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Effect of Heat-Moisture Treatment of Pigeon Pea (*Cajanus cajan*) on the Quality of Its Starch

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Abstract

Heat–moisture treatment (HMT) provides a physical approach to modifying starch properties for food applications. This study evaluated its effects on the composition, functional properties, and pasting characteristics of pigeon pea starch. Starch was extracted at a yield of 21% and treated at 110 °C for 3 h at 30% moisture content. Unmodified and modified starches were evaluated for amylose content, proximate and mineral composition, color, and functional and pasting properties using standard methods. HMT significantly increased protein, fat, fiber, ash, and moisture contents ($p < 0.05$), while decreasing carbohydrate content and energy value. Protein content increased from 6.63% to 8.02%, whereas carbohydrate content decreased from 81.48% to 78.49%. Phosphorus, calcium, iron, magnesium, potassium, and sodium contents increased following treatment, and amylose content rose from 12.76% to 13.21%. HMT reduced lightness from 87.48 to 81.56 and increased redness from 2.33 to 4.50 and yellowness from 9.48 to 11.39. Treatment significantly decreased bulk density, water absorption capacity, foaming capacity, swelling power, and solubility, while increasing oil absorption capacity, dispersibility, and foaming stability. Oil absorption capacity increased from 1.0 to 1.5 g/g, dispersibility from 79.00% to 82.00%, and foaming stability from 92.18% to 97.16%. HMT also significantly reduced peak, trough, breakdown, final, and setback viscosities. Peak viscosity decreased from 3861.00 to 1165.00 RVU, and final viscosity declined from 4628.00 to 1622.50 RVU. Conversely, peak time increased from 5.15 to 7.00 min, and pasting temperature increased from 84.45 to 92.00 °C. These findings demonstrate that HMT alters the compositional, functional, and pasting characteristics of pigeon pea starch,

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supporting its potential as a physical modification strategy for tailoring starch properties for food applications.

Keywords: Pigeon Pea Starch; Heat–Moisture Treatment; Physicochemical Properties; Functional Properties; Pasting Properties

INTRODUCTION

Pigeon pea (*Cajanus cajan*) is a leguminous crop of significant nutritional and economic importance, widely cultivated in tropical and subtropical regions including parts of Asia, Africa, and Latin America (Sarkar *et al*., 2020). It is a drought-tolerant plant that serves as a major source of protein in the diets of low-income populations (Mula *et al*., 2010). In addition to its high protein content (approximately 20–25%), pigeon pea also contains appreciable amounts of starch, dietary fiber, vitamins, and minerals, making it a versatile raw material for food processing industries (Jeevarathinam *et al*., 2020). However, pigeon pea has not been exploited for food applications in the food industries in spite of its high nutrient contents, including starch (Haji *et al,* 2024). This may be linked to the hard-to-cook phenomenon in pigeon pea. Thus, starch may be extracted from the pea for various food systems.

Starch is a carbohydrate polymer composed of amylose and amylopectin (Hoover & Ratnayake, 2002). It is an essential component of many foods and industrial processes because of its special functional qualities, which include thickening, gelling, film-forming, and binding (Hoover, 2010). However, for many industrial processes and product formulations, native starch frequently performs below acceptable levels, being fast in retrogradation, inadequate thermal stability, shear sensitivity, poor or low solubility and low swelling power (Singh *et al.,* 2003; Hoover, 2010). These drawbacks necessitate modification to improve functional characteristics of the starch and to broaden its applications in food systems.

Starch is modified by various methods, which include chemical, physical and enzymatic processes. Physical modification techniques such as heat-moisture treatment (HMT), annealing, and pre-gelatinization treatment have been thoroughly researched as eco-friendly methods to enhance the physicochemical and functional characteristics of starch without the use of chemical reagents. These modifications alter starch granule

structure and crystalline arrangement, thereby enhancing properties like pasting behavior, thermal stability, water absorption capacity, and freeze-thaw stability (Gunaratne & Hoover, 2002; Nawaz *et al*., 2020). For food applications, these improved properties are crucial for achieving desired texture, cooking quality, and shelf stability. These methods, especially heat moisture treatment (HMT), have been reported to increase the resistant starch content (Lee *et al*., 2022), increase gelatinization temperature of starch, which in turn enhances its thermal stability under conditions of shear, high temperature, and acidity, thereby improving its textural and functional properties(Gu *et al*., 2024).

