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Physicochemical properties of yam starches from fifty-five lines of *Dioscorea* species

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Abstract

This study investigated the morphology of the granules, physicochemical and pasting properties of fifty-five starches of *Dioscorea rotundata* and *Dioscorea alata* varieties. The granules sizes and shapes, swelling power, solubility, water absorption capacity, water binding capacity, pH, titratable acidity and pasting properties were evaluated by standard procedures. The result of the granule morphology showed that both varieties were in the range of large starch granules, however, *D. rotundata* varieties (32.40 – 57.01 µm by 22.38 – 35.70 µm) were significantly larger than those of *D. alata* varieties (18.33 - 48.91 µm by 13.38 – 33.10 µm). The granule sizes were observed to have a significant effect on the physicochemical properties, as *D. rotundata* species were significantly higher in swelling power (7.50 g/g) and lower in water absorption (66.20%) and water-binding capacities (57.16%). Also, *D. rotundata* species showed significantly higher peak viscosity (518.50 RVU), holding strength (260.95 RVU) and breakdown viscosity (257.54 RVU), all contributing to their potential industrial uses. The present characterisation of fifty-five varieties of *Dioscorea species* germplasm in Nigeria adds to the database on physicochemical properties of yams, providing relevant information for both food and non-food uses.

1. Introduction

Dioscorea species have been reported to be over 600 in number, with about 10 being staple yams (Zhu, 2015). Yam is primarily produced for consumption at the household level and mainly as a cash crop in all central and southern states of Nigeria, with Oyo, Benue and Nassarawa having the highest production (Foraminifera Market Research, 2013). It has a higher market value, which makes it easy to produce and trade as against some other root and tuber crops, like cassava (Fu *et al.*, 2011). Akinwande *et al.* (2007) mentioned that supply of energy is the primary importance of yam, as it is majorly starchy in nature. Yam starch is about 60 to 80% of the total dry content proportion of yam tubers, which determines the textural, functional and rheological properties of yam food products (Amani *et al.*, 2004). Starch is made up of two polymers, namely amylose and amylopectin. Amylose is made up of between 15-30% of common starch which is mainly a linear chain having minimal branching points at α-1, 6 positions, while amylopectin is highly branched (Alcázar-Alay and Meireles, 2015). Isolation of yam starch has formed an important food process in yam utilization, as yam starches have been utilized for various industrial purposes, both food and non-food purposes (Ferreira *et al.,* 2009; Sobukola *et al.*, 2013). Yam is processed and used industrially in form of flour and starch, in the bakery (for high-quality bread, biscuits and other pastries) (Nindjina *et al.,* 2011; Sobukola *et al.*, 2013), for ice-cream production and thickeners in soups (Iwuoha, 2004). Yam starch is also utilized for the making of all-purpose-adhesives, used for cartons, shoes and other packaging materials (Foraminifera Market Research, 2013).

Physicochemical and functional properties of food, are attributes of food components asides from its nutritional properties that show complex reactions between the compositions, structure and molecular conformation of food components, combined with the nature of the environment where these are associated and measured, having a great impact on their utilisation (Mahajan and Dua, 2002; Chandra and Samsher, 2013). These properties could be affected by a number of factors, including source or type of starch, amylose and amylopectin ratio, water content as well as mucilage (Nadia *et al.*, 2014; Yeh *et al.,* 2009). Yam starches of

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varying landraces have been investigated for their physicochemical properties by Amani *et al.* (2004), Sahore *et al.* (2007a) and Sahore *et al.* (2007b) in Ivory Coast, Otegbayo *et al.* (2014) and Alamu *et al.* (2004) in Nigeria, Shujun *et al.* (2006), Yuan *et al.* (2007) and Jiang *et al.* (2013) in China, Perez *et al.* (2011) in Venezuelan and others. However, yam is a multi-variant crop, which is different across varieties and species. There is a need to continuously document the physicochemical properties of yam starches, especially genetically characterised varieties, providing useful information for industrial utilization. The study, therefore, focused on characterising fifty-five genetically improved varieties and elite landraces of *D. rotundata* and *D. alata* species, which are the important and mostly grown species in Nigeria, for the physicochemical properties of their starches, providing relevant information for both food and non-food uses.

2. Materials and methodology

2.1 Materials

A total of 55 genetically characterised varieties were selected from *D. rotundata* (19 varieties) and *D. alata* (36 varieties), both were obtained from the yam programs of the International Institute of Tropical Agriculture (IITA) and National Root Crops Research Institute (NRCRI), Umudike, Nigeria.

2.2 Sample preparation

Yam starch was extracted from yam tubers by wet method, using the method described by Otegbayo *et al.* (2011), presented in Figure 1. This involves washing the tubers, peeling, washing, and then cutting into cubes. This was followed by milling into a slurry with water using a warring blender (Panasonic mixer grinder, MX-AC210S) with intermittent stopping to prevent heating up of the starch. Sieving was done using triple layers of muslin cloth, then the residue was washed until it was free of starch. The filtrate was left to settle, drained and re-washed numerously with water. The settled starch was dried in shallow trays at a temperature range of 20 - 25° C for 24 hrs, followed by gentle grinding into fine powder, packaging and storage in ziplock bags, prior to analysis.

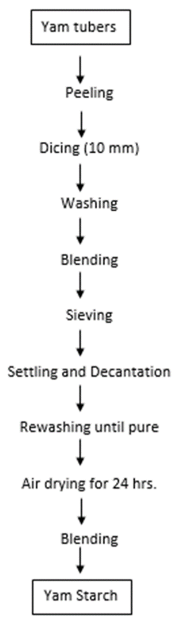


Figure 1. Starch extraction from yam tubers

2.3 Determination of physicochemical properties

A light microscope (Fisher Micromaster) was used to examine the granule shapes and measure the granule sizes of yam starch in the fresh yam tubers, as described by Otegbayo *et al.* (2011). Determination of swelling power and solubility index were carried out using the method of Leach *et al.* (1959), as described by Zakpaa *et al.* (2010); which involves heating, centrifugation, decantation and drying. Water binding capacity and water absorption capacity were determined by slightly modifying the methods of Medcalf and Gilles (1965) and Anderson (1982) methods respectively. The titratable acidity and pH were determined by AOAC (2010) and the method described by Mbaeyi-Nwaoha and Onweluzo (2013) respectively.

The yam starch varieties were evaluated for their pasting properties with the aid of a Rapid ViscoAnalyzer (RVA4500) connected to a PC running Thermocline for Windows (TCW) version 3 software (Perten Instruments of Australia, 2015). The sample calculator of the analyser was used to calculate the weight of the sample to be used for the analysis, based on its moisture content. The estimated sample weight and volume of water were weighed to prepare the starch suspension, amounting to a total of 28.0 g slurry in the canister of the RVA. Peak viscosity, final viscosity, break down viscosity, trough viscosity also known as holding strength, set back viscosity, pasting temperature and peak time were evaluated from the pasting profile.

