Quality Characteristics of Native Starch from Selected Improved Varieties of Sweetpotato *(Ipomoea batatas)*

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Received: 16th February 2017 Accepted: 22nd May 2017

Abstract
Sweetpotato (Ipomoea batatas L.*) is a starchy root crop with a wide range of diversity in physical and compositional characteristics. Links between starch properties and processing characteristics are known to have an impact in utilization. Starches were extracted from six (6) improved varieties of sweetpotato harvested at 3, 4 and 5 months after planting. Starch granule morphologies were characterized at 4 months using Light Microscopy, and starch pasting properties were determined at all harvest times by Rapid Visco Analyzer. Granular shapes were generally heterogeneous and approximate size distributions varied from 2 to 15m to 8 to 40m. peak viscosity ranged from 4077 to 5260 centipoise, pasting temperature ranged from 77.95 to 82.45°C, setback ratio ranged from 1.25 to 1.61 and stability ratio ranged from 0.52 to 0.73. Starches with smaller granules had relatively low peak viscosities and high stability or resistance to breakdown while those with larger granule size ranges had lower setback ratio, indicating less retrogradation and better long-term cold paste stability. The influence of both variety and harvest maturity on all RVA pasting properties were significant at p<0.001. Small starch granule size varieties harvested at 4 and 5 months had the lowest peak viscosities and highest setback ratio; larger granule size varieties harvested at 4 months had the highest peak viscosities and lowest setback ratio. These results are relevant in understanding the processing and utilization quality of the varieties studied, and also in identifying potential niche applications for sweetpotato starch as food ingredients or in other applications.*

Keywords: Starch quality, RVA pasting properties, Harvest maturity, Granule morphology, Ipomoea batatas.

Caractéristiques De La Qualité De L'amidon Locale À Partir De Variétés Améliorées De Patate Douce (Ipomoea batatas)

Résumé
La patate douce (Ipomoea batatas L.*) est une culture racinaire fétide avec une large diversité*

de caractéristiques physiques et de composition. Les liens entre les propriétés de l'amidon et les caractéristiques de formation sont connus pour avoir une incidence sur l'utilisation. Les amidons ont été extraits de six (6) variétés améliorées de patates douces récoltées à 3, 4 et 5 mois après la cultivation. Les morphologies des granulés d'amidon ont été caractérisées à 4 mois à l'aide d'une Microscopie légère, et les propriétés de collage d'amidon ont été déterminées à toutes les heures de récolte par la machine'Rapid Visco Analyzer'. Les formes granulaires étaient généralement hétérogènes et les distributions approximatives des tailles variaient entre 2 et 15 µm à 8 à 40m. La viscosité maximale variait de 4077 à 5260 centipoises, la température de collage variait de 77,95 à 82,45°C, le rapport de retrait variait de 1,25 à 1,61 et le rapport de stabilité variait de 0,52 à 0,73. Les amidons avec des granulés plus petits avaient des viscosités de pointe relativement faibles et une stabilité élevée ou une résistance à la panne tandis que ceux avec des gammes de granulométrie plus grandes avaient un rapport de retrait inférieur, ce qui indique une rétrogradation moins élevée et une meilleure stabilité à la pâte froid à long terme. L'influence de la variété et de la maturité des récoltes sur toutes les propriétés de collage de RVA était significative à p <0,001. Les petites variétés de granules d'amidon récoltées à 4 et 5 mois présentaient les viscosités maximales les plus faibles et le taux de retrait le plus élevé; Les grandes variétés granulométriques récoltées à 4 mois avaient les viscosités maximales les plus élevées et le rapport de retrait le plus bas. Ces résultats sont pertinents pour comprendre la transformation et la qualité d'utilisation des variétés étudiées, et aussi pour identifier les applications de marché potentiel pour l'amidon de la patate douce comme ingrédients alimentaires ou dans d'autres applications.

Mots-clés: la qualité de l'amidon, propriétés de collage de RVA, maturité de la récolte, morphologie des granulés, Ipomoea batatas.

Introduction

Sweetpotato (*Ipomoea batatas* Lam.) is one of the most important starchy crops in the world, with Asia and Africa producing about 95% of total production (Katayama *et al.,* 2006). The crop is known to differ in its starch characteristics and various attempts have been made to establish links between starch properties and cooking, processing and eating qualities (Walter *et al.,* 2000; Chen, 2003). Characterization of sweetpotato starches in various parts of the world is well documented (Garcia 1993; Collado 1997; Ishiguro *et al.,* 2000; Mweta, 2009; Tsakama *et al.,* 2010; Zhu *et al.* 2011; Abegunde et al., 2012; Senanayake *et al.,* 2013; Zhu and Wang, 2014) and efforts have also been made to identify various factors that influence the quality (e.g. growth temperature) (Ishiguro *et al., 2003;* Toyama *et al.,* 2003). Ghanaian varieties have, however, not been studied much in this regard.

