Physicochemical and thermal properties of taro (*Colocasia esculenta* sp) powders as affected by state of maturity and drying method

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Revised: 21 February 2012 / Accepted: 4 April 2012 / Published online: 21 April 2012
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Abstract The study was aimed at determining the effect of harvesting time and drying method on the thermal and physicochemical properties of taro powder, Sosso ecotype. A 5×2 factorial experiment with 5 harvesting times (6, 7, 8, 9 and 10 months after planting) and 2 drying methods (sun and electric oven drying) was used for this purpose. The variance component analysis revealed harvesting time as the most important factor affecting all the variables measured. In particular the proteins and available sugar contents of the powders increased significantly with increase in harvesting time. The same was true of the gelling property and water absorption capacity of the powders. It was equally observed that the temperatures (start, peak and end) and enthalpy of gelatinization of the powders increased with harvesting time. It is concluded that harvesting sosso-taro at full maturity (10 months after planting) and sun-drying produces food powders with excellent gelling properties among others.

Keywords Taro powder · Harvesting time · Drying method · Chemical composition · Physicochemical properties · Thermal properties

Introduction

Taro (*Colocasia esculenta*) is a tuber crop of high food value in many countries of the tropical area of the world. In Central Africa, and especially in Chad and Cameroon, it is generally consumed in the form of a paste obtained by pounding cooked tubers to a smooth homogeneous texture. The tuber is highly perishable after harvest due to its high moisture content. Not long ago a number of studies aimed at reducing post harvest losses and at using taro flour as starting material for the processing of food paste, were initiated in our laboratory (Njintang et al. 2006). Results from subsequent studies showed that the structure of food paste produced from taro flour is made up with intracellular starch in a continuous phase of some extracellular starch (Njintang et al. 2008). In addition it has been shown that good quality paste can be obtained from flour processed from cooked, sliced and solar-dried taro (Ibo coco variety) (Njintang and Mbofung 2003a, b; Njintang et al. 2006, 2007a). The paste made from this flour is prepared by reconstituting the flour in boiling water to attain a moisture level of 70–75 % (Njintang et al. 2007b; Aboubakar et al. 2008).

Although recent investigations had shown a high rate of acceptability of taro flour as starting material for the preparation of several local foods in Chad and Cameroon, a numbers of questions linked to flour made from other varieties of taro remained unanswered. In fact, taro tubers are usually harvested at different periods of time after planting. Farmers usually harvest taro tubers at or beyond the full

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maturity stage and keep it in the field quite a long time for dehydration and storage. A survey undertaken in Chad revealed that taro tubers of the *sosso* variety are usually harvested at varying time periods (6 to 10 months) after planting and processed into flour by peeling, slicing, sun-drying before milling. Drying, as a matter of fact has been reported as a suitable alternative for post harvest management especially in non developed countries where exist poorly established low temperature distribution and handling facilities (Sagar and Suresh Kumar 2010). This method of drying has the added advantage of very often producing good quality products as a result of the relatively lower temperatures involved in the process (Singh et al. 2006; Njintang et al. 2007a). However, the quality of some of the flours so produced leaves a lot to be desired by the local consumers especially with respect to their functional properties which are important indicators of the quality of the end product (Kaur and Singh 2007).

Meanwhile a limited number of previous studies on other types of tubers had shown that the stage of maturity at harvest affect the composition of *Pachyrhizus ahipa* (Leonel et al. 2005) and cassava root (Akingbala et al. 2011) as well as the morphological, thermal and pasting properties of yam starch (Huang et al. 2006). In addition a study by Njintang et al. (2007a) revealed the textural properties of taro flours pastes to significantly vary as a function of the method of drying during the processing of the tuber into flour. The quality problems associated with flours traditionally produced from the *sosso* variety of taro in Chad may not be unrelated to the age of harvesting and the method of processing into flour.

