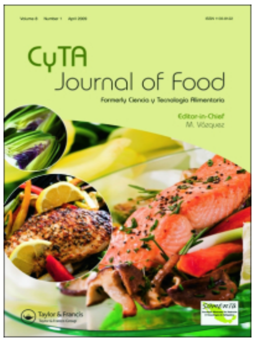

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Chemical, functional and pasting properties of starches and flours from new yam compared to local varieties

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ABSTRACT

The potential uses of starches and flours depend on their physicochemical and functional properties. The chemical composition, functional and pasting properties of starch and flours obtained from some newly developed yam varieties from the Crops Research Institute (CRI), Ghana were evaluated, and compared with the existing local varieties. The results showed that the physicochemical and functional properties varied among the varieties studied. The CRI varieties were grouped in a principal component analysis as moisture (*afase pa*), amylose content (*ahodenfo, soanyinto, afase biri*), high starch content, bulk density and water absorption capacity (*kukrupa, Mankrong pona, CRI pona*). Starch pasting characteristics showed that *Mankrong pona, CRI pona* and *afase pa* exhibited stable pastes whereas *afase biri*, *Mankrong pona* and, *afase soanyinto* could be utilized for high-temperature processing. Overall, the new CRI varieties showed considerable functionalities that could be explored for potential food and industrial applications as compared to the existing local varieties.

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Yam flour; yam starch; physicochemical properties; functional properties; pasting properties

PALABRAS CLAVE
Harina de ñame; almidón de ñame; propiedades fisicoquímicas; propiedades funcionales; propiedades de pegado

Propiedades químicas, funcionales y de pegado de los almidones y las harinas del nuevo ñame en comparación con las variedades locales

RESUMEN

Los usos potenciales de los almidones y las harinas dependen de sus propiedades fisicoquímicas y funcionales. Este estudio se propuso evaluar la composición química y las propiedades funcionales y de pegado de los almidones y las harinas obtenidos de algunas variedades de ñame recientemente desarrolladas por el Crops Research Institute (Instituto de Investigación de Cultivos-CRI) en Ghana, en comparación con las variedades locales existentes. En este sentido, los resultados dieron cuenta de que las propiedades fisicoquímicas y funcionales de las variedades estudiadas presentan ciertas diferencias. Así, las variedades desarrolladas por el CRI se agruparon en un análisis de componentes principales, por ejemplo, humedad (*afase pa*), contenido de amilosa (*ahodenfo, soanyinto, afase biri*), alto contenido de almidón, densidad aparente y capacidad de absorción de agua (*kukrupa, Mankrong pona, CRI pona*). Las características de pegado del almidón mostraron que la *Mankrong pona*, la *CRI pona* y la *afase pa* presentan pastas estables, mientras que la *afase biri*, la *Mankrong pona* y la *afase soanyinto* pueden utilizarse para el procesamiento a alta temperatura. En general, y en comparación con las variedades locales existentes, las nuevas variedades desarrolladas por el CRI mostraron considerables funcionalidades que podrían ser exploradas para potenciales aplicaciones alimentarias e industriales.

1. Introduction

Yam is an essential staple crop in Ghana, sub-Saharan Africa and some tropical regions of the world. It contains about 70–80% moisture, 16–24% starch and, trace quantities of proteins and lipids (Liu et al., 2006) as well as vitamin, minerals, and, dietary fibre (Baah et al., 2009). Like other root and tuber crops, yams are subjected to physiological deterioration after harvest (Kiaya, 2014) due to the high moisture content which makes them more susceptible to microbial proliferation. According to Otoo (2017), breeding activities ensure that new yam varieties developed are able to solve future problems associated with yam production and consumption like improvement on food quality, pest and insect as well as drought-resistant varieties. Whilst breeders do this, the processors desire to further enhance shelf life and marketability by transforming yam into flours and starches. Earlier works by Otegbayo et al. (2014) have established that apart from using yams as staple food source, there is high utilization of yam starches and flours in the Sub-Saharan Africa.

The applicability of starches and flour in the production of various food products is based on their physicochemical and functional properties (Afoakwa et al., 2013). Some yam varieties are widely known and, exploited for their functionalities because their physicochemical and functional properties are well known and reported (Addy et al., 2014; Donaldben et al., 2020). As new yam varieties are introduced, there is need to expand their utilization through industrial

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processing to reduce postharvest losses. Their starches and flours are great sources for enhanced utilization. For instance, starches are employed as thickeners, stabilizers, and, in controlling consistency (Peroni et al., 2006). These functionalities are achieved by affecting pasting, gelatinization and retrogradation properties (Blazek & Gilbert, 2011) which are a result of their chemical and functional characteristics. Variations do occur among different species and, even varieties of same species in terms of their biochemical compositions (Otegbayo et al., 2014) which can be attributed to cultural and climatic factors, maturity stage at harvest and method and duration of storage. Generally, the functional properties of starches are affected by the molecular, granular and crystalline differences (Li et al., 2017).

