Effect of boiling time on chemical composition and physico-functional properties of flours from taro (*Colocasia esculenta* cv *fouê*) corm grown in Côte d'Ivoire

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Revised: 12 August 2011 / Accepted: 17 October 2011 / Published online: 11 November 2011
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Abstract Taro (*Colocasia esculenta* cv *fouê*) corm was subjected to different boiling times and the changes in chemical composition and physico-functional properties were investigated using standard method. The change in boiling time led to a significant ($P<0.05$) reduction in the moisture, reducing sugars, total sugars, crude fat, crude fibre, total phenolic compound contents and iodine affinity of starch, whereas the total carbohydrate content, water absorption capacity, water solubility index, paste clarity and foam capacity increased significantly ($p<0.05$). The crude protein and total ash contents of the flours from taro corm were not affected significantly ($p<0.05$) by the change in boiling time. Taro corm flours exhibited highest total carbohydrate, crude fibre, total ash contents, water absorption capacity, iodine affinity of starch and lowest crude protein and fat contents, foaming capacity and water solubility index. Principal component analysis showed that flours from taro corm boiled during 20 min and 15 min were located at the left of the score plot, while flours from raw and boiled taro corm during 10 min had a large positive score in the first principal component.

Keywords Chemical composition · *Colocasia esculenta* · Corm · Physico-functional property · Taro flour

Introduction

Taro (*Colocasia esculenta* L.) is largely produced for its underground corms and consumed in tropical and subtropical areas of the world (Aboubakar et al. 2008). In Côte d'Ivoire (West of Africa), it is the third most important crop after yam (*Dioscorea spp*) and cassava (*Manihot esculenta*). Its raw corm is relatively low in protein (1.5%) and fat (0.2%) and this is similar to many other tuber crops. It is a source of starch (70–80 g/100 g dry taro) and contains a fair amount of fiber (0.8%) and ash (1.2%) (Jane et al. 1992; Quach et al. 2000). Starch derived from the taro corm is unique because of its very small granular sizes ranging from 1 to 5 μ , significantly smaller than corn or wheat (Jane et al. 1992). The combination of small granules and high soluble dietary fiber content makes taro corm a good source of carbohydrate for extruded special products such as infant weaning diets and low glycemic index foods (Huang et al. 2000). Taro corm has reasonably high contents of potassium and magnesium, whose ranges are 2251–4143 and 118–219 mg/100 g dry matter, respectively. It is a moderately good source of water-soluble vitamins, such as thiamin, riboflavin and ascorbic acid, compared to other tropical roots. Essential amino acid contents of taro corm proteins are fairly similar to the FAO reference pattern, except for the contents of sulfur-containing amino acids, tryptophan and histidine (Huang et al. 2007).

Taro corm is consumed either as staple or mixed with other vegetables, usually after cooking. According to Iwuoha and Kalu (1995), proper cooking eliminates the

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harsh and sharp irritation in the throat and mouth. Also, the cooking processes cause several changes in physical characteristics and chemical compositions of vegetables, affecting the amount of antioxidants, so that food home-processing and/or preparation can strongly affect their nutritional value (Natella et al. 2010). The types of cooking methods (boiling, pressure cooking and baking) differ in many areas of the country and also vary with the ethnic background of the family (Raj Bhandari and Kawabata 2006).

Fresh taro corm is difficult to store and is subject to deterioration during storage. Because it is regarded as health food and not staple food in oriental countries, it is feasible to develop a stable form of taro products to fulfil the health food market. One of the best ways to preserve it is by processing it into flour and/or starch (Perez et al. 2005). Since flour can be easily stored for long period of time and conveniently used in manufacturing formulated foods or capsules for consumption, cooked taro flour is worth developing (Del Rosario and Lorenz 1999). It has been reported that flour of taro corm, dried and milled contains easy digestion starch and therefore is widely used as infant food (Del Rosario and Lorenz 1999). Successful performance of flours as food ingredients depend upon the functional characteristics and sensory qualities they impart to the end product (Kaur and Singh 2007). Agbor-Egbe and Richard (1990) have compared the composition of 32 cultivars of *Xanthosoma sagittifolium* species and *Colocasia esculenta* species. They reported differences among the species. This observation supports earlier work done by Coursey (1968) which indicated that the composition of food commodities are dependent on the variety, location, season, method of processing and storage. For this reason, attempts have been made to characterize taro flours of Hawaiian (Sugimoto et al. 1986; Jane et al. 1992; Tagodoe and Nip 1994), Indian (Kaur et al. 2011a, b), Nigerian (Nwanekezi et al. 2010; Alinnor and Akalezi 2010) and Cameroonian (Mbofung et al. 2006; Njintang and Mbofung 2006; Njintang et al. 2007a, b, c; Aboubakar et al. 2008) varieties but no such studies have been reported on Ivorian (West Africa) taro corms.

