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# Evolution of functional properties of precocious yam starch (*Dioscorea cayenensis-rotundata*) during tuberization

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## ABSTRACT

The behaviour of starch during tuberization was carried out in order to determine the appropriate yam starch properties for industrial applications. Starch was isolated from "Kponan" variety of *D. cayenensis-rotundata* and submitted to functional properties study. Starch granule size increases with tuber maturation from 23.8 µm at 12 weeks, to 25.1 µm at 24 weeks after planting. Granule shape is the same whatever the degree of tuber maturity. Swelling power and solubility pattern of starch increase with tuber maturation. Starch clarity improved during tuberization as well as gel syneresis. The percentage of transmittance increased during the growth of tuber from 9.96% at 12 weeks to 14.6% at 24 weeks. Past instability is not influenced by the tuber maturity. In general starch harvested at mature state could be used to produce satisfactory starch products.


**Keywords:** Precocious yam, tuber, vegetable cycle, harvested period, functional properties.

## INTRODUCTION

Yam (*Dioscorea* spp.) is a monocotyledon tuber-bearing plant belonging to the family *Dioscoreacea* within the genus *Dioscorea* (Riley et al., 2006). It is grown widely in tropical and subtropical regions of the world. *Dioscorea* genus accounts for 600 to 800 species with few edible (Kati et al., 2004). Only five species are cropped in Africa: *D. alata* L, blend *D. cayenensis* Lank - *D. rotundata* Poir., *D. esculenta* (Lour) Burk., *D. dumetorum* (Knuth) Pax. and *D. bulbifera* L.. Among these species, some varieties of *D. cayenensis-rotundata* are precocious, hence could be harvested six month after planting during the vegetable cycle. These varieties are usually used in the ritual festivals in West Africa (Savary, 1992). The importance of yam as staple foods is due to its starch content and technological aptitude favourable for traditional feed. Yam starch properties have been investigated by several studies. According to the macromolecular characteristics, yam starch indicates three classes: *D. alata* and *D. cayenensis-rotundata,* which have large starch granules, high amylose content, high intrinsic and apparent viscosities and low gelatinization enthalpy; the second class, including all *D. esculenta* cultivars, is characterized by small starch granules, low intrinsic and apparent viscosities and high gelatinization enthalpy; the third class, represented by *D. dumetorum* cultivars, has properties close to those of *D. esculenta* and 100% A-type crystallinity (Rolland-Sabaté et al., 2003). Despite the desirable properties of yam starch such as viscosity stability to high temperature and a low pH, the high retrogradation of yam starch gel is disadvantageous when it is applied to food systems (Huang et al., 2006). The starch properties of roots and tubers vary between different cultivars and growth time. The granule size increases with growth, the transition temperature of yam starch decreases during maturation for four varieties of *D. alata* (Huang et al., 2006). Peak viscosity and phosphorus content increase but amylose remaines unchanged during potato growth (Christensen and Madsen, 1996). Retrogradation of potato starch is influenced by cultivation condition as well as for amylose content and the proportion of short unit-chains (DP 9-11) of amylopectin (Ishiguro et al., 2003). The starch content of four varieties of *D. alata* increases as growth progresses (Huang et al., 2006). Starch properties are generally botanic and species dependent, but granule size distribution vary between the three sections (proximal, middle and distal) and some starch properties (Degbeu et al., 2008). According to Ko et al. (2005), starch is synthesized in the chloroplast of photosynthetic tissues as transient starch and in the amyloplast of sink tissues for storage such as tuber, seed and endosperm of cereals by several enzymes. Precocious varieties reach their maturity before the belated.

In the present study, a prize variety of yam named "Kponan" was grown for 24 weeks after planting, in order to understand the changes in the functional properties of starch isolated from precocious variety during growth. We hypothesized that functional properties of starch from precocious variety could have appropriate starch properties needed to produce satisfactory starchy products. Therefore, the starch properties were monitored during the tuberization.

## MATERIALS AND METHODS

### Materials and cultivation methods

The variety of *Dioscorea cayenensis-rotundata* blend named "Kponan" was obtained from the experiment farm of Abobo-Adjamé University (Abidjan, Côte d'Ivoire). The planting density was 1m x 0.5m. The tubers were harvested at different stages of growth (12, 16, 20, 24 weeks). Starch was extracted from two batches of four tubers at each period. All tests were done in triplicates.