Starch and flour contribute to the textural properties of foods and thus the value added products from them will require comprehensive knowledge of chemical, functional and pasting properties. Also cereals are reported to be the major raw materials for starch production worldwide (Bergthaller & Hollmann, 2007). However, starch and flours from the new yam varieties could serve as alternative sources when found to possess quality attributes specific to its application in the food and pharmaceutical industries. This will generally enhance adoption and utilization of the new varieties. Most importantly, postharvest losses of yams will be reduced as yams rapidly deteriorate during storage.

The functional, physicochemical and pasting properties of different local yam varieties grown in Ghana have been reported (Tortoe et al., 2019). Some new yam varieties have been developed and released but their starch and flours have not been characterized. Investigating the properties of starch and flour from the newly developed varieties would be a basis for consideration in their usage in the food industry. Therefore, the present study evaluates the chemical, functional and pasting characteristics of newly developed yam varieties from the Crops Research Institute (CRI), Fumesua in Ghana.

2. Materials and methods

2.1. Sample acquisition

Local yam samples were obtained from a known farmer in Mampong in the Ashanti Region of Ghana. Seven (7) newly developed yam varieties, *D. rotundata poir* (3) and *D. alata* (4) were obtained from the CSIR-Crops Research Institute (CRI), Fumesua-Kumasi, Ghana.

2.2. Flour preparation

Yam samples were peeled, washed and grated into aluminium trays for drying in a solar dryer for two days. The dried chips were milled (Brook Crompton, Huddersfield, England) and passed through a mesh of 200 µm. The milled samples were stored in zip-lock polyethylene bags at room temperature until analysis.

2.3. Starch extraction

The yams were cleaned, peeled, washed and cut into pieces. They were ground into a slurry in the blender (Philips Compact Blender (HR 2027/5, UK)) using the highest speed. The slurry was poured unto a nylon mesh and continuously washed with distilled water until the water was clear. The collected water was allowed to settle and decanted to separate the starch. This was further washed with additional water to remove impurities. It was solar dried for 24 h, milled and stored in a ziploc bag for analysis.

2.4. Amylose content determination

Amylose content was determined according to the protocol used by Gandebe et al. (2007) with slight modificaions. A standard curve was developed by mixing 40 mg of 66% potato amylose (standard) with 1 mL of 95% ethanol and 9 mL of 1 N NaOH. The mixture was heated in a boiling water bath for 10 min. The solution was allowed to cool to room temperature before transferring into a 100 mL volumetric flask covered with aluminium foil and topped up to the mark with distilled water. Aliquots of the mixture (2.5, 2.0, 1.5, 1.0 and 0.5 mL) were pipetted into 50 mL centrifuge tubes respectively and 0.5, 0.4, 0.3, 0.2, and 0.1 mL of 1N acetic acid were respectively added to the aliquots. After that, 1 mL of 0.2% iodine solution was added into each tube and vortexed. Absorbance (A) was read using a spectrophotometer (UV/VIS Excellence UV5 Mettler Toledo GmbH, Switzerland) at 620 nm after the mixtures were kept in the dark for 20 min. A blank solution was prepared by mixing 5 ml of 1N NaOH with 0.1 ml of 1 N acetic acid and 1 ml of iodine solution. Standard curve was then drawn. The same procedure was carried out for starch suspensions (100 mg in 100 ml). The reaction proceeded by adding 2.5 ml of the starch suspension with 0.5 ml of 1 N acetic and, 1 ml of 0.2% iodine and absorbance measured at 620 nm. Concentration of amylose in the samples were calculated using the equation of the standard curve. Amylopectin content was calculated by subtracting the percent amylose from 100.

2.5. Moisture content determination

Moisture content was determined according to AOAC method (AOAC, 2005). About 3 g of sample was weighed into an empty dish of known weight. The dish with its content was placed in a forced air-oven at 105ºC for 5 h. After drying, the dish and its content was transferred to a desiccator and allowed to cool, after which it was reweighed. The moisture content was then calculated as shown below.

$$\text{Moisture } (\%) = \frac{W_1 - W_2}{Wl} \times 100$$

Where,
W_1 = weight (g) of sample before drying
W_2 = weight (g) of sample after drying

2.6. Water absorption determination

Water absorption capacity was determined by mixing 3.0 g of the sample with 20 ml of water in a previously weighed centrifuge tube. The mixture was shaken for 2 min on a vortex mixer and allowed to stand for 30 min at 25ºC. It was then centrifuged at 3000 rpm for 30 min and, the supernatant decanted. The gain in weight of the sediment was calculated and expressed as percentage (Bahir et al., 2016).

$$\text{WAC}(\%) = \frac{\textit{wet pellet weight}}{\textit{dry sample weight}} \times 100$$

2.7. Swelling power and solubility index determination

Swelling power was determined by using the method by Senanayake et al. (2013). Sample (1 g) was weighed into a previously weighed 40 ml capacity centrifuge tube and 40 ml of water added. To avoid rapturing the granules due to excess force, the suspension was stirred uniformly and gently and vortexed at low speed for 1 min. The suspension was then heated in a thermostatically controlled water bath at 85°C with constant stirring. The tubes were then removed and cooled to room temperature, and, centrifuged at 2200 rpm for 15 min. The supernatant was poured into a weighed crucible and evaporated to dryness in an oven at 105°C. The dried supernatant was weighed after cooling, and, weight of dried sample after cooling and was used to calculate the solubility index. For swelling power, the sediment paste obtained after centrifugation was used for the calculation as shown below;

$$\text{Solubility index} = \frac{\textit{wt of dried supernatant}}{\textit{wt of sample taken}} \times 100$$

$$\text{Swelling power} = \frac{\textit{wt of sedimented flour paste}}{\textit{wt of dry sample taken}} \times 100$$