3. Results and discussion

3.1 Granule morphology of starch in fresh yam tubers

The study showed that there were significant variations in the sizes and shapes of the starch granules both within and between species. Light microscopy showed that starch granule sizes of varieties of *D. rotundata* ranged from 32.40 – 57.01 µm by 22.38 – 35.70 µm (Table 1), while those of *D. alata* varieties ranged from 18.33 - 48.91 µm by 13.38 – 33.10 µm (Table 2). The granules dimension showed that *D. rotundata* varieties granules were larger than those of *D. alata* varieties (Figure 2). This is similar to the observations of Rolland-Sabate *et al.* (2003) and

Otegbayo *et al.* (2011). Moreover, both species falls under the classification of large starch granules, based on Lindeboom *et al.* (2004) classification scale, which is granules greater than 25 µm. The variations in the granules size of yam species could be as a result of the physiology of the plant and its biological origin (Mishra and Rai, 2006; Singh and Singh, 2001), and this could be responsible for the disparity in their physicochemical as well as pasting properties. This is because starch granules sizes are affected by starch extractability, as a result of the extent of protein and fine fiber sediments entrapment (Otegbayo *et al.,* 2014). The variation in the granule sizes was reported by Sanguanpong *et al.* (2004) to result in differences in their sensitivity to shear, affecting the texture of food products prepared from them. Otegbayo *et al.* (2011) also reported that larger starch granules of *D. rotundata* as compared with those of *D. alata* may influence the viscosity and swelling of their starches, contributing to its pasting viscosities, swelling power and gelatinization temperature; hence, larger starch granules swell faster and also build higher viscosity, affecting other properties of the starch. In addition, it has been reported that the amylose component is mostly formed as the granules grow larger, this is because amylose has been found to concentrate in the periphery of granules (Jane *et al*., 2003). Hence, starch granule sizes, molecular make-up of polymers of starch including structural characteristics of these starch polymers determine the properties of gel made from different starches (Wickramasinghe *et al*., 2009).

Table 1. Granule sizes of *D. rotundata* varieties

Sample	Granule Length (µm)	Granule Breadth (µm)
Agbanwobe	36.22^{abc}	26.89^{bcde}
TDr95/18531	42.77^{defg}	30.79^{fghi}
TDr89-02665	45.68^{fg}	30.15^{efghi}
TDrUfenyi	46.71^{g}	35.70^{j}
TDr97-00917	43.74^{efg}	29.30^{defgh}
TDr99-02607	57.01^{h}	31.73^{ghi}
TDr89-21-3	35.26^{abc}	26.84^{bcde}
Agba	44.01^{efg}	32.82^{ij}
Agboyo-abbi	32.40^{a}	22.38^{a}
Ameh	40.88^{cdef}	27.55^{bcdef}
Fakinsa	45.82^{fg}	32.75^{ij}
Lagos	34.97^{ab}	28.28^{cdefg}
Nwopoko	46.13^{fg}	26.41^{bcd}
PAA-IITA	37.67^{abcd}	32.15^{hi}
Pampas	38.79^{bcde}	24.99^{abc}
Ogoja	37.45^{abcd}	24.61^{ab}
Sandpaper	37.85^{abcd}	30.39^{fghi}
Takalafia	37.64^{abcd}	28.78^{defgh}
2665	35.19^{abc}	25.32^{abc}
Mean	40.85	28.83
STDEV	5.8	3.3
SE	1.36	0.78

Values are average of 10 replicates results. Values with the same superscript within the same column are not significantly different ($p \geq 0.05$)

Table 2. Granule sizes of *D. alata* varieties

Sample	Granule Length (µm)	Granule Breadth (µm)
TDa11/00011	32.65^{bcdefgh}	21.92^{efgh}
TDa11/00014	30.46^{bcdef}	22.27^{efgh}
TDa11/00020	30.02^{bcde}	21.40^{cdefgh}
TDa11/00022	32.22^{bcdefgh}	18.58^{bcde}
TDa11/00024	33.97^{cdefghijk}	22.10^{efgh}
TDa11/00063	38.98^{jklm}	23.64^{ghi}
TDa11/00102	29.49^{bcd}	21.19^{cdefgh}
TDa11/00110	32.62^{bcdefgh}	23.60^{ghi}
TDa11/00138	42.33^{mn}	28.29^{jk}
TDa11/00162	37.00^{ghijklm}	23.35^{fghi}
TDa11/00164	35.95^{fghijkl}	19.45^{bcdefg}
TDa11/00167	31.37^{bcdefg}	23.40^{fghi}
TDa11/00179	37.17^{hijklm}	24.74^{hij}
TDa11/00189	30.72^{bcdef}	16.14^{ab}
TDa11/00225	33.18^{cdefghi}	24.85^{hij}
TDa11/00232	48.91^{o}	27.01^{ijk}
TDa11/00242	35.05^{defghijk}	21.09^{cdefgh}
TDa11/00247	28.76^{bc}	21.96^{efgh}
TDa11/00275	26.92^{b}	17.62^{bcd}
TDa11/00287	33.46^{cdefghij}	19.21^{bcdef}
TDa11/00292	32.13^{bcdefgh}	21.78^{efgh}
TDa11/00299	46.81^{no}	33.10^{l}
TDa11/00305	39.17^{klm}	21.63^{defgh}
TDa11/00317	30.94^{bcdef}	22.25^{efgh}
TDa11/00324	34.10^{cdefghijk}	22.76^{efgh}
TDa11/00368	34.91^{defghijk}	24.70^{hij}
TDa11/00370	29.44^{bcd}	24.59^{hij}
TDa11/00374	18.33^{a}	13.38^{a}
TDa11/00424	35.67^{efghijkl}	22.89^{fgh}
TDa11/00426	38.80^{ijklm}	21.41^{cdefgh}
TDa11/00428	36.81^{ghijkl}	29.15^{k}
TDa11/00434	28.29^{bc}	20.30^{cdefg}
TDa11/00493	40.82^{lm}	21.44^{cdefgh}
TDa11/00495	30.62^{bcdef}	18.65^{bcde}
TDa11/00541	30.69^{bcdef}	17.49^{bc}
TDa11/00555	31.72^{bcdefgh}	22.36^{efgh}
Mean	33.90	22.21
STDEV	5.61	3.66
SE	0.94	0.61

Values are average of 10 replicates results. Values with the same superscript within the same column are not significantly different ($p \geq 0.05$)

The results of granule sizes of the current research were similar to earlier findings for *D. alata* varieties reported by Otegbayo *et al.* (2014) (29 – 41 µm) and Baah (2009) (29.5 – 41.5 µm), however, the granules were larger than the sizes reported by Tetchi *et al.*, (2012) (22.09 – 23.00 µm), Fauziah *et al.* (2016) (13.3 – 26.0 µm), and Otegbayo *et al.* (2011) (21.5 – 29.24 µm). The *D. rotundata* varieties had similar results of 18.49 – 44.29 µm, for those of Otegbayo *et al.* (2011). Typical representation of starch granule shapes as observed under the light microscope for *D. rotundata* and *D. alata* species are shown in Figure 3a and Figure 3b respectively, with minimal observable variations in the shapes. The *D. rotundata* varieties were majorly oblong, oval and irregular in shape, while those of *D. alata* varieties were more triangular and oblong. The shapes are comparable to previous observations by Tetchi *et al.* (2012), Otegbayo *et al.* (2011); Baah (2009), Fauziah *et al.* (2016), Sahore *et al.* (2013), However, the shapes have not been reported to have any functional roles but could be used to indicate the source of the starch (Otegbayo *et al.*, 2014).

