to evaluate health, meat quality and production consistency.

Finally, multi-location and multi-season trials involving different poultry genotypes and locally available pigeon pea cultivars would improve the external validity of the findings. Economic optimization should be conducted alongside biological evaluation because the optimum inclusion level is likely to vary with ingredient prices, processing costs, feed efficiency and poultry-product prices. Such studies would provide a stronger basis for developing practical recommendations for both smallholder and commercial poultry production systems in Ethiopia.

Conclusion

Processed pigeon pea meal (PPM) can partially replace soybean meal (SBM) in Sasso chicken diets without adversely affecting body weight gain or most carcass characteristics under the conditions of this study. Inclusion of PPM up to 32% in the starter phase and 29% in the finisher phase maintained growth performance and carcass yield compared with the SBM-based control. However, the highest inclusion level was associated with poorer feed conversion, indicating that increasing PPM inclusion may reduce feed-use efficiency beyond an appropriate level. The economic analysis showed that PPM inclusion reduced the magnitude of production losses compared with the control under the market conditions prevailing during the study. Nevertheless, all treatments resulted in negative net returns, indicating that feed cost reduction alone was insufficient to achieve profitability. Thus, the economic advantage of PPM should be interpreted as a reduction in production losses rather than evidence of profitable production. Processed PPM may therefore be considered a practical partial substitute for SBM in Sasso chicken diets, particularly where pigeon pea is locally available at a competitive price. The finisher inclusion level of approximately 29% represents the highest level evaluated without adverse effects on most measured production and carcass traits; however, this should not be considered a universal optimum. Because anti-nutritional factors, amino-acid availability and nutrient digestibility were not directly measured, the mechanisms underlying reduced feed efficiency remain uncertain. Further research should evaluate these factors, alternative processing methods and amino-acid supplementation using adequately replicated trials to establish nutritionally and economically optimized PPM inclusion levels.

Declarations

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The authors declare that they have no competing interests.

Data Availability Statement

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

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Data Availability: The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

Ethical Approval: All procedures involving experimental animals complied with internationally accepted guidelines for the care and use of animals in research. The experimental protocol was approved by the Animal Research Ethics Committee of Arba Minch University (Reference No. AMU/ANSC/2024/01). Bird management, handling, and slaughter procedures were conducted in accordance with the recommendations of the World Organisation for Animal Health (WOAH, formerly OIE, 2023) to minimize stress and ensure animal welfare.

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