2.8. Tapped bulk density

The tapped bulk density was determined by the method of Okezie and Bello (1988). An amount of 10 g of sample was weighed directly into 50 ml capacity graduated cylinder. The measuring cylinder together with the sample was tapped until no change in volume was observed and, the bulk density calculated using the equation below.

$$\text{Bulk density (gm/L)} = \frac{\textit{wt of sample}}{\textit{volume of sample after tapping}(mL)}$$

2.9. Pasting profile determination

The pasting properties were determined using the Rapid Visco Analyzer (RVA 4500, Perten Instrument, Australia) as described by Alamri et al. (2012) with modification in the holding time. About 3 g of yam starch or flour (14% moisture basis) was mixed in 25 g of water in a sample canister. Suspensions contained a total weight of 28.0 g. The sample was mixed thoroughly and fitted into the RVA with a programmed heating and cooling cycle. Samples were heated to and held at 50ºC for 1 min, heated to 95ºC at 6ºC/min and held for 1 min. This was followed by cooling to 50ºC with another 1 min holding time. Corresponding values for peak viscosity, trough viscosity (minimum viscosity at 95ºC), final viscosity (viscosity at 50ºC), breakdown viscosity and setback viscosity were read on a computer connected to the RVA.

2.10. Statistical analysis

Data were analyzed using single factor analysis of variance (ANOVA). The properties of both starch and, flours from the yam varieties were further analyzed by principal component analysis (PCA) to determine correlations using SPSS, (version 16). Standard deviations were calculated and the Pearson's chi-square test was employed to evaluate the statistical significance at $p < .05$.

3. Results and discussion

3.1. Chemical characteristics of *D. alata* and *D. rotundata* yam varieties

The composition of *D. alata* and *D. rotundata* varieties is reported in Table 1. The moisture content of the raw yam varieties varied. All the *D. rotundata* varieties ranged from 45.27% to 60.32% whilst *D. alata* ranged from 63.82% to 72.45%. The moisture contents determined in the study are in the range reported by Polycarp et al. (2012). For *D. rotundata* varieties, Alinnor and Akalezi (2010) reported 54.5% while 74.3% was achieved through the work of Wireko-Manu et al. (2013) for *D. alata* varieties. The slightly lower moisture of the *D. rotundata* varieties in the study show a potential lower rate of deterioration as higher moisture lead to fast deterioration of the yam.

The starch contents of local *D. alata* varieties were lower (14–16%) than *D. rotundata* (18.8–20.5%). Among CRI *D. alata* varieties, *ahodenfo, afase pa* and *afase biri* had low values of 14.6%, 12% and 14.8% respectively. *Soanyinto* (*D. alata*) however had 17.0% corresponding to starch content of CRI *pona* (*D. rotundata*). *Kukrupa* and *mankrong pona* had highest starch contents of 20.5% and 19.5%, respectively. Work done by

Table 1. Selected chemical characteristics of *D. alata and D. rotundata* yam varieties.

Tabla 1. Características químicas seleccionadas de las variedades de ñame *D. alata y D. rotundata.*

Sample	Species	Moisture of raw sample (%)	Starch content (%)	Amylose (%)	Amylopectin (%)
Akaba (L)	*D. alata*	66.00 ± 0.0^{f}	16.00 ± 0.02^{c}	17.98 ± 0.01^{c}	82.02 ± 0.01^{a}
Matches (L)	*D. alata*	70.82 ± 0.02^{h}	14.00 ± 0.05^{b}	18.07 ± 0.00^{c}	81.93 ± 0.00^{a}
CRI Afase ahodenfo	*D. alata*	72.45 ± 0.13^{i}	14.60 ± 0.1^{b}	20.79 ± 0.01^{d}	79.21 ± 0.01^{a}
CRI Afase pa	*D. alata*	68.02 ± 0.41^{g}	12.00 ± 0.03^{a}	13.70 ± 0.02^{a}	86.30 ± 0.02^{c}
CRI Afase soanyinto	*D. alata*	63.82 ± 0.09^{e}	17.00 ± 0.05^{d}	19.57 ± 0.01^{d}	80.43 ± 0.01^{a}
CRI Afase biri	*D. alata*	64.66 ± 0.30^{e}	14.80 ± 0.02^{b}	20.94 ± 0.01^{d}	79.06 ± 0.01^{a}
CRI Pona	*D. rotundata*	45.27 ± 0.06^{a}	17.00 ± 0.00^{d}	16.96 ± 0.00^{b}	$83.04 \pm 0.00^{a,b}$
CRI Kukrupa	*D. rotundata*	50.82 ± 0.01^{b}	$20.50 \pm 0.07^{f,g}$	14.43 ± 0.03^{a}	85.57 ± 0.03^{c}
CRI Mankrong pona	*D. rotundata*	55.10 ± 0.03^{c}	19.50 ± 0.10^{f}	16.97 ± 0.01^{b}	$83.03 \pm 0.01^{a,b}$
Pona (L)	*D. rotundata*	56.41 ± 0.50^{c}	20.00 ± 0.09^{f}	17.90 ± 0.00^{c}	82.10 ± 0.00^{a}
Serwaa (L)	*D. rotundata*	60.32 ± 0.08^{d}	18.80 ± 0.03^{e}	16.14 ± 0.01^{b}	$83.86 \pm 0.01^{a,b}$

