Turkish Journal of Food and Agriculture Sciences

TURJFAS

6(2): 127-137 (2024)

Research Article

DOI: https://doi.org/10.53663/turjfas.1473483

Functional and pasting properties of starches isolated from unripe and ripe cultivars (two) of aerial yam bulbils

Adetunji Ismael LAWAL [1*], Rahman AKINOSO [2], Kazeem Koledoye OLATOYE [3], Folasade Omowumi AFOLABI [1]

[1] Department of Food Science and Technology, Faculty of Engineering and Technology, First Technical University, Ibadan, Nigeria
[2] Department of Food Technology, Faculty of Technology, University of Ibadan, Ibadan, Nigeria
[3] Department of Food Science and Technology, Faculty of Agriculture, Kwara State University, Malete, Ilorin, Kwara State, Nigeria

ARTICLE INFO

HISTORY

Received: 29 April 2024
Revised: 12 June 2024
Accepted: 24 June 2024
Online Published: 30 December 2024

KEYWORDS

Aerial yam bulbils
Functional properties
Harvesting period
Morphology
Resistant starch

* CONTACT

tunjawal@gmail.com

ABSTRACT

The impact of the harvesting period (sixth, seventh and eighth month) on functional and pasting properties of starches from Tob2857 and Tob3059 cultivars of aerial yam was investigated. Matured yam bulbils were classified into two; matured ripe bulbils (MRB) and matured unripe bulbils (MUB) based on their peel colors at harvest. Starch content, amylose, resistant starch (RS), pasting and morphological characteristics of starches were evaluated using standard methods. RS (5.11-12.37%), amylose (14.88-20.15%) and solubility (1.16-3.98%) were higher in MUB than MRB starches and varied with the harvesting period. Pasting profiles revealed that peak, hot, break down, cold paste and set back viscosities, respectively ranged thus; (261.50-528.92 RVU), (269.00-458.38 RVU), (16.95-70.54 RVU), (304.14-576.79 RVU) and (71.42-118.41 RVU). Pasting time and temperature ranged from 4.68-5.92 min and 84.18-88.26 °C, respectively. The swelling power (0.53-9.85%) varied significantly between the cultivars and ripeness of the bulbils. The starch granules showed similar shapes (ovo-triangular-oblong) and granule size (16.80-32.34 μm) varied significantly with the harvesting period. The starch of good functionality was obtained from the MRB of both cultivars in the 8th month. The variation in functionality of aerial yam starch cultivars at different harvesting periods in this study could be exploited for the postharvest valorization of aerial yam starches.

Citation: Lawal, A.I., Akinoso, R., Olatoye, K.K. & Afolabi, F.O. (2024). Functional and pasting properties of starches isolated from unripe and ripe cultivars (two) of aerial yam bulbils. *Turkish Journal of Food and Agriculture Sciences*, 6(2), 127-137.

ORCİD> 0000-0003-3097-8790 (AIL), ORCİD> 0000-0002-2780-5760 (RA), ORCİD> 0000-0003-4250-164X (KKO), ORCİD> 0009-0009-7907-7724 (FOA)

1. Introduction

Yam, a significant staple crop in Africa, is mostly produced in Nigeria (>75% of global production) and is considered a luxury commodity for pounded yam production by traditional people (FAO, 2022). The rising price has required research into alternative lesser-known kinds, such as aerial yam. Aerial yam, *Dioscorea bulbifera* (L.) also known as potato yam is one of the five economically important species in the genus Dioscorea (Akinwande et al., 2008). It is a tropical and sub-tropical crop with vast strength for growing as a wild or cultivated variant and requires fewer pre-planting operations and capital compared to other yams (Olatoye and Arueya, 2019). This yam species had added value over other yams, because of its early maturity, rich sources of phytochemicals and essential nutrients (Lawal and Akinoso, 2019). Aerial yam contains about 77.76% carbohydrate (majorly starch), 6.39% crude protein, 1.50% crude fibre, 0.86% fat, 3.81% ash and 9.50% moisture (Olatoye and Arueya, 2019). Besides the utilization of yam as a staple food, the application of their isolated starch has also been reported by Abiodun and Akinoso (2015). Starches from aerial yam are now gaining research attention as a result of their resistant starch content, which can aid weight loss and act as an essential substrate for promoting the growth of beneficial microorganisms in the gut in addition to the thickening, gelling and stabilizing roles of starch in food industries (Libra et al., 2011). The starch contents like all other food components could exhibit variation based on inherent (cultivars), environmental (harvesting season) and cultural (harvesting period) factors. Attempts have been made by the International Institute of Tropical Agriculture (IITA) to promote aerial yam cultivation by developing new cultivars with better agronomical traits and yields, however, variation existed in their nutrient composition during growth (Lawal et al., 2023). Changes in aerial yam bulbils upon maturity (after 6th month of planting) are easily obvious via the peel color and could be an important parameter for the assessment of harvesting periods since the ripening of bulbils could influence the stability of starch (Lawal and Akinoso, 2019). According to Abiodun and Akinoso (2015), starch content increased with the harvesting period of trifoliate yam, but other studies reported variable levels of starch from different peel colors of aerial yam at a single harvest time (Princewill-Ogbonna and Ibeji, 2011; Libra et al., 2011). The greatest impediment to commercial aerial yam production in Nigeria and other West African nations is a lack of information on the ripening of aerial yam cultivars at various harvesting periods. To exploit the application of aerial yam starches in value-added products, there is a need to have adequate knowledge about their starches during growth and ripening. Thus, this work was carried out to evaluate the role of the ripening and harvesting period on the physicochemical attributes of the starches from two aerial yam cultivars.

2. Materials and methods

The aerial yam germplasms (Tob2857 and Tob3059) used in this study were obtained from the IITA, Ibadan and planted in April 2021, 2022, and 2023. Matured and healthy bulbils were harvested randomly at three different harvest regimes (6, 7 and 8 months after planting), classified into matured unripe bulbils (MUB) and matured ripe bulbils (MRB) based on the visual peel color at harvest (Figure 1).

