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Physicochemical, rheological and thermal properties of taro (*Colocassia esculenta*) starch harvested at different maturity stages

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Abstract

The objective of this study was to evaluate the effects of tubers maturity stage on the physicochemical characteristics and thermal properties of *Colocasia esculenta* (Sosso ecotype) starches. Plantation was done in Chad, tropical area from May to February following a randomized design with 5 maturity stages (6, 7, 8, 9 and 10 months after planting) as the main treatments. The results showed significant increase in phosphorus content (from 113.99 to 145.64µg/100g), temperature (from 80.69 to 84.54°C) and enthalpy of gelatinization (from 13.24 to 16.27 J/g), water absorption capacity (from 140.11 to 304.48 %), solubility index (from 17.50 to 29.42%) and swelling index (from 115 to 135%). In addition the monomolecular moisture content (varying from 2.67 to 3.36 %) and the GAB constant C (varying from 11.73 to 113.22) exhibited significant increase with maturity. Furthermore, a significant decrease in amylose content (from 35.90 to 27.65%) was observed as the maturity increases. In conclusion and on the basis of the correlation observed, the changes in phosphorus and amylose composition of starch during growth seemed to play a role not only on the molecular structure of the starch granules, but also on its functionality.

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Introduction

Taro (*Colocasia esculenta*) is grown widely in tropical and subtropical regions of the world for its underground starch. Taro tubers yield starch between 70 and 85% dry matter (Jane *et al*., 1992). Taro starch has major economic importance due not only to its high yield but also to its functionality (Jane *et al*., 1992; Carr *et al*., 1995; Aboubakar *et al*., 2008). In this respect taro starch has granules of sizes lower than 5µm and as such is highly digestible and recommended for infant foods (Nip, 1997; Aboubakar *et al*., 2008); is useful as a filler in biodegradable plastics, in toilet formulations or aerosol (Nip, 1997). Taro starch has also been proposed to mimic oil droplet in food emulsions such as mayonnaise, thus contributing to reducing the consumption of oil by consumers and risks of cardiovascular diseases (Nip, 1997). In food systems such as achu (taro based paste), taro starch exhibited specific visco-elastic properties characterized by its high hardness, force of adhesion and relaxation (Njintang *et al*., 2007). Several other studies have been conducted on development of taro based-foods emphasizing the properties of taro starch (Rodriguez-Miranda *et al*., 2011; Ahromrit and Nema, 2010; Ammar *et al*., 2009; Onyeike *et al*., 1995). The properties of the starch including the viscosity, the ability to absorb water and swell, and the gelatinization profile have been shown to depend on the content and structure of amylose and amylopectin (Lu *et al*., 2008). The properties of taro starch have been quite studied (Jane *et al*., 1992; Sefa-Dedeh and Sackey 2002; Aboubakar *et al*., 2008).

In the event of taro flour or starch processing in Chad in the Centre Africa, corms are generally harvested at varying periods of maturity from 5 to 10 months depending on the demand. Many studies reported that starch characteristics generally alter with plant developmental stage. In this respect it has been shown that harvesting dates influence *Pachyrhizus ahipa* root and starch characteristics (Leonel *et al*., 2005). In addition a study on the effect of harvest dates on the starch properties of various potato cultivars revealed that late harvest date significantly enhanced the phosphorus content, peak viscosity and breakdown, while it led to slight decreases in amylose content, pasting temperature, and gelatinization temperature and no influences on gelatinization enthalpy (Noda *et al*., 2004). Other studies on potatoes also revealed significant effect of maturity on the properties of starches (Noda *et al*., 1997, Svegmark *et al*., 2002; Liu *et al*., 2003). Similar studies on *Dioscorea* sp. revealed significant changes on their biochemical (Trèche and Agbor-Egbe, 1996), rheological and physicochemical properties (Huang *et al*., 2006)

For taro flour or starch to become economically competitive, the quality of the harvested tubers needs to be guarantee. However the fundamental question concerning the effect of stage of maturity on the utilization of the harvested tubers still to be answered. In other words what are the physicochemical, functional properties, rheological and thermal properties of taro starch harvested at different maturity periods since these parameters constituted the determinant factors of their properties in food systems? To our knowledge very few if none such study has been conducted on taro. The present study was initiated in an effort to investigate this issue.

This research attempted to determine the biochemical, the thermal properties, rheological and physical properties of taro starch, as influenced by harvesting time. The expected result may improve the technological quality and commercialization of this valuable crop.