The percent moisture, starch, amylose and amylopectin are represented. Mean values $n = (3)$ with different superscripts in the same column are significantly different at $p < .05$. L = local variety; CRI = Crops Research Institute variety.

Se presentan los porcentajes de humedad, almidón, amilosa y amilopectina. Los valores medios ($n = 3$) con distintos superíndices en la misma columna son significativamente diferentes ($p < .05$). L = variedad local; CRI = variedad del Crops Research Institute.

Afoakwa et al. (2013) on seven most consumed yams in Ghana show high starch contents 58.26–59.14%. The percent starch from these yams could result from the method of starch extraction (acid hydrolysis) or the varieties used. Riley et al. (2006) worked on in-vitro digestibility of starch and found that digestibility is enhanced for varieties with low amylose content.

For amylose, CRI *D. alata* varieties, *afase biri, soanyinto* and *ahodenfo* with 20.79%, 20.94% and 19.57% respectively had no significant differences at $p < 0.05$ among them. These values were higher than the local *D. alata* varieties. CRI *D. rotundata, pona* and *mankrong pona* had same amylose content of approximately 17% (Table 1). Amylose content of many yam species have been quantified to range from 1.4% to 50% (Pérez et al., 2011) while varieties specific to Ghana have 9.22–21.66% (Afoakwa et al., 2013). The results from the study are in the range of the reported values since the maximum value was 20.94%. CRI *D. alata* varieties (*ahodenfo*, *soanyinto* and *afase biri*) had slightly higher amylose than local varieties. Although Otegbayo et al. (2012) reported significantly higher amylose content for *D. alata* varieties compared to *D. rotundata*, the findings of this study is different as some *D. rotundata* varieties had higher values than *D. alata* varieties (Table 1). These variations in amylose content could be linked to the botanical source, climatic conditions and soil type during growth (Okunlola & Odeku, 2011).

The amylopectin content for CRI *D. alata* ranged from 79.06% to 86.3% while counterpart local varieties had 81.93% and 82.02% for *matches* and *akaba* respectfully. Only CRI *afase pa* differed significantly from the local varieties. The CRI *D. rotundata* ranged from 83.03% to 85.57% and the local varieties had 82.10% and 83.86% for *pona* and *serwaa*, respectively. CRI *kukrupa* had highest amylopectin and significantly differed from counterpart local varieties. The high amylopectin content of *kukrupa* could be due to its biochemical nature. Varieties with high amylopectin contents like CRI *afase pa* (86.30%) and, CRI *kukrupa* (85.57%) could be useful in the manufacture of extrudates since it will result in extrudates with higher expansion (Okunlola & Odeku, 2011).

3.2. Functional properties of starch and flour

The functional properties of starch and flour from the yam varieties are reported in Table 2. The water absorption capacity (WAC) ranged from 296.0% to 396.58% for the flours and 230.0–369.0% for the starches. According to Kannadhason and Muthukumarappan (2010) water absorption capacity (WAC) is important to consider in bulking and consistency of products, especially in baking applications. The starches with relatively high amylose content (CRI *afase ahodenfo*, *afase soanyinto* and *afase biri*) had relatively high WAC. These starches may produce stiffness in food products as reported by Biduski et al. (2018) who found that samples with high amylose content had greater stiffness in hydrogels. CRI *afase pa* and *kukrupa* with high amylopectin (86%, 85% respectively) had high WAC of 329% and 368%, respectively. The differences observed in these two varieties could be due to the type of amylopectin structure present in both varieties (Vamadevan & Bertoft, 2020).

The bulk densities of *D. rotundata* flours (0.81–0.86 g/cm^3) were slightly higher than *D. alata* (0.75–0.81 g/cm^3) flours. Generally, the starches had higher bulk densities (0.89–1.13 g/cm^3) than the flours. According to Chandra et al. (2015) bulk density depends on particle size. Hence, the high bulk densities of the starches suggest that they are denser than the flours (Du et al., 2014). This indicates their suitability and stability for use in various food products. Work done by Kumar and Saini (2016) indicates that when flours with low density are used in formulations they will not show any significant decrease (p > .05) during storage. Complementary foods would also benefit from the use of low bulk density flours (Akpata & Akubor, 1999).

The swelling power (SP) for all the flour samples was significantly different (p < .05), except CRI *D. alata* varieties, *afase soanyinto* and *afase biri* which recorded no differences. The highest value for the starches was 981% for CRI *D. alata*, *afase soanyinto* and least value of 877% for *D. alata, akaba*. The swelling ability of starches or flours is important in many food applications as it measures its ability to imbibe water (Aidoo et al., 2022). The high SP of all the CRI flour samples show that they can be employed in foods requiring high swelling. The observed high SP in some *D. alata* starches contrasts the findings by Niba et al. (2002) who established that *D. rotundata* yam starch has high swelling power than *D. alata*. This could be due to the amylose contents of the starches under study.

