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Original Article

Functional, physico-chemical, and proximate properties of flours from selected NSIC-registered cassava (*Manihot esculenta*) varieties

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ABSTRACT

Cassava flour is known for its functional properties that influence the consistency, texture, and stability of various food products. A single-factor experiment arranged in a Completely Randomized Design was used to evaluate and compare the functional properties of flour from the three selected National Seed Industry Council (NSIC) registered cassava varieties: UPL Ca-2 (Lakan I), NSIC Cv-30 (Rayong 5), and NSIC Cv-48 (Rayong 72), harvested at nine months of maturity. The samples were analyzed for their functional properties, physicochemical properties, and proximate composition. The data obtained were subjected to Analysis of Variance and the Least Significant Difference test for post hoc analysis. The functional properties of the cassava flours were significantly different from each other at $p < .05$. UPL Ca-2 had the highest water absorption capacity and oil absorption capacity at 153.44% and 125.57%, respectively. Meanwhile, NSIC Cv-48 had the highest solubility, emulsion activity, and bulk density at 5.98%, 17.39%, and 0.572g/mL, respectively. Swelling power and emulsion stability of NSIC Cv-30 flour were the highest among the selected varieties at 15.35% and 34.15%, respectively. The pH (5.64) and titratable acidity (0.36% as lactic acid) of NSIC Cv-48 were significantly different from those of the other two varieties. The lightness (L*) of the three varieties did not differ. The (red/green) value a* ranged from -0.19 to 0.32, indicating a color leaning towards redness. However, significant variations in the (b*) yellow/blue value (7.35), Whiteness Index (91.54), and Chroma (7.36) were only observed in UPL Ca-2. Gel-formation ability of the cassava flours was visually observed, showing a difference in gel firmness. Proximate composition of the flours show a low content of fat (0.28%, 0.23%, 0.24%, respectively) and protein (1.82%, 1.24%, 1.35%, respectively) in the flours but had a high total carbohydrate (83.61%, 85.42%, and 84.61%) and ash contents (1.49%, 1.46%, and 1.49%). These findings indicate that each variety has distinct functional properties with potential industrial applications.

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INTRODUCTION

Cassava *(Manihot esculenta* Crantz*)*, locally known as *kamote'ng kahoy* or *balanghuy* in the Philippines, is one of the most important calorie-producing crops in the tropics (Byju & Suja, 2020). The rootcrop is primarily utilized as food, secondarily for flour and as a starch source, and thirdly as animal feed. Production of cassava is dominated by subsistence farmers who plant in small fields or even backyards (Castillo, 1974). Globally, cassava production has increased steadily, reaching 315 million tons in 2021, from 286 million tons in 2017, with Nigeria being the top producer, contributing 20% (63 million tons) of the total global production(Otekunrin, 2024). In the Philippines, about 120,000 hectares of agricultural land is used to grow cassava, producing about 1.8 million tons of cassava roots. However, cassava only contributes about 2% to gross value-adding as a commodity(Bacusmo, 2001).

Cassava is widely utilized but has major setbacks due to its rapid post-harvest physiological deterioration (PPD), which occurs within 24h to 72h of harvest (Zainuddin et al., 2018), and its ability to undergo cyanogenesis, producing hydrocyanic acid or hydrogen cyanide (HCN) content, which is toxic to humans (Thaweewong & Anuntagool, 2023). To address these concerns, the roots are quickly processed into stable products such as cassava chips and cassava flour (Udoro et al., 2021). This prevents PPD and reduces the HCN content via wet milling and drying (Thaweewong et al., 2023). Thus, it is important to process cassava roots into their products, such as flour, to prolong their usability.

The functionality of cassava is heavily influenced by genotypic variations. An extensive study of 670 cassava varieties showed that there were significant ($p <$ .05) genotypic variations in all the pasting properties, except pasting temperature and peak time (Udoro et al., 2021). The most studied aspects of flours are their functional and physicochemical properties. Analyzing the functional characteristics of flours is important because these properties directly affect various applications, including process optimization, ingredient substitution, pharmaceutical applications, and research development (Adeola et al., 2020). Proximate composition of flours is also widely studied since flour composition can significantly influence the quality of the end product(Oyeyinka & Bassey, 2025).

In the Philippines, there are 48 (National Seed Industry Council) NSIC-registered cassava varieties (PNS:BAFS 29:2010), and local journals have studied the properties of some NSIC-registered varieties, often in composite flour blends and other modifications. Lakan I(Hurtada et al., 2020; Murayama et al., 2014; Udoro et al., 2021), Rayong 5 (Charles et al., 2005), and Rayong 72 (Charoenrath et al., 1999) have previously been studied, but the varieties were either modified, not evaluated as flour alone, or were not the same as the variety present in the Philippines. Moreover, these varieties are considered as check varieties by the Philippine Root Crop Research and Training Center (PRCRTC), but the existing literatures focus primarily on the agronomic aspect and limited physico-chemical properties of the roots. Therefore, there is a need to extensively study the functional properties, physico-chemical properties, and proximate composition of the flours produced from these NSIC-registered cassava varieties to better understand their potential for food and industrial applications. Hence, investigating the properties of flour produced from these NSIC-registered varieties is essential.

MATERIALS AND METHODS

Materials

Three NSIC-registered varieties of cassava roots, namely UPL Ca-2 (Lakan I), NSIC Cv-30 (Rayong 5), and NSIC Cv-48 (Rayong 72), were harvested at their ninth (9th) month maturity, as shown in Figure 1. These varieties were recommended by the PRCRTC due to their suitability for industrial processing, specifically, as their hydrocyanic acid (HCN) levels are within the range that allows for safe conversion into flour and starch. Also, UPL Ca-2, NSIC Cv-30, and NSIC Cv-48 are considered check varieties used in the development of new cassava varieties. However, only agronomic and limited physicochemical properties of the roots are available in the literature. Data on the functional properties of these flours and starches has not yet been extensively studied.

The samples were obtained from the germplasm collection from the field of PRCRTC, Visayas State University, Baybay City, Leyte, Philippines, that is characterized as having neutral soil (5.5-6.5). Collected roots were processed immediately within 24h to prevent the development of vascular streaking, which affects the quality of the roots.

UPL Ca-2 (Lakatan I) NSIC Cv-30 (Rayong 5) NSIC Cv-48 (Rayong 72)

Figure 1. Physical appearance of the roots of three NSIC-registered cassava varieties (Philippine Root Crop Research and Training Center, n.d.)

Processing of Cassava Flour

The cassava roots were cleaned with running water to remove the dirt and then sanitized with 2ppm chlorine bleach solution. The cassava was peeled manually, and the peeled cassava was grated in a cassava grater spinner (PRCRTC grater spinner, 1hp motor, 100kg/h capacity) for 5min. After spinning, the grates were dried in a 60°C pneumatic dryer (PRCRTC, 3hp, 25-30kg drying capacity) until they reached a constant weight (<1% change in 24h). The dehydrated grates were then pulverized using a mechanical pulverizer (Vesmach, RT 20HS, 2hp, 15-30kg/h) and sifted through a 60-mesh sieve. The resulting flour was vacuum-packed and stored at room temperature 29-32°C, for further analysis.

