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Nutritional and Some Phytochemical Profiling of Pigeon Pea (*Cajanus Cajan*) Seed Meal: Exploring Its Potential as A Sustainable Protein Source

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ABSTRACT

Nutritional and phytochemical profiling of underutilized legumes is critical for diversifying sustainable protein sources in tropical food systems. This study evaluated the effects of processing on the proximate composition and phytochemical profile of pigeon pea (*Cajanus cajan*) seed meal and its incorporation into composite diets. Raw seed meal contained 87.00% dry matter, 3.20% ash, 2.00% crude fat, 6.25% crude Fiber, 10.85% crude protein and 74.35% carbohydrate. Processing of the seed meal modulated these constituents: moisture decreased from 3.35% (raw) to 2.52% (boiled) and 2.05% (toasted); crude protein ranged from 27.43–31.55%, with toasting giving the highest value (31.55%); crude Fiber varied between 4.13–4.46%, and ash between 3.25–3.61%. Incorporation of processed pigeon pea into diets (4–12%) maintained crude protein at 16.74–17.88%, with toasted 12% inclusion achieving 17.88% protein, 4.32% Fiber and 2.89% ash, alongside modest moisture (2.47–4.54%) and carbohydrates (57.15–62.69%). Thermal processing drastically lowered anti-nutritional factors: oxalate (2.43 to 0.90–1.08 mg/g), phytic acid (10.71 to 2.24–1.06 mg/g), saponins (24.72 to 0.91–1.63 mg/g), tannins (4.17 to 0.92–1.17%), and trypsin inhibitor (29.40 to 2.01–1.61%). Collectively, these results demonstrate that especially toasted *C. cajan* seed meal combines high crude protein (up to 31.55%), appreciable Fibre (up to 10.00%), improved dry matter (88.87%) and markedly reduced anti-nutrients, supporting its utilization as a sustainable plant-based protein ingredient in value-added foods and feeds. Conclusively, thermal processing transforms raw pigeon pea, naturally limited by anti-nutrient content, into a more nutrient-dense, protein-rich, and lowered-moisture ingredient. Further investigations on amino acid profile, digestibility, bioavailability, and functional properties to maximize its utilization is thus recommended.

Keywords: Pigeon pea, proximate analysis, phytochemical analysis, anti-nutritional factors, and Processing

INTRODUCTION

The rapid growth of global population and the pressing need for sustainable food systems have intensified the search for alternative, underutilized plant-based protein sources. Traditional protein crops, such as soybean, face increasing challenges including high water demand, extensive land requirements, and vulnerability to climate change, highlighting the urgent need for more resilient and environmentally adaptable options (Majidian *et al*., 2024). Legumes, notable for their substantial protein content, ability to fix atmospheric nitrogen, and adaptability to diverse agro-ecological conditions, offer a promising solution to these challenges (Jach *et al*., 2022). Within this group, pigeon pea (*Cajanus cajan*) emerges as a particularly resilient and nutrient-rich legume with considerable potential. Pigeon pea is widely cultivated across tropical and subtropical regions, particularly thriving in semi-arid environments where other crops may struggle (Abebe, 2022). Its seeds are rich in protein, dietary Fibre, and essential minerals, contributing significantly to human nutrition in many regions (Nafees *et al*., 2025). Beyond its dietary value, pigeon pea offers ecological benefits such as soil fertility enhancement and drought tolerance, positioning it as an important crop in sustainable agricultural systems. Despite these advantages, pigeon pea remains underutilized in both commercial food and animal feed applications compared with more widely established legumes (Haji *et al*., 2024). A major constraint to the broader utilization of pigeon pea seeds is their content of anti-nutritional factors (ANFs), including trypsin inhibitors, tannins, phytates, and certain oligosaccharides (Samtiya *et al*., 2020). These compounds can reduce nutrient digestibility and mineral bioavailability and, if consumed in large amounts without appropriate processing, may exert negative physiological effects in Monogastric animals and humans (Salim *et al*., 2023). Fortunately, a range of traditional and industrial processing methods—such as soaking, boiling, fermentation, and toasting—can significantly reduce or eliminate these anti-nutritional components, thereby improving the nutritional quality and digestibility of pigeon pea seeds (Noori *et al*., 2025). Understanding how these processing techniques affect both the phytochemical profile and proximate composition is therefore essential for maximizing the value of pigeon pea in food and feed applications. In addition to macronutrients, the phytochemical composition of pigeon pea warrants close attention. Detailed profiling of these compounds in raw and processed pigeon pea seeds can uncover additional functional benefits, positioning pigeon pea not only as a protein source but also as a potential functional food ingredient. Such knowledge is critical for designing innovative food products and feed formulations that fully exploit the nutritional and bioactive potential of this legume. Consequently, a comprehensive evaluation of the nutritional and phytochemical properties of pigeon pea seed meal, particularly in response to various processing methods, is crucial to unlock its full potential as a sustainable protein source. This study aims to address this gap by systematically assessing the proximate composition and phytochemical profile of raw and processed pigeon pea seeds. The findings will provide valuable insights for optimizing the use of pigeon pea in food and feed industries, thereby contributing to global efforts to enhance sustainable protein production and improve food and feed security.

