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Physicochemical properties of five cocoyam (*Colocasia esculenta* and *Xanthosoma sagittifolium*) starches

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ABSTRACT

Physicochemical properties of starches of five cocoyam cultivars were evaluated. CIE L^*, a^*, b^* colour parameters of corm and starches were measured. Amylose, pasting and functional properties of the starches were investigated using colourimetric, Rapid Visco-Analyser and standard methods respectively. Cocoyam starches were white in colour as shown by L^* (84.83–88.65), a^* (+0.01–+1.19), and b^* (+15.33–+16.54) values. Starch granule sizes varied significantly in length (6.47–13.63 μm) and width (5.36–8.45 μm), while amylose content ranged from 11.55% (NCe002) to 33.77% (NXs001). Peak (49.09–141.96 RVU), breakdown (49.09–141.96 RVU), final (189.79–327.42 RVU) viscosities, pasting temperature (84.53–88.75 °C) and time (4.55–4.97 min) varied significantly ($p < 0.05$) among cultivars. Also, water absorption capacity (21–36%), pH (4.8–5.3), gelling point (60.5–69.5 °C), foam capacity (4.46–18.28%), bulk density (0.14–1.15 g/mL) and swelling power (2.31–10.09) varied significantly ($p < 0.05$) among the cultivars. Average yield of the starches varied significantly from 10.03 (NCe001) to 18.61% (NXs001).

1. Introduction

Cocoyam belongs to the monocotyledonous family *Araceae* (the aroids) which contains several plants that are cultivated and used for food in various parts of the tropics and sub-tropics (Onwueme, 1978). *Colocasia esculenta* (L.) Schott and *Xanthosoma sagittifolium* (L.) Schott are the two most important genera generally grown for food. Although cultivated as annual crops, they are perennial herbaceous plants. Nutritionally, cocoyam is superior to cassava and yam as it has nutritional advantages over root and other tuber crops (Lyonga & Nzietchueng, 1986). Cocoyam has been found to have more crude protein than other root and tubers and its starch is highly digestible. Cocoyam contains about (dry matter) 75.5% carbohydrate, 10.95% moisture, 6.93% crude protein, and 2.1% ash (Amanze, 2009). Cocoyam is used essentially the same way as yam, although it is not considered as prestigious as yam. Some cultivars could be eaten boiled, fried or pounded after boiling into fufu while, some cultivars are used as soup thickener. In spite of its unique added advantages when compared to roots and other tubers, post harvest utilization of cocoyam is still limited, as very little study or efforts have been directed to its improved relevance to man.

Cocoyam contains relatively high content of starch which could be extracted and used in different industries based on its suitability (Moorthy, 2002). Starch is a naturally occurring polymer of α-D glucose. It is the main energy reservoir of higher plants, and also a major source of dietary energy for humans and animals. Besides its nutritive value, starch is a very useful raw material with a wide range of applications in both the food and non-food industries. Starch application in industrial related products dates back to ancient times. Today, some uses of starch include: food additive to control consistency and texture of sauces and soups, to resist the breakdown of gel during processing and increase shelf life of an end product in the food industry, laundry sizing of fine fabrics and skin cosmetics in the textile and cosmetic industry, enhancing paper strength and printing properties in the paper industry, tablet fillers in pharmaceutical industry, and binders in the packaging industry (Mweta, 2009).

One of the best ways to preserve cocoyam and increase earning from this crop could be by processing them to obtain starches, due to their high starch concentration that ranges between 22 and 40% (Instituto Nacional de Nutrición (INN), 1999; Montaldo, 1992). Starches of tuber crops are now receiving increasing attention. As a result of the increasing pressure on cereal starch, the starch industry pays attention to other alternatives which could satisfy commercial demands. For these reasons it is necessary to understand the physicochemical properties alongside the characteristics that govern the behaviours of cocoyam during processing, storage and preparation, as they affect the qualities and acceptability of cocoyam starches. Availability of this information would help to recommend the cultivars that may be suitable for specific purposes

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and provide data for use in planning for production and trade. Recent studies also show that cocoyam starch can be incorporated in the development of weaning food which is easily digestible and accessible to low-income earners in developing countries (Oti & Akobundu, 2008). Utilization of starch in both the food and non-food industries depends on its physical, chemical and functional properties. These properties are unique for different crops and varieties, particularly for newly developed cultivars. Although literature abound in physicochemical properties of cocoyam starches, it is necessary to evaluate newly developed cultivars for their properties and utilization in food systems. Therefore, understanding the physicochemical properties of starch from different sources can help in utilization of starch for the different applications. Consequently, this study was investigated the functional and physicochemical characteristics of five cocoyam cultivars.

2. Materials and methods

Fresh samples of five (5) cocoyam (*Colocasia esculenta* (taro) and *Xanthosoma sagittifolium* (tannia)) cultivars used for this study were obtained from the National Root Crops Research Institute, Umudike, Abia State, Nigeria.

2.1. CIE $L^* a^* b^*$ colour determination

Surface colour of the peeled surface of cocoyam corms was evaluated visually, and objectively using a colourimeter (Colour Tec PCM™ Colour Tec Associates Inc, Clinton, NJ, USA). Each peeled cocoyam cultivar was freshly sliced into halves vertically and longitudinally, and $L^* a^* b^*$ parameters of the interior were evaluated. $L^* a^* b^*$ readings were taken at various points on the cut corms and also on the cocoyam starches after preparation. L^* values range from 100 (white) to 0 (black), a^* values range from $+a^*$ (green) to $-a^*$ (red), and b^* value range from $+b^*$ (yellow) to $-b^*$ (blue). Averages of the readings were computed and reported. Chroma (ΔC), colour intensity (ΔE) and hue angle (H) were calculated using Eqs. (1)–(3), respectively (Hunt, 1991), pp.75–76.