Determination of Functional Properties

Bulk Density

Bulk density was determined by following the method of Chimhepo et al. (2021). A flour sample weighing 10g was added to a 25mL graduated cylinder. The lower surface of the cylinder was tapped several times on the laboratory bench until there was no further diminution of the sample level. The bulk density was then determined using the following formula in Equation 1:

$$\text{Bulk Density } \left(\frac{g}{mL}\right) = \frac{\text{Weight of Flour (g)}}{\text{Volume of Flour after Settled (mL)}} \quad (1)$$

Water Absorption Capacity (WAC)

The determination of water absorption capacity followed the method described by Chimphepo et al. (2021), with modifications. Each 2.0g flour sample was dissolved in 40mL of distilled water in a centrifuge tube. The suspensions were thoroughly shaken using a vortex mixer for 2min to ensure the samples were completely saturated. The samples were centrifuged, using a refrigerated centrifuge (GYROZEN, 624R, Republic of Korea), for 10min at 3200rpm. After centrifuging, the free water was decanted from the pellet, then drained for 10min and weighed. Water absorption capacity was determined using the following formula in Equation 2:

$$\text{Water Absorption Capacity(\%)} = \frac{\text{Weight of Absorbed Water}}{\text{Weight of Initial Flour}} x100 \quad (2)$$

Oil Absorption Capacity (OAC)

Oil absorption capacity was determined using the methods of Chimphepo et al. (2021), with modifications. Each 1.0g flour sample was dissolved in 10mL corn oil, then thoroughly shaken for 2min using a vortex mixer to ensure sample saturation. Using a refrigerated centrifuge (GYROZEN, Republic of Korea), the samples were centrifuged for 15min at 4200rpm. The free oil was decanted from the pellet, then drained for 10min, and weighed. Oil absorption capacity was determined using the following formula in Equation 3:

$$\text{Oil Absorption Capacity(\%)} = \frac{\text{Weight of Absorbed Oil}}{\text{Weight of Initial Flour}} x100 \quad (3)$$

Water Solubility

The water solubility of the flours was determined by adopting the method of Chimhepo et al. (2021). About 0.5g of flour was heated in 10mL of distilled water at 60°C in a water bath for 30min, without mixing. The sample was centrifuged at 1600 rpm for 10min, and the supernatant was decanted, dried, and weighed. The water solubility of the flour was calculated using the following formula in Equation 4:

$$\text{Water Solubility (\%)} = \frac{\text{Dried Supernatant Weight}}{\text{Weight of Initial Flour}} x100 \quad (4)$$

Swelling Power

Swelling power was determined by adding 0.1g of flour to 10mL of distilled water and heating at 90°C for 1h, with constant stirring. Then the suspension was rapidly cooled to 25°C (or an ambient temperature) and centrifuged for 30min at 1600 rpm. The swelling power and water solubility of the flour were calculated using the formula below in Equation 5:

$$\text{Swelling Power (\%)} = \frac{\text{Weight of Pellet}}{\text{Weight of Initial Flour}} \text{x}100 \tag{5}$$

Emulsion Activity and Stability

The emulsion activity and stability were determined using the method as described by Chandra et al. (2015), with modifications. About 1.0g of each flour sample was mixed with 5mL of distilled water and 5mL of corn oil. The mixture was centrifuged for 5min at 3000 rpm. Using a vernier caliper, the height of the emulsified layer and the total height of the mixture were measured in centimeters. The emulsion activity of each flour was calculated using the formula below in Equation 6:

$$\text{Emulsion Activity} = \frac{\text{Height of the emulsified layer (cm)}}{\text{Total height of the mixture (cm)}} x100 \tag{6}$$

The samples for the determination of emulsion stability were obtained from the end product of the emulsion activity test. The samples were heated in a water bath at 80°C for 30min. After heating, the samples were cooled in chilled water for 15min, then centrifuged at 3000 rpm for 15min. The height of the emulsion layer and the total height of the mixture were measured in centimeters using a vernier caliper. The emulsion stability of the flour was calculated using the following formula in Equation 7:

$$\text{Emulsion Stability} = \frac{\text{Height of the emulsion layer (cm)}}{\text{Total Height of the mixture (cm)}} x100 \tag{7}$$

Determination of Gelatinization Temperature

Gelatinization temperature was determined by using the method of Gunorubon and Kekpugile (2012), with modifications. Each flour sample (3.0g) was dissolved in a beaker with 20mL distilled water. The mixture was heated using a hot plate with a magnetic stirrer to ensure continuous stirring until the color became milky and thickened. This is the gel point; the temperature at this point was recorded as the gelatinization temperature.

Determination of Physico-chemical Properties

pH and Titratable Acidity

Each cassava flour sample (5g) was weighed into a 50mL beaker, to which distilled water (20mL) was added and mixed well. The mixture was left to stand for 1h at room temperature, and the pH was measured in triplicate using a bench-top pH meter (Sension +, PH3). The titratable acidity (TTA) was determined on the same supernatant of the mixture used for pH by titration using 0.1mol/L NaOH and phenolphthalein indicator (3-4 drops). TTA was expressed as percent lactic acid (0.09 meq).

Water Activity

The water activity of the flour samples was measured using the Smart Water Activity meter (NADE Scientific Instruments, HD-3A, China). Flour samples were placed inside the Smart water activity meter sample container for 10min and then measured for their a_w value.

Color

The color of the different flours was measured using a digital colorimeter instrument (Labtron LCS-A Series, FTL-DFST/VSU). Data were expressed on the three-color coordinates that characterize color points as L*, a*, and b*, where L* is the "lightness" coordinate (0 = black to 100 = white), a* is the "redness-greenness" coordinate (+a* = redness, -a* = greenness) and b* is the "yellowness-blueness" coordinate (+b* = yellowness, -b* = blueness). Values of chroma (C) and Whiteness Index (WI) were determined using the formula below:

$$C = \sqrt{a^{*2} + b^{*2}} \tag{8}$$

$$WI = \sqrt{\left(100 - L^{*}\right)^{2} + a^{*2} + b^{*2}} \tag{9}$$

Determination of Proximate Composition

The proximate compositions of the flour samples were determined using the methods outlined in AOAC (1990). The moisture and ash content of the flours were determined using the gravimetric principle, oven drying, and the ash drying methods, respectively. The Soxhlet extraction method was used to determine the crude fat content of the flours, and the Kjeldahl method was used for the crude protein content determination using a protein factor of 4.7 for flour (Hayes, 2020). The total carbohydrate content of each flour sample was determined by subtracting the sum of the values of crude protein, crude fat, moisture, and ash contents (% wet basis) from 100.

Statistical Analysis

All analyses were performed in triplicates, and data were analyzed using Statistica v.10. One-way analysis of variance (ANOVA) with Fisher's least significant difference (LSD) post hoc test was used for the three NSIC-registered cassava varieties. All analyses were conducted at the 5% significance level.

