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*Corresponding author: C. Tortoe, Council for Scientific and Industrial Research-Food Research Institute, P. O. Box M20, Accra, Ghana
E-mail: ctortoe@yahoo.co.uk

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FOOD SCIENCE & TECHNOLOGY | RESEARCH ARTICLE

Examining the physicochemical, functional and rheological properties in flours of farmers' 7 key yam (*Dioscorea* spp.) varieties in Ghana to enhance yam production

C. Tortoe[1*], S. Dowuona[1], P.T. Akonor[1] and N.T. Dziedzoave[1]

Abstract: Yam (*Dioscorea* spp.) is an important tuber crop in Ghana with high industrial potential. However the suitability of some yam varieties for diverse culinary and industrial purposes have not been widely studied to inform in their production. This study determined the physicochemical, functional and pasting characteristics in flours of farmers' 7 key varieties of *Dioscorea rotundata* (white yam) and *Dioscorea alata* (water yam). Colour, pH, proximate composition, solubility index, swelling power and pasting properties were determined. Flours from the yam varieties were light in colour and fairly neutral in pH (6.3–6.6). Crude protein levels were between 3.7% for *matches* and 5.9% *Serwah* varieties, whereas crude fat was less than 0.5% and the mean ash content was 2.1%. Although significant differences existed between the flours, no clear trend was established to differentiate between *D. rotundata* and *D. alata* varieties based on their proximate composition. Swelling power (SP), solubility index (SI) and water absorption capacity (WAC) of the flours differed clearly. *D. rotundata* varieties had a relatively higher SP (12.5%) and WAC (7.1%), whereas *D. alata* (20.1%) had the highest SI. Significant differences ($p < 0.05$) in pasting behaviour were observed. Apart from *Serwah* and *Mutwumudoo* varieties, higher peak viscosity and positive retrogradation tendency were observed in the *D. rotundata* varieties. Among the 7 varieties, pastes from *Akaba* and *Pona* varieties were the most stable. The study has revealed that the properties of these varieties of Ghanaian yams make them suitable in diverse culinary and industrial applications.

ABOUT THE AUTHOR

C. Tortoe is a middle career scientist of the Council for Scientific and Industrial Research-Food Research Institute, Accra, Ghana. His research areas are food processing and perseveration technology, physicochemical, nutritional, functional and rheological behavior, value addition and value chains of food commodities as well as development of new food products.

PUBLIC INTEREST STATEMENT

Yam (*Discorea* spp.) is a tropical crop with diverse uses. However, studies on the suitability of some varieties for diverse culinary and industrial purposes are limited to inform in their production. This study explore the physicochemical, functional and pasting characteristics of the flours of farmers' 7 key varieties of *Dioscorea rotundata* (white yam) and *Dioscorea alata* (water yam). Key findings on colour, pH, proximate composition, solubility index, swelling power and pasting properties are reported herein. Clear variations in the physicochemical, nutritional and functional properties of the flours are reported. The properties of the flours studied revealed the yam varieties suitability for diverse culinary and industrial applications, thus providing informing on their choice for production.

Subjects: General Science; Nutrition; Food Engineering

Keywords: yam; physicochemical; functional; rheological properties; production

1. Introduction

Yam belongs to the genus *Dioscorea* and consist of more than 600 species. However, only a few are grown and utilized as a staple. In the West African yam zones, white yam (*Dioscorea rotundata*), water yam (*Dioscorea alata*) and yellow yam (*Dioscorea cayenensis*) are the most common species (Aidoo, 2009). Other species of yams grown include the trifoliate yam (*Dioscorea dumetorum*) and aerial/bulbils yam (*Dioscorea bulbifera*). Yam is a major source of income for farmers and traders, and it plays a pivotal role in the socio-cultural lives of both growers and consumers. The importance of yams to Ghanaians is evidenced by the fact that, consistently over the last decade, cropped area and production levels have continually increased (SRID, 2015). In 2014, more than 7 million MT of yam was produced over an area of 420,000 hectares (SRID, 2015). The main production centers in Ghana are Brong Ahafo, Northern and Eastern Regions. Recent data estimates the per capita consumption of yam per annum as 42 kg (SRID, 2015).

