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Original Research Article

Effect of cooking time on biochemical and functional properties of flours from yam "kponan" (*Dioscorea cayenensis-rotundata*) tubers

ABSTRACT

Influence of cooking process on nutritional value of yam "kponan" (Dioscorea cayenensis-rotundata) tubers grown in Côte d'Ivoire were investigated by studying the effect of cooking time on biochemical and functional properties of the tubers. Yam tubers were washed, peeled, cut into pieces and cooked in boiling water at 100°C, for periods of 0 min (FNT), 5 min (F5), 10 min (F10) and 15 min (F15). With the exception of crude fat contents of flours, the results showed that all the biochemical properties measured (dry matter, total ash, organic matters, total and reducing sugars, crude protein, carbohydrate) decreased significantly by the change of cooking time ($p \leq 0.05$). However, among functional properties studied, water absorption capacity, water solubility index and absorption capacity of some oils (palm oil, soybean oil, sunflower oil, red oil and olive oil) showed a significant ($p \leq 0.05$) increased with cooking time, whereas the foam capacity and stability of flours decreased significantly ($p \leq 0.05$). The flours exhibited different properties as showed by the PCA that discriminated raw yam flour (FNT) from cooked yam flours (F5, F10 and F15). The use of cooking in yam flours processing appeared beneficial to improve their nutritional potentialities.

Keywords: Dioscorea cayenensis-rotundata, biochemical properties, functional properties, cooking time

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1. INTRODUCTION

Roots and tubers are widely cultivated all over the world in tropical and subtropical areas. Among tubers, yams (*Dioscorea* spp.) are major staple food crops in Africa, West Indies, South Asia, South and Central America **[1]**.

Yams are an important source of carbohydrate for many people of the sub-Sahara region, especially in West Africa **[2-6]**. Yam belongs to the genus Dioscorea of the family Dioscoreaceae which has about 600 species, including only 10 that are edible **[7]**. The most economically important species are *Dioscorea rotundata*, *D. alata*, *D. cayenensis*, *D. bulbifera*, *D. trifida*, *D. opposita, D. dumentorum, D. japonica* and *D. hispida* **[8]**.

In Côte d'Ivoire, yam plays an important role in food crop production with a production estimated at 5 million tons per year in 2001 **[9]**. This high production is destined for human consumption. Yam also has a cultural importance. Among the edible yams, *Dioscorea cayenensis-rotundata*, cultivar "kponan" is widely used for the ritual ceremony and is valued for the different traditional meals **[10,5]**.

Many losses are recorded during the storage of yam tubers **[11,12]**. To overcome the high perishability of fresh yam, a large proportion is processed before consumption **[13]**. The processing method of yam include cooking (i.e., boiling, baking, frying), drying and grinding into flour **[10]**. Some previous studies have also illustrated these different forms of yam consumption **[14-17]**.

It is well known that the cooking processes causes several changes in physical characteristics and chemical compositions of vegetables and affect their nutritional value **[18]**. Cooking methods differ in many areas of the country and also vary with the ethnic background of the family **[19]**. However, it seems to be important to know the influence of the duration of cooking processes.

Thus the objectives of this work were to evaluate the effect of cooking time on biochemical and functional properties of flours from yam "kponan" (*Dioscorea cayenensis-rotundata*) tubers.

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2. MATERIAL AND METHODS

2.1 Materials

Yam tubers "kponan" (*Dioscorea cayenensis-rotundata*) were randomly harvested at maturity (6 months after planting) from three different farms in Dabakala, Vallée du Bandama Region (8°15'N and 4°25'W), North 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 hours. All other chemicals and reagents used were of analytical grade and purchased from Sigma Chemical Co. (St. Louis, MO).

2.2 Biochemical properties

2.2.1 Preparation of raw and cooked yam tuber flours

Yam tubers (1 kg) were washed free of dirt and peeled using a stainless steel knife. The peeled samples were rewashed twice with clean water and cut into pieces of about 50 g. Water was added to the cut pieces at the ratio of 1:1 (w/w) and cooked in a closed stainless steel vessel (IVOIRAL) on a hot plate at the temperature of 100°C, for periods of 0 ; 5 ; 10 and 15 min. At the end of boiling, the water was drained off and the hot samples were cooled for 25 min. Then, they were cut into 5 millimeters thick slices and dried at 45°C in a ventilated oven (MEMMERT) for 48 h. The dried samples were ground into fine powder. Yam powder was obtained after sieving (250 µm diameter). Dried powdered samples were packed into airtight sealed plastic bags and stored in the refrigerator for later analysis.

2.2.2 Proximate composition

The dry matters contents of the flours were determined by drying in an oven at 105°C during 24 h to constant weight **[20]**. The total ash contents were determined by incinerating flour (2 g) in a furnace at 550°C for 6 h, then weighing the residue after cooling to room temperature in a desiccator **[20]**. The organic matters contents were determined by the difference between the values of dry matter and total ash. The ethanol-soluble sugars extraction was determined as described by Martinez-Herrera *et al*. **[21]**. The method described by Dubois *et al.* **[22]** was used for the total sugar contents analysis. The reducing sugar contents were determined according to the method of Bernfeld **[23]** using 3.5 dinitrosalycilic acid. The crude protein contents were calculated from nitrogen contents (N x 6.25) obtained using the Kjeldahl method by AOAC **[20]**. The crude fat contents were determined by continuous extraction in a

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Soxhlet apparatus for 8 h using hexane as solvent **[20]**. 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 – (% moisture + % ash + % crude protein + % crude fat).

