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Pressure Cooking Triumphs: Maximizing Nutrient Bioavailability and Minimizing Flatulence Factors in Cowpea (*Vigna unguiculata*) Through Modern Culinary Techniques

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ABSRTACT

Cowpea (*Vigna unguiculata*), a nutrient-dense legume, contains flatulence-inducing oligosaccharides and antinutritional factors that limit its utilization. This study evaluated the effects of traditional cooking (soaking, gas stove cooking) and modern cooking (pressure cooking, bicarbonate cooking) methods on two cowpea varieties (brown: I.Ar 48; white: I.Ar 256 -Vita 5) to optimize nutrient retention and reduce antinutrients. Proximate composition, oligosaccharides (raffinose, stachyose), antioxidants, antinutrients (phytate, oxalate), and mineral bioavailability were analyzed. Pressure cooking reduced raffinose and stachyose by 73.7% (1.67 mg/ml) and 81.1% (9.64 mg/ml), respectively, in the brown variety, outperforming other methods. Bicarbonate cooking decreased phytate by 48.5%, while pressure cooking remained 12.3% higher crude protein compared to traditional boiling. Moisture content increased by 15–20% in soaked samples, whereas pressure cooking enhanced carbohydrate retention (68.2%) through the process of starch gelatinization. The brown variety retained 25–30% higher antioxidants post-cooking due to polyphenol-rich seed coats, while the white variety showed superior mineral retention (Fe: 8.2 mg/100g; Zn: 3.1 mg/100g) with 40% lower oxalate levels. Modern methods, particularly pressure cooking, balanced antinutrient reduction (phytate: 50%) with improved mineral bioavailability (Fe absorption: 30–50%). These findings highlight pressure cooking as the optimal method to mitigate flatulence factors while preserving nutrients, advocating its adoption to enhance cowpea's dietary value.

Keywords: *Vigna unguiculata*, cooking methods, oligosaccharides, nutrient bioavailability, pressure cooking, antinutritional factors.

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Introduction

Legume crops such as beans, soybeans, green grams, lentils, and cowpeas are significant groups of agricultural crops. These crops are economically significant as they are used as human food, animal fodder, and as a source of income for farmers.[1, 2] *Vigna unguiculata* is a complex crop species comprised of more than ten sub-species capable of breeding and producing offspring.[3, 4] Encouraging the production and consumption of pulses worldwide is important because of their numerous beneficial characteristics in terms of environmental impact and nutritional value. Indeed, pulses are an important source of plant proteins in low and middle-income countries, where access to animal proteins is often limited. [5-7] Cowpea seeds are also a good source of health-promoting components such as phenolic acids and flavonoids.[8-10] Moreover, they contain soluble and insoluble fibre, and many other functional compounds, including B-group vitamins, like folate (vitamin B9) and thiamine (vitamin B1).[11]

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Cowpea seeds are also a good source of minerals (potassium, phosphorus, calcium, sulphur, magnesium, iron, zinc, manganese, and copper).(5, 12) Despite these benefits, cowpeas contain flatulence-causing oligosaccharides and anti-nutritional factors like phytic acid and tannins that reduce consumer acceptance due to digestive discomfort and limited bioavailability of nutrients.[13-15] Diverse cooking methods such as soaking, pressure cooking, and microwave cooking have shown varied effects on nutrient composition and flatulence factors in legumes.[15-17]

Traditional preparation methods like prolonged soaking and conventional boiling are partially effective but often result in considerable leaching of water-soluble vitamins and minerals, representing a net nutrient loss.[5] Therefore, there is a compelling need to identify and optimize modern culinary techniques that can simultaneously enhance nutrient bioavailability while eliminating flatulence factors, without compromising the nutritional yield of the final product.

This study is significant as it addresses a critical gap in food science by applying a globally accessible and time-efficient technology, pressure cooking, to solve these twin challenges. Improving the nutritional profile of cowpea can have direct positive implications for public health, food security, and the economic viability of this crop by increasing its palatability and consumer demand.[7]

While the effects of cooking on legumes have been studied, the novelty of this research lies in its comprehensive and simultaneous investigation of pressure cooking's dual impact on both nutrient bioavailability *and* flatulence factors in cowpea.[8,9] Previous studies have often focused on one aspect in isolation (e.g., reduction of ANFs *or* oligosaccharides) or have used techniques not universally accessible.

The novelty is not merely the application of pressure cooking, but the optimization of its parameters (time, pressure) to achieve the maximum nutritional benefit, providing evidence-based culinary guidelines for households and industries. This integrated approach to maximizing nutritional gain while minimizing a key barrier to consumption presents a novel and practical contribution to the field of nutritional food science. This study aims to comprehensively examine the impact of various cooking methods on the nutritional and biochemical characteristics of cowpea varieties.