MATERIALS AND METHODS

Experimental Site

The experiment was conducted at the Department of Science Laboratory Technology, Rufus Giwa Polytechnic, Owo, Nigeria.

Test Ingredient and Sample Procurement: The test ingredient used in this study was pigeon pea (*Cajanus cajan*) seed. Mature, dry pigeon pea seeds were purchased from a popular local market in Owo, Nigeria. All reagents and chemicals used for proximate and phytochemical analyses were of analytical grade and were procured from reputable suppliers.

Preparation of Test Ingredients: Pigeon pea seeds were manually cleaned by handpicking to remove dirt, stones, broken seeds, and other foreign materials. The seeds were then winnowed to ensure complete removal of chaff. Clean seeds were divided into three batches: one batch was retained as raw (unprocessed) pigeon pea seed meal (PPSM), while the other two batches were subjected to different processing methods as follows:

Boiling Processing Method

Seeds were boiled in water at 100°C for 45 minutes. After boiling, the seeds were drained and spread on clean polythene sheets, then sun-dried to constant weight over several days. The dried, boiled seeds were subsequently milled using a hammer mill to obtain a fine powder.

Toasting Processing Method: Seeds were toasted using hot sand. Clean, sharp sea sand was first heated in a flat-bottom pan over medium heat until hot. Pigeon pea seeds were then added to the hot sand and toasted for 5 minutes with constant stirring to ensure uniform heating and prevent scorching. The toasting process was considered complete when the seeds turned golden yellow. The toasted seeds were then removed from the sand, allowed to cool to ambient temperature, and milled into a fine powder using a hammer mill. All three forms of pigeon pea seed meal (raw, boiled, and toasted) were stored in airtight containers under cool, dry conditions until subjected to proximate and phytochemical analyses.

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Experimental Diets

Seven experimental diets were formulated to meet the nutritional requirements of laying birds. The diets included a control diet (0% pigeon pea seed meal) and six test diets containing varying inclusion levels of boiled or toasted pigeon pea meal. Other feed ingredients such as maize. Soybean meal, wheat offal, bone meal, and vitamin-mineral premixes were sourced locally and used to formulate iso-nitrogenous and iso-caloric diets.

i. T1 – Control Diet – 0% inclusion level

ii. T2 – 4% Boiled Pigeon Pea Seed Meal Inclusion Level (4% BPPSM)

iii. T3 – 8% Boiled Pigeon Pea Seed Meal Inclusion Level (8% BPPSM)

iv. T4 – 12% Boiled Pigeon Pea Seed Meal Inclusion Level (12% BPPSM)

v. T5 – 4% Toasted Pigeon Pea Seed Meal Inclusion Level (4% TPPSM)

vi.T6 – 8% Toasted Pigeon Pea Seed Meal Inclusion Level (8% TPPSM)

vii.T5 – 12% Toasted Pigeon Pea Seed Meal Inclusion Level (12% TPPSM)