Towards the general objective of bridging our knowledge gap on the issues raised, the present study was carried specifically to investigate the effect of stage of maturity as well as that of method of drying on the chemical composition, physicochemical and thermal properties of *sosso*-taro powder.

Materials 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 to 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 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 powder production.

Sosso-taro powders production The tubers were peeled, cut into 0.5 cm thick slices and separated into two lots, one of which was sun dried for 24 h. Sun drying was carried out on trays with wooden frames and bottoms covered with mosquito netting material. Slices of taro were laid out on the tray and the whole covered with a similar tray so as to prevent the intrusion of insects during the drying process. The trays and their contents were then place on a one meter high stand in the sun. The second lot was dried at 40±2 °C for 24 h in an air drought electric oven (drying oven THERMOSI, Model SR 1000). Once dried to constant weight the slices were hammer milled (Culatti polymix, France) into powder to pass through a 200 µm screen and stored in sealed and polyethylene bags until required for analysis.

Proximate composition and amino acid profile analysis of taro powder Individual powder samples were analyzed in quadruplet for moisture (air oven method), fat (Soxhlet) and ash (incineration method) content following AACC standard methods (1990). Crude protein (Nx6.25) was analyzed using approved methods of Kjeldahl (AACC 1990) in semi automatic machine (GEHARDT, Paris, France). Samples were acid-hydrolyzed, and the reducing sugar known as available carbohydrate was determined by the dinitrosalicylic acid (DNS) method as earlier described by Fisher and Stein (1961).

The amino acid profile was determined in duplicate only for powders made from tubers harvested at 6, 8 and 10 months after the method used by Mbofung et al. (2006). Following this method, protein hydrolysate was prepared by treating 300 mg sample with an acidic solution (6 N HCl, 1 % phenol) in an evacuated test tube for 60 min at 105 °C. After flash evaporation, the dried residue was dissolved in ultrapure water and aliquots were analyzed in an Applied Biosystems 410a automatic amino acid analyzer (Applera Corp, Foster City, CA, USA) using a gradient of buffer system made of 45 mM sodium acetate pH 5.90 (A) and 30 % of a mixture of 105 mM sodium acetate pH 4.60 and 70 % acetonitrile (solution B) at temperature 36 °C and flow rate of 300 µl/min for 31 min. A PITC precolumn derivatization was used while the separation was made using a reverse phase PTC RP Column (2.1 mm Ø and 220 mm long, Applied Biosystems, Applera Corp, Foster City, CA, USA). Detection was made at 254 nm and the amino acid composition expressed as percent of total proteins. Tryptophan was not determined.

Determination of functional properties of taro powder The water absorption capacity (WAC) of the powders was

determined following the method described by Phillips et al. (1988); the water solubility index by the method of Anderson et al. (1969) and the least gelation concentration (LGC) according to the method described by Coffman and Garcia (1977). Triplicate determinations were made.

Flow properties of taro powders Flow properties of the powders were measured using a Hosokawa Powder Tester following the procedures described by Abdullah and Geldart (1999). In this respect the angle of repose (AOR), the aerated bulk density, the tapped bulk density, the dispersibility and compressibility measurements were taken as flowability indicators. Five runs were conducted on each sample.

Differential scanning calorimeter measurements (DSC) DSC thermograms recordings were recorded in quadruplets using a NETZSCH model Phoenix (NETZSCH 204 F1) instrument, set at a heating rate of 5 °C/min within a temperature range of 25–120 °C. Powders were dispersed in distilled water (1:3; w/v) in an aluminium pan 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 to 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.

Color characterization Color measurements of the powder 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-colored reference tile. A glass cell containing the powdered flour was placed above the light source and covered with a white plate and the L^* , a^* and b^* values were recorded. Six measurements were made in each run.

