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Research Article

Partial Study of Yam Tuber (*Dioscorea* spp.) Parts during the Growth Period

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Abstract: Growing gradient into longitudinal axis of yam tuber was study through starch properties and nutritional composition of tuber parts (proximal, median and distal) during the tuberization. Two varieties of the complex *D. cayenensis-rotundata* (kangba and kponan) were used. Clarity, swelling and solubility, flow behavior and syneresis of starch and protein content, alcohol-soluble sugars of the flour were studies. The ash assessed by microanalysis. Starch clarity of tuber parts increased during the growth period. The proximal (56±2.06%) and median (54.5±1.09%) parts exhibited high clarity than the distal (48.2±2.56%) one. At earlier stage of tuberization, the viscosity ratio of tuber parts (var. Kponan) was weak. This indicates the possibility to use it as thickening agent in shearing sauce. Water loss decreased during the growth period for the three tuber parts. It was the same behavior for the swelling power. Concerning the nutritional composition of the flour, amount of protein did not influenced by the degree of tuber maturity. Alcohol-soluble sugars were higher at earlier stage of tuberization than at maturity of the tuber. Mineral content was appreciable at maturity than at beginning of the tuberization. The extent mineral according to their amount was: K, P, Mg and S. Starch properties such as clarity, syneresis and swelling were improved at maturity of the tuber. It was more for the proximal and median parts than the distal one. Yam tuber content a appreciable amount of protein and mineral at maturity.

Keywords: Flour, parts, period, starch

INTRODUCTION

Yams (*Dioscorea* spp.) are voluble plant belonging to the monocotyledons class with more than 600 species identified in inter and subtropical areas of the world. Some of them are used for edible products and those for precursory of pharmaceutical drug. In spite of the important number of yams species, only ten serve as a primary staple food. The pharmaceutical used concerning the wild yams. The main species of the genus *Dioscorea* utilized for pharmaceutical purposes are from Central America (*D. composita* Hemsl., *D. floribunda* Mart. and Gal.and *D. mexicana* Guillem) and from northern South America (*D. trifida* L.) (Chu and Figueiredo, 2002).

The world production of yam is widely dominated by west Africa with more than 96% (FAO, 2009). This high production is destined for human consumption. In this region of Africa particularly in Ivory Cost, yam has a cultural value and an integral parts of the population manners. The precocious specie of *Dioscorea cayenensi-rotundata*, cultuvar kponan is widely used for the ritual ceremony. It meets the assent of the population for its good taste. The second variety, kangba is a late yam specially appreciated by the oldness men for its taste bitter. The importance of yam as staple foods is due to its starch content and technological aptitude favorable for traditional feed.

Yam starch properties have been investigated by several studies (Rasper and Coursey, 1967; Emiola and Delarosa, 1981; Farhat *et al*., 1999; Amani *et al*., 2004, 2005). The two varieties: kangba and kponan starch have been with those of Ivory Coast. These yams could be classified. According to the macromolecular characteristics, yam starch indicates three classes: *D. alata* and *D. cayenensis-rotundata*, which have large starch granules, high amylose content, high intrinsic and apparent viscosities and low gelatinization enthalpy; the second class, including all *D. esculenta* cultivars, is characterized by small starch granules, low intrinsic and apparent viscosities and high gelatinization enthalpy; the third class, represented by *D. dumetorum* cultivars, has properties close to those of *D. esculenta* and 100% A-type crystallinity (Sabaté *et al*., 2003).

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These investigations have generally being done on the whole tuber and at maturity.

The complexity of yam tuber led some authors to study its polarity along the longitudinal axis. The results showed a difference on the granule size distribution (Degras, 1986; Degbeu *et al*., 2008) and yam parenchyma along the longitudinal axis (Trouslot, 1985). Also the growing area of the tuber is localizing in the distal part. The existence of the growth gradient could mean the variability of some properties in the tuber. The firmness of yam tissue, dry matter contents and starch content was higher in the proximal and median parts than distal section. The proximal and median parts are good wonderful cook than the distal one (Brunnschweiler, 2004). Also the growth gradient in the tuber could have as effect, irregularity on degree maturity in longitudinal axis at harvested time.

In the current study, we hypothesized that chemical composition of the tuber and starch properties could be influenced by the variations in the tuber above-mentioned. Therefore, the aim of this investigation was to valorize yam tuber for industrial use and human consumption for its starch property and nutritional compounds. This study will be carried out on the flour and starch isolated from the proximal, middle and distal sections of yam tuber during the tuberization 07747475.

MATERIAL AND METHODS

Materials: Two varieties of *Dioscorea cayenensis-rotundata*: kponan (precocious variety at two harvest time) and kangba (late variety with one harvest time) were cultivated in experiment farm of Abobo-adjamé University (Abidjan, Côte d'Ivoire). The field experiment was conducted in 2007, 2008 and 2009. Tuber pieces about 102 g to 754 g for kangba variety and 138 g to 986 g for kponan variety were planted in nursery gardener sachet (size 40 cm×40 cm). The seed of var kponan was formed by the second harvest tuber that was essentially the head of tuber. The relative high weight of the seed and its variability respects the farmer practice. As for var kangba, the seed was a whole tuber that can be divided to obtain a sample at weak weights. The nursery gardener sachet has been filled up with the land of forest and enriched with droppings then arranged (1 m×0.5 m). The plot of 625 m^2 was submitted to the climate of bass cost. The watering has been done what is necessary. Randomized block design with three replications was used for the experiment. The tubers were harvested randomly at 16, 18, 20, 22, 24 and 26 weeks after planting date. After harvesting, the tubers (five) were measured and divided into three equal sections (proximal, middle and distal) (Degbeu *et al*., 2008). Each batch of tuber parts was subjected to flour and starch extraction.

Starch isolation and flour preparation: The starches were purified according to a previously described procedure by Amani (1994). Tubers and roots were peeled and immediately cut into small pieces. The freshly cut pieces were suspended in distilled water containing 0.1% (w/v) sodium meta bisulphite. The material was crushed in a Warring blender (Moulinex, Lyon, France) and suspended in a large excess of distilled water containing 4% NaCl. The slurry was filtered through a 100 µm sieve. The starch was allowed to settle and the supernatant decanted off. This process was repeated four times and the recovered white prime starch was then oven-dried at 45°C for two days.

As for flour preparation, after peeled and washed as above mentioned, yam tuber was cut into small lamella, oven-dried at 50°C for 48 h then ground. The moisture content of samples was determined by oven-drying for 24 h at 105°C.

Swelling power and solubility: In order to study the influence of tuber maturity on the swelling power and solubility of starch, one temperature (95°C) was used. The starch suspension of 1% (w/w) was heated for 30 min over the pasting temperature (95°C) by immersion in a water bath with gentle stirring. After cooling for 15 min at room temperature, it was centrifuged (SIGMA 3-16P, Germany) at 5000 rpm for 30 min. the supernatant was immediately separated from the sediment, both were oven-dried (105°C for 24 h), weighed. The swelling power and solubility was determined according to Leach *et al*. (1959).