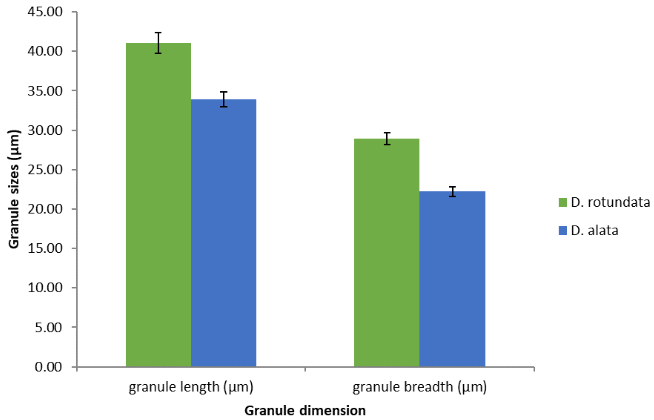
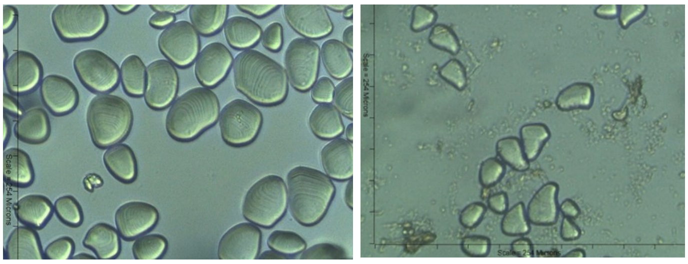


Figure 2. Summary of granule sizes of *D. rotundata* and *D. alata* species



(a) Sandpaper (b) TDa11/00434

Figure 3. Typical starch granules of (a) *D. rotundata* and (b) *D. alata*

The granule sizes were subjected to cluster analysis, and two major clusters emerged for species of *D. rotundata* and *D. alata*, as shown in Figure 4. Cluster A comprises two sub-groups- I and II made up of both *D. rotundata* and *D. alata* varieties. Sub-group I includes 10 varieties of *D. alata* species and 9 varieties of *D. rotundata* varieties, which showed average or medium granule sizes when compared with others. Cluster A sub-group II comprises of majorly *D. rotundata* varieties (TDr99/02607 to TDr95/18531, nine varieties) and three *D. alata* varieties (TDa11/00232 TDa11/00299 and TDa11/00138), with distinctly larger granule sizes. Cluster B showed varieties with relatively small granule sizes, comprising of majorly *D. alata*- 23 varieties and 1 *D. rotundata* variety. This showed that *D. alata* varieties in this study are generally smaller than *D. rotundata* varieties. Hence, it can be inferred that varieties in the same cluster may have comparable contributions to pasting viscosities, swelling power and gelatinization temperature; as granule sizes influence the viscosity and swelling of their starches. The granule sizes of these yam species fall within the group of large starch granules as those of Florido, smooth pea, Kponan and potato starches, which have found utilization in industries where high viscosities and swelling power are needed (Tetchi *et al.*, 2007; Otegbayo *et al.*, 2014). Hence, varieties in cluster A, sub-group II could find use in food that requires high viscosity.

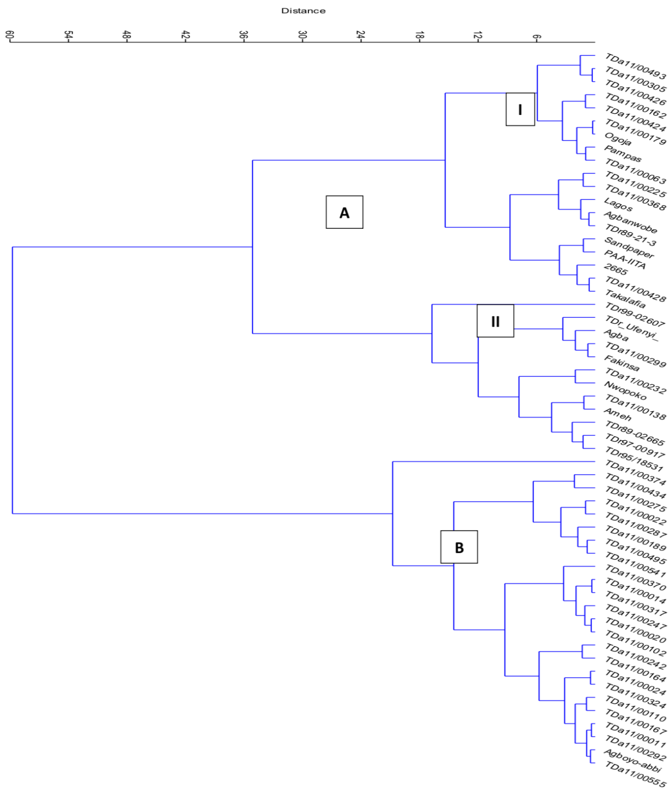


Figure 4. Cluster analysis of granule morphology for *D. rotundata* and *D. alata species*

3.2 *Physicochemical properties*

Figure 5 and Figure 6 show the physicochemical properties of the varieties of *D. rotundata* and *alata* starch respectively. The swelling power of *D. rotundata* and *D. alata* varieties ranged from 4.97 to 8.86 g/g and 2.15 to 8.45 g/g respectively. The swelling power of *D. rotundata* varieties (7.50 g/g) was significantly higher than those of *D. alata* varieties (5.36 g/g). The larger granule sizes of *D. rotundata* varieties could be responsible for its' higher swelling power, as the size increased in proportion to the initial size under the influence of heat and water (Tetchi *et al.*, 2007; Wickramasinghe *et al.*, 2009), which could be an indicator of 'weak internal bonding' within the granules (Otegbayo *et al.*, 2014). This study observed lower swelling power compared to reports of 8.0 to 11.6 (*D. alata*) and 11.0 (*D. rotundata*) by Baah (2009); 6.23 to

