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Biochemical Characteristics of Taro (C*olocasia esculenta*) Cultivated in Côte d'Ivoire According to Maturity Stage

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The study was conducted to determine the maturity stage that produced the best nutritive profile of taro. Biochemical analyses of six varieties of taro (*white achahou, violet achahou, dabehou, gagne pôtè, guèdègué* and *zoukoudjèrè*) cultivated locally were determined at 6, 8, 10 and 12 months of maturity. Except fat content which remained constant, fiber, carbohydrate, ash, reducing sugars and starch contents increased with the reduction of water content of fresh corms while protein, total sugar and energy value decreased during maturation. The highest carbohydrate (84.20 ± 0.07 g/100 g) and starch (40.93 ± 0.62 g/100 g) were reached at the 10th month in *Dabehou* and fiber in *Gagne pôtè* (4.55 ± 0.01 g/100 g. Except sodium which decreased, Minerals increased during maturation. The highest macro-elements (potassium) were showed in *White achiahou* (1751.46 ± 1.01 mg/100g) and *Gagne pôtè* (1751.01 ± 2,39 mg/100g) and microelements (iron) in *Violet achiahou* (39.58 ± 1.22 ppm) at the 10th month. The highest water absorption capacity (374.02 ± 9.25%) and water solubility index (28.25 ± 0.71%) were obtained at 10 months in *Dabehou*. According to these results, the taros should be harvested at the 10th month of maturity to produce the best nutritive profile.

Introduction

Tubers and roots are important food source for many people around the world (FAO, 2007). In developing countries, they constitute an important margin of employment and income for rural populations (Himeda *et al.,* 2012). Native to South-East Asia (Indo-Malaysia), taro (*Colocasia esculenta*) is a monocotyledonous herbaceous plant belonging to araceae family widely cultivated in tropical and subtropical regions because of corms energy value and leaves nutritional value (Mabhaudhi *et al.*, 2014). According to FAO (2012), it is the fifth most harvested root and tuber crop in the world with production estimated at 9 million tons for 2011. Thus, African continent is classified like first large producer of any confused kind taro with Côte d'Ivoire like fifth large world producer (FAO, 2008).

Taro, the potato of the tropics, is an important crop in many parts of Africa (DAFF, 2010). Thus, it is generally consumed in tropical countries like an inexpensive calories source and its use varies by region. In Côte d'Ivoire, it is prepared in stew, puree, foutou and embers (Mabhaudhi *et al.,* 2014). It occupies an important place in the Pacific by providing between 15 and 53% of food energy, which largely covers 43% of recommended energy for consumers in Tonga (Soudy *et al.,* 2010).

Its corms are good sources of carbohydrates with easily digestible starch and have a favorable protein-to-energy ratio (Shange, 2004). Taro's primary use is the consumption of its edible corm and leaves which are a good source of carotene, potassium, calcium, phosphorus, and iron (Deo *et al.,* 2009). In addition, its low sodium content (0 - 0,3% of the matter dries) is the reason for which taro is particularly useful in the diet of hypertensives which must limit their salt intake (Mabhaudhi *et al.,* 2014).

It should be noted that the nutritional value conservation is the main concern when a plant is considered as food source because endogenous toxic factors characteristic of the plant material can affect the nutrient content. Thus, *Colocasia esculenta* has been widely studied for its nutrient and anti-nutrient composition (Mabhaudhi *et al.,* 2014). However, any studies have been conducted on taro nutritional composition according to the maturity degree of the corms (Himeda *et al.,* 2012). But, some studies have indicated that starch characteristics change with the stage of tuber development and that harvest periods influence these characteristics (Leonel *et al.,* 2005). Indeed, Noda *et al.,* (2004) indicated that late harvest period significantly increases phosphorus content, viscosity, while it causes weak decreases in amylose content and gelatinization temperature of the starch of various potato cultivars. In addition, similar studies on Dioscorea species have shown crucial changes in their rheological and physicochemical properties (Huang *et al.,* 2006).

The present work aims to follow the evolution of the biochemical parameters of taro (*Colocasia esculenta*) cultivated in Côte d'Ivoire during tuber development in order to determine the stage of maturity with the best nutrient content and to contribute thus to Ivorian populations food security.

Materials and Methods

Plant material, Experimental site and cropping practice

The six local varieties of taro (*white achiahou, violet achiahou, dabehou, gagne pôtè, guèdèguè* and *zoukoudjèrè*) (*Colocasia esculenta*) used for this research work, were brought from an experiment field located at 5 km of Azaguié a city located at 40 km in the north of Abidjan. This field is in a bottom whose outlet presents a river, favorable environment for the *Colocasia esculenta* cultivation and the culture was ran from March 15, 2016 to March 15, 2017.

The experimental device was sown on 12 plots of 5 m x10 m each one due to two plots per cultivar and they were separated to 2 m. There were 11 rows per plot separated between them to 1 m due to 8 pockets per row separated also to 0.7 m between them and 2 m of border were arranged around of this field.

The planting was done flat using circular holes and the tuber pieces were sown at 10 to 15 cm of depth from ground per pocket. A manual weeding was done at 2 and 4 months after sowing to avoid any competition between the weeds and the interest of plant.

Equally, two series of Phytosanitary antifungal treatments were made after each weeding to ensure crop protection against phytopathogenic agents.

Collection and sampling

The harvests were carried out from September 2016 to March 2017.All the tubers were collected to each 15 of the month (from September 2016 to March 2017). For each harvest, five feet of taro were unearthed in a random way in each plot, which give at least ten tubers by cultivar. Ainsi, the tubers were randomly dug at 6, 8, 10 and 12 months of maturity and the samples were coded (ZOUK: *Zoukoudjèrè*, GAP: *Gagne pôtè*, GUE: *Guèdèguè*, ACW: *White achiahou*, ACV: *Violet achiahou* and DAB: *Dabehou*) and were transported directly to the laboratory.

They were washed, peeled, cut into small pieces (0.3 cm) and oven dried (Memmert, Germany) at 45 °C for 24 h. The dried pieces were ground using a blender (Moulinex; Normandy, France) and sieved with a sieve (mesh: 200 µm). The flours obtained were packaged in food bags and stored at 4 °C until analysis.