The objective of the study was to evaluate the effect of heat moisture treatment of pigeon pea on the quality of its starch.

MATERIALS AND METHODS

Materials

Pigeon pea (*Cajanus cajan)* seeds were purchased from a local market in Wukari Township, Taraba State, Nigeria. All analytical-grade chemicals and reagents required for starch modification and evaluation were obtained from the laboratories, Department of Food Science and Technology, Federal University Wukari, Taraba State, where the study was carried out.

Extraction of pigeon pea starch

Pigeon pea starch was extracted using the technique described by A'yuni *et al.* (2021). Pigeon pea seeds were sorted manually to remove stones, dust and other contaminants. The seeds were washed and soaked in distilled water (1:10, seed: water) at ambient temperature (30± 2°C) for 12 hours to aid dehulling. The hydrated seeds were manually dehulled and thoroughly rinsed with distilled water. The dehulled seeds were milled with distilled water at 1:3 (seed: water, w/v) to smooth slurry using attrition mill. The slurry was filtered through muslin cloth to separate the starch-rich filtrate from fibrous residues. The filtrate was allowed to stand undisturbed at ambient temperature for 12 hours to enable starch sedimentation. The supernatant was carefully decanted, and the resulting starch sediment was washed three times with distilled water to improve purity. The starch was then, dried in an oven at 45°C for 24 hours, milled in attrition mill, sieved through a 250µm sieve, and stored in polyethylene bags prior to use.

Heat moisture treatment of pigeon starch

Heat moisture-treatment of pigeon pea starch was carried out following the method described by the Fonseca (2021). Unmodified pigeon pea starch (1500g) was weighed and mixed thoroughly with distilled water(526.7ml) to 30% moisture content in a container and was then, tightly sealed with aluminum foil to minimize moisture loss . This was stored at 5°C in a refrigerators for 12 hours to allow uniform moisture distribution within the starch granules before the heat treatment. The sample was then, heated in a hot air oven at 110°C for 3 hours. Thereafter, the sample was cooled to ambient temperature (30°C) and then, dried at 50°C to constant weight. The dried sample was milled using attrition mill, sieved through a 250 µm sieve, and stored in plastic bags prior to use. The native (unmodified) starch served as a control.

Experimental Design

The study employed a completely randomized design (CRD) to evaluate the effects of heat moisture treatment on the quality of pigeon pea starch. The experimental treatments consisted of two treatments namely: unmodified (T1) and HMT starch (T2). Each treatment was replicated three times, and the experimental units were randomly assigned to treatments.

Analytical Methods

Determination of starch yield

The percentage starch yield was determined according to method of Osho (2024) as the ratio of the dried starch weight to the initial weight of the pigeon pea seeds.

Determination of proximate composition of starches

Moisture, ash, crude fibre, protein, crude fat, carbohydrate, and energy contents of unmodified and heat-moisture-treated pigeon pea starches were determined according to the methods of Onwuka (2005).

Determination of mineral contents of starches

The calcium (Ca), magnesium (Mg), potassium (K), iron (Fe), sodium (Na), and phosphorus (P) contents of the starches were determined using the dry ashing method described by Latimer (2023).

Determination of instrumental color of starches

The evaluation of instrumental color of the unmodified and heat moisture treated pigeon pea starches was carried out using method described by Xu *et al.*(2020) and Guleria *et al.* (2022) using colorimeter. The instrument was operated in the CIE L*a*b* color space mode, where L* represents lightness (0 = black, 100 = white**),** a* represents the red–green coordinate (+a* = redness, −a* = greenness), and b* represents the yellow–blue axis (+b* = yellowness, −b* = blueness). Each sample was placed on sample holder fully covering the surface or the measurement aperture and the measurement was taken. The overall color difference (ΔE) between treated and unmodified starch was calculated

Determination of pasting properties of starch

The pasting properties of both unmodified and heat-moisture -treated pigeon pea starch samples were determined using a Rapid Visco Analyzer, following the method described by Ikegwu *et al.* (2009) with slight modifications.

Determination of functional properties of starches

Bulk density, water absorption capacity, oil absorption capacity, swelling power, solubility, dispersibility, foaming capacity, and foam stability were determined according to the methods of Onwuka (2005).

Determination of starch purity and amylose contents of starch

The percentage starch purity was calculated by subtracting the sum of the non-starch components (protein, fat, ash, crude and fiber contents) from 100% as described by Vithu *et al.* (2020).