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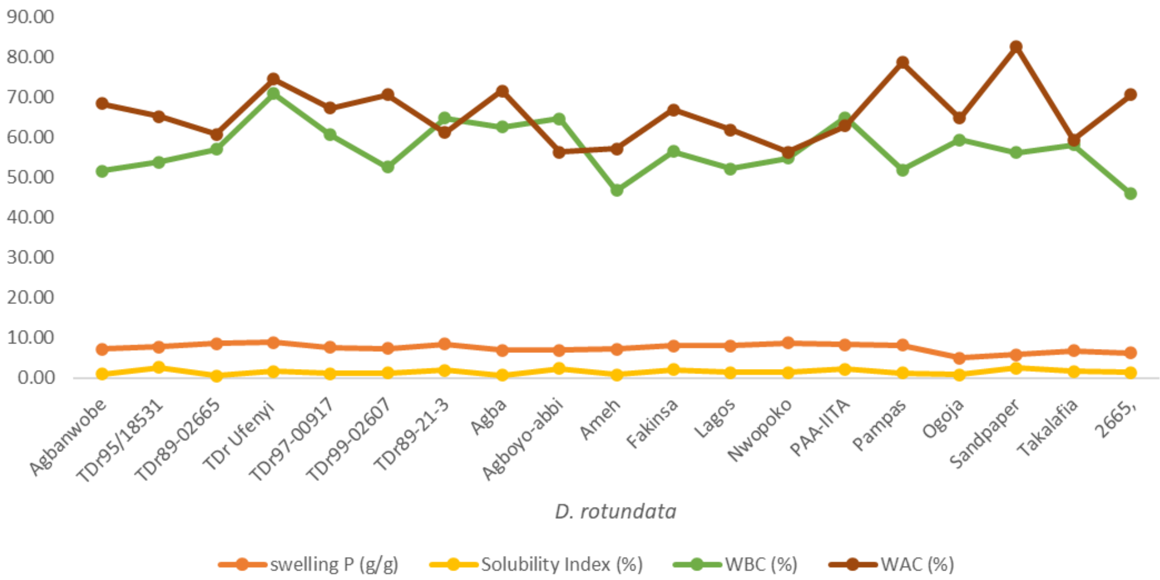

Figure 5. Physicochemical properties of *D. rotundata* starches

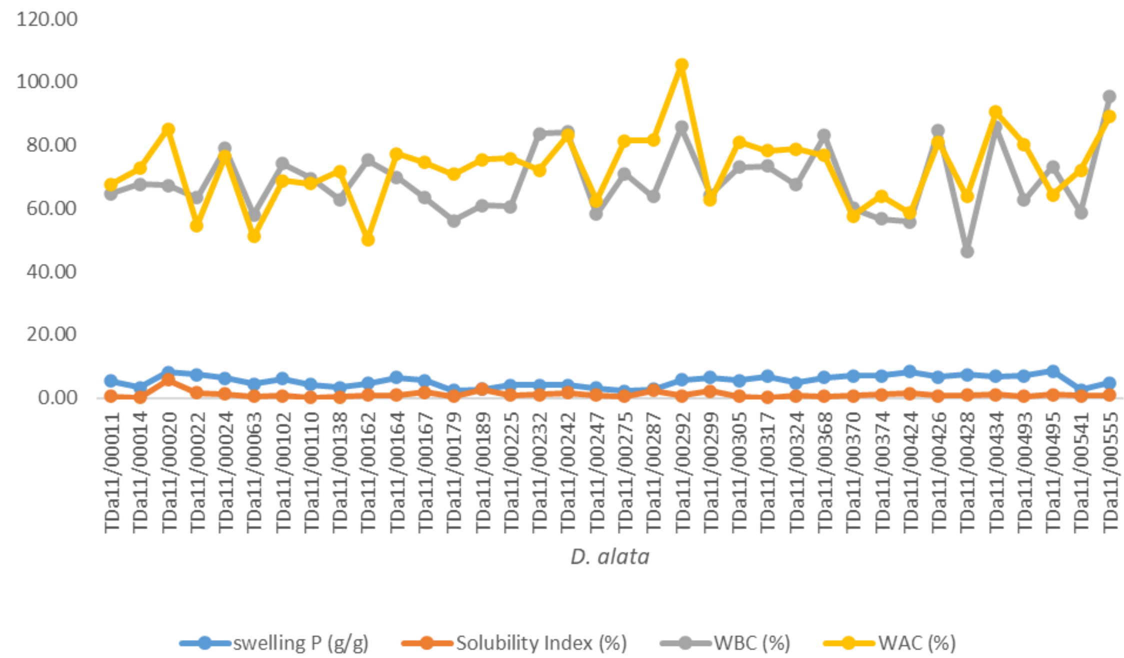

Figure 6. Physicochemical properties of *D. alata* starch

9.75 (*D. alata*) and 12.05 (*D. rotundata*) by Wireko-Manu *et al.* (2011), 9.00 g/g (*D. rotundata*) and 7.15 g/g (*D. alata*) by Otegbayo *et al*. (2014). In addition, the higher swelling power of *D. rotundata* species than *D. alata* species is similar to previous reports (Baah *et al.*, 2009; Walter *et al.*, 2000; Wireko-Manu *et al.*, 2011).

Swelling power is majorly controlled by the strength and character of the amylose molecules, known as the micellar networks that exist within the starch granules; the higher the associative forces, the lower the swelling power (Hoover, 2001; Ikegwu *et al.*, 2009; Wireko-Manu *et al.,* 2011). Ai and Jane (2015) reported that swelling power and viscosity development of starch during cooking is primarily due to the amylopectin component; as amylose with the presence of lipids intertwines with amylopectin thereby restricting swelling of starch granules. Yam starches with generally low swelling capacity, as observed for *D. alata* and *D. rotundata varieties* when compared with commercially utilized starches, could be suitable for use in complementary foods where thick gruels are not desired (Otegbayo *et al*., 2014).

Singh *et al*. (2005) defined solubility as the percentage amount of starch leached out into the supernatant during swelling power estimation. The solubility index ranged from 0.55 to 2.65 and 0.13 to 5.72 for *D. rotundata* (Figure 5) and *D. alata* (Figure 6) respectively. *D. rotundata* species had a higher solubility index than those of *D. alata* species, similar to the report of Otegbayo *et al.* (2011 and 2014). However, the solubility index of yam flour from *D. alata* was higher than that of *D. rotundata* as reported by Ogunlakin *et al.*

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(2013). The result of this study implies that there is the ease of solubility of the linear portion (amylose) of *D. rotundata*, than those of *D. alata* starches. The amylose is loosely linked to the rest of the macromolecular structure, which gets released or leached out during swelling, contributing to the high solubility index of *D. rotundata* (Hoover, 2001). In addition to the interaction between starch chains within the amorphous and crystalline domain, species, variety and the extent of starch granular structure, modification can as well influence the degree of swelling and solubility of yam starch (Otegbayo *et al.*, 2014).