Figure 1. Visual color of aerial yam bulbils at harvest (MUB, matured unripe bulbils; MRB, matured ripe bulbils)

2.1. Preparation of AYB starches

Starch extraction was done using water extraction due to its cost-effectiveness and minimal damage to starch granules as described by Abiodun and Akinoso (2015). Healthy bulbils were peeled, cut into cubes (5 mm) and washed with potable water. The AYB cubes were then blended (Kenwood BL380, Malaysia), mixed with excess water (1:3) and sieved through triple-layered cheese cloth. The filtrate (starch) was allowed to settle (16 h), and water was decanted and centrifuged. The residue starch which was scrapped into trays before oven drying (60 oC for 12 hours) was milled, sieved (600 µm), packaged in laminated packaging, and stored in a freezer until required for further analysis. AYB starch yield was estimated as the percentage ratio of starch mass to the peeled bulbil's mass.

2.2. Determination of amylose, amylopectin and resistant starch contents

The amylose contents of AYB starches were measured as previously described by Li et al. (2020). It is simply a colorimetric method that uses a spectrophotometer (U-1500; Hitachi, Japan) to measure starch-iodine color (blue) formed at pH 4.5-4.8 in acetate buffer (29±2 ^{o}C for 20 min in a dark room). Absorbance was measured (620 nm) and estimation of amylose content was done from a standard potato-amylose curve. Amylopectin was determined by deducting amylose content from 100%.

For the enzymatic determination of resistant starch content, paste aliquots of 100 mg starch were dispersed in 20 mL of phosphate buffer, pH 6.0 (55.6 mM), and 0.16 g of α-amylase (A-3176, Sigma-Aldrich, USA) added to each tube, incubated for 16 h at pH 4.5. About 0.4 mL of amyloglucosidase (A-7095, Sigma-Aldrich, USA) was added, incubated (60 °C for 30 min) and centrifuged (4,000 g for 15 min). The residue obtained was suspended in 20 mL of phosphate buffer, pH 7.5 (0.08 M), and 0.4 mL of protease (P-2143, Sigma-Aldrich, USA) and incubated for 4 h at 42 °C. The sample was centrifuged (6,000 × g for 15 min), dried (60 °C for 24 h) and weighed to determine resistant starch content.

2.3. Swelling power

The swelling power was carried out in glass tubes (with screw caps) containing samples (0.20 g) mixed with distilled water (18 g) and completed to 20 g (AACC, 2000, method 56-21.01). The tubes were constantly agitated in a water bath (60 - 90 °C at 10 ^{o}C intervals) for 30 min and centrifuged for 5 min (1700 g). The supernatant was removed carefully, and swelling power was determined as sediment weight divided by dry weight of flour (g/g).

2.4. Water binding capacity and solubility

Water binding capacity (WBC) and solubility of AYB starches were determined using centrifuge procedure 38-12-02 of AACC (AACC, 2000). The starch sample (0.5 g) mixed with distilled water (10 mL) was stirred for 1 min and centrifuged for 15 min at 500 rpm. The WBC was expressed as the weight of water bound by the dry flour from the residue. For solubility, the supernatant was decanted into a weighed evaporating dish and dried at 100 ^{o}C for 20 min. The difference in weight of the evaporating dish was used to estimate the starch solubility.

2.5. Wettability

The wettability was determined using the method of Akinoso et al. (2021). The AYB sample (1 g) in a graduated cylinder (25 mL) of 1 cm diameter was inverted with a finger placed over the open end and clamped at a height of 10 cm from the surface of a 600 mL beaker containing 500 mL distilled water. The finger was removed, and the sample fell freely into the beaker.

2.6. Pasting properties

Pasting characteristics were determined with a Rapid Visco Analyser (RVA), (RVA Superty, 2011, 2112582-S4A, Australia). The mixture sample (3 g) and distilled water were dispensed into the canister containing the sample to make a total weight of 28 g suspension, held at 50 °C for 1 min and later heated to 95 °C. It was held at 95 ^{o}C for 3 min before subsequently cooled to a constant temperature of 50 °C within 4 min period (Kaushal et al., 2012).

2.7. Morphological properties and granules diameter

Bulbil starch (0.5 mg) was dissolved into distilled water (10 mL) and agitated for 1 min in an ultrasonic bath. Then, a few drops of the starch suspension obtained were placed on a glass slide followed by two to three drops of potassium iodide (KI) stain. Light microscope image was acquired under high-power magnifications (x40 and x100). Starch grain diameters were measured with Image J software and classified according to their size (Singh et al., 2006).

2.8. Statistical analysis

All the experiments were carried out in triplicate and data were analyzed for conformance to normality distribution before analysis of variance (ANOVA) was conducted. Both analyses were carried out using SPSS package 16.0 and the values were expressed as means ± standard deviations and the statistical significance level was selected to be $p<0.05$.

3. Results and discussion

3.1. Starch yield, amylose, amylopectin and resistant starch contents

The starch yield of AYB varied significantly ($p<0.05$) between 8.23% (MUB of Tob3059) and 19.63% (MRB of Tob2857) during the 6th and 8th months harvesting period, respectively. The highest values at 8 months were higher than 10% reported for taro at 10th month of harvest (Abo-El-Fetoh, 2010), but lower than the range (39.62 - 57.26% and 17.28 – 35.37 .68%) reported for potato and cassava (Tsakama et al., 2010; Chisenga et al., 2019). The MRB of both cultivars showed a significantly higher yield of starch than MUB. However, despite the observed lowered starch contents of MUB, these values are within the values reported in trifoliate yam (5.09-12.07%) harvested between 8 and 10 month after planting (Abiodun and Akinoso, 2015). The component regarded as the most important part of starch is amylose since its content is a pointer to the usefulness of the starch (Addy et al., 2014). It ranged from 14.88 to 20.15% (Table 1).