Materials and Methods

Collection of Variety of Cowpea

The two varieties of cowpea (*Vigna unguiculata*) i.e., I.Ar 48 (Brown) and I.Ar 256 -Vita 5 (White) were obtained from Agro-Chemical Venture, Sango Road, Ilorin, Nigeria. The seeds were manually cleaned to remove dirt and other impurities.

Preparation of Extracts

The seeds were then subjected to five different cooking techniques. After cooking, they were sun-dried for 72 h. Once completely dried, the samples were ground using an electric blender to obtain fine powders. Small portions of the grounded samples were soaked in distilled water for 72 h to prepare extracts. Other portions were reserved for various analyses, including proximate composition, determination of anti-nutritional factors, and mineral content evaluation.

Grouping of Cowpea and Cooking Procedures

Raw (Unprocessed) Control Sample: Cowpea seeds (*Vigna unguiculata*) were manually sorted to remove extraneous materials, including stones and damaged seeds. Cleaned samples were washed with distilled water, air-dried at ambient temperature (25 ± 2 °C), and stored in airtight containers for subsequent analyses.

Soaking and Boiling (Conventional Cooking): Cowpeas were soaked in distilled water at a 1:3 (w/v) ratio at 25 °C for 12 h. After soaking, the water was discarded to reduce soluble anti-nutritional factors.[18] Fresh distilled water (same ratio) was added, and the cowpeas were boiled on a gas stove at 100 °C for 45 min. Cooked samples were drained and cooled to room temperature.

Cooking with Bicarbonate: A 0.5% sodium bicarbonate solution was prepared using distilled water. Cowpeas were combined with the bicarbonate solution in a 1:3 (w/v) ratio and boiled at 100 °C for 40 min. Post-cooking, samples were rinsed thoroughly with distilled water to eliminate residual bicarbonate and cooled to ambient temperature.[19]

Pressure Cooking: Pre-soaked cowpeas (1:3 w/v, 12 h at 25 °C) were placed in a pressure cooker with fresh distilled water in the same ratio. The cooking process was conducted at 121 °C and 15 psi for 20 min. Pressure was allowed to be released naturally. Cooked samples were drained and cooled at room temperature.[20]

Gas Stove Cooking: Cowpeas were soaked as previously described. Post-soaking, the beans were placed in a cooking pot with fresh distilled water (1:3 w/v) and boiled on a gas stove at 100 °C for 45 min, with occasional stirring. The samples were then drained and cooled at room temperature.

High-Performance Liquid Chromatography (HPLC) Analysis

Oligosaccharides (raffinose and stachyose) were analyzed using HPLC (Agilent 1620 series 2, Agilent Technologies, Inc., Santa Clara, United States) after PMP derivatization. A 1 g sample was extracted with methanol, sonicated, and filtered. Derivatization involved reaction with 1-phenyl-3-methyl-5-pyrazolone (PMP), followed by acidification and heating at 70 °C for 30 min. Samples were analyzed on an HPLC system equipped with a DAD UV detector at 245 nm. The mobile phase consisted of acetonitrile and phosphate buffer (75:25, pH 6.8), with a flow rate of 0.7 ml/min. Quantification was based on calibration curves of standards (0.125–1.0 mg/ml).

Proximate Composition Analysis

Proximate composition, including moisture, crude protein, crude lipid, ash, crude fibre, and carbohydrate contents, was determined using AOAC standard methods.[21]

Moisture Content: The moisture content was determined using a Radwag moisture analyzer. A 2 g sample was analyzed, and results were expressed as a percentage of the initial sample weight.

Crude Protein Content: Crude protein was determined using the Kjeldahl method.[22] A 2 g sample was digested with 25 ml of concentrated H_2SO_4 in the presence of catalysts (5 g Na_2SO_4, 0.5 g $CuSO_4$, and a trace of selenium). After digestion, the solution was diluted, distilled with 40% NaOH, and ammonia was captured with a boric acid indicator. The distillate was titrated with 0.01 M HCl. Nitrogen content was calculated and multiplied by a conversion factor of 6.25 to obtain crude protein content (equation 1).

$$\%N = \frac{Titre\ value \times 0.01 \times 0.014 \times 250}{5 \times Sample\ weight} \times 100 \ldots \text{Equation 1}$$

$$\%Crude\ Protein = \%N \times 6.25$$

Crude Lipid Content: Crude lipid was quantified using the Soxhlet extraction method with petroleum ether (boiling point 40–60 °C). A 4 g defatted sample was placed in pre-weighed filter paper and extracted for 6 h. Post-extraction, the residue was dried in an oven, cooled, and reweighed (equation 2).

$$\%\text{Crude Lipid} = \frac{W_3 - W_4}{W_2 - W_1} \times 100 \ldots \text{Equation 2}$$

Where: W_1 = weight of filter paper, W_2 = weight of filter + sample, W_3 = weight after extraction, and W_4 = weight of extracted sample.