Paste clarity: Paste clarity was determined according to the method described by Craig *et al*. (1989). Transmittance was determined for 1% (w/w) of yam starch dispersion, employing a spectrophotometer (MILTON Roy, United States).

Gels syneresis: Gel syneresis has been measured after three weeks of refrigeration. A 4% (w/w, dry weight basis) gel was heated with gentle stirring (Agimatic-M Staufen, Germany) for 15 min (Pingault, 1995). The gel was immediately distributed into centrifuge tubes at a rate of 10±0.5 g per tube. The tubes were then kept into a freezer at 4°C for three weeks. After this time, four tubes of each sample were thawed at room temperature for 60±5 min and then centrifuged (SIGMA 3-16P, Germany) at 5000 rpm for 30 min. The syneresis rate was calculated as the weight of removal water divided by the weight of the original gel.

Flow measurement: The paste flow has being analysis with a rheoviscosimeter (Brookfield DV-III ULTRA programmable, model RV, Chicago, United States). The test was done according to the instruction of apparatus manual giving by Brookfield. Starch paste (4%, w/w, dry weight basis) was prepared according to the method previously described (Pingault, 1995). After cooling at 30°C, the gel was placed in a 600 mL low form griffin beaker and kept at this temperature by a water bath (Grant, UK). The flow test was performed at varying speed programmed, (1 rpm to 200 rpm). The time of running at each speed was 30 s. The disc spindle used was dimensioned as follow; diameter

34.69 mm, length 133 mm and thickness 1.65 mm. According to running instruction, the spindle was immersed to the mark (49.21 mm). To study the stability of the gel during the test, the viscosity ratio has being determined. All rheological measurements were carried out in triplicate and the data obtained directly from the key pad:

Viscosity ratio = Vx/V10x

where,
Vx = The viscosity reading at speed x
V10x = The one at speed 10x

Nutritional compound of the flour: Crude protein was calculated from nitrogen (Nx6.25) obtained using the Kjeldahl method described by AOAC (1990). Alcohol-soluble sugars (glucose, fructose and sucrose) were determined with enzymatic kit method (Megazyme, Assay Procedure K-SUFRG 12/05, Ireland). Nutritional composition has been determined by ash analysis. Ash was obtained by incineration of yam flour into a furnace mitten at 550°C for four houses. The test was carried out by microanalysis in energy selection, coupled to a scanning electron microscopy (Zeiss Supra 40 VP, Germany). The apparatus used a system EDS with a resolution of Si detector was 133 eV for the line Kα of the cobalt at 20 Kv. The period of analysis was 120 s and the data was automatically treated by a processor INCA drycool (Oxford instrument).

Statistical analysis: The software SPSS 16.0 was used for the statistical analysis. The statistical study has been done into two dimensions. ANOVA, to compare the means of tuber parts at each period with Duncan test at $p \leq 0.05$ to specify significant difference between the three parts. The correlation of Person was used to evaluate the effect of the growing period on the proprieties of tubers parts. The r value will be negative when the variable decreased and positive for an increased value.

RESULTS

During results analysis, the correlation table will be presented at the end of this section. But the values of r will be cited for each property.

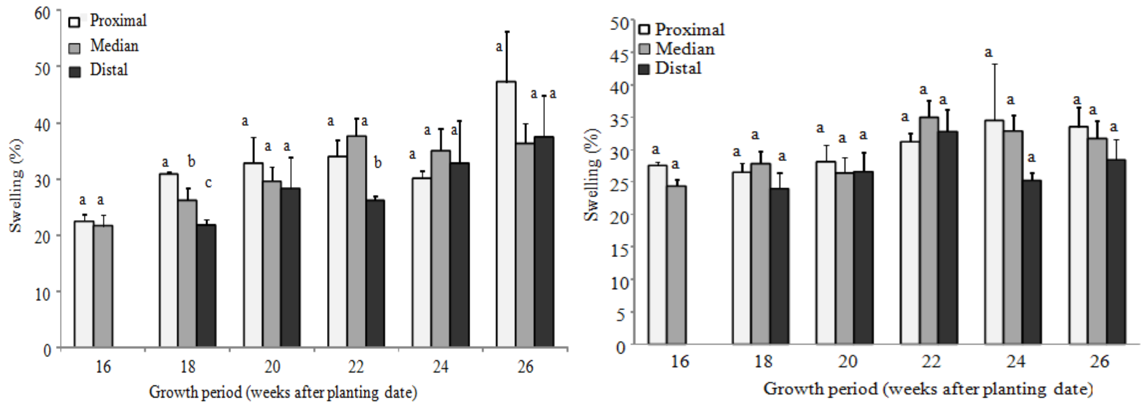
Swelling and solubility: The swelling power of starch granule increased during the tuber maturation whatever the portion and variety studies (Fig. 1a and b).

For Kponan variety, (Fig. 1a), there is not significant variation between the three parts of the tuber during the tuber growth except 18 and 22 weeks where the proximal and median parts absorbed more water ($p<0.05$) than the distal one. The maximum absorption was observed at 26 weeks for the proximal and distal parts and 22 weeks for median one. Evolution of swelling power was positively correlated to growing period ($p<0.01$). The r value of Person was respectively 0.742, 0.843 and 0.731 for proximal, median and distal parts (Table 1).

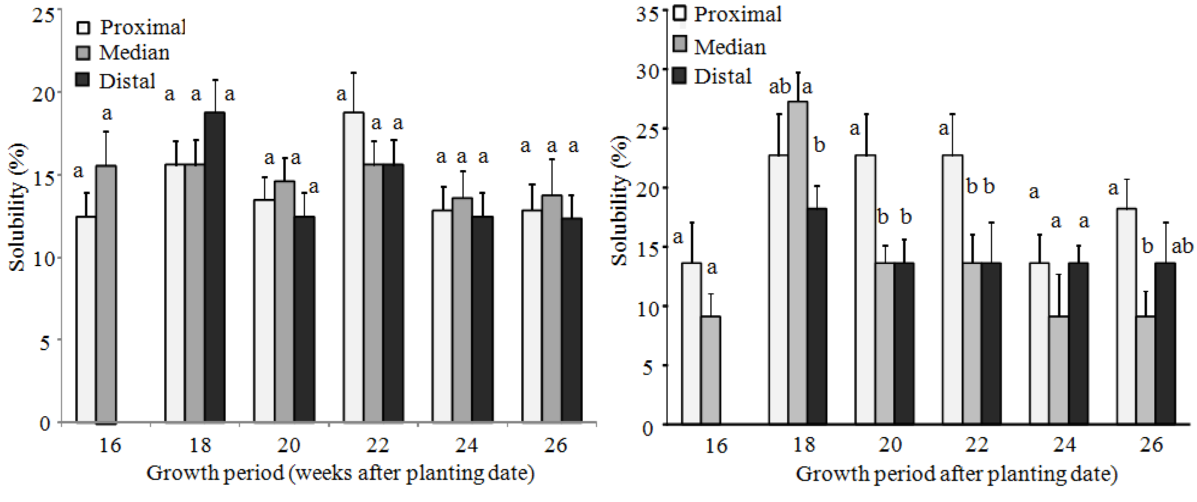
Concerning var. kangba (Fig. 1b), variations between tuber section were not significant ($p<0.05$). Increased swelling of the three parts was important at 22 weeks. For this variety, swelling power was weakly correlated (r = 0.6) to the growth period only for the proximal section ($p<0.05$).