Sweetpotato has a wide range of diversity in physical and compositional characteristics. Being a short duration crop (3 - 4 months) with high potential yields of improved varieties currently available, if cropped continuously throughout the year, sweetpotato could compete favourably with other popular starch sources e.g. cassava which require about 6 - 12 months to mature. Sweetpotato has a very high dry matter productivity rate (Scott *et al.,* 2000) and the starch content of some varieties can be as high as 80% of the dry matter (Zhu and Wang, 2014). Despite the view in some circles that the crop lacks potential in commercial starch exploitation due to relative advantages of other alternative starch sources (Wheatley and Loechl, 2008), sweetpotato starch has performed creditably well in some Asian economies. For example, it has been used for the manufacture of starch noodles in China, Korea and Japan for many years (Chen, 2003). Starch is an important industrial commodity and has numerous applications in both food and non-food sectors. It is believed that the state of a country's economy is linked with its level of demand for starch (Satin, 1988). Approximately 60% of worldwide starch production is used for food applications and 40% for non-food applications (Copeland, 2009). Some food applications of starch include canning, frozen foods, sugar syrups, snack foods, bakery products, soups and sauces, salad dressings, cooked meat binder, flavours and beverage clouds, fat replacers, confectionery, dairy and imitation dairy products and microwavable products. Non-food applications include adhesives, explosives, paper industry (e.g. tissues, cardboard, baby diapers), textiles, feeds, fertilizer, seed coatings, building materials, cement, oil drilling, cosmetic and pharmaceutical industries (Satin, 1988; Copeland, 2009).

Native starch from different sources may have unique characteristics that could be of interest in various specific applications. Although modified starches are used extensively as food ingredients (Abbas *et al.,* 2010) due to desirable features such as better uniformity and functionality, there are often the associated issues of extra costs involved in starch modification processes, legal restrictions on some chemical modification methods and consumer demands for more natural ingredients. Modified food starch is classified as a food additive and so limits of its use and labeling are clearly defined in the US Code of Federal Regulations (21 CFR 172.892) (Sajilata and Singhal, 2005). There is therefore a constant search for specialty starches in the native or natural form to fit into niche applications. In Ghana sweetpotato has been gaining more attention over the years in terms of utilization, research and value addition; it is being promoted as a food security crop as well as an industrial raw material (Baafi *et al.,* 2011). It is therefore important to study not only starch content with regards to processing and eating quality, but also to determine the native starch characteristics of improved and high-yielding varieties available in the country. The objective of this study was to characterize starches from a selection of sweetpotato varieties, as an initial step towards better exploitation of the crop locally.

Materials and Methods

Six (6) high-yielding and disease resistant improved varieties of sweetpotato (Apomuden, Bohye, Faara, Hi-starch, Okumkom and Ligri) were used in the study. They were planted in the research fields of CSIR-Crops Research Institute, Ghana (Fumesua Station) under identical management practices and harvested 3, 4 and 5 months after planting; their starches were extracted within 48 hours after harvest.

Starch extraction

A basic non-chemical procedure was applied to obtain chemical-free native starch. Fresh roots were washed, peeled, macerated and filtered through cheesecloth using tap water. Filtering was repeated and the starch milk was left to settle. The supernatant was discarded and the settled starch re-suspended in water twice (tap water was used in order to simulate local starch extraction practices). Starch sediment was air-dried for 72 hours to approximately 12% moisture levels, packed and sealed in clear polyethylene sample bags and stored at room temperature till analysis.

Starch granule morphology

A starch sample (7 - 10 mg) was taken using the tip of a spatula and placed on a glass slide. The sample was mixed with 1 - 2 drops of 0.2% Iodine solution, spread out and observed under a Light Microscope (Novex, Holland) fitted with a calibrated eyepiece to calculate the size range of the granules. Micrographs were taken with a digital camera (Canon SX210 IS) at magnification of x400. Starch from sweetpotato samples harvested at optimal maturity (4 months) was used for the microscopy.

Starch pasting properties

Starch pasting properties were determined by the Rapid Viscosity Analyzer (RVA model 4500, Perten Instruments-Australia) using 11.2% starch slurries (dry weight basis). Parameters measured were Pasting temperature, Peak viscosity, Peak time, Hot paste viscosity (viscosity at the end of the holding time at 95°C) and cold paste viscosity (viscosity at the end of the holding time at 50°C). From these parameters, stability ratio and setback ratio were calculated. Each test was run in duplicate. Starch from sweetpotato samples harvested at 3, 4 and 5 months were used in the RVA studies.