RESULTS

Functional Properties

Table 4 presents the functional properties of the flours from the three NSIC-registered cassava varieties (UPL Ca-2, NSIC Cv-30, and NSIC Cv-48). Significant differences across all functional parameters ($p < .05$) were observed. Among the three varieties, NSIC Cv-48 exhibited the highest bulk density (0.572g/mL) but was significantly lower compared with wheat flour (0.762g/mL) as shown in Figure 2. UPL Ca-2 demonstrated the highest water absorption capacity (WAC) at 153.44%, significantly surpassing that of wheat flour (140.00%) as shown in Figure 3. In addition, UPL CA-2 displayed the second-highest oil absorption capacity (OAC) (125.57%) and the lowest solubility value at 2.29%. Conversely, NSIC Cv-48 recorded the highest solubility value (5.98%) and the lowest swelling power (4.47%). In terms of emulsion properties, NSIC Cv-48 yielded the highest emulsion activity (17.39%) while NSIC Cv-30 showed the highest emulsion stability (34.15%); the latter was not significantly different from NSIC Cv-48 (33.84%). In both emulsion properties, UPL Ca-2 had the lowest value. Notably, the OAC, swelling power, emulsion activity, and emulsion stability of the three NSIC-registered cassava flours were significantly lower than those of wheat flour (146.0%, 17.60mL, 43.88%, and 38.38%, respectively).

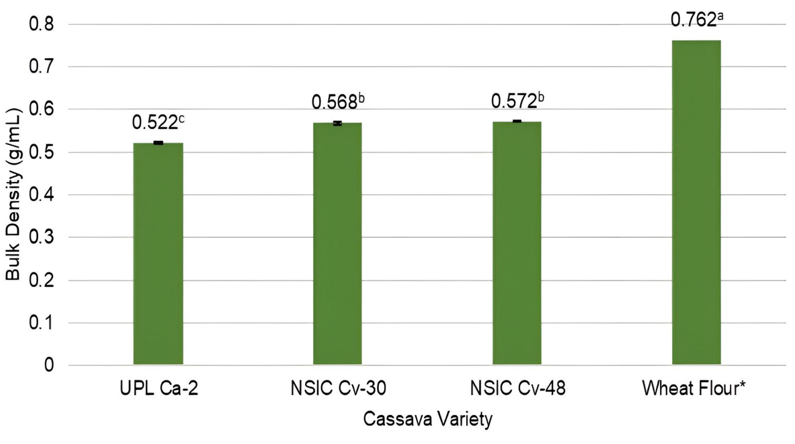

Figure 2. Bulk density of the three NSIC-registered cassava flours as compared with wheat flour. The abcd bars with similar letters are not significantly different at 5% level of significance, error bars = standard error

(*Data adopted from the study of Chandra et al. (2015) used as reference data for comparison)

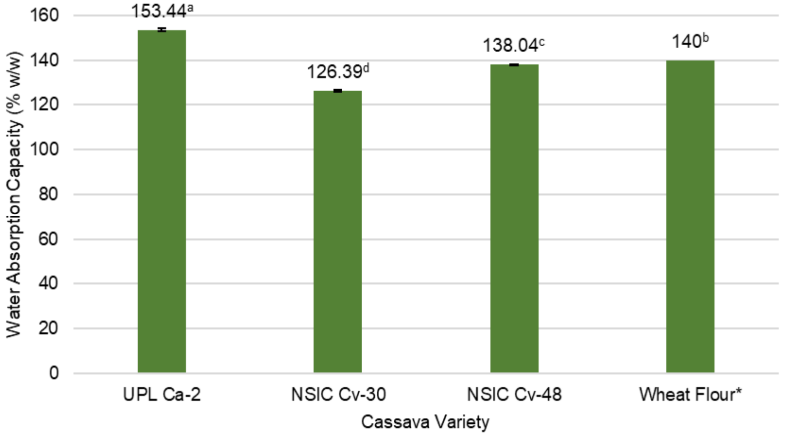

Figure 3. Water absorption capacity of the three NSIC-registered cassava flours as compared with wheat flour. The [abcd] bars with similar letters are not significantly different at 5% level of significance, error bars = standard error.

(*Data adopted from the study of Chandra et al. (2015) used as reference data for comparison)

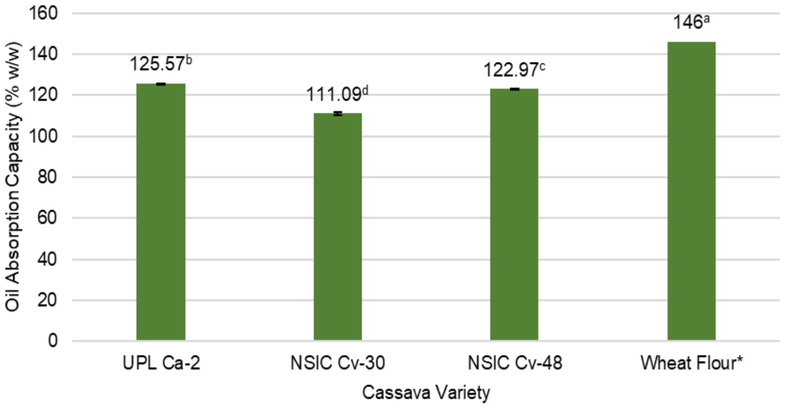

Figure 4. Oil absorption capacity of the three NSIC-registered cassava flours as compared with wheat flour. [abcd] bars with similar letters are not significantly different at 5% level of significance, error bars = standard error

(*Data adopted from the study of Chandra et al. (2015) used as reference data for comparison)

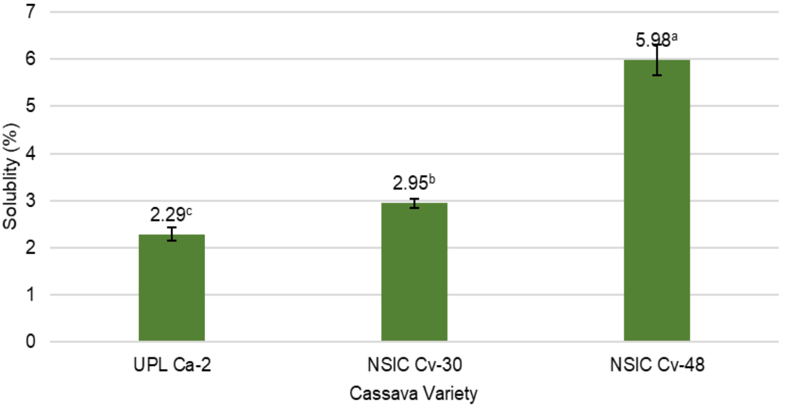

Figure 5. Solubility of the three NSIC-registered cassava flours. The [abcd] bars with similar letters are not significantly different at 5% level of significance, error bars = standard error.

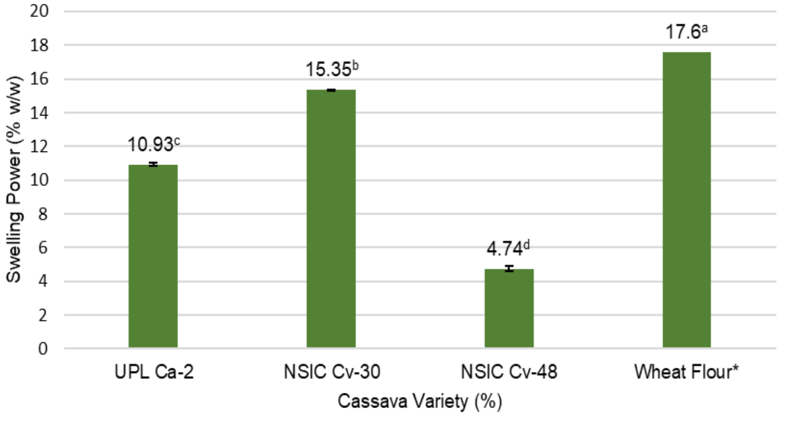

Figure 6. Swelling power of the three NSIC-registered cassava flours as compared with wheat flour. The [abcd] bars with similar letters are not significantly different at 5% level of significance, error bars = standard error.