The objective of this work was to investigate the effect of different boiling times on the chemical composition and physico-functional properties of flours from taro (*Colocasia esculenta* cv *fouê*) corm grown in Côte d'Ivoire. An acquisition of understanding of properties of these flours may demonstrate its further potential uses in the food industry as an alternative source to conventional forms of carbohydrates or in production of new food products. Also, the correlations between different flour properties were established using Pearson correlation and principal component analysis.

Materials and methods

Materials Taro (*Colocasia esculenta* cv *fouê*) corms were randomly harvested at maturity (9 months after planting) from a farm in Affery, South-East portion of Côte d'Ivoire (West Africa). They were immediately transported to the laboratory and stored under prevailing tropical ambient conditions (19–28 °C, 60–85% RH) for 24 h before the preparation of flours from raw and cooked taro corms. All chemicals and reagents used were of analytical grade and purchased from Sigma Chemical Co. (St. Louis, MO).

Preparation of raw and boiled taro corm flours Taro corms were washed with clean water and peeled using a stainless steel knife. The peeled samples were rewashed with clean water and cut into slices (2 cm thickness). Two liters of clean water were put inside pot and boiled on a hot plate at the temperature of 100 °C. Approximately, two (2) kg of the cut samples were placed inside the boiling water and were allowed to boil for 0, 10, 15 or 20 min. The water was drained off after each timing and the hot samples were exposed to the air to allow surface water to evaporate for 20 min. The slice taro corms were then mashed, dried at 52 °C in a ventilated oven (MMM MED center) for 48 h and ground into fine powder in a Hammer mill (Campas 82370, Labastide St-Pierre, France) to pass through a 250 µm sieve. Dried powdered samples were packed into airtight sealed plastic bags and stored in the refrigerator for later analysis.

Proximate composition The dry matters contents were determined by drying in an oven at 105 °C during 24 h to constant weight (AOAC 1990). The crude protein contents were calculated from nitrogen contents ($N \times 6.25$) obtained using the Kjeldahl method by AOAC (1990). The crude fat contents were determined by continuous extraction in a Soxhlet apparatus for 8 h using hexane as solvent (AOAC 1990). The total ash contents were determined by incinerating in a furnace at 550 °C (AOAC 1990). The method described by Dubois et al. (1956) was used for the total sugar contents analysis. The reducing sugar contents were determined according to the method of Bernfeld (1955) using 3,5 dinitrosalicylic acids. The total phenolic compound contents were determined as described in Hanson et al. (2004) from the methanol extracts using Folin-Ciocalteu reagent (Singleton and Rossi 1965). The carbohydrate contents were determined by deference that is by deducting the mean values of other parameters that were determined from 100. Therefore % carbohydrate = $100 - (\% \text{ moisture} + \% \text{ crude protein} + \% \text{ crude fat} + \% \text{ crude fibre} + \% \text{ ash})$.

Mineral composition The minerals, such as calcium, copper, iron, magnesium, sodium, potassium and zinc were

analyzed after first wet-ashing according to the method prescribed by Onwuliri and Anekwe (1992) with an atomic absorption spectrophotometer (Pye-Unicam 969, Cambridge, UK). Phosphorus contents were estimated colorimetrically (UV-visible spectrophotometer, JASCO V-530, MODEL TUDC 12 B4, Japan Servo CO. LTD Indonesia), using potassium dihydrogen phosphate as the standard (AOAC 1980).

Water absorption capacity (WAC) and water solubility index (WSI) WAC and WSI were evaluated according to Phillips et al. (1988) and Anderson et al. (1969) methods, respectively. Exactly 2.5 g of flour (Mo) were mixed with a 30 ml of distilled water in a centrifuge tube and shaken for 30 min in a KS10 agitator. The mixture was kept in a water-bath (37 °C) for 30 min and centrifuged (Ditton LAB centrifuge, UK) at 5,000 rpm for 15 min. The resulting sediment (M2) was weighed and then dried at 105 °C to constant weight (M1). The WAC was then calculated as follows:

$$\text{WAC}(\%) = \frac{M2 - M1}{M1} \times 100 \quad (1)$$

While the WSI was calculated using the following equation:

$$\text{WSI}(\%) = \frac{M0 - M1}{M0} \times 100 \quad (2)$$

Foam capacity (FC) and foam stability (FS): Foam capacity and stability were studied by the method of Coffman and Garcia (1977). Three (3) g of flour were transferred into clean, dry and graduated (50 ml) cylinders. The flour samples were gently levelled and the volumes noted. Distilled water (30 ml) was added to each sample; the cylinder was swirled and allowed to stand for 120 min while the change in volume was recorded every 15 min.