The amylose contents of modified and heat-moisture-treated pigeon pea starches were determined using a colorimetric iodine binding method, following the procedure of Mojo-Quisani *et al.* (2024), with slight modifications.

Statistical analysis

Data obtained were analyzed by one-way analysis of variance (ANOVA) using Statistical Package for Science solution (SPSS) version 26. Duncan's multiple range test (DMRT) was employed to separate means where significant differences ($p < 0.05$) existed. Data were reported as mean ± standard deviation of three replicates

RESULTS

Table 1: Proximate composition (%) and energy value (kcal/100) of unmodified and modified starches from pigeon pea grains

Sample	Protein	Fat	Fiber	Ash	Moisture	Carbohydrate	Energy value
UPS	6.63^{b}±0.02	1.79^{b}±0.04	1.24^{b}±0.02	3.13^{b}±0.01	6.32^{b}±0.01	81.48^{a}±0.59	369.07^{a}±0.10
HPS	8.02^{a}±1.73	1.86^{a}±0.02	1.46^{a}±0.04	3.93^{a}±0.00	6.76^{a}±0.02	78.49^{b}±0.60	362.70^{b}±2.68
p-value	0.000	0.003	0.000	0.000	0.001	0.001	0.024

Values are means ±SD of two replications. Means within a column with p-value less than 0.05 are significantly different. UPS= unmodified pigeon pea starch, HPS=heat-moisture treated pigeon pea starch.

Table 2: Mineral composition (mg/100) of starches from unmodified and modified pigeon pea starches

Sample	P	Ca	Fe	Mg	K	Na
UPS	124.75^{b}±0.18	165.67^{b}±0.04	3.83^{b}±0.04	136.13^{b}±0.04	314.13^{b}±0.02	59.34^{b}±0.03
HPS	158.24^{a}±0.04	173.17^{a}±0.01	4.90^{a}±0.03	165.34^{a}±0.01	356.33^{a}±0.03	63.53^{a}±0.04
P-value	0.000	0.000	0.000	0.000	0.000	0.000

Values are means ±SD of two replications. Means within a column with p-value less than 0.05 are significantly different. UPS= unmodified pigeon pea starch, HPS=heat-moisture treated pigeon pea starch, P=phosphorus, Ca=calcium, Fe=iron, Mg=magnesium, K=potassium, Na=sodium.

Table 3: Color properties of starches from pigeon pea seeds

Starch	L*	a*	b*	ΔE	ΔC
UPS	87.48±1.08	2.33±0.14	9.58±0.08	0.00	0.00
HPS	81.56±2.44	4.50±0.28	11.39±0.22	6.57	2.40
t-value	3.832	-11.994	-13.570	-	-
p-value	0.019	<0.001	<0.001	-	-

Values are means ±SD of three replications. Means within a column with p-value less than 0.05 are significantly different. UPS= unmodified pigeon pea starch, HPS= heat-moisture treated pigeon pea starch, L=brightness, a*=reddishness, b*=yellowness ΔE=total color difference, ΔC= color intensity*

Table 4: Pasting properties of starches from unmodified and modified pigeon pea starch

Starch	UPS	HPS	P-value
Peak viscosity	3861.00^{a}±24.04	1165.00^{b}±94.75	0.000
Trough	2885.50^{a}±160.51	971.50^{b}±103.94	0.001
Breakdown viscosity	975.50^{a}±136.47	193.50^{b}±9.19	0.004
Final viscosity	4628.00^{a}±97.58	1622.50^{b}±135.06	0.001
Setback viscosity	1742.50^{a}±62.93	651.00^{b}±31.11	0.002
Peak time	5.15^{b}±0.07	7.00^{a}±0.00	0.000
Pasting temperature	84.45^{b}±0.57	92.00^{a}±1.06	0.385

Values are means ±SD of two replications. Means within a column with p-value less than 0.05 are significantly different. UPS= unmodified pigeon pea starch, HPS=heat-moisture treated pigeon pea starch