Material and methods

Planting experiments

The experiments were carried out at Kolobo in Mayo-Kebi division (9-11°N, 14-16°E), Chad, from May 2007 to February 2008. This region has a tropical monsoon climate with two main seasons: raining and hot-dry. The hot-dry season lasts from December-April with the

highest temperatures occurring in the months of March-April. The rainy season lasts from May to November with the highest rainfall occurring in August and September. The experiments were carried out following a randomized planting design on a farm space of 200 m² surrounded by a border representing 1/5 the total size. The soil in this area is of the sandy loam quality with moderate fertility, and pH of 5.0 - 6.0. The sosso-taro variety was used for the experiment and harvesting was carried out at varying periods of 6, 7, 8, 9 and 10 months after planting. Each batch of harvested tubers were thoroughly washed with tap water to remove all foreign materials and taken to the laboratory for starch preparation.

Isolation of taro starch

Taro starches were isolated from taro flours of tubers harvested after each harvesting period using standard procedures (Perez et al., 1993). In this respect, the tubers were sliced and dried in air convection at 40 ± 2 °C. The dried slices were first hammer milled (Culatti polymix, France) to pass through a 200 µm screen. Taro flour (1 kg) was steeped in 10 L of 2 % NaCl solution with continue mixing at 40 °C for 5 h before being passed through a 80 µm mesh sieve. The filtrate was allowed to stand overnight and the supernatant discarded. The precipitate (starch sediment) was treated with 10 L NaOH 0,03 M and then centrifuged at 4500 rpm for 15 min. the precipitate was washed twice with distilled water and lastly with ethanol which was evaporated during drying in a convection electric dryer at 30 °C. The starch was then collected ground with a mortar and stored in a sealed dried polyethylene bags until required for analysis. The yield of extraction of starch was evaluated gravimetrically.

Evaluation of Chemical composition of taro starch

Starch of each maturity was analyzed for moisture (air oven method), fat (Soxhlet), crude proteins (Nx6.25) and ash (incineration method) content, as a percentage (w/w), following AACC (1990) procedures. Semi automatic machine (GEHARDT, Paris, France) was used for crude proteins analysis. Phosphorous content, as a percentage (w/w), was determined following the photometric method as described by AOAC (2000). The amylose content was determined using the iodine colorimetric method (Mc Grance *et al.*, 1998). Purity was calculated from the difference between 100 and percent of moisture, crude protein, fatty material and ash content following the equation: % purity = (100-[% crude protein + % fatty materials + % ash]).

Color characterization of taro starch

Color measurements of the starch were carried out using a Chromameter CR210 (Minolta France S.A.S., Carrières-sur-Seine) on the basis of L* a* and b* values. The instrument was calibrated against a standard light yellow-coloured reference tile. A glass cell containing the powdered flour was placed above the light source and covered with a white plate and L*, a* and b* values were recorded. The whiteness index (WI) was determined according to the following equation (Saricoban and Tahsin, 2010).

$$WI = 100 - \sqrt{(100 - L)^2 + a^2 + b^2}$$

Wide – angle X-ray investigations (WAXS)

The crystallographic properties of the different starch maturities were examined on a guinier-camera arrangement with a quartz monochromator. A Cu-anode (Philips PW/ 2273/ 20, The Netherlands) gave and average wavelength of 1.54 Å, and was operated at 40 KV and 20 mA. All the starch samples were examined at a starch to water ratio of 1:1, and mounted in hermetically sealed cuvettes to keep their moisture during examination. The scattered patterns were recorded on reflex 25 Medical X-ray film (CEA AB, Sweden), processed according to the recommendations of the manufacturer.

Differential scanning calorimetry (DSC) analysis of taro starch

DSC thermograms of taro starches were recorded on a NETZSCH model Phoenix (NETZSCH 204 F1), with

heating rate of 5 °C/min and temperature rate range of 25–120 °C. Starch was dispersed in distilled water (1:3; w/v) in an aluminium pan and hermetically sealed. The instrument was calibrated for temperature and enthalpy measurement with indium, and an empty pan was used as reference. The manufacturers' software was used to calculate the heat capacity and integrate the peaks. The onset and end temperatures of the gelatinization peaks were determined by the intersection of tangents fitted to the leading and trailing flanks of the peak with the baseline.

