

Plantain Varieties and Steaming Conditions Influence the Yield, Functional, Pasting, and Sensory Qualities of Instant Plantain Flour

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Abstract

Despite growing evidence on the optimization of plantain flour, few studies have systematically examined the correlations among steaming conditions, varietal differences, and sensory acceptability. Therefore, the yield, functional, pasting, and sensory characteristics of instant plantain flour were examined in this study in relation to plantain varieties and steaming conditions, using standard methods. Results showed that the yellow-fleshed plantains produced greater yields (37.58-37.82%) under steaming at 92-95°C for 5-8 minutes than white-fleshed samples (33.52-34.73%), according to yield analysis, which revealed significant varietal differences ($P < 0.05$). Steaming conditions had a significant impact on functional properties: Oyo yellow-fleshed plantains steamed at 93°C for 7 minutes demonstrated superior water absorption (185.50%) and oil absorption (191.10%) capacities, while Osun yellow-fleshed plantains steamed at 95°C for 5 minutes showed higher dispersibility (50.00%) and solubility index (9.48%). The steaming conditions decreased peak viscosity in comparison to unsteamed controls. Oyo white-fleshed plantains steamed at 92°C for 8 minutes maintained high final viscosities (604.54 Rapid Visco Unit), while Osun yellow-fleshed samples steamed at 94°C for 6 minutes recorded 495.46 Rapid Visco Unit compared to 654.46 Rapid Visco Unit in controls. While commercial pondo consistently rated higher in taste (7.53), color (7.82), and overall acceptability (7.35), sensory evaluation showed no significant differences ($P > 0.05$) across steaming conditions. These results show that yield, functional properties, and pasting properties are greatly influenced by steaming parameters (92-95°C, 5-8 min) and varietal differences, with yellow-fleshed plantains outperforming the white-fleshed varieties in most of the attributes, except sensory attributes. The findings offer useful information for improving steaming conditions to raise the instant plantain flour product quality and sensory acceptability.

Categories: Food processing, Food quality, Food security and sustainability

Keywords: instant plantain flour, steaming conditions, functional properties, pasting properties, sensory attributes

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Introduction

Plantain (*Musa paradisiaca*) is a major staple crop in West Africa, contributing substantially to food security and nutrition. Countries such as Nigeria, Ghana, and Sierra Leone are leading producers, with plantain serving as a vital source of carbohydrates, minerals, and dietary fiber. Yet, despite its importance, plantain is highly perishable, and postharvest losses remain a persistent challenge [1]. Processing into flour has been widely adopted to extend shelf life, reduce waste, and diversify food applications [1]. While conventional plantain flour (dried chips milled into flour) has been studied extensively, instant plantain flour (steamed, sliced and dried plantain fingers milled into flour) remains underexplored, with limited documentation on its processing parameters and quality attributes. This gap underscores the need for research into processing conditions that can optimize instant flour production, such as steaming.

Steaming is a critical unit operation in transforming plantain fingers into instant flour. Thermal processing with saturated steam alters plantain structure by breaking down cell walls, denaturing proteins, and gelatinizing starches [2]. These modifications enhance digestibility and influence starch functionality, including swelling, solubility, and water absorption capacities [3]. Recent studies confirm that steaming modifies starch structure and improves functional properties, but varietal differences between *Musa balbisiana* and *Musa acuminata* complicate flour performance [4], showing that varietal differences influence flour quality. Genotype and processing conditions jointly determine functional outcomes, suggesting that optimization requires a nuanced understanding of both biological and technological factors [4].

Functional and pasting properties are critical indicators of flour performance in reconstituted foods. Swelling power, solubility index, and water absorption capacity determine starch behavior during reconstitution, while pasting properties such as peak viscosity and setback viscosity reflect gelatinization and retrogradation tendencies [5]. Lower setback viscosity in steamed samples indicates reduced staling and improved storage stability, consistent with findings on tropical starches [6]. These physicochemical attributes directly influence consumer perception, with texture, aroma, and color emerging as the strongest sensory drivers of acceptability and willingness-to-pay for plantain-based products [7]. Although steaming has been reported to improve sensory attributes by reducing enzymatic browning and enhancing flavor retention, the relationship between steaming conditions and sensory acceptability remains insufficiently documented.

Despite growing evidence that steaming enhances nutritional, functional, and sensory qualities [2-4], few studies have systematically examined the correlations among steaming conditions, varietal differences, and sensory acceptability in instant plantain flour. This lack of integrated research limits the optimization of processing strategies for industrial and household applications. Addressing this gap is essential for reducing postharvest losses, improving consumer satisfaction, and expanding the economic potential of plantain-based products. Therefore, this study investigates how steaming temperature and time affect yield, functional, pasting, and sensory properties of instant white- and yellow-fleshed plantain flours from different locations. The findings aim to provide evidence-based insights into processing optimization, contributing to sustainable food systems and value addition in West African agriculture.

Materials And Methods

Material sourcing

Bunches of green, mature, unripe, yellow-fleshed plantains were bought at the Sabo market in Ilesha, Osun State; another set of yellow and white-fleshed plantains was bought from the Idi-Ayunre market in Ibadan, Oyo State. For processing, the plantain bunches were shipped to the Nigerian Stored Product Research Institute's (NSPRI) Food Processing unit in Ilorin, Kwara State. At the NSPRI food processing facility, the bunches of green, mature, and unripe plantains were carefully sorted using a stainless-steel knife to distinguish between the varieties with white and yellow flesh. Plantain fruit is considered unripe when its peel is bright green and flesh starchy, mature when it has reached full size with firm green peel, and ripe when the peel turns yellow with black spots, and the flesh becomes sweet and soft. It is imperative to add that the white- and yellow-fleshed varieties are the forms in which the Agbagba plantain landrace is available in the study location.

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Production of instant plantain flour

The plantain bunches were defingered, cleaned in potable water, peeled with a stainless-steel knife, and then cut with an NSPRI mechanical slicer to an average thickness of 3 mm. A locally created device called the NSPRI plantain slicer was developed by NSPRI for mechanized slicing to reduce postharvest losses and boost productivity in the production of plantain chips. It has a throughput capacity appropriate for small and medium-sized businesses, is driven by an electric motor, and uses stainless-steel blades for consistent slicing between 3 mm and 7 mm. The Simplex Lattice Mixture Design in Design Expert software (Version 6.0) was then used to determine the steaming temperature (92-95°C) and steaming time (5-8 min), as shown in Table 1. The control group consisted of cut plantain fingers that were not steamed. Following steaming, the samples were cooled, dried in a gas-powered cabinet drier at 60°C for 48 hours, ground with a stainless-steel grinder, sieved through a 0.2-mm mesh screen, and sealed in Ziploc bags for further analysis.

