Kwaghe International
Journal of Sciences and Technology

ISSN: 1595-7977

Index: Harvard, Boston, Sydney University, Dimensions, Lens, ResearchGet Scilit, Semantic, Google, Base etc

https://doi.org/10.58578/KIJST.v3i3.12593

# Effect of Heat-Moisture Treatment of Pigeon Pea Starch on Quality Characteristics of Its Gluten-Free Noodles

**Layerga T. G., Akubor P. I., Augustine A. O., Dauda M.**
Federal University of Wukari, Taraba State, Nigeria
layergatabithg@gmail.com



| Submitted: | Revised: | Accepted: | Published: |
|---|---|---|---|
| Sep 24, 2026 | Oct 23, 2026 | Nov 3, 2026 | Nov 8, 2026 |



**Abstract**

Pigeon pea starch offers a potential alternative to wheat flour in gluten-free noodle production. This study evaluated the effects of heat–moisture treatment (HMT) on the cooking, textural, color, and sensory characteristics of pigeon pea starch noodles. Extracted starch was treated at 110 °C for 3 h at 30% moisture content and subsequently used to produce noodles. Noodles prepared from untreated pigeon pea starch and wheat flour served as controls. Cooking quality, texture profile, instrumental color, and sensory properties were assessed using standard methods. HMT significantly altered noodle color ($p < 0.05$), including a reduction in lightness from 59.31 to 36.33. Compared with untreated starch noodles, HMT-treated starch noodles exhibited higher cooked weight, water uptake, and cooking yield, accompanied by increased cooking loss. Treatment also increased cohesiveness, springiness, and chewiness, reduced hardness, and altered gumminess. However, less favorable color and taste reduced the overall acceptability of HMT-treated starch noodles relative to both controls. Wheat flour noodles received the highest scores for most sensory attributes, although pigeon pea starch noodles remained generally acceptable. These findings demonstrate that HMT modifies the cooking and textural performance of pigeon pea starch noodles, with accompanying limitations in sensory acceptance. HMT-treated pigeon pea starch shows potential as an ingredient for gluten-free noodle formulations and greater utilization of indigenous crops, although color and taste remain important considerations in product development.

**Keywords:** Pigeon Pea Starch; Heat–Moisture Treatment; Gluten-Free Noodles; Cooking Quality; Sensory Acceptability


KIJST Journal is licensed under a Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License

## INTRODUCTION

Pigeon pea (*Cajanus cajan*), an important drought-tolerant legume cultivated mainly in tropical and subtropical regions, particularly Asia, Africa, and Latin America (Sarkar *et al.*, 2020), is recognized for its nutritional and agronomic potential (A'yuni *et al.*, 2021). The seed contains substantial amounts of protein, carbohydrate, dietary fiber, minerals, and other nutritionally important components, making pigeon pea a promising raw material for the development of value-added food products (A'yuni *et al.*, 2021; Guleria *et al.*, 2022). Despite these attributes, its utilization in processed foods remains relatively limited compared with major cereal crops (Haji *et al,* 2024). This may be linked to the hard-to-cook phenomenon, where it takes a lot of time and energy to cook pigeon pea ((Haji *et al,* 2024). Thus, starch, which is high in pigeon pea, may be extracted from the pea for various food systems, including noodles, to increase its utilization in food processing and contribute to the diversification of food ingredients and the development of products based on locally available crops (Locali-Pereira *et al.*, 2023).

Starch is a carbohydrate polymer that is 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, unmodified 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). To overcome these limitations, starch can be modified through physical modification such as heat moisture treatment (Singh *et al.*, 2003).

Heat moisture treatment (HMT) is an eco-friendly, physical modification technique that alters the physicochemical, structural, and functional properties of starch without breaking covalent bonds (Subroto *et al.*, 2022; Mathobo *et al.*, 2021). These changes increase the degree of internal ordering, reduce molecular mobility, and restrict swelling of the granule upon subsequent heating (Subroto *et al.*, 2019). Thus, HMT starch exhibits restricted water absorption, reduced swelling and solubility, high gelatinization temperature, and improved structural stability (Nawaz *et al.*, 2020). The extent of these changes largely depends on the starch source, amylose, moisture level, and heating conditions during the

treatment (Adebowale *et al*., 2005). These changes are desirable for food applications such as in noodles.

Noodles are among the most widely consumed convenience meals in the world, and their demand is rising significantly in Africa, particularly in Nigeria (Akah *et al*., 2021). Noodles, which are often produced from wheat flour, are high in carbohydrates but deficient in protein and essential nutrients (Niu *et al.,* 2019). In addition, wheat flour noodles are often low in amylose content and have a high glycemic index, which exposes consumers to diseases such as diabetes (Kumar *et al*., 2014). Furthermore, Nigeria imports a lot of wheat every year, which strains foreign exchange reserves and restricts the promotion of indigenous crops. Thus, there is growing interest in creating gluten-free noodles and noodles with high resistant starch content using locally accessible nutrient-rich ingredients such as pigeon pea (Lokpobiri, 2019). Pigeon pea starch, a legume starch, offers a lot of advantages over cereal starch for producing noodles because of its higher protein and amylose contents, better water absorption and gelation properties, lower glycemic index, and the potential to produce nutritionally enhanced and gluten-free noodles(Muldoon,2020; Palthania *et al*.,2025). The use of moisture heat-treated pigeon pea starch as the main raw material for making noodles offers a promising alternative to wheat-based components, providing desirable functional and textural properties suitable for gluten-free noodles (Bangar *et al*., 2023).