The starch solubility of tuber sections decreased generally during the growing period whatever the variety (Fig. 1c and d). This evolution was negatively correlated for the median and distal parts of each variety. The r value was respectively -0.629 and -0.657 for median and distal parts of var. kponan, -0.592 and -0.566 for the same part of kangba variety. High solubility was observed at 18 weeks and 18 to 22 weeks for respectively for median and distal parts of var. kangba ($p<0.05$).

Paste clarity: Starch clarity of three tuber parts increased with the maturity period for the two varieties (Fig. 2). Starch of var. kponan reached a maximum clarity at 22 weeks after the planting date for all tuber section. Clarity of proximal and median parts was generally higher than the distal one at weeks 18 and 22



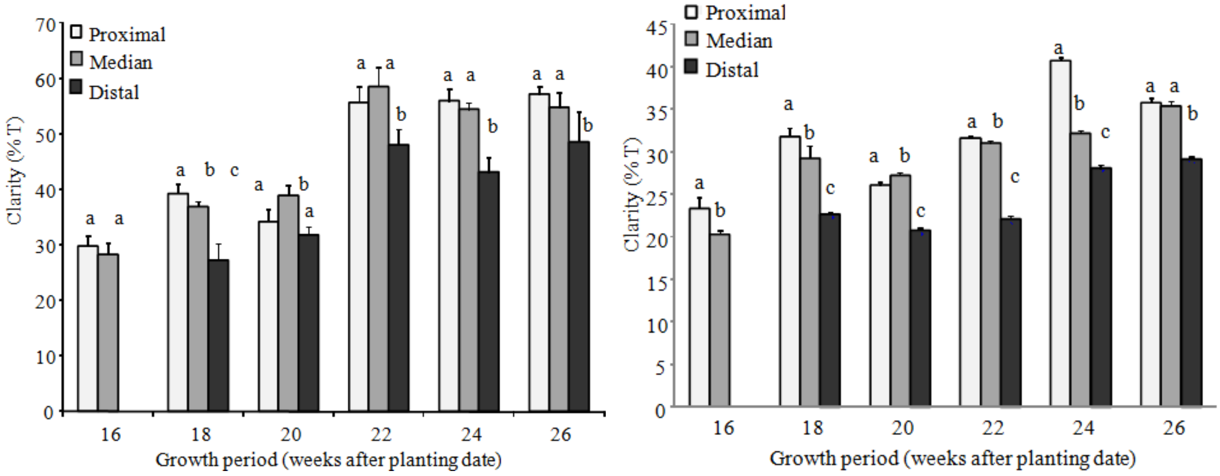
(a) (b)



(c)

(d)

Fig. 1: Swelling (a, b) and solubility (c, d) Patterns of yam starch from three parts of the tuber at 95°C during the growth period. (a, c) var. kponan, (b, d) var. kangba. Histogram bars with different letters are significantly different at p<0.05 for each period



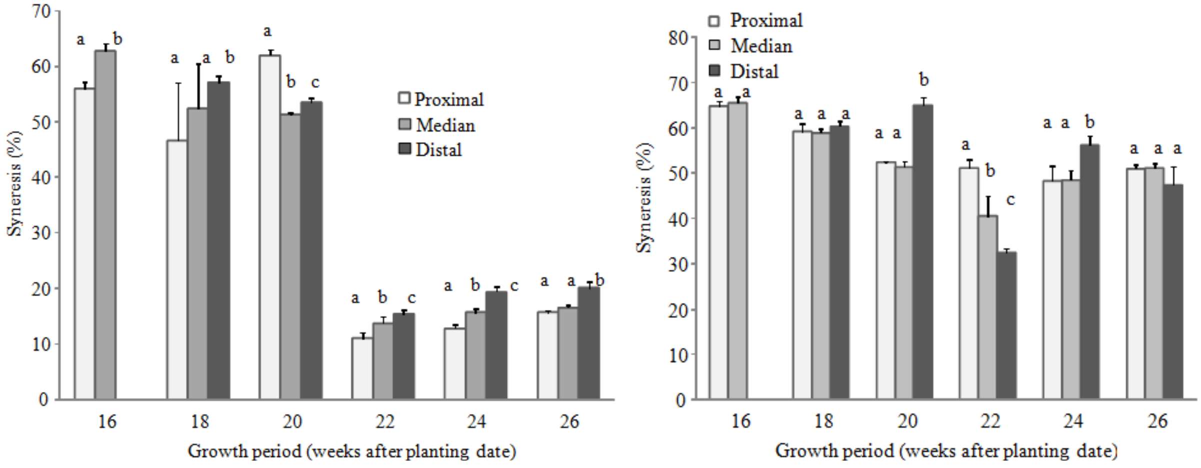
(a)

(b)

Fig. 2: Evolution of yam starch clarity from three parts of the tuber during the tuberization. a) var. Kponan, b) var kangba. Histogram bars with different letters are significantly different at p<0.05 for each period

Table 1: Correlation of yam tuber parts to the growth period. The r-value of person of each parameter study has been presented. More the r is near to 1, more the correlation is important