Statistical analysis The data reported in the tables and figures are average values of duplicates (amino acid) or more replicate determinations. They were subjected to two way analysis of variance (ANOVA) at the significant level of 5 %, using the Statgraphics Program (Statistical Graphics Educational, version 6.0 1992. Manugistics, Inc). When statistical differences were found, the Duncan's Multiple Range Test was further applied in order to classify means within each drying method.

Results and discussions

Proximate and amino acid composition of taro powder

Table 1 shows proximate composition of taro powder as affected by the stage of maturity and the drying method.

With the exception of the ash content, the other measured variables were not significantly influenced by the drying method on the other hand variance component analysis revealed that more than 70 % of the total variation in each of the variables was attributed to differences in stage of maturity.

The moisture content of the powders (8 and 10 %) were lower than 12 %, the range of moisture content regularly observed to cover a conservation period of over 6 months (Kaur et al. 2011). The ash content was significantly influenced by the stage of maturity and the drying method. A significant linear correlation ($r=0.86$) was observed between the stage of maturity and the ash content suggesting an accumulation of minerals with ageing. Sun-dried processed powders however had higher ash content (2.09 g/100 g) than the electric dried flours (1.89 g/100 g). This relative difference could be due to dust contamination during the sun drying process. Contamination of naturally dried food materials is well documented (Yahya et al. 2000). The observation of an increase in ash content of taro powder with age of maturity is consistent with a previous report by Leonel et al. (2005) for the ash content of *Pachyrhizus ahipa* and that of cassava reported by Chotineeranat et al. (2006) and Akingbala et al. (2011). Irrespective of the drying method and maturity, the ash levels reported in this study were lower than those reported for Cameroonian taro varieties (Mbofung et al. 2006) but systematically higher than that reported on India variety (Kaur et al. 2011).

The most important component in the sosso-taro powder is carbohydrates (Kaur et al. 2011). In the present study we observed that the available sugars varied as a function of age of taro at harvest from 42.1 to 44.5 g/100 g while protein content varied from 4.4 to 5.5 g/100 g. In each case the variations were significantly correlated with stage of maturity (carbohydrate $r=0.83$; $P<0.05$; proteins $r=0.96$; $p<0.05$). These significant correlations underline the active physiological and biochemical process known to take place during growth period of plant materials. It has been demonstrated that during maturation of cassava from 12 to 24 months, the starch content decreased significantly while no significant change was observed in sugars levels (Akingbala et al. 2011). The observed protein contents are similar to those reported by Mbofung et al. (2006), but slightly higher than those reported by Kaur et al. (2011), Aboubakar et al. (2008), Sefa-Dedeh and Agyir-Sackey (2004).

At the amino acid level (Table 2) no remarkable changes (Coefficient of variation less than 10 %) were observed in the composition of the powders as a function of drying method or stage of the maturity. However some slight inconsistent variations were observed in the Cysteine, Methionine, Proline, Alanine and Histidine content of the flours probably as a result of sensitivity of the HPLC instrument. The minor changes in amino acid composition with the growing period suggest a

Table 1 Chemical composition of taro powders as affected by state of maturity and drying method

Type of drying	Maturity (months)	Moisture (g/100 g)	Ash (g/100 g)	Protein (g/100 g)	Fats (g/100 g)	Available sugars (g/100 g)
Sun	6	8.2±0.02	1.7±0.09 ^a	4.5±0.05 ^a	0.40±0.002	42.1±0.22 ^a
	7	8.2±0.02	1.8±0.02 ^a	5.0±0.10 ^b	0.41±0.003	42.4±0.96 ^a
	8	8.2±0.02	2.0±0.05 ^b	5.1±0.03 ^c	0.40±0.001	43.2±0.23 ^{ab}
	9	8.1±0.04	2.1±0.08 ^b	5.3±0.02 ^d	0.40±0.014	44.2±0.49 ^{bc}
	10	8.1±0.05	2.7±0.16 ^c	5.5±0.04 ^e	0.41±0.013	44.5±0.78 ^c
Electric	6	8.1±0.06	1.6±0.03 ^a	4.4±0.04 ^a	0.41±0.003	42.1±1.53 ^a
	7	8.1±0.03	1.7±0.01 ^b	4.9±0.03 ^b	0.41±0.002	42.5±0.41 ^a
	8	8.2±0.03	1.9±0.01 ^c	5.0±0.02 ^c	0.40±0.002	43.2±0.25 ^{ab}
	9	8.1±0.01	2.0±0.01 ^d	5.2±0.10 ^d	0.41±0.001	44.2±0.64 ^b
	10	8.0±0.01	2.2±0.05 ^e	5.4±0.04 ^e	0.40±0.004	44.5±0.85 ^b