Table 5: Functional properties of unmodified and modified pigeon pea starches

Starch	UPS	HPS	P- value
Bulk density(g/ml)	0.83^{a}±0.01	0.80^{b}±0.01	0.009
Water absorption capacity(g/g)	2.20^{a}±0.00	2.00^{b}±0.00	0.001
Oil absorption capacity(g/g)	1.00^{b}±0.28	1.50^{a}±0.00	0.03
Dispersibility (%)	76.50^{a}±0.71	76.50^{a}±0.71	0.001
Foam capacity (%)	15.00^{a}±1.41	5.00^{b}±1.41	0.001
Foam stability (%)	92.18^{b}±1.13	97.16^{a}±1.31	0.037
Swelling power (g/g)	7.46^{a}±0.92	6.75^{a}±0.92	0.184
Solubility (%)	23.50^{a}±2.12	10.50^{b}±0.71	0.011

Values are means ±SD of two replications. Means within a column with p-value less than 0.05 are significantly different. UPS= unmodified pigeon pea starch, HPS=heat-moisture treated pigeon pea starch.

Table 6: Starch purity and Amylose contents (%) of unmodified and modified pigeon pea starches

Starch	Starch purity	Amylose	Amylopectin
UPS	87.80^{a}±0.59	12.76^{b}±0.06	87.24^{a}±0.06
HPS	85.34^{b}±0.60	13.21^{a}±0.05	86.79^{b}±1.15
P-value	0.002	0.000	0.000

Values are means ±SD of three replications. Means within a column with p-value less than 0.05 are significantly different. UPS= unmodified pigeon pea starch, HPS=heat-moisture treated pigeon pea starch.

DISCUSSION

Starch yield of pigeon pea seeds

The starch yield obtained from pigeon pea was 21.00%**.** This value indicates a moderate recovery of starch from the raw pea. Lufti A'yuni *et al.* (2021) reported starch yield of 29.83 % for West Nusa Tenggara (NTB) 30.31% for Yogyakarta, and 31.68% for Bali of different varieties of pigeon pea seeds, while Hoover *et al.* (1993) recorded 29.7% of starch yield. The lower starch yield obtained from pigeon pea could be attributed to varietal differences, environmental conditions, geographical location, and incomplete release of starch granules during extraction and possible losses during processing steps such as washing and sieving (Lufti A'yuni *et al.*, 2021).

Proximate composition of pigeon pea starches

Table 1 shows the proximate composition of unmodified pigeon pea starch (UPS) and heat-moisture treated pigeon pea starch (HPS) samples. The HPS had significantly ($p<0.05$) higher levels of protein (8.02%), fat (1.86%), fiber (1.46%), and ash (3.93%) than the UPS. The higher values was attributed to HMT (heat-moisture treatment) that induced structural reorganization of starch molecules (Schafranski *et al.,* 2021). This reorganization promoted interactions that formed starch-protein-lipid complexes that concentrated these minor components (Xiang *et al.*, 2023). The reduction in anti-nutrients like tannins by HMT has been noted (Omer *et al.*, 2025). . Tannins are recognized for forming complexes with proteins and minerals (Embaby 2010). Tannins may have been reduced in this study, which enhanced the proximate composition except for carbohydrate. Carbohydrate decreased significantly from 81.48% in UPS to 78.49% in HPS, suggesting dilution by elevated non-starch fractions. The energy values also decreased from 369.01 kcal/100 to 362.70 kcal/100, which is attributed to the lower carbohydrate content of the HPS.

Mineral composition of unmodified and modified pigeon pea starches

The mineral composition of the starch samples is presented in Table 2. The heat-moisture treated starch (HPS) had higher mineral contents than the unmodified pigeon pea starch (UPS). Phosphorus, calcium, iron, magnesium, potassium and sodium contents increased 124.75 to 158.24 mg/100,165.67 to173.17mg/100, 3.83 to 4.90, 136.13 to 165.34mg/100, 314.13 to 356.33mg/100 and 59.34 to 63.53mg/100 respectively. The increased probably caused the destruction of anti-nutritional factors such as phytates, tannin, trypsin inhibitors, oxalate and saponins, thereby liberating bound minerals and

enhanced their extractability (Omer *et al.*, 2025). The HMT may have altered the physical structure of the starch-protein matrix and facilitated the breakdown of plant cell wall particularly hemicellulose, which increased solubilization of minerals that were previously sequestered within the cellular matrix (Javed *et al.*, 2025). Maillard reaction probably caused increase in the mineral contents of pigeon pea starch. Maillard reaction and complex formation, on reaction to flavor development and non-enzymatic browning, also influences mineral bio-accessibility by reducing mineral-phatate interaction, forming complexes between mineral and protein or sugar in more soluble forms (El Hosry *et al.*, 2025). Omer *et al.* (2025) also documented increased in mineral contents of red and white sorghum flours with heat-moisture treatment.