Experimental design

A split-plot design with variety as the main plot and maturity as the sub-plot was used to determine the influence of harvest maturity on RVA pasting characteristics of starch from the 6 sweetpotato varieties at 3 levels of maturity.

Statistical analysis

All tests were run in duplicate. Statistical analysis was performed using GenStat Release 12.1 (2009). Data were analyzed by General Linear Model (GLM). Differences at $p<0.05$, $p<0.01$, and $p<0.001$ were considered to be significant. Pair-wise comparison of all means was performed using Duncan's multiple comparison procedure.

Results and Discussion

Granule morphology

Granule shapes observed were heterogeneous, mainly spherical, polygonal and truncated oval or 'half egg' shapes. Size distribution ranges were also varied, with Apomuden having the smallest (2 - 15 µm) and Hi-starch the largest (8 - 40 µm) range (Plate 1; Table 1). Sweetpotato starch is generally known to have a granule size distribution range of about 4 - 40 µm. Starch granules from different sources exhibit a broad range of size distributions in nature, and granule size and shape are among the most important morphologically distinguishing factors of starches from different origins; e.g. the English potato is reported to have a very broad granule size distribution of up to over 70 µm while cow cockle (*Saponaria vaccaria* L), starch granule size is smaller than 2 µm (Satin, 1988).

In one study on Malawian sweetpotato, the widest starch granule distribution was found to be 9-36 µm (Tsakama *et al.,* 2010) and in another study, five Sri Lankan sweetpotato varieties were reported to have polygonal or round shaped starch granules with average granule size of 16.8 - 23.5 µm; a low level of *in vitro* starch digestibility was observed in varieties containing larger granules, indicating the presence of resistant starch (Senanayake *et al.,* 2013). This might be linked with the higher amount of surface area available for enzyme action in smaller-sized granules. Apomuden could be recommended for the production of baby foods due to its high nutrient content (unpublished data) and very small starch granule size (Table 1), as it may have the potential for higher starch digestibility than varieties with larger granule sizes. Different size granule fractions of starches from various crops have been characterized (Appolonia and Gilles, 1971; Kulp, 1973; Goering and DeHaas, 1974; Kainuma *et al.,* 1978; Ghiasi *et al.,* 1982;

