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Flour composition and physicochemical properties of white and yellow bitter yam (*Dioscorea dumetorum*) starches

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ABSTRACT

Bitter yam (*Dioscorea dumetorum*) is an underutilized tuber crop that is rich in starch and may be potentially used as a starch source by the industry. In this study, the composition and physicochemical properties of flour and starch from white and yellow bitter yams were studied. Bitter yam showed significant variations in their proximate composition, but mineral contents were very similar. The amylose content (approx. 15%) of white bitter yam starch was slightly lower than the yellow variety (approx. 17%). Bitter yam starch granules were very small (average 5 µm) and polygonal in shape. Starch extracts displayed the A-type crystallinity pattern with varying relative crystallinity: 22.1–28.0%. The peak gelatinisation temperature (approx. 83 °C) and pasting temperature (approx. 87 °C) were fairly high and similar for both starches. Starch peak viscosity of the white bitter yam was significantly higher than the yellow variety, which could be associated with its slightly lower amylose content. Bitter yam starch may find application in the industry where fairly high temperatures (> 80 °C) are frequently encountered.

1. Introduction

Bitter yam is an underutilized yam specie in many parts of Africa including Nigeria. It may be cultivated or may grow in the wild (Abiodun and Akinoso, 2014) and comes in different colours such as pale yellow, deep yellow or white (Oladeji et al., 2016). The underutilization of bitter yam has been partly attributed to its bitter taste and hardening of the tubers that occurs during storage (Afoakwa and Sefa-Dedeh, 2002; Oladeji et al., 2016). Despite these limitations, bitter yam still possess some potentials that can be explored and harnessed for better utilization. For example, bitter yam like other yam cultivars is a good source of starch. The starch yield from bitter yam may vary between 11 and 88%, depending on variety and extraction methods (Akinoso and Abiodun, 2013; Emiola and Delarosa, 1981; Ezeocha and Okafor, 2016). Hence, bitter yam starch may be employed as an alternative to the conventional starch sources such as corn, tapioca and potato starches. However, the utilization of new starch source in the industry requires a knowledge of the composition and the interplay between structure and functional properties.

Several factors such as composition i.e. amylose content, as well as structural properties may influence the functional properties of starch. Previous research found some variations in the amylose contents (approx. 12–28%) of bitter yam starch (Adedokun and Itiola, 2010; Akinoso and Abiodun, 2013; Amani et al., 2004; Ezeocha and Okafor, 2016; Otegbayo et al., 2014). The amylose content of various starches is well-known to restrict starch swelling during gelatinisation and pasting. For example, white bitter yam variety with slightly higher amylose content (13.96%) showed low swelling power and water absorption capacity compared to the yellow variety (amylose content: 13.71%) (Adedokun and Itiola, 2010). Jane et al. (1992) reported that starch with high amylose content and abundant short chain amylopectin showed low pasting viscosity and high pasting temperature. Microscopically, bitter yam starch has remarkably small-sized granules (3 < 5 µm) and are mostly polygonal in shape (Amani et al., 2004; Otegbayo et al., 2014).

In terms of structure, bitter yam starch was found to display the A-type crystallinity which is typical of cereal starches (Farhat et al., 1999; Riley et al., 2004). Starch crystalline patterns have been reported to influence starch functionality. For instance, bitter yam starch with the A-polymorph displayed lower peak viscosity, but higher gelatinisation temperature compared to yam starch with the B-polymorph (Farhat et al., 1999). Other factors that can influence starch functionality include the botanical source and variety of the crop. Bitter yam has two main variety; the white and yellow variety. Most of the reported

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research on starch functionality has focused primarily on the white type (Emiola and Delarosa, 1981; Farhat et al., 1999; Riley et al., 2004; Ukom et al., 2016). Studies on the yellow variety mainly reported material and compaction characteristics of the native and pre-gelatinized starch (Adedokun and Itiola, 2010). Due to the growing demand for starch by the industry for various applications, the knowledge of composition and functional properties of starch extracted from bitter yam is important to facilitate their utilization beyond traditional usage. To the best of our knowledge, there are no studies on the functional properties of starch extracted from the yellow variety of bitter yam. Hence, this study investigated flour composition and functional properties of starch from yellow and white varieties of bitter yam.