Interestingly, in the commercialization and industrialization of an agricultural commodity, there is the need for the presence of some unique properties, which are absent from other commodities and the stable shelf-life of fresh or value added products of these commodities. Yam is among such agricultural commodities with bioactve compounds and shelf-stable ability for commercialization and industrialization. Yam contain amounts of phenolic compounds, alkaloids and diosgenin, a steroid saponin with probably anti-cancer and anti-inflammatory effect (Green & Simons, 1994; Mishra, Mishra, & Ruth, 1989), and play a role in reducing diabetes and obesity in humans (Kwon et al., 2003). According to Osunde (2008), the chemical composition of yam is characterized by high moisture and dry matter mainly of carbohydrates. Starch, which makes up a bulk of the carbohydrates is frequently converted into sugars resulting in its typical sweet taste. In studies reported by Opara (1999), yam contains good amount of vitamin C, minerals, dietary fiber and proteins, compared to other root and tuber crops. Additionally, yam has numerous health benefits such as vitamin B6, vitamin E, potassium, manganese, carbohydrate and fibers that form key ingredients for health and vitality products (FAO, 1985).

White yam (*D. rotundata*) and water yam (*D. alata*) are the two most important varieties cultivated in Ghana. Whereas white yam accounts for over 80% of yams planted and is the most preferred, water yam, which is high-yielding and stores longer, is not economically competitive. There are several landraces of these two varieties with high culinary and socio-cultural significance in most yam growing areas. These included *Pona, Dente, Punjo, Asana*, which are *D. rotundata* varieties and *Matches, Akaba,* and *Apoka*, which belong to *D. alata*. Other species of yam cultivated in Ghana included yellow yam (*D. cayensis*), Chinese yam (*Dioscorea esculenta*), aerial yam (*D. bulbifera*) and trifoliate yam (*D. domentorum*).

In order to reduce postharvest losses of food crops and ultimately enhance food security in Africa, there is a drift towards a paradigm of value-addition to food crops. Yam utilization in Ghana is narrow and skewed towards food applications. It is usually processed into boiled, fried, pounded, roasted or mashed food forms. Its potential for industrial application, such as the production of beverages, ice cream, cosmetic and pharmaceutical products, largely remain untapped. This situation may be partly attributed to the fact that the physicochemical, functional and rheological behavior of many varieties of Ghanaian yams have not been characterized.

Some previous studies have elucidated the properties of certain underutilized yam varieties in Ghana, including *D. dometorum* (Afoakwa & Sefa-Dedeh, 2001), improved varieties of *D. alata* (Wireko-Manu, Ellis, Oduro, Asiedu, & Maziya-Dixon, 2011) and *D. bulbifera* (Sanful, Oduro, & Ellis, 2013). However, the functional and rheological properties of some key varieties of *D. rotundata* and *D. alata* still remain unknown. In order to expand the utilization yam, this study was conducted to evaluate the physicochemical, functional and rheological behaviour in flours of farmers' 7 key yam varieties of *D. rotundata* and *D. alata*.

2. Methodology

2.1. Yam varieties

Different varieties of fully matured Ghanaian white yam (*Pona*, *Lariboko*, *Dente*, *Mutwumudoo*, and *Serwah*) and water yam (*Akaba* and *Matches*) were used in this study (Table 1). The selection of the farmers' 7 key yam varieties of *D. rotundata* and *D. alata* was based on previous studies reported by Tortoe, Dowuona, and Dziedzoave (2014). Samples of these yam varieties were obtained directly from farms in Atebubu-Amantin District of Brong Ahafo, in Ghana in September, 2014 and identified by Extension Officers of the Ministry of Food and Agriculture (MoFA).

2.1.1. Preparation of flour from yam

Fresh yam tubers were cleaned, washed several times with clean water to remove adhering sand particles. The tips of each tuber (1 cm) was cut off and the remaining section peeled manually using stainless steel knife. The peeled tubers were washed several times with potable water before slicing under water to prevent browning. The slices were spread in a single layer on drying trays and dried at 60 °C for 12 h in a thermostat controlled mechanical dryer (Apex, England). Dried yam slices were milled into flour using a hammer mill to pass through a 250 μm sieve (Tortoe et al., 2014). Yam flour was then packaged into polypropylene bags and sealed.

2.2. Physicochemical properties of flour

2.2.1. Colour

Colour was determined using a Minolta Chroma meter (CR-310 Minolta, Japan). The device was calibrated with a reference white porcelain tile ($L_0 = 97.63$, $a_0 = 0.31$ and $b_0 = 4.63$) before the determinations. Colour of the flours was described in L^* a^* b^* notation, where L^* is a measure of lightness, a^* defines components on the red-green axis and b^* defines components on the yellow-blue axis. All determinations were done in triplicates.