$$\text{FC}(\%) = \frac{\text{Vol. after homogenization} - \text{Vol. before homogenization}}{\text{Vol. before homogenization}} \times 100 \quad (3)$$

$$\text{FS}(\%) = \frac{\text{Foam volume after time (t)}}{\text{Initial foam volume}} \times 100 \quad (4)$$

Iodine affinity of starch Iodine affinity of starch was assayed according to the method of Kawabata et al. (1984). Three (3) g of flour were introduced into 50 ml beakers and made up to 30 ml dispersions using distilled water. The dispersion was stirred occasionally within the first 30 min and then filtered through Whatman no.42 filter paper. A 10 ml aliquot of the filtrate was pipetted into a

conical flask, phenolphthalein (four drops) was added and the filtrate titrated with 0.1 N I₂ solution to a bluish black end-point. The starch cell damage (free starch content) was calculated using the titre value and expressed as iodine affinity of starch, IAS (ppm):

$$\text{IAS}(\text{ppm}) = \frac{VD}{VA} \cdot \frac{Vt}{Ms} \cdot \frac{NA}{100} \cdot 106 \quad (5)$$

Where

VD	Total volume of dispersion
VA	Volume of aliquot used for titration
Vt	Titre value
Ms	Mass (db) of flour used
NA	Normality of iodine solution used.

Paste clarity Paste clarity of flour was determined according to the method of Craig et al. (1989). A 1% aqueous suspension was made by suspending 0.2 g of flour in 20 ml of distilled water in a stoppered centrifuge tube and vortex mixed. The suspension was heated in a boiling water (100 °C) bath for 30 min thoroughly shaking every 5 min. After cooling, clarity of each flour was determined by measuring percent transmittance at 650 nm against a water blank on a spectrophotometer JASCO V-530 (UV/VIS, Model TUDC 12 B4, Japan Servo CO. LTD Indonesia).

Statistical analysis The data reported in all the tables are average values of triplicate determinations ($n=3$). The mean values and standard deviations of each analysis are reported. Analysis of variance (ANOVA) was performed as part of the data analyses (SAS 1989). When F-values were significant ($p<0.05$) in ANOVA, then least significant differences were calculated to compare treatment means. Pearson correlation coefficients (r) for relationships between various flour properties were calculated. The variations observed in the chemical compositions and physico-functional properties of the flours from taro corm were examined by principal component analysis (PCA) with the Minitab Statistical Software version 13.

Results and discussion

Principal component analysis Principal component analysis was used to visualize the variation in the properties among flours from different boiling times. This analysis showed two axes explaining the essential variability that were axis 1 and 2. The first and the second PCs described 80.8 and 12.7% of the variance respectively. Together, the first two PCs represented 93.5% of the total variability. Flours from taro corm boiled during 20 min (FBTC20) and 15 min (FBTC15) were located

at the left of the score plot, while flours from raw (FRTC) and boiled taro corm during 10 min (FBTC10) had a large positive score in the first principal component (PC1) (Fig. 1). FBTC20 had a large negative score whereas FRTC had a large positive score in PC1. FBTC10 showed a large positive score while FRTC had a negative score in second principal component (PC2). FBTC15 was located close to zero both in PC1 and PC2. The loading plot of the two PCs provided the information about correlations between the measured properties (Fig. 2). The properties whose curves lie close to each other on the plot are positively correlated while those whose curves run in opposite directions are negatively correlated.

Chemical composition and physico-functional properties Table 1 showed the proximate composition of flours from raw and boiled taro (*Colocasia esculenta* cv *fouê*) corm grown in Côte d'Ivoire. The change in boiling time led to a significant ($P<0.05$) reduction in the moisture, reducing and total sugars, crude fat, crude fibre and total phenolic compound contents, whereas the total carbohydrate content increased significantly ($p<0.05$). The decrease in the biochemical characteristic contents of flours from boiled taro corm is a result of the heat treatment which caused loss of these parameters in the taro corm. This occurred probably because soluble sugars, crude fat, crude fibre and phenolic compounds leached into the processing water with long cooking time and higher temperature (Kaur et al. 2011a). These results are in agreement with those of Onuegbu et al. (2009) in three-leaved yam (*Dioscorea dumetorum* pax) tubers. Moisture content of all the flour samples was below 9%, thereby giving the flours a better shelf life (Aryee et al.