Color properties of pigeon pea starches

The instrumental color values of the unmodified and heat-moisture treated starches are shown in Table 3. The L* value (lightness) of the starches significantly decreased ($p<0.05$) from 87.48 in UPS to 81.56 in HPS. The decreased in the L* value of modified the starch caused starch to be darker in color than the unmodified starch. The significant decreased is attributed to increased molecular interactions within the starch matrix and possible non-enzymatic browning reactions during the heat moisture treatment as reported by Majzoobi *et al.* (2015). The a* values (green–red component) increased from 2.33 in UPS to 4.50 in HPS. The increased in a* value signified that the modified starch became more reddish in color compared to the unmodified starch. Similarly, the b* values of the starches increased from 9.58(UPS) to 11.39(HPS). The increased in b* value indicated increased yellowness of HPS. The total color difference (ΔE) between UPS and HPS was 6.57, which represents a perceptible and practically significant color change. In food and food ingredient applications, a ΔE value greater than 3–5 is generally considered visually noticeable to the human eye (Foroni *et al.*, 2016). A ΔE of 6.57 indicates that the color change due to HMT is not only statistically significant but also visually relevant. The Chroma difference ($\Delta C = 2.40$) indicated increased color intensity in HPS compared to UPS, suggesting that heat-moisture treatment enhanced the saturation of the starch color. The increase in redness and yellowness, as well as the decrease in lightness observed in HPS, may be attributed to Mallard reactions that occurred during heat–moisture treatment. Lorlowhakarn & Naivikul (2006) reported decreased in the L* value, and increased in a* and b*values of chai Nat 1 rice flour subjected to HMT at 110^{o}C for 3 hours.

Pasting properties of wheat flour and pigeon pea starches

The Table 4 shows the RVA pasting profile parameters for two starch samples (UPS and HPS). These values described how each starch swells, thickens, and breaks down after heating and cooling, which relates to their suitability in various food processing applications.

The peak viscosity (PV) is the maximum swelling capacity of starch granules during heating and is an important indicator of water-binding ability and paste thickening potential (Berggren, 2018). The HPS (1165.00 RVU) had lower value than UPS (3861.00 RVU). Subroto *et al.* (2019) reported decrease in PV of 7841 RVU to 1113 RVU at 110°C with HMT of potato. The decrease in peak viscosity was due to the interaction between molecules of water and amylose-amylopectin, which occurred in starch granules through hydrogen bonds. This interaction caused rearrangement of the structure of starch granule, which caused the bonds formed between amylose-amylose, amylose-amylopectin, and amylopectin-amylopectin to be stronger to decrease peak viscosity (Gunaratne and Hoover, 2002).

Trough viscosity is the minimum viscosity attained by starch paste during the holding phase at high temperature**,** reflecting the combined effects of granule swelling and their ability to withstand thermal and mechanical stress (Wang & Ren, 2020). The UPS (2885 RVU) had higher trough viscosity than HPS (971.00 RVU). The higher value for the UPS was attributed to greater granule swelling and higher viscosity development during heating. In contrast, the lower trough viscosity for the heat-moisture treated starch (HPS) reflects restricted swelling and reduced paste viscosity. Decreased in trough value was also reported by Cahyana *et al.* (2019) for the banana flour. The deceased in trough viscosity is attributed to structural reorganization of starch granules, which resulted in double helix amylopectin bonds during HMT leading to stronger internal bonding that restricted swelling and reduced viscosity development upon heating (Adebowale *et al.*, 2005).

Breakdown viscosity is the difference between peak viscosity and trough viscosity**,** which shows how much the starch paste collapsed under heat and shear. The UPS (975.50 RVU) had higher breakdown viscosity than HPS (193.50 RVU). The breakdown viscosity decreased during the HMT. Kaur & Singh (2019) also reported decrease in breakdown viscosity of starches with modification. The high breakdown viscosity of UPS indicated that despite the fact that the unmodified pigeon pea starch swelled significantly (high peak

viscosity), its granules were weak and highly susceptible to disintegration with prolonged heating and mechanical shear. In contrast, low breakdown viscosity in HPS made it very resistant to thermal and shear-induced disintegration. Heat-moisture treatment promotes internal restructuring of starch molecules, which strengthen granular structure by increasing inter-molecular interactions (Nawaz *et al*., 2020).