2.2.2. Proximate composition

Moisture, crude protein, crude fat and ash were determined by approved methods of the AOAC International (Association of Official Analytical Chemists [AOAC], 2000) and carbohydrate was estimated by difference.

2.2.3. pH

The pH of the flours were determined using approved methods of the Association of Official Analytical Chemists (AOAC, 2000).

Table 1. Physical characteristics of 7 key yam varieties of farmers'

Yam variety (local name)	Species	Shape
Pona	*Dioscorea rotundata*	Elongated with thick, rough, hairy skin
Lariboko	*Dioscorea rotundata*	Elongated with thin skin
Dente	*Dioscorea rotundata*	Elongated with smooth skin
Mutwumudoo	*Dioscorea rotundata*	Elongated with head protruding out, thin skin
Serwah	*Dioscorea rotundata*	Elongated with head curved inward, thin smooth skin
Akaba	*Dioscorea alata*	Elongated, thick skin with spikes
Matches	*Dioscorea alata*	Elongated, thick skin with spikes

2.3. Functional properties of flour

The method described by Afoakwa, Budu, Asiedu, Chiwona-Karltun, and Nyirenda (2012) was used to determine the water absorption capacity (WAC) of the flours at 30 °C, swelling power (SP) and solubility index (SI). SP and SI were respectively calculated as:

$$SP = \frac{\text{wt of precipitated paste}\,(W_p)}{\text{wt of sample}\,(W_o)} - \text{wt of residue in supernatant}\,(W_r)$$

$$SI = \frac{\text{wt of residue in supernatant}\,(W_r)}{\text{wt of sample}\,(W_o)} \times 100$$

where W_o is the weight of sample

2.4. Rheological behaviour of flour

The pasting properties of the yam flours were determined on an 8% slurry of flour using a Brabender Visco-amylograph (Viskograph-E, Brabender Instrument Inc., Duisburg, Germany) equipped with a 1000cmg sensitivity cartridge. The slurry was heated from 50 to 95 °C at a rate of 1.5 °C/min, held at this temperature for 15 min, cooled to 50 °C at a rate of 1.5 °C/min and held at this temperature for 15 min. Viscosity profile indices recorded were pasting temperature, peak viscosity, viscosity at 95 °C, viscosity after 30 min hold at 95 (95 °C-hold), viscosity at 50 °C and viscosity after 15 min hold at 50 °C (50 °C-hold), breakdown and setback.

2.5. Statistical analysis

All determinations were done in triplicate and data generated were analyzed using ANOVA, and significantly different means separated by Duncan's Multiple Range Tests (SPSS 17.0.1, SPSS Inc.). Statistical significance was set at a level of 95% confidence interval. Results were reported as mean ± SE.

3. Results and discussion

3.1. Physicochemical parameters

3.1.1. Colour parameters

The L^* value, which is an indicator of whiteness or lightness, ranged between 86.1–91.8 for *D. rotundata* varieties and 89.3–90.9 for the *D. alata* varieties (Table 2). Lightness of flours was affected by browning reactions, which occur during its processing (Van Hal, 2000), and this may have extensively affected *Lariboko* and reduced its lightness. Redness/greenness index ranged from −3.3 to 1.7. Although significant differences ($p < 0.05$) occurred in this colour component, there was no trend that clearly distinguished the *D. rotundata* from *D. alata* cultivars, based on this index alone. The b^* value of flours observed for varieties of *D. rotundata* appeared more yellowish than the varieties of

Table 2. Colour components of yam flour

Variety	L^*	a^*	b^*
Pona	90.53 ± 0.03^c	-3.27 ± 0.01^a	7.65 ± 0.02^d
Lariboko	86.06 ± 0.15^a	-1.70 ± 0.16^b	6.38 ± 0.12^b
Dente	91.76 ± 0.15^d	-2.16 ± 0.19^b	6.52 ± 0.14^b
Mutwumudoo	90.53 ± 0.14^c	-1.87 ± 0.41^b	7.07 ± 0.13^c
Serwah	90.82 ± 0.14^c	-2.86 ± 0.18^a	8.39 ± 0.13^e
Akaba	89.34 ± 0.11^b	-2.28 ± 0.12^b	5.80 ± 0.10^a
Matches	90.85 ± 0.03^c	-1.70 ± 0.02^b	6.06 ± 0.02^b

Note: Means with same superscript along a column are not significantly different ($p > 0.05$).
*Colour notations.