Mean ± SD in the same column within each drying method followed by different letters in superscript are significantly different at probability level 0.05 ($n=4$)

similarity in the type of proteins synthesized in the course of the growing period of the tubers. Worthy of note here is the fact that Aspartic acid and Asparagine (both coded Asx) were the predominant (15.3±0.4 % of total) amino acids followed by Glutamic acid and Glutamine (both coded Glx) with a mean value of 12.4±0.3 %. Occurring at relatively very low levels were Methionine (0.55±0.40 %), Cystein (0.90±0.66 %), and Histidine (1.89±0.33 %) while tyrosine was undetectable. The predominance pattern of acidic amino acids in taro samples has been reported in our earlier work (Mbofung et al. 2006).

Physical and flow properties of the powders The overall differences in the chemical composition of powders coupled

with those in their physical properties are indications of the possible differences in their functionality. The measured flow functions of the foods powders tested are presented in Table 3, together with their physical properties. While harvesting time was observed to have a significant effect on the specific surface area ($p<0.002$) and on particle size ($p<0.03$), the same was not true of drying method. Generally the specific surface of the powders tended to increase while the particle size decreased with increase in age of maturity. However some inconsistencies occurred in the case of powders obtained from oven dried taro. This may not be unrelated to occurrence of Maillard reactions during electric oven drying process. A review by Sagar and Suresh Kumar (2010) reported on the negative effect of air drying on the

Table 2 Amino acid (g/100 g protein) profile of taro powders

Amino acids	Sun drying			Electric drying		
	6 months	8 months	10 months	6 months	8 months	10 months
Thr	7.8±0.03 ^b	7.3±0.02 ^a	8.5±0.04 ^c	7.8±0.03 ^a	8.1±0.04 ^b	7.8±0.03 ^a
Ile	6.2±0.02 ^a	6.6±0.02 ^b	6.9±0.04 ^c	5.8±0.02 ^a	6.7±0.03 ^c	6.0±0.02 ^b
Leu	6.6±0.02 ^a	6.8±0.02 ^b	6.6±0.02 ^a	7.10±0.02 ^b	7.2±0.04 ^c	7.0±0.04 ^a
Lys	8.9±0.02 ^c	8.2±0.03 ^b	8.0±0.03 ^a	7.8±0.02 ^b	8.1±0.02 ^c	7.4±0.04 ^a
Met	0.92±0.05 ^b	1.2±0.03 ^c	0.36±0.02 ^a	0.82±0.02 ^b	0.14±0.01 ^a	2.0±0.02 ^c
Phe	4.1±0.05 ^c	3.7±0.04 ^a	3.9±0.05 ^b	4.4±0.04 ^b	4.0±0.04 ^a	4.0±0.04 ^a
Tyr	nq	nq	nq	nq	nq	nq
Val	5.2±0.03 ^a	5.36±0.04 ^a	5.52±0.04 ^b	5.75±0.02 ^a	5.69±0.04 ^a	5.7±0.04 ^a
His	2.2±0.03 ^b	1.78±0.04 ^a	2.35±0.04 ^b	1.8±0.04 ^b	1.8±0.04 ^b	1.4±0.04 ^a
Ala	3.2±0.04 ^a	4.05±0.05 ^b	5.14±0.04 ^c	4.4±0.04 ^c	4.0±0.03 ^b	3.5±0.05 ^a
Asx	15.0±0.03 ^b	15.4±0.03 ^c	14.9±0.02 ^a	15.5±0.03 ^b	15.2±0.04 ^a	15.9±0.03 ^c
Glx	12.0±0.04 ^a	12.6±0.03 ^c	12.2±0.05 ^b	12.2±0.03 ^a	12.9±0.03 ^c	12.7±0.03 ^b
Gly	9.5±0.02 ^a	10.1±0.01 ^b	9.5±0.02 ^a	10.1±0.01 ^a	10.2±0.04 ^b	10.1±0.03 ^a
Pro	7.6±0.04 ^c	5.4±0.03 ^a	6.5±0.02 ^b	4.9±0.04 ^a	5.4±0.04 ^c	5.2±0.02 ^b
Ser	6.9±0.02 ^b	7.4±0.01 ^c	6.6±0.05 ^a	7.8±0.03 ^c	7.3±0.02 ^a	7.5±0.02 ^b
Arg	3.0±0.07 ^b	2.8±0.03 ^a	3.5±0.05 ^c	3.44±0.04 ^c	3.1±0.01 ^a	3.3±0.02 ^b
Cys	0.84±0.013 ^b	1.2±0.05 ^c	0.38±0.012 ^a	0.39±0.022 ^b	0.09±0.001 ^a	0.38±0.014 ^b