The study evaluate the effect of heat-moisture treatment of pigeon pea starch on quality characteristics of its gluten-free noodles.

## MATERIALS AND METHODS

### Materials

Pigeon pea (*Cajanus cajan)* seeds, eggs and salt 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.

**Production of gluten free noodles**

Noodles were produced from pigeon pea starch as described by Mir *et al.* (2024) with slight modification. Table 1 shows the recipe used for the noodles production. The pigeon pea starch (unmodified or modified) (100g) was weighed into cleaned mixing bowl and 0.5g of salt was added and mixed thoroughly to ensure uniform distribution. One medium-sized whole egg (50g) was poured into separate bowl, beaten, and poured into the starch-salt mixture. The ingredients were mixed thoroughly using a mixer until a uniform

dough was formed. Water (20ml) was added gradually just enough to bind the dough. The dough was kneaded for 10 minutes (until it became smooth and elastic), covered with a damp cloth and allowed to rest at ambient temperature (30°C) for 30 minutes. Thereafter, it was rolled in a pasta maker and cut into uniform noodle strands. The noodle strips were steamed over boiling water for 5minutes (until partially gelatinized), cooled to ambient temperature (30°C) then, dried in a hot air oven at 45°C for 5 hour (to constant weight). The dried noodles were packed in polyethylene bags and stored at ambient temperature (30°C) prior to use. The same procedure was followed for the preparation of wheat flour noodles, which was also used as control.

**Table 1: Recipe for the production of noodles**

| Ingredient | Treatment $T_1$ | Treatment $T_2$ | Treatment $T_3$ |
|---|---|---|---|
| Wheat flour (g) | 100 | - | - |
| Unmodified pigeon starch(g) | - | 100 | - |
| HMT pigeon pea starch(g) | - | - | 100 |
| Salt(g) | 0.5 | 0.5 | 0.5 |
| Egg(ml) | 50 | 50 | 50 |
| Water(ml) | 20 | 20 | 20 |

Source: Mir *et al.* (2024). HMT= heat moisture treated

## Analytical Methods

### Determination of instrumental color of noodles

The color evaluation of wheat flour, unmodified and heat-moisture treated pigeon pea starch noodles were carried out using the method described by Guleria *et al.* (2022) using a 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 native starch or control noodles was calculated as:

$$\Delta E = \sqrt{(L2 * - L1 *) + (a2 * - a1*) + (b2* - b1*)}$$

*Where* $L_1$*, $a_1$*, $b_1$* are the color coordinates of the reference sample (native)

$L_2$*, $a_2$*, $b_2$*are those of the modified sample.

**Determination of cooking quality of noodles**

The cooking quality, such as cooking time, cooking yield, water uptake, cooking temperature, and cooking loss, of noodles produced from wheat flour, unmodified and heat-moisture treated pigeon pea noodles were determined by the methods described by Kulkarni *et al* (2020).

**Determination of textural properties of noodles**

The hardness, springiness, gumminess, cohesiveness and chewiness of noodle strands produced from wheat flour, unmodified and heat-moisture treated pigeon pea starches were determined using method described by Bourne (2002) utilizing the Texture Profile Analysis (TPA) method with a Texture Analyzer.

**Evaluation of sensory properties of noodles**

The sensory properties of noodles were assessed using the method described by Wichchukit *et al.* (2022). A total of 20 trained panelists were selected from students and staff of the Department of Food Science and Technology, Federal University Wukari, Taraba state, Nigeria. The unmodified and modified pigeon pea starch noodles were cooked at standardized conditions such as uniform boiling time, water ratio and temperature. The cooked noodles were drained and served at a controlled temperature (30 °C). Each sample was presented in ceramic plates coded with three-digit random numbers to the panelists in a randomized order to minimize bias. Panelists assessed the noodle samples using a 9-point Hedonic scale where 9 = like extremely, 8=like very much, 7= like moderately, 6= like slightly, 5 = neither like nor dislike, 4= dislike slightly, 3= dislike moderately, 2= dislike very much and 1 = dislike extremely on structured questionnaires. Sachet water was provided to panelists to rinse their mouths between evaluations. The sensory attributes that were evaluated included color, aroma**,** texture**,** taste**,** and overall acceptability**.** The evaluation was carried out in a sensory evaluation laboratory at controlled conditions of adequate lighting and ventilation.

**Experimental design and statistical analysis**

The study employed a completely randomized design (CRD) to evaluate the effects of heat moisture treatment of pigeon pea starch on the quality of its noodles. The experimental treatments consisted of three treatments namely: wheat flour (T1).

Unmodified starch (T2), HMT starch (T3). Each treatment were replicated two times and the experimental units were randomly assigned to treatments.

Data obtained were analyzed by one-way analysis of variance (ANOVA) (Wang *et al.*, 2025) using Statistical Package for Science solution (SPSS) version 26. Duncan's multiple range test (DMRT) was used to separate means where significant differences existed. Data were reported as mean ± standard deviation of three replicates.