Final viscosity reflects the ability of starch to form viscous paste or gel after cooling and is associated with the re-association of starch molecules particularly amylose (retrogradation tendency) (Chen, 2020). The UPS (4628.00 RVU) had higher final viscosity than HPS (1622.50 RVU). The very high final viscosity of UPS indicated strong tendency for molecular re-association during cooling, leading to the formation of thick and cohesive paste, which implies that unmodified pigeon pea starch has high capacity for retrogradation (Bangar *et al*., 2022). In contrast, the lower final viscosity for HPS suggests that heat-moisture treatment reduced the ability of the starch to re-associate during cooling due to the structural rearrangements and strengthened internal bonding formed (Bangar *et al*., 2022).

Setback viscosity (final-trough***)*** reflects retrogradation and gel-forming tendency. The UPS (1742.50 RVU) had higher setback viscosity than the HPS (651.00 RVU)**.** Subroto *et al.* (2019) also recorded significant decreased in the setback viscosity of sweet potato until 110^{o}C. The decrease in the setback viscosity was due to increase in the interaction of amylose and amylopectin molecules during cooling (Yu *et al*., 2014).

Peak time represents the time required for starch granules to reach maximum viscosity during heating. The HPS (7.00 min) had longer peak time than the UPS (5.15 min). The shorter peak time for the UPS indicated that native pigeon pea starch (UPS) gelatinized rapidly and implied that its granules readily absorbed water and swelled quickly due to less restricted internal structure, allowing faster viscosity development (Singh *et al*., 2003). In contrast, the significantly longer peak time for HPS shows that heat-moisture treatment delayed gelatinization because it induces stronger internal bonding and structural reorganization within starch granules, making them more resistant to water penetration and swelling. As a result, more time is required to reach maximum viscosity (Gunaratne and Hoover, 2002).

The peak temperatures of the samples showed that HPS (92.00^{o}C) had higher temperature than the UPS (84.45^{o}C). The higher pasting temperature for HPS indicated

that heat-moisture treatment increased the resistance of starch granules to swelling and gelatinization due to stronger inter-molecular association and enhanced crystalline stability, thereby requiring more heat energy to disrupt the structure (Bangar *et al.*, 2022).

Functional properties of unmodified and heat-moisture treated pigeon pea starches

The functional properties of unmodified pigeon pea starch (UPS) and heat moisture treated pigeon pea starch (HPS) are presented in Table 5.

The bulk density of the samples were 0.83 g/g and 0.80g/g for unmodified and modified pigeon pea starch, respectively**.** The higher bulk density for the UPS indicated that the particles are more densely packed. The slight reduction in bulk density of HPS (0.80g/ml) compared to the UPS could be attributed to the effect of heat-moisture treatment, as HMT modified the internal structure of starch granules, resulting in partial rearrangement and decreased packing effectiveness that lead to a less compact structure(Hoover, 2010).

The water absorption capacity of the samples ranged from 2.00g/g to 2.20g/g. The UPS (2.20g/g) had higher water absorption capacity than HPS (2.0g/g). The decreased in water absorption capacity of HPS could be attributed to the effect of HMT, which caused increase in the crystalline area where the portion had a denser and stronger structure that made it harder for the starch to absorb water (Hoover, 2010). Subroto *et al.* (2019) also reported decrease in water absorption capacity until 110^{o}C and increased beyond 120^{o}C. The oil absorption capacity (OAC) of the samples ranged from 1.00g/g to 1.50 g/g. The HPS (1.5 g/g) had higher oil absorption capacity then UPS (1.00g/g). The increased OAC was attributed to the effect of HMT, which exposed hydrophobic region and enhanced the interaction between starch and lipids (Umar *et al.*, 2015). Sharma *et al.* (2015) also reported increase in the oil absorption capacity of pearl millet starch.

Dispersibility of starch is the ability of starch powder to separate and distribute uniformly throughout a liquid without forming clumps or aggregates (agglomerates) (Lee & Yoo.2023). The dispersibility of the samples ranged from 79.00% to 82.00%. The HPS (82.00%) had higher dispersibility than the UPS (79.00%). The increase probably caused disruption of weak hydrogen bonds, which allowed individual granules to disperse more easily (Schafranski *et al.*, 2021).