Runs	Steaming temperature (°C)	Steaming time (min)
1	94	6
2	95	5
3	94	7
4	93	7
5	92	8

TABLE 1: Steaming temperatures and times used to produce instant plantain flour.

Product yield

The weight of the product was divided by the weight of the fresh plantain fingers to determine the percentage yield of the instant plantain flour. Each variety and location's yield was calculated in triplicate [5].

Functional properties

Bulk Density

A 100-mL measuring cylinder was filled with flour samples, and the contents were weighed after tapping on a flat table until a constant volume was attained. The bulk density was determined by dividing the sample weight (g) by the sample volume (100 mL) [8].

Dispersibility

By weighing 10 g of each flour sample in a 200-mL measuring cylinder (100 mL) and filling the remaining space with distilled water, the dispersibility of the flour samples was assessed. After being vortexed, the setup was given 3 hours to settle. After measuring the amount of settled material, it was deducted from 100. The difference was quantified as a percentage of dispersibility using the approach described by Abass et al. [9].

Water and Oil Absorption Capacity

To determine the flour sample's water and oil absorption capacity, 10 mL of distilled water and oil were combined with 1 g of flour. The mixture was allowed to stand at $30\pm 2^{\circ}\text{C}$ for 30 minutes before being centrifuged at 2,000 *g* for 30 minutes. The water and oil absorption capacity was calculated as one gram of water or oil for each gram of flour, according to Abass et al. [9].

Swelling Power

The swelling power was calculated by dissolving 10% of the samples in distilled water. In a water bath, the sample was heated to between 50°C and 90°C while being constantly stirred for 30 minutes. The suspension was centrifuged at 3,400*g* for 20 minutes to extract the supernatant, which was subsequently disposed of. By weighing the swelled starch residue after centrifugation and dividing it by the original weight of starch on a dry weight basis, Equation 1 was utilized to determine swelling power [9].

$$\text{Swelling power} = (\text{Weight of starch paste})/(\text{Weight of dry starch sample}) \times 100 \quad (1)$$

Solubility Index

One gram of the sample and 5 mL of distilled water were carefully mixed in a centrifuge tube. In a water bath, the finished mixture was heated to 80°C for 30 minutes. To prevent clumping, the slurry was gently swirled during heating. After the designated period, the paste-containing tube was centrifuged for 15 minutes at 2,200 rpm. After centrifugation, the liquid portion above the sediment, known as the supernatant, was promptly drained away. The solubility index was computed using Equation 2 [9].

$$\text{Solubility index} = (\text{Weight of solubles})/(\text{Weight of sample}) \times 100 \quad (2)$$

Least Gelation Concentration

The least gelation concentration was evaluated using the method described by Moongngarm et al. [10]. In a test tube, 2, 4, 6, 8, 10, 12, 14, 16, 18, and 20% suspensions of flour samples were made in 5 mL of distilled water. After 1 hour of heating in boiling water, the test tubes containing the flour suspensions were cooled under running water for another hour. The lowest gelation concentration was determined using the concentration at which the sample from the inverted test tubes did not fall or slip.

Pasting properties

The samples' pasting characteristics were measured using a Rapid Visco Analyser (Model RVA 4500, Perten Instrument, Australia) fitted with a 1,000 cmg sensitivity cartridge. Approximately 3.5 g of the samples and 25 mL of distilled water were put into an empty, dried canister. The canister was placed into the RVA in accordance with the instructions after the mixture had been well mixed. The slurry was heated from 50°C to 95°C at a rate of 1.5°C per minute, held there for 15 minutes, and then cooled to 50°C . The viscosity profile, which was derived from the pasting profile using Thermocline for Windows Software connected to a computer, had peak, trough, breakdown, final, and setback viscosities in Rapid Visco Units (RVU), the peak time in minutes, and pasting temperature in $^{\circ}\text{C}$ [11].

Preparation of instant plantain flour samples for evaluation and ethical approval

To prepare homogeneous cooked dough, 100 g of flour samples were reconstituted in 105 mL of boiling water inside a stainless-steel pot using a wooden stirrer. Before being evaluated, the cooked dough was coded with three-digit numbers, covered in aluminum foil, and stored in a closed warmer. The Kwara State University Centre for Research and Development granted the project ethical approval under the approval number KWASU/CR & D/REA/2023/0035. Before the evaluation, participants also gave their verbal agreement.

Training of Sensory Participants

The panelists were selected based on their regular consumption of yam pouno, demonstrated interest, availability, and ability to articulate their perceptions. A pre-screening exercise was conducted to ensure normal sensory acuity. This involved a basic taste test using aqueous solutions of sucrose (sweetness), sodium chloride (saltiness), citric acid

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(sourness), and quinine sulphate (bitterness), alongside an odor recognition test and intensity ranking tests as described by Awoyale et al. [5]. Sensitivity, defined as the ability to discriminate between varying levels of specific sensory characteristics, was further assessed by presenting four consecutive samples from a hardness scale in random order and requiring panelists to grade them according to increasing hardness. Only those who successfully passed this pre-screening were selected for subsequent training.

Training was conducted in a quiet, well-lit, ventilated, and spacious room equipped with a large table accommodating at least 14 panelists, with chairs and a whiteboard for illustrations. Six 1-hour training sessions were held for over 2 weeks before the sensory evaluation. The first session introduced simple definitions of sensory attributes (color/appearance, texture, flavor, mouthfeel, and overall acceptability) and familiarized panelists with the distinctions among basic sensory attributes. The second session focused on describing the sensory attributes of cooked instant plantain flour individually, while the third session emphasized differentiating these attributes from one another to enhance precision in evaluation.

In the fourth session, panelists practiced applying these attributes to coded samples of cooked instant plantain flour, thereby reinforcing consistency in description and evaluation. The fifth session was devoted to calibration exercises, where panelists compared reference samples of varying intensities to establish a common scale of judgment and minimize individual bias. The sixth and final session integrated all prior training by conducting mock evaluations under conditions simulating the actual sensory test, ensuring that panelists were confident, consistent, and reliable in their assessments.

Sensory Evaluation

A well-structured questionnaire modified from Awoyale et al. [5] was used at the NSPRI, Ilorin, to evaluate the sensory characteristics of the flour samples. Using a 9-point hedonic scale, where 1 represents extreme dislike and 9 represents extreme liking, about 15 trained panelists from NSPRI staff and interns who regularly used the product evaluated the coded samples based on taste, texture, color, appearance, aroma, and overall acceptability.

Statistical analysis

All the analyses done on the samples were technically replicated, except for the sensory evaluation, which was done using 15 panelists. The analysis of variance and separation of means of the produced data were examined using a Statistical Package for the Social Sciences (SPSS version 21).