Biochemical compounds analysis

Proximate composition analysis

Moisture contents, total ash and Crude fat were respectively determined by drying in an oven at 105ºC during 24h to constant weight, by incinerating in a furnace muffle (Nabertherm, Germany) at 550 °C and by continuous extraction in a Soxhlet apparatus for 8h using hexane as solvent while, crude protein was calculated from nitrogen (Nx6.25) obtained using the Kjeldahl (AOAC, 1990). rude fiber was determined according to the gravimetric method of Van (1963). The method described by Dubois *et al.*, (1956) was used for the total sugars determination while reducing sugars was determined according to Bernfeld method (1955) using 3.5 dinitrosalysilic acid (DNS). Total carbohydrates and starch content were calculated according to AOAC (2000) while energy value was calculated according to FAO (2002).

Minerals analysis

Minerals were analyzed by IITA (1981) method. It consists to determine minerals after ash solubilization in a solution acid using an atomic absorption spectrophotometer (AAS 20; VARIAN) with standards at different specific wavelength for each mineral: K (766.5 nm), Na (589 nm), Ca (422.7 nm), Mg (285 nm), Fe (248,3 nm (279.5 nm), and Zn (213.9 nm).

Functional properties (Water absorption Capacity and solubility index in water)

Water absorption Capacity and solubility index in water were determined using the methods described by Phillips *et al.,* (1988) and Anderson *et al.*, (1969) respectively.

Determination of anti-nutritional factors (oxalates and phytates)

Oxalates were determined using the method described by Ukpabi and Ejidoh (1989) and phytates was carried out according to Latta and Eskin (1980) method based on discoloration of Wade reagent by phytates.

Statistical analysis

Statistical tests were performed using the statistica software version 7.1. The analysis of variance (ANOVA I) was used to determine the differences between treatments. When a difference was observed, a Duncan test at 5% was performed to separate treatment means and the data were presented as mean ± standard deviation (SD).

Results and Discussion

Proximate composition

The result of water content of fresh tubers is presented in Figure 1. Proximate composition of the different samples is shown in Table 1 and ethanosoluble sugars are shown in Figure 2 (total sugars) and Figure 3 (reducing sugars).

There was a significant decrease of the Water content in fresh tubers in all varieties from the 6^{th} to 12^{th} month of maturity (Figure 1). Thus, the highest Water content were observed at the 6^{th} month (78.67 ± 0.47 to 83.17 ± 0.71 g/100 g fresh matter (FM)) and the lowest at the 12^{th} month (74.16 ± 0.47 to 68.67 ± 0.94 g/100 g DW). This water loss was a result of the increase in dry matter which could be related to the accumulation of the nutriments and especially the starch during maturation and also due probably to the use of water in the various metabolic activities caused by the environmental conditions (strong temperatures, wind, etc) (Huang *et al.,* 2007). This loss was also observed by Tchumou *et al.,* (2015) during similar studies with *Phaseolus lunatus* seeds.

The moisture content of the flours varies from 7.17 to 8.83%, but not according to maturity stage. These moisture values arranged between 8 and 10% are lower than 12%, the range of moisture content regularly observed to cover more than 6 months of conservation because these moisture rates are favorable to limit microbial load increase (Kouakou *et al.,* 2017).

These results are similar those reported by Aboubakar *et al.*, (2008) on six varieties of Cameroun taro (*Reb Ibo Coco Ekona*, *Reb Ibo Coco Ngaoundere*, *Coco Ekona*, *coco Ngaoundere*, *Kwanfre 1* and *Kwanfre 2*) which ranged from 8.2 to 9.6%.

All the varieties showed low rate and had roughly the same fat contents (Table 1). So, any significant differences were noted during maturation for fat content. Similarly, the fat rate of Cameroun taro *Sosso* is low and doesn’t vary across maturity stage (Himeda *et al.*, 2012). The weak fat rates observed in this study suggest that these taros could be recommended for lipid lowering and hypoglycaemic diets (Osei, 2003).

There was a significant decrease of protein content from the 6^{th} to the 12^{th} month of maturity for DAB (8.11 ± 0.45 to 4.94 ± 0.84 g/100 g DW) and ACV (9.58 ± 0.44 to 4.90 ± 0.73 g/100 g DW) while ACW (9.92 ± 0.54 to 4.36 ± 0.50 g/100 g DW), GAP (9.93 ± 0.55 to 4.36 ± 0.50 g/100 g DW), GUE (9.19 ± 0.27 to 4.96 ± 0.74 g/100 g DW) and ZOUK (9.40 ± 0.56 to 5.05 ± 0.54 g/100 g DW) decreased until the 10^{th} month and remains stable at the 12^{th} month (Table 1). This proteins content decrease was also observed with the cassava during maturation (Chotineeranat *et al.,* 2006). Our results are lower compared to those of Cameroun taro harvested between the 8^{th} (7.29 g/100 g) and 9^{th} months (11.83 g/100 g) Aryee *et al.*, 2006). This contradiction could be explained by the influence of ecological zone because planting dates differ generally from a locality to another and probably because these varieties are different. However, these contents should not be neglected because proteins are implicated in cells died replacement for adults, good infant and children growth, good fetus development for pregnant women and good secretion of the mother's milk during breast feeding.

The energetic value decreased significantly ($P < 0.05$) during maturation. Thus, they vary from 325,41 ± 0.12 to 315,46 ± 0.28, 321,64 ± 0.08 to 313,02 ± 0.26, 320,58 ± 0.24 to 313,60 ± 0.26, 320, 15 ± 0.67 to 313,53 ± 0.25, 323,81 ± 0.09 to 317,12 ± 0.09 and

322,54 ± 0.23 to 316,99 ± 0.12 Kcal/100 g DW respectively for DAB, ACV, ACW, GAP, GUE and ZOUK. Carbohydrate and starch levels increased significantly up to 10^{th} month before declining to the 12^{th} month of maturity for all varieties. The high carbohydrate and starch levels were observed at the 10^{th} month with the highest carbohydrate (84.90 ± 0.07 g/100 g DW) and starch (40.91 ± 0.62 g/100 g) values contained in ACV and DAB respectively. This increase and decrease of carbohydrates rate were positively correlated to starch levels. The tuber, during its growing period, accumulates substances of reserve such as the starch. These substances are used to ensure the continuation of the metabolism after harvest (Manner, and Taylor, 2010). This would explain the increase of carbohydrates up to 10^{th} months because the carbohydrates are composed mainly of starch (Aryee *et al.*, 2006). Its reduction after 10 months can be attributed to the transformation of starch into soluble sugars under the action of phosphorylase enzyme during maturation (Huang *et al.,* 2007). The high carbohydrate contents in the samples enable these taro tubers to act as a good source of calories which would be antimarasmus, especially for infant nutrition (Tchumou *et al.*, 2015). Soudy *et al.*, (2010) reported that taro corm is a source of carbohydrate benefic for diabetics and gastrointestinal disorders. This may suggest that taro tuber contain slow digestible starches and dietary fiber which are of nutritional importance (Srilakshmi, 2008). The best carbohydrate and starch rate were obtained with the tubers harvested at 10 months. Thus, based on starch and carbohydrate content, the ideal maturity of these six varieties of taro is observed at 10 months. The food energy value was based on crude protein, crude lipid and total carbohydrates. Thus, the decrease of the energy value observed in this study can be explained by the decrease of protein rate during maturation and the weak values were due to its low-fat content. The food energy values of these taros were lower than those of maize flour (382.25 Kcal) Kouakou *et al.*, (2017) but were comparable to that of white bean *Phaseolus lunatus* (300.79-310.71 Kcal) (Tchumou *et al.*, 2015).