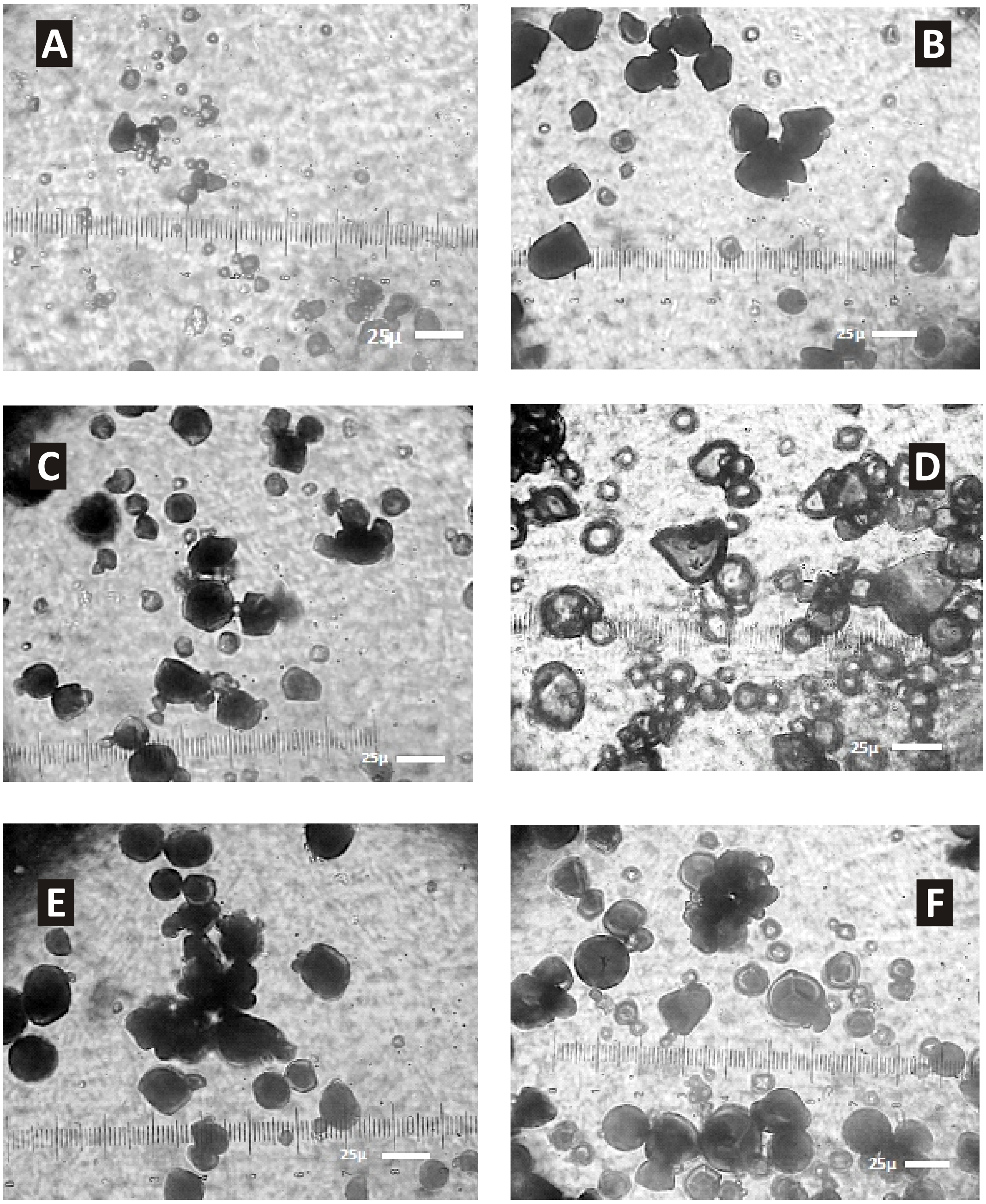


Plate 1. Photomicrographs of native starch granules extracted from six sweetpotato varieties. A: Apomuden, B: Bohye, C: Faara, D: Hi-starch, E: Okumkom, F: Ligri (white bar in each micrograph is 25 microns)

Table 1.Starch granule morphologies of six sweetpotato varieties

Variety	*Granule size distribution range (microns)*	*Description of Granule shapes (predominant)*
Apomuden	2 - 15	Truncated oval, spherical
Bohye	6 - 34	Truncated oval, spherical
Faara	4 - 22	Polygonal, spherical
Hi-starch	8 - 40	Spherical, truncated oval
Okumkom	6 - 26	Spherical, polygonal
Ligri	5 - 30	Spherical, polygonal, truncated oval

Soulaka and Morrison, 1985; Jane *et al.,* 1992; Vasanthan and Bhatty, 1995; Wilhelm et al., 1998; Takeda *et al.,* 1999; Fortuna *et al.,* 2000; Tang *et al.,* 2001a, 2001b). It is reported that starches with small granules and narrow granule size distributions are very useful for many different applications, e.g. as fat substitutes, starch-filled degradable plastic films, stabilizers in baking powder. The small granule size of rice starch (2 - 13μm) makes it suitable for application in skin cosmetics and laundry-stiffening agents (Jane, 1992; Jane *et al.,* 1992). In this study, Apomuden, Faara and Okumkom were found to have smaller size distribution ranges compared to the other three varieties studied (Table 1).

Starch pasting characteristics

The influence of both variety and harvest maturity on all RVA pasting properties were significant ($p<0.01$, $p<0.001$) (Table 2). Peak Viscosities ranged from 4077 to 5260 cp and were highest in varieties that had larger granule sizes while the lowest were observed in Apomuden, Faara and Okumkom, the smaller-sized granule varieties (Table 3). There is less molecular bonding in larger granules and this leads to faster swelling. The larger granules therefore tend to give higher viscosities than smaller granule fractions, and the physical size of the granule also makes it more sensitive to shear (Chen *et al.,* 2003; Thao and Noomhorm, 2011). Stability ratio indicates the extent of a cooked starch's resistance to viscosity breakdown in the presence of shear stress, and is calculated as the ratio of the lowest (trough) viscosity to the highest (peak) viscosity attained during the heating phase of the pasting cycle. Stability ratio ranged from 0.52 to 0.73; starches with high peak viscosity (Bohye, Hi-starch and Ligri) were found to have low stability ratio, i.e. they were more susceptible to breakdown

Table 2. Mean Square values from Analysis of variance of the influence of variety and harvest maturity on starch RVA pasting properties

Source of variation	*d.f*	*Pasting Temperature*	*Peak Time*	*Peak Viscosity*	*Stability Ratio*	*Setback Ratio*
VARIETY	5	7.971***	0.227***	7809***	0.025***	0.061***
MATURITY	2	0.908**	0.013***	3149***	0.009***	0.002***
VARIETY. MATURITY	10	0.501**	0.036***	8022***	0.002***	0.007***
Residual	15	0.109	0.001	5272	0.00006	0.0001