(*Data adopted from the study of Chandra et al. (2015) used as reference data for comparison)

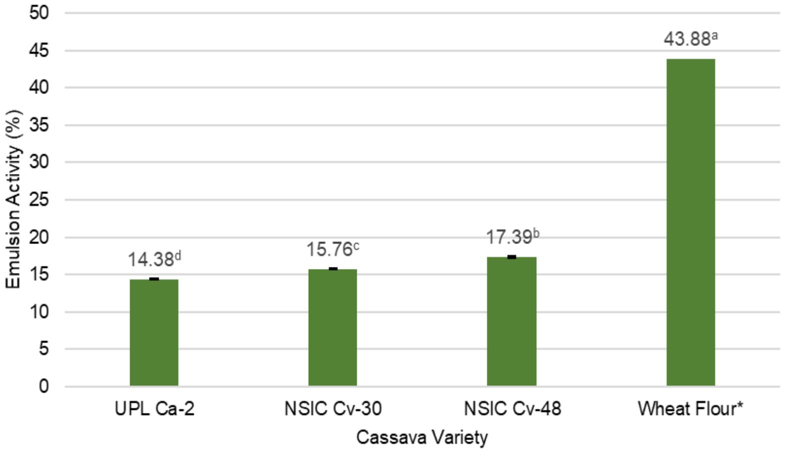

Figure 7. Emulsion Activity of the Three NSIC-Registered Cassava Flours as compared with Wheat flour. The [abcd] bars with similar letters are not significantly different at 5% level of significance, error bars = standard error.

(*Data adopted from the study of Chandra et al. (2015) used as reference data for comparison)

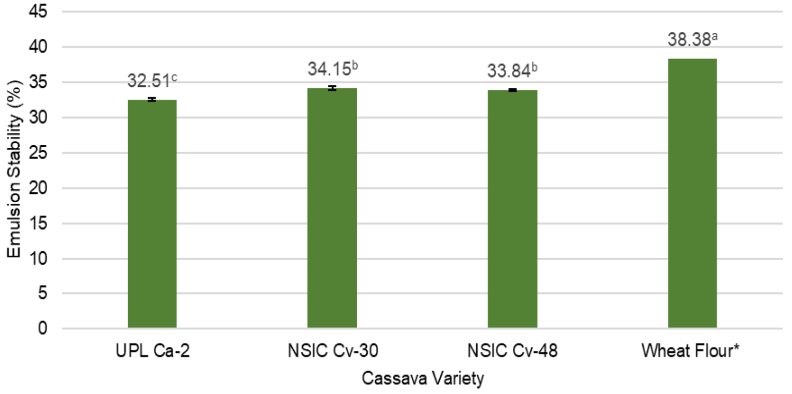

Figure 8. Emulsion stability of the three NSIC-registered cassava flours as compared with wheat flour. The [abcd] bars with similar letters are not significantly different at 5% level of significance, error bars = standard error.

(*Data adopted from the study of Chandra et al. (2015) used as reference data for comparison)

Gelatinization Temperature

The gelatinization temperature differed significantly among the three varieties, ranging from 66°C to 67°C (Table 5). UPL Ca-2 exhibited the highest gelatinization temperature at 67.17°C, which is significantly higher ($p < .05$) than both NSIC Cv-30 and NSIC Cv-48. Conversely, NSIC Cv-48 recorded the lowest gelatinization temperature at 66.18°C, but it is not statistically different from that of NSIC Cv-30. Moreover, wheat flour has a significantly lower gelatinization temperature (59.22°C) than the three NSIR-registered cassava varieties, as shown in Figure 9.

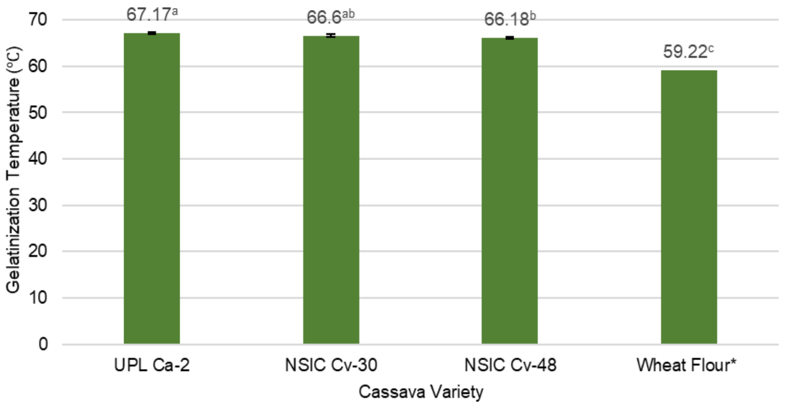

Figure 9. Gelatinization Temperature of the three NSIC-Registered Cassava Flours as compared with Wheat Flour. The [abcd] bars with similar letters are not significantly different at 5% level of significance, error bars = standard error.

(*Data adopted from the study of Chandra et al. (2015) used as reference data for comparison)

Physico-chemical Properties

Table 1. Physico-chemical Properties of the Three NSIC-Registered Cassava Flours[1]

Cassava Varieties	Physico-chemical Properties		
	pH	Titratable Acidity (%)	Water activity (a_W)
UPL Ca-2	5.78±0.022^{a}	0.330±0.003^{b}	0.67±0.003^{a}
NSIC Cv-30	5.74±0.005^{b}	0.326±0.003^{bc}	0.68±0.005^{a}
NSIC Cv-48	5.64±0.007^{c}	0.357±0.001^{a}	0.61±0.007^{b}
Wheat Flour*	5.62±0.110^{c}	0.320±0.000^{c}	---

[1]Means ± SE: Columns with similar superscript letters are not significantly different at 5% level of significance
*Data adopted from the study of Akoja and Coker (2018) used as reference for comparison

The pH, titratable acidity (TA), and water activity (a_w) of the flour samples are presented in Table 1. Significant differences (p < .05) were observed across all parameters. Notably, flours from NSIC Cv-48 exhibited a pH, TA, and a_w that is significantly different from the other two varieties evaluated. Moreover, wheat flour is shown to have a significantly lower pH and TA compared to the three NSIC-registered varieties.