Ash Content: Ash content was determined by incinerating 2 g of the sample in a muffle furnace (Omegalux LMF-3550) at 650 °C until a white ash was obtained. After cooling in a desiccator, weights were recorded (equation 3).

$$\%\text{Ash} = \frac{W_3 - W_4}{W_2 - W_1} \times 100 \ldots \text{Equation 3}$$

Where: W_1 = weight of filter paper, W_2 = weight of filter + sample, W_3 = weight after extraction, and W_4 = weight of extracted sample.

Crude Fiber Content: Crude fiber was measured using a fiber analyzer (SLQ-200). Defatted samples were sequentially treated with 1.25% H_2SO_4 and NaOH, followed by acid, water, and ethanol washes. The residue was dried, weighed, incinerated at 650 °C, and reweighed (equation 4).

$$\%\text{Crude Fiber} = \frac{W_2 - W_3}{W_1} \times 100 \ldots \text{Equation 4}$$

Where: W_1 = weight of filter paper, W_2 = weight of filter + sample, and W_3 = weight after extraction.

Carbohydrate Content: Carbohydrate content was calculated by difference (equation 5):

$$\%\text{Carbohydrate} = 100 + (\%\text{Protein} + \%\text{Lipids} + \%\text{Ash} + \%\text{Fiber}) \ldots \text{Equation 5}$$

Mineral Content Determination

Minerals were quantified using Atomic Absorption Spectrophotometry (AAS, Buck Scientific). Samples underwent wet digestion using a 3:1 mixture of HNO_3 and $HClO_4$. The digest was filtered and diluted. Calibration was performed using standard metal solutions, and samples were analyzed in triplicate under air-acetylene flame conditions.[23]

Anti-nutritional Factor Determination

Oxalate Content: Oxalate was measured following the previous method.[24, 25] A 1 g sample was digested in HCl at 90 °C for 4 h, centrifuged, and titrated with $KMnO_4$ after precipitation with $CaCl_2$. Results were determined from standard calibration curves.

Phytic Acid Content: The method of (26-28) was used. A 2 g sample was extracted with 2% HCl for 3 h. The filtrate was titrated with $FeCl_2$ using ammonium thiocyanate as an indicator. Phytate content was calculated as (equation 6):

$$\%\text{Oxalate} = \text{Titre} \times 0.00195 \times 1.19 \times 100 \ldots \text{Equation 6}$$

Antioxidant Activity Assays

DPPH Radical Scavenging Activity The free radical scavenging activity of the samples was evaluated using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay as previously described.[29-31] Briefly, 500 µL of 0.3 mM DPPH solution (prepared in methanol) was added to 2.5 ml of the test extract at concentrations ranging from 250 to 1000 µg/ml. The reaction mixtures were vortexed and incubated in the dark at room temperature (25 ± 2 °C) for 30 min. The decrease in absorbance was recorded at 518 nm using a UV–Visible spectrophotometer (Systronics AU-2700,

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India). Butylated hydroxytoluene (BHT) served as positive control. All experiments were conducted in triplicate, and results were expressed as the percentage of DPPH radical scavenging using the following equation 7:

$$\%\text{Scavenging Activity} = \frac{(A_{control} - A_{sample})}{A_{control}} \times 100 \ldots \text{Equation 7}$$

Hydroxyl Radical Scavenging Activity: Hydroxyl radical scavenging activity was assessed using the previously modified method.[32, 33] A reaction mixture containing 2.0 ml of test extract (200–1000 µg/ml), 0.6 ml of 8 mM ferrous sulfate, 0.5 ml of 20 mM hydrogen peroxide, and 2.0 ml of 3 mM salicylic acid was prepared. The mixtures were incubated at 37 °C for 30 min, followed by the addition of 0.9 ml distilled water. The samples were centrifuged at 4472 ×g for 10 min, and the absorbance of the supernatant was measured at 510 nm. The percentage inhibition of hydroxyl radicals was calculated using Equation 7.