***Significant at $p<0.001$ **Significant at $p<0.01$ *Significant at $p<0.05$

(Table 3); Tsakama *et al.*, (2010) reported a similar trend where starches with high peak viscosities were found to break down easily, leading to weak gels. They also reported that starches with longer peak time were more susceptible to shear-induced disintegration. However, our varieties showed a contrary trend, where longer peak times were rather associated with higher stability (Table 3). Starches with smaller granules had relatively low peak viscosities and high stability (i.e. resistance to breakdown). These starches (Apomuden, Faara and Okumkom) may therefore be suitable as thickening agents for sauces, cream soups, pie fillings and other applications requiring more stability and resistance to various stresses during the heating process. Pasting temperatures ranged from 77.95 - 82.45°C.

Pasting temperature for sweetpotato starches are reported to generally range from 61.5°C to 86.3°C (Moorthy 2002) and a study in Vietnam reported values of 80.1°C to 82.3°C (Thao and Noomhorm, 2011). Pasting temperature relates to the ease of cooking and has implications for the efficiency of energy usage in processing. Chen *et al* (2003) found that in 3 sweetpotato starches, the larger the granule size the higher the gelatinization temperature . In our study, two of the larger sized granule varieties (*Bohye* and *Ligri*) had the highest pasting temperatures; *Hi-starch* was however unique, having the largest granule size range and yet the lowest pasting temperature among all the varieties (Table 3). Peak time ranged from 3.97 to 4.80 min, and again was lowest in Hi-starch variety; this was however to be expected since larger granules tend to build viscosity faster than smaller sized granules. The varieties with smaller granule sizes were found to have the longest peak times, the longest being *Apomuden* which had the smallest granule size range. Peak time is the length of time to reach the highest viscosity during the heating phase. Other workers reported peak times ranging from 4.15 minutes to 4.40 min (Thao and Noomhorm, 2011). Setback ratio ranged from 1.25 to 1.61, and was found to be higher among the smaller granule sized starches (*Apomuden, Bohye* and *Faara*). It is described as the ratio of final viscosity (at the end of cooling) to viscosity at the start or onset of cooling, and is used to predict the retrogradation tendency of starch. Retrogradation is an important characteristic in starch utilization. Cooked or gelatinized starch molecules tend to re-associate with one another after cooling, forcing water out of the molecule and thereby causing the starch to recrystallize. The tendency of a starch to recrystallize or retrograde determines its suitability in certain products when long-term stability is a requirement. Sweetpotato starch is reported to retrograde more slowly or has less setback than cereal starches (Takeda *et al.,* 1986). *Bohye* and *Ligri* starch had the lowest values for setback (Table 3), indicating less retrogradation and better long-term cold paste stability; these starches may therefore be suitable for adhesives and also in cold desserts and frozen foods.

For other product types, retrogradation is a desirable feature and it may even be promoted to modify structural, mechanical, or organoleptic properties of certain starch-based products e.g. breakfast cereals and parboiled products. This is because retrogradation results in hardening and reduces stickiness. Setback is therefore considered an important criterion for starch selection for many industrial food applications such as noodles (Chen *et al.,* 2003; Thao and Noomhorm, 2011). Among the small-sized granule starches *Okumkom* had the least setback ratio or retrogradation tendency (Table 3). Park *et al* (2001) demonstrated the importance of starch granule size and

Table 3. RVA pasting indices of starch from six sweetpotato varieties across three (3) levels of harvest maturity