D. alata varieties had significantly higher water absorption capacity (WAC) and water-binding capacity (WBC) than *D. rotundata* varieties. The water absorption capacity is a measure of the amount of water retained in yam flour during processing, affecting the ability of the yam flour to form a paste (Ezeocha *et al.,* 2015). While water-binding capacity was defined by Otegbayo *et al.* (2014) to be the amount of water that an insoluble starch can hold in relation to its own weight. The water-binding capacity reported in this study for *D. rotundata* varieties (46.79 – 70.90%) (Figure 5) and *D. alata* (46.56 – 95.59%) (Figure 6) were lower than 72.97 – 80.01% (*D. rotundata*) and 21 – 120% (*D. alata*) reported by Otegbayo *et al.* (2011 and 2014 respectively) for Nigeria yam germplasm; 108 – 144% by Alamu *et al.* (2014) for *D. rotundata* varieties; as well as those reported by Baah (2009) for *D. alata* varieties (159.7 – 202.4%). Some varieties of *D. alata* and a few of *D. rotundata* starches of this study could be useful in frozen desserts to increase viscosity and delay the formation of large ice crystals, since starches with high WBC bind more water, thereby preventing syneresis (Otegbayo *et al.*, 2014).

WBC has been reported to be a reflection of the degree of association between starch polymers in their native granules; hence high WBC is an indication of a loose association of amylose and amylopectin in the starch granules, while low WBC is related to a close association between the starch polymers in the granules (Otegbayo *et al.*, 2014). An increase in association of starch polymers in native starch granules has been reported to decrease the water-binding capacity (Soni *et al.*, 1993); hence *D. rotundata* varieties have weak starch polymer associations than those of *D. alata* varieties with closer associative forces. The variations could as well be due to differences in genotype, cultivations practices, origin and the fact that yam is a multi-variant species crop. Water binding capacity has been reported to be significant in influencing the quality of finished products or starch end products. High water binding capacity and low swelling power has been observed by Otegbayo *et al.* (2011) to contribute to the stickiness, extreme softness and in-cohesive nature of pounded yam from *D. alata*. Hence, physicochemical properties are greatly influenced by the size of granules and amylose content of the starch, and hence, could be important quality indicators of yam food products.

The acidity content of the starch of the yam species as expressed by the pH and titratable acidity (TTA) are presented in Figure 7 and Figure 8. These parameters are of significance in measuring the acid content of a food substance, which tell how acidic or alkaline a food is. The pH and titratable acidity ranged from 6.29 to 7.26 and 0.14 to 1.99 for *D. rotundata* respectively, and 5.59 to 7.71and 0.74 to 2.00 for *D. alata* respectively. The results showed that there are significant differences among some varieties for both the pH and titratable acidity of *D. rotundata* and *D. alata* starches. The acidic contents of these yam starches show that they are almost neutral, indicating that they are very low acid food,

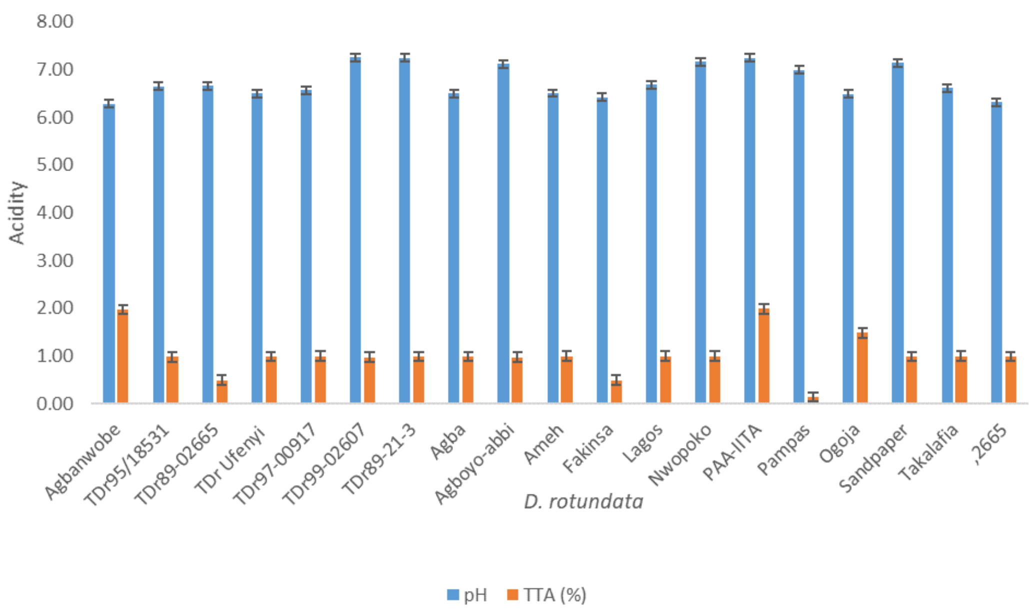

Figure 7. pH and Titratable Acidity of *D. rotundata* varieties

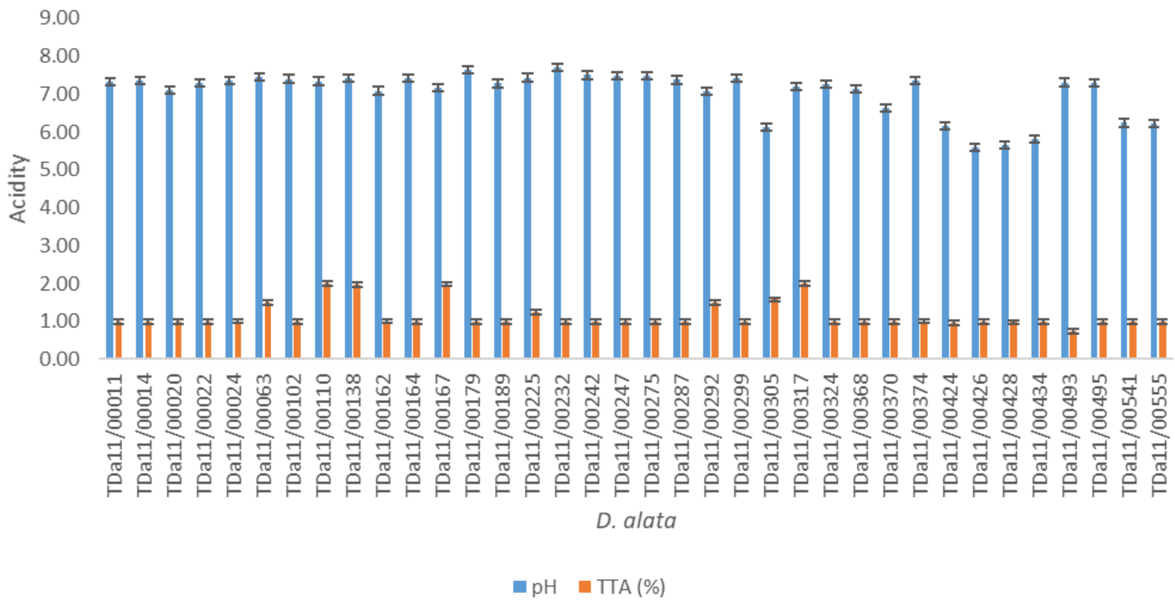

Figure 8. pH and Titratable Acidity of *D. alata* varieties

suitable for use in the industries.