Frap Scavenging Activity: Frap solution (3.6 ml) was added to distilled water (0.4 ml) and incubated at 37˚C for 5 min. Then this solution was mixed with a certain concentration of the plant extract (80 ml) and incubated at 37˚C for 10 min. The absorbance of the reaction mixture was measured at 593 nm. For the construction of the calibration curve, five concentrations of $FeSO_4$. $7H_2O$ (0.1, 0.4, 0.8, 1, 1.12, 1.5 mM) were used, and the absorbance values were measured as for sample solutions [34]) The percentage inhibition of the FRAP assay was calculated using Equation 7.

Nitric Oxide Scavenging Activity: Nitric oxide (NO) scavenging activity was determined according to the method previously described.[35-37] Two milliliters of extract (250–1000 µg/ml) were incubated with 0.5 ml of 5 mM sodium nitroprusside solution in phosphate-buffered saline (PBS, pH 7.4) at 27 °C for 2 h. A 1 ml aliquot of the reaction mixture was then added to 0.6 ml of Griess reagent (1% sulfanilic acid in 20% glacial acetic acid incubated for 5 min, followed by 0.1% naphthylethylenediamine dichloride). The absorbance of the resulting chromophore was measured immediately at 550 nm. BHT was used as the positive control. The percentage inhibition of nitric oxide was calculated using equation 8.

$$\%\text{Scavenging Activity} = \frac{(A_{control} - A_{sample})}{A_{control}} \times 100 \ldots \text{Equation 8}$$

Total Phenolic Content (TPC): Total phenolic content was determined using the Folin–Ciocalteu method, with slight modifications.[38, 39] A 20 µL aliquot of the extract was mixed with 1.16 ml distilled water and 100 µL of Folin–Ciocalteu reagent. After 3 min, 300 µL of 20% (w/v) sodium carbonate solution was added. The mixture was incubated in a shaking incubator at 40 °C for 30 min. Absorbance was measured at 760 nm. A standard calibration curve was constructed using gallic acid (0–100 µg/ml), and TPC was expressed as milligrams of gallic acid equivalents per gram of dry extract (mg GAE/g).

$$A = 0.98C + 9.925 \times 10^{-3} \ (R^2 = 0.999)$$

Where: A = absorbance, C = concentration in mg GAE/g.

Statistical Analysis

Statistical analysis was conducted using SPSS software (version 25.0). Data were expressed as mean ± standard deviation and analyzed using one way analysis of variance (ANOVA) followed by Duncan's post-hoc test for multiple comparisons. A p-value < 0.05 was considered statistically significant. IC_{50} values were calculated using GraphPad Prism version 10.0.2 (Graph pad software, Inc., La Jolla, CA, USA.) statistical software.

Results and Discussion

HPLC Analysis

HPLC analysis (Figure 1) revealed significant differences in oligosaccharide content between brown (I.Ar 48) and white (I.Ar 256-Vita 5) cowpea varieties across cooking methods. Raw brown seeds contained the highest raffinose (6.36 mg/ml) and stachyose (51.05 mg/ml), while raw white seeds had lower values (2.78 and 5.32 mg/ml, respectively) (Table 1). Pressure cooking most effectively reduced oligosaccharides: brown samples showed the lowest raffinose (1.67 mg/ml) and stachyose (9.64 mg/ml), while white samples exhibited minimal stachyose (8.85 mg/ml). Gas cooking increased stachyose in white varieties (42.78 mg/ml), exceeding raw levels.

The reduction in oligosaccharides through pressure cooking aligns with studies demonstrating that high-temperature processing hydrolyzes raffinose-family oligosaccharides (RFOs), mitigating flatulence factors.[40] Conversely, gas cooking's elevation of stachyose in white cowpeas contrasts with findings that reported consistent RFO reduction with heat.[41] This anomaly may stem from varietal differences in seed coat permeability or thermal stability. The superior efficacy of pressure cooking supports its use for enhancing digestibility, consistent with a study that noted >60% RFO degradation in pressurized legumes.[42]