Table 1: Percentage (%) Composition of the Experimental Diets

1ngredients	**Treatment 1 0%BPPSM**	**Treatment 2 4%BPPSM**	**Treatment 3 8% BPPSM**	**Treatment 4 12% BPPSM**	**Treatment 5 4% TPPSM**	**Treatment 6 8% TPPSM**	**Treatment 7 12% TPPSM**
Maize	50.00	50.00	50.00	50.00	50.00	50.00	50.00
Soyabean Meal	22.00	18.00	14.00	10.00	18.00	14.00	10.00
Pigeon pea	0.00	4.00	8.00	12.00	4.00	8.00	12.00
Wheat Offal	15.40	15.40	15.40	15.40	15.40	15.40	15.40
Bone meal	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Limestone	8.70	8.70	8.70	8.70	8.70	8.70	8.70
Lysine	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Methionine	0.10	0.10	0.10	0.10	0.10	0.10	0.10
*Premix	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Salt	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**
Calculated Analysis							
Crude Protein (%)	**17.61**	**16.01**	**16.14**	**16.22**	**16.19**	**16.34**	**16.42**

Crude Fat (%)	**4.32**	**3.96**	**3.65**	**3.34**	**3.96**	**3.65**	**3.34**
Crude Fibre (%)	**3.93**	**3.87**	**3.85**	**3.84**	**3.87**	**3.85**	**3.84**
ME (Kcal/Kg)	**2688.02**	**2587.25**	**2576.45**	**2565.65**	**2577.25**	**2596.45**	**2582.65**

**Premix (2.5kg/1000kg) supplied: vitamin A (10,000,0001), vitamin D. (3,000,000/U), vitamin E (30,000IU), vitamin K (2.3gm), vitamin B1 (2.0gm), Riboflavin (5.0gm), Pyridoxine (3.0gm), vitamin B12 (160mg), Biotin (60mg), Niacin (3 1gm), panthotenic acid (8gm), folic acid (1gm), manganese (85gm), zinc (50gm), iron (25gm), copper (6gm), iodine (1gm), selenium (120gm), cobalt (220mg), antioxidant (125gm), choline chloride (200gm).*

BPPSM: Boiled Pigeon Pea Seed Meal, **TPPSM:** Toasted Pigeon Pea Seed Meal

Proximate Analysis of Pigeon Pea Seed Meal: The proximate composition of untreated, boiled, and toasted pigeon pea seed meals was evaluated following procedures described by the Association of Official Analytical Chemists (AOAC, 2010), with slight modifications for laboratory convenience.

Moisture Determination: Moisture content was assessed using the air-oven drying technique. Pre-dried and cooled petri dishes were weighed, after which about 3g of each sample was placed into the dishes. The samples were oven-dried at 105°C for approximately 6 hours until a constant weight was obtained. After cooling in a desiccator, the dishes were reweighed, and moisture percentage was computed from the weight loss during drying.

Ash Determination

For ash evaluation, porcelain crucibles were pre-heated at 350°C in a muffle furnace, cooled, and weighed. 1g of sample was then added into each crucible. The samples were incinerated at 550°C for about 5 hours until light grey ash was obtained. The crucibles were again cooled in a desiccator and weighed. Ash content was reported as a percentage of the original sample mass.

Crude Protein Determination

Crude protein was quantified using the Kjeldahl procedure. Approximately 0.5g of each sample was digested with concentrated H_2SO_4 and a catalyst mixture at 420°C for 45 minutes. The digest was subsequently neutralized with NaOH, and the released ammonia was distilled into 4% boric acid. The distillate was titrated with 0.2 N HCl, and nitrogen content was converted to crude protein using the standard factor of 6.25.