$$\Delta C = \sqrt{(\Delta a^*)^2 + (\Delta b^*)^2} \quad (1)$$

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (2)$$

$$\text{Hue angle} = \text{Tan}^{-1} b/a \quad (3)$$

2.2. Preparation of cocoyam starch

Cocoyam corms (1–1.2 kg) were sorted, washed with potable tap water and manually peeled with sharp stainless steel knife. The peeled samples were rewashed and cut into cubes ($1 \times 1 \times 1$ cm), blended for 3–4 min with distilled water at a low speed setting, using a Waring blender (Model HGBTWT; Warring Commercial, Torrington, USA). The resulting slurry was then washed with potable tap water through a fine triple cheese (muslin) cloth to separate cell debris and the suspension, as described by Peshin (2001). The filtrate was then allowed to settle for 3–6 h then centrifuge (Serial No. ST00103; Model No. L-708-2; Phillips Drucker, Oregon, USA) at $300 \times g$ for 15 min, the supernatant was decanted and the residue starch was removed from the centrifuge tubes unto perforated oven trays lined with paper towel, then oven (using a cross flow Precision Gravity Convection Oven; Model No. STG40, Chicago) dried at 45 °C for 24 h. The dried starches were finely ground using an electric hand mill (Romer serial II mill, Romer, USA), and packaged separately in transparent poly propylene bags, sealed, labelled and stored until required for analysis. Yield of starch was calculated as: weight of starch/weight of peeled root.

2.3. Determination of pasting properties

Pasting properties were determined in duplicate in a Rapid Visco Analyzer (Serial No. 2031531, Model RVA-4; Newport Scientific Pty. Ltd, Warriewood, Australia). A suspension of 15% starch (dry weight basis) in distilled water was heated from 30 °C to 95 °C with constant stirring at $1600 \times g$. The sample was held at 95 °C for 6 min (breakdown), and then cooled to 50 °C (setback). Total cycle time was 38 min; pasting curves were obtained for the starch samples of each cocoyam cultivar. Viscoamylograph profiles were determined as follows: the pasting temperature was defined as the temperature at which an increase in viscosity was first detected by the instrument; peak viscosity was defined as the equilibrium point between swelling and polymer leaching; trough was defined as the lowest viscosity; final viscosity was defined as the viscosity of the sample at the end of the cycle period; setback was defined as the difference between final viscosity and peak viscosity; peak time was defined as the time the peak viscosity occurred (Jangchud, Phimolsiripol, & Haruthaithanasan, 2003).

2.4. Granular size and shape distribution

This was determined using the method as described by Mweta (2009), with little adjustments. The granular size and shape of the cocoyam starches were examined using a Microscope Digital Camera System (Model No. BX51/BX52). 2 mL of distilled water was mixed with two (2) drops of safranin dye. Then two drops of the solution was placed on a clean slide, a pinch of starch (about 2 mg) was dispersed unto the solution on the slide, while making sure that the starch grains settled down, and were thinly spread onto the slide. The slides were covered with a transparent cover slip piece, and then examined under the microscope. The range of the granular starch sizes were determined by measuring the length and width of 30 granules at random, using a Light Microscope (Model No. SE1991, Labourlux, Portugal).

2.5. Swelling power and solubility determination

Swelling power and solubility of cocoyam starches were determined in triplicate, by heating a starch–water slurry (0.35 g starch in 12.5 mL of distilled water) in a water bath at 60 °C for 30 min, with constant stirring (Crosbie, 1991). The slurries were centrifuged using a Super-speed centrifuge at $168 \times g$ for 15 min, the supernatant was decanted into a weighed evaporating dish and dried at 100 °C for 20 min. The difference in weight of the evaporating dish was used to calculate starch solubility. Swelling power was obtained by weighing the residue after centrifugation and dividing by original weight of starch on dry weight basis (Osundahunsi, Fagbemi, Kesselman, & Shimoni, 2003).

2.6. Amylose and amylopectin determination

Amylose content of the starch samples was determined in duplicate by colourimetric method (AACC 2000; method 61–03). The colour of starch–iodine complex developed at pH 4.5–4.8 in acetate buffer was read in a Helios spectrophotometer (Pye Unicam, Germany) at 620 nm. The blue colour developed was read against a standard amylose curve plotted from solutions with concentrations of 0–100 mg amylose per 100 mL of water.

The amylopectin content was calculated by subtracting the amylose content from 100%.

2.7. Gelling and boiling points determination

The method of Narayana and Narasinga-Rao (1982) was adopted in the determination of gelling and boiling points. The starch sample (10 g) was dispersed in distilled water, in a 250 mL beaker and made up to 100 mL. A thermometer was clamped on a retort stand such that its bulb submerged in the suspension. With a magnetic stirrer the suspension was continuously stirred and heated. This continued until the suspension began to gel and the corresponding temperature recorded. The temperature as soon as boiling commenced was also noted and recorded. This analysis was done in triplicate.

2.8. Foam capacity and foam stability determination

The method described by Narayana and Narasinga-Rao (1982) was used for the determination of foam capacity and foam stability in triplicate. Two grammes of starch sample was added to 50 mL distilled water at 30 ± 2 °C in a 100 mL measuring cylinder, stirred and the volume noted. The suspension blended in a warring blender (Model HGBTWT; Warring Commercial, Torrington, USA) at $160 \times g$ for 5 min to form foam, then returned to the measuring cylinder and the volume of the foam after 30 s was recorded. The foam capacity was expressed as a percentage increase in volume using the formula of Abbey and Ibeh (1988). The foam volume was recorded in 1 h after whipping to determine the foam stability as a percentage of the initial foam volume. Analysis was conducted in triplicate.

2.9. Determination of pH

A 10% (w/v) starch–water suspension for each sample was prepared and allowed to settle at room temperature (30 ± 2 °C) for 15 min in a clean beaker (200 mL). The pH metre switched on and allowed for 15 min to stabilize. The electrodes were standardized chemically, using buffer solution of pH 4, 7 and 9.9 respectively the electrode was then inserted into the test suspension and the pH value read and recorded (Onwuka, 2005). Analysis was conducted in triplicate.

2.10. Determination of water absorption capacity

Water absorption capacity was determined using methods described by Beuchat, Cherry, and Quinn (1975), pp.140–149. 1 g of sample was weighed into 25 mL graduated conical centrifuge tubes; both weight noted, then 10 mL of water added. The suspensions were allowed to stand at room temperature (30 ± 2 °C) for 1 h. The suspension was centrifuged (Serial No. ST00103; Model No. L-708-2; Phillips Drucker, Oregon, USA) at $200 \times g$ for 30 min. The supernatant was decanted and then the sample was reweighed. The change in weight was expressed as percent water absorption based on the original sample weight. Analysis was conducted in triplicate.