2. Materials and methods

2.1. Materials

White and yellow variety of bitter yam was obtained from a local farm in Osun State, Nigeria. Yams were cleaned and transferred into the Food Processing Laboratory, Department of Home Economics and Food Science, University of Ilorin, Nigeria for further processing into flour and starch.

2.2. Preparation of yam flour and starch

Flour and starch were prepared as previously described (Naidoo et al., 2015). Briefly, freshly yam tubers were washed, peeled, re-washed and sliced into a thickness of 5 mm. Sliced yam were dried at 50 °C for 48 h in the oven (D-37520, Thermo Fisher Scientific, Germany). The dried chips were milled and sieved (screen size: 180 µm) to obtain flours which were stored at 4 °C until analyzed. Starch was extracted by dispersing yam flour in water (1:10). The mixture was stirred at room temperature and sieved (180 µm) to separate non-starchy components and the filtrate was allowed to settle at room temperature for 24 h. Thereafter, the slurry was centrifuged (Ependorf 5810R, Germany) at 14000 × *g* for 20 min and the supernatant discarded. The remaining sediment (starch fraction) was dried at 50 °C for 24 h in an oven (D-37520, Thermo Fisher Scientific, Germany).

2.3. Chemical composition of yam flour

Moisture, fat and ash contents were determined using AOAC (2000) methods. Protein content was determined by the Kjeldahl method (6.25 × N) and total carbohydrate was calculated by difference. Fibre content were determined by standard laboratory procedure. Mineral content of amadumbe flour was determined as described by Amonsou et al. (2014) using Inductively Coupled Plasma (ICP) spectroscopy. Samples were acid-digested by the addition of 1 ml of 55% (v/v) HNO_3.

2.4. Microscopy

Starch granule morphology was examined using a scanning electron microscope (EVO 15 HD) with an accelerating potential of 4 KV. Briefly, a thin layer of the starch granule was mounted on the aluminium specimen holder with double-sided tape. Starch samples were coated with a thin film of gold for 2 min with a thickness of about 30 nm (Naidoo et al., 2015).

2.5. Amylose contents

Amylose contents of starches were determined by the iodine binding method described in previous studies Oyeyinka et al. (2015).

2.6. X-ray diffraction

X-ray diffraction patterns of amadumbe starches were done as described by Oyeyinka et al. (2015).

2.7. Pasting properties of flour and starch

The pasting properties of yam flour and starch were examined using a Rapid Visco-Analyzer (Newport Scientific Australia) as previously reported (Oyeyinka et al., 2016a,b). Briefly, samples (2.8 g) were weighed into the test canister containing 25 ml of distilled water. The mixture was agitated by mixing manually before inserting the canister into the instrument. Starch was stirred at 960 rpm for 10 s before the shear input was decreased and held constant at 160 rpm during the subsequent heating and cooling cycles.

2.8. Thermal properties of starch

The gelatinisation temperatures of the starch samples were determined using a differential scanning calorimeter (SDT Q600, USA) as previously reported (Oyeyinka et al., 2016a,b). Briefly, starch (3 mg) was weighed into the aluminum DSC pan and distilled water (12 µl) added before the pan was sealed. Pans were allowed to equilibrate and samples were scanned at 10–110 °C with an interval heating rate of 10 °C/min. An empty pan was used as reference for all measurements.

2.9. Statistical analysis

All analyses were performed in triplicate. Data was analysed using analysis of variance (ANOVA) and means were compared using the Fisher Least Significant Difference (LSD) test ($p < 0.05$).