2006). Moisture content was shown to be positively correlated to the total sugars ($r=0.95$, $p<0.05$) and crude fat ($r=0.95$, $p<0.05$) levels and negatively correlated to crude protein ($r=-0.99$, $p<0.05$) and total carbohydrate ($r=-1$, $p<0.05$) contents both by Pearson correlation (Table 2) and PCA analysis (Fig. 2). The result showed that total carbohydrate (84.4 to 87.4%) is the most important chemical component in the flours. This finding corroborated well with those reported by Aboubakar et al. (2008) for six varieties of Cameroon taro flours. Therefore, the taro (*Colocasia esculenta* cv *fouê*) corm is an important staple food in Côte d'Ivoire (West Africa). It is an excellent energy supplier (Huang et al. 2007). Onwueme (1978) reported that taro corm is a source of carbohydrate for diabetics and for those with gastrointestinal disorders. This may suggest that taro corm contain slowly digestible starches and dietary fibre which are of nutritional importance (Srilakshmi 2008). This improve taro competitiveness alongside other roots and tuber crops, enhance its application in other food systems and improve marketing potential. Pearson correlation (Table 2) and PCA analysis (Fig. 2) revealed a negative correlation of total carbohydrate level with moisture ($r=-1$, $p<0.05$) content and a positive with crude protein level ($r=0.99$, $p<0.05$). The result also showed that besides carbohydrates, total ash and crude fibre represent another important group of component in flours of Ivorian taro corm. Total ash content was not affected significantly ($p<0.05$) by the change in boiling time. This result is contrary to that obtained by Edem et al. (1994) who reported that soluble minerals get lost by dissolving into cooking water.

Fig. 1 Sample plot of principal components 1 and 2 of flours from raw and boiled taro (*Colocasia esculenta* cv *fouê*) corm grown in Côte d'Ivoire. FRTC: Flour from raw taro corms; FBTC"10 min": Flour from taro corm boiled in water during 10 min; FBTC"15 min": Flour from taro corms boiled in water during 15 min; FBTC"20 min": Flour from taro corm boiled during 20 min

Fig. 2 Circle of correlation of chemical composition and physico-functional properties of flours from raw and boiled taro (*Colocasia esculenta* cv *fouê*) corm grown in Côte d'Ivoire on axes 1 and 2. WAC: Water absorption capacity; WSI: Water solubility index; IAS: Iodine affinity of starch; PC: Paste clarity; FC: Foam capacity; M: Moisture; CP: Crude protein; TC: Total carbohydrate; CF: Crude fat; CFib: Crude fibre; TPC: Total phenolic compounds; TA: Total ash; PC: principal component

The total ash content ($2.5 \pm 0.11\%$) is higher compared to those of tubers from taro *Colocasia esculenta* corm originated to India (0.71%, Kaur et al. 2011b) and Nigeria (1.40%, Alinnor and Akalezi 2010) and lower than observed for soyabean (3.8%, Kaur et al. 2011b). This suggests that the flours from Ivorian taro corm could be a source of mineral elements having nutritional importance. The result in the present study indicated that flours of taro corm originated from Côte d'Ivoire (1.6 ± 0.01 to $1.7 \pm 0.01\%$) have higher crude fibre content than flours from taro (*Colocasia esculenta*) corms originated to Nigeria (0.20–1%, Nwanekezi et al. 2010; Alinnor and Akalezi 2010). This finding is important because crude fibre has useful role in providing roughage that aids digestion and reduces the risks of cardiovascular diseases (Verma and Banerjee 2010; Sharma et al. 2011; Dhingra et al. 2011). Reports have shown that increase in fibre consumption might have contributed to the reduction in the incidence of certain diseases such as diabetes, coronary heart disease, colon cancer and various digestive disorders (Augustin et al. 1978). Fibre consumption also soften stools and lowers plasma cholesterol level in the body (Verma and Banerjee 2010; Sharma et al. 2011; Dhingra et al. 2011). Reducing sugar levels in flours of taro corm grown in Côte d'Ivoire (0.73 ± 0.02 to $0.35 \pm 0.01\%$) is lower than those reported

by Njintang et al. (2007b) in flours of taro (*Colocasia esculenta*) cv *Sosso Chad* (2.3%) and *Ekona* (1.3%) corm. The presence of reducing sugars in flours of Ivorian taro corm may cause caking and damping during their storage because of sugar's hygroscopic property. However, sugars may be desirable in bakery products like bread and cake where the tenderising effects positively affect texture and where sugars serve as substrate for fermentation of the dough (Aina et al. 2010). The result showed that crude protein contents of flours from taro (*Colocasia esculenta* cv *fouê*) corm were not also affected significantly ($p < 0.05$) by the change in boiling time. In comparison to other flours, flours of Ivorian taro corm exhibit lower crude protein content, indicating that this corm is not a good source of protein. Similar observations were recorded by Nwanekezi et al. (2010) and Alinnor and Akalezi (2010) when using taro (*Colocasia esculenta*) corms cultivated in Nigeria (0.066–5.08%). The crude fat content of the flours from taro corm cultivated in Côte d'Ivoire (0.60 ± 0.01 to $0.75 \pm 0.05\%$) was below 1%. Similar observations were recorded by Owuamanam et al. (2010) when using taro (*Colocasia esculenta*) cv *ede cocoindia* ($0.82 \pm 6 \times 10^{-3}\%$) and cv *ede ofe* ($0.78 \pm 0.00\%$) corms, tannia (*Xanthosoma sagittifolium*) cv *ede uhie* ($0.8 \pm 9.6 \times 10^{-3}\%$) and cv *ede ocha* ($0.74 \pm 1.89 \times 10^{-2}\%$) tubers.