2.11. Determination of oil absorption capacity

The method of Sosulski (1962) as described by Abbey and Ibeh (1988) was adopted in determining the oil absorption capacity. 1 g of each sample was weighed into a dry, clean centrifuge tube and both weight noted. Grand soya oil (10 mL) with density of 0.98 gm^{-1}, was poured into the tube and properly mixed with the samples using a stainless steel spatula; the suspension was centrifuged (Serial No. ST00103; Model No. L-708-2; Phillips Drucker, Oregon, USA) at $350 \times g$ speed for 15 min, then, the supernatant was discarded and the tube with its content re-weighed. The gain in mass expressed as a percentage of oil bound is the oil absorption capacity of the sample. Analysis was conducted in triplicate.

2.12. Bulk density determination

This was determined in triplicate by the method of Narayana and Narasinga-Rao (1984). Each sample (50 g) was filled into graduated cylinder and their weight noted. The cylinder was tapped continuously until there was no further change in volume. The weight and final volume of the starch in the cylinder noted and the difference in weight and volume determined. The bulk density was computed as grams per millilitre (g/mL) of the sample. Analysis was conducted in triplicate.

2.13. Statistical data analysis

Data were analyzed using the Analysis of Variance (ANOVA) statistical method using SAS (Statistical Analysis System Institute, Inc., 2008, Cary, NC, USA.) version 9.2 program of the Complete Randomized Design (CRD). Mean separation method was done by Least Significant Difference (LSD) method and Duncan's (1955) multiple range test. Significant differences were established at $p \leq 0.05$.

3. Results and discussion

For the purposes of this study the cultivars: Coco India, Ede ofe green, Ede ofe purple, Ede ocha, and Okorokoro will be discussed as NCe001, NCe002, NCe003 (*Colocosia* spp.), NXs001 and NXs003 (*Xanthosoma* spp.), respectively. The corms varied in weight and geometry (length, width); the weight of the NCe001, NCe002, NCe003 (*Colocosia* spp.), NXs001 and NXs003 (*Xanthosoma* spp.) cultivars were 36.21 ± 18.36, 14.26 ± 9.13, 39.64 ± 33.75, 179.20 ± 120.74, and 605.94 ± 547.01 g; the length were 41.58 ± 2.85, 41.98 ± 1.77, 46.12 ± 5.75, 95.16 ± 15.40 and 151.46 ± 91.44 mm; and the width 41.33 ± 11.84, 25.65 ± 6.27, 36.24 ± 10.20, 78.03 ± 20.08 and 75.29 ± 26.34 mm, respectively. The shapes were round, and some could be described as long, semi-circle and gourd.

3.1. CIE L^*, a^*, b^* and other colour parameters of peeled cocoyam flesh and starches of cocoyam

The L^*, a^*, b^* colour space scale is a more visual uniform colour scale for measuring colour of samples. The L^*, a^*, b^*, chroma (ΔC), colour intensity (ΔE) and hue angle colour parameters of the peeled cocoyam flesh cultivars are shown in Table 1. Visually, flesh colours of the tubers could be described as cream to yellow. The colours of the flesh were generally lighter than the peel colour, which appeared brown in colour. L^* (lightness) value of the flesh colour ranged from 72.08 (NCe001) to 78.93 (NCe002), higher L^* value indicated lighter (whiter) colour. The L^* value of the cocoyam flesh colour was significantly different ($p < 0.05$). The NCe002 and NCe003 cultivars were similar but appeared lighter than other cultivars, however, NCe001 with the significant lower L^* value had a darker flesh colour. The flesh showed a^* values ranging from +1.06 (NCe001) to +3.45 (NXs003), while the b^* values of the flesh varied from +17.65 (NCe002) to +35.8 (NXs003). The b^* values were higher for the *Xanthosoma* spp. than the *Colocasia* spp. cocoyam flesh. The $+a^*$ and $+b^*$ values appear as red, and orange to yellow colour, respectively. The intensity of yellow is dependent on the concentration of the beta carotene pigment (Woolfe, 1992). The

Table 1
CIE Tristimulus L^*, a^*, b^* and other colour parameters of the flesh of peeled cocoyam corms.

Cultivars	L^*	a^*	b^*	ΔE	ΔC	Hue angle
NCe001	$72.08^{c} \pm 2.33$	$3.25^{ab} \pm 1.03$	$22.06^{bc} \pm 1.03$	$75.49^{c} \pm 1.75$	$22.31^{bc} \pm 2.05$	$81.70^{a} \pm 2.03$
NCe002	$78.93^{a} \pm 1.13$	$1.06^{b} \pm 0.68$	$17.65^{c} \pm 2.59$	$80.92^{b} \pm 1.28$	$17.70^{a} \pm 2.53$	$86.19^{a} \pm 3.08$
NCe003	$78.69^{a} \pm 1.05$	$2.15^{ab} \pm 3.80$	$19.9^{bc} \pm 3.81$	$81.12^{b} \pm 1.26$	$19.59^{bc} \pm 2.50$	$81.86^{a} \pm 15.70$
NXs001	$76.85^{ab} \pm 2.59$	$3.50^{a} \pm 1.52$	$27.58^{ab} \pm 7.32$	$81.92^{b} \pm 4.82$	$27.88^{ba} \pm 7.13$	$81.85^{a} \pm 4.53$
NXs003	$76.47^{b} \pm 1.42$	$3.45^{a} \pm 0.81$	$35.80^{a} \pm 15.53$	$85.62^{a} \pm 3.97$	$36.07^{a} \pm 15.26$	$80.42^{a} \pm 11.59$
LSD	2.16	2.31	9.51	3.58	9.22	10.83

Means in a column with the same letter are not significantly different ($P < 0.05$). Means of six replicates. LSD – Least Significant Difference.

higher $+b$ value and the visual bright yellow appearance adequately reflected the colour of the NXs003 which was locally called the "egg yolk" cocoyam because of its yellow colouration. The high $+a^*$ and $+b^*$ values recorded in some of the cocoyam cultivars (NXs003 and NCe001), although advantageous in foods, may adversely affect starch quality since the extraction and leaching of the colour pigments result in discolouration of the starch granules (Moorthy, 2002).