Ash content as well as fiber content was significantly influenced by maturity stage. However, for all varieties, ash content increases during maturation and the high contents were observed at the 10^{th} month with ACW and GAP containing the highest ash content at any stage of maturity. This content varies from 4.19 ± 0.00 to 7.60 ± 0.01 g/100 g, 4.77 ± 0.00 to 7.85 ± 0.05 g/100 g, 4.98 ± 0.03 to 7.92 ± 0.01 g/100 g, 4.97 ± 0.10 to 7.91 ± 0.07 g/100 g, 4.73 ± 0.01 to 7.27 ± 0.08 g/100 g and 4.77 ± 0.03 to 6.77 ± 0.04 g/100 g DW respectively for DAB, ACV, ACW, GAP, GUE and ZOUK. Fiber content increased from 6^{th} to 10^{th} months before remained constant until 12 months for all the varieties except GUE in which it decreased until the 12^{th} month. The high values were observed at the 10^{th} months and ranged from 4.39 ± 0.08 to 4.55 ± 0.01 g/100 g DW. The ash content represents all the minerals contained in samples (Himeda *et al.*, 2012). The correlation observed between the maturation stage and ash content indicates a minerals accumulation during maturation. The high ash content observed would be an indicator of their mineral element's wealth nutritionally important (Nielsen and Harbers, 2003). A similar increase liked to maturity stage was reported by Leonel *et al.,* (2005) and Chotineeranat *et al.,* (2006) for the ash content of *Pachyrhizus ahipa* and cassava respectively. Moreover, fiber content increase of ours samples during maturity was also remarked with *Sosso* Chad variety of taro with also the highest content obtained at the 10^{th} month. However, our values are higher than those of *Sosso* Chad variety (2.84 to 3.39

g/100 g: 6th to 10th month of maturity) (Himeda *et al.*, 2012). This suggests that these Ivorian taros have higher crude fiber than those cultivated in Chad. Thus, the best fiber profile of our taro will be obtained with the tubers harvested at 10 months. The presence of fibers in the diet is useful for digestion and for elimination of wastes. The contraction of muscular walls of the digestive tract is stimulated by fibers, thus counteracting constipation (Tchumou *et al.*, 2015). A high fiber diet is also very beneficial because it helps to prevent diseases of the gut such as appendicitis and colon cancer (Fiagan, 2007). Indeed, the fibers have a high hydrophilic power. This great ability to retain water along their path in the stomach and intestine facilitates the reduction of food intake and increases stool volume (N'Guessan *et al.*, 2018). In addition, the fibers form a viscous gel eliminating the lining of the intestine, which slows the intestinal absorption of carbohydrates and cholesterol.

Figure 2 shows that, whatever the variety, a significant (P <0.05) decrease of the total sugars was observed from 6 to 10 months before to increase up to 12th month. Concerning the reducing sugars, a significant (P <0.05) increase was revealed during maturation (Figure 3). These contents vary respectively from 8.53 ± 0.02 to 17.49 ± 0.05 g/100 g, 9.59 ± 0.03 to 17.20 ± 0.05 g/100 g, 10.74 ± 0.03 to 20.87 ± 0.05 g/100 g, 9.61 ± 0.02 to 17.23 ± 0.02 g/100 g, 12.19 ± 0.03 to 17.51 ± 0.59 g/100 g and 10.94 ± 0.05 to 18.19 ± 0.10 g/100 g DW for DAB, ACW, ACV, GAP, GUE and ZOUK. The fall of the high content of the total sugars during maturation could due to the starch degradation which occurs during maturation under the action of amylase, thereby producing the sugars (Manner and Taylor, 2010). Reducing sugars in these Ivorian taros is higher than those from Cameroun taro *Sosso* (2.3%) and Tchad taro *Ibo coco* (1.3 %) (Njintang *et al.*, 2007). It was suggested that reducing sugars in taro tuber may cause caking and damping during their storage because of sugar's hygroscopic property (Aina *et al.*, 2010). However, sugars may be desirable in bakery products like bread and cake where the tenderizing effects positively affect texture and where sugars serve as substrate for fermentation of the dough (Amon *et al.*, 2011).

Mineral composition

In general, the Minerals increased significantly (P <0.05) up to 10th month before decreasing or remains constant up to the 12th month except sodium which decreased for all varieties during maturation. Concerning the macro-elements, phosphorus, potassium and calcium levels increased until the 10th month before decreasing to the12th month of maturity for all varieties except ACW and GAP which, after the10th month, remained constant up to the 12th month. Indeed, for all varieties, potassium showed the high rate and Phosphorus the low rate at all maturity levels. The highest potassium (1536.26 ± 1.77 mg/100 g DW (DAB) to 1751.46 ± 1.01 mg/100 g DW (ACW) and Phosphorus (27.89 ± 0.13 (ACV) to 38.59 ± 0.27 mg/100 g DW (GAP) contents was obtained at the 10th month.

For magnesium content, a significant increase was observed from 6 to 10 months and remained constant up to the 12th month for all varieties except GUE and ZOUK which, after 10 months, dropped significantly. Thus, the values varying from 133.06 ± 0.28 (ACV) to 162.83 ± 2.99 mg/100 g DW (ACW) constituted the highest values recorded at 10 months. For the micro-elements, although sodium decreased, it indicated the highest values while manganese except ACW and GAP (6th month of maturity) recorded the lowest values at all levels of maturity and whatever the variety.