## RESULTS

**Table 2: Color properties of noodles from wheat flour and pigeon pea starch samples**

| Noodles | L* | a* | b* | ΔE | ΔC |
|---|---|---|---|---|---|
| **WFN** | $35.04^{c}$±0.27 | $3.41^{b}$±0.14 | $7.38^{b}$±0.16 | 0.00 | 0.00 |
| **UPN** | $59.31^{a}$±0.15 | $1.73^{c}$±0.13 | $12.15^{a}$±0.49 | 24.81 | 4.14 |
| **HPN** | $36.33^{b}$±0.44 | $4.59^{a}$±0.16 | $7.96^{b}$±0.36 | 1.90 | 1.6 |

*Values are means ±SD of three replications. Means within a column with different superscripts are significantly different (p<0.05).WFN=wheat flour noodles, UPN=unmodified pigeon pea starch noodles, HPN=heat moisture treated pigeon starch noodles, L*=brightness, a*=reddishness, b*=yellowness, ΔE=total color difference, ΔC= color intensity*

**Table 3: Cooking quality of noodles from wheat flour, unmodified and modified pigeon pea starches**

| Noodles | Cooking time(min) | Cooked weight(g) | Water uptake(g) | Cooking yield (%) | Cooking loss (%) |
|---|---|---|---|---|---|
| WFN | $12.50^{a}$±001 | $8.96^{c}$±0.23 | $3.73^{c}$±0.23 | $174.50^{c}$±4.67 | $6.60^{a}$±0.28 |
| UPN | $7.14^{c}$±0.04 | $11.78^{b}$±0.06 | $6.78^{b}$±0.06 | $235.50^{b}$±1.27 | $2.30^{a}$±1.83 |
| HPN | $7.24^{b}$±0.01 | $14.70^{a}$±2.69 | $9.79^{a}$±0.65 | $294.00^{a}$±13.01 | $3.70^{a}$±1.56 |

*Values are means ±SD of two replications. Means within a column with different superscripts are significantly different (p<0.05). WFN=wheat flour noodles, UPN=unmodified pigeon pea starch noodles, HPN= heat moisture treated pigeon starch noodles*

**Table 4: Textural profile of noodles from wheat flour and pigeon pea starches**

| Noodles | Hardness(N) | Cohesiveness(N) | Gumminess(N) | Springiness(mm) | Chewiness(N) |
|---|---|---|---|---|---|
| WFN | $47.40^{a}$±19.35 | $0.09^{b}$±0.90 | $3.19^{b}$±2.99 | $0.70^{b}$±0.50 | $2.33^{b}$±2.29 |
| UPN | $12.70^{b}$±5.01 | $0.12^{b}$±0.11 | $1.28^{c}$±0.72 | $0.76^{b}$±004 | $0.98^{c}$±0.59 |
| HPN | $10.23^{c}$±2.12 | $0.45^{a}$±0.05 | $4.67^{a}$±1.40 | $0.88^{a}$±0.03 | $4.12^{a}$±1.34 |

*Values are means ±SD of three replications. Means within a column with different superscripts are significantly different (p<0.05). WFN=wheat flour noodles, UPN=unmodified pigeon pea starch noodles, HPN= heat moisture treated pigeon starch noodles*

**Table 5: Sensory properties of noodles from wheat flour, unmodified and modified pigeon pea starches**

| Noodles | Color | Aroma | Texture | Taste | General acceptability |
|---|---|---|---|---|---|
| WFN | $7.25^{a}$ ±1.45 | $6.60^{a}$±2.06 | $7.55^{a}$±5.17 | $6.95^{a}$±1.61 | $7.00^{a}$±1.52 |
| UPN | $7.00^{c}$±1.17 | $6.30^{b}$±1.73 | $6.40^{c}$±1.82 | $6.35^{b}$±2.08 | $6.50^{b}$±1.57 |
| HPN | $6.15^{b}$1.18 | $6.30^{b}$±1.72 | $6.50^{b}$±1.70 | $6.05^{c}$±2.08 | $6.40^{c}$±1.19 |

*Values are means ±SD of twenty replications. Means within a column with different superscripts are significantly different (p<0.05). WFN=wheat flour noodles, UPN=unmodified pigeon pea starch noodles, HPN= heat moisture treated pigeon starch noodles.*

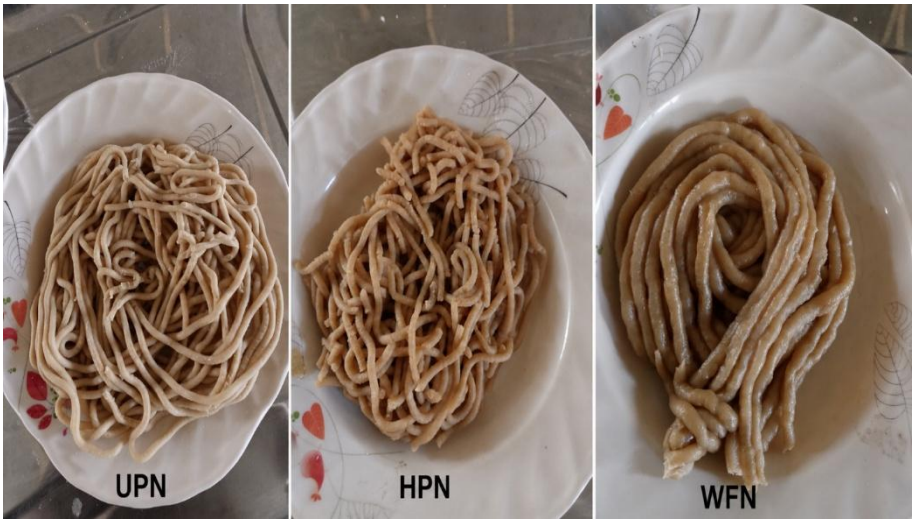



Plate 1: Visual appearance of noodles produced from unmodified pigeon pea starch noodles (UPN), heat-moisture treated pigeon pea starch noodles (HPN), and 100% wheat flour noodles (WFN)