Table 2. Functional properties of starch and flour from local and CRI yam varieties.

Tabla 2. Propiedades funcionales del almidón y la harina de las variedades de ñame locales y del CRI.

		Bulk density (g/cm^3)		WAC (%)		Swelling power (SP) (%)		Solubility index (%)	
Sample	Species	Flour	Starch	Flour	Starch	Flour	Starch	Flour	Starch
Akaba (L)	*D. alata*	0.80 ± 0.01^{a}	0.96 ± 0.01^{b}	$396.58 \pm 0.3^{f,g}$	246 ± 1.00^{c}	877 ± 0.03^{a}	$887 \pm 0.01^{b,c}$	7.08 ± 0.02^{a}	0.96 ± 0.00^{g}
Matches (L)	*D. alata*	0.80 ± 0.01^{a}	0.89 ± 0.02^{a}	298.3 ± 1.90^{b}	230 ± 2.10^{a}	927 ± 0.01^{c}	844 ± 0.11^{b}	$8.36 \pm 0.01^{c,d}$	1.40 ± 0.21^{d}
CRI afase ahodenfo	*D. alata*	0.75 ± 0.00^{a}	0.91 ± 0.10^{a}	385 ± 0.80^{e}	337 ± 0.84^{b}	965 ± 0.05^{e}	981 ± 0.24^{e}	9.55 ± 0.00^{f}	1.5 ± 0.00^{d}
CRI afase pa	*D. alata*	0.80 ± 1.2^{a}	0.90 ± 0.01^{a}	$397.0 \pm 0.33^{f,g}$	329 ± 0.30^{f}	940 ± 0.02^{d}	822 ± 0.02^{b}	7.29 ± 0.02^{b}	1.28 ± 0.2^{d}
CRI afase soanyinto	*D. alata*	0.87 ± 0.02^{a}	1.13 ± 0.02^{b}	$397.0 \pm 2.00^{f,g}$	360 ± 0.21^{i}	981 ± 0.01^{f}	824 ± 0.03^{b}	10.55 ± 0.01^{g}	1.80 ± 0.00^{e}
CRI afase biri	*D. alata*	0.79 ± 0.02^{a}	0.88 ± 0.00^{a}	377.0 ± 1.80^{d}	369 ± 0.28^{j}	950 ± 0.04^{e}	684 ± 0.02^{a}	8.16 ± 0.00^{c}	2.59 ± 0.00^{f}
CRI pona	*D. rotundata*	0.81 ± 0.9^{a}	0.95 ± 0.02^{b}	296.0 ± 0.50^{a}	250 ± 0.02^{d}	901 ± 0.02^{b}	922 ± 0.00^{d}	8.56 ± 0.00^{d}	$1.22 \pm 0.00^{c,d}$
CRI kukrupa	*D. rotundata*	0.86 ± 0.63^{b}	0.87 ± 0.02^{a}	392.0 ± 0.70^{f}	368 ± 0.22^{j}	892 ± 0.06^{a}	880 ± 0.03^{c}	10.54 ± 0.02^{g}	1.08 ± 0.00^{c}
CRI Mankrong pona	*D. rotundata*	0.82 ± 0.5^{a}	0.91 ± 0.04^{a}	371.0 ± 0.35^{d}	355 ± 0.20^{h}	930 ± 0.1^{c}	853 ± 0.03^{b}	8.27 ± 0.01^{c}	0.16 ± 0.00^{b}
Pona (L)	*D. rotundata*	0.86 ± 0.02^{b}	0.89 ± 0.07^{a}	364.0 ± 0.22^{c}	325 ± 0.32^{e}	878 ± 0.05^{a}	845 ± 0.02^{b}	8.98 ± 0.00^{e}	0.02 ± 0.00^{a}
Serwaa (L)	*D. rotundata*	0.86 ± 0.08^{b}	0.91 ± 0.03^{a}	387.0 ± 0.30^{e}	350 ± 0.20^{g}	948 ± 0.03^{d}	804 ± 0.04^{b}	8.59 ± 0.00^{d}	0.85 ± 0.00^{c}

Functional properties of starches and flours are shown for each yam variety. WAC, water absorption capacity, Mean values (n = 2) with different superscripts in the same column are significantly different at $P < .05$. L-local variety; CRI- Crops Research Institute variety.

Se presentan las propiedades funcionales de los almidones y las harinas para cada variedad de ñame. WAC, capacidad de absorción de agua. Los valores medios (n = 2) con distintos superíndices en la misma columna son significativamente diferentes ($P < .05$). L- variedad local; CRI- variedad del Crops Research Institute.