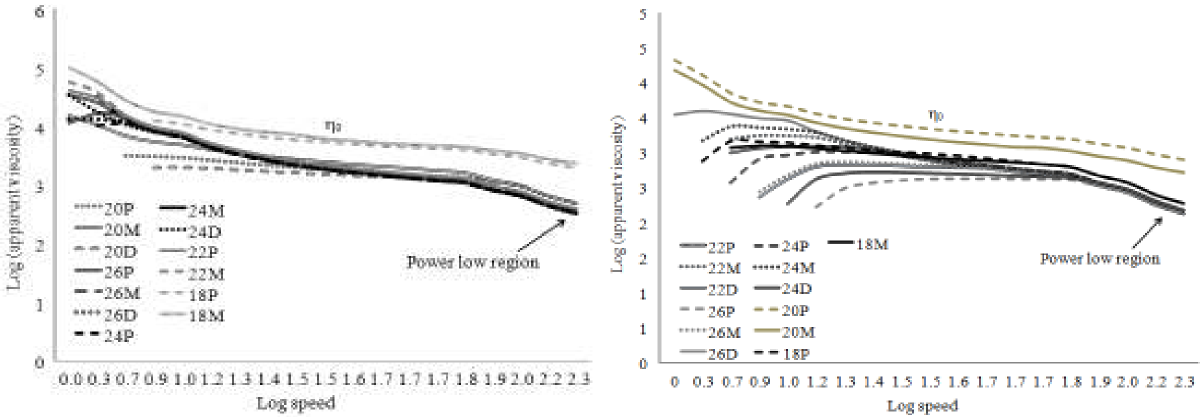
Varieties	Kponan			Kangba		
Tuber parts/variables	Proximal	Median	Distal	Proximal	Median	Distal
Swelling	0.742	0.843	0.731	0.600	0.410	0.338
Solubility	-0.025	-0.629	-0.657	-0.207	-0.592	-0.566
Clarity	0.889	0.878	0.826	0.794	0.903	0.843
Syneresis	-0.742	-0.478	-0.837	-0.851	-0.683	-0.424
Viscosity ratio	0.853	0.874	0.941	-0.191	0.269	0.883
Protein	-0.213	-0.87	-0.543	0.392	0.122	-0.242
Glucose	-0.740	-0.423	-0.376	-0.970	-0.929	-0.975
Frucose	-0.901	-0.919	-0.877	-0.933	-0.950	-0.834
Surose	-0.952	-0.906	-0.973	-0.979	-0.991	-0.993



(a)

(b)

Fig. 3: Gel syneresis of yam starch from the three parts of the tuber as function growth period, a) var. kangba. Histogram bars with different letters are significantly different at $p<0.05$ for each period b) var. kponan



(a)

(b)

Fig. 4: Flow behavior of yam starch from three parts of the tuber during its growing, a) var. kangba. Histogram bars with different letters are significantly different at $p<0.05$ for each period, b) var. kponan,

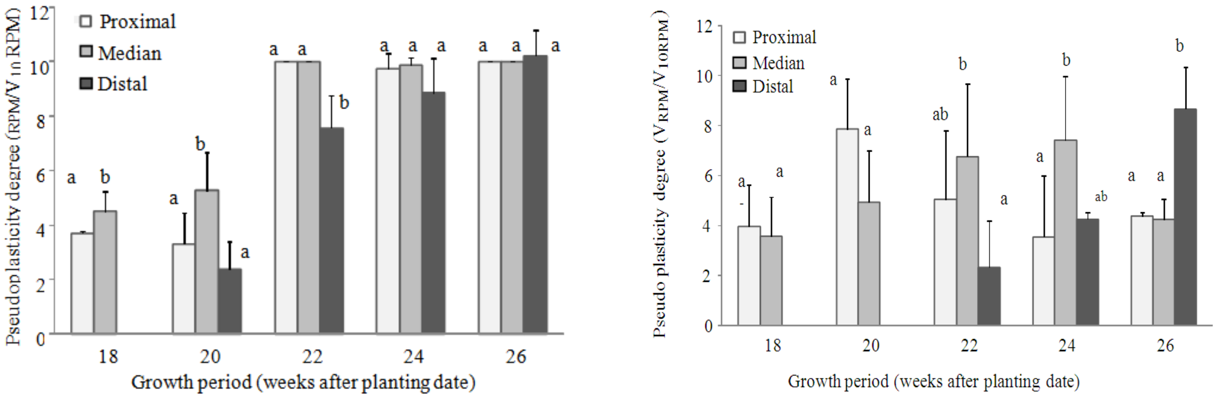
to 26 ($p<0.05$). Increasing of starch clarity was positively correlated to the maturity period for the three portions ($p<0.01$). The correlate coefficient of Pearson was 0.889, 0.878 and 0.826 for respectively proximal, median and distal parts of the tuber.

Concerning var. kangba (Fig. 2), starch clarity of proximal section was higher than the median and distal part at weeks 18 to 24 ($p<0.05$). At week 26, proximal and median parts showed the same clarity high than the distal one ($p<0.05$). The maximum clarity was reached at 24 weeks after planting date for the proximal part and week 26 for median and distal ones. Increasing starch clarity was positively correlated to the maturity period ($p<0.01$) for three sections: proximal ($r = 0.794$), median ($r = 0.903$) and distal ($r = 0.843$).

Gel syneresis: Amount of water loss by the gel decreased during the tuberization for the two varieties studies and three tuber parts (Fig. 3). High value of syneresis was observed at 16 to 20 weeks for each tuber part of var. kponan with a variation from 45 % to 65 %. Beyond this period, gel syneresis was weak for all the three parts of tuber. This decreasing was negatively correlated to the growth period for the distal ($r = -0.837$) and proximal ($r = -0.742$) parts of var. kponan. From week 22 to 26, water loss decreased from the distal part toward the two other ones.

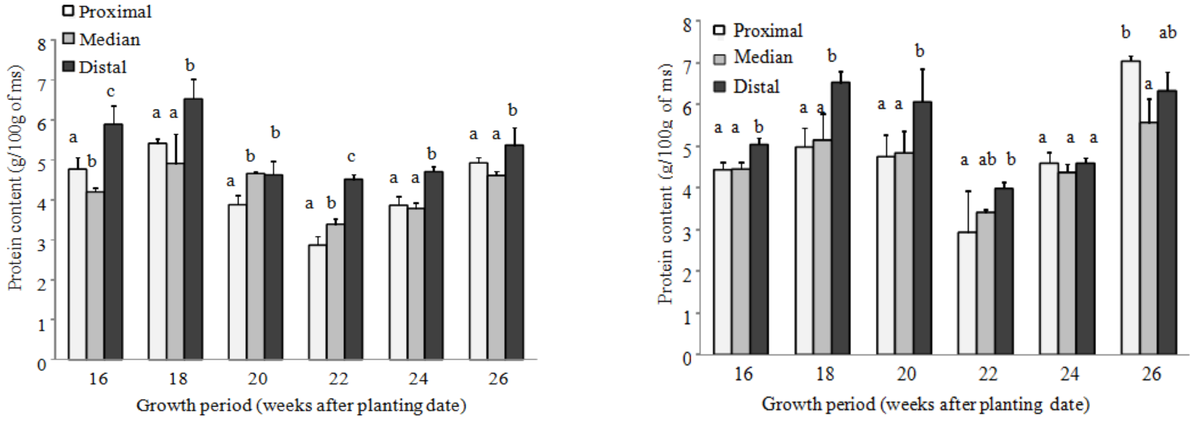
Concerning var. kangba, gel syneresis decreased weakly during tuber maturity (Fig. 3). The maximum value was observed at beginning of the tuberization and week 20 for respectively proximal, median and distal parts ($p<0.05$). Only the proximal ($r = -0.851$) and median ($r = -0.683$) parts showed a negative correlation between growth period and syneresis evolution.