Equilibrium moisture content (EMC) and adsorption isotherm of taro starch

The EMC of the taro starch was determined at 20 °C according to the static gravimetric method (Wolf et al., 1985). The desorption isotherms were determined on samples hydrated in a glass jar over distilled water at a room temperature to approximately 30% dry basis moisture content. Samples of 1.00 ± 0.02 g were weighed in weighing bottles which were put in hygrostats with six saturated salt solutions (LiCl, CH_3COOK, MgCl2, $Mg(NO_3)_2$, NH_4Cl and $BaCl_2$) used to obtain constant water activity environments between 0.1 and 0.9. All the salts used were of reagent grade. At high water activities (aw > 0.70) crystalline thymol was placed in the hygrostats to prevent the microbial spoilage of the starch. The hygrostats were kept in thermostats at 20 ± 0.2 °C. Samples were weighed (balance sensitivity ± 0.0001 g) every three days. Equilibrium was acknowledged when three consecutive weight measurements showed a difference less than 0.001 g. The moisture content of each sample was determined by the oven method (105 °C for 24 h) by means of triplicate measurements. The resulting adsorption curve was tested to follow the multilayer GAB model of adsorption of the general form

$$M = \frac{M_0 k_b c a_w}{[1 - k_b][1 - k_b a_w + c k_b a_w]}$$

where M is the moisture content expressed in g/g dried weight, and a_w is the water activity. The GAB model was transformed to a quadratic equation (Chen and Jayas 1998), and the constants M_o (g/g), k_b and C were determined using the nonlinear power equation category of Sigma plot 8.02 (Chicago, IL, USA) statistical package. The coefficient of determination (R^2) and the mean relative percent error (P) were determined.

$$P(\%) = \left[\sum_{n=1}^{n} \frac{X_{obs} - X_{pred}}{X_{obs}}\right]\frac{100}{n}$$

Xobs is the measured equilibrium moisture content expressed in %; Xpred is the predicted equilibrium moisture content expressed in % and n is the number of data points.

Determination of water absorption capacity and water solubility index of taro starch

For the determination of these variables, 1 g of starch was suspended in 10 mL of distilled water and incubated with mixing for 30 min in a shaking water-bath (Kottermann, Germany) set at 20, 40, 60, 80 and 100 °C and centrifuged at 5600 rpm for 30 min. The pellet was dried at 105 °C for 12 h and the water absorption capacity calculated as g of water absorbed per 100 g of dried pellet (Phillips et al., 1988) and the water solubility index calculated as the soluble matter per 100g of dried pellet (Anderson et al., 1969).

Evaluation of the Swelling index of taro starch

Three grams portions of each starch were transferred into cleaned, dry and graduated (50 mL) cylinders. The starch samples were gently leveled and the volumes noted. Distilled water (30 mL) was added to each sample; the cylinder was swirled and allowed to stand for 60 min while the change in volume (swelling) was recorded after 60 min. The swelling index of each starch sample was calculated as a multiple of the original volume (Ukpabi and Ndimele, 1990).

Statistical analysis

All measurements were carried out in triplicate. Analysis of variance was performed to determine the effect of harvesting time on the responses parameters.

When statistical differences were found, the Duncan's Multiple Range Test was applied in order to classify samples at the significant level of 5%. Statgraphics Program (Statically Graphics Educational, version 6.0 1992 Manugistics, Inc. and Statistical Graphics Corp., USA) was used for the statistical analysis.

Results and discussion

Chemical composition of taro starches

The compositions of taro starches from each maturity are shown in Table 1. Ash, fat and crude protein present in starches of different maturities of *Colocasia esculenta* variety Sosso were very limited, indicating high purity of the starch fractions. Similar to values earlier on *Colocasia* starch (Perez et al., 2005), it can be observed that the purity of our taro starches is quietly high (98.89 - 99.00%), given evidence of low levels of ash and proteins in the starches. One important parameter in response to the effect of maturity is the starch yield which significantly and continuously increased following ageing. Such observations have been made on other food such as cassava (Sriroth *et al.*, 1999), yam (Huang *et al.*, 2006) and potatoes (Liu *et al.*, 2003). This is an important observation since dry matter and starch act as important indicators for quality evaluation of starchy foods (Huang *et al.*, 2006). In this respect the optimum period for harvesting has very often been based on starch yield. In our case since no significant variation was observed beyond 8 months, 8 months could be considered as the optimum period of harvesting. This approach of determination of optimal harvesting time assumed the quality of starch is constant all aver the growth time. This is not the case since the most important parameter of starch, the amylose content often varied with growth time (Liu *et al.*, 2003; Huang *et al.*, 2006). In this respect the amylose content in our starch samples decreased from 35.9 % to 27.6 % in a linear manner ($R= -0.97$; $p < 0.05$). The amylose content were relatively close to those reported in our previous studies (16.65 %-30.85 %), but significantly higher compared to the other values (8.7-13.4 %) reported on taro starches (Aboubakar *et al.*, 2008; Lu *et al.*, 2008).