3. Results and discussion

3.1. Proximate composition of yam flour

The proximate compositions of white and yellow bitter yam flours were significantly ($p < 0.05$) different (Table 1). Carbohydrate was the major component of the flours (approx. 78%). Both white and yellow bitter yam flour had low ash (5.09–5.39%), fat (0.64–0.74%), fibre (1.97–2.34%) and protein (5.67–6.18%) contents. The fibre, fat and protein contents of the yellow bitter yam flour was significantly ($p < 0.05$) higher than the white variety. Bitter yam is reportedly richer in protein than other yam varieties (Afoakwa and Sefa-Dedeh, 2001). Yellow bitter yam is rich in carotenoids and β-cryptoxanthin, which is responsible for the colouration of the tuber (Abiodun et al., 2014; Oladeji et al., 2016). Hence, the slightly higher fat content of the yellow bitter yam may be attributed to the presence of higher contents of carotenoids. The proximate composition data of the bitter yam in this study are in agreement with the literature (Ogbuagu, 2008).

Table 1
Proximate composition of bitter yam flour (%).

Parameters	White variety	Yellow variety
Moisture	$8.18^a \pm 0.01$	$7.94^b \pm 0.02$
Protein	$5.67^b \pm 0.01$	$6.18^a \pm 0.01$
Fat	$0.64^b \pm 0.01$	$0.74^a \pm 0.02$
Ash	$5.39^a \pm 0.01$	$5.07^b \pm 0.02$
Fibre	$1.97^b \pm 0.01$	$2.34^a \pm 0.02$
Carbohydrate	$78.15^a \pm 0.01$	$77.74^a \pm 0.01$

Mean ± SD. Mean with different superscript along the row are significantly different ($p < 0.05$).

Table 2
Mineral composition of yam flour.

Minerals mg/100 g	White variety	Yellow variety
Magnesium	0.72[a] ± 0.01	0.65[b] ± 0.01
Manganese	0.34[a] ± 0.01	0.38[a] ± 0.01
Iron	0.13[a] ± 0.01	0.16[a] ± 0.01
Calcium	0.19[a] ± 0.01	0.21[a] ± 0.01
Sodium	0.02[a] ± 0.01	0.02[a] ± 0.01
Potassium	0.03[a] ± 0.01	0.03[a] ± 0.00
Copper	1.36[b] ± 0.01	1.48[a] ± 0.01
Zinc	0.03[b] ± 0.02	0.18[a] ± 0.01

Mean ± SD. Mean with different superscript along the row are significantly different ($p < 0.05$).

3.2. Mineral composition of ~~amadumbe~~ flour

With the exception of the magnesium, copper and zinc, the mineral contents of the bitter yam flours were similar (Table 2). Copper (1.36–148 mg/100 g) and magnesium (0.65-0.72 mg/100 g) were the most abundant mineral elements in the bitter yam flours. Manganese, iron, calcium, sodium, potassium and zinc were generally very low (<0.4 mg/100 g). Copper is an essential trace elements that is important for proper functioning of organs and metabolic processes.

3.3. Starch morphology and apparent amylose contents

Micrographs of extracted starches were mostly polygonal in shape and very small, with an average size of 5 µm (Fig. 1). A few granules were irregularly shaped suggesting that these are compound starches. The starch granule shape and size results in this study are in agreement with those reported by previous authors for bitter yam starch (Akinoso and Abiodun, 2013; Riley et al., 2004; Ukom et al., 2016). The small sized granules of bitter yam starch suggest that they can potentially be used as an excellent filler for biodegradable plastic film. Furthermore, they could have application in certain foods such as salad dressings and as alternative to lipids for better mouth feel (Daniel and Whistler, 1990; Jane et al., 1992).

The amylose content of white bitter yam starch (approx. 15%) was significantly ($p < 0.05$) lower than that of the yellow type (approx. 17%) (Table 4). Values of amylose content observed in this study is in agreement with values previously reported for bitter yam starch (Adedokun and Itiola, 2010; Akinoso and Abiodun, 2013; Amani et al., 2004; Ezeocha and Okafor, 2016; Farhat et al., 1999; Otegbayo et al., 2014; Ukom et al., 2016).