3.3 Pasting properties of yam starch

The pasting properties of root and tuber crops are one of the important determinants of their resulting product quality. Cooking quality and texture of different food products have been associated with the pasting characteristics of starches (Moorthy, 2002, Otegbayo, *et al.*, 2006) Pasting is known as the formation of a more or less thick paste from swollen starch granules and amylose leaching from the granules (Batey and Bason, 2015). Zhu (2015) as well described pasting as the heating and cooling of starch-water mixture between 50 and 95°C to a programmed cycle under a constant shearing force. The pasting properties of starches tell largely their use as an ingredient in foods and other industrial applications, hence it affects the properties of the resulting product. Table 3 and Table 4 show the pasting properties of starches of *D. rotundata* and *D. alata* varieties.

The ability of the starch granules to swell freely before breaking down, shown by peak viscosity (Singh *et al.*, 2003; Wireko-Manu *et al*., 2011) ranged from 291.08 to 654.79 RVU and 252 to 467.46 RVU for *D. rotundata* and *D. alata* varieties respectively (Table 3 and Table 4). High peak viscosity has been reported to influence the water-binding capacity of starch granules and increase the strength of formed paste during processing (Adebowale *et al.*, 2005). This could make them useful in high viscous products such as thickeners, binders and fillers (Otegbayo *et al.*, 2014). The study showed that *D. rotundata* species have higher peak viscosities than those of *D. alata* species (Figure 9). Similar trends of higher peak viscosity for *D. rotundata* were observed by Wireko-Manu *et al.* (2011) (*D. rotundata*- 291.17RVU; *D. alata*- 74.80 – 284.60 RVU), Otegbayo *et al.* (2014) (*D. rotundata* 360.51 RVU; *D alata* 341.17 RVU). The significantly lower peak viscosity of *D. alata* has been attributed to the lower swelling power of its starch in comparison to that of *D. rotundata* (Otegbayo *et al.*, 2006; Baah *et al.*, 2009; Wireko-Manu *et al.,* 2011), as well as it lower granule sizes as peak viscosity is higher in starches with larger granules (Wickramasinghe *et al.*, 2009). Moreover, this study observed higher peak viscosities than those reported by Wireko-Manu *et al.* (2011), Baah *et al*. (2009) and Otegbayo *et al.* (2014).

Holding strength, also known as trough viscosity ranged from 140.33 to 362.58 RVU and 106.54 to 368.63 RVU (Table 3 and 4) for *D. rotundata* and *D. alata* varieties respectively, with the significant difference among the varieties for each species. *D. rotundata* varieties have significantly higher holding strength than *D. alata* varieties (Figure 9), hence it could be observed that *D. rotundata* species can remain intact and undisrupted over a hold period and temperature than those of *D. alata,* which could be of industrial advantage where the stable gel is desired. This holding strength is the ability of a paste to withstand stress, or remain undisrupted when subjected to a hold period of constant high temperature and mechanical shear stress (Madsen and Christensen, 1996; Kinn-Kabari *et al*., 2015). The breakdown viscosity varied from 150.75 to 361.17 RVU and 20.83 to 212.83 RVU for *D. rotundata* and *D. alata* respectively. The significantly higher breakdown viscosity observed for *D. rotundata* starch implies a stronger ability to withstand shear-thinning by resisting breakdown in viscosity, as a result of minimum starch granule rupture, hence, resulting in more stable cooked paste than those of *D. alata* (Otegbayo *et al.*, 2006). The high breakdown viscosity often accompanies holding strength, and this is an indication of the level of

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Table 3. Pasting properties of starch for *D. rotundata*

Sample	Peak visc. (RVU)	Holding strength (RVU)	Breakdown (RVU)	Final Visc (RVU)	Setback (RVU)	Peak Time (min)	Pasting Temp (°C)
Agbanwobe	571.58[ijk]	310.38[i]	261.21[cdef]	420.96[g]	110.58[cd]	4.83[def]	81.63[bcd]
TDr95/18531	585.79[jk]	262.08[efg]	323.71[ghi]	372.88[ef]	110.79[cd]	4.77[cd]	79.58[a]
TDr89-02665	642.96[m]	281.79[ghi]	361.17[i]	378.75ef	96.96[abc]	4.73[bcd]	79.38[a]
TDrUfenyi	499.08[efg]	219.13[cd]	279.96[defg]	326.13[cd]	107.00[cd]	4.70[bcd]	82.40[def]
TDr97-00917	534.29[ghi]	362.58[j]	171.71[a]	493.58[i]	131.00[d]	4.97[fg]	83.28[f]
TDr99-02607	654.79[m]	349.79[j]	305.00[fgh]	483.38[hi]	133.58[d]	4.70[bcd]	80.90[b]
TDr89-21-3	426.25[bc]	202.21[bc]	224.04[bc]	272.92[b]	70.71[ab]	4.60[b]	81.63[bcd]
Agba	631.33[lm]	285.58[ghi]	345.75[hi]	393.54[fg]	107.96[cd]	4.73[bcd]	81.65[bcd]
Agboyo-abbi	406.04[b]	241.08[de]	164.96[a]	375.96[ef]	134.88[d]	5.07[g]	82.43[def]
Ameh	604.21[kl]	362.29[j]	241.92[cd]	458.08[h]	95.79[abc]	4.97[fg]	82.38[def]
Fakinsa	453.25[cd]	193.38[bc]	259.88[cdef]	265.58[b]	72.21[ab]	4.60[b]	82.55[def]
Lagos	471.33[de]	248.33[def]	223.00[bc]	353.50[de]	105.17[cd]	4.97[fg]	81.93[bcde]
Nwopoko	464.33[de]	269.58[efg]	194.75[ab]	364.29[ef]	94.71[abc]	5.00[g]	82.83[ef]
PAA-IITA	291.08[a]	140.33[a]	150.75[a]	209.63[a]	69.29[a]	4.40[a]	82.00[cde]
Pampas	562.25[ij]	238.00[de]	324.25[ghi]	328.25[cd]	90.25[abc]	4.67[bc]	79.63[a]
Ogoja	510.71[fgh]	257.46[efg]	253.25[cde]	352.50[de]	95.04[abc]	4.73[bcd]	82.40[def]
Sandpaper	477.92[def]	176.63[b]	301.29[efgh]	310.29[c]	133.67[d]	4.70[bcd]	83.23[f]
Takalafia	519.92[gh]	265.83[efg]	254.08[cde]	380.21[ef]	114.38[cd]	4.80[cde]	81.20[bc]
2665	544.29[hi]	291.63[hi]	252.67[cde]	393.88[fg]	102.25[bcd]	4.93[efg]	81.98[cde]
Mean	518.5	260.95	257.54	364.96	104.01	4.78	81.73
STDEV	90.89	60.34	60.52	71.97	20.36	0.17	1.16
SE	20.85	13.84	13.88	16.51	4.67	0.04	0.27

Values with the same superscript within the same column are not significantly different ($p \geq 0.05$)

resistance of starch granules to mechanical fragmentations during shearing and heating, hence higher paste stability (Otegbayo *et al.*, 2014).