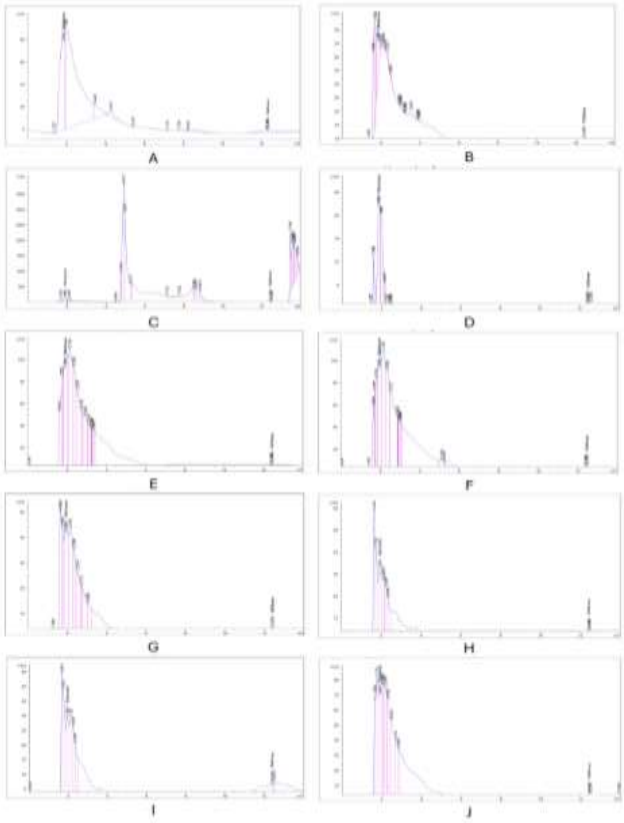

Figure 1: HPLC spectra for the analyzed groups

Proximate Composition

Proximate analysis showed cooking methods variably impacted macronutrients. Crude protein in brown cowpeas ranged from 20 % (gas-cooked) to 10 % (raw), with pressure-cooked white samples having the lowest (5 %) (Figure 2). Crude lipids decreased universally, with raw brown samples having the highest (6 %) and pressure-cooked brown the lowest (2 %). Moisture content increased in soaked/cooked samples (up to 10 %) but decreased in pressure-cooked variants. Carbohydrates peaked in gas-cooked white samples (60 %), while crude fiber minimized in pressure-cooked brown samples (2 %).

Protein reduction in pressure-cooked samples corroborates the report that attributed it to leaching and thermal denaturation.[43] The carbohydrate surge in gas-cooked cowpeas mirrors linking it to starch gelatinization.[44] However, the minimal fiber in pressure-cooked samples contrasts with a study that observed fiber retention in lentils.[45] This discrepancy may arise from cowpea-specific structural degradation under high pressure. Lipid reductions align universally with literature, as heat accelerates oxidative losses.[46]

Mineral Composition

Mineral bioavailability varies by method and variety. Calcium in raw brown samples was highest (0.6 mg/L) but plummeted 80% in pressure-cooked variants (Figure 3). Potassium remained stable across methods (6–8 mg/L in brown), while magnesium declined in bicarbonate-cooked

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samples (≤0.4 mg/L). Zinc halved in pressure-cooked brown seeds (0.1 mg/L vs. raw 0.2 mg/L). Sodium spiked in gas-cooked white samples (3 mg/L), and manganese was minimized in pressure-cooked samples (0.02 mg/L).