Table 1. Effect of harvesting period on starch yield, amylose, amylopectin and resistant starch

Cultivar	Harvesting period (months)	Ripeness	Starch yield (%)	Amylose (%)	Amylopectin (%)	Resistant starch (%)
Tob2857	6	MUB	12.02 ± 0.15^{f}	18.64 ± 0.30^{b}	81.36 ± 0.51^{de}	10.62 ± 0.32^{c}
		MRB	15.76 ± 0.18^{c}	16.56 ± 0.14^{ef}	83.44 ± 0.07^{abc}	$7.67.44 \pm 061^{f}$
	7	MUB	14.31 ± 0.32^{d}	19.85 ± 0.21^{a}	80.15 ± 0.08^{e}	11.84 ± 0.22^{b}
		MRB	17.62 ± 0.20^{b}	18.45 ± 0.19^{bc}	81.55 ± 0.32^{de}	6.61 ± 0.40^{g}
	8	MUB	13.94 ± 0.21^{de}	20.15 ± 0.06^{a}	79.85 ± 0.24^{e}	12.37 ± 0.50^{a}
		MRB	19.63 ± 0.18^{a}	17.44 ± 0.32^{cde}	82.56 ± 0.09^{bcd}	9.56 ± 0.17^{d}
Tob3059	6	MUB	8.23 ± 0.26^{g}	18.03 ± 0.27^{bcd}	81.97 ± 0.16^{c}	7.52 ± 0.30^{f}
		MRB	11.28 ± 0.14^{f}	14.88 ± 0.45^{f}	85.12 ± 0.25^{a}	5.11 ± 0.26^{h}
	7	MUB	9.27 ± 0.41^{g}	19.09 ± 0.32^{ab}	80.91 ± 0.07^{d}	8.80 ± 0.29^{e}
		MRB	12.58 ± 0.35^{ef}	17.37 ± 0.18^{de}	82.63 ± 0.56^{bcd}	6.87 ± 0.06^{g}
	8	MUB	9.57 ± 0.23^{g}	19.97 ± 0.12^{a}	80.03 ± 0.34^{e}	7.05 ± 0.27^{fg}
		MRB	14.59 ± 0.34^{cd}	15.94 ± 0.08^{f}	84.06 ± 0.02^{ab}	7.43 ± 0.41^{f}

Values in the same column with different superscripts are significantly different ($p < 0.05$)

There was an increase in the amylose content of both MRB between the 6th and 7th month and then declined in the 8th month, this could be attributed to the effect of genetics variability in the aerial yam cultivars. The MUB were significantly higher ($p<0.05$) than the MRB harvested in the same month. The observed increases were 12.56, 7.59 and 15.53% for Tob2857 and 21.17, 9.90 and 25.28% for Tob3059 harvested at the 6th, 7th and 8th months, respectively. The amylose content of MUB was in a range of 18.03-20.15%, which was within the values of 14.45-32.72% reported for other varieties of yam (Ezeocha and Okafor, 2016). High amylose content is also an indication of the lower swelling power of the starches, and such are reputable ingredients for the preparation of low glycemic index starches foods (Arici et al., 2016).

The range (79.85-85.12%) observed for amylopectin was within the range (67.28-85.45%) reported for trifoliate yam starches (Ezeocha and Okafor, 2016).

3.2. Starch granule morphology and swelling power

Starch granules of aerial yam cultivars were detected to be oval, triangular and oblong in shape (Figures 2-3) and the shapes were similar for both MUB and MRB irrespective of the harvesting period. These were consistent with shape classification for D. alata tubers (Tetchi et al., 2012). All the granules had sphericity values (0.48-0.66) that were less than one (Table 5) which is an indication of non-spherical granules. According to Akinoso and Lasisi (2013), sphericity values farther from 1 were regarded as non-spherical. The surfaces of the granules were generally smooth and lacked fissures. Although, fissure on the granules could aid starch hydrolysis, the granules of potato and other yam cultivars have been associated with granules smoothness (Arici et al., 2016). The granule size of aerial yam cultivars was between 20.87 and 27.39 µm. The granules of MRB had higher values than MUB harvested in the same month and the values were significantly different at all harvesting periods except Tob2857 harvested in the 7th month. The increase in sizes of starch granules with the harvesting period recorded in the two cultivars supported the report of Abiodun and Akinoso (2015) that the size of the starch granule increases with the harvesting period of storage organs. For swelling power, the starches of MRB (0.82-9.85 g/g) had higher swelling power than MUB (0.53-7.26 g/g) harvested in the same month, and the values were significantly different ($p<0.05$). Starches with large granule sizes are known for their accelerated swelling rate, high viscosity and ability to withstand shear during processing (Schirmer et al., 2015). Addy et al. (2014) also reported that the size and shape of granules had a very strong influence on the functional, textual and utilization potential of starch. Generally, the swelling power increased with the increase in temperature, and this could be linked to the higher diffusion of water through the amorphous region of amylose and the dissolution of associative chains at higher temperatures. Other researchers have reported higher swelling power for other food crops. Sasaki and Matsuki (2014) reported 13-18 g/g for different varieties of wheat starches. According to Li and Yeh (2001), the swelling power of potato starch was reported as 16.26-30.30 g/g. The open structures and effect of genetics could be responsible for variation in starch contents of different crops (Abiodun and Akinoso, 2015). According to Addy et al. (2014), yam starches with low amylose content were reported to have high swelling power and the increase in randomness of granules resulted in higher swelling of the starches. A similar observation was reported by Abiodun and Akinoso (2015) for trifoliate starches. Thus, the high content of amylopectin in MRB is an indication of the suitability of their starches for incorporation in food products where swelling is desirable.