2.3 Functional properties of flours

2.3.1 Water absorption capacity and water solubility index

The water absorption capacity (WAC) and solubility index (WSI) of flours were evaluated according to Phillips *et al*. **[24]** and Anderson *et al*. **[25]** methods, respectively. Exactly 2 g of flour (M_0) were mixed with a 50 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 5000 rpm for 15 min. The resulting sediment (M_2) was weighed and then dried at 105°C to constant weight (M_1). The WAC was then calculated as follows:

$$WAC(\%) = \frac{M_2 - M_1}{M_1} \times 100 \qquad (1)$$

While the WSI was calculated using the following equation:

$$WSI(\%) = \frac{M_0 - M_1}{M_0} \times 100 \qquad (2)$$

2.3.2 Oil absorption capacity

The oil absorption capacity (OAC) or flours was assayed according to the method of Sosulski **[26]**. One (1) g of flour (M_0) were mixed with a 10 ml of oil. The mixture was shaken for 30 min in a KS10 agitator and centrifuged (Ditton LAB centrifuge, UK) at 4500 rpm for 10 min. The resulting sediment (M_1) was weighed and the OAC was then calculated as follows:

$$OAC(\%) = \frac{M_1 - M_0}{M_0} \times 100 \qquad (3)$$

2.3.3 Foam capacity and foam stability

The foam capacity (FC) and stability (FS) of flours were studied by the method of Coffman and Garcia **[27]**. Three (3) g of flour were transferred into clean, dry and graduated (50 ml) cylinders. The flour samples were gently leveled and the volumes noted. Distilled water (30

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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 one (1) hour.

$$FC(\%) = \frac{Vol.\ after\ homogenization - Vol.\ before\ homogenization}{Vol.\ before\ homogenization} \times 100 \qquad (4)$$

$$FS(\%) = \frac{Foam\ volume\ after\ time\ (t)}{Initial\ \ foam\ volume} \times 100 \qquad (5)$$

2.4 Statistical analysis

All the analyses reported in this study were carried out in triplicates. In each case, a mean value and standard deviation were calculated. Analysis of variance (ANOVA) was also performed and separation of the mean values was carried out using Duncan Multiple Range Test at $p \leq 0.05$ **[28]**. Pearson correlation coefficients (r) for relationships between various flour properties were calculated. The variations observed in the biochemical composition and functional properties of the flours from yam tubers were examined by principal component analysis (PCA) with the STATISCA Software version 7.1.

3. RESULTS AND DISCUSSION

3.1 Principal component analysis

Principal Component Analysis (PCA) was used to visualize the variation in the properties among flours from raw and cooked yam "kponan" (*Dioscorea cayenensis-rotundata*) tubers at different times. This analysis showed two axes (axis 1 and 2) explaining the essential variability revealed by the fifteen (15) biochemical and functional variables. The first and the second PCs described 88.23 and 07.78% of the variance respectively. Together, the first two PCs represented 96.01% of the total variability. Flours from yam tubers cooked during 15 min (F15) and 10 min (F10) were located at the left of the score plot, while flours from raw (FNT) and cooked yam tubers during 5 min (F5) had a large positive score in the first principal component (PC1) **(Fig. 1).** FNT and F15 had a large positive score, whereas F5 had a

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negative score in PC2 **(Fig. 1)**. F10 was located close to zero both in PC1 and PC2. Thereby, the properties of flours from yam "kponan" (*D. cayenensis-rotundata*) tubers would be different. The correlation circle provides information about correlations between the measured properties **(Fig. 2)**. The properties whose curves lie close to each other on the plot were positively correlated while those whose curves run in opposite directions were negatively correlated.

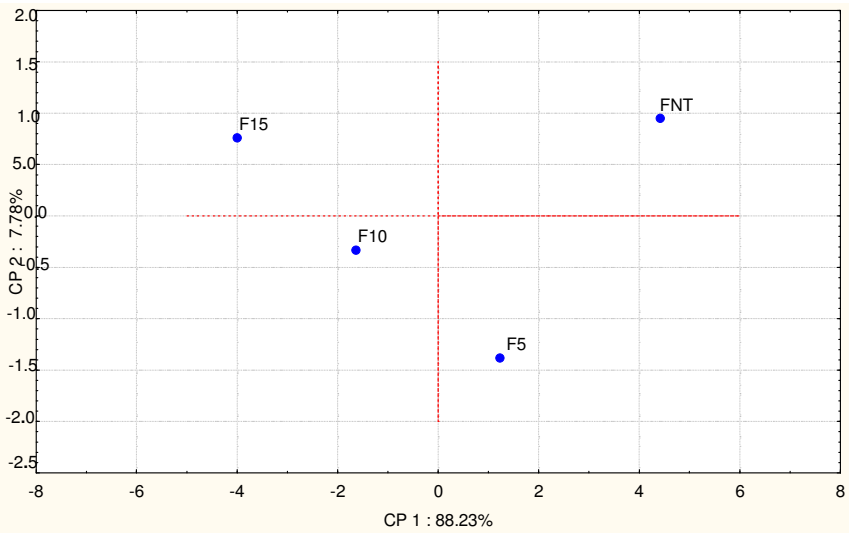

Fig. 1: Sample plot of principal components 1 and 2 of flours from raw and cooked yam "kponan" (*D. cayenensis-rotundata*) tubers. FNT: Flour from raw yam (*D. cayenensis-rotundata*); F5: Flour from (*D. cayenensis-rotundata*) cooked in water at 100°C during 5 min; F10: Flour from (*D. cayenensis-rotundata*) cooked in water at 100°C during 10 min; F15: Flour from (*D. cayenensis-rotundata*) cooked in water at 100°C during 15 min