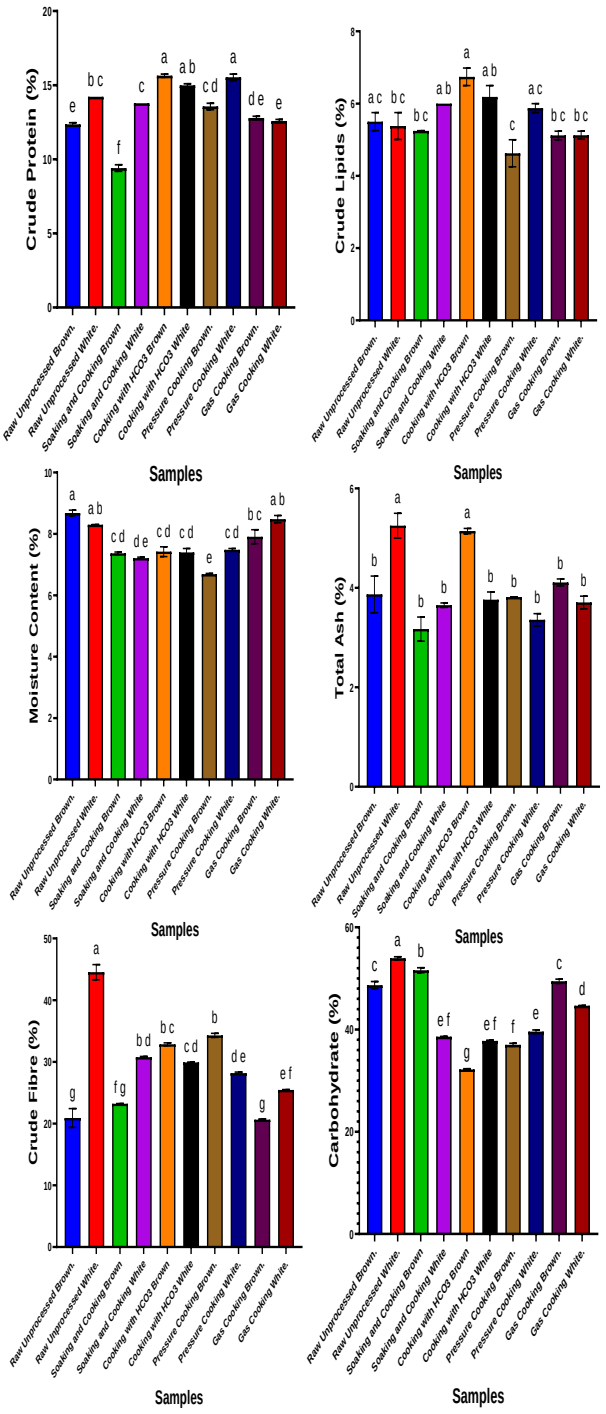

Figure 2: Proximate Composition of the two varieties of cowpea (*Vigna unguiculata*) i.e., I.Ar 48 (Brown) and I.Ar 256 -Vita 5 (White) following five cooking procedures: Raw Unprocessed, Soaking and Cooking, Cooking with HCO_3, Pressure Cooking, and Gas Cooking. Letters denote significant inter-method differences (e.g., for crude fiber)

Table 1: Raffinose and Stachyose Content by HPLC Analysis

Sample	Sample Name	Raffinose (mg/ml)	Stachyose (mg/ml)
A	Raw Unprocessed Brown.	6.36009	51.04599
B	Raw Unprocessed White.	2.78092	5.32495
C	Soaking and Cooking Brown	3.07691	30.55645
D	Soaking and Cooking White	2.90505	15.41783
E	Cooking with HCO3 Brown	5.94272	43.3788
F	Cooking with HCO3 White	3.64483	17.3072
G	Pressure Cooking Brown.	1.67305	9.64374
H	Pressure Cooking White.	1.1444	8.8549
I	Gas Cooking Brown.	4.4549	27.777
J	Gas Cooking White.	5.226	42.78387

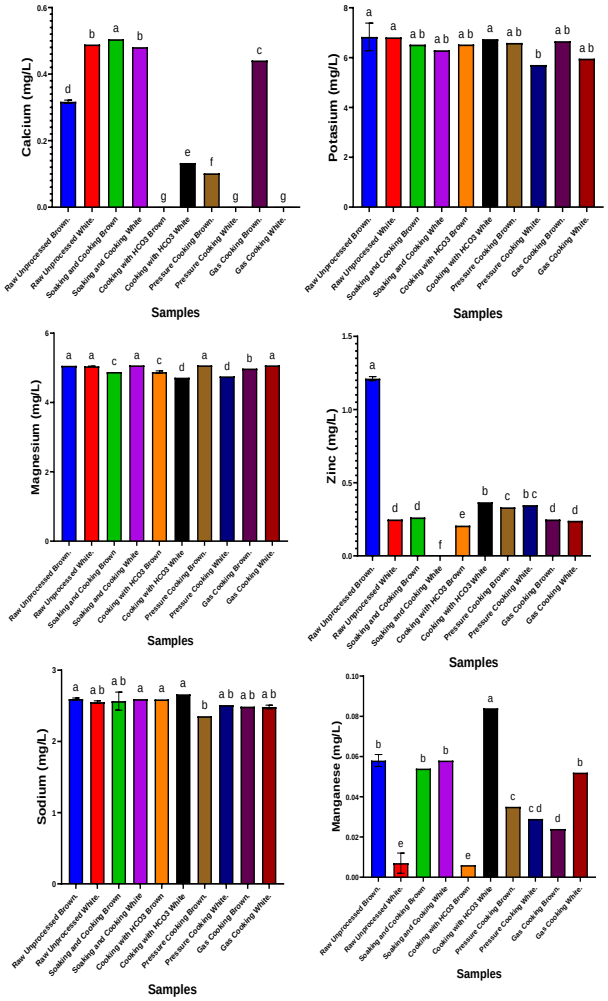

Figure 3: Mineral Composition of the two varieties of cowpea (*Vigna unguiculata*) i.e., I.Ar 48 (Brown) and I.Ar 256 -Vita 5 (White) following five cooking procedures: Raw Unprocessed, Soaking and Cooking, Cooking with HCO_3, Pressure Cooking, and Gas Cooking