Results And Discussion

Product yield

Yellow-fleshed plantains consistently produced higher yields (~37.7%) than white-fleshed plantains (~34.3%), according to Table 2's product yield findings. With a product yield of 32.95% for the white-fleshed plantain control and 35.98% for the yellow-fleshed plantain control, steaming increased the yield in comparison to unsteamed controls. The best steaming temperatures for yield were 95°C for 5 minutes (yellow: 37.82%) and 94°C for 6 minutes (white: 34.73%; yellow: 37.70%). The product yield shows significant differences ($P < 0.05$), with yellow-fleshed types outperforming white-fleshed varieties under all steaming conditions. Because yellow-fleshed plantains contain more dry matter and starch, which improves flour recovery, their output is higher. The results of Mosuro et al. [4] are consistent with this observation. When compared to unsteamed controls, the steaming conditions increased instant plantain flour yield by decreasing moisture loss and enzymatic browning, which increased flour recovery [4]. The higher yield of the steamed instant plantain flours in comparison to the unsteamed sample may be explained by the rearrangement of the amylose-amylopectin chains during steaming [7]. Increased yield results in increased affordability and economic efficiency, both of which have an indirect impact on consumer acceptance. According to Dzandu et al. [7], consumers' willingness to pay for plantain-based foods is influenced by both processing efficiency and sensory quality. Therefore, yellow-fleshed steamed plantains may be more commercially feasible to produce instant plantain flour due to higher yield.

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Plantain varieties	Steaming temperature (°C)	Steaming time (min)	Product yield (%)
White	94	7	34.35 ± 1.56b
White	92	8	33.52 ± 1.79b
White	95	5	34.19 ± 1.32b
White	93	7	34.02 ± 1.08b
White	94	6	34.73 ± 2.44ab
Unsteamed white (control)	0	0	32.95 ± 0.21b
Yellow	94	7	37.77 ± 0.73a
Yellow	92	8	37.58 ± 0.60a
Yellow	95	5	37.82 ± 0.61a
Yellow	93	7	37.74 ± 1.07a
Yellow	94	6	37.70 ± 0.28a
Unsteamed yellow (control)	0	0	35.98 ± 2.29ab
Mean			35.69
<i>P</i> level			*

TABLE 2: Effect of different varieties and steaming conditions on the yield of instant plantain flour.

**P* < 0.05. Means with the same letter within the column are not significantly different.

Functional properties

A food material's application and final usage are determined by its properties. In other words, functional properties indicate how the food products under study will interact, directly or indirectly, with other food components, thereby affecting food quality, processing applications, and final acceptability [5]. The functional characteristics of the instant plantain flour samples and the control are displayed in Table 3. The Osun yellow-fleshed instant plantain flour's functional characteristics include bulk density of 95.67%, water absorption capacity (WAC) of 122.93%, oil absorption capacity (OAC) of 110.37%, dispersibility of 45.50%, swelling power (SWP) of 84.64%, solubility index (SI) of 8.06%, and least gelation concentration (LGC) of 6.77%. All these characteristics were significantly (*P* < 0.05) affected by the steaming conditions. With a mean bulk density of 97.08%, WAC 163.63%, OAC 128.41%, dispersibility 42%, SWP 88.06%, SI 8.18%, and LGC 6.17%, there are significant variations (*P* < 0.05) in every functional property of the Oyo yellow-fleshed instant plantain flour, except the WAC. With a mean bulk density of 95%, WAC 145.09%, OAC 129.08%, dispersibility 32.92%, SWP 76.84%, SI 7.73%, and LGC 5.45%, the steaming conditions also had a significant (*P* < 0.05) impact on the functional properties of

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the Oyo white-fleshed instant plantain flour. In line with the findings of Mosuro et al. [4], who observed that varietal variations in starch content affect functional behavior, yellow-fleshed plantains typically displayed greater functional properties than white-fleshed plantains.

Bulk Density

The bulk density indicates the compactness of flour particles, which affects packaging, storage, and reconstitution [10]. The bulk density ranged from 87.55% (Oyo white instant plantain flour, 94°C for 6 min) to 102.70% (Oyo yellow instant plantain flour, 94°C for 7 min). The instant plantain flour produced by steaming at 94°C for 7 min generally had a significantly higher bulk density compared to the control unsteamed sample across all varieties and locations. Higher bulk density in steamed samples suggests improved particle compactness, which may enhance packaging efficiency [10]. This means that more of the instant plantain flour produced from the Oyo yellow-fleshed plantain steamed at 94°C for 7 min may fill a smaller space in packaging materials, and thus reduce the costs of packaging materials and transport because of its high bulk density, compared to that from the Oyo white-fleshed plantain steamed at 94°C for 6 min with a lower bulk density. However, the Oyo white-fleshed plantain steamed at 94°C for 6 min may be suitable for the formulation of complementary foods because of its low bulk density [7]. The bulk densities reported for 100% plantain flour (98.00%) [7] and the instant flour from blends of yam and unripe plantain flours (76-95%) were within the range of the present study [12]. Conversely, the bulk density of unripe plantain flour by Anajekwu et al. [11] (72-77%) and Awoyale et al. [5] (63%) were lower than that of this study. The variation in the bulk density may be attributed to the plantain varieties, age and time of harvest, and the processing methods [13].

Water Absorption Capacity

The WAC reflects the capacity of food particles to retain significant amounts of water and prevent exudation, and this is influenced by factors such as particle size, protein, carbohydrate and lipid contents, pH, and salt concentration [14]. WAC is also the amount of water taken up by food/flour to achieve the desirable consistency and create a quality food product [15]. The WAC was higher in Oyo yellow-fleshed instant plantain flour (185.50% at 93°C for 7 min), showing strong hydration capacity, and lower in the unsteamed Oyo white-fleshed plantain flour (100.10%), showing less hydration capacity. Also, the high WAC of the Oyo yellow-fleshed instant plantain flour steamed at 93°C for 7 min may be attributed to high amounts of hydrophilic constituents with a complex molecule that demands more water during hydrolysis compared to the unsteamed Oyo white-fleshed plantain flour [15,16]. A higher WAC may also assure product cohesiveness [15]. Therefore, the cooked dough from the Oyo yellow-fleshed instant plantain flour steamed at 93°C for 7 min may be mouldable compared with the unsteamed Oyo white-fleshed plantain flour with low WAC. The observations in the WAC of Adejuyitan et al. [12] for yam-unripe plantain pondo (124-135%), and Anajekwu et al. [11] (143.59 - 174.08) and Awoyale et al. [5] (140.31%) for unripe plantain flour were all within the range of values of this study. However, a lower range of WAC capacity (66.43-76.53%) was reported for unripe plantain flour by Dzandu et al. [7]. Differences in plantain varieties, age and time of harvest, and the processing methods may be attributed to these variations [13].