Table 2. Effect of harvesting period on swelling power of aerial yam starches

Cultivar	Harvesting period (months)	Ripeness	Swelling power (g/g)			
			Temperature (°C)			
			60	70	80	90
Tob2857	6	MUB	0.76 ± 0.05^{fg}	1.70 ± 0.03^{f}	4.39 ± 0.02^{g}	6.49 ± 0.02^{f}
		MRB	1.43 ± 0.02^{bc}	2.47 ± 0.04^{c}	5.06 ± 0.01^{d}	8.13 ± 0.05^{c}
	7	MUB	1.01 ± 0.01^{d}	2.81 ± 0.03^{b}	4.26 ± 0.11^{g}	7.14 ± 0.09^{e}
		MRB	1.50 ± 0.10^{b}	2.84 ± 0.01^{b}	5.83 ± 0.04^{b}	8.53 ± 0.04^{b}
	8	MUB	$0.87 \pm 0.05^{d-f}$	2.45 ± 0.01^{c}	4.87 ± 0.05^{ef}	7.26 ± 0.03^{e}
		MRB	1.72 ± 0.04^{a}	3.34 ± 0.02^{a}	6.15 ± 0.03^{a}	9.85 ± 0.03^{a}
Tob3059	6	MUB	0.53 ± 0.01^{f}	1.41 ± 0.02^{g}	2.65 ± 0.07^{h}	5.11 ± 0.06^{h}
		MRB	0.82 ± 0.03^{c}	1.96 ± 0.03^{e}	5.01 ± 0.05^{de}	7.15 ± 0.07^{e}
	7	MUB	0.74 ± 0.02^{fg}	1.61 ± 0.04^{f}	4.21 ± 0.04^{g}	6.26 ± 0.10^{fg}
		MRB	0.95 ± 0.03^{de}	2.21 ± 0.03^{d}	5.34 ± 0.05^{de}	7.98 ± 0.03^{d}
	8	MUB	0.68 ± 0.05^{gh}	1.94 ± 0.01^{e}	4.75 ± 0.10^{f}	6.23 ± 0.05^{g}
		MRB	1.24 ± 0.05^{bc}	2.23 ± 0.05^{d}	5.32 ± 0.02^{c}	8.26 ± 0.01^{c}

Values in the same column with different superscripts are significantly different ($p < 0.05$)

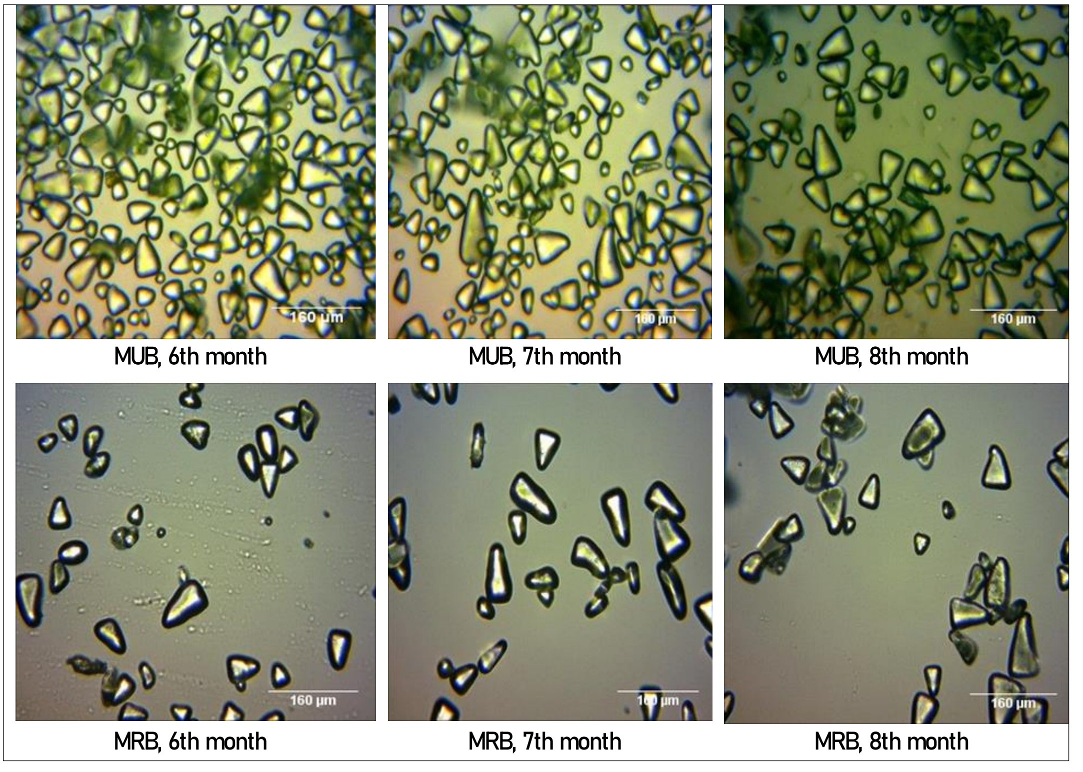

Figure 2. Starch granule morphology of Tob2857 bulbils at different harvesting periods (MUB, matured unripe bulbils; MRB, matured ripe bulbils)