### Starch isolation

The starches were purified according to a previously described procedure (Amani et al., 2004). Tubers and roots were peeled and immediately cut into small pieces. The freshly cut pieces were suspended in distilled water containing 0.1% (w/v) sodium metabisulphite. The material was crushed in a Warring blender (Moulinex, Lyon, France) and suspended in a large excess of distilled water containing 4% NaCl. The slurry was filtered through a 100 µm sieve. The starch was allowed to settle and the supernatant decanted off. This process was repeated four times and the recovered white prime starch was then oven-dried at 45 °C for two days. The moisture content was determined by oven-drying for 2 h at 130 °C.

### Starch granule measurements

A pinch of starch sample in water was prepared, and the slide was placed on the stage of a compound microscope CETI and observed (Degbeu et al., 2008). The length and the width of granules were determined by KAPPA software incorporated to computer. One thousand counts were performed with 200 granules counted per slide for each sample.

### Paste clarity

Paste clarity was determined according to the method of Craig et al. (1989). Transmittance was determined for 1% (w/w) of yam starch dispersion, using a Unico spectrophotometer (N°1100).

### Gels syneresis

A 4% (w/w, dry weight basis) gel was heated with gentle stirring (Agimatic-M Staufen, Germany) for 15 min (Pingault, 1995). The gel was immediately distributed into centrifuge tubes at a rate of 6 g ± 0.5 g per tube. Three tubes of every sample were cooled to room temperature and then centrifuged (J. P. SELECTA, THIS 95 N° 289886, Barcelona, Spain) at 5000 rpm for 30 min. This constituted the initial syneresis (week 0). The remaining tubes were frozen at -20 °C (4 weeks). Each week, three tubes of each sample were thawed at 50 °C for 90 ± 5 min, and then centrifuged in the same conditions previously described. After centrifugation, the syneresis rate was calculated as the weight of leaked-out water divided by the weight of the original gel.

**Swelling power and solubility**

The starch suspension of 1% (w/w) was heated for 30 min over the pasting range 60 to 95 °C by immersion in a water bath with gentle stirring. After cooling for 15 min at room temperature it was centrifuged at 5000 rpm for 30 min. The supernatant was immediately separated from the sediment, both were oven-dried (130 °C for 2 h) weighed and the swelling power and solubility determined (Leach et al., 1959).

**Pasting characteristic**

The Pasting Characteristic of 6% starch paste (27g of starch on a dry weight basis in 450 ml of water) was obtained with a Brabender viscoamylograph (OHG Duisburg, Germany) by heating an aqueous starch suspension from 50 °C to 95 °C, maintaining it at this temperature for 15 min and then cooling it down to 50 °C. The speed of the rotor was fixed at 75 rpm and the rate of heating and cooling was fixed at 1.5 $min^{-1}$ throughout the range of gelatinization, holding and cooling steps.

**Statistical analyses**

Statistical analyses were carried out by StatSoft software (statistica, 99th Edition, Paris, France). The differences between the samples were established with the test of Newman-Keuls at $p<0.05$.

## RESULTS

**Granule size and shape**

Starch granule microscopy showed no specific shape differences between samples (Fig. 1). Likewise, the shape was not influenced by the degree of maturity of yam tuber. Three shapes were observed in all samples: ovoid more or less flat, ellipsoids, polygonal. These shapes were specific to the *Dioscorea cayenensis-rotundata* species. The means of the starch granule diameters increased with the degree of tuber maturity from 23.8 µm at 12 weeks, to 25.1 µm at 24 weeks. The granule size distribution varied (Fig. 2) from 7 µm to 51 µm for all samples. These variations showed the presence of small and large granules in all samples (Fig. 1). Large granules were more important after 20 weeks inversely for the small granules. Statistical analysis indicated a significant difference ($p<0.001$) between values observed from the 12 weeks samples and the rest of the dates.

**Clarity and syneresis**

The percentage of transmittance increased during the growth of tuber from 9.96% (12 weeks) to 14.6% (24 weeks) (Fig. 3). The variance analysis indicated significant difference ($\alpha = 0.05$) between samples. Gel clarity was improved with the physiological maturity of tubers.

Gel syneresis decreased with the degree of tuber maturity for each sample (Fig. 4). For all the samples studied, gel syneresis decreased during the storage period at -18 °C. The statistical analysis shows a meaningful difference ($p<0.001$) between samples except for 16 and 20 weeks ($p = 0.317$). Starch from mature tubers resist to syneresis compared to starch at earlier developmental stages.