Chroma, colour intensity and hue angle of the flesh colour were calculated from the L^*, a^*, b^* parameters as shown by Eqs. (1)–(3), respectively. Chroma (ΔC) value of the flesh varied significantly ($p < 0.05$) from 17.70 (NCe002) to 36.07 (NXs003), while the colour intensity (ΔE) of the flesh ranged from 75.49 (NCe001) to 85.62 (NXs003). The flesh of *Xanthosoma* spp showed comparable higher colour intensity values than the *Colocasia* spp. The chroma (ΔC) values exhibited some significant variations among the cocoyam cultivars. The hue angle is another parameter frequently used to characterize colour in food products and has been used extensively in the evaluation of colour parameter in green vegetables, fruits and meat (Barreiro, Milano, & Sandoval, 1997). Calculated hue angle of the flesh of the cocoyam corms ranged between 80.42 (NXs003) and 86.19 (NCe002). The five cocoyam corms showed similarity in hue angle of their flesh colours.

Table 2 shows the L^*, a^*, b^*, chroma (ΔC), colour intensity (ΔE) and hue angle colour parameters of the cocoyam starches. The L^* (lightness) value of the starches ranged from 84.83 (NCe001) to 88.65 (NCe003). No similarity ($p < 0.05$) was observed in the L^* values of all the cocoyam cultivars. Confirmed by the lower L^* value, NCe001 appeared visually darker than other cultivars, while NCe002 and NCe003 had lighter colour when compared to the L^* value of their starch and other cultivars. The cocoyam starches showed a^* values ranging from +0.01 (NXs003) to +1.19 (NCe001), while the b^* values varied from +15.33 (NXs003) to +16.54 (NCe001). Significant variations ($p < 0.05$) was observed in the a^* values of the cocoyam starches, except for the *Xanthosoma* spp which were similar. However, the NCe001 starch was significantly different ($p < 0.05$) from other cultivars which showed similarity in their b^* values. It could be deduced that the extent of starch discolouration due to leaching of colour pigments from cocoyam was minimal (Table 2).

Chroma (Eq. (1)) value of the starch samples varied from 15.33 (NXs003) to 16.58 (NCe001), while the colour intensity (Eq. (2)) of the starch ranged from 86.43 (NCe001) to 89.97 (NXs003). The chroma (ΔC) values of the cocoyam starches were similar, except for NCe001 which differed significantly ($p < 0.05$). Colour intensity (ΔE) of the starches was significantly different ($p < 0.05$) among the *Colocasia* spp, while the *Xanthosoma* spp. showed similarity. Calculated hue angle of the cocoyam starches significantly varied between 86.43 (NXs003) and 89.97 (NCe002). The differences in the visual as well as objectively measure colour parameters of the cocoyam cultivars could be due to genetic variation, climate and agronomic factors. Such variations have been ascribed to differences in the genetic background as well as climate, season (Lu, Chen, Lin, & Chang, 2005), and the agronomic factors. Sefa-Dedeh and Agyir-Sackey (2004) observed that the chemical composition of three varieties of cocoyam, *X. sagittifolium* (red-flesh and white-flesh) and *C. esculenta var esculenta* showed wide variations among the varieties and across their respective cormels. Cocoyam starches could be recommended for food products requiring bright colours as little or no bleaching actions will be required (Liu, Donner, Yin, Huang, & Fan, 2006).

3.2. Amylose and amylopectin content of cocoyam starch

Starch consists of two basic molecules; amylose and amylopectin, in most cases the amylose content of starch is assumed to be made up to a 100% by the amylopectin content (Mweta, 2009). Amylose and amylopectin contents of the cocoyam starches varied significantly ($p < 0.05$) among some cultivars, ranging from 11.55% (NCe002) to 33.77% (NXs001) and 66.23% (NXs001) to 88.45% (NCe002), respectively (Table 3). For instance, amylose content of NXs001 was about double that of other cultivars. The amylose values in this study differed from the amylose content of 21.3–25.4% and 22.7% reported by Lauzon et al. (1995) and Lawal (2004), but agrees with the amylose content (3–43%) of cocoyam stated by Moorthy (2002). Differences in the composition of taro corms might have been related to their species origin, fertility, geographical sources, or planting periods (Bradbury & Holloway, 1988), pp.75–76. Multiple range analysis ($P \leq 0.05$) showed that most notable sources of variation were between the Xanthosoma species and the Colocasia species (Sefa-Dedeh & Agyir-Sackey, 2004). The variation in levels of nutrients and anti-nutritional factors observed among the varieties and field preparations may offer some meaningful information for taro cultivation and for further processing operations (Huang, Chen, & Wang, 2007).

Table 2
CIE Tristimulus L^*, a^*, b^* and other colour parameters of the cocoyam starches.

Cultivars	L^*	a^*	b^*	ΔE	ΔC	Hue angle
NCe001	$84.83^{d} \pm 0.12$	$1.19^{a} \pm 0.06$	$16.54^{a} \pm 0.10$	$86.43^{d} \pm 0.14$	$16.58^{a} \pm 0.10$	$85.90^{d} \pm 0.20$
NCe002	$87.10^{b} \pm 0.09$	$0.78^{b} \pm 0.02$	$15.47^{b} \pm 0.19$	$88.46^{b} \pm 0.12$	$15.48^{b} \pm 0.19$	$87.13^{c} \pm 0.11$
NCe003	$88.65^{a} \pm 0.06$	$0.39^{c} \pm 0.09$	$15.39^{b} \pm 0.11$	$89.97^{a} \pm 0.04$	$15.39^{b} \pm 0.11$	$88.57^{b} \pm 0.33$
NXs001	$86.26^{c} \pm 0.18$	$0.05^{d} \pm 0.01$	$15.45^{b} \pm 0.21$	$87.63^{c} \pm 0.21$	$15.45^{b} \pm 0.21$	$89.83^{a} \pm 0.03$
NXs003	$86.40^{c} \pm 0.12$	$0.01^{d} \pm 0.00$	$15.33^{b} \pm 0.26$	$87.74^{c} \pm 0.04$	$15.33^{b} \pm 0.26$	$89.96^{a} \pm 0.00$
LSD	0.28	0.13	0.47	0.33	0.47	0.46

Means in a column with the same letter are not significantly different ($P < 0.05$). Means of six replicates. LSD – Least Significant Difference.