Crude Fat Determination

Crude lipid content was measured using Soxhlet extraction. Roughly 3g of sample was placed in a thimble and extracted with analytical-grade acetone at 70°C for about 3 hours. After extraction, the solvent was evaporated, and the residue remaining in the receiving flask represented the crude fat, expressed as a percentage of the initial sample weight.

Crude Fibre Determination

Crude fibre was analyzed using sequential acid and alkaline digestion. 2g of finely ground sample were digested first with 0.128 M H_2SO_4 and later with 0.223 M KOH, using a hot extraction unit. Between steps, the residue was thoroughly washed with hot water and acetone. The final residue was dried at 105°C, ignited at 550°C, and the difference in weight before and after the determination of the ash content was used to calculate crude fibre content.

Carbohydrate Determination

Carbohydrate concentration was obtained by difference using:
Carbohydrate (%) = 100 – (Moisture + Protein + Fat + Ash + Fibre)

Phytochemical Analysis of Pigeon Pea Seed Meal

Phytochemical components in the raw and processed samples were determined using established colorimetric and spectrophotometric procedures.

Tannins: Tannin concentration was assessed using a Folin–Ciocalteu-based protocol. Ground samples were extracted with 70% acetone in an ice bath shaker. The clarified extract was reacted with Folin reagent and sodium carbonate, then read at 725 nm. Tannin content was determined from a tannic acid standard curve and reported as tannic acid equivalents.

Saponins: Saponins were quantified using the method of Brunner (1994). Samples were extracted in isobutyl alcohol, filtered, and clarified with magnesium carbonate. The filtrate was reacted with 5% $FeCl_3$, allowed to develop color for 30 minutes, and absorbance was measured at 380 nm. Saponin concentration was expressed as a percentage of sample weight.

Alkaloids: Alkaloid content was analyzed according to Harborne (1973). Samples were macerated in 10% acetic acid in ethanol, filtered, and the filtrate was concentrated and precipitated with ammonium hydroxide. The dried precipitate was weighed, and alkaloid content was expressed relative to the original sample mass.

Statistical Analysis: All analyses were executed in triplicate. Data were subjected to one-way ANOVA, and mean differences were compared using Duncan's Multiple Range Tests at a significance level of $P< 0.05$. Results were presented as mean ± standard error (SEM).

RESULTS AND DISCUSSION

3.1 Proximate Composition of Diets Containing varying levels of Processed Pigeon Pea

Table 1 reveals the proximate composition of diets containing boiled and toasted *Cajanus* *cajan* seed meal at varying. Incorporating processed pigeon pea seed meal into the experimental diets resulted in measurable changes in proximate composition compared with the control diet without pigeon pea (WPP). The diets tested included boiled pigeon pea (BPP) at 4%, 8%, and 12% (4%BPP, 8%BPP, and 12% BPP) and toasted pigeon pea (TPP) at the same inclusion levels (4%TPP, 8%TPP, and 12% TPP). Evaluated parameters included moisture, ash, crude fat, crude Fiber, crude protein, and calculated carbohydrate.

Moisture Content: Moisture varied significantly among the diets. The highest value was observed in the 12%BPP diet (4.54%), which was significantly higher than other treatments. Moderate moisture (3.60%) occurred in the 4%TPP diet. Other diets—including the control, 4%BPP, 8%BPP, and 8%TPP, and 12%TPP—had similar lower moisture values ranging from 2.10% to 2.50%.

Ash Content: Ash content, reflecting total mineral matter, differed across treatments. The highest mineral level was found in the 12%TPP diet (2.89%), followed by 12%BPP (2.55%) and intermediate values in 4%TPP, 8%TPP, and 4%BPP (2.04–2.30%). The control diet contained 2.50% ash. The lowest ash concentration occurred in 8%BPP (1.60%).