**Swelling power and solubility**

The ability of starch granule to swell and solubilize increased during the tuber maturation (Fig. 5). The order of this evolution is the same for both swelling and solubility phenomena. A linear correlation ($r^2 > 0.97$) was noted between swelling power and solubility of granules. Swelling power increased with starch solubility during tuberization. Statistical analysis indicated no significant difference between samples.

**Paste viscosity**

The viscograms of different samples presented (Fig. 6) regular evolution characteristic of yam starch. Starch of the four developmental stages showed the same initial pasting temperature (76 °C). The peak of viscosity increased slowly from 520 UB (12 weeks) to 540 UB (24 weeks) during tuber maturation. During the isothermal period at 95 °C, the viscosity decreased weakly indicating the stability of yam starch to mechanical shear. However, after this period the viscosity increased strongly despite the developmental stage.

## DISCUSSION

Starch granule morphology showed no difference during tuber maturation. The shapes viewed are ovoid more or less flat, ellipsoids and polygonal. The developmental stage has no influence on the starch shape.

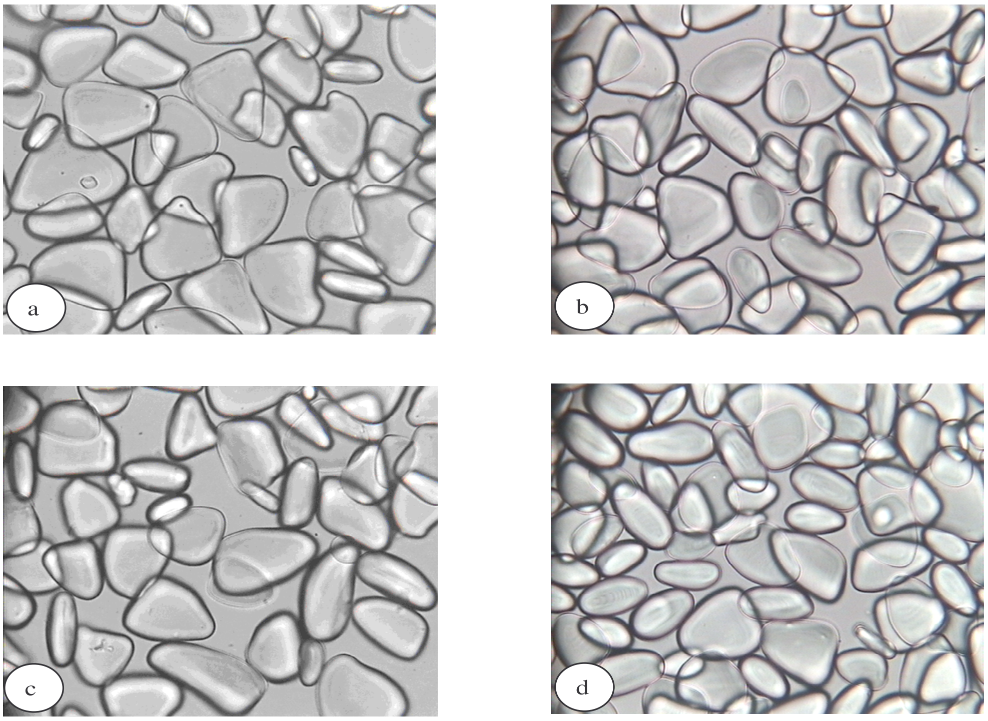


**Figure 1:** Light micrographs (G X 400) of starch granule according to their degree maturity: a) starch extracted at 12 weeks of plantation, b) 16 weeks maturity granules, c) 20 weeks maturity granules and d) 24 weeks maturity granules.