## DISCUSSION

### Color properties of noodles

The instrumental color properties of noodles are presented in Table 2. The L* values of the noodle samples differed significantly ($p < 0.05$), with unmodified pigeon pea starch (59.31) having the highest lightness values, followed by heat moisture treated pigeon pea starch (36.33), while WFN (35.04) had the lowest value. This implied that noodles produced from unmodified pigeon pea starch was lighter and brighter than the HPN as well as noodles produced from wheat flour. Plate 1 shows the appearance of noodles produced from unmodified pigeon pea starch noodles (UPN), heat- moisture treated pigeon pea starch (HPN) and 100% wheat flour (WFN). The a* value ranged from 1.73 to 4.59. The heat moisture treated pigeon pea starch (HPN) (4.59) had the highest a* value, followed by WFN (3.41), and then, the UPN (1.73). This suggests that the noodles produced from heat-moisture-treated starch were the most reddish, while those from unmodified pigeon pea starch were the least in the reddish value. The highest b* value was demonstrated by UPN (12.15), while WFN (7.38) and HPN (7.96) had substantially lower and comparable yellow values. The combined variation in L*, a*, and b* values indicates that noodles from unmodified pigeon pea starch were lighter and more yellow, while noodles from heat-moisture treated starch are darker and more reddish, underscoring the substantial impact of starch modification on noodles' visual quality. Similar result was reported by Liu et al. (2019) on effect heat moisture treatment of germinated wheat on the quality of Chinese white salted noodles where L* decreased and the a* and b* values increased. The UPN had the highest ΔE value (24.81) Indicating the greatest visual color difference from wheat flour noodles (WFN) while HPN showed much lower ΔE value (1.90), suggesting that heat moisture treated starch produced noodles with color characteristic closer to wheat flour noodles (WFN). Furthermore, the UPN had higher ΔC value (4.14), which indicated great color intensity or saturation compared to the WFN while HPN showed slight variation in Chroma compared with the WFN.

### Cooking quality of noodles

The cooking qualities of noodles are presented in Table 3.

The cooking time for the noodle samples ranged from 7.14 to 12.51min. The wheat flour noodles (WFN) took longest time to cook at 12.15min, followed by heat moisture treated pigeon pea starch noodles (HPN) at 7.24 min and then unmodified pigeon pea

starch noodles (UPN) at 7.14min. The higher cooking time for WPN was due to the presence of gluten, which produced strong protein-starch network that slowed water penetration and starch gelatinization (Sharma *et al.*, 2015). The slightly higher cooking time for HPN over that of UPN may be associated with structural rearrangement induced by heat-moisture treatment (HMT), which increased internal bonding and slowed water penetration making the granules more resistant to swelling and gelatinization(Sharma *et al.*, 2015). The lower cooking time for UPN is attributed to faster hydration and quicker gelatinization of starch granules (Sharma *et al.*, 2015).

The cooking yield of the noodle samples ranged from 174.50% to 294.67%**.** The HPN (294.67%) had the greatest cooking yield, followed by UPN (235.50%), and then, WFN (174.50%) with the lowest value. The significantly higher cooking yield of the HPN indicated increased capacity for water absorption and retention, which may be attributed to the effect of heat-moisture treatment that caused slight expansion of the amorphous region. This in turn caused disruption and breakage of hydrogen bonds between the amorphous and crystalline region (Tsakama *et al.*, 2013). This caused increase in water absorption capacity of the noodles all which gave higher cooking yield (Tsakama *et al.*, 2013).

The cooking loss of the noodles ranged from 2.30% to 6.60%**.** The WFN had the highest cooking loss (6.60%), followed by HPN (3.70%), while UPN (2.30%) had the lowest value. In contrast, Subroto *et al.* (2019) reported significant decreased in cooking loss of potato noodles. Ungureanu-Iuga & Mironeasa (2023) reported the highest cooking loss at 100$^{o}$C for 3 hours at 30% moisture content of wheat flour and pasta. The higher cooking loss in HPN might be due to the HMT of the pigeon pea starch.

The cooked weight of the noodle samples showed significant differences, with values ranging from 8.96 g to 14.70 g. HMT increased the cooked weight of the noodles from 14.70g (HPN), to 11.78g (UPN), and then 8.96g (WFN) with the lowest cooking weight .The increased in cooked weight for HPN indicates greater water absorption and swelling capacity during cooking. This may be due to improved water-binding ability of modified starch structures, which allowed more hydration without structural collapse (Sindhu *et al.*, 2019). The UPN also had higher cooked weight than the WFN, suggesting that pigeon pea starch-based noodles have greater water absorption capacity than wheat flour noodles.

Water uptake showed significant differences ($p < 0.05$) among the samples. The HPN had the substantial water uptake (9.79 g), followed by UPN (6.78 g), and then, WFN (3.73 g).The high water uptake for HPN indicates enhanced hydration capacity, likely due to structural modifications induced by heat-moisture treatment that increased the availability of hydrophilic sites within the starch matrix (Ariyantoro *et al.*,2022). This is attributed to the effect of HMT, which altered the structural organization and increased the availability of water- binding site (Wang *et al.*, 2023). The UPN also demonstrated moderate water absorption, while WFN showed limited water uptake, which may be attributed to the dense protein-starch network that restricts water penetration (Zang *et al.*, 2022).

**Textural profile of noodles**

The textural properties of noodles produced from wheat flour (WFN), unmodified pigeon pea starch (UPN), and heat-moisture treated pigeon pea starch (HPN) are presented in Table 4.