Minerals are important components of diet because of their physiological and metabolic function in the body. The result presented in Table 1 showed the mineral composition of the flours from taro (*Colocasia esculenta* cv *fouê*) corm. Generally, the mineral contents were not affected significantly ($p < 0.05$) by the change in boiling time. Within these flours, calcium (7.3 ± 0.36 mg/100 g dry weight), iron (8.6 ± 0.40 mg/100 g dry weight), sodium (3.7 ± 0.70 mg/100 g dry weight), zinc (6.7 ± 0.91 mg/100 g dry weight) and copper (0.40 ± 0.10 mg/100 g dry weight) had the lowest values, while phosphorus (350.1 ± 7.45 mg/100 g dry weight), potassium (217.9 ± 3.37 mg/100 g dry weight) and magnesium (94.7 ± 2.95 mg/100 g dry weight) had the highest values. The K:Na ratio (56.0 to 58.1) was close to the recommended 5.0 (Szentmihalyi et al. 1998). Dietary changes leading to reduce consumption of potassium than sodium have health implications. Diets with higher ratio K:Na are recommended and these are found usually in whole foods (Arbeit et al. 1992). Foods, naturally higher in potassium than sodium, may have a K/Na ratio of 4.0 or more (CIHFI 2008). The high K:Na suggests that the flours from Ivorian taro corm could be suitable in helping to ameliorate sodium-related health risk (Appiah et al. 2011). The Ca:P ratio of the flours from taro corm grown in Côte d'Ivoire was below 1. However, according to SCSG (2007) a good menu should have a Ca:P ratio over 1. Foods high in phosphorus and low in calcium tend to make the body over

Table 1 Chemical composition and physico-functional properties of flours from the raw and boiled taro (*Colocasia esculenta* cv *fouê*) corm grown in Côte d'Ivoire

Parameter	Flour from raw taro corm	Flours from boiled taro corm		
		10 ^a	15	20
Chemical composition				
Moisture, %	8.1 ^a ±0.02	7.4 ^b ±0.05	6.4 ^c ±0.03	5.4 ^d ±0.04
Crude protein,%	2.4 ^a ±0.09	2.4 ^a ±0.07	2.4 ^a ±0.14	2.4 ^a ±0.07
Reducing sugars, %	0.73 ^a ±0.02	0.42 ^b ±0.01	0.36 ^b ±0.01	0.35 ^b ±0.01
Total sugars, %	3.3 ^a ±0.03	3.1 ^b ±0.01	3.0 ^b ±0.03	2.6 ^c ±0.01
Total carbohydrate, %	84.4 ^a	85.3 ^a	86.2 ^b	87.4 ^b
Crude fat, %	0.75 ^a ±0.05	0.71 ^a ±0.02	0.65 ^b ±0.05	0.60 ^c ±0.01
Crude fibre, %	1.7 ^a ±0.01	1.6 ^b ±0.05	1.6 ^b ±0.05	1.6 ^b ±0.01
Total phenolic compound, %	0.12 ^a ±0.01	0.094 ^b ±0.01	0.085 ^c ±0.02	0.076 ^d ±0.01
Total ash, %	2.5 ^a ±0.11	2.4 ^a ±0.23	2.5 ^a ±0.23	2.5 ^a ±0.72
Calcium, mg/100 g dry weight	7.3 ^a ±0.36	7.0 ^a ±0.80	6.8 ^a ±0.37	6.9 ^a ±0.42
Iron, mg/100 g dry weight	8.6 ^a ±0.40	8.6 ^a ±0.55	8.6 ^a ±2.1	4.9 ^b ±1.1
Magnesium, mg/100 g dry weight	94.7 ^a ±2.9	95.1 ^a ±1.2	91.8 ^a ±4.3	93.2 ^a ±3.4
Phosphorus, mg/100 g dry weight	350.1 ^a ±7.4	355.2 ^a ±9.4	347.1 ^a ±8.4	354.6 ^a ±6.4
Potassium, mg/100 g dry weight	217.9 ^a ±3.3	215.0 ^a ±13.2	219.9 ^a ±5.2	221.7 ^a ±9.1
Sodium, mg/100 g dry weight	3.7 ^a ±0.70	3.7 ^a ±0.70	3.8 ^a ±0.96	3.9 ^a ±1.0
Zinc, mg/100 g dry weight	6.7 ^a ±0.91	6.8 ^a ±1.1	6.8 ^a ±0.90	4.5 ^b ±0.65
Copper, mg/100 g dry weight	0.40 ^a ±0.10	0.46 ^b ±0.11	0.43 ^b ±0.25	0.43 ^b ±0.11
K:Na	58.10	57.66	57.00	56.00
Ca/P	0.02	0.02	0.02	0.02
Physico-functional properties				
Water absorption capacity,%	198 ^a ±0.81	548 ^b ±0.05	608 ^c ±0.54	506 ^d ±0.07
Water solubility index, %	7.8 ^a ±0.34	9.7 ^b ±0.37	12.3 ^c ±0.45	16.0 ^d ±0.27
Iodine affinity of starch, ppm	330.0 ^a ±0.65	258.3 ^b ±7.6	241.6 ^b ±12.5	220.0 ^c ±0.11
Paste clarity,% T	28.56 ^a ±0.61	37.3 ^b ±0.41	42.7 ^c ±0.65	49.3 ^d ±1.1
Foam capacity, %	7.07 ^a ±0.12	9.51 ^b ±0.07	10.0 ^c ±0.08	10.0 ^c ±0.04