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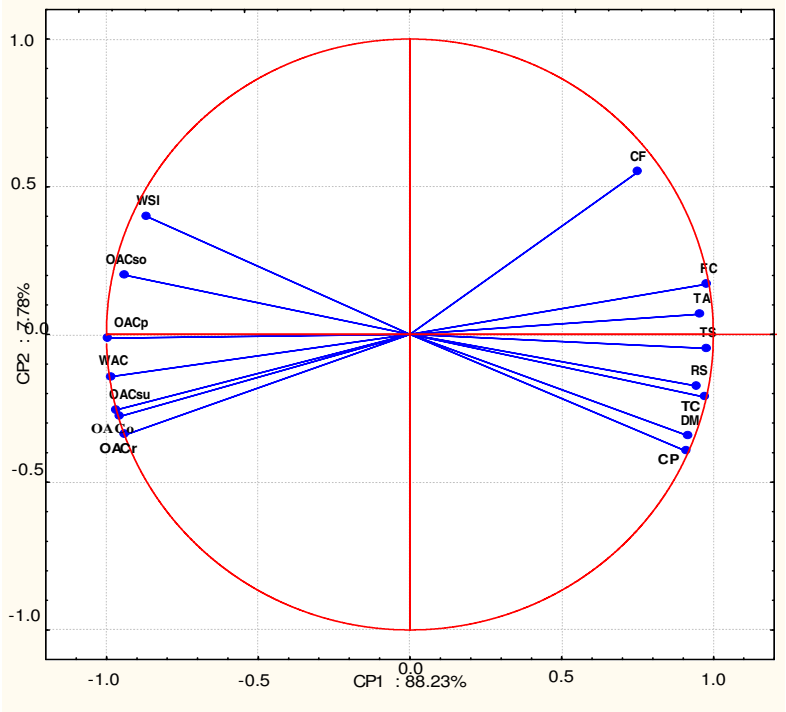

Fig. 2: Circle of correlation of biochemical composition and functional properties of flours from raw and cooked yam "kponan" (*D. cayenensis-rotundata*) tubers on axis 1 and 2. DM: Dry matter; TA: Total ash; TS: Total sugars; RS: Reducing sugars; CP: Crude protein; CF: Crude fat; TC: Total carbohydrate; OAC: Oil absorption capacity; OACp: OAC for palm oil; OACsu: OAC for sunflower oil; OACso: OAC for soybean oil; OACr: red oil; OACo: OAC for olive oil; WAC: Water absorption capacity; WSI: Water solubility index; FC: Foam capacity

3.2 Biochemical composition

The biochemical composition of flours from raw and cooked yam "kponan" (*D. cayenensis-rotundata*) tubers was presented in **Table 1**. The change in cooking time led to a significant ($p \leq 0.05$) reduction in dry matters, ash, total and reducing sugars, crude protein and carbohydrate contents, whereas the crude fat content was not affected by the changes in cooking time. The decrease in the biochemical characteristic contents of flours from cooked yam may be due to the heat treatment, which caused loss of these parameters in yam tubers. This result is in agreement with those of Onuegbu et al. **[29]** in three-leaved yam (*D. dumetorum pax*) tubers.

The significant decrease ($p \leq 0.05$) of dry matter contents of the flours from yam "kponan" (*D. cayenensis-rotundata*) tubers (93.33 ± 0.31 to 86.07 ± 0.31%) may be related to the decrease of some organic matters level, such as proteins, ash and soluble sugars **(Table 1)**. The dry matter content would reflect low content of moisture that might be favourable for prolonged

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storage of yam flours. Moisture contents of flours from yam "kponan" (*D. cayenensis-rotundata*) are higher than those of flours from three varieties of yams prepared by different drying methods **[30]**, while these values are lower than those of five varieties of aerial yam (*D. bulbifera*) (61.55 to 71.09%) **[31]**. Dry matter contents were shown to be positively correlated to the total ash ($r = 0.91$, $p \leq 0.05$), total and reducing sugars ($r = 0.87$, $p \leq 0.05$), and crude protein ($r = 1.00$, $p \leq 0.05$) contents both by Pearson correlation **(Table 2)** and PCA analysis **(Fig. 2)**.

Ash contents of yam "kponan" (*D. cayenensis-rotundata*) flours were decreased significantly ($p \leq 0.05$) from 2.10 ± 0.40 to 1.53 ± 0.44% **(Table 1)**. These values are comparable to values as reported in literature **[11,32-35]**, but are lower than those of flours from five varieties of aerial yam (*D. bulbifera*) (2.8 to 5.57%) **[31]**. Ash content gives an indication of minerals present in a particular food sample and it is very important in many biochemical reactions which aid physiological functioning of major metabolic processes in the human body **[36,37]**. Ash contents decreasing of yam "kponan" (*D. cayenensis-rotundata*) flours may be referred to leaching of minerals in boiling water.

Yams, with relatively high protein contents, are important food in many African countries **[38]**. The crude protein contents of yam "kponan" (*D. cayenensis-rotundata*) flours ranged from 2.63 ± 0.01 to 4.69 ± 0.17% **(Table 1)**. These values are lower than those of yam flours from Taiwan **[30]** and from Ghana **[31]**. However, they are higher than values reported for several cultivated tropical yam species from the south pacific region **[33]**, yam species from Sri Lanka **[39]** and wild yam species from Nepal **[32]**. The high protein content of yam "kponan" (*D. cayenensis-rotundata*) indicated its nutritional superiority over the other yam species. The decreasing of crude protein of yam "kponan" (*D. cayenensis-rotundata*) flours after cooking could be explained by solubilization of soluble protein fractions in boiling water **[40]**. This result agreed with Lima et al. **[41]** who reported a decrease of the protein content in some cooked vegetables.

Low fat contents (below 0.2%) obtained in yam "kponan" (*D. cayenensis-rotundata*) flours are similar to reported values for tropical yam tubers from the south pacific region **[33]** and for Cameroonian yams species **[42]**. However, these values are lower than values ranged from 0.2 to 0.3% reported by Afoakwa and Sefa-Dedeh **[11]**, Bhandari et al. **[32]** and Hsu et al.

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[30]. It appeared that cooking time had no significant effect ($p \leq 0.05$) on the crude fat contents of yam "kponan" (*D. cayenensis-rotundata*) flours **(Table 1)**. Similar result was observed by Onuegbu et al. **[29]** in flours from three-leaved yam (*D. dumetorum* pax) tubers. This may be due to the cooking process in boiling water and the short cooking time.