Flow measurement: Starch gel flow of tuber parts exhibited generally the same behaviour during shearing



(a) (b)

Fig. 5: Viscosity ratio of yam starch from three parts of the tuber during its growing. a) var. kponan, b) var. kangba. Histogram bars with different letters are significantly different at $p<0.05$ for each period



(a) (b)

Fig. 6: Protein content of three parts of the tuber during the growth period, b) var. kangba. Histogram bars with different letters are significantly different at $p<0.05$ for each period, a) var. kponan,

(Fig. 4). The viscosity decreased when the rotational speed increased. But some differences have being observed at beginning of the test. The viscosity increased at low speed (0.3 to 1.3 rpm) for some samples. They presented a curve into "U" inverted.

For var kponan, only (Fig. 4a) the proximal and median parts of 24 weeks after planting date exhibited this form. This phenomenon was observed for all samples of kangba variety except the proximal and median section of 20 weeks after planting date (Fig. 4b). In any case starch dispersion of the three parts of the tuber presented three-stage viscous response when shearing. At low speeds (0.3 to 1.3 rpm), the viscosity increased or decreased according to the sample. Over the first stage (1.3 to 1.8 rpm), viscosity was stable. The last stage was characterized by a high decrease of the viscosity.

Viscosity ratio: During the shearing, starch paste viscosity of tuber parts decreased. The viscosity ratio has been measured to assess extent of this fall. In other words it indicates the stability of the paste during the shearing. It increased during the tuber maturity for the three sections of var. kponan (Fig. 5a). The same behavior has being observed for the distal and median parts of var. kangba up to 24 weeks after planting date (Fig. 5b). For the proximal part of this variety, viscosity ratio decreased.

Concerning var. kponan a maximum of viscosity ratio was reached at 22 weeks after the planting date. Increasing of viscosity ratio was positively correlated to the maturity period ($p<0.01$). The r value of Pearson was 0.853, 0.874 and 0.941 for respectively proximal, median and distal parts of the tuber. The distal section of kangba variety showed only a positive correlation between the viscosity ratio and the maturity period (r = 0.883).

Protein content: The crude protein of tuber sections varied weakly during the maturity period with a decreasing at 20 to 24 weeks after the planting date (Fig. 6). Protein content of the distal part of var. kponan

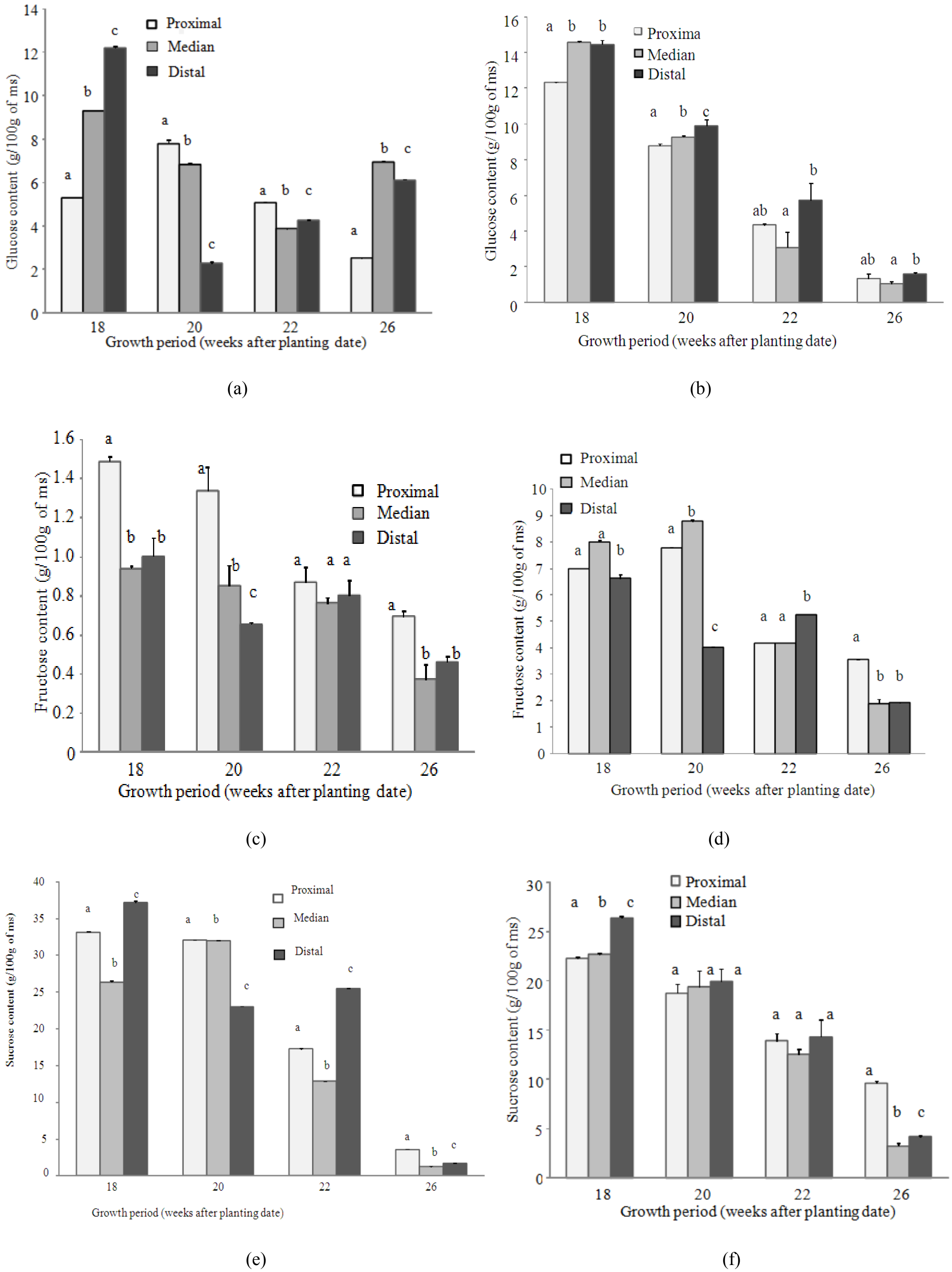


Fig. 7: Alcohol-soluble sugars of three parts of the tuber during its maturity: a, b) glucose, c, d) fructose, e, f) sucrose, a, c e) var. kponan, b, d, f) var. kangba. Histogram bars with different letters are significantly different at $p<0.05$ for each period

was higher than the two over parts ($p<0.05$) with a tendency to decreasing during the tuber maturity. It was negatively correlated to the growth period (r = -0.543). But at week 26, it remained high than the proximal and distal parts.