Hardness values of the noodles ranged from 10.23 to 47.40N decreasing from WFN (47.40N), to UPN (12.70N) and then, HPN (10.23 N). Hardness is the force required to compress food sample. It reflects the firmness and resistance of noodles to compression and it influenced by starch gelatinization and network formation (Sharma *et al.*, 2015). The highest hardness of the WFN may be attributed to the presence of stronger gluten-starch interaction, which resulted in a more rigid and cohesive structure (Hoover, 2010). The slightly lower hardness of HPN compared to UPN may be attributed to the effect of heat-moisture treatment (HMT), which restricted swelling and limited expansion of starch granules (Sharma *et al.*, 2015). This is desirable for noodle quality as excessively hard noodles may be perceived as tough (Wang *et al.*, 2023). Similar observation was documented by Deng & Luo (2023).

The cohesiveness of the noodle samples varied between 0.09 N and 0.45 N, with HPN having the greatest value at 0.45N, followed by UPN at 0.12N, and WFN at lower with 0.09N. Cohesiveness is a textural property that denotes the extent to which food sample remains intact following compression or deformation (Hoover, 2010). The significantly higher cohesiveness for the HPN suggests a stronger internal bonding within the noodle matrix, which may be attributed to structural rearrangements induced by heat-moisture treatment promoting stronger intermolecular associations (amylose–amylose and amylose–amylopectin interactions) ( Hoover, 2010).

Gumminess values ranged from 1.28N to 4.677N where HPN (4.67N) had the highest value, followed by WFN (3.19N) and UPN (1.28N) had the lowest. Contrarily to what Chandla *et al.* (2017) reported for amaranth starch noodles. The slightly higher gumminess of HPN may be associated with its more compact and structured starch network caused by HMT, while the lower value for UPN may reflect weaker internal bonding (Hoover, 2010).

The springiness of the noodle samples ranged from 0.70mm to 0.88mm. WFN (0.70mm) had the minimum value, followed by UPN (0.76mm**)** and HPN (0.88) had the maximum value. There was no significant difference ($p > 0.05$) in the springiness of WFN and UPN but HPN significantly ($p<0.05$) differed from them. The higher springiness of the HPN showed that HMT slightly enhanced elasticity by promoting reorganization of starch molecules, improving the ability of noodles to recover after compression. Chandla *et al.* (2017) recorded increase in the springiness of heat moisture treated amaranth starch relative to the native amaranth starch noodles.

The chewiness of the noodle samples ranged from 0.98 to 4.12N, with HPN having the highest value (4.12N), followed by WFN (3.33N**)** and then, UPN (0.98N). The higher chewiness of HPN suggests improved elastic recovery, likely due to structural rearrangement and strengthened intermolecular associations induced by heat-moisture treatment (Iuga & Mironeasa .2020).The higher protein, fat and fiber contents of the heat moisture treated pigeon pea starch noodles (HPN) (Table 4.8) may have formed protective networks around the starch, which boosted chewiness by slowing disintegration (Li *et al.*, 2021; Zhang *et al.*, 2021). In contrast, the lower values for WFN and UPN indicated reduced elasticity and weaker structural recovery after compression. Chandla *et al.* (2017) reported increased in the chewiness of heat- moisture treated amaranth starch noodles compared to the native corn starch noodles.

**Sensory properties of noodles**

The sensory properties of noodles from wheat flour, native and modified pigeon starches are presented in Table 5.

Color is a critical sensory attribute that strongly influences consumer perception and acceptance of food products, including noodles. The sensory scores for color differed significantly ($p < 0.05$) among the samples. The WFN (wheat flour noodles) (7.25) had the highest color score, followed by UPN (7.00), while HPN (6.15) had the lowest rating.

Higher color score of WFN may be attributed to the natural brightness and slight cream color of wheat noodles. The slightly low color score for UPN (unmodified pigeon starch noodles) is attributed to the inherent pigmentation of pigeon pea starch. The lowest color score for HPN (heat moisture treated pigeon starch noodles) was due to intensified non-enzymatic browning (Maillard reactions) (Schutte *et al.*, 2024) that led to darker appearance, hence lower preference.

Aroma is an important sensory attribute that contributes to the overall acceptability of food products, as it influences initial perception and consumer preference. The aroma scores of the noodle samples ranged from 6.30 to 6.60. WFN recorded a score of 6.60 whereas UPN and HPN had the same score of 6.30. The high score for the WFN was obvious because it was prepared from wheat flour with familiar noodle aroma. There was no significant difference ($p>0.05$) between UPN and HPN in the aroma scores, indicating that starch modification (HMT) did not affect the aroma of the noodles. The reduced aroma acceptability in UPN and HPN) may be linked to beany or legume-like odors, which are common in pulses.

Texture is a sensory attribute that determines the mouth-feel and overall eating quality of noodles, influencing consumer preference and acceptability (Wang *et al.*, 2019). The sensory texture scores differed significantly ($p < 0.05$) among the samples with the greatest score from WFN (7.55), followed by HPN (6.50), and then UPN (6.40). The higher texture score for WFN may be ascribed to the presence of gluten, which formed strong viscoelastic network that contributed to desirable attributes such as firmness and elasticity (Zhang *et al.*, 2023). The HPN had slightly higher texture score than UPN indicating that heat-moisture treatment improved starch functionality by strengthening the gel and enhancing starch–starch interactions, leading to improved firmness and bite (BeMiller & Huber, 2015).