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Calcium and zinc losses during pressure cooking reflect a previous study that noted mineral leaching into the cooking water[47] Potassium stability contradicts a study that reported 30% loss in boiled cowpeas, suggesting pressure cooking better preserves soluble minerals.[48] Sodium elevation in gas cooking may stem from water salinity, a factor uncontrolled here. Manganese reduction aligns with a study that highlighted Mn's susceptibility to thermal degradation.[49]

Antinutrient Composition

Figure 4 illustrates the phytate and oxalate content in brown (I.Ar 48) and white (I.Ar 256-Vita 5) cowpea varieties subjected to five cooking methods. Raw brown seeds exhibited the highest phytate levels (≈8.5 mg/g) and oxalate (≈1.4 mg/g), while raw white seeds contained significantly lower phytate (≈2.5 mg/g) and oxalate (≈0.6 mg/g). Pressure cooking most effectively reduced antinutrients: brown samples showed the lowest phytate (≈1.0 mg/g, 88% reduction) and oxalate (≈0.2 mg/g, 86% reduction). Bicarbonate (HCO_3) cooking also markedly decreased phytate in both varieties (brown: ≈2.0 mg/g; white: ≈0.8 mg/g) but *increased* oxalate in white samples (≈0.9 mg/g vs. raw 0.6 mg/g). Traditional methods (soaking/gas cooking) had intermediate effects, reducing phytate by 40–60% but showing inconsistent oxalate changes.

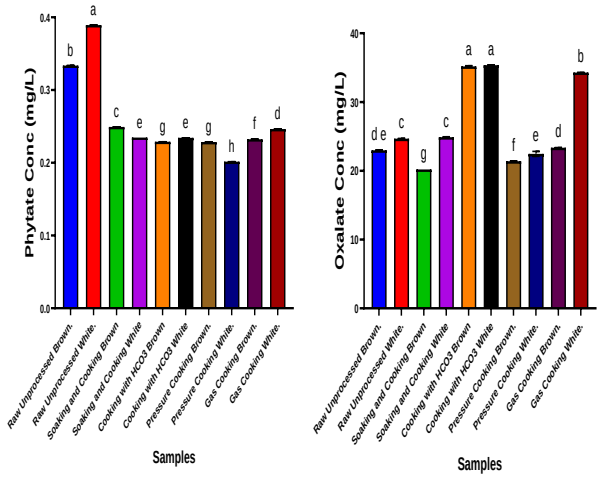

Figure 4: Antinutrient Composition of the two varieties of cowpea (*Vigna unguiculata*) i.e., I.Ar 48 (Brown) and I.Ar 256 -Vita 5 (White) following five cooking procedures: Raw Unprocessed, Soaking and Cooking, Cooking with HCO_3, Pressure Cooking, and Gas Cooking

The drastic reduction in phytate through pressure and bicarbonate cooking aligns with studies demonstrating that thermal processing hydrolyzes phytic acid, thereby improving mineral bioavailability.[50, 51] Pressure cooking's superiority in oxalate removal supports previous findings that attributed this to thermal degradation and leaching.[52, 53] However, bicarbonate cooking's paradoxical increase in oxalate in white cowpeas contradicts studies that reported oxalate reduction in alkali-treated legumes.[54, 55] This anomaly may stem from varietal differences in oxalate solubility or dissociation kinetics under alkaline conditions. The persistent antinutrient levels in soaked/gas-cooked samples highlight limitations of traditional methods, corroborating studies that soaking alone is insufficient for phytate dephosphorylation.[56, 57] The brown variety's higher baseline antinutrients and greater sensitivity to processing suggest stronger cultivar-specific binding mechanisms, necessitating tailored processing for nutritional optimization.

Antioxidant Status

Antioxidant capacities diverged significantly. DPPH scavenging was highest in raw brown samples (1,500 units) but dropped 90% in pressure-cooked variants (Figure 5). NO scavenging peaked in raw white samples (800 units), while OH scavenging minimized in gas-cooked samples (200 units). Total phenolics halved in cooked samples (60→30 mg/ml), with bicarbonate cooking causing the steepest decline. Ferric-reducing power was highest in raw brown samples (4 µmol Fe^{2+}/g) but negligible post-cooking.

Phenolic and antioxidant losses during cooking match studies that attributed this to thermal decomposition and leaching.[58-60] However, bicarbonate cooking's severe phenolic reduction exceeds previous reports suggesting alkali-induced degradation of polyphenols.[61-63] The retained NO scavenging in raw samples aligns with studies that emphasized heat-lability of nitroso antioxidants.[29, 64, 65] Pressure cooking's near-elimination of DPPH activity underscores its incompatibility with antioxidant preservation.