For var. kangba, the distal part (Fig. 6) showed a high amount of protein than the two other ones at beginning of the tuberization (16 to 20 weeks). At week 26, the proximal and distal parts exhibited the same amount of protein weakly higher than the distal content ($p<0.05$).

Alcohol-soluble sugars: The glucose content of tuber sections decreased during the maturity period (Fig. 7). For var. kponan, a relatively increased of glucose content was observed for the distal parts at 20 to 26 weeks after planting date (Fig. 7a). His amount was important with the median one than the proximal week 26 ($p<0.05$). Glucose content behavior was negatively correlated (r = -0.740) to the degree of maturity only for the proximal part of tuber.

Concerning var kangba, the decreasing of glucose content was correlated to the growth period for the three parts of tuber. The r value was around -0.958. The median and distal parts showed a higher amount of glucose than the proximal portion during the tuber growth except weeks 22 and 26 (Fig. 7b).

The fructose content tuber parts decreased during the growth period (Fig. 7). As for var. kponan (Fig. 7c), proximal and median parts contained high amount of fructose at earlier stage of tuberization. At week 26, the proximal part showed an important content than the two other parts ($p<0.05$). The decreasing of fructose content for each part was negatively correlated to the growth period.

For var. kangba (Fig. 7d), the proximal part exhibited a high content of fructose during the tuber growth except the week 22 ($p<0.05$). The decreasing of fructose content was correlated to the growth period for all tuber part.

Sucrose content of tuber parts decreased during the growth period (Fig. 7e and f) for the two varieties studies. This decreasing was negatively correlated to the degree of maturity. At week 26, the proximal part contained high amount of sucrose than the two over parts ($p<0.05$). Flour of the distal part generally showed a high content of sucrose at earlier stage of the tuberization.

Chemical composition of the ash: Mineral content of tuber parts for the two varieties could be subdivided into three groups on amount basis (Table 2).

For var. Kponan (Table 2a), the first group was characterized by their abundant concentrations (K and P). The amount of potassium did not change from one portion to an over during the growth period, except 18 and 26 weeks ($p<0.05$). At period 18, the distal and median parts showed a high content of potassium. As

Table 2: Evaluated concentration (g/100 g of dry matter) of mineral from three parts of yam tuber during the growth period

Growth period (weeks) /Mnx, parts		16	18	20	22	26
C	P	38.3 ± 7.67^{a}	58.1 ± 3.04^{c}	$39.7\pm9,49^{ab}$	40.9 ± 1^{ab}	31 ± 3.3^{a}
	M	34 ± 1.78^{a}	31.5 ± 2.55^{a}	37.3 ± 5.17^{a}	35.5 ± 4.21^{a}	49.8 ± 12.7^{bc}
	D	39.6 ± 10.6^{ab}	35.2 ± 3.5^{a}	37.6 ± 2.14^{a}	39.21 ± 2.32^{ab}	37.7 ± 6.82^{a}
	P	0.37 ± 0.06^{ab}	0.35 ± 0.02^{a}	0.7 ± 0.1^{bdc}	0.94 ± 0.12^{d}	2.47 ± 0.05^{f}
Na	M	0.39 ± 0.04^{ab}	0.48 ± 0.1^{abc}	0.73 ± 0.08^{dc}	0.75 ± 0.15^{dc}	1.47 ± 0.59^{e}
	D	0.52 ± 0.05^{abc}	0.39 ± 0.1^{ab}	0.6 ± 0.07^{abc}	0.46 ± 0.05^{bca}	3.14 ± 0.16^{g}
	P	0.25 ± 0.22^{ab}	1.09 ± 0.37^{c}	0.52 ± 0.18^{ab}	0.44 ± 0.1^{ab}	1.64 ± 0.5^{d}
Mg	M	0.25 ± 0.23^{ab}	0.25 ± 0.14^{a}	0.32 ± 0.07^{ab}	0.2 ± 0.18^{ab}	1.89 ± 0.49^{d}
	D	0.26 ± 0.11^{ab}	0.07 ± 0.12^{a}	0.65 ± 0.14^{b}	0.3 ± 0.01^{ab}	0.31 ± 0.04^{ab}
	P			0.15 ± 0.13^{ab}	0.2 ± 0.02^{a}	0.26 ± 0.08^{b}
Si	M			0.22 ± 0.13^{ab}	0.27 ± 0.02^{ab}	0.21 ± 0.03^{ab}
	D		0.3 ± 0.06^{b}		0.28 ± 0.03^{ab}	0.2 ± 0.06^{ab}
	P	6.69 ± 0.65^{a}	8.33 ± 0.47^{abe}	12.1 ± 3^{cde}	11.4 ± 0.52^{cd}	14.9 ± 0.7^{e}
P	M	14.1 ± 0.6^{de}	15.1 ± 1.28^{d}	13.8 ± 1.3^{de}	14.7 ± 1.72^{e}	10.6 ± 2.77^{bc}
	D	13.9 ± 2.09^{de}	11.5 ± 3^{cd}	13.3 ± 0.57^{cde}	6.12 ± 1.69^{a}	11 ± 1.07^{bcd}
	P	1.13 ± 0.17^{abc}	2.38 ± 0.19^{e}	2.16 ± 0.35^{de}	1.3 ± 0.14^{abc}	2.48 ± 0.23^{e}
S	M	1.34 ± 0.52^{bc}	0.92 ± 0.18^{ab}	0.92 ± 0.03^{ab}	0.79 ± 0.07^{ab}	3.82 ± 0.79^{f}
	D	0.99 ± 0.35^{ab}	0.72 ± 0.1^{a}	1.64 ± 0.11^{cd}	2.25 ± 0.33^{e}	1.06 ± 0.13^{ab}
	P		0.09 ± 0.05^{ab}	0.16 ± 0.08^{abc}	0.13 ± 0.07^{abc}	0.22 ± 0.02^{d}
Cl	M	0.13 ± 0.07^{abc}	0.09 ± 0.05^{abc}	0.1 ± 0.06^{abc}	0.08 ± 0.05^{a}	
	D	0.13 ± 0.07^{abc}				
			0.18 ± 0.09^{bc}	0.09 ± 0.03^{ab}	0.15 ± 0.02^{c}	0.24 ± 0.05^{d}
	P	53.1 ± 7.48^{b}	29.4 ± 2.51^{a}	44.3 ± 6.88^{b}	44.6 ± 1.93^{b}	46.5 ± 2.17^{b}
K	M	49.8 ± 2.32^{b}	51.7 ± 1.32^{b}	46.7 ± 4.01^{b}	47.8 ± 2.3^{b}	31.5 ± 8^{a}
	D	44.5 ± 8.44^{b}	51.6 ± 1.74^{b}	45.9 ± 1.61^{b}	51.1 ± 0.32^{b}	46.3 ± 5.7^{b}
	P	0.32 ± 0.17^{cde}	0.33 ± 0.06^{de}	0.31 ± 0.04^{bcd}	0.32 ± 0.06^{cde}	0.62 ± 0.08^{f}
Ca	M	0.19 ± 0.01^{ab}		0.13 ± 0.06^{ab}	0.21 ± 0.05^{abc}	0.42 ± 0.14^{e}
	D	0.28 ± 0.01^{bcd}	0.27 ± 0.02^{bcd}	0.28 ± 0.04^{bcd}	0.32 ± 0.06^{de}	0.37 ± 0.05^{de}
	P					
Zn	M	0.12 ± 0.02^{a}	0.25 ± 0.08^{a}	0.3 ± 0.18^{a}		
	D					