Table 1. Chemical composition of taro starch differing in maturity stage.

Parameters	Maturity (months)				
	6	7	8	9	10
Moisture (g/100g)	7.76±0.09	7.78±0.20	7.91±0.08	7.85±0.26	7.83±0.04
Ash (g/100g)	0.31±0.00^{a}	0.32±0.00^{b}	0.32±0.00^{b}	0.33±0.01^{c}	0.35±0.01^{d}
Protein (g/100g)	0.62±0.01^{a}	0.64±0,01^{b}	0.66±0.02^{b}	0.69±0.00^{c}	0.69±0.01^{c}
Fats (g/100g)	0.063±0.001	0.064±0.001	0.065±0.001	0.070±0.010	0.068±0.010
Amylose (%)	35.9±0.92^{e}	33.8±0.49^{d}	31.1±0.36^{c}	29.7±0.80^{b}	27.6±0.40^{a}
Phosphorus (µg/100g)	114.0±0.70^{a}	126.0±1.14^{b}	130.0±0.92^{c}	143.6±0.95^{d}	154.6±1.03^{e}
Yield (%)	57.9	60.9	68.0	68.1	68.3
Purity (%)	99.0	99.0	99.0	98.9	98.9

N=3; means±standard deviation; Means in the same line followed by different letters in superscript are significantly different at probability level 0.05.

The effect of harvesting time on the amylose level observed in this study agreed with those observed by some authors on cassava varieties who further reported the highest increase at the early harvest time (Asaoka *et al.*, 1992). Similarly a decrease in potatoes amylose content has equally been observed, but this

happened only after the first harvest and remained unchanged during growth of tubers (Liu *et al*., 2003). In addition a decrease (during growth from 5 to 7 months) in amylose level was observed on *Pachyrhizus ahipa* starch, but the magnitude of decrease depend on the planting period with those planted in October exhibiting 4% decrease while those planted in February showed a magnitude decrease of 13.3%. These observations contrasted with a study on cassava which revealed inconsistent changes of amylose content within a narrow band during the growth from 6 to 16 months. In the same vein studies on potatoes showed an increase in the amylose content with maturity (Sugimoto *et al*., 1995). Our observation coupled to those in literature suggested that the amylose content not only depends on the specie and the variety but also on the cultivation conditions and the harvesting time.

Table 2. Variation in color parameters of taro starch at different maturity stages

Maturity (months)	L*	a*	b*	WI
6	98.4±1.36^{a}	1.16±0.10^{a}	3.6±1.17^{a}	95.9^{a}
7	98.6±1.18^{a}	1.36±0.35^{a}	4.6±1.00^{a}	95.0^{a}
8	98.8±1.13^{a}	1.59±0.18^{a}	4.5±1.39^{a}	95.1^{a}
9	98.8±0.79^{a}	1.33±0.15^{a}	3.9±0.68^{a}	95.1^{a}
10	98.7±0.56^{a}	1.39±0.24^{a}	3.4±0.81^{a}	96.0^{a}

N=3; means± standard deviation; Means in the same column followed by different letters in superscript are significantly different at probability level 0.05

Table 3. Degree of crystallinity and relative crystallinity of taro starch

Maturity (months)	Peaks of diffraction at 2□θ□(°)			Degree of crystallinity (%)	Relative crystallinity (%)
	17°	20°	27°		
6	17.50	19.90	26.50	27.22	37.48
7	17.80	19.93	26.50	27.11	37.34
8	17.75	19.90	27.00	27.31	37.57
9	17.80	20.00	26.70	27.47	37.82
10	17.80	19.95	27.00	27.40	37.69

Table 4. Starch gelatinization properties by DSC in taro differing in maturity stage

Maturity (months)	To (°C)	Tp (°C)	Tc (°C)	ΔH (J/g)
6	72.5±0.27^{a}	80.7±0.40^{a}	89.3±0.41^{a}	13.2±0.17^{a}
7	73.5±0.36^{b}	81.6±0.70^{b}	90.4±0.18^{b}	13.7±0.16^{b}
8	74.3±0.35^{c}	82.7±0.09^{c}	91.4±0.48^{c}	14.6±0.25^{c}
9	75.2±0.35^{d}	83.5±0.28^{d}	92.5±0.30^{d}	15.4±0.35^{d}
10	76.2±0.34^{e}	84.5±0.32^{e}	93.2±0.35^{e}	16.3±0.21^{e}

N=3; means± standard deviation; Means in the same column followed by different letters in superscript are significantly different at probability level 0.05.