D. alata. *Serwah* recorded the highest b^* value of 8.4 while *Akaba* had the lowest (5.8). Apart from the inherent colour pigments present in yams, yellowness in yam flours has also been linked to total phenol content and the activity of polyphenoloxidase (Akissoé, Hounhouigan, Mestres, and Nago, 2003). As observed in the other tristimulus colour parameters, significant differences ($p < 0.05$) occurred within the b^* values of the flours. Overall, flour made from variety *Dente* was the whitest ($L = 91.8$) and will therefore be preferred in application (as in white bread) where white flours are desirable.

3.1.2. Proximate chemical composition

Protein in the different varieties was substantial and ranged from 3.7% for *Matches*, to 5.9% for *Serwah* (Table 3). Although this range is comparable to observations made in previous studies, some varieties had lower protein than earlier reported. Further, *Pona*, *Lariboko*, *Akaba* and *Matches* had lower protein levels than what was reported by Polycarp, Afoakwa, Budu, and Otoo (2012), for these same varieties. Some studies have also reported higher protein levels in *D. alata* than *D. rotundata*. The protein levels suggest that white yams and water yams are not poor in protein, although the levels observed were not necessarily associated with protein quality.

No significant differences ($p > 0.05$) were recorded in the crude fat content of the yams (Table 3). The levels of fat in this study ranged from 0.2 to 0.5%, which was comparable to the range of 0.1–0.4% observed for yams by Opara (2003). However, the values obtained, for both *D. rotundata* and *D. alata* varieties, were comparatively lower than those reported by Polycarp et al. (2012) and Lebot, Malapa, Molisale, and Marchand (2006) for some yam varieties belonging to *D. rotundata*. Interestingly, the low fat content of yams makes it a healthier choice of food, as perceived by consumers, especially in relation to cardio-vascular diseases. Ash, which reflects the mineral content in food, differed significantly ($p < 0.05$) among the varieties and was highest in *Akaba* (2.73%), and *Serwah* (2.70%) (Table 3). The levels of ash in these varieties indicated that they could serve as a fairly good source of dietary minerals. Carbohydrate levels in all the yam varieties were more than 90% and affirms the fact that yams are a valuable source of dietary carbohydrates. Although the differences between carbohydrate content was generally significant ($p < 0.05$), some varieties had comparable values. For instance, the carbohydrate in *Matches* (*D. alata*) was equivalent to that of *Pona*, *Dente* and *Mutwumudoo* (*D. rotundata*).

3.1.3. pH of flour

The pH of the yam flours was neutral, an indication that the flours had not undergone fermentation (Table 3). At pH (> 6), flours do not have a sour taste, may show little or no starch breakdown and is desirable and suited for a wide range of dietary applications including baking.

Table 3. Proximate chemical composition of yam flour (dry weight basis)

Variety	Protein (g/100 g)	Fat (g/100 g)	Ash (g/100 g)	CHO (g/100 g)	pH
Pona	3.82 ± 0.01^{ab}	0.25 ± 0.07^{a}	2.00 ± 0.09^{a}	93.94 ± 0.01^{d}	6.46 ± 0.01^{b}
Laribokor	5.19 ± 0.10^{c}	0.25 ± 0.02^{a}	1.98 ± 0.02^{a}	92.59 ± 0.11^{c}	6.35 ± 0.03^{a}
Dente	4.02 ± 0.01^{b}	0.21 ± 0.03^{a}	1.81 ± 0.03^{a}	93.97 ± 0.07^{d}	6.44 ± 0.00^{b}
Mutwumudoo	3.71 ± 0.01^{a}	0.34 ± 0.02^{a}	2.15 ± 0.04^{a}	93.80 ± 0.02^{d}	6.44 ± 0.05^{b}
Serwah	5.89 ± 0.02^{d}	0.47 ± 0.17^{a}	2.70 ± 0.02^{b}	90.95 ± 0.17^{a}	6.58 ± 0.03^{c}
Akaba	5.10 ± 0.12^{c}	0.23 ± 0.01^{a}	2.73 ± 0.28^{b}	91.94 ± 0.17^{b}	6.28 ± 0.02^{a}
Matches	3.66 ± 0.01^{a}	0.41 ± 0.15^{a}	2.13 ± 0.06^{a}	93.81 ± 0.09^{d}	6.46 ± 0.03^{b}

Note: Within a column, significantly different means ($p < 0.05$) are assigned different superscripts.