Table 2: (Continue)

Growth period(weeks) /Mnx, parts		16	18	20	22	24	26
C	P	33.9±1.02^{a}	82.7±1.42^{ef}	79.9±4.06^{de}	51.1±1.82^{c}	75.2±2.91^{d}	53.9±3.02^{bc}
	M	56.8±2.17^{c}	84.3±2.24^{ef}	85.9±2.54^{f}	54.6±3.97^{bc}	84.2±2.12^{ef}	76.5±1.26^{d}
	D	54.1±0.92^{bc}	79.2±3.19^{de}	77±4.18^{d}	54.4±5.63^{bc}	51.2±3.78^{c}	80.2±0.49^{de}
Na	P	3.41±0.53^{e}	0.13±0.03^{ab}	0.12±0.03^{ab}	0.31±0.05^{ab}	0.13±0.03^{ab}	0.36±0.05^{bc}
	M	0.34±0.03^{bc}	0.11±0.01^{ab}	0.09±0.01^{ab}	0.33±0.06^{abc}	0.12±0.01^{ab}	0.15±0.02^{ab}
	D	1.01±0.24^{d}	0.1±0.01^{ab}	0.06±0.06^{a}	0.26±0.03^{ab}	0.58±0.06^{c}	0.13±0.01^{ab}
Mg	P	1.11±0.05^{de}	0.79±0.11^{bcd}	0.68±0.11^{abc}	1.93±0.11^{f}	1.24±0.13^{e}	0.97±0.04^{cde}
	M	3.64±0.26^{g}	0.68±0.13^{abc}	0.34±0.07^{a}	2.18±0.01^{f}	0.45±0.18^{ab}	2±0.46^{f}
	D	0.98±0.3^{cde}	0.85±0.22^{bcde}	0.71±0.09^{abcd}	2.3±0.54^{f}	0.64±0.14^{abc}	0.37±0.04^{a}
Si	P	0.19±0.03^{a}	0.28±0.16^{a}	0.1±0.01^{a}	1.05±0.05^{d}	0.12±0.01^{a}	0.2±0.06^{a}
	M	0.16±0.02^{a}		0.06±0.01^{a}	0.69±0.1^{c}	0.14±0.09^{a}	0.13±0.03^{a}
	D	0.19±0.03^{a}	0.16±0.04^{a}	0.12±0.01^{a}	2.18±0.19^{e}	0.38±0.04^{b}	0.06±0.02^{a}
P	P	15.2±0.55^{g}	3.14±0.36^{ab}	3.53±0.59^{ab}	10.4±0.32^{ef}	5.67±0.56^{c}	8.52±2.41^{d}
	M	10.9±0.46^{ef}	2.91±0.42^{ab}	2.6±0.35^{ab}	10.9±0.77^{ef}	3.15±0.58^{ab}	4.88±0.7^{bc}
	D	9.87±0.41^{de}	3.68±0.49^{ab}	3.94±0.45^{ab}	10.9±2.11^{ef}	11.9±1.83^{f}	3.39±0.06^{ab}
S	P	0.93±0.21^{cde}	0.97±0.06^{def}	0.61±0.07^{abcd}	1.96±0.1^{i}	1.2±0.09^{efg}	1.5±0.09^{gh}
	M	4.18±0.25^{k}	0.86±0.25^{bcde}	0.33±0.05^{a}	2.54±0.56^{j}	0.46±0.12^{ab}	2.57±0.18^{j}
	D	1.5±0.11^{fgh}	1.16±0.25^{efg}	0.54±0.07^{abc}	1.94±0.42^{i}	1.63±0.21^{hi}	0.87±0.1^{cde}
Cl	P	0.29±0.16^{ab}	0.08±0.02^{a}	0.11±0.01^{a}	0.13±0.02^{a}	0.12±0.03^{a}	1.8±0.8^{c}
	M	0.3±0.03^{ab}	0.07±0.01^{a}	0.13±0.03^{a}	0.17±0.01^{a}	0.13±0.03^{a}	0.27±0.02^{ab}
	D	0.56±0.02^{ab}	0.07±0.01^{a}	1.4±0.58^{c}	0.25±0.11^{ab}	0.68±0.31^{b}	0.35±0.01^{ab}
K	P	44.4±0.61^{g}	12.1±1.05^{ab}	14.7±3.35^{bc}	32.2±1.23^{f}	15.8±2.14^{c}	32±1.7^{f}
	M	22.1±1.34^{d}	11±1.44^{a}	10.4±2.09^{a}	27.4±2.43^{e}	11.3±1.32^{ab}	13.1±0.31^{abc}
	D	31.6±1^{f}	14.5±2.24^{bc}	16.2±3.14^{c}	27.5±2.53^{e}	32.7±2.2^{f}	14.5±0.37^{bc}
Ca	P	0.54±0.29^{ef}		0.21±0.04^{abc}	0.61±0.03^{fg}	0.49±0.11^{ef}	0.73±0.08^{g}
	M	1.33±0.03^{h}	0.13±0.04^{ab}	0.05±0.02^{ab}	0.5±0.01^{ef}	0.07±0.02^{ab}	0.45±0.02^{e}
	D	0.4±0.08^{de}	0.18±0.01^{abc}		0.29±0.08^{cd}	0.22±0.02^{ab}	0.12±0.03^{ab}
Zn	P	0.1±0.08^{a}					
	M	0.12±0.02^{a}					
	D			0.09±0.02^{a}			
Fe	P			0.07±0.02^{a}	0.1±0.04^{a}		
	M						
	D						

a) var. kponan, b) var. kangba. Means of three parts affected of the same letter are not significantly different for each mineral and line at $p<0.05$

for P, the median and distal parts of tuber contained a high amount at weeks 16 to 20 ($p<0.05$). The general tendency was an increasing of the amount of phosphor for the proximal part. A weak decreasing was observed for the median section and no variation for the distal part ($p<0.05$) except week 22.