The total and reducing sugars contents of yam "kponan" (*D. cayenensis-rotundata*) flours ranged from 4.41 ± 0.02 to 6.51 ± 0.09% and from 2.26 ± 0.21 to 3.82 ± 0.24%, respectively, in response to different cooking times. The variability of these levels may be due to the hydrolysis of polysaccharides of yam into simple sugars during cooking in water. The level of reducing sugars in yam "kponan" (*D. cayenensis-rotundata*) flour (3.82%) was found to be higher than those of flours from several cultivated tropical yam species from the south pacific region (0.12 to 1.03%) **[33]**, from taro (*Colocasia esculenta*) cv *Sosso Chad* (2.3%) and *Ibo ekona* (1.3%) corm **[43]**, but it is lower than those obtained in cooked breadfruit (*Artocarpus altilis*) flour (6.86%) **[44]**. It has been suggested that reducing sugars in flour may cause caking and damping during their storage because of sugar's hygroscopic property. Indeed, 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 **[45]**.

Carbohydrate values of yam "kponan" (*D. cayenensis-rotundata*) flours ranged from 72,76 ± 0,02 to 79,80 ± 0,02% and show to be the most important biochemical component in the flours. These values are comparable to literature values of 76.80 to 78.3% **[46,47]**, 81.31 to 87.64% **[48]** and 77.53 to 87.31% **[49]**, while lower range of values (11.86 to 25.78%) were observed by Sanful et al. **[31]** in ghanaian aerial yam (*D. bulbifera*). These results also agree with the work of Onyenuga **[50]**, who reported that dry matter of most root and tuber crops is made up of about 60 to 90% carbohydrate. The high percentage of carbohydrates in yam flour makes it an energy food. **Table 1** analysis also showed that carbohydrate contents of yam "kponan" flour decreased significantly ($p \leq 0.05$) with cooking time. This may have been due to the fact that carbohydrates may have absorbed water to bulk up via cross-linking reaction probably induced by heat generated by cooking **[51]**. This decreasing may also be related to the decrease of total sugars and protein contents. These results were also supported by Pearson correlation **(Table 2)** and PCA analysis **(Fig. 2)** who revealed a positive correlation

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291 of carbohydrate level with protein (r = 0.98, p≤0.05), total and reducing sugars (r = 0.95,
292 p≤0.05) levels.
293
294
295 **Table 1. Proximate composition of flours from raw and cooked yam "kponan" (*D. cayenensis-rotundata*)**
296 **tubers**

	Flours			
Parameter	**FNT**	**F5**	**F10**	**F15**
Dry matter (%)	93.33±0.31[a]	92.61±0.60[a]	90.60±1.20[b]	86.07±0.31[c]
Total ash (%)	2.10±0.40[c]	1.82±0.63[b]	1.80±0.26[b]	1.53±0.44[b]
Organic matters (%)	91.23±0.40[a]	90.79±0.63[a]	88.8±0.26[b]	84.54±0.44[c]
Total sugars (%)	6.51±0.09[d]	5.91±0.02[c]	4.65±0.01[b]	4.41±0.02[a]
Reducing sugars (%)	3.82±0.24[b]	3,62±0.16[b]	2.44±0.14[a]	2.26±0.21[a]
Crude protein (%)	4.69±0.17[c]	4.65±0.05[c]	3.85±0.04[b]	2.63±0.01[a]
Crude fat (%)	0.18±0.03[a]	0.15±0.02[a]	0.16±0.03[a]	0.15±0.01[a]
Total carbohydrate (%)	79.80±0.02[a]	78.43±0.09[a]	75.79±0.05[b]	72.76±0.02[c]

297 *The obtained values are averages ± standard deviation of triplicate determinations. On the lines of each parameter, the*
298 *averages affected of no common letter are significantly different between them on the threshold of 5% according to the test of*
299 *Duncan.*
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303 **Table 2. Pearson correlation coefficients between various biochemical composition and functional properties of flours from the raw and cooked yam "kponan" (*D.*
304 ***cayenensis-rotundata***) **tubers**

	DM	TA	TS	RS	CP	CF	TC	OACp	OACsu	OACso	OACr	OACo	WAC	WSI	FC
DM	1.00														
TA	0.91	1.00													
ST	0.87	0.87	1.00												
SR	0.87	0.82	0.99	1.00											
CP	1.00	0.88	0.88	0.90	1.00										
CF	0.58	0.86	0.63	0.52	0.51	1.00									
TC	0.98	0.93	0.95	0.95	0.98	0.64	1.00								
OACp	-0.89	-0.93	-0.99	-0.97	-0.89	-0.72	-0.96	1.00							
OACsu	-0.80	-0.95	-0.93	-0.87	-0.78	-0.87	-0.89	0.96	1.00						
OACso	-0.87	-0.81	-0.99	-1.00	-0.90	-0.50	-0.94	0.96	0.85	1.00					
OACr	-0.73	-0.90	-0.92	-0.85	-0.71	-0.86	-0.84	0.94	0.99	0.83	1.00				
OACo	-0.76	-0.91	-0.94	-0.88	-0.75	-0.84	-0.87	0.96	0.99	0.86	1.00	1.00			
WAC	-0.83	-0.92	-0.98	-0.94	-0.82	-0.78	-0.92	0.99	0.98	0.92	0.98	0.99	1.00		
WSI	-0.99	-0.89	-0.81	-0.82	-0.99	-0.54	-0.95	0.84	0.74	0.81	0.66	0.70	0.77	1.00	
FC	0.81	0.91	0.97	0.93	0.81	0.79	0.91	-0.99	-0.99	-0.92	-0.98	-0.99	-1.00	-0.75	1.00

305 *DM: Dry matter; TA: Total ash; TS: Total sugars; RS: Reducing sugars; CP: Crude protein; CF: Crude fat; TC: Total carbohydrate; OAC: Oil absorption capacity; OACp: OAC for palm oil;*
306 *OACsu: OAC for sunflower oil; OACso: OAC for soybean oil; OACr: red oil; OACo: OAC for olive oil; WAC: Water absorption capacity, WSI: Water solubility index, FC: Foam capacity.*

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3.3 Functional properties

3.3.1 Water absorption capacity (WAC) and water solubility index (WSI)

The water absorption capacity (WAC) and solubility index (WSI) of yam "kponan" (*D. cayenensis-rotundata*) flours are presented in **Fig. 3** and **4**, respectively. In this study, the cooking time significantly ($p \leq 0.05$) increased the WAC and the WSI.