Means ± SD in the same line within each drying method followed by different letters in superscript are significantly different at probability level 0.05 ($n=2$); nq = non quantified; Asx corresponds to the sum of amino acids Asp and Asn; Glx corresponds to Glu and Gln. Trp was not evaluated

Table 3 Flowing properties of taro powders as affected by state of maturity and drying method

Drying method	Stage of maturity	Angle of repose (°)	Tapped density (g/cm ³)	Aerated density (g/cm ³)	Specific surface area (m ² /g)	Particle size <100 µm (%)
Sun drying	6	42.8±0.71 ^a	0.69±0.002 ^a	0.43±0.003 ^b	0.62±0.022 ^c	71.2±0.34 ^d
	7	43.6±1.10 ^{ab}	0.70±0.001 ^b	0.44±0.001 ^{bc}	0.82±0.014 ^b	77.6±0.09 ^c
	8	44.7±1.11 ^{bc}	0.70±0.003 ^b	0.43±0.002 ^b	0.88±0.009 ^a	79.4±0.13 ^b
	9	46.1±0.45 ^c	0.72±0.005 ^c	0.44±0.002 ^c	0.89±0.033 ^a	80.2±0.69 ^a
	10	48.5±1.20 ^d	0.69±0.002 ^a	0.43±0.002 ^a	0.81±0.025 ^b	70.6±0.45 ^d
Electric drying	6	43.4±0.45 ^a	0.72±0.001 ^a	0.45±0.001 ^b	0.80±0.013 ^d	80.4±0.34 ^a
	7	45.3±1.05 ^b	0.72±0.002 ^{ab}	0.46±0.002 ^c	0.82±0.014 ^c	78.2±0.31 ^b
	8	46.0±0.37 ^{bc}	0.72±0.002 ^b	0.45±0.001 ^b	0.73±0.019 ^e	73.7±0.52 ^e
	9	46.9±0.25 ^c	0.73±0.003 ^c	0.46±0.002 ^c	0.85±0.014 ^b	76.2±0.11 ^c
	10	48.7±0.45 ^d	0.72±0.002 ^a	0.45±0.002 ^a	0.86±0.012 ^a	75.2±0.34 ^d

Means ± SD in the same column within each drying method followed by different letters in superscript are significantly different at probability level 0.05 ($n=5$)

browning of vegetables. Meanwhile irrespective of the method of drying, the angle of repose was observed to increase with the stage of maturity. The angle of repose indicates the cohesion among the individual units of powder. The higher the cohesion, the higher would be the angle of repose (Karaj and Müller 2010). The observed variation of the angle of repose suggests a linear relationship between the increase in harvesting time of taro tubers and the cohesion in taro powder. The increase in cohesion between particles has long been associated with smaller particle size (Fitzpatrick and Ahrne 2005).