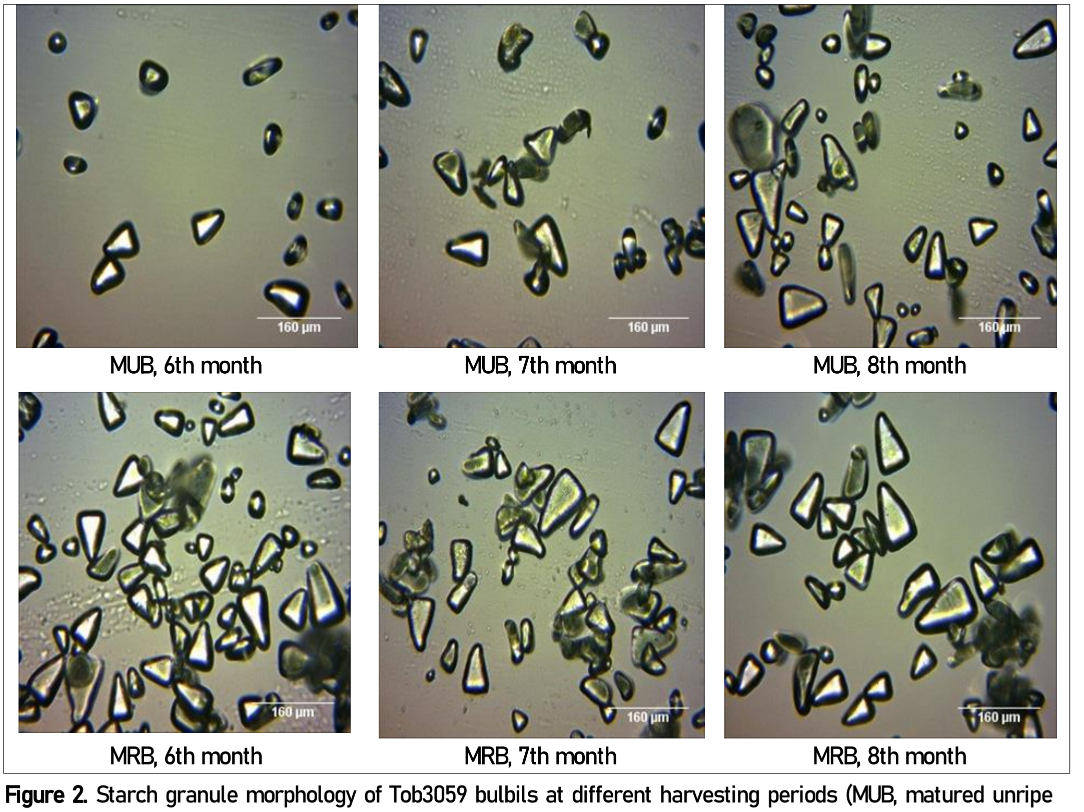

Figure 2. Starch granule morphology of Tob3059 bulbils at different harvesting periods (MUB, matured unripe bulbils; MRB, matured ripe bulbils)

3.3. Water binding, solubility and wettability

Table 3 shows the mean values for water binding capacity (WBC), solubility and wettability of AYB starches. Sample MRB of Tob3059 (8th month) had the highest WBC which differed significantly ($p<0.05$) from all the MUB samples regardless of the harvesting period and cultivars. The WBC ranged from 78.16 to 102.16% and the values increased with the harvesting period for MRB (Tob3059). A similar trend was observed for their MUB harvested between 6 and 7th month after planting. All the MRB showed significantly higher ($p<0.05$) values than MUB harvested in the same month. According to Oke et al. (2013), a lower value of WBC could be attributed to the loss of soluble components of starch during starch extraction. Apart from the leaching of soluble components, the morphology of starches (size, shape and distribution of particles in starches), salts and the presence of sulphur in the starches could contribute to increasing WBC (Abiodun and Akinoso, 2015). Kone et al. (2014) concluded that WBC is an important parameter and a pointer to good textured quality products with higher resistance to the syneresis effect of starch. The solubility of starches samples from MUB and MRB differed significantly ($p<0.05$). MUB of Tob2857 had the highest value in the 6th month and was significantly different ($p<0.05$) from MRB regardless of the harvesting period. Also, the solubility of all MRBs was lower than their respective MUB harvested in the same month. The values of solubility in this study decreased slightly with the harvesting period for MUB of both cultivars and MRB of Tob3059 (between 6 and 8th month). Although solubility had a detrimental effect on the WBC of the starches, higher values have been reported to aid the finely dispersed colloidal liquid with a homogenous structure (Akinoso et al., 2021). This observation was in agreement with the findings of Libra et al. (2011) who indicated the lower starch solubility value (0.01-1.17%) of mauve aerial yam grown in Cote d'Ivoire to maturity effect. The values (2.86-3.98%) observed for MUB of Tob2857 were within the range (2.98-6.68%) reported for water yam starches in Nigeria (Oke et al., 2013).

The wettability of MUB (Tob2857) was lowest (13.00 sec) in the 6th month, and that of the 7 and 8th months (15.00 sec) showed no significant change with the harvesting period. The increase in harvesting period (6-8th months) of MRB showed a relatively high amount of wettability with values ranging from 18.00-25.00 sec and there was a significant difference ($p<0.05$) between MUB and MRB of the same cultivars harvested at the same month except Tob3059 harvested at the sixth month. Wettability measures the ease of samples dispersing in water and the result suggests a faster rate for dissolution of MUB than MRB, which is an advantage in the production of weaning food (Akinoso et al., 2021). The results of MRB (18.00-25.00 sec) were compatible with those found by Oke et al. (2013) who reported wettability values of 17.40-25.62 sec for water yam starches in Nigeria.

Table 3. Water binding capacity, solubility and wettability of aerial yam starches

Cultivar	Harvesting period (months)	Ripeness	Water Binding Capacity (WBC) (%)	Solubility (%)	Wettability (sec)
Tob2857	6	MUB	78.16 ± 0.83^{f}	3.98 ± 0.22^{a}	13.00 ± 1.45^{f}
		MRB	84.56 ± 1.32^{de}	2.06 ± 0.21^{c}	18.00 ± 2.01^{e}
	7	MUB	80.10 ± 0.37^{f}	3.34 ± 0.18^{a}	15.00 ± 1.72^{f}
		MRB	88.21 ± 1.00^{cd}	2.50 ± 0.20^{bc}	21.00 ± 1.33^{cd}
	8	MUB	80.18 ± 0.64^{f}	2.86 ± 0.09^{b}	15.00 ± 2.00^{f}
		MRB	86.76 ± 1.23^{cd}	2.31 ± 0.30^{bc}	23.00 ± 2.41^{abc}
Tob3059	6	MUB	80.12 ± 0.88^{f}	2.15 ± 0.33^{c}	20.00 ± 2.12^{de}
		MRB	95.47 ± 1.20^{b}	1.17 ± 0.21^{d}	22.00 ± 2.20^{bcd}
	7	MUB	84.82 ± 0.58^{d}	2.02 ± 0.30^{c}	20.00 ± 2.36^{de}
		MRB	97.38 ± 0.71^{b}	1.21 ± 0.13^{d}	24.00 ± 2.62^{ab}
	8	MUB	81.72 ± 1.13^{ef}	1.96 ± 0.20^{c}	22.00 ± 1.45^{bcd}
		MRB	102.16 ± 0.87^{a}	1.16 ± 0.10^{d}	25.00 ± 1.45^{a}

Values in the same column with different superscripts are significantly different ($p < 0.05$)

3.4. Pasting properties of AYB starches

The peak viscosity of AYB starches varied significantly from 261.50 RVU (MUB of Tob3059) to 528.92 RVU (MRB of Tob3059) (Table 4). Starches of MRB had the highest value in the 8th month and MUB had the lowest in the 6th month.