Table.1 Evolution of some biochemical parameters of 6 varieties of taro (*Colocasia esculenta*) during maturation (g/100 g DW)

Biochemical parameters									
Varieties	maturity stage (months)	Proteins	Fat	Fiber	Ash	moisture	carbohydrate	Energy value (Kcal/100 g DW)	Starch
DAB	6	8.11±0.45^{d}	1.12±0.08	3.58±0.07^{a}	4.19±0.00^{a}	8.50±0.23^{b}	82.07±0.18^{a}	325.41±0.12^{d}	31.14±0.95^{a}
	8	7.21±0.66^{c}	1.13±0.02	3.89±0.14^{b}	4.67±0.04^{a}	7.83±0.23^{a}	83.09±0.13^{b}	323.72±0.53^{c}	34.13±0.85^{c}
	10	5.49±0.54^{b}	1.16±0.03	4.43±0.07^{c}	5.17±0.00^{b}	7.42±0.12^{a}	84.18±0.07^{c}	322.58±0.43^{b}	40.91±0.62^{d}
	12	4.94±0,84^{a}	1.14±0.03	4.01±0.04^{c}	7.60±0.01^{c}	7.83±0.23^{a}	82.71±0.00^{a}	315.46±0.28^{a}	35.59±0.56^{b}
ACV	6	9.58±0.44^{d}	1.01±0.05	3.46±0.04^{a}	4.77±0.00^{a}	8.42±0.12^{c}	81.17±0.10^{a}	321.64±0.08^{c}	25.93±0.18^{a}
	8	6.40±0.55^{c}	1.11±0.03	3.91±0.06^{b}	5.16±0.01^{b}	8.17±0.23^{b}	83.41±0.05^{c}	321.04±0.35^{c}	30.79±0.18^{b}
	10	5.14±0.54^{b}	1.14±0.03	4.42±0.01^{c}	5.80±0.04^{c}	7.33±0,47^{a}	84.90±0.04^{d}	319.34±0.38^{b}	39.69±1.50^{c}
	12	4.50±0.73^{a}	1.10±0.01	4.40±0.01^{c}	7.85±0.05^{d}	7.25±0.35^{a}	82.34±0.04^{b}	313.02±0.26^{a}	26.76±0.81^{a}
ACW	6	9.92±0.54^{c}	1,09±0.03	3.55±0.07^{a}	4.98±0.03^{a}	7.83±0.23^{ab}	80.45±0.01^{a}	320.58±0.24^{c}	23.13±0.81^{a}
	8	5.75±0.54^{b}	1.12±0.04	4.05±0.07^{b}	5.62±0.01^{b}	7.33±0.00^{a}	81.96±0.00^{b}	319.79±0.37^{b}	32.22±0.13^{c}
	10	4.36±0.50^{a}	1.16±0.02	4.51±0.03^{c}	6.25±0.00^{c}	8.42±0.12^{b}	83.71±0.03^{c}	319.18±0.00^{b}	38.27±0.04^{d}
	12	4.32±0.45^{a}	1.13±0.04	4.40±0.02^{c}	7.92±0.01^{d}	7.75±0.35^{a}	82.23±0.01^{b}	313.620±0.26^{a}	28.42±0.05^{b}
GAP	6	9.93±0.55^{c}	1.02±0.05	3.58±0.02^{a}	4.97±0.10^{a}	7.75±0.35^{a}	80.50±0.06^{a}	320.15±0.67^{c}	23.16±0.43^{a}
	8	5.78±0.74^{b}	1.11±0.06	4.03±0.06^{b}	5.61±0.01^{b}	7.50±0.23^{a}	81.96±0.15^{b}	319.86±0.05^{bc}	32.24±0.71^{c}
	10	4.36±0.50^{a}	1.16±0.04	4.55±0.01^{c}	6.26±0.00^{c}	8.50±0.23^{b}	83.87±0.02^{c}	319.03±0.30^{b}	38.28±1.29^{d}
	12	4.33±0.40^{a}	1.13±0.04	4.41±0.01^{c}	7.91±0.07^{d}	7.75±0.35^{a}	82.21±0.00^{b}	313.53±0.25^{a}	28.41±0.64^{b}
GUE	6	9.19±0.27^{c}	1.06±0.03	3.09±0.08^{a}	4.73±0.01^{a}	7.75±0.35	81.92±0.12^{a}	323.81±0.09^{d}	26.42±0.85^{a}
	8	6.19±0.54^{b}	1.10±0.05	4.02±0.01^{b}	4.88±0.00^{a}	8.17±0.23	83.60±0.06^{c}	322.04±0.25^{c}	35.33±0.86^{c}
	10	4.96±0.74^{a}	1.14±0.02	4.42±0.04^{d}	5.22±0.05^{b}	7.67±0.47	84.15±0.02^{d}	321.41±0.19^{b}	39.96±1.10^{d}
	12	4.89±0.71^{a}	1.12±0.06	3.71±0.02^{b}	7.20±0.04^{c}	7.83±0.23	82.89±0.13^{b}	317.12±0.09^{a}	30.04±0.59^{b}
ZOUK	6	9.40±0.56^{c}	1.10±0.06	3.39±0.05^{a}	4.77±0.03^{a}	8.83±0.23^{bc}	81.32±0.05^{a}	322.54±0.23^{c}	25.54±0.57^{a}
	8	5.97±0.58^{b}	1.12±0.04	4.05±0.03^{b}	5.23±0.03^{b}	8.33±0.47^{b}	82.52±0.00^{b}	320.72±0.38^{b}	35.83±0.15^{c}
	10	5.05±0.54^{a}	1.17±0.03	4.39±0.08^{c}	5.82±0.04^{c}	8.25±0.35^{b}	83.57±0.16^{c}	320.45±0.29^{b}	39.87±0.20^{d}
	12	5.05±0.58^{a}	1.12±0.03	4.35±0.07^{c}	6.77±0,08^{d}	7.17±0.23^{a}	82.70±0.06^{b}	316.99±0.12^{a}	31.22±0.77^{b}

Mean values ± SD, n = 3. Means in column following by letters (a, b, c, or d) is significantly different at 5% according to Duncan test.