Table 2. Color Properties of the Three NSIC-Registered Cassava Flours[1]

Cassava Varieties	Color Properties				
	L*[3]	a*[3]	b*[3]	WI[2]	Chroma
UPL Ca-2	95.83±0.25[a]	0.32±0.05[b]	7.35±0.37[a]	91.54±0.44[a]	7.36±0.37[a]
NSIC Cv-30	96.57±0.23[a]	-0.19±0.02[d]	5.63±0.12[b]	93.41±0.14[b]	5.63±0.12[b]
NSIC Cv-48	96.56±0.31[a]	0.12±0.02[c]	5.62±0.05[b]	93.40±0.12[b]	5.62±0.05[b]
Wheat Flour*	71.98[b]	1.78[a]	7.40[a]	---	---

[1]Means ± SE: Columns with similar superscript letters are not significantly different at 5% level of significance
[2]Whiteness Index
[3]*L**: "Lightness" (0 = black to 100 = white); *a**: "Redness to Greenness" (+*a** = redness, -*a** = greenness); *b**: "Yellowness to Blueness" (+*b** = yellowness, -*b** = blueness).
*Data adopted from the study of Aleviola and Monterde (2018) used as reference for comparison

The color properties (L*, a*, b*, WI, and Chroma) of the flour samples are summarized in Table 2. The lightness (L*) values of the three samples were not significantly different ($p < .05$), suggesting that all three flours exhibited comparable brightness. However, the chromaticity coordinate (a*, b*) values showed significant differences ($p < .05$) among the three varieties. UPL Ca-2 and NSIC Cv-48 leaned towards the red spectrum, with UPL Ca-2 having a stronger red hue, while NSIC Cv-30 was shown to lean towards the green spectrum. Moreover, UPL Ca-2 exhibited a more pronounced yellow hue compared to NSIC Cv-30 and NSIC Cv-48. Consequently, UPL Ca-2 recorded a significantly ($p < .05$) lower WI and higher chroma values, indicating greater color saturation compared with NSIC Cv-30 and NSIC Cv-48. Comparatively, wheat flour has a significantly lower lightness value (71.98) but has higher chromaticity values (a* = 1.78 and b* = 7.40).

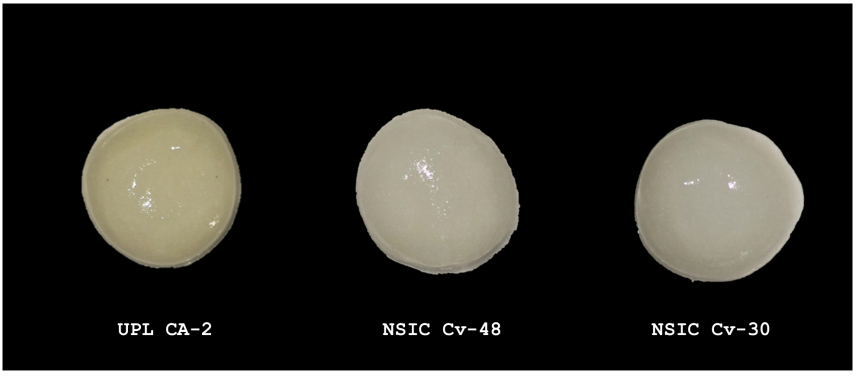

Figure 10. Gel-formation ability of the three NSIC-registered cassava flours.

Figure 10 presents the visual observation of the gels from flours of the three NSIC-registered cassava roots after hydro-thermal treatment at 95°C. UPL Ca-2 produced a faint yellow color and formed a firmer gel. In contrast, both NSIC Cv-48 and NSIC Cv-30 produced white, opaque gels with varying firmness. NSIC Cv-48 exhibited a more paste-like consistency, while NSIC Cv-30 had a firmness comparable to that of UPL Ca-2.

Proximate Composition

Table 3. Proximate Properties of the Three NSIC-Registered Cassava Flour Varieties[1]

Cassava Varieties	Proximate Properties				
	Moisture (%)	Ash (%)	Fat (%)	Protein (%)	Carbohydrate (%)
UPL Ca-2	12.87±0.048^{a}	1.49±0.010^{a}	0.28±0.026^{b}	1.82±0.053^{b}	83.61
NSIC Cv-30	11.65±0.060^{c}	1.46±0.009^{b}	0.21±0.032^{c}	1.24±0.001^{c}	85.42
NSIC Cv-48	12.31±0.051^{b}	1.49±0.007^{a}	0.25±0.014^{c}	1.35±0.043^{c}	84.61
Wheat Flour*	12.74^{a}	0.42^{c}	1.18^{a}	13.60^{a}	78.80

[1]Means ± SE: Columns with similar superscript letters are not significantly different at 5% level of significance
*Data adopted from the study of Aleviola and Monterde (2018) used as reference for comparison

The proximate composition of the three flour samples is presented in Table 3. The proximate profiles were significantly different ($p < .05$) across the three varieties. UPL Ca-2 exhibited significantly higher moisture, fat, and protein content than the flours from NSIC Cv-30 and NSIC Cv-48. Moreover, NSIC Cv-30 exhibited the lowest amount of ash and consequently the highest carbohydrate content. Notably, all three varieties are good sources of carbohydrates. Comparatively, wheat flour has significantly greater protein and fat content but has a significantly lower ash content value. The moisture content of wheat flour is shown to be similar to the moisture content of UPL Ca-2.

DISCUSSION

Functional Properties of NSIC-Registered Cassava Flours

Bulk Density

Variations in bulk density are critical for determining functional applications of the flour. The bulk density of UPL Ca-2, NSIC Cv-30, and NSIC Cv-48 (0.522 – 0.572g/mL) falls within the range of 0.5 to 0.8 as reported by Akinsola et al. (2025) and Kesselly et al. (2022) for cassava flours, but was lower than the standard tapped bulk density of wheat flour, which typically ranges from 0.60 to 0.80g/mL as reported by Barbosa-Canovas et al (2005), as illustrated in Figure 2. This lower density in cassava flour is characteristic of tuber starches, which often exhibit higher porosity compared to cereal flours (Barbosa-Canovas et al., 2005). According to Chandra et al. (2015), high bulk densities in flours suggest suitability for food preparation, such as thickeners in various food products. This indicates that the higher bulk density of NSIC Cv-30 and NSIC Cv-48 cassava flours in this study makes them suitable for thickening. The opposite may be true for UPL Ca-2, which has the lowest bulk density among the three varieties. Conversely, lower bulk density of the flour could be an advantage in the formulation of infant foods, as more importantly, a high nutrient density to low bulk density ratio is desired (Akapata & Akubor, 1999).

In industrial applications, bulk density is a critical parameter that influences the selection of packaging materials. Specifically, higher bulk density flour necessitates denser packaging materials due to their lower porosity, which impacts the design and efficiency of packaging (Awuchi et al., 2019). This means that NSIC Cv-48 and NSIC Cv-30 flours require denser packaging materials. According to Bhattacharya and Prakash (1994), the variation in bulk densities could be attributed to the amount of starch present in the flours. Generally, an increase in starch content correlates with a higher bulk density.

Water Absorption Capacity (WAC)

High WAC is desirable in bread baking because it retards the rate of staling due to the added moisture coming from the environment (Alviola & Monterde, 2018). In this study, UPL Ca-2, exhibited the highest WAC (153.44%), suggesting superior potential for baking applications compared to NSIC Cv-30 (126.39%) and NSIC Cv-48 (138.04%). This is positively correlated with its protein content, which is significantly higher than the other varieties evaluated. Proteins contain hydrophilic polar amino acid residues that form hydrogen bonds with water molecules, thereby enhancing the overall water-holding capacity of the flour (Kaushal et al., 2012, as cited by Chandra et al., 2015). Wheat flour typically contains 10-14% protein and exhibits a WAC ranging from 140 % to 160% (Adebowale et al., 2005). Notably, UPL Ca-2 displayed a significantly higher WAC than wheat flour (Figure 3 and Table 4) despite having significantly lower protein content. This suggests that the WAC of cassava flours is likely driven by the loose associative forces within their starch granules rather than protein content alone. The relatively high WAC values are indicative of weak associative forces between starch granules, which allows for more molecular surfaces to be available for binding with water molecules. Moreover, the values of water binding capacity reported here are in the same range as reported by Aryee et al. (2006). The WAC reflects the ability of flour to associate with hydrophilic substances, influencing its hydration behavior (Chimphepo et al., 2021), which relates to the attainment of the necessary consistency of certain foods and baked products. WAC levels vary across different bakery products and formulations, each requiring specific WAC levels to ensure optimal quality(Chandra et al., 2015). Nevertheless, the elevated protein in UPL Ca-2 provides a functional advantage over NSIC Cv-30 and NSIC Cv-48, making it the most competitive alternative to wheat flour for applications requiring moisture retention.