The solubility index of flours were generally higher than the starches. Among the flours, the highest value obtained was 10.55% for *afase biri* (*D. alata*) and least was 7.29% for *afase pa* (*D. alata*). Values for *D. rotundata* ranged from 8.27% to 8.98%. For the flour, lower values (0.02–1.08%) were recorded for all the *D. rotundata* varieties compared to the *D. alata* with high values (0.96–2.59%). High swelling power usually gives a correspondingly low solubility index as previously reported (Aidoo et al., 2022). High solubility index has been attributed to easy solubility of amylose which is loosely linked with the rest of the molecular structure and leaches out during the swelling process. However, flours contain more water absorbing molecules (including proteins and other carbohydrates) than the starch. The amylose and amylopectin ratio of the flour/starches also influence its swelling and solubility whereby the stronger intermolecular interaction and higher hydrophocity accounts greatly for greater swelling power and lower solubility (Aidoo et al., 2022; Oko et al., 2013).

3.3. Principal component analysis (PCA) of chemical and functional properties

The correlation analyses from the PCA showed associations existing between bulk density and amylopectin; moisture and swelling power; solubility index with amylopectin; swelling power and total starch content; but were non-significant ($p > .05$). The only significant correlation was the total starch content against bulk density ($p = .013$). Bulk density, a good index of structural changes (Sreerama et al., 2009) indicates the weight of a volume unit of powder expressed in g/cm^3 or g/100 g. CRI *afase soanyinto* had highest bulk density of 1.13 g/cm^3 making it desirable for reducing packaging and shipping costs (Haohan et al., 2020). CRI *afase biri* and *kukrupa* (*D. alata* and *D. rotundata*) respectively with lower bulk density of 0.88 and 0.87 g/cm^3 however can influence flowability and instant characteristics of products made from them according to Haohan et al. (2020). A significant negative correlation (r = 1.00) was also found between amylose and amylopectin ($p < .05$). This is because, amylopectin aids swelling while amylose acts as a diluent (Kumar & Khatkar, 2017).

The location of the varieties in the multivariate space of two principal component score vectors is shown in Figure 1. Three groups were identified by PCA to characterize the yam varieties. First, group 1 consists of *D. alata* varieties; two local and one CRI variety. These varieties are associated with high moisture content. From the graph, members of group 2 are all CRI *D. alata* varieties and are characterized by similar amylose contents. However, *afase soanyinto* may vary in characteristics compared to *ahodenfo* and *afase biri* due to the distance from these two varieties. This may be explained by the high starch content (17%) of *afase soanyinto* compared to 14.6% and 14.8% for *ahodenfo* and *afase biri*, respectively. High moisture varieties may be suitable for pudding while varieties with comparatively high amylose (CRI *D. alata ahodenfo*, *soanyinto* and *afase biri*) could be used for gluten-free food recipes for celiac disease patients. This is because high levels of amylose starches are characterized by slower rate of digestion Giuberti et al. (2016). Group 3 has both local and CRI *D. rotundata* varieties and are characterized by high starch content, bulk density and WAC.

3.4. Starch and flour pasting properties

The peak viscosity indicates the highest viscosity which can be reached in the preparation of starch paste. For starches (Table 3), the peak viscosities of *D. alata* varieties were 2527–4415 cP whereas *D. rotundata* were from 3345–4393cP. Values for the flour also show a similar trend (Table 4). Generally, the starches had high values of peak than flours. The low starch contents in the flour compared to the pure starches, and the presence of proteins and lipids may have restricted starch granule swelling as suggested by Moorthy et al. (2018). The peak viscosity is often correlated with the final product quality and provides an indication of the viscous load likely to be encountered during mixing (Maziya-Dixon et al., 2007). Overall, the starch of *afase ahodenfo* and

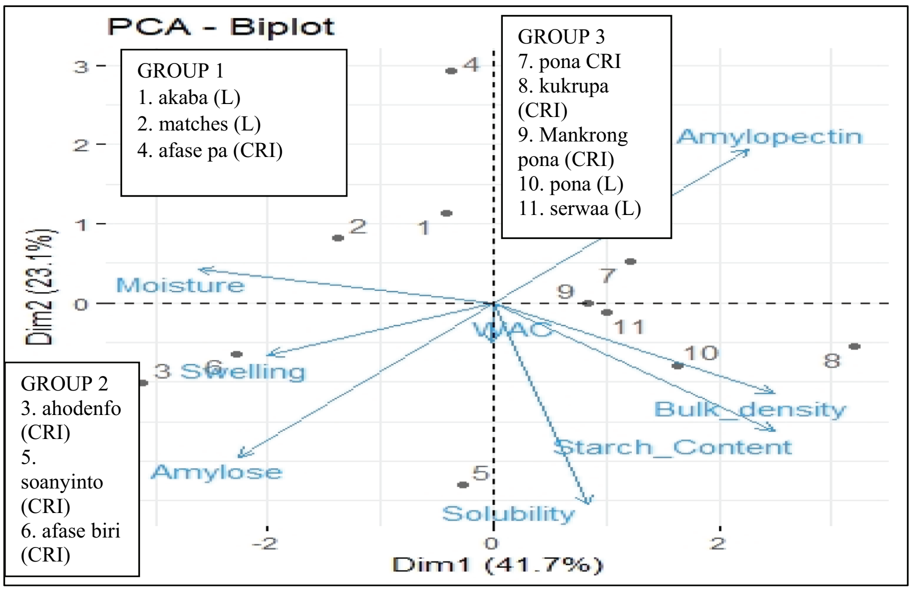

Figure 1. Biplot of the principal component analysis (PCA) of chemical and functional properties of local (L) and CRI yam varieties.