Taste is an important sensory element that affects customer acceptance and preference for food products. It reflects the combined sense of flavor components derived from source ingredients and processing conditions (Wang *et al.*, 2019). The taste scores of the noodle samples differed significantly ($p < 0.05$). WFN (6.95) had the greatest taste score, compared UPN (6.35), and HPN (6.05) had the lowest rating. The highest taste score for WFN may be attributed to the familiar and widely accepted flavor of wheat-based products. The moderate taste score for the UPN shows that noodles made from untreated

pigeon pea starch are relatively palatable, but may have some beany or legume-like flavors characteristic of pigeon peas. The lowest taste score for HPN could be attributed to the effects of heat-moisture treatment (HMT), which caused minor off-flavor alterations due to thermal reactions that negatively affected taste perception (Mathobo *et al.*,2021).

General acceptability expresses panelists' overall preference for a product, taking into account all sensory aspects such as color, taste, aroma, and texture. It is a strong predictor of consumer acceptability and product success (Wang *et al.*, 2019). General acceptability scores differed significantly ($p < 0.05$) among the noodle samples where WFN (7.00) received the highest score, followed by UPN (6.50), while HPN (6.40) had the lowest rating. The highest overall acceptability of WFN may be attributed to its balanced sensory qualities, particularly its familiar taste, desirable texture, and appealing color. Wheat-based noodles are widely consumed and generally preferred due to their well-established sensory characteristics. The relatively high acceptability of UPN indicates that noodles produced from untreated pigeon pea starch (UPN) are reasonably acceptable to consumers, which suggests that despite slight differences in flavor and texture compared to wheat noodles, pigeon pea starch can be successfully utilized in noodle production without major compromise in sensory quality. In contrast, the slightly lower acceptability score for the HPN may be due to cumulative effects of changes in color, taste, and texture associated with heat–moisture treatment (HMT). As the HPN had darker color (lower L*), higher redness (a*) (Table 2) and slightly reduced taste and texture scores, which may have negatively influenced overall perception. Despite these variations, all samples received scores higher than 6.0, suggesting that the panelists found them to be generally acceptable, which implies that there is good chance of customer acceptability for both untreated and heat-moisture treated pigeon pea starch noodles.

## CONCLUSION

The study showed that heat- moisture treatment (HMT) of pigeon pea starch improved the textural profile and cooking quality of gluten-free noodles. The HMT altered the color of the starch by reducing the brightness, resulting in a darker appearance, and adversely affected taste, which negatively affected the general sensory acceptability of HMT noodles relative to both wheat flour noodles and those from unmodified pigeon pea starch. Despite these sensory limitations, the enhanced cooking and textural profile of heat

moisture treated pigeon pea starch noodles highlighted its potential for replacing wheat flour in gluten-free noodle formulations, particularly for individuals with celiac disease or gluten intolerance, to increase the utilization of indigenous crops, boost local economies and improve food security.

**Recommendation**

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

1. Natural color additives such as turmeric extract should be added to improve the sensory appeal of the heat-moisture treated pigeon pea starch noodles.
2. Hydrocolloids such as guar gum should be used to enhance the textural firmness and reduce cooking loss of the heat-moisture treated pigeon pea starch noodles

**Conflict of Interest Statement**

The authors declare that they have no conflict of interest

**Acknowledgment**

The authors sincerely acknowledge the Federal University, Wukari, for granting the authors the opportunity to conduct this research and also acknowledge the Department of Food Science and Technology, Federal University, Wukari, Nigeria, for providing the facilities and support required for this study. The authors also appreciate all individuals who contributed technical assistance and support during the course of the research.

## REFERENCES

Akah, N. P., Kunyanga, C. N., Okoth, M. W., & Njue, L. G. (2021). Pulse production, consumption and utilization in Nigeria within regional and global context. *Sustainable Agriculture Research, 10*(2), 48–64. https://doi.org/10.5539/sar.v10n2p48

A'yuni, N. R. L., Marsono, Y., Marseno, D. W., & Triwitono, P. (2021). Composition, structure, and physicochemical characteristics of pigeon pea (*Cajanus cajan*) starches from Indonesia. *Biodiversitas Journal of Biological Diversity, 22*(8), 3430–3439. https://doi.org/10.13057/biodiv/d220840

Bangar, S. P., Ali, N. A., Olagunju, A. I., Pastor, K., Ashogbon, A. O., Dash, K. K., Lorenzo, J. M., & Ozogul, F. (2023). Starch-based noodles: Current technologies, properties, and challenges. *Journal of Texture Studies, 54*(1), 21–53. https://doi.org/10.1111/jtxs.12730

BeMiller, J. N. (1997). Starch modification: Challenges and prospects. *Starch–Stärke, 49*(4), 127–131. https://doi.org/10.1002/star.19970490402

BeMiller, J. N., & Huber, K. C. (2015). Physical modification of food starch functionalities. *Annual Review of Food Science and Technology, 6*(1), 19–69. https://doi.org/10.1146/annurev-food-022814-015552

Chandla, N. K., Saxena, D. C., & Singh, S. (2017). Processing and evaluation of heat moisture treated (HMT) amaranth starch noodles; an inclusive comparison with corn starch noodles. *Journal of Cereal Science, 75*, 306–313. https://doi.org/10.1016/j.jcs.2017.05.003

Deng, C., Melnyk, O., & Luo, Y. (2021). The effect of heat-moisture treatment conditions on the structure properties and functionalities of potato starch. *Potravinarstvo Slovak Journal of Food Sciences, 15*, 824–834. https://doi.org/10.5219/1647