The WAC is a functional property used in determining the suitability of utilizing a material in baked foods such as bread where high WAC is needed **[29]**. The WAC varies from 155.31 ± 8.87% in raw yam "kponan" (*D. cayenensis-rotundata*) flour (FNT) to 351.14 ± 3.57% in yam flour cooked during 15 min (F15) **(Fig. 3)**, indicating that cooked sample has higher WAC. This behavior indicates that flour of cooked yam tubers has more hydrophilic constituents **[52]**. The range of WAC observed for the yam "kponan" (*D. cayenensis-rotundata*) flour is comparable to values described in previous works **[53,54,43,55,56]**. These values are lower than those of flours from yam (*D. dumetorum*) tubers (454%, **[40]**) and raw and cooked taro (*Colocasia esculenta*) corms cultivated in Côte d'Ivoire (312.21-526.76%, **[57]**).

The ability of food materials to absorb water is sometimes attributed to its protein contents **[58]**) and to the capacity of boiling to dissociate or alter the protein molecules to monomeric subunits which may have more water-binding sites **[59]**. In this study, a negative correlation of protein content with WAC ($r = -0.82$, $p \leq 0.05$) of flour from yam "kponan" (*D. cayenensis-rotundata*) tubers was observed **(Table 2; Fig. 2)**. This observation deviates from the accepted theory that protein solubility is positively correlated with WAC. This may suggest that the proteins of yam "kponan" (*D. cayenensis-rotundata*) tubers are rigid or folded. Therefore, the observed WAC of yam "kponan" flour cannot be attributed only to the proteins. Indeed the results of Pearson correlation **(Table 2)** and PCA analysis **(Fig. 2)** revealed a positive correlation of WAC with WSI ($r = 0.77$, $p \leq 0.05$) and a negative with dry matter ($r = -0.83$, $p \leq 0.05$), ash and carbohydrate ($r = -0.92$, $p \leq 0.05$), total sugars ($r = -0.98$, $p \leq 0.05$), reducing sugars ($r = -0.94$, $p \leq 0.05$) and fat ($r = -0.78$, $p \leq 0.05$) contents.

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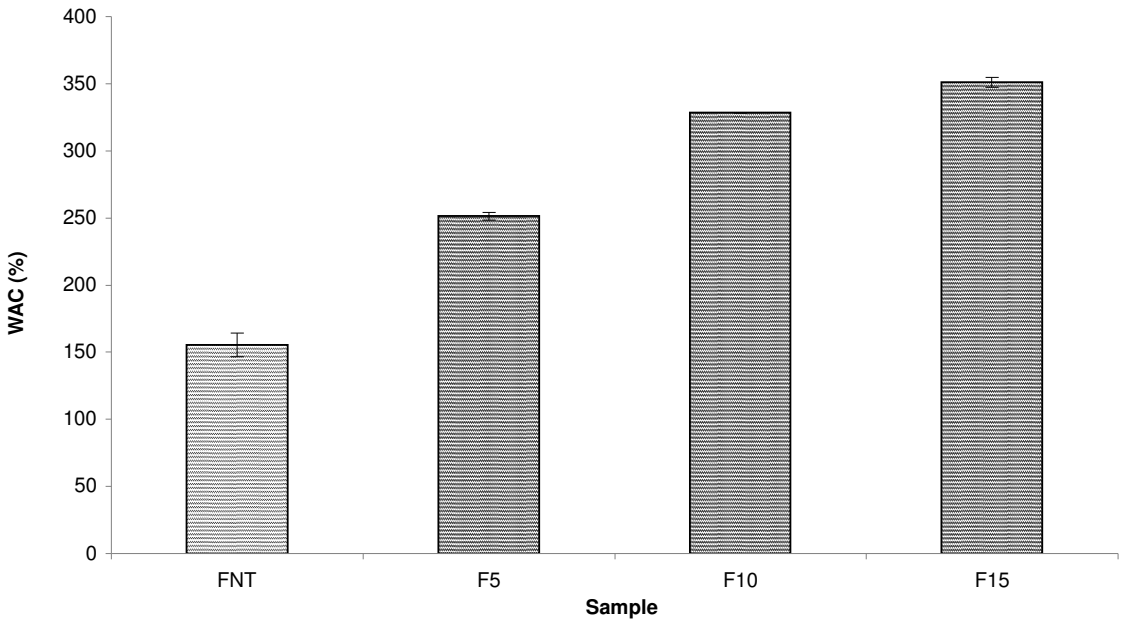

Fig. 3: Water absorption capacity (WAC) of flours from raw and cooked yam "kponan" (*D. cayenensis-rotundata*) tubers. FNT: Flour from raw yam (*D. cayenensis-rotundata*); F5: Flour from yam (*D. cayenensis-rotundata*) cooked in water at 100°C during 5 min; F10: Flour from yam (*D. cayenensis-rotundata*) cooked in water at 100°C during 10 min; F15: Flour from yam (*D. cayenensis-rotundata*) cooked in water at 100°C during 15 min