Oil Absorption Capacity

The OAC of food materials, which contributes to flavor retention and enhances mouthfeel, is an important functional property measured in food science [10]. The OAC varied widely; Oyo yellow-fleshed instant plantain flour at 95°C for 5 minutes had the highest (191.10%), while Osun yellow-fleshed instant plantain flour at 94°C for 7 minutes had the lowest (70.10%). The wide variation in OAC reflects varietal differences. High OAC (191%) in Oyo yellow-fleshed instant plantain flour suggests better flavor retention, consistent with the findings of Mosuro et al. [4]. It is important to add that significant variations ($P < 0.05$) occur in the OAC of the instant plantain flour compared to the unsteamed control sample; the Osun yellow-fleshed instant plantain flour steamed at 94°C for 6 minutes (145.55%) was higher than the control unsteamed flour (98.70%), and Oyo yellow-fleshed instant plantain flour steamed at 95°C for 5 minutes (191.10%) was higher than the unsteamed control flour (122.50%). The high OAC of the steamed plantain flour samples could suggest the presence of a large proportion of hydrophobic groups as compared with the hydrophilic groups on the surface of protein molecules of the steamed samples compared to the unsteamed [17]. Although the OAC of the unsteamed white-fleshed control sample (157.15%) was higher than all the steamed samples in the Oyo white-fleshed instant plantain

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flour. This may be attributed to a more organized starch structure in the unsteamed white-fleshed control sample, which may have appeared to entrap lipid better than the disorganized, white-fleshed steamed plantain flour structure due to thermal effect [15]. This implies that both steaming conditions and varieties play a key role in the OAC of instant plantain flour. The OAC reported by Awoyale et al. [5] (150.04%) and Anajekwu et al. [11] (98.07-100.66%) falls within the range of values of the present study.

Dispersibility

The dispersibility of flour is a measure of its ability to reconstitute in water, and higher dispersibility indicates better reconstitution performance [5]. In practical terms, this means that the Osun yellow-fleshed instant plantain flour steamed at 95°C for 5 min, with a dispersibility of 50%, is likely to reconstitute efficiently in hot water without forming lumps when prepared into dough. In contrast, the Oyo white-fleshed flour steamed at 92°C for 8 minutes exhibited lower dispersibility (29.5%), suggesting reduced reconstitution ability. Steamed samples generally demonstrated improved dispersibility compared to their unsteamed controls. For instance, the Osun yellow-fleshed flour steamed at 95°C for 5 minutes (50%), and the Oyo white-fleshed flour steamed at 92°C for 8 minutes (40%) both exceeded the dispersibility of their respective unsteamed controls. Similarly, the Oyo yellow-fleshed flour steamed at 92°C for 8 minutes (47%) showed higher dispersibility than its control sample (38.50%). These findings emphasize the positive impact of steaming on dispersibility, a property critical for reconstituted foods such as instant plantain flour. This observation aligns with Fonseca et al. [18], who reported that hydrothermal treatments enhance starch dispersibility by reducing granule aggregation. Previous studies have documented higher dispersibility ranges for unripe plantain flour [5, 11, 19]. The differences between the present study and earlier reports may be attributed to varietal differences, maturity stage at harvest, and processing methods [13].

Swelling Power

The SWP of starchy foods reflects the strength of associative forces within starch granules; a higher SWP indicates weaker internal bonding and greater granule expansion [5]. Functionally, SWP measures the hydration capacity of flour, as it determines the extent to which a sample increases in volume when soaked in water relative to its initial volume [17]. In this study, SWP was highest in the Oyo yellow-fleshed instant plantain flour (132.15% at 94°C for 7 minutes) and lowest in the Osun yellow-fleshed flour (41.6% at 94°C for 6 minutes). The relatively high SWP of the Oyo yellow-fleshed flour suggests that steaming at 94°C for 7 minutes did not fully disrupt the internal starch granule arrangement, thereby reducing retrogradation and enabling greater water absorption. By contrast, the Osun yellow-fleshed flour steamed at 94°C for 6 min may have undergone partial retrogradation, limiting its hydration capacity [16]. From an economic perspective, the high SWP of Oyo yellow-fleshed flour steamed at 94°C for 7 minutes is advantageous: a smaller quantity of flour can yield a larger volume of cooked dough upon reconstitution in hot water, offering potential cost benefits to consumers [5]. Compared to unsteamed controls, the Osun yellow-fleshed flour (111.30%) and Oyo yellow-fleshed flour (132.15%) steamed at 94°C for 7 minutes exhibited markedly higher SWP than their controls (81.70% and 69.40%, respectively). Similarly, the Oyo white-fleshed flour steamed at 93°C for 7 minutes (135.55%) surpassed its control (39.35%). These findings indicate that steaming enhances SWP, thereby improving dough consistency and economic efficiency in instant plantain flour production [19]. Previous studies reported considerably lower SWP values for unripe plantain flour, including 15.02% by Awoyale et al. [5] and 10.63-11.82% by Anajekwu et al. [13]. Such discrepancies may be attributed to differences in plantain variety, maturity stage at harvest, processing methods [14], and the structural arrangement of starch granules during heat treatment [15].

Solubility Index

The solubility index (SI) reflects the extent of amylose leaching from starch granules during swelling and is influenced by intermolecular forces that determine the strength of starch chain associations [5]. A higher SI indicates weaker associative forces, while a lower SI suggests stronger granule integrity. In this study, the Osun yellow-fleshed instant plantain flour steamed at 94°C for 7 minutes exhibited the highest SI (9.48%), implying the presence of weakly associated starch chains. By contrast, the same variety steamed at 95°C for 5 minutes showed a lower SI (6.0%), suggesting that starch granules were more strongly associated with an extensive and firmly bonded micellar structure [5]. The SI of the unsteamed Osun

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yellow-fleshed flour (8.49%) was significantly lower than that of the steamed sample at 94°C for 7 minutes (9.48%) ($P < 0.05$). Similarly, the SI of the unsteamed control sample (7.35%) and the Oyo white-fleshed flour steamed at 95°C for 5 minutes (8.87%) indicate that steaming generally promotes weaker starch associations, enhancing solubility. These findings suggest that the Osun yellow-fleshed flour steamed at 94°C for 7 minutes and the Oyo white-fleshed flour steamed at 95°C for 5 minutes are likely composed of weakly associated starch chains due to their elevated SI values compared to unsteamed controls [5]. Previous studies reported lower SI ranges for unripe plantain flour, including 5.58-6.71% by Anajekwu et al. [11], which partially overlaps with the present results. Conversely, Awoyale et al. [5] reported a much higher SI (26.07%) for unripe plantain flour, exceeding the values observed here. Such variations in SI across studies may be attributed to differences in plantain variety, maturity stage at harvest, processing methods [13], and the structural arrangement of starch granules during heat treatment [15].