Table.2 Evolution of some mineral contents of 6 varieties of taro (*Colocasia esculenta*) during maturation

Varieties	maturity stage (months)	Macro-elements (mg/100 g DW)				Microelements (ppm)			
		P	K	Ca	Mg	Iron	Na	Zn	Mn
DAB	6	17.41±0.42^{a}	1507.15±1.37^{b}	223.67±0.58^{a}	135.11±1.31^{a}	9.51±0.70^{a}	49.21±0.01^{d}	3.87±0.00^{a}	2.75±0.23^{a}
	8	24.62±0.38^{b}	1514.07±5.48^{c}	263.33±0.58^{b}	137.44±0.32^{b}	17.81±0.01^{b}	47.05±0.51^{c}	7.04±0.26^{b}	6.26±1.23^{b}
	10	29.74±0.89^{d}	1536.26±1.77^{d}	288.33±0.58^{d}	140.24±1.45^{c}	32.73±0.60^{d}	45.48±1.57^{b}	13.88±0.61^{c}	11.79±0.49^{c}
	12	26.88±0.07^{c}	1162.67±0.58^{a}	270.67±0.58^{c}	140.00±0.00^{c}	27.81±0.01^{c}	40.34±0.27^{a}	15.62±0.48^{d}	11.57±0.00^{c}
WAC	6	14.53±0.58^{a}	1696.57±2.07^{b}	158.67±1.53^{a}	147.97±2.57^{a}	10.47±0.16^{a}	58.78±1.14^{d}	2.38±0.00^{a}	3.03±0.09^{a}
	8	18.37±2.23^{b}	1707.65±4.19^{c}	275.00±0.00^{b}	150.18±1.78^{b}	12.80±0.07^{b}	49.14±1.67^{c}	11.55±0.18^{b}	4.39±0.06^{b}
	10	37.92±1.24^{d}	1751.46±1.01^{d}	354.00±1.00^{c}	163.00±2.99^{c}	19.06±0.81^{c}	45.20±0.00^{b}	19.68±1.10^{c}	6.56±0.15^{c}
	12	33.22±0.97^{c}	1622.67±0.58^{a}	355.67±0.58^{c}	162.83±2.00^{c}	19.71±0.00^{c}	34.56±0.05^{a}	23.89±1.17^{d}	6.11±0.21^{c}
VAC	6	16.03±0.36^{a}	1553.03±3.43^{b}	213.33±0.58^{a}	129.60±1.17^{a}	9.66±0.62^{a}	47.51±0.01^{d}	2.63±0.28^{a}	0.74±0.02^{a}
	8	18.53±0.57^{b}	1606.52±1.72^{c}	322.00±0.00^{b}	131.60±0.42^{b}	20.89±0.44^{b}	38.07±0.64^{c}	3.00±0.00^{b}	0.77±0.02^{ab}
	10	27.89±0.13^{d}	1662.94±1.85^{d}	375.67±0.58^{d}	133.06±0.28^{c}	39.58±1.22^{d}	36.00±1.14^{b}	3.79±0.20^{b}	0.81±0.01^{b}
	12	24.72±0.70^{c}	1234.00±1.00^{a}	323.67±0.58^{c}	133.00±0.00^{c}	26.07±0.00^{c}	26.13±1.04^{a}	7.68±0.50^{c}	0.67±0.02^{a}
GAP	6	14.53±0.66^{a}	1637.83±3.33^{b}	158.33±1.53^{a}	147.64±0.71^{a}	10.32±0.00^{a}	59.29±0.48^{d}	2.50±0.00^{a}	3.03±0.11^{a}
	8	18.74±0.67^{b}	1717.44±2.08^{c}	274.67±0.58^{b}	150.23±1.33^{b}	13.06±0.81^{b}	49.46±0.57^{c}	11.68±0.42^{b}	4.57±0.42^{b}
	10	38.59±0.27^{d}	1751.01±2.39^{d}	354.67±1.53^{c}	163.00±0.73^{c}	19.12±0.04^{c}	45.21±0.38^{b}	14.07±1.62^{c}	6.93±0.58^{c}
	12	32.79±1.04^{c}	1619.33±0.58^{a}	355.33±0.58^{c}	162.72±1.00^{c}	18.41±0.00^{c}	34.79±0.00^{a}	17.89±0.41^{d}	6.46±0,48^{c}
GUE	6	18.66±0.22^{a}	1550.43±5.46^{a}	507.67±0.58^{a}	129.01±0.74^{a}	6.30±0.39^{a}	76.60±0.85^{c}	0.55±0.02^{a}	0.69±0.06^{a}
	8	25.27±0.06^{b}	1688.10±3.55^{b}	643.67±0.58^{b}	135.92±0.65^{b}	7.72±0.20^{b}	75.04±0.14^{c}	2.21±0.11^{b}	0.81±0.05^{b}
	10	30,42±0.43^{d}	1735.67±5.77^{c}	733.33±0.58^{d}	143.11±056^{d}	7.89±0.21^{b}	62.59±1.73^{b}	3.81±0.11^{c}	1.10±0.00^{d}
	12	28.89±0.56^{c}	1496.08±4.12^{d}	721.33±0.58^{c}	137.00±0.00^{c}	6.40±0.00^{a}	45.61±0.00^{a}	3.58±0.00^{c}	0.94±0.04^{c}
ZOUK	6	23.50±0.22^{a}	1594.46±1.84^{b}	235.67±0.58^{a}	133.33±0.58^{a}	6.85±0.32^{a}	47.96±0.49^{d}	2.13±0.00^{a}	1.12±0.03^{a}
	8	25.91±0.01^{b}	1600.34±5.88^{b}	293.67±0.58^{b}	138.95±0.34^{b}	7.37±0.63^{b}	42.10±0.01^{c}	3.45±0.10^{b}	2.12±0.00^{b}
	10	32.22±1.12^{d}	1649.34±3.17^{c}	395.67±0.58^{d}	146.40±0.49^{c}	7.89±0.00^{b}	39.69±0.72^{b}	4.49±0.33^{c}	2.18±0.01^{b}
	12	28.61±0.95^{c}	1280.67±0.58^{a}	3530.33±0.58^{c}	138.52±0.89^{b}	6.34±0.00^{a}	35.62±0.42^{a}	4.27±0.09^{c}	1.17±0.02^{a}

Mean values ± SD, n = 3. Means in column following by letters (a, b, c, or d) is significantly different at 5% according to Duncan test

Fig.1 Evolution of water content at different stages of maturity of 6 taro (*Colocasia esculenta*) varieties (g/100 g DW). DAB (*Dabehou*); ACW (*White achiahou*); ACV (*Violet achiahou*); GAP (*Gagne pôtè*); GUE (*Guèdèguè*) and ZOUK (*Zoukoudjèrè*)