The bulk density (BD) of the powders flours depends from the procedure used, either tapped (Bd tapped) or aerated (Bd aerated); this reflect the way of loading the packaging required (Akubor 2005). The Bd tapped varied from 0.686 to 0.725 g/ml while the BD aerated varied from 0.436 to 0.458. While inconsistent variation were observed on BD aerated, the BD tapped increase with increase in stage of maturity up to 9 months, over with the density decreased. In addition the values of density were systematically higher for electric drying.

The BD tapped reported here are in the range (0.57–0.71 g/ml) reported earlier by Kaur et al. (2011) and Njintang et al. (2007a, b). The low values of density associated to fast electric drying indicates the case hardening (densification) that usually occurs due to crust formation (Sagar and Suresh Kumar 2010).

Thermal properties of taro powders Thermal properties of the taro powders, measured by DSC, varied with the different variables. Endothermic peaks for powders from different maturities and drying methods of taro powders appeared between 69 °C and 94 °C. The transition temperatures (To, Tp and Tc) and ΔH_{gel} of different taro powders are

summarized in Table 4. Lower ranges To, Tp, Tc such as observed here had earlier been reported by Aboubakar et al. (2008) and associated with differences in variety and/or agro-ecological origin of taro tuber. Generally, all measured thermal properties increased significantly with age of maturity but were not significantly influenced by method of drying. The observed effect of harvesting time on the thermal properties of powders may be attributed to the changes in the starch granular structure, and amylose and phosphorus contents during tuber growth; this was however not verified. Previous studies had however reported a linear correlation between ΔH_{gel} and starch size in wheat (Peng et al. 1999). The increase in temperature and enthalpy of gelatinization with harvesting time suggested that the heat stability of the powder increased with maturity. This is an important observation worthy of consideration in the pasteurization/sterilization of products made from powders of sosso-taro. The present results are in agreement with those reported by Noda et al. (1992) for two varieties of sweet potatoes. In fact these authors indicated that the enthalpy liberated during growing was generally low for the first months of maturity. On the other hand the initial temperature of gelatinization of sweet potato tended to be low at the end of maturity Noda et al. (1996). Meanwhile the values of energy flux liberated are within the interval reported for other taro flour varieties (Jane et al. 1992; Tattiyakul et al. 2007; Aboubakar et al. 2008).

Functional properties The water absorption capacity (WAC) of taro powders obtained by solar and electrical drying methods are shown in Fig. 1a. The figures reveal that irrespective of drying method the water absorption capacity increased with increase in maturity. Meanwhile powders produced from electric oven dried sosso-taro exhibited higher WAC (mean value 281±1 %) as opposed

Table 4 Differential scanning calorimeter of taro powders

Type of drying	Maturity (months)	To (°C)	Tp (°C)	Tc (°C)	ΔH (J/g)
Sun	6	69.9±0.27 ^a	79.3±0.36 ^a	87.6±0.48 ^a	10.2±0.10 ^a
	7	70.6±0.68 ^a	80.2±0.47 ^b	88.6±0.47 ^b	10.8±0.15 ^b
	8	71.6±0.60 ^b	81.2±0.26 ^c	89.6±0.60 ^c	11.3±0.22 ^c
	9	73.0±0.22 ^c	82.0±0.14 ^c	90.4±0.41 ^c	12.5±0.15 ^d
	10	74.1±0.29 ^d	83.0±0.83 ^d	91.7±0.63 ^d	13.1±0.24 ^e
Electric	6	69.2±0.28 ^a	79.2±0.35 ^a	87.3±0.30 ^a	10.2±0.09 ^a
	7	70.4±0.50 ^b	80.2±0.25 ^b	88.4±0.79 ^b	10.7±0.12 ^b
	8	71.8±0.58 ^c	81.3±0.39 ^c	89.9±0.67 ^c	11.4±0.14 ^c
	9	73.0±0.14 ^d	82.0±0.22 ^d	90.4±0.43 ^c	12.6±0.10 ^d
	10	74.0±0.42 ^c	83.2±0.38 ^c	91.5±0.62 ^d	13.2±0.25 ^e