Least Gelation Concentration

The LGC represents the minimum amount of starchy food required to form a gel; thus, a higher LGC indicates that more flour is needed to achieve gelation [5]. In this study, the Osun yellow-fleshed instant plantain flour steamed at 95°C for 5 minutes exhibited the lowest LGC (4.17%), meaning only a small quantity was sufficient to form a gel in hot water. This property suggests economic advantages, as less flour is required to produce food gels compared to the unsteamed Oyo white-fleshed flour with a higher LGC (10.13%). Generally, steamed plantain flours displayed higher LGC values than their unsteamed counterparts, consistent with the notion that steaming initiates partial pre-gelatinization of starch granules [19]. For example, the Osun yellow-fleshed flour (10.03%) and Oyo yellow-fleshed flour (8.24%) steamed at 93-94°C for 7 minutes both showed higher LGC than their respective unsteamed controls (4.22% and 4.17%). This indicates that steaming alters starch structure, increasing the concentration of flour required for gel formation. Previous studies reported higher LGC ranges (8-18%) for unripe plantain flour across different varieties [21]. Such variations in LGC may be attributed to differences in protein-lipid interactions within the flour matrix [21], as well as plantain variety, maturity stage at harvest, and processing methods [13].

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Sample	Bulk density (%)	Water absorption capacity (%)	Oil absorption capacity (%)	Dispersibility (%)	Swelling power (%)	Solubility index (%)	Least gelation concentration (%)
Osun yellow-fleshed plantain							
94°C for 6 min	96.65 ± 3.32a	122.15 ± 6.71b	145.55 ± 4.45a	44.50 ± 0.71c	41.60 ± 8.06d	8.60 ± 0.01b	8.04 ± 0.02b
93°C for 7 min	97.30 ± 0.57a	117.00 ± 0.28b	128.25 ± 0.92b	43.50 ± 0.71c	100.05 ± 0.21ab	7.67 ± 0.04d	6.09 ± 0.01c
95°C for 5 min	96.40 ± 0.85a	117.35 ± 1.34b	88.30 ± 3.82d	50.00 ± 1.41a	93.25 ± 4.31bc	6.00 ± 0.00e	4.17 ± 0.04d
92°C for 8 min	97.00 ± 1.41a	146.90 ± 0.99a	131.30 ± 4.53b	48.00 ± 0.00b	79.90 ± 1.84c	8.10 ± 0.01c	8.06 ± 0.03b
94°C for 7 min	97.30 ± 2.83a	115.75 ± 1.91b	70.10 ± 2.12e	41.50 ± 0.71d	111.35 ± 11.53a	9.48 ± 0.03a	10.03 ± 0.01a
Unsteamed (Control)	89.35 ± 0.35b	118.40 ± 0.99b	98.70 ± 1.41c	45.50 ± 0.71c	81.70 ± 2.55c	8.49 ± 0.12b	4.22 ± 0.03d
Mean	95.67	122.93	110.37	45.5	84.64	8.06	6.77
P level	*	***	***	***	***	***	***
Oyo yellow-fleshed plantain							
94°C for 6 min	90.05 ± 0.78c	171.50 ± 18.53a	83.80 ± 6.93e	32.50 ± 0.71d	52.35 ± 0.78c	8.45 ± 0.01ab	8.17 ± 0.04a
93°C for 7 min	98.65 ± 1.48b	185.50 ± 42.43a	73.20 ± 1.84f	43.50 ± 0.71b	78.45 ± 1.77b	8.40 ± 0.41ab	8.24 ± 0.26a
95°C for 5 min	98.20 ± 0.99b	168.85 ± 13.22a	191.10 ± 6.36a	44.50 ± 0.71ab	129.30 ± 11.74a	8.12 ± 0.14b	4.07 ± 0.07c
92°C for 8 min	95.65 ± 1.48b	128.50 ± 42.99a	156.35 ± 1.63b	47.00 ± 1.41a	66.70 ± 0.99b	8.70 ± 0.00a	6.19 ± 0.01b
94°C for 7 min	102.70 ± 2.26a	153.20 ± 33.53a	143.50 ± 2.12c	46.00 ± 1.41ab	132.15 ± 3.32a	7.03 ± 0.00c	6.16 ± 0.06b

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Unsteamed (Control)	97.25 ± 1.48b	174.25 ± 23.26a	122.50 ± 2.12d	38.50 ± 0.71c	69.40 ± 4.10b	8.40 ± 0.00ab	4.17 ± 0.04c
Mean	97.08	163.63	128.41	42	88.06	8.18	6.17
<i>P</i> level	**	NS	***	***	***	**	***
Oyo white-fleshed plantain							
94°C for 6 min	87.55 ± 1.63c	151.20 ± 8.06ab	108.90 ± 0.71d	32.50 ± 0.71c	44.85 ± 1.63c	7.03 ± 0.00e	4.17 ± 0.06c
93°C for 7 min	97.00 ± 1.13a	139.75 ± 9.83bc	139.85 ± 3.32b	36.00 ± 1.41b	135.55 ± 1.48a	6.08 ± 0.00f	4.10 ± 0.08c
95°C for 5 min	98.45 ± 0.78a	130.20 ± 37.34bc	88.55 ± 2.62e	40.00 ± 0.00a	102.00 ± 3.11b	8.87 ± 0.00a	6.04 ± 0.03b
92°C for 8 min	93.30 ± 0.42b	192.35 ± 4.45a	156.35 ± 2.62a	29.50 ± 0.71d	37.80 ± 1.98c	8.60 ± 0.00b	4.12 ± 0.08c
94°C for 7 min	99.15 ± 0.21a	156.95 ± 27.08ab	123.70 ± 6.51c	30.00 ± 0.00d	101.50 ± 2.69b	8.43 ± 0.01c	4.13 ± 0.13c
Unsteamed (Control)	94.55 ± 0.07b	100.10 ± 0.28c	157.15 ± 2.62a	29.50 ± 0.71d	39.35 ± 8.41c	7.35 ± 0.01d	10.13 ± 0.04a
Mean	95	145.09	129.08	32.92	76.84	7.73	5.45
<i>P</i> level	***	*	***	***	***	***	***

TABLE 3: Effect of different steaming conditions and location/varieties on the functional properties of instant plantain flour.

P* < 0.05, *P* < 0.01, ****P* < 0.001. Means with the same letter within the column are not significantly different (*P* > 0.05).