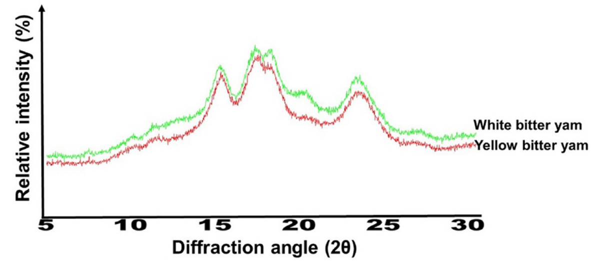

Fig. 2. Diffractograms of starches isolated from white and yellow bitter yam.

3.4. X-ray diffraction

White and yellow bitter yam starches exhibited similar diffraction pattern with strong peaks at 15° (2θ), a doublet at 17° and 18° (2θ), and a single peak at 23° (2θ) (Fig. 2) typical of A-type starches. Similar peak positions have been reported for bitter yam starch in previous studies (Farhat et al., 1999; Riley et al., 2004). The relative crystallinity (28.0%) of white bitter yam starch was significantly higher than that of the yellow bitter yam (22.1%) (Table 4), which may be associated with differences in their amylose contents (Table 4).

3.5. Pasting properties of bitter yam flour and starches

The pasting profile of white bitter yam and yellow bitter yam starches were very similar (Fig. 3). The same trend was observed for their flour counterparts. With the exception of the pasting temperature (approx. 87 °C) of the flour and starches which was very similar, other pasting properties of the flours were significantly lower than those of the starches (Table 3). The lower pasting properties observed for the flours in comparison with the starches may be attributed to the presence of non-starch components such as proteins, fat and mucilage in the flour. The pasting temperature of the starches in this study is within the range of values (80–89 °C) previously reported (Ezeocha and Okafor, 2016; Farhat et al., 1999; Ukom et al., 2016). Bitter yam starches appear to have substantially higher pasting temperature compared to other commercial tuber starches such as potato starch (64–69 °C) (Gałkowska et al., 2014; Jane et al., 1999; Joshi et al., 2013) and cassava starch (67–68 °C) (Nwokocha et al., 2009; Srichuwong et al., 2005). However, the pasting temperature of bitter yam starches are very much similar to those reported for taro (Falade and Okafor, 2015, 2013; Jane et al., 1992; Sit et al., 2013; Tattiyakul et al., 2006) or amadumbe starches (Naidoo et al., 2015). Differences in starch pasting temperature among tuber starches could relate to the small granule size

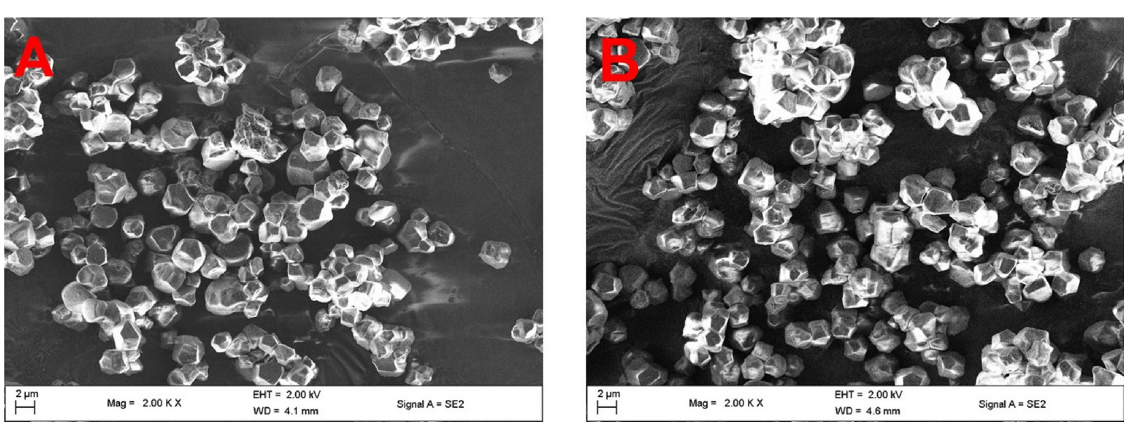

Fig. 1. SEM Images of starches isolated bitter yam.
A: White bitter yam variety, B: Yellow bitter yam variety.