Table 4. Pasting properties of aerial yam starches

Cultivar	HP (month)	Ripeness	Peak viscosity (RVU)	Hot paste (RVU)	Break down (RVU)	Cold paste (RVU)	Setback (RVU)	Time (min)	Temperature (°C)	Pasting time (min)
Tob2857	6	MUB	330.08±23.34^{c}	304.38±32.51^{cde}	25.70±25.55^{b}	412.13±32.38^{bc}	107.75±3.41^{d}	5.83±0.18^{abc}	87.30±2.30^{a}	5.83±0.18^{abc}
		MRB	521.13±37.52^{a}	451.75±11.89^{a}	69.38±28.36^{a}	568.25±60.44^{a}	116.50±2.18^{ab}	5.74±0.19^{abc}	84.78±1.56^{b}	5.74±0.19^{abc}
	7	MUB	288.75±19.34^{de}	269.00±24.72^{ef}	19.75±14.27^{b}	371.00±28.36^{cde}	102.00±1.69^{e}	5.92±0.21^{a}	88.26±1.90^{a}	5.92±0.21^{a}
		MRB	515.33±14.31^{a}	447.82±34.72^{a}	67.51±22.31^{a}	561.32±45.51^{a}	113.50±3.40^{bc}	5.64±1.20^{bc}	84.32±1.21^{b}	5.64±1.20^{bc}
	8	MUB	312.72±25.16^{cd}	289.00±37.23^{def}	23.72±26.62^{b}	401.25±28.52^{bcd}	112.25±3.19^{abc}	5.89±0.15^{ab}	87.82±2.30^{a}	5.89±0.15^{ab}
		MRB	528.92±43.65^{a}	458.38±50.21^{a}	70.54±31.35^{a}	576.79±64.75^{a}	118.41±3.25^{a}	5.61±0.16^{c}	84.64±1.40^{b}	5.61±0.16^{c}
Tob3059	6	MUB	267.42±24.51^{e}	250.47±42.35^{e}	16.95±15.28^{b}	321.89±29.96^{f}	71.42±2.14^{h}	5.87±0.11^{ab}	87.16±1.26^{a}	5.87±0.11^{ab}
		MRB	405.92±42.16^{b}	339.91±24.45^{bc}	66.01±21.66^{a}	435.41±35.16^{b}	95.50±2.62^{f}	4.68±0.20^{e}	84.26±1.42^{b}	4.68±0.20^{e}
	7	MUB	261.50±31.34^{e}	243.64±27.51^{f}	17.86±14.64^{b}	304.14±61.52^{f}	60.50±1.57^{i}	5.31±0.14^{d}	87.56±2.17^{a}	5.31±0.14^{d}
		MRB	399.67±27.44^{b}	334.75±32.32^{bcd}	64.92±25.37^{a}	433.33±33.26^{bc}	98.58±3.11^{f}	4.82±0.16^{e}	84.35±1.15^{b}	4.82±0.16^{e}
	8	MUB	293.83±17.76^{cde}	274.63±40.43^{ef}	19.20±13.60^{b}	348.97±31.52^{def}	74.34±2.52^{gh}	5.24±0.18^{d}	87.64±1.22^{a}	5.24±0.18^{d}
		MRB	425.67±40.71^{b}	359.37±31.46^{b}	66.30±27.48^{a}	461.87±37.32^{b}	102.50±2.42^{e}	5.18±0.13^{d}	84.18±1.25^{b}	5.18±0.13^{d}

Values in the same column with different superscripts are significantly different (p < 0.05), HP: Harvesting period

The peak viscosities of MRB were significantly higher (p<0.05) than the MUB regardless of the harvesting period and the cultivars. The higher peak viscosity of MRB showed the maximum swelling of the granule starches before disintegration and could be an added advantage for food product development that requires strong gel strength and elasticity. Abiodun and Akinoso (2015) also relate the ability of starch to swell freely before breakdown to peak viscosity. Kaushal et al. (2012) opined peak viscosity to be an equilibrium point between granules swelling and breakdown. It is also a valuable parameter useful during the formulation of ingredients and serves as mechanical stress resistance during mixing and kneading. The higher peak viscosity of MRB at different harvesting periods is in consistent with the findings of Akinwande et al. (2008) who observed higher peak viscosity for yam starches with an increase in the swelling power of starches granules. Genetic factors, growing conditions, phosphorus content, starch content and interactions among the components may play an important role in the behavior and texture of starch granules (Schirmer et al., 2015). According to Kaushal et al. (2012), the hot paste viscosity is the starch granules' ability to resist breakdown at high temperatures under mechanical shear stress, the values ranged from 269.00 to 458.38 RVU. The MRB of Tob3059 had the highest in the 8th month and the values reduced in the starches harvested earlier. The hot paste viscosities of both cultivars had lower values than their respective peak viscosities in the same month. In a similar trend to peak viscosity, the starch granules of MRB had significantly higher paste values (334.75-458.38 RVU) than MUB (243.64-304.38 RVU) at all the harvesting periods. The hot paste values for the MUB in this study were within the range of 84.04-356.79 RVU reported by Ezeocha and Okafor (2016). Abiodun and Akinoso (2015) reported a similar trend for trifoliate yam cultivated in Nigeria, in which white had much more hot paste than starches of yellow varieties. For breakdown viscosity, the pattern of results between MUB and MRB at different harvesting periods were similar to peak and hot paste viscosities results. The 8th month harvest of MRB starches had the highest (70.54 RVU), followed by its 6th month (69.38 RVU) while the 6th month harvest of MUB (Tob3059) had the lowest (16.95 RVU) breakdown viscosity. According to Schirmer et al. (2015), higher breakdown viscosity of starches is an indication of lower resistance to heat and shear stress during cooking, and the values obtained in this study were lower than the maximum level of 184.37 RVU reported by Oke et al. (2013) for starches of water yam cultivars cultivated in Nigeria. Thus, lower breakdown viscosity of AYB suggests better stability of the starches under hot conditions compared to starches from water yam.