RVA Pasting Parameter					*Mean*
Peak Viscosity (Centipoise)	Variety	3 months	4 months	5 months	
	Apomuden	4882	4202	4336	4473.3 [+360.2] c
	Bohye	5260	5233	5027	5173.3 [+127.4] a
	Faara	4540	4442	4077	4353.0 [+243.9] d
	Hi-starch	4902	5146	4866	4971.3 [+152.3] b
	Okumkom	4722	4210	4082	4338.0 [+338.6] d
	Ligri	4867	5062	4845	4924.6 [+119.4] b
Setback ratio	Variety	3 months	4 months	5 months	
	Apomuden	1.43	1.61	1.58	1.54 [+0.098] a
	Bohye	1.29	1.28	1.28	1.281.28 [+0.004] e
	Faara	1.37	1.49	1.45	1.44 [+0.060] b
	Hi-starch	1.46	1.35	1.34	1.38 [+0.067] c
	Okumkom	1.36	1.37	1.33	1.35 [+0.020] d
	Ligri	1.27	1.25	1.28	1.27 [+0.016] e
Stability Ratio	Variety	3 months	4 months	5 months	
	Apomuden	0.73	0.72	0.67	0.71 [+0.029] a
	Bohye	0.62	0.60	0.57	0.60 [+0.028] d
	Faara	0.65	0.69	0.68	0.67 [+0.018] b
	Hi-starch	0.64	0.55	0.50	0.500.56 [+0.070] e
	Okumkom	0.68	0.61	0.61	0.63 [+0.042] c