3.2. Functional characteristics

The functional properties of the yam flours are important since they affect the end use of the flours. Swelling power (SP) of the flours was relatively higher in *D. rotundata* compared to *D. alata*, and ranged from 10.48–13.33 and 10.97–11.62, respectively (Table 4). The higher SP in *D. rotundata* varieties suggests a tenuous association of its starch polymers. Differences in SP have also been ascribed to starch content (including damaged starch) and the presence of lipids, which forms a complex with amylose and inhibits swelling (Zheng & Sosulski, 1997). The trends in swelling observed in the present study agree with an earlier study by Wireko-Manu et al. (2011). These authors found that the SP for *Pona* (*D. rotundata*), was nearly 1.5 times more than that of several cultivars of *D. alata*. The Solubility Index (SI) of the *D. alata* cultivars were higher than that of the *D. rotundata* cultivars. The SI is related to the extent of leaching of amylose out of starch granules during swelling and affected by intermolecular forces and the presence of surfactants and other related substances (Moorthy, 2002). Significant differences ($p < 0.05$) were recorded in SP and SI for all the varieties used in this study. As noted by Singh and Singh (2001), the differences observed in these parameters may be ascribed to the flours having different morphological structures and variability in their amylose and amylopectin content.

The Water absorption capacity (WAC) was less than 6.0 for *D. alata* and approximately 7.0 for *D. rotundata*, with the exception of *Serwah* variety (Table 3). The yam varieties showed significant differences in WAC, with *Dente* variety having the highest (7.70) and *Matches* recording the lowest (5.72). WAC reflects the amount of water that the starch can hold in relation to its weight (Awoyale, Maziya-Dixon, Sanni, & Shittu, 2016). The results imply that, at room temperature, *D. rotundata* varieties, especially, *Dente* is capable of holding more water than the flours made from *D. alata* varieties.

3.3. Rheological behaviour of flour

The pasting properties of the yam flours are associated with the characteristics of starch and are essential in predicting the behaviour of flours in food processing applications. The flours indicated distinct differences in all the indices that describe the pasting behaviour of flours (Table 5). Pasting temperature ranged from 76–81 °C and is in agreement with the range reported for different varieties of yams by Wireko-Manu et al. (2011), but slightly lower than the temperatures obtained by Otegbayo, Oguniyan, and Akinwumi (2014). Flour made from *Matches* variety had the highest pasting temperature (81.0 °C). Pasting temperature indicates the point at which starches begin to thicken, during the heating cycle, and may signify the gelatinization temperature (Chen, Schols, & Voragen, 2003; Otegbayo et al., 2014). This observation indicates that among the 7 yam varieties, *Matches* flour required the most heat to cook.

Table 4. Functional properties of yam flour

Variety	SP (%)	SI (%)	WAC (%)
Pona	13.06 ± 0.22^{c}	5.88 ± 0.11^{a}	6.94 ± 0.14^{d}
Laribokor	12.87 ± 0.28^{bc}	7.53 ± 0.31^{b}	7.01 ± 0.08^{d}
Dente	12.56 ± 0.23^{bc}	8.41 ± 0.55^{bc}	7.70 ± 0.19^{e}
Mutwumudoo	13.33 ± 0.75^{c}	8.67 ± 0.29^{bc}	7.07 ± 0.07^{d}
Serwah	10.48 ± 0.37^{a}	9.59 ± 0.38^{c}	6.52 ± 0.20^{c}
Akaba	10.97 ± 0.24^{a}	17.26 ± 0.09^{d}	5.85 ± 0.11^{b}
Matches	11.62 ± 0.08^{ab}	22.91 ± 0.43^{e}	5.72 ± 0.01^{a}

Note: Within a column, significantly different means ($p < 0.05$) are assigned different superscripts.