Table 3
Amylose[x], amylopectin[x], starch yield[x] and granular sizes of cocoyam starches.

Cultivars	Amylose[x] (%)	Amylopectin[x] (%)	Starch yield[x] (%)	Length[y] (μm)	Width[y] (μm)	Shape
NCe001	$15.06^{bc} \pm 0.65$	$84.94^{b} \pm 0.65$	$10.03^{c} \pm 1.50$	$6.47^{a} \pm 4.4$	$5.58^{a} \pm 3.0$	Round
NCe002	$11.55^{c} \pm 0.15$	$88.45^{a} \pm 0.15$	$13.98^{b} \pm 0.93$	$13.63^{a} \pm 24.5$	$5.99^{a} \pm 6.0$	Round
NCe003	$17.97^{b} \pm 0.00$	$82.03^{c} \pm 0.00$	$11.72^{c} \pm 1.03$	$8.48^{a} \pm 8.9$	$5.36^{a} \pm 5.7$	Round
NXs001	$33.77^{a} \pm 1.49$	$66.23^{d} \pm 1.48$	$18.61^{a} \pm 1.44$	$10.76^{a} \pm 6.8$	$8.45^{a} \pm 5.2$	Round, hexagonal
NXs003	$16.01^{b} \pm 0.79$	$83.99^{bc} \pm 0.79$	$10.85^{c} \pm 1.20$	$9.71^{a} \pm 11.8$	$6.48^{a} \pm 6.0$	Round, long
LSD	3.96	2.81	1.79	7.76	3.10	

Means in a column with the same letter are not significantly different ($P < 0.05$). x – means of 3 replicates, y – means of thirty replicates. LSD – Least Significant Difference.

According to Riley et al. (2004) the difference in amylose content observed may be attributed to genetic variations among the cultivars. In fact, it has been postulated that the amylose content of starches is affected by the expression of the amylose extender gene (Noda, Takahata, & Nagata, 1992). Previous reports (Noda et al., 1992; Riley et al., 2004) have shown that the amylose content plays a key role in the digestion of starches, as starches with low amylose contents were found to be more digestible than starches with high amylose content. Amylose content of starch is also an important characteristic that affects its functionality (Lu et al., 2005). Amylose content correlated positively with final viscosity (0.82), setback viscosity (0.88) and pH (0.92). However, amylose content of the starches correlated negatively with water absorption capacity (−0.72) (Table 6). Functional properties of starches depend on the amylose content to a large extent (Adebowale & Lawal, 2003). It is noteworthy to state that the cocoyams have very little protein and fat and this would minimise these components contaminating the starch.

3.3. Sizes and shape and yield of starch granules

Table 3 shows the starch granular size of the cocoyam cultivars. The size of starch granules in food crops is of importance to the food processor, as it affects the behaviour of the food during processing. For example, small starch granules are more resistant to rupture and loss of molecular order (Dreher & Berry, 1983). The size of the starch granules is known to vary with botanical sources (Mweta, 2009). Granule sizes ranging from 0.05 to 0.08 μm, 2.96 to 5.19 μm and 0.5 to 5.0 μm (Jobling, 2004; Maeda, Maryant, & Morita, 2004; Moorthy, Thankamma-Pillai, & Unnikrishnan, 1993; Pérez, Schultz, & Delahaye, 2005; Sefa-Dedeh & Kofi-Agyir Sackey, 2002) have been reported for cocoyam starches. Granule size of cocoyam starch in this study is comparatively larger (length = 6.47–13.63 μm; width = 5.36–8.45 μm) than most reported values but within the range reported for native cocoyam starch (4–18.7 μm) from Malawian (Mweta, 2009). Mean granular starch size of all the cultivars was similar ($p < 0.05$). *Colocasia* spp. showed smaller width than the *Xanthosoma* spp. Similar trend was observed for the length except for NCe002 which showed a comparative higher value. A comparison of starch granule sizes showed that sweet potato starch has larger granules than cassava and cocoyam starches (Wickramasinghe, Takigawa, Matsuura-Endo, Yamauchi, & Noda, 2009). Different environments and growing conditions also affect the size of the starch granules (Lu, Lin, Chen, & Chang, 2008). Thus, variations in starch granule size observed in this study could be due to genetic variations and/or different environmental conditions (Noda, Kobayashi, & Suda, 2001; Tester & Karkalas, 2001). Average yield of the starches ranged from 10.03 (NCe001) to 18.61% (NXs001). The NXs 001 cultivars showed significantly higher starch yield than other selected cultivars. Among the *Colocasia spp*., NCe002 showed significantly higher starch yield.

3.4. Pasting properties of cocoyam starches

The ability of starch to imbibe water and swell is primarily dependent on the pasting temperature. Starch granules swell and form paste by imbibing water in the presence of water and heat. Table 4 shows the pasting properties of the cocoyam starch samples. The pasting temperatures for the starch samples varied significantly ($p < 0.05$) between 84.53 °C (NCe001) and 88.75 °C (NCe003). The pasting temperature depends on the size of the starch granules; small granules are more resistant to rupture and loss of molecular order (Dreher & Berry, 1983). This might explain the relatively high pasting temperature which does not correspond with range of 50–86.6 °C in literature for sweet potatoes (Aina, Falade, Akingbala, & Titus, 2009; Liu et al., 2006; Osundahunsi et al., 2003). Moreover, cocoyams have small starch granule sizes; *Colocasia* spp. with smaller granular size showed higher pasting temperatures compared to *Xanthosoma* spp. Pasting temperature significantly correlated with peak (−0.95), breakdown (−0.97) and peak time (0.96) (Table 6).

Peak viscosity ranged from 191.3 RVU (NCe003) to 306 RVU (NXs003). Peak viscosity which shows the maximum swelling of the starch granule prior to disintegration has also been described as the equilibrium point between swelling and breakdown of the granules (Liu et al., 2006). Hoover (2001) stated that granules with high peak viscosity have weaker cohesive forces within the granules than those with lower values and would disintegrate more easily. Peak viscosity showed a significant ($p < 0.05$) positive correlation with breakdown viscosity (0.87), but a significant negative correlation with peak time (−0.91) and pasting temperature (−0.95).