The foam capacities ranged from 5.00% to 15.00%**.** The UPS (15.00%) had higher foaming capacity than the HPS (5.00%). The reduction in foam capacity of HPS could be attributed to the protein aggregation and flexibility, increase in molecular interaction with starch matrix caused by HMT, which further limited air incorporation during the treatment process at high temperature (Wang *et al*., 2021). On the other hand, the HPS had higher foam stability (97.16%) than the UPS (92.18%). The increased foam stability of HPS may be due to enhanced molecular interactions and stronger structural networks formed during heat-moisture treatment, which stabilized the air bubbles once formed (Nawaz *et al*., 2020).

The swelling power of the HPS (6.75g/g) was lower than that of UPS (7.45g/g). This result shows significant difference ($p < 0.05$) in the ability of the samples to absorb water and swell upon heating where UPS had superior property. Subroto *et al* (2019) studied the effect of heat-moisture on the functional and pasting properties of potato starch and document decrease in the swelling power of the starch with increased in temperature but increased beyond 110^{o}C. Kaur & Singh (2019) reported significant decrease in swelling power of Starches from different Indian oat. The deceased in the swelling power could be attributed to molecular rearrangement within the amorphous and crystalline regions of the starch resulting in the formation of A-tpye starch crystals and reduction B-type starch crystals. This lead to formation of stronger intermolecular interactions (amylose-amylose and amylose-amylopectin), increased crystallinity and structural rigidity that limited water penetration and granules expansion thereby reducing swelling capacity (Nawaz *et al*., 2020).

The solubility of the samples ranged from 10.50% to 23.50% with HPS (10.50%) having the lowest solubility and UPS (23.50%) with the highest solubility. Adebowale and Lawal (2002) studied the effect of annealing and heat-moisture treatment on the physicochemical characteristics of bambarra groundnut and reported decease in the solubility at all temperatures compared to the unmodified starch. Also Kaur & Singh (2019) reported decrease in solubility of starches from different Indian oats with HMT. The reduction in solubility could be due to rearrangement of the starch granules, formation of more ordered double helical amylopectin side-chain clusters and the formation of amylose–lipid complexes within the granule (Kumar *et al*., 2023).

Starch purity and amylose content of unmodified and heat-moisture treated pigeon pea starches

The amylose contents of the unmodified (UPS) and modified pigeon pea (HPS) starches were 12.76% and 13.21%, respectively, as displayed in Table 6. The increase in amylose content of HPS could be attributed to the effect of heat-moisture treatment, which caused molecular rearrangement within the starch granule that promoted partial debranching of amylopectin into linear chains of amylose **(**Srikaeo & Sangkhiaw, 2014**).** The increase is not due to new amylose being formed but a structural rearrangement. Chandla *et al.* (2017) also reported increase in amylose content of amaranth starch with physical modification (HMT).

The amylopectin content decreased significantly ($p<0.05$) from 87.24 % in UPS to 86.79% in HPS. The decrease in amylopectin content was induced by HMT, which affected granular architecture, potentially reducing the long-branched amylopectin chains that govern swelling and viscosity (Li *et al.*, 2022).

The percentage starch purity is presented in Table 6. The starch purity varied significantly ($p < 0.05$) between the samples with UPS (87.80 %) having higher purity than the HPS (85.24%). The decreased in starch purity for HPS (85.24%) compared to UPS (87.80%) was attributed to the effect of HMT, which may have induced structural rearrangement that made starch granules formed starch-protein (Xiang *et al.* 2023).

CONCLUSION

The study showed that heat- moisture treatment (HMT) improved the functional and pasting properties of pigeon pea starch and increased its amylose content. Heat-moisture-treated starch had significantly higher protein, fat, fiber, ash, and mineral contents than the unmodified pigeon pea starch. Heat moisture treatment reduced the brightness (L*) while increased the reddishness (a*) and yellowness (b*) values of the starch. The findings indicated that heat moisture treatment can effectively alter pigeon pea starch to produce desirable physicochemical and nutritional properties, which would enhance its use in food product development.

Recommendation

Based on the findings of this study, it is recommended that:

1. The modified starch could be explored as an ingredient in the development of value-added food products, particularly gluten-free products.
2. Further studies should investigate the optimization of HMT conditions, including moisture level, temperature, and treatment time, to obtain starch with desirable properties for specific food applications.

Conflict of Interest Statement

The authors declare that they have no conflict of interest

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