Pasting properties

The pasting properties of starchy flours are critical indicators of their behavior during and after cooking, particularly since these flours are typically reconstituted in hot water to form dough before consumption [9, 20]. Table 4 presents the pasting properties of instant plantain flours and their unsteamed controls across different varieties and steaming conditions. For the Osun yellow-fleshed instant plantain flour, the mean values were peak viscosity 526.91 RVU, trough viscosity 371.39 RVU, breakdown viscosity 155.52 RVU, final viscosity 528.00 RVU, setback viscosity 156.61 RVU, peak time 5.28 minutes, and pasting temperature 82.05°C. The Oyo yellow-fleshed flour recorded a mean peak viscosity of 485.94 RVU, trough viscosity 358.99 RVU, breakdown viscosity 126.95 RVU, final viscosity 525.53 RVU, setback viscosity 166.54 RVU, peak time 5.39 minutes, and pasting temperature 83.42°C. Meanwhile, the Oyo white-fleshed flour exhibited a mean peak viscosity of 527.00 RVU, trough viscosity 400.44 RVU, breakdown viscosity 126.23 RVU, final viscosity 579.88 RVU, setback viscosity (179.44 RVU), peak time 5.52 minutes, and pasting temperature 83.58°C. Statistical analysis revealed

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significant differences ($P < 0.05$) among the pasting properties of the instant plantain flours and their controls, with the exception of trough viscosity, final viscosity, and pasting temperature, which were not significantly different ($P > 0.05$). Similarly, the setback viscosity of the Oyo white-fleshed flour did not differ significantly ($P > 0.05$).

Peak viscosity represents the maximum viscosity attained during or immediately after heating, and it is a critical parameter contributing to the texture and quality of cooked starchy products [9]. In this study, the unsteamed Osun yellow-fleshed plantain flour exhibited the highest peak viscosity (654.56 RVU), significantly exceeding that of all Osun yellow-fleshed instant flours. Conversely, the Oyo yellow-fleshed (602.17 RVU) and Oyo white-fleshed (591.54 RVU) instant flour produced under steaming at 94°C for 6 minutes displayed significantly higher peak viscosities than their respective unsteamed controls (393.04 RVU and 505.38 RVU, respectively). These differences may be attributed to location-specific factors influencing starch structure and functionality. From a consumer perspective, the findings suggest that individuals seeking a firm-textured dough may prefer reconstituting the Oyo yellow- and white-fleshed instant flours steamed at 94°C for 6 minutes, owing to their elevated peak viscosities. In contrast, those desiring a softer-textured product may opt for the unsteamed Oyo flours, which exhibited lower peak viscosities [5]. It is important to note, however, that dough texture is also influenced by external factors such as the amount of hot water added, cooking temperature, and the duration of gelatinization [9]. Comparative analysis with previous studies reveals variability in reported peak viscosities. Awoyale et al. [5] documented a higher value (723.63 RVU) for unripe plantain flour, while Wulan et al. [22] reported considerably lower values (166.81-259.47 RVU), and Fadimu et al. [24] reported 461.37 RVU. These discrepancies may be explained by differences in plantain variety, processing methods, and maturity stage at harvest [14]. Notably, the peak viscosities observed in the present study fall within the range (568.17-761.64 RVU) reported by Anajekwu et al. [11], thereby reinforcing the reliability of the findings.

The breakdown viscosity reflects the resistance of starchy products to heating and shear stress during cooking; this resistance decreases as breakdown viscosity increases [9]. In this study, the Oyo yellow-fleshed instant plantain flour (221.42 RVU) and Oyo white-fleshed flour (194.50 RVU), both produced under steaming at 94°C for 6 minutes, exhibited relatively high breakdown viscosities. This suggests that dough prepared from these samples may be less capable of withstanding mechanical shear stress and preserving intact starch granules, thereby reducing structural stability during cooking [9]. Comparative literature highlights notable differences. Wulan et al. [22] reported a lower range of breakdown viscosities (52.44-93.67 RVU) for unripe plantain flour, while Anajekwu et al. [11] reported considerably higher values (283.80-385.45 RVU). The breakdown viscosities observed in the present study fall between these ranges, underscoring the variability across different investigations. Such variations are likely attributable to differences in plantain variety, processing methods, and maturity stage at harvest [13]. These factors influence starch granule integrity and susceptibility to thermal and mechanical disruption, thereby shaping the breakdown viscosity profile of plantain flours.

The setback viscosity represents the viscosity of the cooked paste after cooling to 50°C, reflecting the extent of starch retrogradation or molecular reordering [5]. A lower setback viscosity indicates greater resistance to retrogradation, which is desirable for maintaining product freshness and reconstitution quality [9]. In this study, the Osun yellow-fleshed flour steamed at 93°C for 7 minutes (151.00 RVU) and the Oyo yellow-fleshed flour steamed at 94°C for 6 minutes (135.29 RVU) exhibited relatively low setback viscosities, suggesting enhanced resistance to retrogradation. Conversely, the Osun yellow-fleshed flour steamed at 94°C for 7 minutes (178.17 RVU), and the Oyo yellow-fleshed flour steamed at 95°C for 5 minutes (197.29 RVU) showed higher setback viscosities, indicating reduced resistance to retrogradation. These findings highlight the significant influence of varietal differences and steaming conditions on setback viscosity. Chamorro et al. [6] emphasized that reduced setback viscosity in tropical starches improves consumer perception of freshness and reconstitution quality. Accordingly, the Osun yellow-fleshed flour steamed at 93°C for 7 minutes, and the Oyo yellow-fleshed flour steamed at 94°C for 6 minutes may offer superior reconstitution quality due to their lower setback viscosities. Comparative literature reveals variability in reported values. Anajekwu et al. [11] documented setback viscosities ranging from 92.39 to 115.53 RVU, while Wulan et al. [22] reported even lower values (61.97-75.72 RVU) for unripe plantain flour. In contrast, Awoyale et al. [5] reported a setback viscosity of 130.05 RVU, which falls within the range observed in the present study. Such differences are likely attributable to plantain variety, maturity stage at harvest, and processing methods [13].

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The peak time represents the duration required for flour samples to reconstitute into cooked dough in boiling water [9]. In this study, the Osun yellow-fleshed flour steamed at 95°C for 5 minutes and 92°C for 8 minutes (5.47 minutes), the Oyo yellow-fleshed flour steamed at 94°C for 7 minutes (5.67 minutes), and the Oyo white-fleshed flour steamed at 95°C for 5 minutes (5.73 minutes) all exhibited significantly longer peak times compared to their respective unsteamed controls ($P < 0.05$). Steamed samples generally required slightly longer peak times (~5.3-5.7 minutes) than controls (~4.9 minutes), indicating slower gelatinization. Despite these differences, the pasting temperature remained relatively stable across samples (~82-84°C), suggesting that varietal differences influenced viscosity more strongly than gelatinization temperature. This observation is consistent with the findings of Mosuro et al. [4]. Importantly, all flour samples required approximately 5 minutes to cook, just below the boiling point of water (~83°C), highlighting their suitability for rapid preparation. Comparable peak times and pasting temperatures have been reported in previous studies [5,11], reinforcing the reliability of these results and underscoring the influence of steaming conditions and varietal differences on pasting behavior.