The maturity stage had a large effect on the starch phosphorus content; and in contrary to the behavior in amylose content. A significant and linear increase ($r = 0.98$; $p < 0.05$) in phosphorus level was observed with the harvesting time. In this respect the phosphorus value at 6 months was 114.0 µg/100 g while the value at 10 months was 154.6 µg/100 g. This behavior is in agreement with report on potatoes (Liu et al., 2003). Hence a negative significant correlation ($r = -0.95$; $p < 0.05$) was observed between the phosphorous level and the amylose content in our starch samples. This observation was good evidence in favor of the concept that tuber starches with higher amylose had less phosphorus, since the phosphate groups are covalently bound to amylopectin molecules (Zaidul *et al*., 2008). Since the planting started during the raining season (lower temperature) and ended during the hot season (higher temperature), it is possible that this could have influenced the observed increase in phosphorus content of the starch. This however disagreed with the concept developed on potato tubers that lower environmental temperature during the development of potato tubers is associated with higher phosphorus content in starch granules (Noda *et al*., 2004).

Physical properties of taro starch

Color is an important criterion for starch quality, especially for use in food industries and textile (Moorthy, 2002). The color indexes L*, a*, b* and WI characteristics of the starches samples extracted at different maturity stage are presented in Table 2. Narrow range values of L* (98.43 - 98.85), a* (1.16 - 1.59), b* (3.37 - 4.64) and WI (94.95 – 96.00) were observed during growth time of taro tubers, and no statistically significant effect of maturity was found on the color coordinate of starch. In general the starches were white (high values of L* and WI), less red (low a* value) and less yellow (low b* value). The overall whiteness of the starch expressed as Whiteness index (WI) showed values higher than 94, thus justifying the good color of our sample (Hsu *et al*., 2003). This is probably a consequence of peeling and rinse prior to grinding which otherwise could have induced browning (Kurup and Nanda, 1994). Due to the presence of mucilages, aroids starches especially *Colocasia* have been thought to have a bad color and use of ammonia has been suggested as a means to improve it (Moorthy, 2002). The variety sosso may probably be poor in mucilages and phenols which are generally responsible of browning in aroids (Moothy, 2002).

The X-ray diffraction of the starches was done in order to investigate the changes in crystallinity of starch due to maturity stage of taro tubers (Sosso variety), since this has a connection with the functionality of the starches. Irrespective of the maturity stage, the diffraction curves were similar suggesting a unique type of starch during growing. Fig. 1 shows the typical X-ray diffraction pattern of starches extracted from taro at different maturity stages. For all starch samples, characteristic peaks appeared at the Bragg reflection angle 2θ 17.50°, 19.90° and 27° suggesting an A-type starch pattern. The A type crystal pattern suggested the amylopectin of our starch samples have shorter chain and are packed in a more compact structure (Jane, 2006). Previous studies reported that *Colocasia and Xanthosoma* starches also possess "A" pattern while the edible *Dioscorea* starches possessed "B" patterns (Moorthy, 2002). Cassava starch possesses "A", "C" or a mixed pattern with three major peaks at $2\theta = 15.3$, 17.1 and 23.5°. It has been reported that most starches from root and tuber exhibited a typical "B" - type X-ray diffraction pattern, but this was not the case with the sosso variety (Les Copeland et al., 2009). In a theoricall view point it has been hypothesized that the development of "A" or "B" type diffraction patterns during aging is dependent on the amount of water present, with water content higher than 43% leading to development of a "B" type pattern while water content lower than 29% leads to an "A" type pattern (Osella et al., 2005). This seems to be not the case in our studies since the moisture content of the starch during the growth period was always higher