Crude Fat: Crude fat mirrored the ash trend. The 12%TPP diet had the highest fat (2.89%), followed by 12%BPP (2.55%) and 8%TPP (2.30%). The control diet was 2.50%. The lowest fat values were in 4%TPP (1.39%) and 8%BPP (1.60%).

Crude Fibre: Fiber content increased with pigeon pea inclusion. The 4%TPP diet showed the highest crude Fiber (4.90%), while 4%BPP and 8%TPP diets had 4.64% and 4.57%, respectively. Lowest values occurred in the control diet (3.86%) and 12%BPP (4.00%).

Crude Protein: Protein levels ranged from 16.74% to 17.88%, with statistically meaningful differences. The 12%TPP diet had the highest protein (17.88%), followed by 8%TPP (17.86%), 4%TPP (17.84%), and 4%BPP (17.81%). The control diet contained 17.76%. Lower protein values were noted for 8%BPP and 12%BPP (16.79% and 16.74%, respectively).

Carbohydrate Content

Carbohydrates constituted the largest nutrient fraction, decreasing with higher pigeon pea inclusion. The control diet had the highest carbohydrate level (62.69%). Boiled diets decreased progressively from 61.36% (4%BPP) to 59.32% (12%BPP). Toasted diets showed a more pronounced reduction, with the 12%TPP diet containing 57.15%.

The incorporation of processed pigeon pea seed meal into diets resulted in clear changes in nutrient composition, demonstrating its utility as a plant-derived protein ingredient. Both processing method and inclusion level influenced the nutrient profile, particularly affecting protein, Fibre, ash, and carbohydrates. Moisture remained low across treatments (2.10–4.54%), minimizing spoilage risk. The slightly higher moisture in the 12%BPP diet likely reflects water retention from boiling, but overall levels remain compatible with good storage stability.

Ash content increased most notably in toasted diets, especially at 12% inclusion. Toasting, a dry-heat method, helps retain minerals by preventing leaching, whereas boiling may result in some loss of water-soluble minerals. This trend indicates that toasted pigeon pea can contribute meaningfully to dietary mineral intake, which is especially relevant for populations at risk of micronutrient deficiencies.
Crude fat content was generally low but increased slightly in toasted diets. These low levels are favorable for shelf stability and reduce the risk of oxidative rancidity, while still supporting the inclusion of essential dietary lipids from other sources if needed.

Fibre content rose with pigeon pea inclusion, with toasted diets showing the greatest increase. Dry-heat processing likely preserves structural carbohydrates better than boiling, offering potential digestive benefits and promoting satiety in human diets or improved gut health in Monogastric animals.
Protein levels were maintained or improved in toasted diets, even at higher inclusion levels. Boiled diets at high inclusion showed modest decreases, possibly due to nutrient leaching or dilution effects. This suggests that dry-heat processing preserves protein integrity while reducing anti-nutritional factors, enhancing the functional and nutritional quality of the meal (Cheng *et al.*, 2025).
Carbohydrate content decreased with higher pigeon pea levels, particularly in toasted diets. This reflects a relative shift toward Fibre, protein, and mineral fractions, increasing the nutritional density of the diets. Such changes are advantageous for formulations targeting protein–energy balance.

Table 2: Proximate composition of diets containing differently processed Pigeon pea at graded level

Parameters (%)	WPP (Control)	4% BPP	8% BPP	12% BPP	4% TPP	8% TPP	12% TPP	SEM
Moisture content	2.10^{b}	2.25^{b}	2.48^{b}	4.54^{a}	3.60^{ab}	2.50^{b}	2.47^{b}	0.24
Ash content	2.50^{c}	1.39^{g}	2.04^{e}	2.55^{b}	1.60^{f}	2.30^{d}	2.89^{a}	0.00
Crude Fat	2.50^{c}	1.39^{g}	2.04^{e}	2.55^{b}	1.60^{f}	2.30^{d}	2.89^{a}	0.11
Crude Fibre	3.86^{g}	4.64^{b}	4.09^{e}	4.00^{f}	4.90^{a}	4.57^{c}	4.32^{d}	0.08