Diosady et al. **[60]** reported that the WSI reflects the extent of starch degradation. The WSI (37.00 ± 1.60%) observed for the raw yam "kponan" (*D. cayenensis-rotundata*) flour (FNT) is lower compared to that of yam flour after cooking for 15 min (F15) (42.50 ± 0.10%) **(Fig. 4)**, indicating that cooking time had more profound effects on starch degradation. Similar observations were noted by Hsu et al. **[30]**, when using yam (tubers of the *Dioscorea spp*) flours (9.26 ± 0.11 to 15.31 ± 0.85%). These WSI values were higher than those of flour from *Tacca leontopetaloides* tubers (0.79-10.72%, **[61]**) and yam *D. dumetorum* tubers (15.0 ± 0.10%, **[40]**). Pearson correlation **(Table 2)** and PCA analysis **(Fig. 2)** revealed no significant correlation of WSI with fat content ($r = -0.54$, $p \leq 0.05$) and a negative with ash ($r = -0.89$, $p \leq 0.05$), total sugars ($r = -0.81$, $p \leq 0.05$), reducing sugars ($r = -0.82$, $p \leq 0.05$), total carbohydrate ($r = -0.95$, $p \leq 0.05$), dry matter and crude protein ($r = -0.99$, $p \leq 0.05$) levels. This suggests that the WSI cannot be attributed only to the extent of starch degradation. The biochemical properties play an important role in this functional property change, as we can see in this study.

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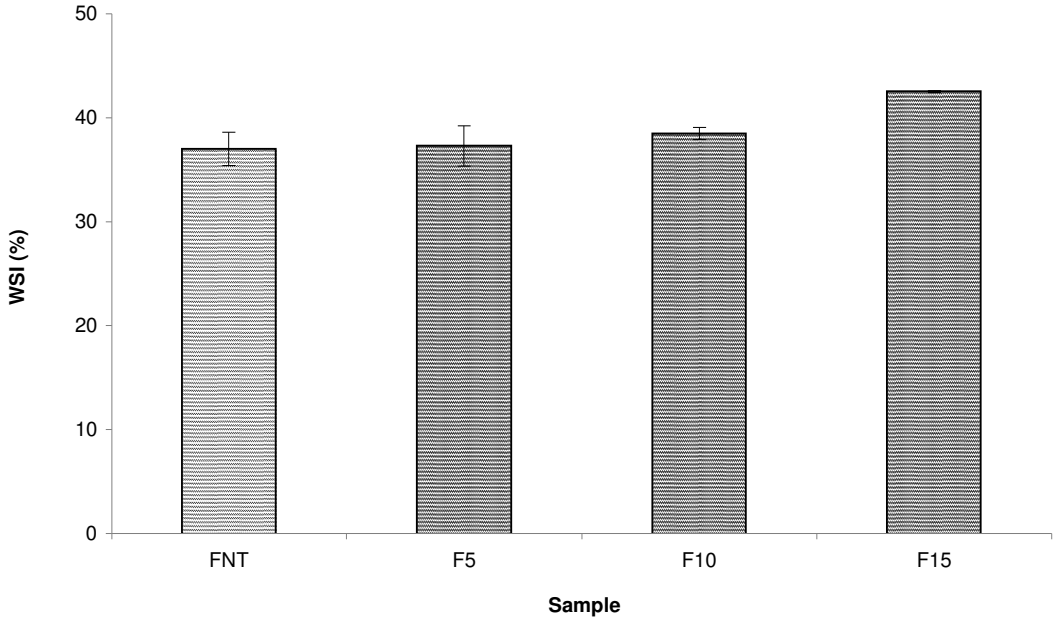

Fig. 4: Water solubility index (WSI) of flours from raw and cooked yam "kponan" (*D. cayenensis-rotundata*) tubers. FNT: Flour from raw yam (*D. cayenensis-rotundata*); F5: Flour from yam (*D. cayenensis-rotundata*) cooked in water at 100°C during 5 min; F10: Flour from yam (*D. cayenensis-rotundata*) cooked in water at 100°C during 10 min; F15: Flour from yam (*D. cayenensis-rotundata*) cooked in water at 100°C during 15 min

3.3.2 Oil absorption capacity (OAC)

The results of oil absorption capacities (OAC) of flours are showed in **Fig. 5**. Oil absorption is an important property in food formulations because fats improve the flavour and mouthfeel of foods **[58].** Analysis of variance of the absorption capacity of palm oil, soybean oil, sunflower oil, red oil and olive oil for yam "kponan" (*D. cayenensis-rotundata*) flours showed a significant ($p \leq 0.05$) increase with cooking time. The absorption capacity of palm oil were observed to increase from 80.65 ± 0.60% for the raw yam "kponan" (*D. cayenensis-rotundata*) flour (FNT) to 92.33 ± 0.60% for yam flour after cooking for 15 min (F15). While the OAC ranged between 67.00 ± 1.00 to 80.00 ± 3.46% for sunflower oil, 61.33 ± 2.3 to 90.00 ± 1.53% for soybean oil, 68.67 ± 1.15 to 82.67 ± 2.50% for red oil and 67.33 ± 1.25 to 70.00 ± 0.82% for olive oil **(Fig. 5)**.

The OAC for these different oils ranging from 60 to 90% are comparable to than reported by Oshodi and Ekperigin **[62]** for pigeon pea flour (89.7%) and are higher than those obtained by Medoua **[40]** for yam *D. dumetorum* flour (15%). However these values are lower than flours from yam *D. rotundata* (137-228%, **[63]**), from okra seed (229.4-253.5%, **[64]**) and from plantain (96.8-123.2%, **[65]**). The variations of OAC depend on the presence of non-polar side chains, which bind the hydrocarbon side chain of oil. The cooking process in boiling

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water would cause the dissociation and denaturation of proteins, which unmask the non-polar residues of the protein molecules **[66]**.

The mechanism of oil absorption may be explained as a physical entrapment of oil related to the non-polar side chains of proteins. Both the protein content and the type contribute to the oil-retaining properties of food materials **[67]**. The increase in protein also enhances the hydrophobicity and exposed more of the polar amino acid to the fat **[68]**. Thus, the decrease in protein yam "kponan" flours would tend to reduce the hydrophobicity, and thereby causing a low fat binding to protein. The obtained results in this study confirmed this hypothesis since no significant ($p \leq 0.05$) variation of fat contents and low OAC values from yam "kponan" (*D. cayenensis-rotundata*) flours were obtained **(Fig.5; Table 1)**.