Table 5. Viscoelastic properties of yam flour

Variety	PT (°C)	PV (BU)	Viscosity at 95 °C (BU)	Viscosity at 95 °C hold (BU)	Viscosity at 50 °C (BU)	Viscosity at 50 °C hold (BU)
Pona	77.2 ± 1.0^{ab}	514.5 ± 3.4^{e}	508.3 ± 2.1^{e}	282.5 ± 0.2^{g}	306.5 ± 1.8^{e}	485.0 ± 3.0^{f}
Laribokor	76.1 ± 0.8^{ab}	522.5 ± 2.0^{f}	510.0 ± 1.9^{e}	172.5 ± 0.7^{c}	180.4 ± 0.9^{b}	474.3 ± 2.5^{d}
Dente	76.0 ± 0.3^{a}	508.0 ± 2.3^{e}	485.6 ± 0.5^{d}	204.5 ± 1.4^{e}	283.2 ± 0.8^{d}	471.5 ± 1.6^{d}
Mutwumudoo	79.6 ± 0.2^{c}	343.5 ± 1.1^{b}	241.1 ± 0.8^{a}	144.5 ± 1.7^{a}	159.0 ± 0.4^{a}	342.5 ± 1.2^{b}
Serwah	79.4 ± 0.4^{c}	373.8 ± 2.2^{c}	351.5 ± 0.6^{b}	193.0 ± 0.8^{d}	212.0 ± 0.1^{c}	349.0 ± 2.0^{c}
Akaba	77.2 ± 0.3^{ab}	473.1 ± 0.9^{d}	453.5 ± 2.5^{c}	279.0 ± 1.1^{f}	322.1 ± 1.4^{f}	459.0 ± 3.2^{e}
Matches	81.0 ± 0.1^{d}	301.5 ± 2.8^{a}	246.5 ± 1.1^{a}	165.5 ± 0.7^{b}	181.0 ± 0.8^{b}	301.3 ± 0.6^{a}

Notes: Within a column, significantly different means ($p < 0.05$) are assigned different superscripts. PT-Pasting Temperature; PV-Peak Viscosity.

Generally, a wide variation was observed in Peak Viscosity (PV). The highest (522BU) was observed for the *Lariboko* variety, and the lowest (301BU) in *Matches* variety. The PV is an important indicator of the paste forming ability of starches during cooking and high PV is associated with starches that are less resistant to swelling and rapturing. Flours with high PV may be desirable in applications such as soups and puddings. At 95 °C, all the flours showed a slight reduction in their viscosities, but this reduction in viscosity was highest for *Matches* variety. Holding at 95 °C depicts the strength (breakdown) of paste when they are subjected to shear forces. A steeper reduction in viscosity was observed again, for all the flours. However, this drop was highest in *Lariboko* flour (523–173 BU). This suggest that starch granules from this variety can hardly withstand mechanical disintegration when exposed to shear forces at high temperatures. A steady rise in viscosity occurred during cooling, and this expresses the tendency of starches to retrograde (Zaidul, Norulaini, Omar, Yamauchi, & Noda, 2007). Flours with low setback values have a lower tendency to retrograde and therefore the ability for this phenomenon to occur was lowest in *Matches* variety. As observed in previous studies by Wireko-Manu et al. (2011) and Otegbayo et al. (2014), the mean setback viscosity of *D. rotundata* varieties was higher than *D. alata*. In the present study as well as the earlier studies, a few varieties of *D. alata* had a higher tendency to retrograde than some varieties of *D. rotundata*. Staling in bread has been linked to retrogradation (Krog, Olesen, Toenaes, & Joensson, 1988). Among the 7 yam varieties, *Matches* variety would be the best suited for bakery products as retrogradation was unfavorable.

4. Conclusion

There were variations in the physicochemical, nutritional and functional properties in flours from the farmers' 7 key yam varieties in Ghana. Chemical analysis revealed considerable protein content for varieties of *Serwah, Lariboko* and *Akaba.* There were pronounced differences in the behaviour of the yam flours in water. Apart from *Serwah* and *Mutwumudoo*, all the *D. rotundata* varieties had a relatively higher peak viscosity than *Akaba* and *Matches* (*D. alata*) varieties. Paste stability and retrogradation tendencies also varied greatly among the varieties and made the flours suited for a wide range of food products. *Akaba*, *Dente* and *Pona* varieties may be applicable in products where high stability is required, whereas *Matches*, may serve a good purpose in bakery. The obtained results provide useful information for the utilization of these yam varieties in different applications and selection for specific end uses, thus information on their choice for production.

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Competing Interest
The authors declare no competing interest.

Author details
C. Tortoe[1]
E-mail: ctortoe@yahoo.co.uk
S. Dowuona[1]
E-mail: niibinio@yahoo.com
P.T. Akonor[1]
E-mail: papatoah@gmail.com
N.T. Dziedzoave[1]
E-mail: nanamtay@yahoo.com
[1] Council for Scientific and Industrial Research-Food Research Institute, P. O. Box M20, Accra, Ghana.

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