than 50% while the starches exhibited an "A" type crystallinity. In Table 3 are reported the crystallinity indexes of the starches. The index of crystallinity was not significantly influenced by the growth time, and this agreed with previous studies on sweet potato, potato and yam starches (Noda *et al.*, 1995; Chiang *et al.*, 2007; Liu *et al.*, 2003; Huang *et al.*, 2006). The degree of crystallinity of taro tuber varied from 27.1 to 27.5 % and the relative crystallinity from 37.3 to 37.8 %. The absolute crystallinity values of starch from five varieties of cassava were found to be in the range 8 – 14 % (Moorthy *et al.*, 1996). Absolute crystallinity of some Colombian cassava varieties were determined and values (15.3 - 17.3%) did not varied significantly through the different seasons and all of them belonged to "C_A" pattern (Asaoka *et al.*, 1992). The similar X-ray diffraction pattern indicated that the organization of semi-crystalline structure of starch was not affected by taro maturity stage. Although differences existed in the peak intensities among the taro starches examined, more detailed information, such as the crystallinity development during taro growth is to be investigated in the future.

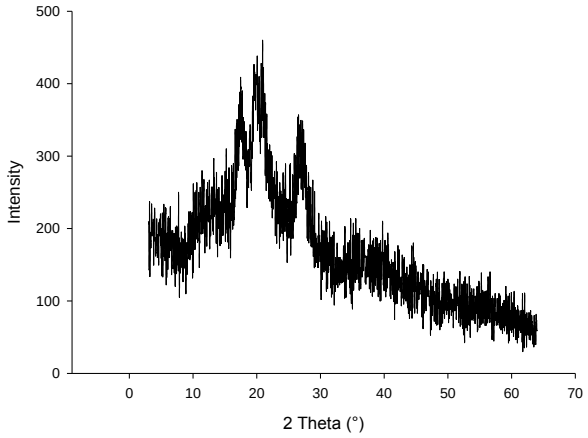

Fig.1. A typical of X-ray diffraction pattern of taro sosso starch during growth.

Differential scanning calorimetry of taro starch

During heating, all starches exhibited a single endothermic transition between 70 and 95 °C, indicating starch gelatinization (Liu *et al.*, 2003). The parameters of the thermogram from differential scanning calorific analysis (onset temperature (To), peak temperature (Tp), completion temperature (Tc) and enthalpy of gelatinization (ΔH)) of starch harvested at five different levels of maturity are presented in Table 4. The gelatinization temperature (To, Tp and Tc) and enthalpy (ΔH) increased significantly ($P<0.01$) with increase in maturity in a linear manner ($r = 0.98$, $p < 0.05$). For the period of vegetative growth under study, the enthalpy of gelatinization (ΔH) of taro starch significantly increased from 13.24 ± 0.17 J/g at 6 months maturity to 16.27 ± 0.21 J/g at 10 months. Similar behavior has been reported for *Trapa quadrispinosa Roxb* (Chiang et al., 2007) and taro (Wang *et al.*, 2001) starch during growth while a reverse tendency was reported for the gelatinization temperature of potatoes (Liu et al., 2003; Huang et al., 2006). The high values of enthalpy of gelatinization were generally associated with high levels of amylose in starches (Jane *et al.*, 1992: Aboubakar *et al.*, 2008). Unfortunately in this study while the level of amylose decreased, there was an increase in the enthalpy. This suggested that not only the amylose content influenced the enthalpy of gelatinization, but also other parameters such as crystallinity, intermolecular bonding, treatment conditions, etc (Moorthy, 2002).

Adsorption isotherm of taro starch

The ability of taro starch to hold water is shown in Figure 2. This figure corresponds to the adsorption isotherm of water and describes the change in water content of a product based on the water activity (aw). The curves show that the change in water content of starch depends on the relative humidity (RH) of the atmosphere in which they were stored. If the HR decreases, starches reject water, but, if the RH increases, they absorb moisture (Swinkels, 1985). Without exception, the adsorption isotherm of starches of different degrees of maturity shows an increase in humidity with increasing water activity at a constant temperature. This behavior which results in a sigmoid

shaped curve reflects a Type II isotherm according to Brunauer's classification. The adsorption isotherm of starch is due to hydrogen bonds between water molecules and hydroxyl groups available in the amorphous regions and on the crystallite surfaces (Urquhart, 1959). Very long time, several authors refer to three general areas of a sorption isotherm, with a particular method of attachment of the water on the product (Aboubakar *et al.*, 2008). The area for which the water activity is between 0 and 0.3 corresponds to the formation of a molecular monolayer on the surface of the product (Van der Waals forces between hydrophilic groups and water molecules).