Means ± SD in the same column within each drying method followed by different letters in superscript are significantly different at probability level 0.05 ($n=4$); T_o onset gelatinization temperature; T_p peak gelatinization temperature; T_c end gelatinization temperature; ΔH enthalpy of gelatinization

Fig. 1 Effect of stage of maturity of taro tubers on (a) water absorption capacity and (b) water solubility index of taro powders obtained following sun and electric drying techniques

to that (mean value $275 \pm 1\%$) from sun-dried samples. The high water absorption capacity of electric dried taro powder suggested that the crusting associated to it has not highly impaired its ability to absorb water, or some gelatinization or damage occurred on starch during electric drying more than sun-drying.

Generally the WAC of the powders from electric dried oven increased with drying temperature up to a temperature of 60°C followed by a drop. The ability of a powder to absorb water is usually related to its content of hydrophilic molecules such as proteins and sugars. In this respect the increase in WAC with maturity can be attributed to the increased presence of such molecules with increase in harvesting time. This seemed to be confirmed by the observation of a significant linear correlation between WAC at 20°C and the proteins content ($r=0.84$; $p<0.001$) as well as with the sugars contents ($r=0.75$; $p<0.001$). The increase in WAC of the powders with maturity was equally associated with the increase in their Water solubility index (WSI) as confirmed by their correlation coefficient ($r=0.67$; $p<0.001$). Variation in WSI is represented in Fig. 1b. It can be seen that WSI exhibited a behavior similar to that observed for WAC.

One important parameter that has always been associated with the ability to absorb water is the gelling capacity of the powder, expressed in the present work as the least concentration that forms a gel (Fig. 2). In this respect the higher the gelling property, the lower is the least gelation concentration (LGC). LGC is the minimum quantity (in gram) of powder which when put in 100 ml of water allowed to form a stable gel after boiling. Gel formation is a very important functional property of starch and protein. The presence of genuine starch in flour could be responsible for certain phenomena such as formation of starch paste (in cold water) and an amorphous gel more or less rigid after gelatinization. According to Singh (2001), the gelification process often entails a competition for water in the process of starch gelatinization and protein in the process of gelification. This competition end up with the formation of proteins and polysaccharides network encapsulating water in its meshes (Schmidt 1981). In general the LGC of taro powder decreased as the harvesting time increased in a linear manner ($r=-0.53$; $p<0.01$). The increase in gelling capacity is probably justified by the increase in protein and carbohydrate content in the powder. This observed variation is of great technological interest since its flours are commonly used in the preparation of several foods with specific textural properties. Powders made from sun-dried Sosso-taro generally exhibited lower LGC values compared to electrical dried powders suggesting that the latter highly altered the ability of the powder to form a gel, probably through the Maillard reaction. The maillard reaction due to crusting occurring during the

Fig. 2 Effect of stage of maturity of taro tubers on the least gelation concentration of taro powders for two drying methods sun and electric

drying has already been pointed out for its contribution to the densification of the flour, which currently leads to inability of the powder to absorb water, and hence affects the ability to form gel. The high performance of solar dried powders, compared to electrically dried powders, has been pointed out in our earlier studies and assumed to be due to the slow rate of dehydration (Njintang et al. 2007a). On the whole the gelling capacity of sosso-taro powder was observed to be highly affected by the harvesting time than by drying method.