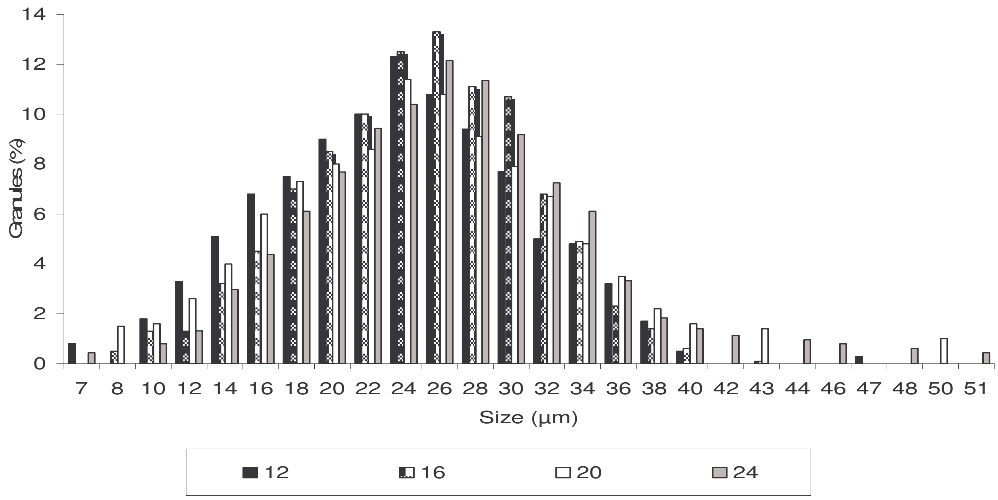


**Figure 2:** Granules size distribution during the tuber maturation. 12 (12 weeks), 16 (16 weeks), 20 (20 weeks), 24 (24 weeks).

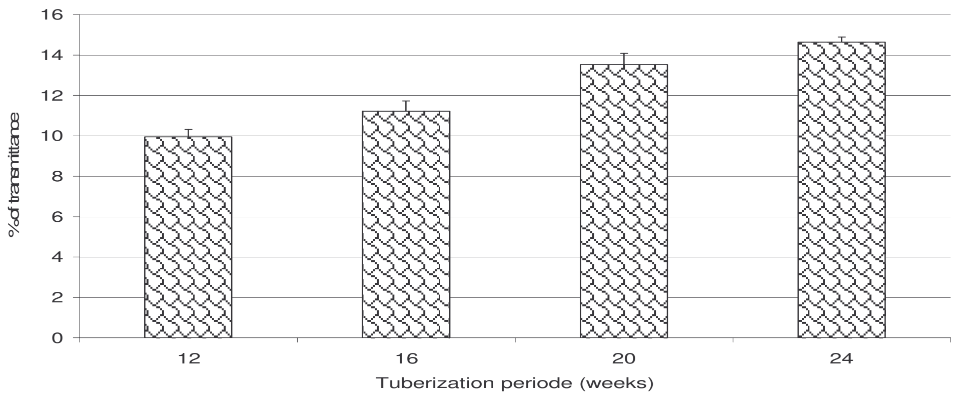


**Figure 3:** Starch clarity during granules maturation. 12 (12 weeks), 16 (16 weeks), 20 (20 weeks), 24 (24 weeks).

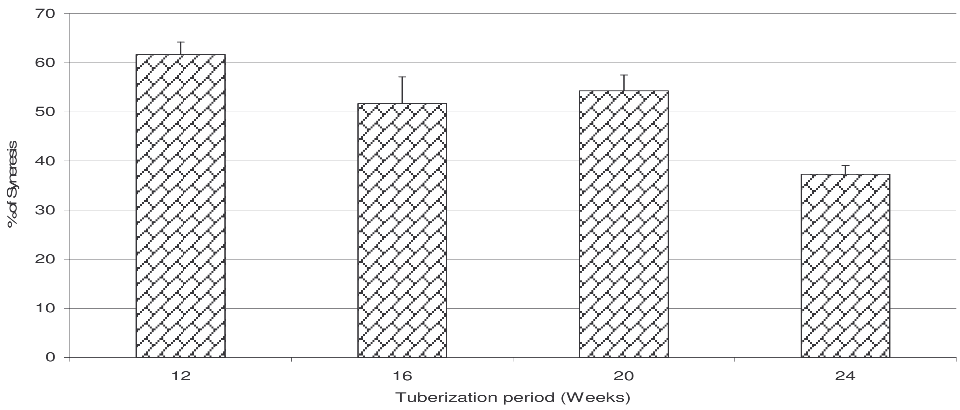


**Figure 4:** Starch syneresis evolution during granules maturation. 12 (12 weeks), 16 (16 weeks), 20 (20 weeks), 24 (24 weeks).