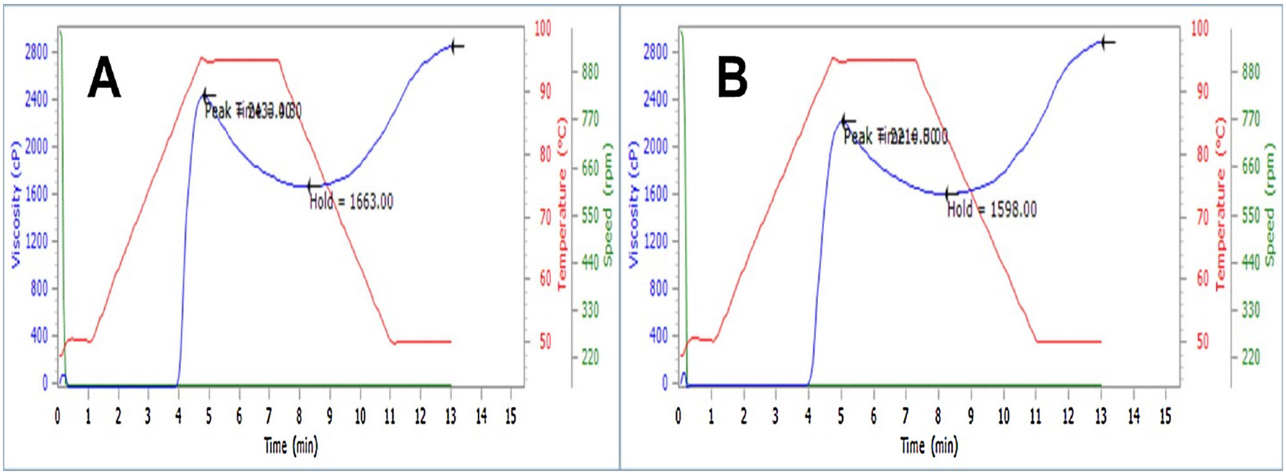

Fig. 3. Pasting curves of white and yellow bitter yam starches.
A: white bitter yam starch B: yellow bitter yam starch.

of bitter yam starch and those of taro. Small starch granules have been found to exhibit greater resistant to rupture and loss of molecular order (Dreher and Berry, 1983).

The peak viscosity also referred to as the swelling peak of white bitter yam (approx. 2438 cP) is significantly ($p < 0.05$) higher than that of the yellow bitter yam (approx. 2230 cP). The higher peak viscosity of white bitter yam starch could be due to its low amylose content (approx. 15%) compared to the yellow bitter yam starch (approx. 17%) (Table 4). Amylose content of starch has been suggested to restrict starch swelling during pasting (Jane et al., 1992; Noda et al., 2004). Sang et al. (2008), suggested that amylose prevents swelling of starches during pasting by forming a barrier around the starch granules.

The final viscosities of the flours were significantly different, but those of the starches were similar (Table 3). The starch viscosity values in this study are quite higher than those reported for bitter yam starch (156.7 cP) by Ukom et al. (2016). These authors used 5% starch suspension which was smaller than the 12% used in this study. Hence the variation could be due to the starch concentration used as well as cultivar differences. The relatively high final viscosities observed for bitter yam starches suggest that these starches can potentially be used in various industrial applications.

3.6. Thermal properties

The peak gelatinisation temperature (approx. 83 °C) and conclusion gelatinisation temperature (approx. 88 °C) of the bitter yam starches was very similar (Table 4). However, the onset gelatinisation temperature, gelatinisation temperature range (T_p–T_o) and gelatinisation enthalpy varied significantly (Table 4). Amylose content of starches have been found to influence starch gelatinisation temperature. In general, low amylose starch is expected to display high gelatinisation temperature (Naidoo et al., 2015). In this study, amylose content appear not to influence the gelatinisation temperatures of the starches. According to Oyeyinka et al. (2016a,b), amylose content is not the only factor that affects starch gelatinisation. Other factors such as the distribution of amylopectin chains has been reported to influence the melting properties of starch (Noda et al., 1996). Huang et al. (2007) found that cowpea starch with larger portion of amylopectin chains correlated with a higher gelatinisation temperature compared with chick pea and yellow pea starches. The peak gelatinisation temperature in this study is similar to values (approx. 83 °C) previously reported (Farhat et al., 1999; Ukom et al., 2016).