Color parameters The effect of maturity and the drying method on the color of the powder was evaluated by measuring the color coordinates L^* , a^* and b^* which are shown in Table 5. The value of L^* represents the powder vividness

Table 5 Color parameters of taro powders

Type of drying	Maturity (months)	L^*	a^*	b^*
Sun	6	74.8 ± 2.95^a	2.3 ± 0.21^a	7.3 ± 0.64
	7	78.9 ± 0.94^b	2.1 ± 0.20^{ab}	6.4 ± 0.69
	8	80.9 ± 0.67^b	1.9 ± 0.03^{bc}	6.5 ± 0.36
	9	81.5 ± 0.25^b	1.8 ± 0.03^c	6.6 ± 0.41
	10	81.7 ± 0.32^b	1.6 ± 0.04^d	6.9 ± 0.33
Electric	6	78.8 ± 0.43^a	1.9 ± 0.06^a	6.9 ± 0.31^a
	7	79.6 ± 0.13^a	1.8 ± 0.09^b	6.6 ± 0.12^{ab}
	8	80.4 ± 1.03^{ab}	1.7 ± 0.04^b	6.4 ± 0.24^{ab}
	9	82.2 ± 1.88^{bc}	1.6 ± 0.04^c	6.6 ± 0.11^{ab}
	10	82.9 ± 0.67^c	1.5 ± 0.04^c	6.7 ± 0.02^b

Means $\pm$ SD in the same column within each drying method followed by different letters in superscript are significantly different at probability level 0.05 ($n=6$); L^* black-white index of color, higher values (close to 100) are associated to white; a^* Green-Red index of color, positive values associated to red; b^* Blue-yellow index of color, positive values are associated to yellow

or lightness, a^* the redness and b^* the yellowness. The color parameters of taro powders were significantly influenced by maturity and drying method. In particular the redness of taro powder significantly ($p < 0.001$) decreased with tuber ageing ($r = -0.75$; $p < 0.001$), and was particularly high for solar dried powders. In contrary the lightness of the powder was significantly ($p = 0.01$) high for electric drying and significantly ($p < 0.001$) increased with the maturity ($r = 0.79$; $p < 0.001$). In addition the yellowness was not significantly influenced by the drying method whereas inconsistent variation was observed with maturity ($p = 0.04$). A particular observation made in this study was the negative correlation observed between the L^* coordinate and a^* ($r = -0.86$; $p < 0.001$) or b^* ($r = -0.54$; $p = 0.002$) color coordinates. This simply means that the increase in redness and yellowness of the powder altered their lightness. The color development is an important reaction that occurs during drying (Sagar and Suresh Kumar 2010).

The results showed as demonstrated in our earlier findings (Aoubakar et al. 2008) that taro powders from electric dryer were more light, less red and yellow. The low values of a^* and b^* of the electrical dried powders did not reflect the browning we above-mentioned, but rather the visual colour we observed. While the variation in b^* value is generally linked to the proteins content and the non enzymatic browning (Jamin and Flores 1998), this was not the case in the present study where a negative significant correlation was observed ($r = -0.66$; $p < 0.001$). This suggest that the colour developed during drying is not only the consequence of the reaction between sugars and proteins, but also other parameters such as coloured pigments which are more important in this case.

Conclusion

The physicochemical properties as well as the chemical composition of sosso taro flours were mostly influenced by the degree of maturity of the tuber from which they were produced. The highest maturity was accompanied with higher ash, protein and carbohydrate contents. The effect of maturity on the composition of the powders also reflects the variation in the functional properties. Taro powders with higher water absorption capacity and higher water solubility index gave gels with lower least gelation concentration. The gelatinization enthalpies are crescents as the harvesting time increases. This information may be useful in the harvesting of sosso-taro and production of powders from them for use in the food preparation processes.

Acknowledgment The authors wish to thank the Cooperation pour la Recherche Universitaire (CORUS) for financial support.

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