Breakdown viscosity, a measure of the resistance to heat and shear, of the cocoyam cultivars varied significantly ($p < 0.05$) between 49.09 RVU (NCe003) and 141.96 RVU (NCe001). Since breakdown viscosity is an estimation of paste resistance to disintegration in

Table 4
Pasting properties of starches of cocoyam cultivars.

Sample	Peak viscosity (RVU)	Trough viscosity (RVU)	Breakdown viscosity (RVU)	Final viscosity (RVU)	Setback viscosity (RVU)	Peak time (min)	Pasting temperature (°C)
NCe001	$280.67^{a} \pm 2.12$	$138.71^{c} \pm 2.53$	$141.96^{a} \pm 4.65$	$208.63^{d} \pm 2.06$	$69.92^{c} \pm 0.47$	$4.63^{bc} \pm 0.09$	$84.53^{b} \pm 0.60$
NCe002	$227.25^{b} \pm 15.56$	$170.59^{b} \pm 6.84$	$56.67^{c} \pm 8.72$	$228.96^{c} \pm 8.43$	$58.38^{d} \pm 1.59$	$4.97^{a} \pm 0.03$	$88.13^{a} \pm 0.04$
NCe003	$191.30^{c} \pm 1.59$	$142.21^{c} \pm 0.06$	$49.09^{c} \pm 1.53$	$189.79^{e} \pm 1.00$	$47.58^{e} \pm 1.06$	$4.97^{a} \pm 0.03$	$88.75^{a} \pm 0.28$
NXs001	$298.92^{a} \pm 3.77$	$196.96^{a} \pm 1.24$	$101.96^{b} \pm 2.53$	$327.42^{a} \pm 3.77$	$130.46^{a} \pm 2.53$	$4.73^{b} \pm 0.05$	$85.30^{b} \pm 0.07$
NXs003	$306.29^{a} \pm 17.73$	$173.00^{b} \pm 10.01$	$133.29^{a} \pm 7.72$	$252.17^{b} \pm 12.61$	$79.17^{b} \pm 2.60$	$4.55^{c} \pm 0.02$	$84.83^{b} \pm 0.25$
LSD	27.63	14.31	14.81	18.16	4.74	0.13	0.82

Means in a column with the same letter are not significantly different ($P < 0.05$). LSD – Least Significant Difference Means of two replicates; Viscosity; unit: 1 RVU = 0.01 Pa s.

Table 5
Functional properties of cocoyam starches of different cultivars.

Sample	PH	Water absorption capacity (%)	Oil absorption capacity (%)	Gelling point (°C)	Boiling point (°C)	Foam capacity (%)	Foam stability (%)	Bulk density (g/mL)	Swelling power	Solubility (%)
Nce001	$4.76^{e} \pm 0.01$	$27.5^{c} \pm 0.71$	$25.0^{d} \pm 0.00$	$67.0^{a} \pm 1.41$	$78.5^{c} \pm 0.71$	$14.05^{b} \pm 0.09$	$3.70^{d} \pm 0.02$	$0.14^{d} \pm 0.01$	$2.94^{c} \pm 0.00$	$2.67^{e} \pm 0.06$
Nce002	$4.84^{d} \pm 0.02$	$36.0^{a} \pm 0.00$	$28.0^{c} \pm 1.41$	$66.5^{a} \pm 0.71$	$84.0^{b} \pm 1.41$	$9.21^{c} \pm 0.01$	$1.26^{e} \pm 0.06$	$1.18^{a} \pm 0.01$	$2.77^{c} \pm 0.02$	$3.66^{c} \pm 0.03$
Nce003	$5.05^{b} \pm 0.00$	$32.0^{b} \pm 1.41$	$33.5^{a} \pm 0.71$	$69.5^{a} \pm 0.71$	$87.0^{a} \pm 1.41$	$4.46^{e} \pm 0.04$	$5.87^{c} \pm 0.06$	$1.15^{ab} \pm 0.01$	$2.31^{d} \pm 0.08$	$2.89^{d} \pm 0.01$
Nxs001	$5.30^{a} \pm 0.01$	$21.0^{d} \pm 1.41$	$27.5^{c} \pm 0.71$	$62.5^{b} \pm 0.71$	$86.5^{ab} \pm 0.71$	$18.28^{a} \pm 0.08$	$9.87^{b} \pm 0.02$	$1.11^{c} \pm 0.01$	$8.45^{b} \pm 0.04$	$5.18^{b} \pm 0.12$
Nxs003	$4.95^{c} \pm 0.02$	$23.5^{d} \pm 0.71$	$31.0^{b} \pm 0.00$	$60.5^{b} \pm 2.12$	$71.5^{d} \pm 0.71$	$8.39^{d} \pm 0.02$	$10.81^{a} \pm 0.03$	$1.06^{c} \pm 0.03$	$10.09^{a} \pm 0.16$	$8.19^{a} \pm 0.04$
LSD	0.03	2.57	1.99	3.25	2.70	0.15	0.10	0.04	0.21	0.16

Means in a column with the same letter are not significantly different ($P < 0.05$). Means of three replicates. LSD – Least Significant Difference.

response to heat and shear, lower breakdown viscosity showed greater resistance which would be expected of starches with lower peak viscosities (Table 4). Breakdown viscosity correlated negatively with peak time (−0.97), pasting temperature (−0.97), water absorption capacity (−0.70) and boiling point (−0.75).

Setback, defined as the difference between the breakdown viscosity and the viscosity at 50 °C, determines the tendency of starch to retrogradation (Owuamanam, Ihediohanma, & Nwanekezi, 2010). The setback values differed significantly between 47.58 RVU (NCe003) and 130.46 RVU (NXs001). Higher setback viscosity indicates higher tendency to retrogradation during cooling, and higher staling rate of the products made from the starch samples (Adeyemi & Idowu, 1990). Starches with high setback viscosity would tend to have stiffer pastes than low setback viscosity (Seog, Park, Nam, Shin, & Kim, 1987), but are susceptible to weeping when used as filling in frozen product application. Setback viscosity correlated positively with pH (0.71), foam capacity (0.85) and swelling power (0.70), while negative correlation was shown between the setback viscosity and the foam capacity (−0.85). Final viscosity ranged from 189.79 RVU (NCe003) to 327.42 RVU (NXs001).