Figura 1. Biplot del análisis de componentes principales (PCA) de las propiedades químicas y funcionales de las variedades de ñame locales (L) y del CRI.

Table 3. Starch pasting characteristics of *D. alata and D. rotundata* yam varieties.

Tabla 3. Características de pegado del almidón de las variedades de ñame D. alata y *D. rotundata.*

Variety	Species	PV (cP)	Trough (cP)	Breakdown (cP)	Final viscosity(cP)	Setback(cP)	Peak time(min)	Pasting temp. (^{0}C)
Akaba (L)	*D. alata*	2527 ± 1.00^a	2123 ± 0.05^a	404 ± 0.08^b	3024 ± 1.00^c	901 ± 1.00^i	5.13 ± 0.02^b	$84.85^d \pm 0.09$
Matches(L)	*D. alata*	3599 ± 0.09^g	2332 ± 0.01^b	228 ± 0.04^a	2560 ± 0.08^b	806 ± 0.01^h	9.13 ± 1.00^d	$79.1 \pm .08^b$
CRI ahodenfo	*D. alata*	3099 ± 0.01^b	2933 ± 0.06^g	1411 ± 0.01^h	3411 ± 0.06^i	423 ± 0.03^c	4.73 ± 0.09^a	50.25 ± 0.01^a
CRI afase pa	*D. alata*	3542 ± 0.05^e	2738 ± 0.09^d	526 ± 0.04^e	3264 ± 1.00^f	361 ± 0.09^b	5.4 ± 0.02^b	83.2 ± 1.00^c
CRI soanyinto	*D. alata*	4399 ± 1.00^i	2787 ± 0.01^e	1628 ± 0.05^i	4415 ± 1.00^k	812 ± 0.01^g	4.8 ± 0.08^a	79.9 ± 0.03^b
CRI afase biri	*D. alata*	4017 ± 1.00^f	4394 ± 1.00^j	686 ± 0.05^f	3331 ± 0.06^g	1063 ± 0.01^j	5.73 ± 0.00^c	84.05 ± 0.07^d
CRI pona	*D. rotundata*	4393 ± 0.01^h	3025 ± 0.09^g	517 ± 0.01^d	3386 ± 0.08^h	361 ± 0.03^b	5.27 ± 0.06^b	83.2 ± 0.09^c
CRI kukrupa	*D. rotundata*	3317 ± 1.00^c	2614 ± 0.08^c	1783 ± 0.06^j	3255 ± 0.02^e	641 ± 1.00^f	4.67 ± 0.04^a	79.95 ± 1.00^b
CRI Mankrong pona	*D. rotundata*	3690 ± 1.00^g	2826 ± 0.01^f	864 ± 0.07^g	3690 ± 1.00^j	490 ± 0.03^d	5.28 ± 0.00^b	$83.4 \pm 0.01^{b,c}$
Pona (L)	*D. rotundata*	3345 ± 0.01^d	3345 ± 0.05^h	498 ± 1.00^c	3086 ± 0.03^d	300 ± 0.09^a	5 ± 0.00^b	78.9 ± 0.07^b
Serwaa (L)	*D. rotundata*	4041 ± 0.01^f	4041 ± 0.00^i	1628 ± 1.00^k	2929 ± 0.06^a	516 ± 0.05^e	4.6 ± 1.00^a	84.1 ± 0.00^d

PV, peak viscosity, Mean values (n = 2) with different superscripts in the same column are significantly different at $p < .05$. L-local variety; CRI- Crops Research Institute variety.

PV, viscosidad máxima. Los valores medios (n = 2) con distintos superíndices en la misma columna son significativamente diferentes ($p < .05$). L- variedad local; CRI- variedad del Crops Research Institute.

Table 4. Flour pasting properties of *D. alata and D. rotundata* yam varieties.

Tabla 4. Propiedades de pegado de la harina de las variedades de ñame *D. alata y D. rotundata.*