Mean ± SD with different superscripts in a row differ significantly ($p < 0.05$) ($n = 3$).
^aboiling time in minute

Table 2 Pearson correlation coefficients between various chemical composition and physico-functional properties of flours from the raw and boiled taro (*Colocasia esculenta* cv *fouê*) corm grown in Côte d'Ivoire

	WAC	WSI	IAS	PC	FC	M	CP	TC	CF	CFib	TPC
WSI	0.58										
IAS	−0.88	−0.89									
PC	0.75	0.97	−0.97								
FC	0.96	0.78	−0.98	0.90							
M	−0.63	−0.99	0.91	−0.98	−0.81						
CP	0.57	0.99	−0.88	0.97	0.77	−0.99					
TC	0.65	0.99	−0.92	0.99	0.83	−0.99	0.99				
CF	−0.38	−0.96	0.73	−0.88	−0.59	0.95	−0.94	−0.93			
CFib	−0.94	−0.76	0.97	−0.89	−0.99	0.79	−0.77	−0.81	0.55		
TPC	−0.86	−0.91	0.99	−0.98	−0.97	0.93	−0.91	−0.94	0.77	0.96	
TA	−0.12	0.03	0.15	−0.04	−0.13	−0.05	−0.03	0.01	−0.25	0.29	0.10

In thick, the significant correlation values on the threshold of 5%. *WAC* Water absorption capacity, *WSI* Water solubility index, *IAS* Iodine affinity of starch, *PC* Paste clarity, *FC* Foam capacity, *M* Moisture, *CP* Crude protein, *TC* Total carbohydrate, *CF* Crude fat, *CFib* Crude fibre, *TPC* Total phenolic compounds, *TA* Total ash

acid deplete it of calcium and other minerals and increase the tendency towards inflammations (Appiah et al. 2011). In order to avoid this problem, these flours need supplementation with calcium to prevent mineral and osmotic imbalance (Appiah et al. 2011).