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Sample	Peak viscosity (RVU)	Trough viscosity (RVU)	Breakdown viscosity (RVU)	Final viscosity (RVU)	Setback viscosity (RVU)	Peak time (min)	Pasting temp (°C)
Osun yellow-fleshed plantain							
94°C 6 min	495.46 ± 6.78b	368.04 ± 16.56a	127.42 ± 9.78b	535.67 ± 11.08ab	167.63 ± 5.48ab	5.43 ± 0.05a	82.35 ± 1.20a
93°C 7 min	454.88 ± 89.98b	325.42 ± 62.81a	129.46 ± 27.16b	476.42 ± 72.01b	151.00 ± 9.19c	5.17 ± 0.05b	81.90 ± 0.64a
95°C 5 min	528.17 ± 48.08b	390.00 ± 23.45a	138.17 ± 24.63b	546.46 ± 27.28ab	156.46 ± 3.83bc	5.47 ± 0.09a	81.95 ± 0.64a
92°C 8 min	508.00 ± 31.35b	365.29 ± 14.55a	142.71 ± 16.79b	525.46 ± 20.92ab	160.17 ± 6.36bc	5.47 ± 0.00a	82.40 ± 0.00a
94°C 7 min	520.50 ± 0.00b	390.33 ± 0.00a	130.17 ± 0.00b	568.50 ± 0.00a	178.17 ± 0.00a	5.27 ± 0.00b	82.25 ± 0.00a
Unsteamed (Control)	654.46 ± 4.30a	389.25 ± 0.00a	265.21 ± 4.30a	515.50 ± 4.83ab	126.25 ± 4.83d	4.90 ± 0.05c	81.45 ± 0.00a
Mean	526.91	371.39	155.52	528	156.61	5.28	82.05
P level	*	NS	*	NS	**	***	NS
Oyo yellow-fleshed plantain							
94°C 6 min	602.17 ± 34.18a	380.75 ± 24.51a	221.42 ± 9.66a	516.04 ± 17.62ab	135.29 ± 6.89c	5.03 ± 0.05c	83.23 ± 1.24a
93°C 7 min	481.88 ± 6.07b	364.25 ± 5.42ab	117.63 ± 0.65b	541.96 ± 0.65ab	177.71 ± 6.07ab	5.40 ± 0.19b	83.18 ± 0.04a
95°C 5 min	495.08 ± 12.26b	388.63 ± 10.55a	106.46 ± 1.71b	585.92 ± 5.89a	197.29 ± 4.66a	5.50 ± 0.05ab	83.53 ± 0.53a
92°C 8 min	476.50 ± 6.84b	355.08 ± 1.53ab	121.42 ± 8.37b	528.54 ± 0.29ab	173.46 ± 1.24ab	5.47 ± 0.09ab	82.65 ± 0.57a
94°C 7min	467.00 ± 9.90b	362.58 ± 0.24ab	104.42 ± 10.14b	522.46 ± 1.59ab	159.88 ± 1.83bc	5.67 ± 0.09a	83.98 ± 1.24a
Unsteamed (Control)	393.04 ± 89.98b	302.67 ± 62.34b	90.38 ± 27.64b	458.29 ± 86.56b	155.63 ± 24.22bc	5.30 ± 0.05b	83.95 ± 0.00a
Mean	485.94	358.99	126.95	525.53	166.54	5.39	83.42

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<i>P</i> level	*	NS	*	NS	*	**	NS
Oyo white-fleshed plantain							
Sample	Peak visc	Trough visc	Breakdown visc	Final visc	Setback visc	Peak Time	Pasting Temp
94°C 6min	591.54 ± 29.88a	397.04 ± 11.96a	194.50 ± 17.91a	570.46 ± 21.39a	173.42 ± 9.43a	5.10 ± 0.05c	83.18 ± 0.04b
93°C 7 min	493.50 ± 11.90c	383.75 ± 19.33a	109.75 ± 7.42c	563.17 ± 20.74a	179.42 ± 1.41a	5.53 ± 0.00b	83.58 ± 0.67ab
95°C 5 min	501.75 ± 3.06c	404.46 ± 2.89a	97.29 ± 5.95c	580.25 ± 14.73a	175.79 ± 11.84a	5.73 ± 0.00a	84.00 ± 0.07ab
92°C 8 min	552.13 ± 5.24ab	417.42 ± 10.84a	134.71 ± 5.60b	604.54 ± 0.06a	187.13 ± 10.90a	5.50 ± 0.14b	84.40 ± 0.49a
94°C 7 min	515.75 ± 26.40bc	405.92 ± 18.74a	109.83 ± 7.66c	591.21 ± 23.28a	185.29 ± 4.54a	5.67 ± 0.09ab	83.15 ± 0.07b
Unsteamed (Control)	505.38 ± 13.85c	394.08 ± 16.26a	111.29 ± 2.43c	569.67 ± 8.60a	175.58 ± 7.66a	5.60 ± 0.00ab	83.58 ± 0.67ab
Mean	527	400.44	126.23	579.88	179.44	5.52	83.65
<i>P</i> level	*	NS	***	NS	NS	**	NS

TABLE 4: Effect of different steaming conditions and location/varieties on the pasting properties of instant plantain flour.

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$. Means with the same letter within the column are not significantly different ($P > 0.05$). RVU, Rapid Visco Units

Sensory attributes

The sensory evaluation of instant plantain flour demonstrated that steaming conditions exerted only a limited influence on consumer perception, with most attributes scoring between “like slightly” (6) and “like moderately” (7) (Table 5). Across both Osun and Oyo varieties, sensory attributes such as taste, texture, aroma, and overall acceptability did not differ significantly ($P > 0.05$), whereas color and appearance showed significant variation ($P < 0.05$). Commercial pouno consistently outperformed instant plantain flour in terms of color and overall acceptability, achieving scores above 7 (like moderately to very much), while instant plantain flour samples averaged between 6.4 and 6.9, indicating moderate sensory acceptance. These findings corroborate earlier reports that steaming conditions have minimal impact on sensory scores, though viscosity remains an important determinant of sensory preference [2]. The relatively lower color scores of instant plantain flour compared to commercial pouno may reflect consumer bias toward the familiar appearance of yam-based products. Nevertheless, despite slightly lower sensory ratings, instant plantain flour remains a viable alternative. Thus, while sensory optimization, especially in color and flavor standardization, may enhance market competitiveness, the overall acceptability of the instant plantain flour compared favorably with that of the commercial pouno.