Variety	Species	PV (cP)	Trough (cP)	Breakdown (cP)	Final viscosity (cP)	Setback (cP)	Peak time (min)	Pasting temp. (ºC)
Akaba (L)	*D. alata*	2120 ± 1.00^j	142 ± 0.03^i	2265 ± 0.09^i	2387 ± 0.00^i	287 ± 0.04^e	6.8 ± 0.09^b	86.5 ± 0.06^c
Matches (L)	*D. alata*	1958 ± 0.09^h	89 ± 1.00^g	2263 ± 0.05^i	2394 ± 0.09^j	394 ± 1.00^h	7 ± 0.01^b	84.85 ± 0.06^b
CRI ahodenfo	*D. alata*	1422 ± 0.06^e	52 ± 0.01^b	1555 ± 0.04^e	1845 ± 0.07^f	185 ± 1.00^d	6.9 ± 0.07^b	86.35 ± 0.02^c
CRI afase pa	*D. alata*	633 ± 0.01^a	74 ± 0.08^d	736 ± 0.00^a	277 ± 1.00^a	177 ± 0.08^b	7 ± 1.00^b	90.45 ± 0.05^c
CRI soanyinto	*D. alata*	1510 ± 0.09^g	70 ± 0.05^c	1626 ± 0.01^g	1806 ± 1.00^e	186 ± 0.05^d	7 ± 0.06^b	85.55 ± 0.02^c
CRI afase biri	*D. alata*	1272 ± 0.00^c	84 ± 0.08^f	1362 ± 0.06^b	1471 ± 1.00^d	171 ± 0.01^a	7 ± 0.00^b	85.65 ± 0.09^c
CRI pona	*D. rotundata*	1495 ± 1.00^f	88 ± 0.00^h	1594 ± 0.05^f	$1837 \pm 0.09^{e,f}$	187 ± 0.01^c	7 ± 0.08^b	84.85 ± 1.00^b
CRI kukrupa	*D. rotundata*	1289 ± 0.06^b	182 ± 0.01^j	1402 ± 0.09^c	1295 ± 1.00^c	295 ± 0.07^g	7 ± 0.02^b	83.1 ± 0.09^a
CRI Mankrong pona	*D. rotundata*	1604 ± 1.00^g	24 ± 0.03^a	1843 ± 0.01^h	2063 ± 0.06^g	263 ± 0.08^f	6.8 ± 0.04^b	85.15 ± 0.09^c
Pona (L)	*D. rotundata*	1401 ± 1.00^d	80 ± 0.00^e	1494 ± 0.07^d	1177 ± 0.09^b	177 ± 0.1^b	6.87 ± 0.03^b	84 ± 0.00^b
Serwaa (L)	*D. rotundata*	2054 ± 0.00^i	134 ± 0.03^g	2342 ± 0.04^j	2422 ± 0.09^h	422 ± 0.00^i	5 ± 0.01^a	84.5 ± 0.00^b

PV, pasting viscosity, Mean values (n = 2) with different superscripts in the same column are significantly different at $p < .05$. L-local variety; CRI- Crops Research Institute variety.

PV, viscosidad de pegado, Los valores medios (n = 2) con distintos superíndices en la misma columna son significativamente diferentes ($p < .05$). L- v.

kukrupa possesses high tendency of forming thicker pastes on cooking.

The trough is the ability of granules to remain undisrupted when starch is subjected to a period of constant high temperature and mechanical shear stress. Among all the starch samples, CRI *afase biri* possesses the ability to withstand high temperature and, long duration processing. For the flours, *Mankrong pona* and *afase soanyinto* will be valuable in terms of long duration processing. Breakdown for local varieties (Table 3) were generally low (228–498 cP) except serwaa (*D. rotundata*) which had a high value of 1628 cP. The breakdown establishes the difference between peak and trough viscosity and shows how stable the starch paste is during heating (Otegbayo et al., 2014). Starches of CRI *Kukrupa*, *ahodenfo*, and *soanyinto* with high values (1783, 1411, 1628 cP) respectively may be associated with low stability (Sandhu & Singh, 2007). The local *D. alata* varieties however had very low values (228, 404 cP), making them more stable than the new varieties.

CRI *D. rotundata* flours had higher setback values (187–263 cP) than *D. alata* varieties (171–186 cP). However, no specific trend is detected for the starches. For starch, CRI *afase biri* had extremely high setback value of 1063cP. All other varieties ranged from 300 to 901 cP. This variety would be less stable during processing as lower setback values depict stability (Sandhu & Singh, 2007). Thus, the starches of CRI *afase pa* and, CRI pona with same low setback value of 361 cP would be most stable for processing.

Peak temperature is essential in the selection of starches for industrial processing. The pasting temperatures of all the starches (78–84.1ºC) and flours (83.1–90.45ºC) show that they all form paste below boiling temperature which will be beneficial for commercial applications due to energy savings. However, flour of CRI *afase pa* with the highest pasting temperature (90.45ºC) may not be recommended for industrial processing. These values are within the range obtained by Wahab et al. (2016).

Generally, the peak time for all the starches (4.6–5.73 min) were lower than the flours (5–7 min) except *D. alata* local variety, *akaba* which had a high peak time of 9.13 min. Starches with shorter pasting time such as CRI *afase pa*, *soanyinto* and *kukrupa* may be suitable for the production of foods that require shorter processing time, such as puddings. For such products, starch could be pre-gelatinized to achieve thickening or water retention which would require little or no heat (MTPS, 2012).With a peak time of averagely 7 min for all the flours, the results align with the work done by (Olumurewa et al., 2019). The variations in the pasting properties for the same species could be due to the amylose/amylopectin ration and presence of substances such as lipids and proteins.

4. Conclusion

The study has demonstrated diversity in the chemical, functional and pasting characteristics of the different varieties of yams released by the CRI, Ghana. The categorization of the varieties into moisture, amylose content and those with high total starch content by the PCA summarizes their usefulness for industrial purposes. It is evident form the work that the new CRI varieties could be utilized for various industrial applications and have comparatively better commercial potential than counterpart local varieties on the basis of their chemical, functional and pasting properties. Their use in food and pharmaceutical industries is therefore recommended.

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