Peak time of the cocoyam starches ranged from 4.55 min (NXs003) to 4.97 min (NCe002 and NCe003). However, these cultivars with higher peak time also recorded low peak viscosities (Table 4). This is to be expected as high peak times characterize low swelling starch granules in the flour. Garcia and Walter Jr (1998) stated that starch which exhibits low viscosity should not be used in applications with extensive cooking. Garcia and Walter Jr (1998) described an ideal starch for many food products as one that at low concentrations produces a smooth texture with a heavy bodied paste, which remains soft and flexible at low temperature and retains its thickening power at high temperatures and high shear. Also, peak time showed a positive correlation with pasting temperature (0.96), water absorption capacity (0.79), gelling point (0.72) and boiling point but, a negative correlation with swelling power (−0.69) (Table 6).

Peak paste viscosity of most of the starches showed a sharp peak curve (Fig. 1), indicating uniformity of granule size and swelling within each sample. However, after peak paste viscosity, the samples showed differences in their patterns of pasting properties (Fig. 1), which can be grouped to predict the cooking and other food utilization properties of the cultivars. The broad grouping consists of samples with low pasting homogeneous starch granules with no apparent retrogradation, e.g. NCe001 and NXs003 (Table 4). Such starches despite their relative low viscosity can be used as fillings because of their low retrogradation and paste clarity (BeMiller & Whistler, 1996).

3.5. Functional properties

The pH values of starches were within the low acid range (Table 5). All the cocoyam cultivars varied significantly ($p < 0.05$) from 4.76 (NCe001) to 5.30 (NXs003) in their pH value. The pH is important in determining the acid factor which is an indicator for the rate of conversion of starch to dextrin (Holleman & Aten, 1956). Water absorption capacity refers to the water retained by a food product following filtration and application of mild pressure of centrifugation (Hagenmainer, 1972; Kinsella, 1976). Table 5 shows the water absorption capacity of the cocoyam starches. The water absorption capacity of the cocoyam starches differed significantly ($p < 0.05$) ranging from 21% (NXs001) to 36% (NCe002). Colocasia spp. differed significantly in their water absorption capacity while the *Xanthosoma* were similar. Water absorption capacity is mostly influenced by the degree of disintegration of native starch granules (Greer & Stewart, 1959), suggesting that undamaged starches have low potential absorption capacities. Water absorption capacity had a positive correlation with the boiling point of the starch, but showed a negatively correlation with foam stability (0.87) and swelling power (−0.83). Oil absorption capacity showed a negative correlation with foam capacity (0.79) (Table 6).

Oil absorption capacity reflects the emulsifying capacity, a highly desirable characteristic in products such as mayonnaise (Escamilla-Silva, Guzman-Maldonado, Cano-Medinal, & Gonzalez-Alatorre, 2003). It denotes the amount of oil that can be picked up by a sample during processing, for instances how samples will react during frying. The starch samples showed higher oil absorption capacity when compared to the flour samples ranging from 25.0% (NCe001) to 33.5% (NCe003) (Table 5). Significant variation ($p < 0.05$) also occurred among the starch samples except for NCe002 and NXs001 that were similar. High oil absorption properties are also required in meat replacers and extenders, doughnuts, baked goods and soups (Sai-Ut, Ketnawa, Chaiwut, & Rawdkuen, 2009).

The gelling temperature is the temperature at which a food solution forms an observable thicker consistency when heat is applied (Sat-Ut et al., 2009). *Colocasia* spp. showed similar gelling points, but were significantly different from the *Xanthosoma* spp. which were also similar (Table 5). The gelling point for the starches varied from 62.5 °C (NXs001) to 69.5 °C (NCe003). Gelling temperatures of the starches are so because, the starches have enough room to swell and form gels at relatively lower temperature. The temperature at which the vapour pressure of the liquid equals the pressure of the surrounding gases is known as the boiling point temperature (Nwokocha, Aviara, Senan, & Williams, 2009). Table 5 shows the boiling point of the cocoyam starch samples. The starches varied significantly ($p < 0.05$) from 71.5 °C (NXs003) to 87.0 °C (NCe003). The cocoyam cultivars differed significantly, except for NXs001 which showed similarity with NCe002 and NCe003.

Foam capacity and stability properties are determined by the ability to rapidly adsorb on the air–liquid interface during whipping or bubbling, and by its ability to form a cohesive viscoelastic film by way of intermolecular interactions (Mine, 1995). Table 5 presented the foam capacity and stability of the starch samples. Foam capacity and stability of starch samples varied significantly

Table 6
Correlation matrix between the pasting and functional parameters of cocoyam starches.