In this study, the change in boiling time led to a significant ($P<0.05$) reduction in iodine affinity of starch, whereas the water absorption capacity, water solubility index, paste clarity and foam capacity increased significantly ($p<0.05$) as shown in Table 1. The water absorption is important for certain product characteristics, such as the moistness of the product, starch retrogradation, and subsequent product scaling (Siddiq et al. 2010). The water absorption capacity of the flour from raw taro corm was $198\pm0.81\%$ while those of flours from boiled taro (*Colocasia esculenta* cv *fouê*) corm ranged from 506 ± 0.07 -to $608\pm0.54\%$, indicating that cooked sample has higher water absorption capacity. Cooked sample therefore has higher affinity for water which is informed by its lower moisture content (5.40 ± 0.04 to $7.4\pm0.05\%$). According to Prinyawiwatukul et al. (1997) and Sila and Malleshi (2011), flours with high water absorption have more hydrophilic constituents, such as polysaccharides. Therefore, the higher water absorption of flours from boiled taro corm than flour from raw taro corm could be attributed to the presence of greater amounts of hydrophilic constituents in them. These results are in close conformity with the findings of Fagbemi and Olaofe (2000) in raw and pre-cooked taro flours, Nwabueze et al. (2001) in raw and cooked breadnut flours and Abulude (2004) in soaked and cooked rice flours. The range of water absorption capacity observed for the different flours analyzed is higher compared to those of flours from taro (*Colocasia esculenta*) corm originated to Hawaii (1.50–1.80 g/g, Tagodoe and Nip 1994), India (2.2%, Kaur et al. 2011b) and Cameroon (2.70–3.75 g/100 g, Njintang et al. 2007b) and potato (2.16 g/g, Kaur et al. 2011b) tuber and soybean (2.17 g/g, Akubor 2007). The ability of food materials to absorb water is sometimes attributed to its proteins content (Kinsella 1976) and to the capacity of boiling to dissociate or alter the protein molecules to monomeric subunits which may have more water-binding sites (Lin et al. 1974). The observed water absorption capacity of flours studied cannot, however, be attributed only to their protein since Pearson correlation (Table 2) and PCA analysis (Fig. 2) revealed no significant correlation of water absorption capacity with protein content ($r=0.57$, $p<0.05$). The high WAC of taro corm flours could be also attributed to the presence of higher amount of carbohydrates in these flours, because in this study, a positive correlation ($r=+0.65$, $p<0.05$) between water absorption capacity and carbohydrate content of flours from Ivorian taro corm was obtained (Table 2 and Fig. 2). Similar observations were recorded by Aboubakar et al. (2008).

These authors suggested that the non-starch component of the flours contribute highly to the water absorption capacity of taro flours. The good WAC of taro flour may prove useful in enhancing the applicability of this flour in products where good viscosity is required, such as in soups and gravies (Kaur et al. 2011b). Foams are used to improve texture, consistency and appearance of foods (Akubor 2007). Under the conditions of the present study, foam stability tended to decrease with the passage of time at room temperature (Fig. 3). This result may be due to collapsing and bursting of the formed air bubbles (Kinsella 1976). The flours of cooked taro corm exhibited the highest foam capacity (9 to 10%). This value is lower than those of flours reported by Tagodoe and Nip (1994) (29–31 ml/100 ml) and Njintang et al. (2007b) (18–27 ml/100 ml). The primary factors involved in foam formation are surface tension, viscosity and the character of the protein film that is formed at the surface of the liquid (Kinsella 1976). In this study, foam capacity was shown to be negatively correlated to the reducing sugars ($r=-1$, $p<0.05$), total phenolic compounds ($r=-0.97$, $p<0.05$), total carbohydrate ($r=-1$, $p<0.05$) and crude fibre ($r=-0.99$, $p<0.05$) levels and iodine affinity of starch ($r=-0.98$, $p<0.05$) and positively correlated water absorption capacity ($r=0.96$, $p<0.05$) both by Pearson correlation (Table 2) and PCA analysis (Fig. 2). This suggests that phenolic compound, reducing sugars, crude fibre and carbohydrate contents affected negatively the FC. Kinsella (1976) reported that phenolic compound could affect the FC by destabilising the protein films surrounding the air droplets and causing the foam to collapse. The negative action of the carbohydrates in foam formation may be attributed probably to the high increase of the viscosity at the surface of the colloidal solution, thereby reducing coalescence of gas bubbles. Diosady et al. (1985) reported that the water solubility index reflects the extent of starch degradation. The water solubility index ($7.8\pm0.34\%$)

Fig. 3 Foam stability of flours from raw and boiled taro (*Colocasia esculenta* cv *fouê*) corm grown in Côte d'Ivoire after 20, 40, 60, 90, and 120 min of storage. The obtained values are averages $\pm$ standard deviation of triplicate determinations. (♦) Flour from raw taro corms; (■) Flour from taro corm boiled in water during 10 min; (▲) Flour from taro corms boiled in water during 15 min; (●) Flour from taro corm boiled during 20 min