Table 4. Functional Properties of the Three NSIC-Registered Cassava Flours[1]

Functional Properties	NSIC-Registered Cassava Florus			Reference Flour
	UPL Ca-2	NSIC Cv-30	NSIC Cv-48	Wheat Flour (Chandra et al. 2015)*
Bulk Density (g/mL)	0.522±0.002[c]	0.568±0.003[b]	0.572±0.001[b]	0.762±0.00[a]
Water Absorption Capacity (% (w/w))	153.44±0.654[a]	126.39±0.430[d]	138.04±0.280[c]	140.00±12.25[b]
Oil Absorption Capacity (% (w/w))	125.57±0.189[b]	111.09±0.831[d]	122.97±0.222[c]	146.00 ± 08.94[a]
Solubility (% (w/w))	2.29±0.138[c]	2.95±0.096[b]	5.98±0.323[a]	--------
Swelling Power (% (w/w))	10.93±0.095[c]	15.35±0.019[b]	4.74±0.166[d]	[2]17.60±1.85[a]
Emulsion Activity (%)	14.38±0.104[d]	15.76±0.092[c]	17.39±0.148[b]	43.88±4.12[a]
Emulsion Stability (%)	32.51±0.202[c]	34.15±0.233[b]	33.84±0.109[b]	38.38±4.78[a]

[1]Means ± SE: Rows with similar superscript letters are not significantly different at 5% level of significance
[2]Swelling power adopted from Chandra et al. (2015) was expressed in mL
*Data adopted from the study of Chandra et al. (2015) used as reference data for comparison

Oil Absorption Capacity (OAC)

In food applications, a high value of OACs facilitates flavor retention, improves the palatability of foods, and extends shelf life (Chandra et al., 2015). The OAC of the flours is presented in Table 4 and illustrated in Figure 4. The cassava varieties exhibited OAC values that are significantly lower ($p < .05$) than wheat flour. Among the three cassava varieties evaluated, UPL Ca-2 demonstrated the highest capacity. However, it is significantly lower than the OAC of wheat flour (Figure 4). The superior OAC of wheat flour is attributed to its higher protein content and the presence of gluten, which possesses hydrophobic side chains that facilitate strong interactions with the hydrocarbon chains of lipids (Kaushal et al., 2012).

OAC reflects the binding of fat by the non-polar side chains of proteins, an important functional property that enhances mouthfeel and flavor retention in food products. Nilusha et al. (2021) reported OAC values of Sri Lankan cassava varieties, with a value ranging from 96.72 to 118.83%, which are comparable to the OAC values obtained from the three cassava varieties in this study (ranging from 111.09% to 125.57%). Compared to wheat flour and wheat flour composites, which have an OAC value ranging from 130% to 156% (Chandra et al., 2015), the OAC of NSIC Cv-30 is lower.

Solubility

Water solubility index is a critical parameter reflecting the degree of molecular dispersion of starch granules in aqueous systems. It is influenced by factors such as particle size, crop variety, and environmental conditions (Aryee et al., 2006). At higher temperatures, low solubility indicates a high stability of the amylopectin structure in the flour, which prevents degradation and the release of amylose during heating, which is the soluble matter. Further swelling of starch beyond its critical point results in the disintegration of granules with the release of soluble matter (Singh et al., 2003). In food systems, such as pastries, solubility is essential since flour with high solubility may produce a soggy and less cohesive dough (Osei Tutu et al., 2024). Moreover, flours with low solubility are suitable for making dough with high elasticity (Aidoo et al., 2022). This indicates that UPL Ca-2, having the lowest solubility value of 2.29% (Table 4 and Figure 5), is preferable for baking applications. The results suggest that UPL Ca-2 has a more stable amylopectin structure that restricts amylose release, leading to lower solubility. This may also be true for NSIC Cv-30 since its solubility value is closer to UPL Ca-2, albeit significantly different. This is in agreement with the results of Kusumayanti et al. (2015) stating that cassava flour has higher swelling power due to its higher amylopectin. This stability may provide greater resistance to heat and processing stress, making these flours suitable for applications requiring high structural integrity. In contrast, the higher solubility of NSIC Cv-48 may indicate a weaker starch structure and greater amylose leaching, favoring its use in products where higher dispersion is desired, such as the case for the beverage industry, which favors starches with low digestibility but high solubility (Lee et al., 2008).

Table 5. Gelatinization Temperature of the Three NSIC-Registered Cassava Flours[1]

Cassava Varieties	Gelatinization Temperature (℃)
UPL Ca-2	67.16±0.16[a]
NSIC Cv-30	66.60000±0.34[ab]
NSIC Cv-48	66.17778±0.24[b]
Wheat Flour (Chandra et al., 2015)	59.22±0.15[c]

[1]Means ± SE: Columns with similar superscript letters are not significantly different at 5% level of significance

Swelling Power

Swelling power is the abilityof a substance to be hydrated (Adams et al., 2019). It is commonly reported that swelling power is inversely proportional to protein, fat, and amylose content. This means protein lowers the capacity to swell by forming a stiff matrix and lipids and amylose that form insoluble complexes (Shimelis et al., 2006; Aprianita et al., 2014). This is true for NSIC Cv-30, which was observed to have the highest swelling power (15.35%), since it also contains the lowest protein content, as shown in Table 3. Moreover, swelling power and solubility were reported to be negatively proportional (Aidoo et al., 2022). This is congruent with the results of the present study since the higher swelling power of UPL Ca-2 and NSIC Cv-30 (10.93% and 15.35%, respectively) corresponds to their lower solubility. Additionally, NSIC Cv-48 with a low swelling power (4.47%) corresponds to its high solubility value. The high swelling power of NSIC Cv-30 and UPL Ca-2 indicates that these flours could be good ingredients for viscous foods due to their high swelling ability (Aidoo et al., 2022).

There are factors considered for the variations in the swelling power, such as the presence of non-starch components, such as lipids, proteins, and other flour components (Chisenge et al., 2019). However, the study by Alviola and Monterde (2018) shows that the swelling power of different flours, including cassava flour, had a highly significant positive correlation with amylose content but was not significantly correlated with fat or protein. Thus, this indicates that swelling is mainly influenced by amylose content. This implies that UPL Ca-2 and NSIC Cv-30 have a high amylose content. Conversely, NSIC Cv-48 shows a lower swelling power accompanied by the high solubility indicating a weak associative force in the starch granules. Moreover, the NSIC Cv-48 variety can be hydrolyzed easily to produce starch sugars without using external energy input (Morthy & Ramanujam, 1986).

Notably, the swelling power of all three NSIC-registered cassava varieties was significantly lower than that of wheat flour (Table 4 and Figure 6). This suggests that cassava flours may form more stable, less viscous pastes than wheat flour, at equivalent concentrations. This is considered a desirable trait for manufacturing food products such as noodles or confectionery where excessive thickening is detrimental (Moorthy, 2002).