	Peak	Trough	Breakdown	Final viscosity	Setback	Peak time	Past temp	pH	Wac	Oac	Gp	Bp	Fc	Fs	Bd	Sp	Solubility	Amy	Amp
Peak1	1.00																		
Trough1	0.51	1.00																	
Breakdown	**0.87**[a]	0.03	1.00																
Final viscosity	0.67	**0.93**[a]	0.25	1.00															
Setback	0.73	0.80	0.40	**0.96**[a]	1.00														
Peak time	**−0.91**[a]	−0.15	**−0.97**[a]	−0.34	−0.46	1.00													
Pasting temp	**−0.95**[a]	−0.22	**−0.97**[a]	−0.46	−0.59	**0.96**[a]	1.00												
PH	0.14	0.66	−0.21	0.72	0.71	0.07	0.03	1.00											
Wac	−0.85	−0.50	−0.70	−0.72	−0.82	0.79	0.80	−0.54	1.00										
Oac	−0.50	−0.11	−0.52	−0.28	−0.38	0.35	0.57	0.29	0.17	1.00									
Gelling pt	−0.86	−0.75	−0.58	−0.75	−0.68	0.72	0.67	−0.32	0.75	0.11	1.00								
Boiling pt	−0.61	0.08	−0.75	0.08	0.07	0.79	0.64	0.48	0.34	0.08	0.58	1.00							
Foam cpt	0.69	0.52	0.51	0.75	0.85	−0.44	−0.66	0.34	−0.62	−0.79	−0.42	0.09	1.00						
Foam stb	0.61	0.51	0.42	0.61	0.63	−0.60	−0.50	0.66	−0.87	0.32	−0.75	−0.33	0.21	1.00					
Bulk density	−0.30	0.56	−0.67	0.30	0.08	0.49	0.58	0.56	0.13	0.66	−0.20	0.33	−0.35	0.27	1.00				
Swelling power	0.80	0.72	0.52	0.75	0.70	−0.69	−0.62	0.49	−0.83	0.07	**−0.96**[a]	−0.50	0.35	**0.89**[a]	0.28	1.00			
Solubility	0.66	0.60	0.43	0.52	0.41	−0.61	−0.46	0.26	−0.60	0.24	**−0.92**[a]	−0.66	0.04	0.78	0.37	**0.93**[a]	1.00		
Amylose	0.39	0.64	0.09	0.82	0.88	−0.16	−0.28	0.92	−0.72	−0.08	−0.37	0.40	0.67	0.62	0.22	0.50	0.18	1.00	
Amylopectin	0.42	0.64	0.12	0.83	0.89	−0.19	−0.31	0.91	−0.74	−0.10	−0.39	0.38	0.68	0.64	0.20	0.52	0.20	0.99	1.00

Wac – Water absorption Capacity; Oac – Oil absorption capacity; Gp – Gelling point; Bp – Boiling point; Fc – Foam capacity; Bd – Bulk density; Sp – Swelling power; Amy – Amylose; Amp – Amylopectin.
[a] n = Significant correlations at 5%.

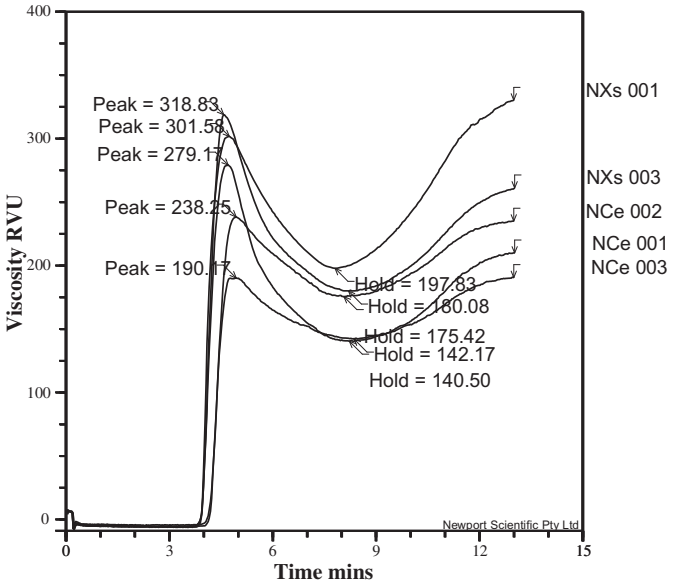

Fig. 1. RVA patterns of starches of Colocosia (NCe 001- Coco India, NCe 002- Ede ofe green, NCe 003-Ede ofe purple) and Xanthosoma (NXs 001, Ede ocha, NXs 003-okorokoro) cultivars of cocoyam.

($p < 0.05$) from 4.46% (NCe003) to 18.28% (NXs001) and 1.26% (NCe002) to 10.81% (NXs003) respectively.

Bulk density is a measure of heaviness of solid samples. It is important for determining packaging requirements, material handling and application in the food industry. Bulk density is depended upon the particle size of the samples. The result of the bulk density of the starch samples is presented in Table 5. The starch samples differed significantly in their bulk density, ranging from 0.14 g/mL (NCe001) to 1.18 g/mL (NCe002). Except for NCe002 and NCe003; NXs001 and NXs003 which showed similarity, other cultivars varied significantly.

Swelling power is a measure of hydration capacity, because the determination is a weight measure of swollen starch granules and their occluded water. Food eating quality is often connected with retention of water in the swollen starch granules (Rickard, Blanshard, & Asaoka, 1992). The swelling power of the starch samples ranged from 2.31 (NCe003) to 10.09 (NXs003) as shown in Table 5. Except for NCe001 and NCe002 that were similar, other cultivars differed significantly in their swelling power. *Colocasia* spp were observed to be generally lower than *Xanthosoma* spp. starch samples. This difference in cultivars is so because *Xanthosoma* spp. with larger starch granules is expected to display higher swelling power (Kaur, Singh, & Sodhi, 2002). Positive correlation occurred between the final viscosity and setback (0.96), pH (0.72), foam capacity (0.75) and swelling power (0.75) and amylopectin (0.83) (Table 6).

Solubility is the ability of solids to dissolve or disperse in an aqueous solution (mostly water). Table 5 presents the solubility values of the cocoyam starch samples, ranging from 2.67% (Nce001) to 8.19% (NXs003). All the cocoyam cultivars differed significantly in solubility value of the starch samples, with the *Xanthosoma* spp having higher solubility values than the *Colocasia* spp (Table 5). This is because *Colocasia* spp. has smaller size starch granules; the smaller the granular starch size, the lower the solubility (Kaur et al., 2002). Gelling point correlated negatively with foam stability (−0.75), swelling power (−0.96) and solubility (0.92). Foam stability correlated positively with swelling power (0.89) and solubility (0.78). Swelling power correlated positively with

solubility (0.93) (Table 6). Amylose content correlated positively with trough (0.64), final (0.82) and setback (0.88) viscosities, and with pH (0.92), foam capacity (−0.72), WAC (0.67), foam stability (0.62) and solubility (0.50).

4. Conclusion

Physicochemical properties of five cocoyam starches were significantly different particularly across species. The NXs001 cultivar showed higher amylose content (33.77%), while the granular starch sizes showed no significant ($p < 0.05$) variations among the cultivars. Pasting properties of the NXs003 cultivar were higher than others. Significant variations ($p < 0.05$) occurred in the functional properties of the cocoyam starches. The results of this study is hoped to prompt more utilization and investigation on the wider application of cocoyam in food processing.

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