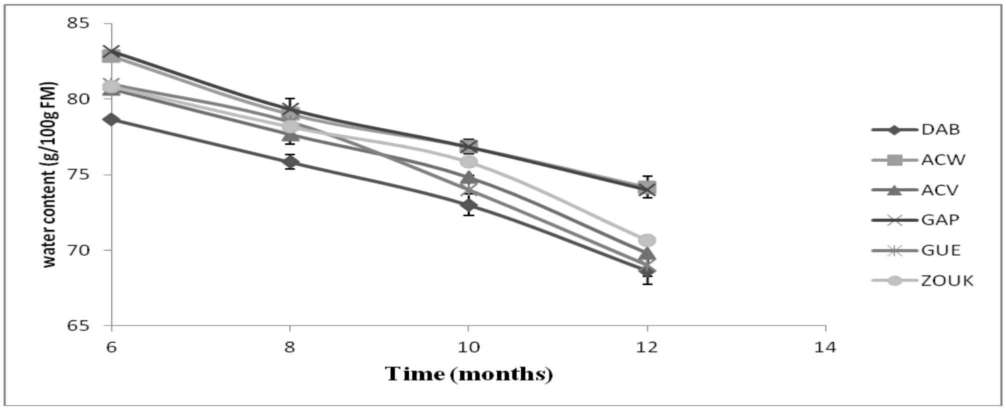


Fig.2 Evolution of total sugars at different stages of maturity of 6 taro (*Colocasia esculenta*) varieties (g/100 g DW). DAB (*Dabehou*); ACW (*White achiahou*); ACV (*Violet achiahou*); GAP (*Gagne pôtè*); GUE (*Guèdèguè*) and ZOUK (*Zoukoudjèrè*)

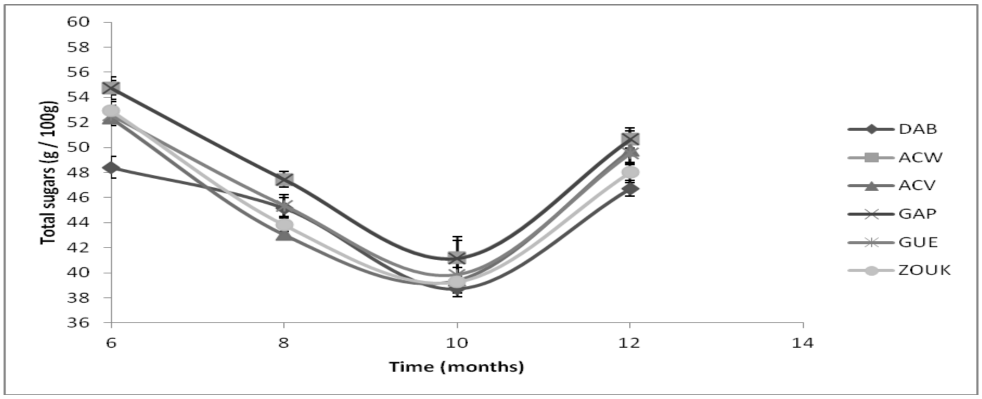


Fig.3 Evolution of reducing sugars at different stages of maturity of 6 taro (*Colocasia esculenta*) varieties (g/100 g DW). DAB (*Dabehou*); ACW (*White achiahou*); ACV (*Violet achiahou*); GAP (*Gagne pôtè*); GUE (*Guèdèguè*) and ZOUK (*Zoukoudjèrè*)

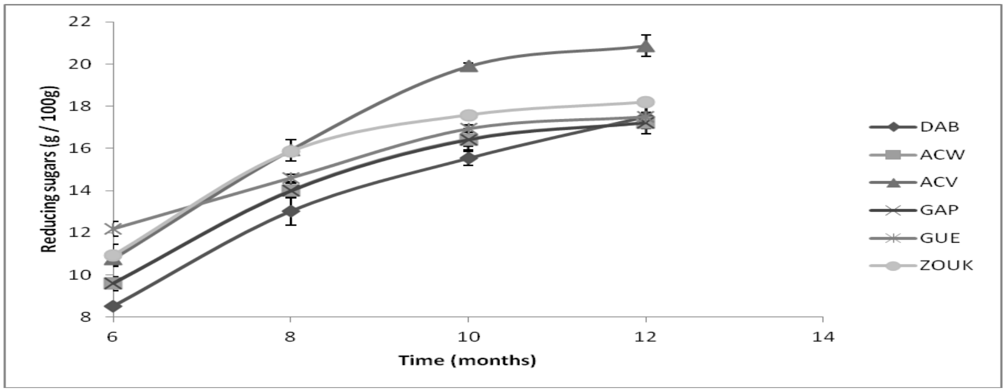


Fig.4 Evolution of Water Absorption Capacity (WAC) at different stages of maturity of 6 taro (*Colocasia esculenta*) varieties (g/100 g DW). DAB (*Dabehou*); ACW (*White achiahou*); ACV (*Violet achiahou*); GAP (*Gagne pôtè*); GUE (*Guèdèguè*) and ZOUK (*Zoukoudjèrè*)

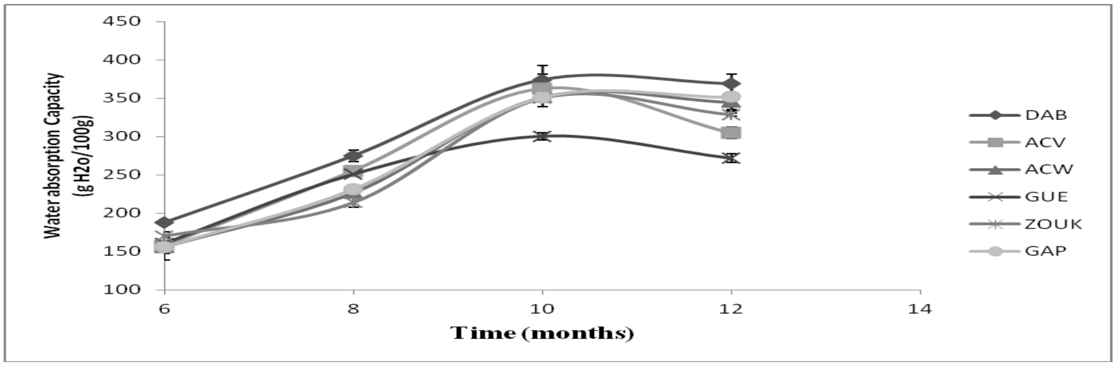


Fig.5 Evolution of Water Solubility Index (WSI) at different stages of maturity of 6 taro (*Colocasia esculenta*) varieties (g/100 g DW). DAB (*Dabehou*); ACW (*White achiahou*); ACV (*Violet achiahou*); GAP (*Gagne pôtè*); GUE (*Guèdèguè*) and ZOUK (*Zoukoudjèrè*)