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Samples	Taste	Texture	Colour	Appearance	Aroma	Overall acceptability
Osun yellow-fleshed plantain						
95°C 5 min	6.65 ± 1.11ab	7.00 ± 1.32a	6.94 ± 0.90ab	6.82 ± 1.85a	6.47 ± 1.01ab	6.82 ± 1.13a
94°C 6 min	6.06 ± 1.82b	6.71 ± 1.21a	6.12 ± 1.87b	6.88 ± 1.27a	6.06 ± 1.64b	6.47 ± 1.42a
92°C 8 min	6.71 ± 1.61ab	6.59 ± 1.54a	6.94 ± 1.25ab	6.82 ± 1.42a	6.65 ± 1.62ab	6.94 ± 1.34a
93°C 7 min	6.18 ± 2.07b	6.35 ± 1.93a	6.35 ± 1.50b	6.59 ± 1.77a	6.24 ± 1.68ab	6.41 ± 1.70a
94°C 7 min	6.24 ± 1.60b	6.59 ± 1.91a	6.71 ± 1.72ab	6.71 ± 1.83a	6.59 ± 1.84ab	6.76 ± 1.60a
Unsteamed (control)	6.47 ± 1.46ab	6.12 ± 1.96a	6.76 ± 1.86ab	6.82 ± 1.85a	6.76 ± 1.39ab	6.53 ± 1.81a
Commercial poundo	7.53 ± 0.94a	6.71 ± 1.49a	7.82 ± 1.19a	7.53 ± 1.33a	7.35 ± 1.06a	7.35 ± 0.79a
Mean	6.55	6.58	6.81	6.88	6.59	7.35
P level	NS	NS	*	NS	NS	NS
Oyo yellow-fleshed plantain						
95°C 5 min	5.94 ± 2.16b	6.00 ± 1.80a	6.47 ± 1.33b	6.29 ± 1.49b	6.24 ± 1.09b	6.47 ± 1.42ab
93°C 7 min	5.88 ± 1.80b	5.94 ± 1.60a	6.24 ± 0.75b	6.06 ± 1.03b	6.29 ± 1.26b	6.24 ± 1.35b
94°C 7 min	6.29 ± 1.40b	6.18 ± 1.33a	6.29 ± 1.40b	6.41 ± 1.33b	6.29 ± 0.92b	6.53 ± 1.18ab
94°C 6 min	5.71 ± 2.02b	5.82 ± 1.78a	6.24 ± 1.99b	6.29 ± 1.57b	6.59 ± 1.12ab	6.47 ± 1.37ab
92°C 8 min	6.18 ± 1.74b	6.41 ± 1.28a	7.06 ± 1.20ab	6.94 ± 1.14ab	7.18 ± 0.95a	6.76 ± 0.97ab
Unsteamed (control)	6.12 ± 1.54b	6.35 ± 1.69a	6.59 ± 1.84b	6.29 ± 1.83b	6.35 ± 1.22b	6.65 ± 1.50ab
Commercial poundo	7.53 ± 0.94a	6.71 ± 1.49a	7.82 ± 1.19a	7.53 ± 1.33a	7.35 ± 1.06a	7.35 ± 0.79a
Mean	6.24	6.2	6.67	6.55	6.61	6.64
p level	*	NS	*	*	**	NS

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Plantain Varieties and Steaming Conditions Influence the Yield, Functional, Pasting, and Sensory Qualities of Instant Plantain Flour

Oyo white-fleshed plantain						
94°C 6 min	6.59 ± 1.28ab	6.24 ± 1.56a	6.65 ± 1.37b	6.65 ± 1.32ab	6.47 ± 1.23a	6.76 ± 1.03ab
95°C 5 min	6.41 ± 1.54b	6.59 ± 1.58a	6.41 ± 1.58b	6.59 ± 1.37ab	6.47 ± 1.42a	6.82 ± 1.29ab
94°C 7 min	5.88 ± 1.58b	6.35 ± 1.77a	6.18 ± 1.85b	5.59 ± 1.80b	6.59 ± 1.62a	6.06 ± 1.34b
92°C 8 min	6.53 ± 1.50ab	6.53 ± 1.55a	6.24 ± 1.52b	6.29 ± 1.40ab	6.76 ± 1.60a	6.76 ± 1.39ab
93°C 7 min	6.35 ± 1.69b	6.76 ± 1.30a	6.59 ± 1.70b	6.47 ± 1.37ab	6.29 ± 1.53a	6.53 ± 1.77ab
Unsteamed (control)	6.65 ± 1.58ab	6.59 ± 1.66a	6.59 ± 1.54b	6.71 ± 1.57ab	6.82 ± 1.55a	6.88 ± 1.27ab
Commercial poundo	7.53 ± 0.94a	6.71 ± 1.49a	7.82 ± 1.19a	7.53 ± 1.33a	7.35 ± 1.06a	7.35 ± 0.79a
Mean	6.56	6.54	6.64	6.55	6.68	6.74
P level	NS	NS	*	*	NS	NS

TABLE 5: Effect of different steaming conditions and location/varieties on the sensory attributes of cooked instant plantain flour.

* $P < 0.05$, ** $P < 0.01$, NS, Not significant. Means with the same letter within the column are not significantly different ($P > 0.05$). 9 - like extremely; 8 - like very much; 7 - like moderately; 6 - like slightly; 5 - neither like nor dislike; 4 - dislikes slightly; 3 - dislikes moderately; 2 - dislikes very much; 1 - dislike extremely. Number of respondents = 15

Conclusions

This study shows that plantain variety, location, and steaming conditions significantly influence yield, functional, pasting, and sensory attributes of plantain poundo. Yellow-fleshed plantains, especially from Osun, produced higher yields, while Oyo varieties demonstrated stronger functional and pasting properties. Steaming improved the functional and pasting properties of the instant plantain flour, although sensory scores remained moderate compared to commercial poundo. Thus, these findings provide a framework for possible process optimization and varietal selection that can improve the quality of instant plantain flour, as it compares favorably with the commercial poundo in terms of overall acceptability.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

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Disclosures

Plant subjects: All authors have confirmed that this study did not involve any herbarium specimen. **Human subjects:** Consent was obtained or waived by all participants in this study. Kwara State University Centre for Research and Development issued approval KWASU/CR & D/REA/2023/0035. The ethical approval of the study was given by the Kwara State University Centre for Research and Development, with approval number KWASU/CR & D/REA/2023/0035. Verbal consent was also obtained from the participants before the study. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** This study was funded by the National Research Fund of the Tertiary Education Trust Fund (NRF-TETFUND) of the Federal Republic of Nigeria with grant number TETF/ES/DR&DCE/NRF2023/SETI/AFS/00317/VOL.1. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

Data Availability Statements

The datasets (and/or code) supporting this study are available from the corresponding author upon reasonable request.

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