Fonseca, L. M., El Halal, S. L. M., Dias, A. R. G., & da Rosa Zavareze, E. (2021). Physical modification of starch by heat-moisture treatment and annealing and their applications: A review. *Carbohydrate Polymers, 274*, Article 118665. https://doi.org/10.1016/j.carbpol.2021.118665

Gu, Z., Cheng, G., Sha, X., Wu, H., Wang, X., Zhao, R., Huang, Q., Feng, Y., Tang, J., & Jiang, H. (2024). Heat-moisture treatment of freshly harvested high-amylose maize kernels improves its starch thermal stability and enzymatic resistance. *Carbohydrate Polymers, 340*, Article 122303. https://doi.org/10.1016/j.carbpol.2024.122303

Guleria, P., & Yadav, B. S. (2022). Effect of chemical treatments on the functional, morphological and rheological properties of starch isolated from pigeon pea (*Cajanus cajan*). *Current Research in Food Science, 5*, 1750–1759. https://doi.org/10.1016/j.crfs.2022.10.001

Gunaratne, A., & Hoover, R. (2002). Effect of heat–moisture treatment on the structure and physicochemical properties of tuber and root starches. *Carbohydrate Polymers, 49*(4), 425–437. https://doi.org/10.1016/S0144-8617(01)00354-X

Haji, A., Teka, T. A., Yirga Bereka, T., Negasa Andersa, K., Desalegn Nekera, K., Geleta Abdi, G., Lema Abelti, A., & Makiso Urugo, M. (2024). Nutritional composition, bioactive compounds, food applications, and health benefits of pigeon pea (*Cajanus cajan* L. Millsp.): A review. *Legume Science, 6*(2), Article e233. https://doi.org/10.1002/leg3.233

Hoover, R. (2010). The impact of heat-moisture treatment on molecular structures and properties of starches isolated from different botanical sources. *Critical Reviews in Food Science and Nutrition, 50*(9), 835–847. https://doi.org/10.1080/10408390903001735

Hoover, R., & Ratnayake, W. S. (2002). Starch characteristics of black bean, chick pea, lentil, navy bean and pinto bean cultivars grown in Canada. *Food Chemistry, 78*(4), 489–498. https://doi.org/10.1016/S0308-8146(02)00163-2

Iuga, M., & Mironeasa, S. (2020). A review of the hydrothermal treatments impact on starch based systems properties. *Critical Reviews in Food Science and Nutrition, 60*(22), 3890–3915. https://doi.org/10.1080/10408398.2019.1664978

Jeevarathinam, G., & Chelladurai, V. (2020). Pigeon pea. In A. Manickavasagan & P. Thirunathan (Eds.), *Pulses: Processing and product development* (pp. 275–296). Springer. https://doi.org/10.1007/978-3-030-41376-7_15

Kulkarni, A. T., Agarkar, B. S., Sawate, A. R., & Pawar, P. P. (2020). Determination of cooking quality of the composite flour noodles incorporated with chia seeds

powder. *Journal of Pharmacognosy and Phytochemistry, 9*(5), 76–78. https://www.phytojournal.com/archives/2020.v9.i5.12194/determination-of-cooking-quality-of-the-composite-flour-noodles-incorporated-with-chia-seeds-powder

Kumar, S. B., & Prabhasankar, P. (2014). Low glycemic index ingredients and modified starches in wheat based food processing: A review. *Trends in Food Science & Technology, 35*(1), 32–41. https://doi.org/10.1016/j.tifs.2013.10.007

Lee, C.-S., & Chung, H.-J. (2022). Enhancing resistant starch content of high amylose rice starch through heat–moisture treatment for industrial application. *Molecules, 27*(19), Article 6375. https://doi.org/10.3390/molecules27196375

Li, H.-T., Li, Z., Fox, G. P., Gidley, M. J., & Dhital, S. (2021). Protein-starch matrix plays a key role in enzymic digestion of high-amylose wheat noodle. *Food Chemistry, 336*, Article 127719. https://doi.org/10.1016/j.foodchem.2020.127719

Liu, C., Jiang, X., Wang, J., Li, L., Bian, K., Guan, E., & Zheng, X. (2019). Effect of heat-moisture treatment of germinated wheat on the quality of Chinese white salted noodles. *Cereal Chemistry, 96*(1), 115–128. https://doi.org/10.1002/cche.10115

Locali-Pereira, A. R., Boire, A., Berton-Carabin, C., Taboga, S. R., Solé-Jamault, V., & Nicoletti, V. R. (2023). Pigeon pea, an emerging source of plant-based proteins. *ACS Food Science & Technology, 3*(11), 1777–1799. https://doi.org/10.1021/acsfoodscitech.3c00268

Lokpobiri, H. (2019). Nigerian Agriculture Promotion Policy 2016–2020: Towards a new paradigm for domestic food security and foreign exchange earnings in agricultural production. *Public Policy and Administration Research, 9*(3), 47–57. https://doi.org/10.7176/PPAR/9-3-07

Mathobo, V. M., Silungwe, H., Ramashia, S. E., & Anyasi, T. A. (2021). Effects of heat-moisture treatment on the thermal, functional properties and composition of cereal, legume and tuber starches—A review. *Journal of Food Science and Technology, 58*(2), 412–426. https://link.springer.com/article/10.1007/s13197-020-04520-4