The OAC from different oils studied were shown to be negatively correlated to protein ($-0.90 \leq r \leq -0.71$, $p \leq 0.05$) and fat ($-0.87 \leq r \leq -0.50$, $p \leq 0.05$) contents, and positively to WAC ($0.92 \leq r \leq 0.99$, $p \leq 0.05$) and WSI ($0.66 \leq r \leq 0.84$, $p \leq 0.05$) levels, both by Pearson correlation **(Table 2)** and PCA analysis **(Fig. 2)**. Liquid retention is an index of the ability of proteins to absorb and retain oil/water which in turn influences the texture and mouth feel characteristics of foods and food products like comminuted meats, extenders or analogues and baked dough **[69]**. Any processing method that influences these parameters would tend to influence the oil absorption characteristics of the food system **[70]**.

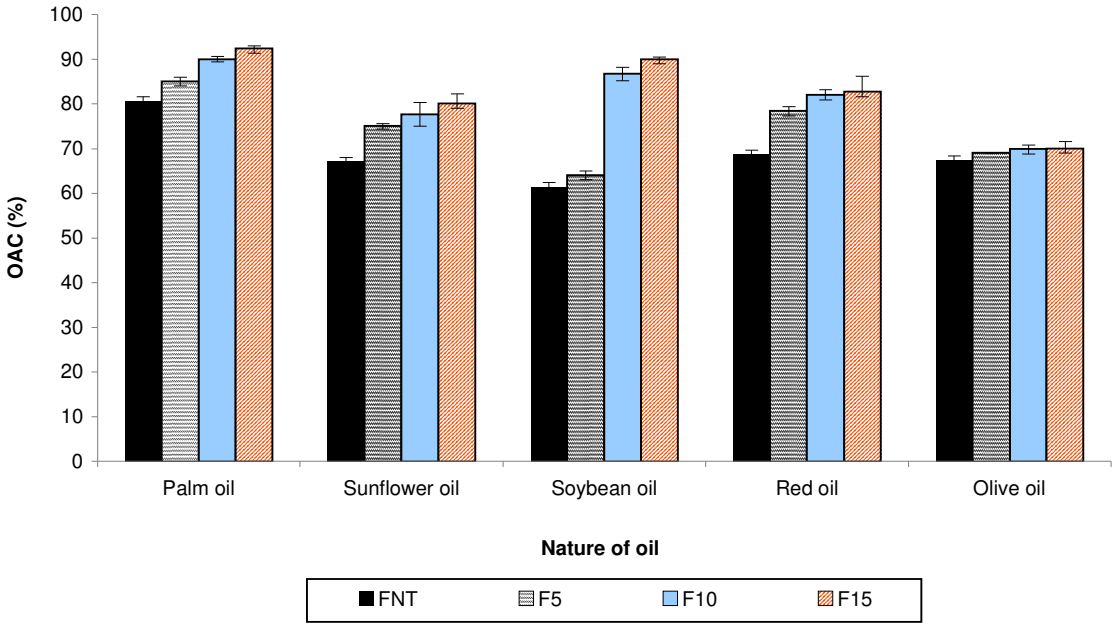

Fig. 5: Oil absorption capacity (OAC) for palm oil, sunflower oil, soybean oil, red oil and olive oil of flours from raw and cooked yam "kponan" (*D. cayenensis-rotundata*) tubers. FNT: Flour from raw yam (*D.*

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cayenensis-rotundata); F5: Flour from yam (*D. cayenensis-rotundata*) cooked in water at 100°C during 5 min; F10: Flour from yam (*D. cayenensis-rotundata*) cooked in water at 100°C during 10 min; F15: Flour from yam (*D. cayenensis-rotundata*) cooked in water at 100°C during 15 min

3.3.3 Foam capacity (FC) and foam stability (FS)

Foams are used to improve texture, consistency and appearance of foods **[71]**. Results showed that foam capacity (FC) of yam "kponan" (*D. cayenensis-rotundata*) flours varied from 25.80 ± 3.23% in raw yam (FNT) to 13,32 ± 2,64% for yam cooked during 15 min (F15) **(Fig. 6)**. The FC values obtained are higher than those reported by Oshodi and Fagbemi **[72]** (13.2%) for pumpkin flavours, by Mbofung et al. **[54]** (9-14%) and Amon et al. **[57]** (9-10%) for different cooked taro flours. On the other side, these values are lower than those of flours recorded by Abbey and Ibeh **[73]** (40%), Tagodoe and Nip **[56]** (29-31 ml/100 ml) and Njintang et al. **[43]** (18-27 ml/100 ml).

Foam stability (FS) of yam "kponan" (*D. cayenensis-rotundata*) flours tended to decrease significantly ($p \leq 0.05$) with cooking time and foam from FNT flour melts slowly compared to other flours **(Fig. 7)**. This result may be due to collapsing and bursting of the formed air bubbles **[58]**.