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Crude Protein	17.76^{e}	17.81^{d}	16.79^{f}	16.74^{g}	17.84^{c}	17.86^{b}	17.88^{a}	0.11
Carbohydrates	62.69^{a}	61.36^{b}	60.33^{c}	59.32^{e}	60.23^{d}	58.97^{f}	57.15^{g}	0.05

^{abc}: Means on the same row with different superscripts differ significantly(P<0.05).

SEM = standard error of means. WPP: Without Pigeon pea, BPP: Boiled Pigeon pea,

TPP: Toasted Pigeon pea

Effect of Processing on Proximate Composition of Seed Meal (Raw and Processed)

The proximate composition of raw, boiled, and toasted pigeon pea seed meals is summarized in Table 3, showing how thermal treatments altered moisture, lipid, Fiber, protein, and carbohydrate content.

Moisture Content: Moisture differed significantly among samples (P < 0.05). The unprocessed meal contained 3.35% moisture, which decreased to 2.52% after boiling and 2.05% after toasting. Both processing methods reduced water content, with toasting producing the driest product.

Ash Content: Ash values were relatively consistent, ranging from 3.25% to 3.61%. Boiling slightly increased ash content compared to the raw meal (3.61% vs. 3.28%), whereas toasting produced a minor reduction (3.25%).

Crude Fat: Crude fat declined with processing. Raw meal contained 2.07% fat, dropping to 1.19% after boiling and 1.60% after toasting.

Crude Fibre: Fibre content showed slight variation across treatments. Toasted meal had the highest Fibre (4.46%), followed by raw (4.25%), with boiled meal the lowest (4.13%).

Crude Protein: Protein content was most affected by processing. Toasted meal had the highest protein (31.55%), raw meal contained 30.85%, and boiled meal dropped to 27.43%.

Carbohydrates; Carbohydrate content, calculated by difference, ranged from 56.25% to 60.41% (SEM = 0.64). Boiled meal had the highest carbohydrate proportion (60.41%), while toasted and raw meals contained 57.10% and 56.25%, respectively.

Discussion of Processing Effects on Proximate Composition

Processing substantially altered the proximate composition of pigeon pea seed meal, with important implications for nutritional quality and functional use as a plant-based protein source. Observed ranges—protein (27.43–31.55%), fat (1.19–2.07%), and Fibre (4.13–4.46%)—are comparable to those reported for many legumes used in sustainable protein systems.

Moisture Dynamics and Storage: All samples had low moisture (2.05–3.35%), well below thresholds that support microbial growth. Toasting produced the driest meal, improving storage stability, transportation potential, and shelf life, particularly in regions with limited refrigeration.

Mineral Retention (Ash): Ash content varied slightly among treatments. Boiling caused minor increases, likely due to water loss concentrating minerals, whereas toasted samples showed small reductions, potentially reflecting heat-induced changes in mineral complexes (Belinda *et al*., 2025). Overall, total mineral content remained stable, although further mineral-specific analysis is warranted.

Lipid Changes: Crude fat declined, with the greatest reduction during boiling, probably due to leaching into water. Toasting retained more lipids, maintaining functional and nutritional value. Low fat content is

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advantageous for shelf stability but may necessitate supplemental fats in energy-dense formulations (Fadillah *et al*., 2024).

Fibre Response: Fiber content decreased with boiling and increased with toasting. Wet heat may soften or partially solubilize Fiber, whereas dry heat preserves or concentrates it. Increased Fiber in toasted meal can enhance digestive health and satiety, beneficial for both human diets and Monogastric animal feeding (Ioniță-Mîndrican *et al*., 2022).