Emulsion activity and emulsion stability

Emulsion activity and stability measure different aspects of emulsion behavior. Emulsion activity reflects a substance's ability to form emulsions, while emulsion stability indicates its resistance to separation over time (Xiao et al., 2025). Since cassava is naturally low in protein, its emulsifying capacity is limited. NSIC Cv-48, having the highest emulsion activity (17.39%), will readily form emulsions, while NSIC Cv-30, with the highest emulsion stability (34.15%), is expected to have better long-term emulsion maintenance. This may indicate that NSIC Cv-30 possesses structural characteristics enabling better emulsion stability. Thus, both NSIC Cv-30 and NSIC Cv-48 may function as good emulsifiers for certain food products, such as ice cream and baked goods (Xiao et al., 2025). However, they may not be able to compete with flours containing higher concentration of proteins. According to Chandra and Samsher (2013), these properties are influenced by pH, solubility, and viscosity. The observed differences among the cassava varieties may relate to variations in these parameters, particularly protein content and solubility. Overall, cassava flour demonstrates moderate emulsifying properties suitable for composite flour applications.

Despite the variations among the three NSIC-registered cassava varieties evaluated, their emulsion properties were significantly lower than those of wheat flour (Table 4, Figures 7 and 8). This disparity is primarily attributed to the difference in the protein concentration and composition of the cassava and wheat flours. Wheat flour contains gluten, which possesses substantial hydrophobic residues that interact effectively with oil at the oil-water interface, reducing interfacial tension and stabilizing the emulsion (Kaushal et al., 2012). In contrast, the lower protein content of the cassava flours (Table 3) limits their amphiphilic capacity.

Gelatinization Temperature

The gelatinization temperature provides critical insight into the thermal energy required to initiate the structural transition of starch granules from a crystalline to an amorphous state. Flour contains starch that gelatinizes at certain temperatures. This occurs when water penetrates amorphous regions causing the starch granules to swell. Upon hitting a critical threshold, these granules burst and create a gel-like formation (Renzetti et al., 2025). The gelatinization temperature of starch in flour influences pasting behaviors and the rheological properties (Tester & Morrison, 1990). According to Wheatly et al. (2003), cassava starch gelatinizes at relatively low temperatures; initial gelatinization occurs around 60°C, which coincides with the results of this study wherein starch gelatinization temperature ranges from 66°C to 67°C. Notably, UPL Ca-2 has the highest gelatinization temperature (67.17°C), indicating a higher degree of granular structural integrity and thermal stability compared with NSIC Cv-30 and NSIC Cv-48. The elevated gelatinization temperature makes UPL-Ca-2 particularly suitable for food applications involving harsh thermal processing where a delayed onset of viscosity is advantageous to facilitate heat transfer before the product fully thickens (Moorthy, 2002).

Comparatively, wheat flour has a significantly lower gelatinization temperature (59.22°C) compared to the three NSIC-registered varieties. The observed difference in gelatinization temperature between wheat flour and the cassava flours could be due to a difference in amylose content. According to Bringhurst (2022), as amylose content increases, gelatinization temperature decreases. Wheat flour was reported to have around 25% amylose content (Chen et al., 2016), while cassava was reported to have around 19.49% amylose content (Oladunmoye et al., 2014).

In terms of application, cassava starch (and flours in extension) stabilizes gluten-free white sauces, preventing phase separation. Moreover, with a pasting temperature of around 70°C, it is also included in salad cream preparation as it produces salad cream with an acceptable sensory property. This implies that cassava flour is better suited for low-temperature food processing instead of high-temperature processing (Chisenga et al., 2019). This may also apply to the other cassava varieties since their gelatinization temperatures are closer to each other, albeit significantly different.

Physico-chemical Properties of NSIC-Registered Cassava Flours

The pH. values of the flours from the NSIC-registered cassava varieties (UPL Ca-2, NSIC Cv-30, and NSIC Cv-48) were within the acceptable pH range of 5-7 (Chimphepo et al., 2021), with NSIC Cv-48 (5.64) having the significantly lower pH value than NSIC Cv-30 (5.74) and UPL Ca-2 (5.78), which are not significantly different from each other. Cassava flour with a lower pH (<4) is indicated as a sour type due to the level of fermentation. The titratable acidity is also consistent with the results obtained by Eriksson et al. (2014) in three local flour cassava varieties in Sweden. Also, pH and titratable acidity are two interrelated parameters used to depict acidity. The titratable acidity provides a better indication of the impact of acidity on flavor, whereas pH is better suited to predicting potential for microorganism growth. Moreover, pH has been studied to affect pasting and texture properties of flour, with lower pH resulting in gel hardness due to the strengthening of ionic and hydrophobic bonds (Park et al., 2021). Since the NSIC-registered cassava varieties have relatively low pH, this would explain the ability of the NSIC-registered cassava flours to form firm gels, as shown in Figure 1. Moreover, wheat flour has a significantly lower pH (5.62) and TA (0.320%) value when compared to UPL Ca-2 and NSIC Cv-30, but does not show a significant difference with NSIC Cv-48, as shown in Table 1. The reported value of wheat flour is consistent with the findings of Grah et al. (2014).

Additionally, the water activity of the selected cassava flours, ranging from 0.61 to 0.68, with NSIC Cv-48 being significantly different from the two other varieties, showed that all three varieties may be susceptible to mold growth. Theoretically, microbiological stability can be ensured with a_w>0.6 (Chisté et al., 2015); however, all varieties (UPL Ca-2, NSIC Cv-30, and NSIC Cv-48) go beyond 0.6, albeit slightly. Molds can grow within an intermediate range of water activity between 0.6 and 0.84 (Vermelho et al., 2024), which is within the range of the observed water activities of the selected NSIC-registered cassava flours. However, this susceptibility to mold growth may be addressed with proper storage.

Color Profile

An important quality attribute of a flour is its color, which affects the appearance and consumer acceptability of products made from it. The L* values of the tested cassava flours show the same high whiteness. Nilusha et al. (2021) and Eriksson et al. (2014) reported that cassava flour has high whiteness and lightness with low redness and yellowness. These differences can be observed visually in the flesh and flour but not in the starch. The whiteness of the flour indicates that no fermentation or microbial contamination has occurred. Low a* values were attributed to the tested flours, which means that they have fewer red components. The high value of b* in the UPL Ca-2 variety may be attributed to the high carotene content. Cassava varieties with colored flesh contain a higher amount of carotene than varieties with white flesh.

WI values are influenced by the temperature and duration of drying, where higher temperatures and longer drying times result in higher b* and a* values, thereby reducing WI. The generally high WI of the selected cassava flours indicates they can be used in food production without altering the color of the food, potentially enhancing the acceptance of the final product (Chimphepo et al., 2021). In this case, NSIC Cv-30 and NSIC Cv-48 may not alter the food color.

Chroma is influenced by higher values of a* and b*; the greater these values are, the higher the chroma. Chroma values observed in the selected cassava varieties were lower than those reported by Aleviola and Monterde (2018) (a* = 1.78 and b* = 7.40). In baking applications, the desired color of wheat flour is characterized by a high L* value and a low chroma value (Chisenga et al., 2020). The chroma values of the flours of the selected NSIC-registered cassava roots indicate that NSIC Cv-30 and NSIC Cv-48 can be incorporated at varying substitution levels comparable to wheat flour.