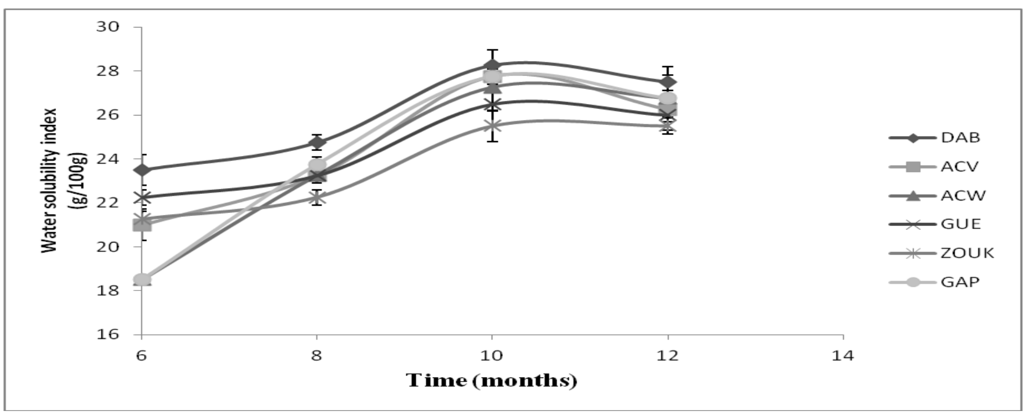


Fig.6 Evolution of phytate content at different stages of maturity of 6 taro (*Colocasia esculenta*) varieties (g/100 g DW). DAB (*Dabehou*); ACW (*White achiahou*); ACV (*Violet achiahou*); GAP (*Gagne pôtè*); GUE (*Guèdèguè*) and ZOUK (*Zoukoudjèrè*)

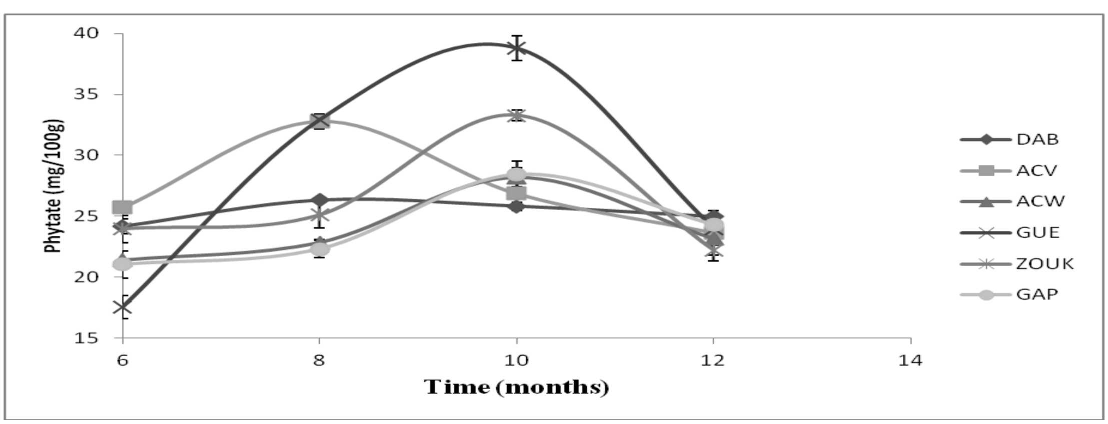
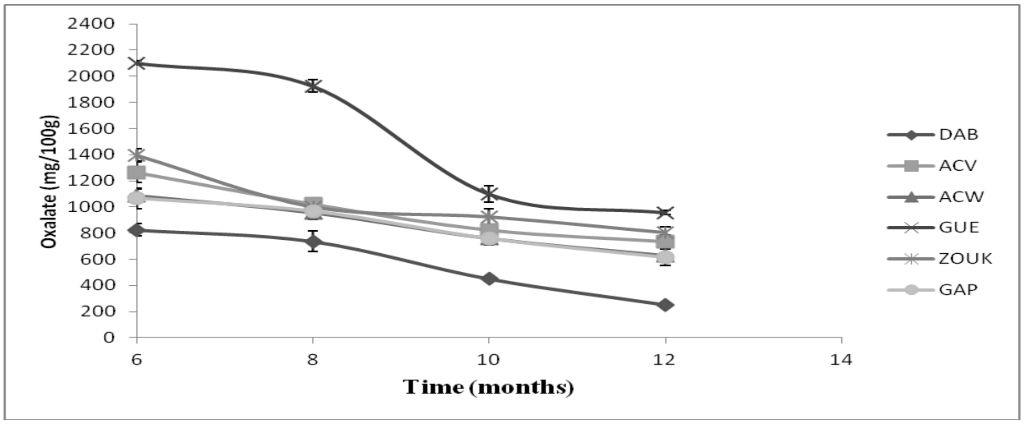


Fig.7 Evolution of oxalate content at different stages of maturity of 6 taro (*Colocasia esculenta*) varieties (g/100 g DW). DAB (*Dabehou*); ACW (*White achiahou*); ACV (*Violet achiahou*); GAP (*Gagne pôtè*); GUE (*Guèdèguè*) and ZOUK (*Zoukoudjèrè*)



However, manganese increased until the 10th month and remained constant up to 12th month for DAB, ACW and GAP while ACV, GUE and ZOUK drops up to the 12th month after the peak. The highest manganese contents observed at 10 months vary from 0.81 ± 0.01 (ACV) to 11.79 ± 0.49 mg/Kg (DAB). Iron content increased until the 10th month for all varieties before to remains constant for ACW and GAP and to decrease for DAB, ACV, GUE and ZOUK until the 12th month while for zinc, a significant increase was noted up to the 12th month for all variety except GUE and ZOUK which after 10 months, remained constant. At 10 months, the highest iron contents vary from 7.89 ± 0.00 (ZOUK) to 39.58 ± 1.22 mg/Kg (ACV). However, DAB, ACV, ACW and GAP recorded the high Zn contents at 12 months of maturity with the highest contents including 7.68 ± 0.50 (ACV) and 23.9 ± 1.17 mg/Kg (ACW) while for GUE (3.81 ± 0.11 mg/Kg) and ZOUK (4.49 ± 0.33 mg/Kg), the high Zn contents were observed at 10 months of maturity. Thus, based on minerals, the optimal maturity of these six varieties of Ivorian taro was observed at 10 months. These observations corroborate those of Himeda *et al.*, (2012) who reported that the maximum values of minerals (K, Ca, Mg, Mn, Fe, Cu and Zn) of taro *Sosso* was fund at the growth period end (10th month). However, the investigation of Trèche, and Agbor-Egbe (1996) on two species of yam showed that the tubers maturity degree involves a reduction of certain minerals (Zn, Ca, Mg and Fe). The variation of minerals according to the maturity stage between the various tubers suggests the varied metabolism of these tubers. These Ivorian taros contained relatively high rate of potassium, calcium and magnesium and low rate of sodium, zinc and manganese compared to those of Himeda *et al.*, (2012). Changes in the mineral profile of taro can be explained by different factors, including genotypic variability in absorption of minerals from soil (Vadivel and Janardhanan, 2001), genetic factors, the environment (temperature and moisture), effect of fertilizers on metallic composition of plants and levels of soil salinity (Tchumou *et al.*, 2015). Minerals are inorganic elements, which play very important roles in human metabolism. Deficiencies of these minerals can lead to metabolic disorders and organ damage, leading to acute and chronic disease and ultimately death (Gorinstein *et al.*, 2001). These taros provide various minerals that can fully or partially cover the daily requirements recommended for pregnant or breastfeeding women, the elderly and children (Sinh *et al.,* 2017). The minerals play various significant biological roles. So, Calcium and magnesium are essential for the body growth and maintenance. Iron plays numerous biochemical roles in the body, including oxygen blinding in hemoglobin and acting as an important catalytic center in many enzymes as the cytochrome oxidase (Geisler and Power, 2005). While zinc contributes to the growth, development and maintenance of immune function (Yao *et al.,* 2019).