Protein Considerations: Protein was strongly affected by processing. Boiling reduced crude protein due to soluble nitrogen losses, while toasting concentrated protein by reducing moisture. Although higher protein content is beneficial, it does not automatically indicate superior biological quality (Calvez *et al*., 2024). Wet heat may reduce anti-nutrients and improve digestibility, while toasting could cause Maillard reactions that slightly impair lysine availability (El Hosry *et al*., 2025). Amino acid profiling and digestibility assays are recommended for comprehensive assessment.

Carbohydrate Trends: Carbohydrates increased in boiled samples due to reductions in protein and fat rather than absolute carbohydrate gains, reflecting a compositional trade-off. Toasted samples maintained lower carbohydrate fractions, contributing to higher protein and fibre density. Thermal processing significantly modifies pigeon pea seed composition. Toasting emerges as the preferred method for producing protein-rich, Fibre-enhanced, shelf-stable meals (Onimawo *et al*., 2006), while boiling effectively reduces anti-nutrients but lowers protein density (Deol *et al*., 2010). These results support the development of sustainable pigeon pea–based ingredients for food and feed applications.

Table 3: Proximate composition raw and processed pigeon pea seed meal

Parameters (%)	RPPSM	45 mins BPPSM	5 mins TPPSM	SEM
Moisture content	3.35^{a}	2.52^{b}	2.05^{c}	0.19
Ash content	3.28^{a}	3.61^{a}	3.25^{b}	0.06
Crude Fat (E.E)	2.07^{a}	1.19^{b}	1.60^{c}	0.07
Crude Fibre	4.25^{b}	4.13^{c}	4.46^{a}	0.05
Crude Protein	30.85^{b}	27.43^{c}	31.55^{a}	0.64
Carbohydrates (NFE)	56.25^{c} 50.11	60.41^{a}	57.10^{b}	0.64

^{abc}: Means on the same row with different superscripts differ significantly($P<0.05$).

SEM = standard error of means. RPPSM: Raw pigeon pea Seed meal, BPPSM: Boiled pigeon pea Seed meal, TPPSM: Toasted pigeon pea Seed meal, NFE= Nitrogen Free Extract, EE= Ether Extract

Table 4 presents the chemical composition of raw, boiled, and toasted pigeon pea seed meals, highlighting the effects of short-duration heat processing on nutrient and phytochemical content.

Crude Protein: Protein content increased with thermal treatment. Raw seeds contained 28.10% protein, which rose to 29.37% after boiling for 45 minutes and reached 30.17% after a brief 5-minute toasting. Toasted seeds thus exhibited the highest protein concentration, reflecting the concentration effect due to moisture loss.

Ether Extract (Crude Fat): Fat levels were low across all samples but slightly increased following heat treatment: 2.10% in raw, 2.20% in boiled, and 2.21% in toasted meal.

Crude Fibre: Fibre increased markedly with processing. Raw seeds contained 7.49% Fibre, which rose to

9.88% after boiling and 10.00% after toasting.

Ash Content: Ash, reflecting total mineral content, increased progressively: 4.81% in raw, 5.17% in boiled, and 5.54% in toasted meals.

Nitrogen-Free Extract (Carbohydrates): The carbohydrate fraction, calculated by difference, declined as other components increased. Raw meal had 50.11% NFE, which decreased to 45.60% after boiling and 44.95% after toasting.

Dry Matter: Heat treatment increased dry matter content, from 86.61% in raw seeds to 88.22% in boiled and 88.87% in toasted seeds.

Phytochemicals and Anti-Nutritional Factors: Processing substantially reduced anti-nutritional compounds. Oxalates decreased from 2.43 mg/g (raw) to 0.90 mg/g (boiled) and 1.08 mg/g (toasted), reductions of 63% and 56%, respectively.