	Ligri	0.56	0.52	0.53	0.54 [+0.021] f
Peak Time (mins)	Variety	3 months	4 months	5 months	
	Apomuden	4.80	4.60	4.43	4.61 [+0.184] a
	Bohye	4.23	4.47	4.33	4.34 [+0.117] c
	Faara	4.33	4.47	4.46	4.42 [+0.078] b
	Hi-starch	4.10	3.97	4.03	4.034.03 [+0.067] e
	Okumkom	4.43	4.20	4.53	4.534.23 [+0.170] d
	Ligri	4.33	4.13	4.23	4.39 [+0.099] b
Pasting Temp (^{0}C)	Variety	3 months	4 months	5 months	
	Apomuden	80.33	79.95	80.33	80.20 [+0.217] c
	Bohye	81.13	82.40	82.45	81.99 [+0.751] a
	Faara	79.48	79.95	80.68	80.04 [+0.607] d
	Hi-starch	79.15	77.95	79.13	78.74 [+0.686] d
	Okumkom	80.80	79.90	80.75	81.51 [+0.506] b
	Ligri	81.48	81.55	81.50	80.48 [+0.036] c

Numbers in square brackets represent standard deviation. Means followed by a common letter are not significantly different (mean separation by LSD, p < 0.01, for main effects of variety).

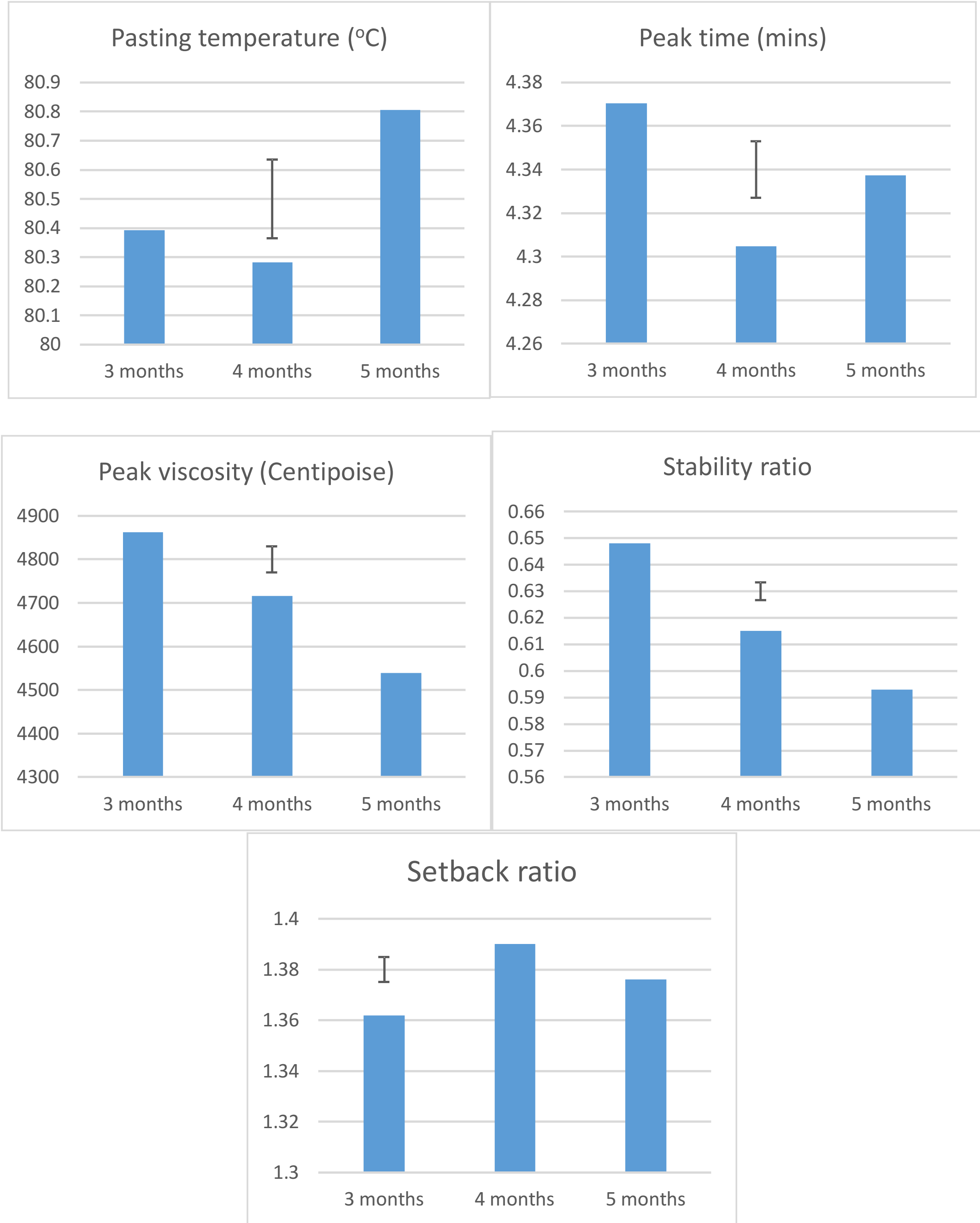
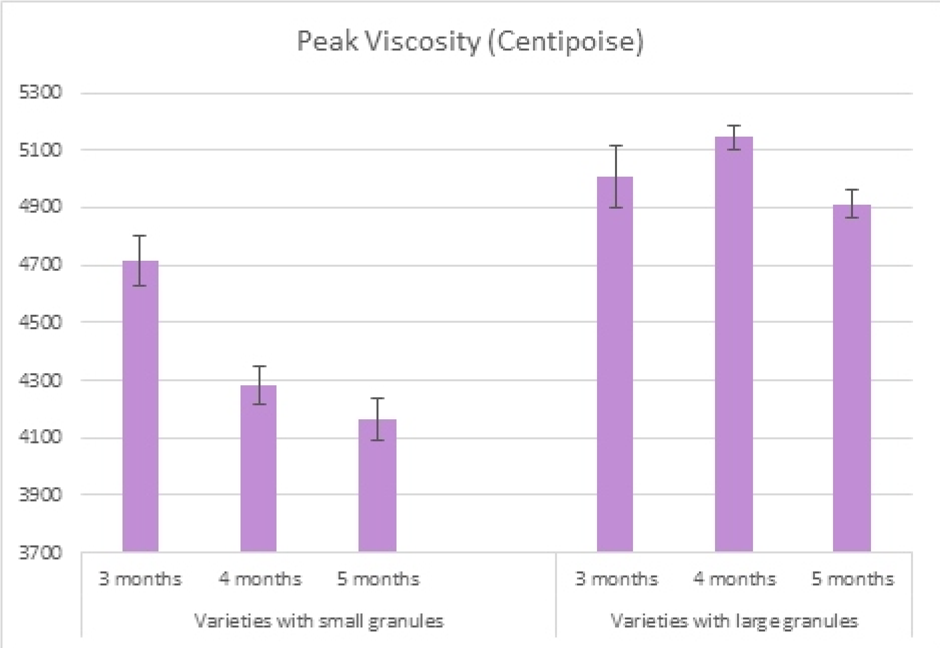