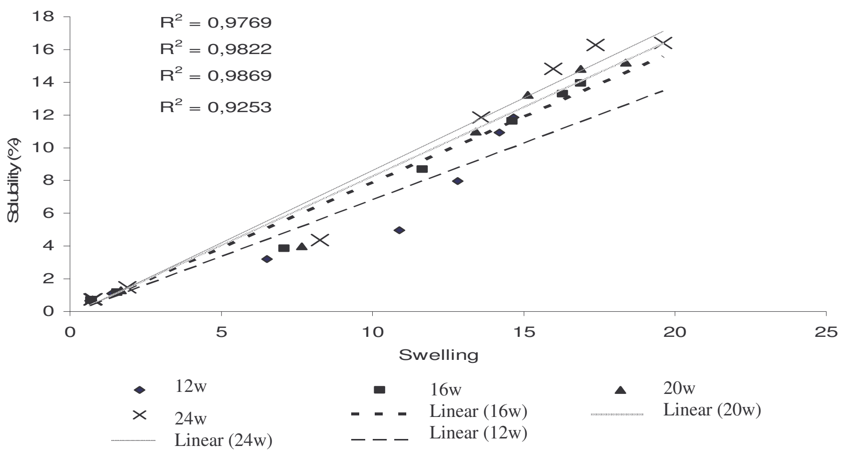


**Figure 5:** Correlation between starch swelling and solubility. 12w (12 weeks), 16w (16 weeks), 20w (20 weeks), 24w (24 weeks).

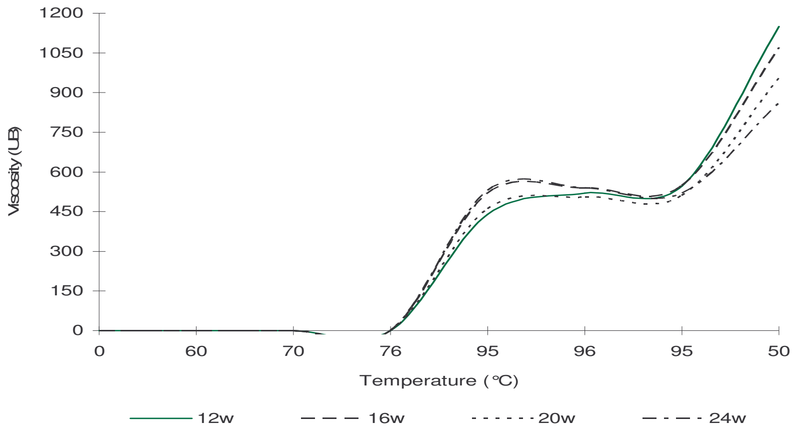


**Figure 6:** Brabender viscosity curve of starch according to tuberization period.
12w (12 weeks), 16w (16 weeks), 20w (20 weeks), 24w (24 weeks).

This result could be explained by origin dependent of starch granules (Lindeboom et al., 2004). In spite of the identical shape, starch size increased with the degree of tuber maturation as observed by Huang et al. (2006) on four yams of *D. alata* species. Granule growth could be attributed to the biosynthesis character of starch granules (Geigenberger et al., 2004; Ral et al., 2006). These phenomena generally were observed on the biological system and contributed partly to the general evolution of tuber. The mechanism of starch biosynthesis has been investigated on potato tuber due to its relatively simple anatomy and the ease with which transgenic plants can be produced (Geigenberger et al., 2004). Whatever the degree of the tuber maturity, a small amount of granule was noted in all samples. The amount of small granule was lower at tuber maturity. This phenomenon could be explained by physiological key of starch formation, which decreased with the degree of tuber maturity. According to Martin and Smith (1995), starch biosynthesis varies both quantitatively and qualitatively during the course of storage organ formation. Some isoforms of the biosynthetic enzymes may be active early in starch granule formation and others active later. The presence of small granules has been reported in cereal starch studies during the plant development (Gallant and Bouchet, 1986; Morrison and Gadan, 1987). Tubers growth improved starch clarity, gel syneresis and swelling power and solubility. It seemed to be bound by the size evolution. Despite starch clarity and syneresis increases, values obtained remain low compared to previous study for the clarity on the same variety (Degbeu et al., 2008). Gel syneresis values indicated instability during the storage at -20 °C versus cassava starch (Tetchi et al., 2007). Improvement of these properties during tuber growth indicated that harvested yam tuber at end of the vegetable cycle is beneficial to the yield and starch properties. However, starch components were not only responsible of granules properties but vegetable cycle in this experiment and other factors such as environment effect and cultural condition (Tester and Karkalas, 2001; Ishiguro et al., 2003). Concerning pasting behaviour of starch granule during tuber maturation, the results agreed with those of previous studies (Huang et al., 2006) about the viscogram keys. The high viscosity observed during the cooling period expressed the hard retrogradation of yam starches. This behaviour is not affected by the tuber maturity.

## Conclusion

The influence of tuberization on physicochemical properties of yam starch was studied. Granule size, paste clarity, swelling power and solubility index increased with the tuber maturation. These functional properties were improved during the vegetable cycle. Inversely, gel syneresis decreased. However, past viscosity showed instability during cooling and storage (-20 °C) period. For industrial used, starch harvested at mature state is more appropriate.

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