Table 5. The GAB coefficients (M_o, C and k_b), coefficient of determination (R^2) and mean relative percent error (P) of the adsorption isotherm modeling of taro starch at different maturities

Maturity (Month)	K_b	C	M_o (g/100g)	R^2	P
6	0.82	11.73	2.80	0.99	6.05
7	0.84	11.73	2.72	0.99	10.13
8	0.83	33.93	2.67	0.99	5.05
9	0.83	81.94	2.86	0.99	6.08
10	0.82	113.22	3.36	0.98	7.60

The GAB model was used to describe the sorption of taro starch presented in Fig. 2. The GAB coefficients (M_o, C and k_b) of the model are given in Table 5 along with the correlation determination (R^2) and mean relative percent error (P). The correlation determination were all higher than 98% and P lower than 10% suggesting that the experimental results fitted quite well to the GAB model. In this respect the five constants of the model were estimated with reasonable accuracy. The monolayer moisture content, M_o, considered as that corresponding to the amount adsorbed at specific sites varied from 2.67 (maturity 8 months) to 3.36 (maturity 10 months). Increase in monolayer moisture with the maturity suggested an increase of the amorphous character of the starch granules during growth, and hence its hydroscopicity. The monolayer moisture content determined in this study fall in the range reported for potatoes starch (2.1-3.7%) (Al-Muhtaseb *et al.,* 2004). Significant variation was observed on the constant k_b (range 0.82-0.84). Relatively high k_b values (range 0.88-0.89) have been reported for high amylose and high amylopectine potatoes starch (Al-Muhtaseb *et al.*, 2004). The most important change observed on the GAB model parameters was on the C value. Known as the surface energy constant, C value significantly increased with increase in maturity varying from 11.7 to 113.2. As equally reported in literature, the most varying constant of the GAB model with temperature is C which decreases as the temperature increases (Al-Muhtaseb *et al.*, 2004; Peng *et al.*, 2007). Theoretically type II isotherm generally exhibited C values between 2 and 50, while values higher (range 50-200) reflected type 1 isotherm with significant chemisorptions (Labuza, 1975). This observation suggested that during growing the surface energy constant of starch granule increase, such as the gelatinization temperature determined by DSC.

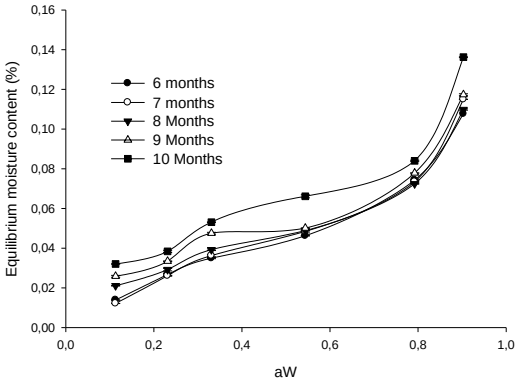

Fig. 2. Adsorption isotherm of taro starch influenced by maturity stage.

Water absorption capacity, swelling power and water solubility index of taro starch

Fig. 3 shows the water absorption capacity (WAC) of taro starch Sosso variety as a function of maturity time and incubating temperature. As usual the WAC increased with increase in incubating temperature up to 60 °C from which further increase in temperature resulted in decrease in WAC (Aboubakar et al., 2008). In this respect the WAC values at 20°C and 60°C incubating temperature were respectively 140.11g/100g and 226.81g/100g for starch harvested at 6 months after planting. The corresponding values for starch harvested after 10 months planting were 173.33g/100g and 304.48g/100g respectively. In can then been seen that the water absorption capacity significantly increased with maturity in agreement with the changes in monomolecular moisture content, thus conformed the concept developed above from the desorption isotherm: the hydroscopicity of starch increased with growth time. The amylopectin constituent of starch is prone to increased water absorption capacity (Aboubakar *et al.,* 2008) while high amylose content and important numbers of intermolecular bonds reduce the overall capacity of water absorption (Delpeuch and Favier, 1980). This concept seems to be confirmed in our study since a significant and negative correlation was observed between the amylose level and WAC ($R= -0.95$; $p<0.01$). Absorption of water by starch granules generally prompts to swelling and disruption of the structural organization of the granules. The swelling power of the starches is shown in Figure 4 and it can be seen as for WAC that it increased with increase in maturity. The swelling was studied at ambient temperature (25°C) and varied from 115 % to 135 %. Similar increase in swelling with increase in growth time was pointed out on potatoes (Liu *et al*., 2003). Such increase probably reflected the decrease in amylose during growth. In addition difference in interaction between amylose and amylopectin may also be responsible for the difference in swelling. In this respect difference in leaching of amylose has often been associated with solubility (Liu *et al.,* 2003). Although they did not conduct experiment to verify this, our findings invalidated the assumption as far as the variation with maturity is concerned. In fact while the amylose content in starch decreased as growth time increased, the solubility index increased (Fig. 5). This suggests that molecules other than amylose contributed to solubility, and/or amylose - amylopectine interactions may play a key role on the swelling. The assumption stated above has always been used to explain the variation in solubility with temperature. At all maturities, the WSI increased as the incubation temperature increased. In this respect at 20 ° C starch exhibited a lower solubility and formed only a temporary suspension when agitated in water. The low solubility of starch at low temperatures has always been justified by the semi-crystalline structure of starch granules, the granular structure due to the hydrogen bonds formed between the hydroxyl groups in starch molecules (Eliasson and Gudmundsson, 1996). In overall the increase in incubation temperature and degree of maturity is accompanied by an increase in the water solubility index (WSI). The concept of increase in solubility during heating of starch in water underlines the breakdown of starch granules and exposure of hydrophilic groups, and leaching of amylose (Aboubakar *et al*., 2008; Chiang *et al*., 2007).