The second group was the minor mineral (Na, S, Mg, Cl, Ca and Si). The amount of sodium increased for tuber parts during the growth period with a maximum at week 26. The same evolution has been observed for Mg, S, Cl, Ca and Si. Mg, S and Ca content of the distal section did not change during the growth period ($p<0.05$). The last group was the trace element. Only the Zn was observed at 16, 18 and 20 weeks after planting date for the median part of the tuber.

Concerning var kangba (Table 2b), the abundant compound were K, P. their content decreased during the tuber growth in each portion of the tuber ($p<0.05$). The maximum content of K was observed at 16 and 22 weeks after the planting date for the proximal and median parts. The weeks 16 and 24 after planting date corresponded to the maximum content for the distal section of the tuber. The same evolution has being observed for the median part about the phosphor content. A high amount of P was noted at 16 and 24 weeks for the distal part. As for the proximal section, the periods 16, 22 and 26 weeks presented a high amount of phosphor ($p<0.05$).

The second group was constituted by the mineral which the amount was higher than 1 % (Mg and S) and those with less 1 % content (Na, Cl, Si and Ca). For Mg and S, amount of the median part decreased during the tuber growth period. It was high at weeks 16 to 22 after planting date for the proximal and distal parts. Beyond, it decreased ($p<0.05$). Na decreased during the maturity of the tuber for the proximal and distal parts. The same evolution for the median section about Ca content was observed. Chlorine content did not change during the tuberization except the maximum observed at weeks 26 and 20 after planting date for respectively the proximal and distal parts. Amount of Si did not change during the growth period except the maximum observed for the three sections at week 22 after the planting date.

The third group was constituted by Zn, Cu and Fe. These traces elements were observed at 16 and 20 weeks after planting date for Zn, at week 18 and 22 weeks after planting date for Cu, at weeks 20 and 22 for Fe.

DISCUSSION

Increasing of starch clarity of tuber parts during the tuberizaion has being previously published (Amani *et al*., 2008). The mean clarity ranges from 20.3±0.38%

to 58.6±3.52% was higher than those reported by these authors on yam starch. Our results were similar to cassava clarity (47 %) and waxy maize (35%) (Tetchi *et al*., 2007). The median and proximal parts generally exhibited a high clarity than the distal section of the tuber (Degbeu *et al*., 2008). Increasing of starch clarity could be due to the degree of maturity of starch granule. In fact, at earlier stage of tuberization, starch granule was more brittle and has tendency to make soluble, so the gel obtained become opaque. While at maturity, starch granules swell more and solubilize weakly. Its let oneself traversed by the light and gave a clearly gel. This phenomenon could explain swelling and solubility behavior of starch from tuber parts during the growth period. The values of swelling (21.8±1.1 to 47.32±8.82) and solubility (12.35±1.43% to 22.73±3.43%) obtained at maturity concurred to those published (Zuluaga *et al*., 2007) on the complex *D.cayenensis-rotundata* (36.6±0.6 for swelling and 17.7±0.2% of solubility). Also the swelling and solubility evolution during the tuber growth could explain the weak syneresis of the gel at maturity. In fact at early harvest time, the high solubilzation of starch granule means to an important expulsion of water from the gel during cooling period at 4°C. According to Huang *et al*. (2006), immature yam starch past was thermo-stable during heating but has a high setback after cooling, which might result in a tendency towards high retrogradation.

Gel flow behavior of three parts of the tuber during shearing was characteristic of shear thinning fluids for all harvested period. The viscosity decreased when the rotational speed increased. This result has being observed on var. florido (proximal and distal parts) and krenglè (Brunnschweiler *et al*., 2005). The three stages of the curve could be interpreted as follow: At low speeds (stage I), the viscosity increased as the shear thickening fluids. At second part of the curve, the viscosity was relatively stable characteristic of Newtonian fluids with a constant zero-shear viscosity (η_0). Stage 3 corresponding to a power law region, a transition from Newtonian to pseudoplastic behavior. The viscosity variation observed could due to a degree of rearrangement of the polymer chain (Rao, 1998). Rearrangement was respectively for the three stage little, mean and extent.

Viscosity ratio of the three parts of the tuber was extent at maturity of starch granule. This could due to the heterogeneity in the gel composed by swollen granules, fragment of swollen granules (dispersed phase) and amylose (continued phase). In fact, immature starch granule was less resistant and solubilized more, so the gel obtained was homogeneous. The cohesion between the particles of this medium was more stable during the shearing contrary to the heterogeneous one. In the second case, there was an interaction between different particulars more sensible to the shearing (Morris, 1998; Rao, 1998).

For the nutritional composition of yam flour, protein content did not influenced by the degree of tuber maturity, except the distal part of var. kponan. Its content decreased significantly during the growth period, but remained high compared to the tow over parts. This important content of protein could be due to the residual activity located in the apex, responsible to the tuber growth (Trouslot, 1985). This activity was influenced by the nitrogen content in the growth medium. High concentration of nitrogen was favorable to yielding larger microtuber (Dobranszki *et al*., 2008). The distal part could be played the role of front-door for almost nutriments in the tuber and the two other parts an accumulation zone. This hypothesis justified the high content in mineral of the proximal and median parts compared to the distal one for the two varieties except sodium content of var. kponan. Protein average obtained was in accordance of the range reported in the literature (Behera *et al*., 2009; Ojokoh and Gabriel, 2010; Ukpabi, 2010) on yam flour (6.11 to 9.67%) at maturity. Simple sugars decreased during the tuber growth. This high content at beginning of the tuberization could due to the extent of physiological activity responsible of the tuber growing and starch accumulation. During starch formation, the sucrose was transported from the chloroplast to amyloplasts of storage organs, where it is incorporated into storage starch (Davis *et al*., 2003). This could justify the high content of simple sugars during the forte growing period (16 to 22 weeks after planting date) of the tuber. Average of simple sugars was generally higher than those published by Kouassi *et al*. (2010) (1.05 to 2.02% of sucrose and 0.11 and 0.2% of glucose and fructose) on whole yam tuber at maturity. Mineral content was generally high at maturity of the tuber; this could be resulted to the phenomenon of bioaccumulation. These results showed the wealth of mineral compound into yam tuber. A similar result has been obtained by Chen and Pan (2001) on 22 varieties of *D. alata* harvested at maturity.

CONCLUSION

Yam tuber parts (proximal, median and distal) have been studied during the tuberization.

Starch properties such as clarity, syneresis and swelling were improved at maturity of the tuber. At earlier stage of tuberization, the viscosity ratio was weak indicating the possibility to use this gel as thickening agent for shearing sauce.

The nutritional compound (Glucose, fructose and sucrose) of yam tuber was important at early stage of growing period. The maturity of the tuber improved protein content and some of mineral such as K, S and Na for var. kponan. Harvested the tuber before maturity could provide an excellent amount of simple sugar but for agronomic raison such as the yield, it was not benefic.

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