The resulting viscosity after cooling cooked paste to 50°C, and its ability to form a gel after cooking is known as final viscosity (Wireko-Manu *et al.*, 2011). This is an important pasting parameter used to estimate the property of starch-based product quality, as high final viscosity shows that paste formed is more resistant to mechanical shear, forming more rigid gel (Zhang *et al.*, 2011). The final viscosity of *D. rotundata* varieties ranged from 209.63 to 493.58 RVU and an average of 364.96 RVU (Table 3), with an insignificant difference with those of *D. alata* varieties, ranging from 159.54 to 533.54 RVU with a mean value of 386.28 RVU (Table 4). Hence, both species have the ability to form gel after cooking with that of *D. alata* species insignificantly higher than that of *D. rotundata*. Moreover, with the exception of varieties TDr89/21-3 and PAA-IITA for *D. rotundata* and TDa11/00189, these yam species gave similar final viscosity with those of kponan (409.75 RVU), smooth pea (512.08 RVU) and maize (340.33 RVU) which have found use in the commercial world (Tetchi *et al.*, 2007). Furthermore, there were varieties within both species (TDr89-21-3, Fakinsa, PAA-IITA, TDa11/00020, TDa11/00189 and TDa11/00370) that exhibited low viscosities after cooling, similar to those of potato and cassava starches, which make them appropriate for use as thickening agents in dessert creams (Tetchi *et al.*, 2007).

Generally, yam starch has a high setback viscosity than other root and tuber crops, showing a higher capacity for retrogradation (Peroni *et al.*, 2006). *D. alata species* (160.32 RVU) has significantly higher set back viscosity than that of *D. rotundata species* (104.01 RVU) (Figure 9), within a range of 69.29 – 134.88 RVU and 53.00 – 266.58 RVU for *D. rotundata* and *D. alata* respectively. However, this is in contrast with previous observations by some researchers, that *D. rotundata* has higher setback viscosity than *D. alata* (Otegbayo *et al.*, 2006; Baah *et al.*, 2009; Wireko-Manu *et al.*, 2011). The generally high setback viscosity of *D. alata* and *D. rotundata* could be useful in a product like noodles where high retrogradation is desired (Kaur and Singh, 2005). The retrogradation process help fix the noodle's structure, as this impact the noodle's strength from increased gel formation due to sufficient leaching out of amylose, as the ageing time of the gelatinised starch increases (Thao and Noomhorm, 2011). The peak time, which is a measure of the cooking time, during the pasting cycle ranged from 4.40 to 5.07 mins for *D. rotundata* varieties and 4.23 to 5.33 mins for *D. alata*

Table 4. Pasting properties of starch for *D. alata*

Sample	Peak visc. (RVU)	Holding strength (RVU)	Breakdown (RVU)	Final Visc (RVU)	Setback (RVU)	Peak Time (min)	Pasting Temp (°C)
TDa11/00011	283.96^{abcde}	263.13^{mn}	20.83^{a}	456.96^{l}	193.83^{jk}	5.33^{m}	83.60^{b}
TDa11/00014	300.00^{bcdefg}	220.96^{hij}	79.04^{defg}	421.29^{jk}	200.33^{jk}	4.87^{hij}	84.43^{b}
TDa11/00020	351.75^{ijklm}	166.08^{cde}	185.67^{s}	236.92^{bc}	70.83^{b}	4.40^{bcd}	80.45^{b}
TDa11/00022	435.79^{pq}	315.00^{p}	120.79^{lkmno}	419.71^{jk}	104.71^{de}	5.03^{kl}	83.10^{b}
TDa11/00024	282.88^{abcde}	236.63^{jkl}	46.25^{abc}	458.04^{l}	221.42^{lm}	5.03^{kl}	83.33^{b}
TDa11/00063	353.75^{jklm}	261.46^{lm}	92.29^{efghijk}	403.67^{ij}	142.21^{gh}	4.90^{ijk}	67.10^{a}
TDa11/00102	329.46^{ghijk}	286.38^{no}	43.08^{ab}	524.04^{op}	237.67^{no}	5.30^{m}	84.50^{b}
TDa11/00110	330.58^{ghijkl}	233.33^{ijk}	97.25^{fghijk}	451.29^{l}	217.96^{lm}	4.73^{fgh}	84.45^{b}
TDa11/00138	363.79^{lmn}	237.67^{jkl}	126.13^{lmno}	346.04^{f}	108.38^{ef}	4.93^{ijkl}	84.03^{b}
TDa11/00162	444.96^{qr}	289.96^{o}	155.00^{pqr}	382.79^{hi}	92.83^{cd}	5.07^{l}	83.00^{b}
TDa11/00164	281.25^{abcde}	186.13^{defg}	95.13^{efghijk}	307.17^{e}	121.04^{f}	4.67^{efg}	83.15^{b}
TDa11/00167	321.38^{fghij}	190.38^{efg}	131.00^{mnopq}	346.17^{f}	155.79^{h}	4.50^{cde}	82.40^{b}
TDa11/00179	277.67^{abc}	173.75^{cdef}	103.92^{ghijklm}	365.17^{fgh}	191.42^{j}	5.07^{l}	85.65^{b}
TDa11/00189	318.08^{fgh}	106.54^{a}	211.54^{t}	159.54^{a}	53.00^{a}	4.23^{a}	82.88^{b}
TDa11/00225	354.17^{jklm}	247.29^{klm}	106.88^{ghijklmn}	439.83^{kl}	192.54^{jk}	4.87^{hij}	84.10^{b}
TDa11/00232	343.25^{hijklm}	287.67^{no}	55.58^{bcd}	494.71^{mn}	207.04^{kl}	5.03^{jkl}	83.63^{b}
TDa11/00242	467.46^{r}	368.63^{q}	98.83^{fghijkl}	504.21^{no}	135.58^{g}	5.23^{m}	82.40^{b}
TDa11/00247	356.33^{klm}	238.58^{jkl}	117.75^{jklmno}	456.92^{l}	218.33^{lm}	4.60^{ef}	83.30^{b}
TDa11/00275	308.17^{cdefg}	194.50^{fg}	113.67^{ijklmno}	369.46^{gh}	174.96^{i}	4.87^{hi}	85.20^{b}
TDa11/00287	319.54^{fghi}	208.42^{ghi}	111.13^{hijklmno}	319.42e	111.00^{ef}	4.63^{ef}	81.20^{b}
TDa11/00292	272.92^{ab}	190.42^{efg}	82.50^{efgh}	364.29^{fgh}	173.88^{i}	4.80^{ghi}	83.68^{b}
TDa11/00299	435.79^{pq}	327.71^{p}	108.08^{hijklmn}	504.54^{no}	176.83^{i}	4.67^{efg}	82.35^{b}
TDa11/00305	322.63^{fghij}	270.58^{mno}	52.04^{bc}	533.54^{p}	262.96^{p}	5.07^{l}	84.40^{b}
TDa11/00317	313.13^{efgh}	209.21^{ghi}	103.92^{ghijklm}	435.88^{kl}	226.67^{mn}	4.83^{hi}	82.73^{b}
TDa11/00324	312.33^{defgh}	226.75^{hijk}	85.58^{efghi}	493.33^{mn}	266.58^{p}	4.73^{fgh}	83.63^{b}
TDa11/00368	252.42^{a}	161.29^{bc}	91.08^{efghij}	306.42^{e}	145.21^{gh}	4.82^{ghi}	83.00^{b}
TDa11/00370	278.46^{abcd}	139.54^{b}	138.92^{opqr}	224.79^{b}	85.25^{c}	4.37^{abc}	82.03^{b}
TDa11/00374	363.25^{lmn}	205.00^{gh}	158.25^{qr}	314.54^{e}	109.54^{ef}	4.50^{cde}	82.43^{b}
TDa11/00424	406.21^{op}	271.42^{mno}	134.79^{nopqr}	392.17^{i}	120.75^{f}	4.93^{ijkl}	81.65^{b}
TDa11/00426	394.25^{no}	233.00^{ijk}	161.25^{r}	351.54^{fg}	118.54^{ef}	4.67^{efg}	81.68^{b}
TDa11/00428	292.50^{bcdef}	163.54^{bcd}	128.96^{mnop}	267.67^{d}	104.13^{de}	4.50^{cde}	82.60^{b}
TDa11/00434	301.50^{bcdefg}	205.63^{gh}	95.88^{efghijk}	359.08^{fg}	153.46^{h}	4.60^{ef}	82.88^{b}
TDa11/00493	345.33^{hijklm}	188.75^{efg}	156.58^{qr}	310.04^{e}	121.29^{f}	4.53^{de}	81.83^{b}
TDa11/00495	371.04^{mn}	158.21^{bc}	212.83^{t}	247.63^{cd}	89.42^{c}	4.30^{ab}	80.25^{b}
TDa11/00541	307.71^{cdefg}	237.17^{jkl}	70.54^{cdef}	457.33^{l}	220.17^{lm}	5.07^{l}	84.48^{b}
TDa11/00555	302.67^{bcdefg}	233.88^{ijk}	68.79^{bcde}	479.92^{m}	246.04^{o}	4.93^{ijkl}	84.78^{b}
Mean	336.01	225.96	110.05	386.28	160.32	4.80	82.67
STDEV	52.64	55.22	44.18	92.66	57.93	0.28	2.94
SE	8.77	9.20	7.36	15.44	9.66	0.05	0.49