observed for the flour of raw taro corm is higher compared to that of flours from boiled taro corm (9.7 ± 0.37 – 16.0 ± 0.27 , Table 1), indicating that boiling time had more profound effects on starch degradation. Similar observations were recorded by Hsu et al. (2003) when using yam (tubers of the *Dioscorea* spp) flours (9.26 ± 0.11 to $15.31 \pm 0.85\%$). Pearson correlation (Table 2) and PCA analysis (Fig. 2) revealed a positive correlation of water solubility index with pasting clarity ($r=0.97$, $p<0.05$), crude protein ($r=0.99$, $p<0.05$) and total carbohydrate ($r=0.99$, $p<0.05$) and a negative with moisture level ($r=-0.99$, $p<0.05$), total sugars ($r=-0.96$, $p<0.05$) and crude fat ($r=0.96$, $p<0.05$) levels. This suggests that the water solubility index cannot be attributed only to the extent of starch degradation. The proteins, total sugars and crude fat play an important role in this functional property change. The pasting characteristics play an important role in the selection of a variety for use in the industry as a thickener, binder or for any other use (Kaur et al. 2011b). The iodine affinity of starch from raw taro corm flour (28.5 ± 0.61 ppm) is higher than those for flours from boiled taro corm (37.3 ± 0.41 to 49.3 ± 1.10 ppm). The result showed that the boiled taro corm flour contained starch granules with the highest affinity for iodine or, in consonance with reports by Raja (1992), contained more amylose. Brunnschweiler et al. (2006) reported that amylose aggregation has a strong impact on the texture of the pastes. Changes in the amylose fraction were also found to influence the texture of other starch rich products such as pasta, mashed potatoes and bread (Escher et al. 1979; Hug-Iten et al. 2001). Iodine affinity of starch was shown to be positively correlated to the reducing sugar ($r=0.99$, $p<0.05$), total phenolic compound ($r=0.99$, $p<0.05$) and crude fibre ($r=0.97$, $p<0.05$) levels and negatively correlated to the paste clarity ($r=-0.97$, $p<0.05$) and foaming capacity ($r=-0.98$, $p<0.05$) both by Pearson correlation (Table 2) and PCA analysis (Fig. 2). This suggests that high iodine affinity of starch exhibit moderate or lower paste clarity and foam capacity. Starch gel clarity is a much desirable functionality of starches for its utilization in food industries since it directly influences brightness and opacity in foods that contain it as thickeners (Mweta et al. 2008). Light transmittance of flour from Ivorian taro corm ranged between $28.5 \pm 0.61\%$ and $49.3 \pm 1.10\%$. The moderate clarity (flour of raw taro corm) would be explained by the fact why the not swollen starch granules remained dense, thus, they reflected the maximum of light entering the medium (Tetchi et al. 2007). Consequently, pastes appeared turbid or opaque, in agreement with literature (Craig et al. 1989). The increase in transmittance (flours of boiled taro corm) shows that it evolved with the gelatinization phenomenon. Pastes obtained after gelatinizations were more transparent than native starch suspension (Lizuka and Aishima 1999; Nuessli et al. 2000).

The increasing in starch paste clarity could be due to reduction in light refraction by the granule remnants (Tetchi et al. 2007). Amylose content is known to influence the clarity of starch pastes as lower amylose starches are easily dispersed, increasing transmittance and clarity. However, our results are contrary to this observation. Taro flour which showed the lowest clarity had comparatively lower amylose content. On the other hand, 83350 and 81/00015 starches which showed the highest paste clarity had higher amylose content except for Maunjili which had both lower paste clarity and amylose content. These results suggest that paste clarity was influenced by so many factors, not only amylose to amylopectin ratio (Craig et al. 1989). Tetchi et al. (2007) reported that light transmittance (%T) of the paste depended mainly on the spectrophotometer type, starch concentration, treatment temperature and storage time. In this study, Pearson correlation (Table 2) and PCA analysis (Fig. 2) revealed a positive correlation of paste clarity with crude protein ($r=0.97$, $p<0.05$) and total carbohydrate ($r=0.99$, $p<0.05$) and a negative with moisture ($r=-0.98$, $p<0.05$), total sugars ($r=-0.96$, $p<0.05$) and total phenolic compounds ($r=-0.98$, $p<0.05$) levels. This suggests that high total carbohydrate and crude protein exhibit high paste clarity and low moisture, total sugars and total phenolic compounds levels.

Conclusion

This report shows that the boiling time has significant ($p<0.05$) effect on the moisture, reducing sugars, total sugars, crude fat, crude fibre, total phenolic compound, total carbohydrate contents, iodine affinity of starch, water absorption capacity, water solubility index, paste clarity and foam capacity of flour from the Ivorian taro (*Colocasia esculenta* cv *fouê*) corm. The crude protein and total ash contents were not affected significantly ($p<0.05$) by the change in boiling time. The taro corm flour is a good source of carbohydrate, crude fibre and total ash going by the chemical score and therefore should be appreciated as a food security crop those people living in Côte d'Ivoire (West Africa) where this taro corm is produced in abundance. The crude protein and fat scores of the Ivorian taro corm flour are lower than those reported in flours from taro yam or cassava. The chemical composition and functional properties of flour from Ivorian taro corm differed significantly from flours of other botanical sources. The results pointed out that flour from taro corm cultivated in Côte d'Ivoire exhibited highest WAC and lowest foaming capacity in comparison to other flours. The high WAC of taro flour makes it a good body providing agent and can thus be used as a thickener or gelling agent in

various food products. Based on these results, taro flour has a good potential to be used in food industry either for development of new food products.

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