Cold paste viscosity of the starches ranged from 304.14 RVU (MUB of Tob2857) to 576.79 RVU (MRB of Tob3059). Tob3059 had the lowest value in the 7th month, while Tob2857 had the highest in the 8th month, but there was no significant difference (p<0.05) between starches from the same peel color at different harvesting periods. Since cold paste viscosity provides appropriate information for the gelling ability of the starch samples after cooking, higher cold paste viscosity of MRB is an indication of stronger gel formation after cooking compared to MUB starches. Chung et al. (2014) pointed out that continuous aggregation of leached amylose molecules rapidly during cooling results in the formation of amylose chains, responsible for final product viscosity. In a similar study, Schirmer et al. (2015) attributed such an increase in final product viscosity to the formation of an amylose junction zone during the cooling of starches.

The setback viscosities, an estimate of the difference between the final and hot paste viscosities provide knowledge on the tendering of starch to retrogradation (re-association of starch). The setback viscosities of aerial yam starches were between 60.50 and 118.41 RVU. As seen from Table 4, as the harvested period significantly influenced the setback value of MUB, they did not have a generally remarkable effect on MRB irrespective of the cultivars. The starches of MRB of Tob2857 had the highest value at all harvesting periods. The high cohesive paste and low retrogradation tendency during cooling were mentioned in different studies regarding high setback viscosity (Arici et al., 2016; Chung et al., 2014). Since the staling of pastries (bread) is an essential problem in bakeries and other related food products, setback viscosity is, therefore, an important parameter during the incorporation of starches in such foods (Akinoso et al., 2021; Lawal et al., 2024). The food applications such as pounded yam that requires highly cohesive paste could make use of MRB with high setback values (102.00-118.41 RVU), while low setback values (60.50-102.50 RVU) of MUB are added advantage in low viscosities and paste stability food products (weaning food) at low temperature. The selection of AYB for food processing could vary depending on the final quality features of the products in terms of viscosity or texture. The result is in agreement with the observation of Arıcı et al. (2016) on the pasting properties of taro starches.

Pasting time ranged from 4.68 to 5.92 min. The MUB harvested in the 6th month had the lowest pasting time, while pasting time ranged from 4.68 to 5.92 min. The MUB of Tob2857 harvested in the 6th month had the highest pasting time while the MRB of Tob3059 had the lowest. Also, starches from MUB with higher peak time recorded low peak, hot paste, breakdown and cold paste viscosities. According to Addy et al. (2014), higher pasting and cooking time of starches were projected by elevated levels of amylose content which inhibits swelling, similar to those reported in this research for pasting time. The pasting times at different harvesting periods of aerial yam were within the range of values (4.52-6.30 min) reported for taro and trifoliate yam flours (Abiodun and Akinoso, 2015; Arici et al., 2016). For pasting temperature, the values recorded (84.18-88.26 °C) were higher than values (62.20-65.80 °C) reported for sweet potato (Chung et al., 2014) but within the range of values (78.05-86.05 °C) reported for different varieties of water yam (Oke et al., 2013). In the consideration of ideal starch for different food products, energy consumed during production may play a significant role in the cost of the product (Olatoye et al., 2014).

Table 5. Morphological parameters of aerial yam starches

Cultivar	Harvesting period (months)	Ripeness	Shapes	Sphericity	Size (µm)
Tob2857	6	MUB	Ovo triangular oblong	0.66 ± 0.16^{a}	20.87 ± 1.36^{def}
		MRB	Ovo triangular oblong	$0.55 \pm 0.15^{b-e}$	23.97 ± 1.75^{c}
	7	MUB	Ovo triangular oblong	0.59 ± 0.14^{b}	22.48 ± 1.25^{cde}
		MRB	Ovo triangular oblong	0.53 ± 0.11^{def}	24.24 ± 1.64^{c}
	8	MUB	Ovo triangular oblong	0.64 ± 0.15^{a}	23.66 ± 1.42^{c}
		MRB	Ovo triangular oblong	0.48 ± 0.17^{g}	27.39 ± 1.53^{b}
Tob3059	6	MUB	Ovo triangular oblong	0.58 ± 0.20^{b}	16.80 ± 1.92^{g}
		MRB	Ovo triangular oblong	0.57 ± 0.16^{bcd}	19.59 ± 2.07^{f}
	7	MUB	Ovo triangular oblong	0.51 ± 0.18^{efg}	20.25 ± 1.29^{ef}
		MRB	Ovo triangular oblong	$0.54 \pm 0.18^{c-f}$	24.35 ± 2.34^{c}
	8	MUB	Ovo triangular oblong	0.53 ± 0.17^{def}	23.22 ± 1.58^{cd}
		MRB	Ovo triangular oblong	0.50 ± 0.14^{fg}	32.34 ± 2.30^{a}

Values in the same column with different superscripts are significantly different ($p < 0.05$), HP: Harvesting period

4. Conclusion

The effect of the harvesting period on the functional and pasting properties of aerial yam starches was investigated to determine their suitability for different food applications in the food industry. The condition of bulbils at harvest (unripe and ripeness) played an important role in the functional and pasting properties of the starches. The MUB starches of both cultivars (Tob2857 and Tob3059) showed higher resistant starch, solubility and amylose content than their corresponding MRB starches while swelling power increased significantly ($p<0.05$) with the harvesting period and cooking temperature of both cultivars.

The pasting properties of MUB and the corresponding MRB also varied with harvesting period and cultivars. MRB of both cultivars had a high value of peak viscosity in the 8th month, providing useful information to the potential application of aerial yam starches in food processing. The granular sizes of the starches were generally high and varied with the harvesting period and conditions of bulbils at harvest.

Compliance with Ethical Standards

Conflict of Interest

The author declares no conflict of interest.

Authors' Contributions

All authors contributed to the emergence of the manuscript and approved the final version.

Ethical approval

Not applicable.

Funding

This research received no financial support.

Data availability

Not applicable.

Consent for publication

Not applicable.

Acknowledgment

We would like to thank the gene bank unit of the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria for providing aerial yam germplasms used in this study.