Values with the same superscript within the same column are not significantly different ($p \geq 0.05$)

varieties.

The pasting temperatures for *D. rotundata* and *D. alata* species varied from 79.38 to 83.28°C and 67.10 to 85.65°C (Table 3 and 4). The lower pasting temperature of *D. rotundata* species compared with those of *D. alata* (Figure 9) implies a lower gelatinisation temperature, indicating a shorter cooking time (Otegbayo *et al.*, 2014). It is also an indication of the strength of associative forces within starch granules, relating to the stability of the paste (Afoakwa and Sefa-Dedeh, 2002), as well as inhibition of swelling (Kaur and Singh, 2005). High pasting temperatures of *D. species* compared with other starches may limit its utilization in industries, since starches with low pasting temperatures are of more advantage in reducing energy cost, however, this is an advantage in canned and sterilized foods, processed at high temperatures. The larger granules of *D. rotundata*

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species contributes to its lower pasting temperature as less molecular bonding exist, making it swell faster and building higher viscosity. Figure 10a and Figure 10b give the typical pasting graph for *D. rotundata* and *D. alata* varieties starch. Pasting properties have shown that yam starches exhibit good gel-forming properties, which could be said to be on the average when compared with other starches that have been accepted for industrial uses, from which the exceptional varieties can be selected; this could be useful as thickeners, fillers and gelling agents for industrial use. However, these starches could as well

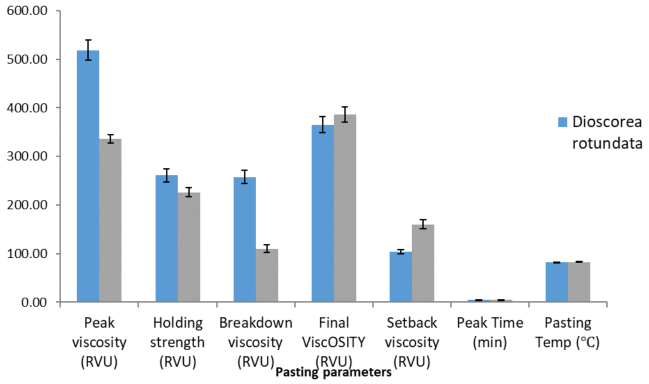
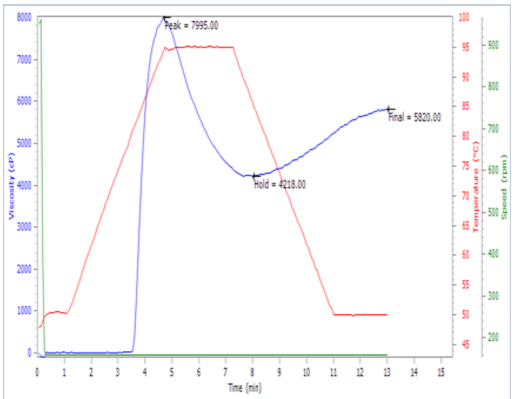
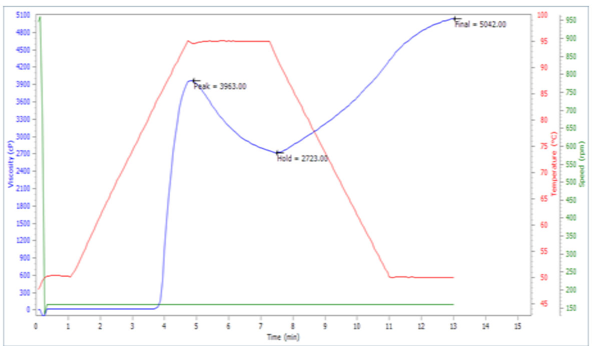


Figure 9. Pasting properties of *D. rotundata* and *D. alata* species

be



(a) TDr99-02607



(b) TDa11/00225

Figure 10. Typical pasting graphs for starch of: (a) *D. rotundata* and (b) *D. alata*

slightly modified using suitable methods, to achieve varying desired purposes.

4. Conclusion

The study affirmed the multi-variability of *Dioscorea* species, as shown by the physicochemical properties of *D. rotundata* and *D. alata starches*, both within and between species. The present characterisation of fifty-five varieties of *Dioscorea species* germplasm in Nigeria adds to the database on physicochemical properties of yams, providing relevant information for both food and non-food uses. However, for optimum results and wider applications from the starch utilisation, starch modifications could be done to circumvent the disadvantages of native starch and increase its application.

Conflict of interest

The authors declare no conflict of interest.

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