Figure 1. Influence of harvest age on RVA pasting properties of starch from six (6) sweetpotato varieties (Error bar in each chart = LSD for effect of maturity; $p<0.001$)



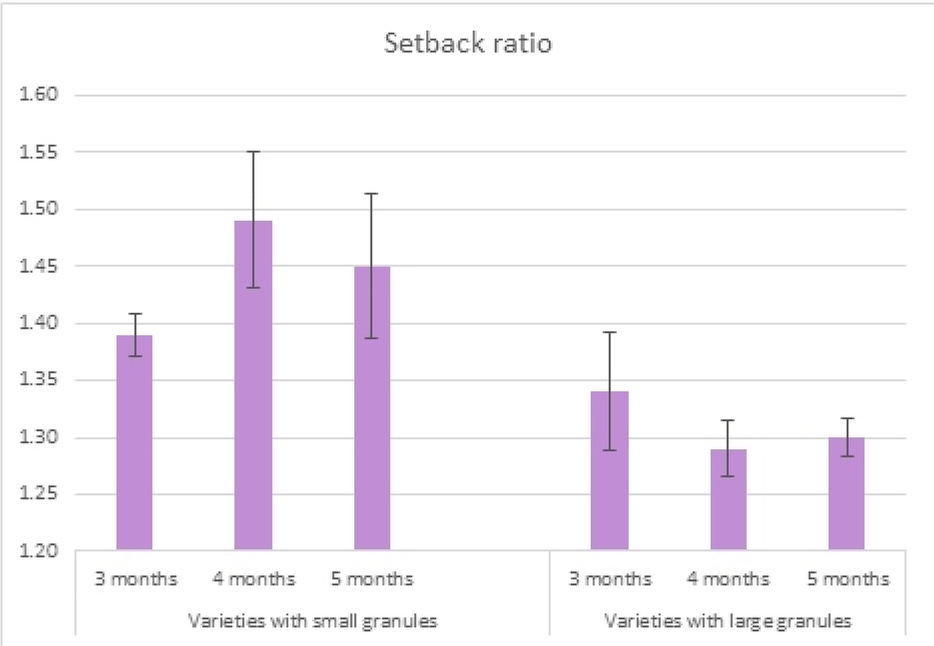


Figure 2. Influence of granule size on changes in peak viscosity and setback ratio with increasing maturity. Small granule size category: < 26µm; large granule size category: < 40µm. (Error bars are standard deviations for varieties)

retrogradation tendency in some snack formulations; starches with smaller granules and low degree of retrogradation yielded products with the best puffing quality as well as a smooth mouth feel.

The influence of maturity

Although varietal and environmental differences have received more emphasis in most studies, the influence of maturity on sweetpotato starch properties have also been reported (Noda *et al.,* 1997; Yempew *et al.,* 2001; Ishiguro *et al.,* 2003). This is of relevance due to the fact that sweetpotato has no clear-cut maturity time. Harvesting is often done when storage roots have reached sizes desirable for marketing, making it very subjective. In Ghana, the recommended harvest maturity for improved varieties is 4 months. Noda *et al* (1997) observed that sweetpotato starches of the same variety but grown and harvested at different times had varying properties, and reported that starch extracted from older roots had higher gelatinization temperature and peak viscosity, but lower hot paste stability. Our study confirmed this with the exception of peak viscosity, which was lower at advanced maturity i.e. mean peak viscosity for all the varieties reduced with increasing harvest maturity and was lowest at 5 months (Fig 1).

However, when varieties were categorized according to starch granule size range, differences in the effects of maturity became obvious. For larger granule varieties a slight increase in peak viscosity was observed between 3 and 4 months while for smaller granule varieties, reduction in peak viscosity occurred progressively with advancing maturity (Fig 2).

Granule size category may be an important factor to consider when studying trends in the influence of maturity on starch functional properties. Other workers also reported that granule size had substantial effects on sweetpotato starch pasting properties, although the link between granule size and how pasting properties variation during maturation or crop development was not factored into those studies (Chen *et al.,* 2003; Abegunde *et al.,* 2012). With the exception of *Faara*, early harvested samples (i.e. 3 months) had the highest final viscosities (cold paste or gel viscosities), indicating harder texture of gels formed upon cooling. The lowest cold paste viscosities at the end of the pasting profiles (indicating softest gels) were observed at 5 months for all the varieties (Fig 1). *Okumkom* starch at 5 months may be suitable for incorporation into flours for baked products, due to its low peak viscosity coupled with good stability (resistance to breakdown) and very low cold paste viscosity observed at the end of the pasting cycle (Fig.1). The best performance of sweetpotato starch in industry may be achieved by selecting not only the appropriate variety but also the best recommendations for harvest maturity.

Conclusions

Starch granule shapes and size ranges showed some amount of diversity among the varieties studied. *Apomuden* starch was observed to be unique, showing a very small size range close to that of rice and uncharacteristic of sweetpotato starches. *Bohye* and *Ligri* starch had the lowest values for setback, indicating less retrogradation and better long-term cold paste stability. These starches may therefore be suitable for adhesives and also in cold desserts and frozen foods. Starches with smaller granules (*Apomuden, Faara* and *Okumkom*) had relatively low peak viscosities and high stability ratio or resistance to breakdown. They may therefore be suitable as thickening agents for sauces, cream soups, pie fillings and other applications requiring more stability and resistance to various stresses during the heating process. *Okumkom* starch at 5 months may be suitable for incorporation into flours for baked products, due to its low peak viscosity coupled with good stability and very low cold paste viscosity observed at the end of the pasting cycle.

RVA pasting properties of the starches were influenced significantly by variety and harvest maturity. The influence of maturity on peak viscosity and setback ratio followed different trends based on granule size category. Small starch granule size varieties (< 26 microns) when harvested at 4 and 5 months, had the lowest peak viscosities and highest setback ratio (retrogradation tendency. The larger granule size varieties (< 40 microns) when harvested at 4 months had the highest peak viscosities and lowest setback ratio. Selection of sweetpotato starch for utilization must take into account not only varietal uniqueness but also harvest maturity. These results are relevant in the industrial utilization of the starches studied, as food ingredients and also in other applications.

Acknowledgement
The Authors gratefully acknowledge the West Africa Agricultural Productivity Program (WAAPP)-Ghana (under the World Bank) for providing funds for this study.

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