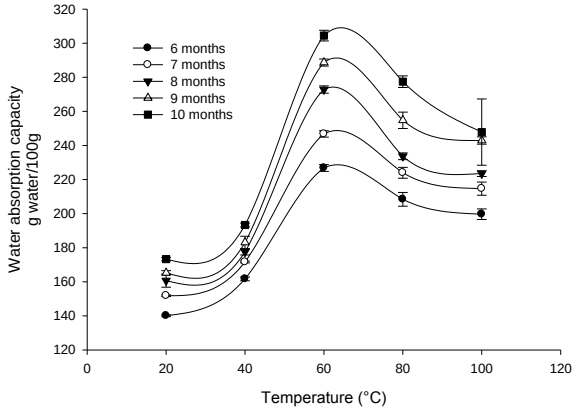

Fig. 3. Water absorption capacity of taro starch affected by maturity stage and incubation temperature.

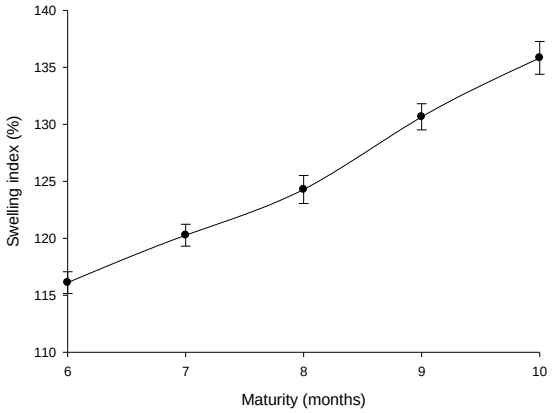

Fig. 4. Swelling power of taro starch affected by maturity stage.

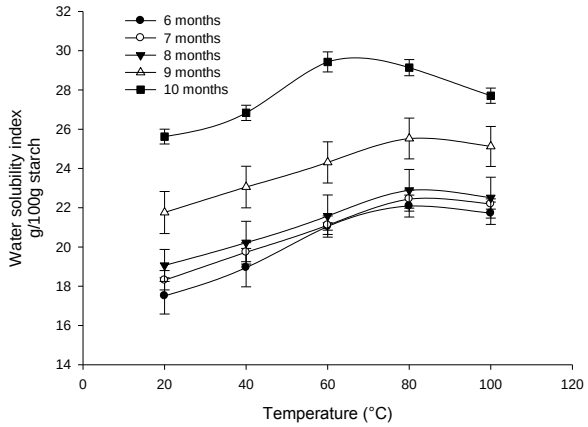

Fig. 5. Water solubility index of taro starch affected by maturity stage and incubation temperature.

Conclusion

In this study, the physicochemical properties of taro starches from tubers harvested at different maturities were investigated. The maturity stage significantly influences the composition, physicochemical and thermal properties of taro starch. While the amylose content decreases, the phosphorus content increases with maturity. The change in amylose and amylopectine content induces significant changes on the molecular structure of the granules reflected on their monomolecular moisture and surface energy with significantly increase with maturity. All the changes on composition and structure induce significant changes on the thermal and functional properties. In this respect the gelatinization temperature, the water absorption capacity, the swelling power and the water solubility index significantly increases with increase in maturity.

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