Phytic acid dropped from 10.71 mg/g (raw) to 2.24 mg/g (boiled) and 1.06 mg/g (toasted), representing reductions of 79% and 90%. Saponins fell dramatically from 24.72 mg/g (raw) to 0.91 mg/g (boiled) and 1.63 mg/g (toasted), a decrease exceeding 93% in both cases. Tannins declined from 4.17% (raw) to 0.92% (boiled) and 1.17% (toasted), reductions of 72–78%. Trypsin inhibitor activity dropped from 29.40% (raw) to 2.01% (boiled) and 1.61% (toasted), indicating over 93% inactivation.

The results indicate that even brief heat treatments—boiling for 45 minutes or toasting for 5 minutes significantly modify the nutritional and anti-nutrient profile of pigeon pea seed meal.

Proximate Composition: Thermal processing increased crude protein, with toasting producing the greatest effect. Protein rose from 28.10% in raw seeds to 29.37% (boiled) and 30.17% (toasted), largely due to moisture loss and corresponding concentration of nutrients, as supported by the reduction in nitrogen-free extract and increase in dry matter. Ether extract and Fiber also increased slightly. The rise in Fiber may reflect structural modifications induced by heat, while ash increases indicate a higher concentration of mineral residues (Maj *et al*., 2025), although the identity and bioavailability of specific minerals were not determined.

Anti-Nutritional Factors: Heat treatments dramatically lowered anti-nutrients. Boiling was slightly more effective in reducing water-soluble compounds like oxalates and saponins, likely via leaching, whereas toasting achieved the greatest reduction in phytic acid. Both methods inactivated trypsin inhibitors almost completely, improving protein digestibility potential.

Comparison of Processing Methods: While both boiling and toasting enhanced nutritional quality, their impacts differed. Boiling effectively removed some anti-nutrients but led to lower protein concentration, whereas toasting maximized protein, Fiber, ash, and dry matter while substantially reducing anti-nutrient levels (Ravi *et al*., 2024). Toasting also avoids water use and effluent production, offering practical advantages in regions with limited water resources.

Table 4: Phytochemical analysis of raw and differently processed pigeon pea

Parameters	Raw	45 mins boiled	5 mins Toasted	SEM
Oxalate (mg/g)	2.43^a	0.90^c	1.08^b	0.24
Phytic acid (mg/g)	10.71^a	2.24^b	1.06^c	1.00
Saponins (mg/g)	24.72^a	0.91^c	1.63^b	0.51
Tannin (%)	4.17^a	0.92c	1.17^b	0.42
Trypsin inhibitor (%)	29.40^a	2.01^b	1.61^c	0.61

CONCLUSION AND RECOMMENDATION

Conclusion

Thermal processing transforms raw pigeon pea, naturally limited by anti-nutrient content, into a more nutrient-dense, protein-rich, and lowered-moisture ingredient. Toasted seed meal, in particular, offers an optimal balance of enhanced nutrient density and substantial anti-nutrient reduction, making it a strong candidate for incorporation into fortified foods, complementary diets, and sustainable plant-based protein products.

Recommendation

Thermally processed *Cajanus cajan* seed meal—especially toasted—shows marked nutritional enhancement and reduced anti-nutrient levels. Therefore, we recommend:

1. **Adopt Toasted Pigeon Pea Meal:** Incorporate toasted pigeon pea meal into food and feed formulations, as it delivers higher protein (30.17%), Fiber (10.00%), and significantly reduced anti-nutrients (phytic acid 1.06 mg/g), supporting improved nutrient composition at up to 12% inclusion.

2. Prioritize Toasting: Promote toasting as the standard processing method for pigeon pea due to its superior nutritional and anti-nutrient outcomes.

3. Foster Product Innovation: Encourage development of diverse, value-added products using toasted pigeon pea as a functional ingredient.

4. Enhance Food Security: Integrate this improved protein source into nutrition and food-security interventions to support sustainable dietary protein supply.

5. Expand Research: Conduct further investigations on amino acid profile, digestibility, bioavailability, and functional properties to maximize its utilization.

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