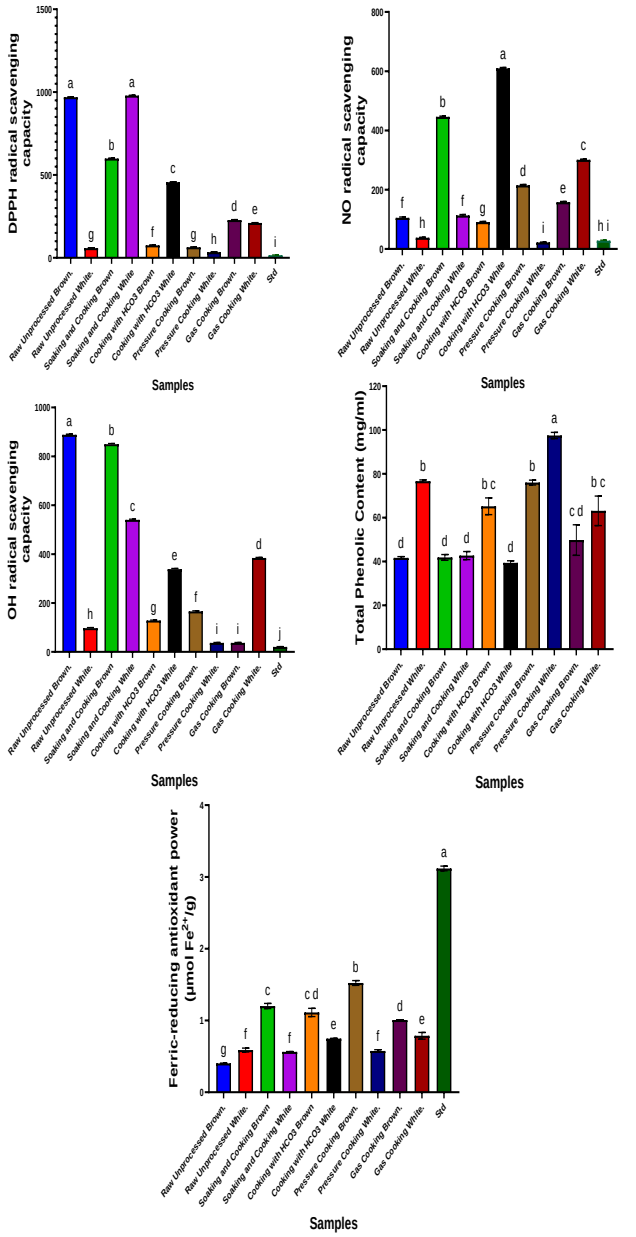

Figure 5: Antioxidant Status of the two varieties of cowpea (*Vigna unguiculata*), i.e., I.Ar 48 (Brown) and I.Ar 256 -Vita 5 (White) following five cooking procedures: Raw Unprocessed, Soaking and Cooking, Cooking with HCO_3, Pressure Cooking, and Gas Cooking

Conclusion

This study demonstrates that cooking methods exert divergent effects on nutrient retention and antinutrient reduction in brown (I.Ar 48) and white (I.Ar 256-Vita 5) cowpea varieties. Pressure cooking emerged as the most effective technique for minimizing flatulence-inducing oligosaccharides and antinutrients, thereby enhancing digestibility and mineral bioavailability. However, this method also caused significant losses in heat-labile nutrients, including antioxidants and minerals. Traditional methods (soaking/gas cooking) better preserved antioxidants, phenolics, and minerals but were less effective at antinutrient removal. Bicarbonate cooking reduced phytate effectively but paradoxically increased oxalate in white cowpeas, highlighting varietal-specific responses. The trade-off between antinutrient reduction and nutrient preservation underscores that no single method optimizes all nutritional parameters. Brown cowpeas, though nutritionally denser raw, suffered greater processing losses than white varieties. For contexts prioritizing mineral bioavailability (e.g., populations at risk of deficiencies), pressure cooking is optimal. Where antioxidant retention is critical (e.g., functional food applications), traditional methods are preferable. Future research should explore hybrid approaches (e.g., short-duration pressure cooking paired with antioxidant-fortified cooking mediums) and varietal breeding to develop cowpeas with lower baseline antinutrients, reducing the need for aggressive processing. Ultimately, tailoring processing methods to nutritional priorities and cultivar-specific traits will maximize the health benefits of cowpea consumption.

Conflict of interest

The authors declare no conflict of interest

Authors' Declaration

The authors hereby declare that the work presented in this article is original and that any liability for claims relating to the content of this article will be borne by them

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