Gel-Formation Ability

Visual observation of the gel formation of the three NSIC-registered cassava varieties showed that all the selected flours were capable of gel formation. According to Almazan (1988), the paste viscosity and amylose content were correlated to the gel consistency of the cassava flour. This indicates that all the cassava varieties (UPL Ca-2, NSIC Cv-30, NSIC Cv-48) contain considerable amylose content.

Flours function as thickening agents, binding agents, gelling agents, and stabilizers in food products. Under continuous heating and stirring, flours suspended in water eventually develop viscosity. Upon cooling, these pastes turn into gels; a solid-in-liquid colloid having a defined shape without fluidity (Yuan et al., 2021). Assessing the gel-forming ability of flour samples helps determine their effectiveness as thickening agents. Flours and starches with strong gelling properties are valuable in baking because the gel network structure enhances batter viscosity and fortifies the air cells in the bread's crumb (Alviola & Monterde, 2018). Similar to the results of Lu et al. (2019), this implies that, in terms of gel-formation, all NSIC-registered cassava varieties are suitable for the processing of baked goods.

Proximate Composition of NSIC-Registered Cassava Flours

The flour produced from the NSIC-registered cassava varieties was below the accepted moisture content (14.5%), indicating that the cassava flours are relatively safe from degradation caused by high moisture content. Moisture content is an important parameter in flours since high moisture (over 14.5%) attracts mold, bacteria, and insects as well as enzymatic activities, and caking of the flour (Wheat Marketing Center, Inc., 2004). Moreover, the reported moisture content of wheat flour is 12.74% (Aleviola & Monterde, 2018), showing no significant difference with the moisture content of UPL Ca-2.

The ash content of the NSIC-registered cassava flours was found to be comparatively similar, ranging from 1.46% to 1.49%. These findings are also similar to those of Rojas et al. (2007) and Nyawose et al. (2022), who observed 1.46% and 1.47% ash contents, respectively. The ash content reflects the inorganic mineral content of the flour samples. Findings from Nilusha et al. (2021) indicate that wheat flour has an ash content of 1.52%, which is comparable to the findings of Harris and Marshall (2017), who reported an ash content of 1.6% for wheat flour. Moreover, the study of Lu et al. (2019) shows that the cassava flour they studied contained higher ash content (2.0%) than their studied wheat flour (0.3%). Moreover, Aleviola and Monterde (2018) reported that the ash content of wheat flour is 0.42%, the same as this study as shown in Table 3. This indicates that the NSIC-cassava flour (UPL Ca-2, NSIC Cv-30, and NSIC Cv-48) can compete with commercial wheat flour in terms of ash content.

The cassava flours exhibited fat content ranging from 0.23 to 0.28%, which falls within the results of Hasmadi et al. (2020) and Moorthy (2002), with fat content values ranging from 0.55% to 0.68% and 0.19% to 0.98%, respectively. Nyawose et al. (2019) reported a much lower fat content of cassava flours, ranging from 0.013 to 0.024%, while Imoisi et al. (2024) reported the fat content of their studied flour was 0.95%. Variations of fat content may be influenced by agroecological conditions and varietal differences. Despite the variations in fat content, the cassava flours have significantly lower fat content when compared to wheat flour (1.18%). Additionally, fat content in flour influences paste texture, where fat is used to obtain stability (Moorthy, 2002). However, high-fat content in cassava flour is undesirable since too much fat will lead to a higher likelihood of rancidity and increased flour cloudiness (Hasmadi et al., 2020). Moreover, high-fat content is likely related to low swelling power and solubility in flour (Roa et al., 2014).

The flour produced from NSIC-registered cassava varieties has a low protein content, ranging from 1.24% to 1.82%. Similar protein contents were reported by Tulin et al. (2023), Aryee et al. (2006), and Nilusha et al. (2021), which were 1.80%, 1.31% and 1.18%, respectively. The low protein content of cassava flour is likely caused by the general low protein content in roots/products that have 1-2% or no more than 4% protein (Shifa Putri Mohidin et al., 2023; Beninca et al., 2013). This is substantially lower than wheat flour, which has a reported protein content ranging from 8.5% (Lu et al., 2019) to 13.60% (Aleviola & Monterde, 2018). Protein plays a vital role in food; its content and quality influence the structure and quality of the product. However, cassava flour does not contain enough gluten protein, making it unsuitable for baked products requiring gluten(Lu et al., 2019). The NSIC-registered cassava flour may be used in the formulation of gluten-free foods.

The total carbohydrate is the major component of cassava flour, accounting for 85-90%, with very low fiber, protein, and fat content (Ek et al., 2020). Similar carbohydrate contents were observed by Nilusha et al. (2021), which were in the range of 86.28 to 93.13%. Due to the high amount of carbohydrate content of the flours produced from the NSIC-registered varieties (UPL Ca-2, NSIC Cv-30, and NSIC Cv-48), they can be utilized in formulating composite flour blends that require a high carbohydrate content. Additionally, wheat flour has a lower carbohydrate content (78.80%) compared to the flours produced from the three NSIC-registered cassava varieties. Moreover, cassava flour has been used as an unconventional filler in comminuted meat products, which produces an affordable product as well as increasing its nutritional content (Annor-Frempong et al., 1996) by adding carbohydrates.

CONCLUSION

This study establishes that a significant variation exists in the functional properties, proximate composition, and physico-chemical properties of the NSIC-registered cassava flours (UPL Ca-2, NSIC Cv-30, and NSIC Cv-48), influencing their suitability for specific applications in food systems. UPL Ca-2 was characterized by superior water and oil absorption capacities with a firm yellow gel, suggesting suitability for products requiring moisture and fat retention. NSIC Cv-48 was distinguished by its high solubility, emulsion activity, and stability, and reduced swelling power, suggesting its suitability for products where rapid dispersion without excessive viscosity is necessary. Conversely, NSIC Cv-30 displayed the highest swelling power and emulsion stability, which is ideal for products requiring high viscosity and phase stability to prevent syneresis. The functional and physicochemical characteristics of these cassava flours indicate their versatility as food ingredients, but further research in model food systems is required for confirmation. Future research should explore their performance in composite flours and assess the impact of processing modifications on enhancing their functional performance.

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Author Contributions

ICE - conceptualized the research project and developed the research proposal; managed and monitored the research project; ensured the integrity, rigor and reliability of data, methods, results and resources through reviewing, and verification; Reviewed, copy-edited, refined language and provided comments and suggestions.

EBC - conceptualized the research project and developed the research proposal; managed and monitored the research project; Ensured the integrity, rigor and reliability of data, methods, results and resources through reviewing, and verification; Revised content based on feedback from internal and external reviewers; Provided review input of figures, tables, and supplementary materials.

RDL - Assisted in the conceptualization of the research project

APV - collected and gathered data through experiments; performed statistical analysis, reported progress of the project; drafted the full paper article.

KOS - collected and gathered data through experiments; performed statistical analysis, reported progress of the project; revised the rough draft of the full paper; Provided review input of figures, tables, and supplementary materials.

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Availability of Data and Materials

The data and materials analyzed during this study are not included in this article. However, these data, materials, and its supplementary files are available upon request from the corresponding authors.

Ethical Considerations

Not applicable. No human respondents were used in the data collection of the project.

Competing Interest

The authors of the paper discloses no competing interests.

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