Functional properties

The water absorption capacity (Figure 4) and the water solubility index (Figure 5) increase significantly (P < 0,05) during maturation until the 10^{th} month then remain constant or decrease. However, the highest values observed at the 10^{th} month were from 374.02 ± 18.25 and 28.25 ± 0.71% (DAB), 362.62 ± 18.28 and 27.75 ± 0.35% (ACV), 351.55 ± 7.51 and 27.25 ± 1.06% (ACW), 351.21 ± 12.29 and 27.75 ± 0.35% (GAP), 300.34 ± 4.81 and 26.50 ± 0.00% (GUE) and 349.67 ± 4.71 and 25.50 ± 0.71% (ZOUK) respectively for water absorption capacity (WAC) and water solubility index (WSI). This study revealed a positive correlation of WAC with WSI. The WAC increase is in conformity with the findings of Himeda *et al.,* (2012) in the taro *Sosso*. These results indicate that the tubers store more hydrophilic constituents during the maturation. The WAC of these Ivorian taros cannot be attributed to proteins as indicated by Amon *et al.,* (2011) but rather to their starch rates because the variation of WAC as well as those of starch rates evolves in the same order. So, the hypothesis according to which the WAC also depends to the starch content was previously justified. The WSI increase was already recorded on the taro *Sosso* as affected by state of maturity (Himeda *et al.,* 2012). So, the WSI increase was attributed to the exposure of the hydrophilic groupings of the amylose molecules which increase with the starch during the maturation. Thereby, the constant or decrease after 10 months of the WAC and WSI could be due to the decrease of starch after 10 months. Thus, the optimal WAC and WSI recorded at the 10^{th} month showed that the best maturity stage of these taros investigated is observed at 10 month of maturity. The range of WAC observed for the flour from these taros is higher compared to those of flours from wheat (*Aestium triticium*) (130.70% and taro cultivated in Hawaii (150-180%). But, it is lower compared to those of flours from taro cultivated in Cameroon (375 g/100 g) and Tchad (374.86 g/100 g) (Ikpeme *et al.,* 2010; Njintang *et al.,* 2007). This variation could be due to the organization degree difference of the hydroxyl groups to form connections hydrogens and covalent between the amylopectin and amylose chains, but it could be also due to the variety and the differences in the analytical methods used by these authors who did not consider the soluble fraction of the flour (Himeda *et al.,* 2012).

Anti-nutritional factors

A significant increase was noted in phytate contents from 6 to 10 months of maturity before decreasing to the 12^{th} month for ACW, GAP, GUE and ZOUK while DAB and ACV increased until the 8th months and declined to the 12th (Figure 6). This contents varies from 825 ± 46.67 to 253 ± 15.56 mg/100 g, 1265 ± 77.78 to 737 ± 46.68 mg/100 g, 1089 ± 46.69 to 627 ± 15.57 mg/100 g, 1067 ± 77.79 to 616 ± 62.22 mg/100 g, 2101 ± 15.56 to 957 ± 15.57 mg/100 g and 1397 ± 46.68 to 803 ± 46.68 mg/100 g DW respectively for DAB, ACV, ACW, GAP, GUE and ZOUK. The phytate rates increase could be explained by the phytates accumulation in the phosphorus form in tuber (Loewus, 2002). During the development, the phytic acid is deposited in the organelles Tchumou *et al.,* (2015). Their declining after 10 months shows that these tubers are mature at this state of maturity. Indeed, beyond of this maturity stage, the tuber enters in a senescence time leading to the cellular disorganization and death and thereby the loss of certain elements (Manner and Taylor, 2010). The phytate rates of these Ivorian taros (17.51 to 38.78 mg/100 g DW) are lower than those of the yam *Dioscorea alata* (58.6 to 198 mg/100 g of dry matter) (Tchumou *et al.*, 2015). In contrast to phytate, oxalate content decreased during maturation (6-12th months) for all varieties (Figure 7). However, for all maturity stages GUE containing the highest oxalate content and DAB the lowest one. This oxalate decrease would be related to the calcium increase. Indeed, logically, while the calcium increases with the maturity degree, the oxalates should decrease (Contreras-Padilla *et al.*, 2011). Also**,** during the earlier stage of the growing, there is a fast accumulation of oxalates followed by a reduction at the maturation end (Tchumou *et al.*, 2015). However, our results disagree with those obtained by Himeda *et al.*, (2012) which showed an increase of oxalates content during maturation. So, this contradiction shows that the oxalates content during the growing is influenced by other parameters such as the plant needs during the growth and to the seasonal and environmental conditions (Contreras-Padilla *et al.*, 2011). High oxalate content in plants affects negatively the food nutritional quality and thereby causes deleterious effects on digestibility (Adeola *et al.*, 2014). Indeed, oxalate forms complexes with essential minerals, making minerals unavailable to the body. Anti-nutritional compunds are naturel substances that interfere with the bioavailability of nutrients, inhibiting their absorption into the gastrointestinal tract. Phytates and oxalates are among those anti-nutritional compounds that chelate some minerals by forming insoluble complexes with divalent cations and reduce their absorption (Yao *et al.*, 2019). Thus, the consumption of our taros with the loss of oxalate content at the maturity (2101-957 mg/100 g; 6th-12th months) would be without major risk because the oxalate lethal dose in a food is between 2000 and 5000 mg/100 g (Agiang *et al.*, 2010).

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