Gelatinisation enthalpy (14.63 J/g) of yellow bitter yam starch was significantly higher than the white variety (11.72 J/g) (Table 4). Gelatinisation enthalpy is a reflection of the loss of double helical order or the overall crystallinity of amylopectin (Tester and Morrison, 1990a,b).

Table 4
Amylose contents, relative crystallinity and thermal properties of bitter yam starches.

Parameters	White variety	Yellow variety
Amylose content (%)	$15.09^b \pm 0.02$	$16.95^a \pm 0.43$
Relative crystallinity (%)	$28.00^a \pm 0.12$	$22.10^b \pm 0.04$
Onset gelatinisation temperature (°C)	$78.65^a \pm 0.64$	$76.00^b \pm 0.28$
Peak gelatinisation temperature (°C)	$83.05^a \pm 0.21$	$81.94^a \pm 0.02$
Conclusion gelatinisation temperature (°C)	$87.40^a \pm 1.13$	$88.35^a \pm 1.34$
Gelatinisation temperature range (°C)	$8.75^b \pm 0.24$	$12.35^a \pm 0.12$
Gelatinisation enthalpy (J/g)	$11.72^b \pm 0.17$	$14.63^a \pm 0.24$

Mean ± SD. Mean with different superscript along the row are significantly different ($p < 0.05$).

Table 3
Pasting properties of bitter yam flour and starch.

Parameters	White variety		Yellow variety	
	Flour	Starch	Flour	Starch
PV (cP)	$1781.04^c \pm 0.12$	$2438.12^a \pm 0.07$	$1322.02^d \pm 0.18$	$2230^b.00 \pm 0.28$
TV (cP)	$1355.56^c \pm 0.11$	$1673.04^a \pm 1.14$	$1058.23^d \pm 0.14$	$1588^b.00 \pm 1.14$
BV (cP)	$384.50^c \pm 0.04$	$775.25^a \pm 1.07$	$264.40^c \pm 0.94$	$632.00^b \pm 0.28$
SV (cP)	$902.40^b \pm 0.36$	$1193.13^a \pm 1.04$	$596.50^c \pm 1.12$	$1292^a.00 \pm 1.02$
FV (cP)	$2263.51^b \pm 0.54$	$2861.02^a \pm 1.14$	$1624.10^c \pm 0.02$	$2890^a \pm 1.07$
PT (°C)	$87.36^a \pm 0.42$	$86.70^a \pm 0.21$	$87.30^a \pm 0.08$	$86.90^a \pm 0.07$
Peak time (min)	$5.09^a \pm 0.02$	$4.82^a \pm 0.13$	$5.08^a \pm 0.02$	$5.00^a \pm 0.01$

Mean ± SD. Mean with different superscript along the row are significantly different ($p < 0.05$).
PV: Peak viscosity; TV: Trough viscosity; BV: Breakdown viscosity; SV: Setback viscosity; FV: Final viscosity; PT: Pasting temperature.

The lower gelatinisation enthalpy of white bitter yam starch suggest the presence of long amylopectin chains in the starch (Noda et al., 1996).

4. Conclusion

Bitter yam is good source of carbohydrate and minerals especially copper. Varietal differences did not substantially influence the physiochemical properties of the extracted starches. Bitter yam starch appeared polygonal and small sized. Amylose content was slightly different between the yam varieties. Isolated starches showed the A-type crystallinity with fairly high peak gelatinisation and pasting temperatures. Starch peak viscosity of the white variety was significantly higher than the yellow variety, which could be associated with its slightly lower amylose content. Bitter yam starches may be employed in the industry in the small, medium and cottage industry for various applications such as in biodegradable film.

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