Mir, S. A., Naseem, Z., & Wani, S. M. (2024). Development of composite cereal flour noodles and their technological, antioxidant and sensory characterization during storage. *Food Chemistry Advances, 4*, Article 100650. https://doi.org/10.1016/j.focha.2024.100650

Mula, M. G., & Saxena, K. B. (2010). *Lifting the level of awareness on pigeonpea—A global perspective*. International Crops Research Institute for the Semi-Arid Tropics. https://oar.icrisat.org/193/

Nawaz, H., Waheed, R., Nawaz, M., & Shahwar, D. (2020). Physical and chemical modifications in starch structure and reactivity. In M. O. Emeje (Ed.), *Chemical properties of starch*. IntechOpen. https://doi.org/10.5772/intechopen.88870

Niu, M., & Hou, G. G. (2019). Whole wheat noodle: Processing, quality improvement, and nutritional and health benefits. *Cereal Chemistry, 96*(1), 23–33. https://doi.org/10.1002/cche.10095

Palthania, R., Chaturvedi, S., Sandhu, K. S., & Srivastava, Y. (2025). Comparative study of physicochemical, thermal, rheological, and digestibility properties of starches from six Indian legume cultivars. *International Journal of Biological Macromolecules, 323*, Article 147161. https://doi.org/10.1016/j.ijbiomac.2025.147161

Sarkar, S., Panda, S., Yadav, K. K., & Kandasamy, P. (2020). Pigeon pea (*Cajanus cajan*) an important food legume in Indian scenario—A review. *Legume Research—An International Journal, 43*(5), 601–610. https://arccjournals.com/journal/legume-research-an-international-journal/LR-4021

Schutte, M., Hayward, S., & Manley, M. (2024). Nonenzymatic browning and antioxidant properties of thermally treated cereal grains and end products. *Journal of Food Biochemistry, 2024*(1), Article 3865849. https://doi.org/10.1155/2024/3865849

Sharma, M., Yadav, D. N., Singh, A. K., & Tomar, S. K. (2015). Effect of heat-moisture treatment on resistant starch content as well as heat and shear stability of pearl millet starch. *Agricultural Research, 4*(4), 411–419. https://doi.org/10.1007/s40003-015-0177-3

Sindhu, R., Devi, A., & Khatkar, B. S. (2019). Physicochemical, thermal and structural properties of heat moisture treated common buckwheat starches. *Journal of Food Science and Technology, 56*(5), 2480–2489. https://doi.org/10.1007/s13197-019-03725-6

Singh, N., Singh, J., Kaur, L., Sodhi, N. S., & Gill, B. S. (2003). Morphological, thermal and rheological properties of starches from different botanical sources. *Food Chemistry, 81*(2), 219–231. https://doi.org/10.1016/S0308-8146(02)00416-8

Subroto, E., Indiarto, R., Marta, H., & Shalihah, S. (2019). Effect of heat-moisture treatment on functional and pasting properties of potato (*Solanum tuberosum* L. var. Granola) starch. *Food Research, 3*(5), 469–476. https://doi.org/10.26656/fr.2017.3(5).110

Subroto, E., Mahani, Indiarto, R., Yarlina, V. P., & Izzati, A. N. (2022). A mini review of physicochemical properties of starch and flour by using hydrothermal treatment. *Polymers, 14*(24), Article 5447. https://doi.org/10.3390/polym14245447

Tsakama, M., Mwangwela, A. M., & Kosamu, I. B. M. (2013). Effect of heat-moisture treatment (HMT) on cooking quality and sensory properties of starch noodles from eleven sweetpotato varieties. *International Research Journal of Agricultural Science and Soil Science, 3*(7), 256–261. https://www.interesjournals.org/abstract/effect-of-heatmoisture-treatment-hmt-on-cooking-quality-and-sensory-properties-of-starch-noodles-from-eleven-sweetpotato-15857.html

Ungureanu-Iuga, M., & Mironeasa, S. (2023). Changes induced by heat moisture treatment in wheat flour and pasta rheological, physical and starch digestibility properties. *Gels, 9*(6), Article 449. https://doi.org/10.3390/gels9060449

Wang, H., Zhang, Y., Su, P., Pan, N., Liu, X., Zhang, Y., & Zhang, H. (2023). Insights into the aggregation structure and physicochemical properties of heat-moisture treated wheat starch and its associated effects on noodle quality. *Journal of Cereal Science, 112*, Article 103704. https://doi.org/10.1016/j.jcs.2023.103704

Xu, J., Bock, J. E., & Stone, D. (2020). Quality and textural analysis of noodles enriched with apple pomace. *Journal of Food Processing and Preservation, 44*(8), Article e14579. https://doi.org/10.1111/jfpp.14579

Zang, P., Gao, Y., Chen, P., Lv, C., & Zhao, G. (2022). Recent advances in the study of wheat protein and other food components affecting the gluten network and the properties of noodles. *Foods, 11*(23), Article 3824.

Zhang, B., Qiao, D., Zhao, S., Lin, Q., Wang, J., & Xie, F. (2021). Starch-based food matrices containing protein: Recent understanding of morphology, structure, and properties. *Trends in Food Science & Technology, 114*, 212–231. https://doi.org/10.1016/j.tifs.2021.05.033

Zhang, M., Jia, R., Ma, M., Yang, T., Sun, Q., & Li, M. (2023). Versatile wheat gluten: Functional properties and application in the food-related industry. *Critical Reviews in Food Science and Nutrition, 63*(30), 10444–10460. https://doi.org/10.1080/10408398.2022.2078785