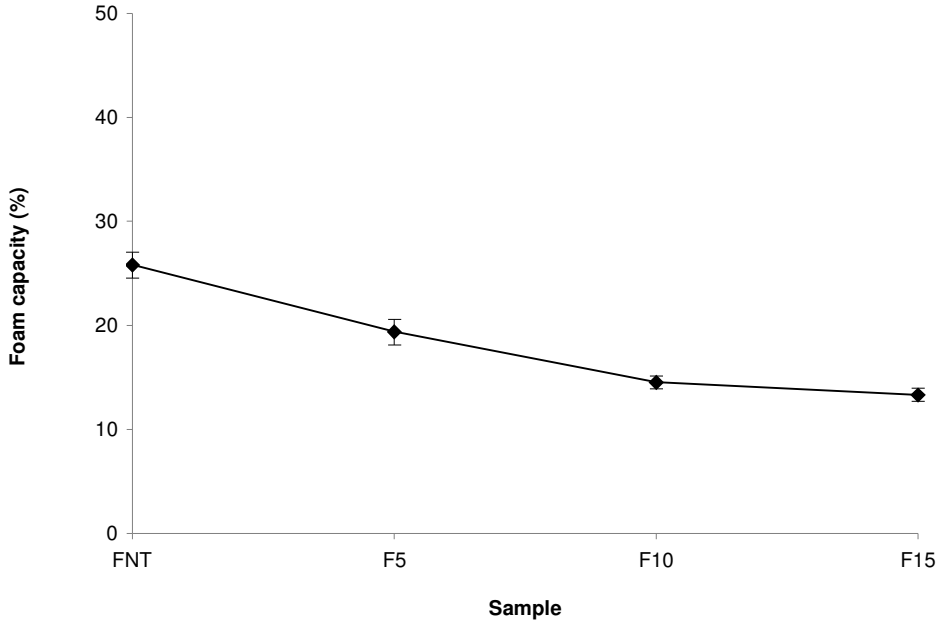

Fig. 6: Foam capacity of flours from raw and cooked yam "kponan" (*D. cayenensis-rotundata*) tubers. FNT: Flour from raw yam (*D. cayenensis-rotundata*); F5: Flour from yam (*D. cayenensis-rotundata*) cooked in water at 100°C during 5 min; F10: Flour from yam (*D. cayenensis-rotundata*) cooked in water at 100°C during 10 min; F15: Flour from yam (*D. cayenensis-rotundata*) cooked in water at 100°C during 15 min

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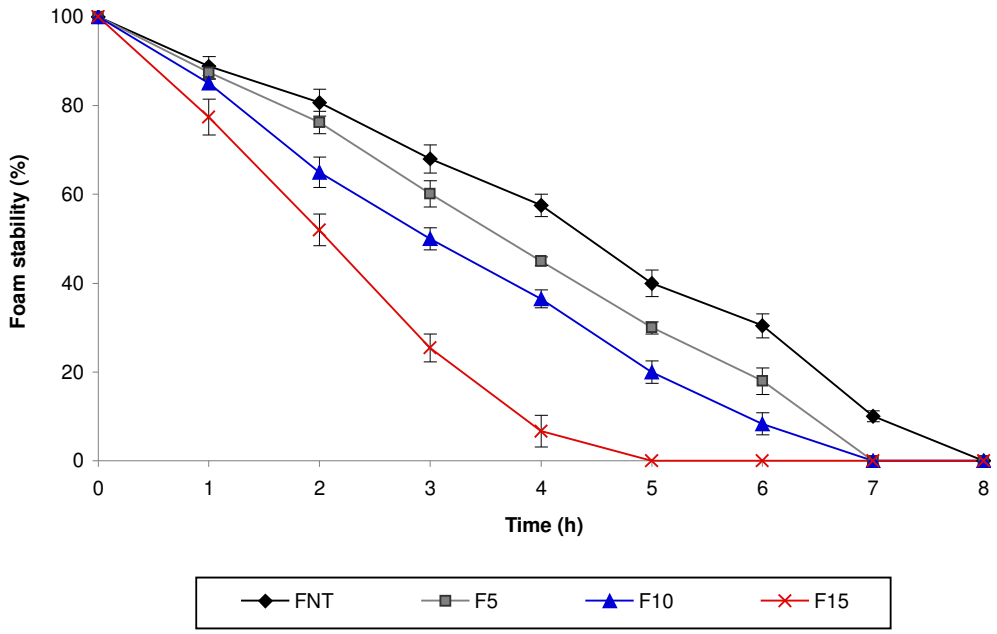

Fig. 7: Foam stability of flours from raw and cooked yam "kponan" (*D. cayenensis-rotundata*) tubers. The obtained values are averages ± standard deviation of triplicate determinations. (♦) Flour from raw yam tubers; (■) Flour from yam tubers cooked during 5 min; (▲) Flour from yam tubers cooked during 10 min; (×) Flour from yam tubers cooked during 15 min

The reduction of foaming properties showed in **Fig. 6 and 7** was mainly related to protein denaturation. These results agree with the finding of Lin et al. **[59]** that the native protein gives higher foam stability than denatured one. It is well known that, for a protein to have good foaming properties, it has to be very soluble, because foam capacity requires rapid adsorption of protein at the air/water interface during whipping, penetration into the surface layer and re-organisation at the interface **[74]**. This is confirmed by the results of Pearson correlation **(Table 2)** and PCA analysis **(Fig. 2)**, which show that FC was positively correlated to the protein contents ($r = 0.81$, $p<0.05$) and negatively correlated to WAC ($r = -1.00$, $p\leq0.05$), WSI ($r = -0.75$, $p\leq0.05$) and OAC ($-0.99 \leq r \leq -0.92$, $p\leq0.05$) levels.

4. CONCLUSION

The obtained results in this study confirmed that the cooking process in boiling water has significant ($p\leq0.05$) effect on some important components like total sugars, reducing sugars, proteins and carbohydrate contents of flours from yam "kponan" (*D. cayenensis-rotundata*) tubers, thus affecting their nutritional value. However, the fat contents were not affected significantly ($p\leq0.05$) by the change in cooking time.

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Yam "kponan" flours contained substantial amounts of carbohydrate and therefore constituted an excellent dietary energy source, hence the reason that yams are considered to constitute an important staple food source in a number of developing countries. The use of these yam flours in various food formulations requires the use of other foods to satisfy the nutrient losses observed.

The use of cooking process enhances significantly ($p \leq 0.05$) some functional properties like WAC, WSI and OAC of yam "kponan" flours. This is an advantage for the use of yam flours as substitutes in the infant foods formulation and bakery products.

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