References

AACC, (2000). Approved Methods of the American Association of Cereals Chemists. *American Association of Cereal Chemists, St, Paul, MN*

Abiodun, O. A., & Akinoso, R. (2015). Textural and sensory properties of trifoliate yam (*Dioscorea dumetorum*) flour and stiff dough 'amala.' *Journal of Food Science and Technology, 52*(5), 2894–2901. https://doi.org/10.1007/s13197-014-1313-y

Addy, R. N., Wireko-Manu, F. D., & Oduro, I. (2014). Physicochemical and pasting properties of starch extracted from four yam varieties. *Journal of Food and Nutrition Sciences, 2*(6), 262-269. https://doi:10.11648/j.jfns.20140206.14

Akinoso, R., & Lasisi, I. M. (2013). Effect of cooking time on selected physical and mechanical properties of dried pigeon pea (*Cajanus cajan*). *The West Indian Journal of Engineering, 35*, 45-50.

Akinoso, R., Lawal, A. I., Olatoye, K. K., & Olayioye, D. O. (2021). Physicochemical, textural and organoleptic characteristics of West African stiff dough 'amala' made from soaked and unsoaked cocoyam flour. *Journal of Microbiology, Biotechnology and Food Sciences, 10*, 1-5. https://doi.org/10.15414/jmbfs.3728

Akinwande, B. A., Asiedu, R., Maziya-Dixon, B., & Adeyemi, I. A. (2008). Determination of an effective maturity index for white yam (*Dioscorea rotundata*). *Journal of Food, Agriculture and Environment, 6*(2), 192–196.

Arici, M., Yıldırım, R. M., Özülkü, G., Yaşar, B., & Toker, O. S. (2016). Physicochemical and nutritional properties of taro (*Colocasia esculenta L. Schott*) flour as affected by drying temperature and air velocity. *LWT-Food Science and Technology, 74*, 434-440. https://doi.org/10.1016/j.lwt.2016.08.006

Chung, H. J., Li, X. Q., Kalinga, D., Lim, S. T., Yada, R., & Liu, Q. (2014). Physicochemical properties of dry matter and isolated starch from potatoes grown in different locations in Canada. *Food Research International, 57*, 89-94. https://doi.org/10.1016/j.foodres.2014.01.034

Ezeocha, C. V., & Okafor, J. C. (2016). Evaluation of the chemical, functional and pasting properties of starch from trifoliate yam (*Dioscorea dumetorum*) landraces. *European Journal of Advanced Research in Biological and Life Science*, *4*(2), 55-62.

Kaushal, P., Sharma, H. K., & Kumar, V. (2012). Physicochemical, pasting and anti-nutritional properties of rice, pigeon pea and taro flour blends. *LWT - Food Science and Technology*, *45*, 59-68. https://doi.org/10.1016/j.lwt.2012.02.028

Kone, D., Kone, M. F., Dje, K., Kouame, L. P., & Dabonne, S. (2014). Functional and biochemical properties of *Dioscorea cayenensis-rotundata* flours. *Applied Science and Technology*, *4*(23), 3402-3418.

Lawal, A. I., & Akinoso, R. (2019). Physical properties, proximate composition and antioxidant activities of aerial yam (*Dioscorea bulbifera*) bulbils grown in Nigeria. *Acta Periodica Technologica*, *352*(50), 143–151. https://doi.org/10.2298/apt1950143l

Lawal, A. I., Akinoso, R., & Afolabi, F. O. (2023). Nutritional, antinutritional and bioactivity of raw and thermal processed cultivars (five) of aerial yam bulbils. *Food and Humanity*, *1*, 1040–1045. https://doi.org/10.1016/j.foohum.2023.08.018

Lawal, A. I., Olatoye, K. K., & Babalola, K. A. (2024). Beta-carotene retention, physical, phytochemical and storage characteristics of value added snacks from pigeon pea and yellow-fleshed cassava. *Food and Humanity*, 2, 1-10. https://doi.org/10.1016/j.foohum.2024.100257

Li, M. C., Chou, C. F., Hsu, S. C., & Lin, J. S. (2020). Physicochemical characteristics and resistant starch of different varieties of banana from Taiwan. *International Journal of Food Properties*, *23*(1), 1168–1175. https://doi.org/10.1080/10942912.2020.1788077

Libra, M. A., Gonnety, J., Ahi, A. P., Dabonne, S. D., & Kouame, L. P. (2011). Physicochemical changes in bulbils of two cultivars of *Dioscorea bulbifera* during the ripening period. *Advance Journal of Food Science and Technology*, *3*(5), 327–331.

Oke, M. O., Awonorin, S. O., & Workneh, T. S. (2013). Effect of varieties on physicochemical and pasting characteristics of water yam flours and starches. *African Journal of Biotechnology*, *12*(11), 150-1256.

Olatoye, K. K., & Arueya, G. L. (2019). Nutrient and phytochemical composition of flour made from selected cultivars of Aerial yam (*Dioscorea bulbifera*) in Nigeria. *Journal Food Composition and Analysis*, *79*, 23–27. https://doi.org/10.1016/j.jfca.2018.12.007

Olatoye, K. K., Akinoso, R., Lawal, A. I., & Babalola, K. A. (2014). A comparative study of energy demand of instant-pounded yam flour production methods. *Journal of Energy Technologies and Policy*. 4 (3); 14-18.

Schirmer, M., Becker, T., & Jekle, M. (2015). Starch gel and its complexity. *Starch/Staerke*, *67*(2), 30–41. https://doi.org/10.1002/star.201400071.

Singh, D. K., Goswami, T. K., & Chourasia, M. (2006). Physical properties of two popular Indian potato varieties. *Journal of Food Process Engineering*, *29*(4), 337–348. https://doi.org/10.1111/j.1745-4530.2006.00066.x

Tetchi, F. A., Dje, K. M., Dabonne, S., & Kouame, L. P. (2012). Morphological characteristics of yam starch granules. *Pakistan Journal of Nutrition*, *11*(1), 66-77. https://doi.org/10.3923/pjn.2012.66.77