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Biochemical and Functional Properties of Yam Flour during the Post-harvest Conservation of *Dioscorea alata* Cultivar « Azaguié »

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Authors' contributions

This work was carried out in collaboration between all authors. Authors KCJN and KLP designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors KKH and AYDP managed the analyses of the study. Author DCG managed the literature searches. All authors read and approved the final manuscript.

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Original Research Article

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ABSTRACT

Aims: To be follow the biochemical and functional properties of yam flour during the post-harvest conservation of yam « Azaguié » (*Dioscorea alata*) tubers.
Study Design: Analysis of variance (ANOVA) was carried out in this work.
Place and Duration of the Study: Food Science and Technology Training and Research Unit, Nangui Abrogoua University, Abidjan, Côte d'Ivoire, from December 2014 to February 2016.
Methodology: The yam tubers stored after harvest in a warehouse were kept for 6 months. Tubers were randomly taken for the preparation of flour every two months. Flours were obtained after grinding and sieving the pulp pieces and dried at 45℃ for 48 h. Thereafter, the biochemical and functional analyses were performed on these different flours.

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Results: except for the lipid contents, all biochemical properties that were measured vary significantly ($P \leq 0.05$) with post- harvest conservation time of the yam tubers. Dry matter, total sugars and reducing sugars increased. By cons, protein, phenolic compound, ash and minerals (calcium, copper, potassium, magnesium and zinc) decreased with post- harvest conservation time of the yam species tubers. With regard to functional properties studied, water absorption capacity (WAC), oil absorption capacity (OAC) and wettability increased significantly ($P \leq 0.05$) with post-harvest conservation time of the yam tubers. However, the water absorption index (WSI), hydrophilic lipophilic index (HLI), bulk density, foaming capacity and foam stability decreased significantly ($P \leq 0.05$) during post-harvest conservation of yam tubers.

Conclusion: This study shows the importance of post-harvest conservation time of the yam tubers in the use of these categories of flours in food technology.

Keywords: Dioscorea alata; biochemical properties; functional properties; post- harvest conservation.

1. INTRODUCTION

Yam (*Dioscorea spp.*, Dioscoreaceae) is the third most important tropical root crop after cassava and sweet potato [1]. The tubers of various species of *Dioscorea* constitute one of the stable carbohydrate foods for the people in many tropical countries [2]. Many different forms and cultivars of the edible yam species are available in different areas and it is likely that these differ in composition and nutritional values [3]. Water yam (*Dioscorea alata*) is the most economically important yam species which serve as a staple food for millions of people in tropical and subtropical countries [4,5]. *D. alata* is a crop with potential for an increased consumer demand due to its low sugar content necessary for diabetic patients [6]. Yam is an excellent source of starch, which provides calorific energy [7]. Yams have generally high moisture content; in addition to starch, the dry matter is composed mainly of vitamins, sugars and minerals. Yams may also contain small quantities of proteins, lipids and most vitamins as well as polyphenolic compounds [8]. Phenolic compound, widely existing in plants, are important for their contribution to colour, sensory attributes and nutritional and antioxidant properties of foods [9]. Nutrient content varies with species, cooking procedures [10] and conservation [11]. But yam suffers a high degree of a post-harvest loss due to its high moisture content [12]. Yam flour is therefore a means of limiting post-harvest losses. This product makes it possible to extend the supply of the commodities through the off-season, thereby reducing storage losses as well as marketing and transportation costs [13]. This flour of yam tubers is commonly used in various culinary preparations. Rehydrated, it helps replenish elastic pasta distinct *fufu* and *foutou***.** [13,14].Yam flour has found increasing use in bakery [13]. However, quality of the tuber for the production of yam-based food products is a major criterion for acceptance of yam varieties by the stakeholders: farmers, processors and consumers [15]. The food quality of stored yam tubers is usually preferred than the fresh yam tubers, hence it is usually more expensive than fresh yam tubers in the market. This is probably because of its perceived better food quality (especially textural quality and taste) compared with fresh tubers [16]. Also, the use of most flours as food ingredients depends to a large extent on their interaction with water or oil during food preparation.Thus, in view of these various uses of yam flour. It is therefore necessary to determine biochemical and functional properties. Several authors have worked on the use of yam flour by studying their biochemical and functional properties but very few have reported the influence of post- harvest conservation of yam tubers on these properties in yam flour. This study was designed to investigate the effect of post-harvest storage of yam on physicochemical and functional properties of yam flours from yam “Azaguié” (*Dioscorea alata*) tubers.

2. MATERIALS AND METHODS

2.1 Materials

Cultivars « Azaguié » of *D. alata* species were selected in the department of Bondoukou, in the North-East of Côte d’Ivoire. Yam tubers were randomly harvested at physiological maturity (6 months after planting) from three differents farms of village named Kouakoukankro s/p to Sandégué in December 2014. They were immediately transported to the laboratory of biocatalysis and bioprocesses of the Nangui Abrogoua University in Abidjan (Côte d’Ivoire) where a study was conducted. Yam tubers were stored for six months in a heap aired store in which the temperature and the relative humidity rate were respectively 26.56 ± 3℃ and 82 ± 5%. All other chemicals and reagents used were of analytical grade and purchased from Sigma Chemical Co. (St. Louis, MO).

2.2 Sample Preparation

Every two (2) months during the storage period (six months), tubers were randomly picked. These yams were washed with clean water. They peeled and cut into small slices (3x3x3 cm thickness) using a stainless steel knife. The slices were rewashed with clean water in order to remove much mucilaginous material. After washing, slices were dried in an oven at 45℃ for 48 hours. The dried slices were ground into powder and pass sieved with 250 µm mesh sieve and then stored in airtight containers for analysis.

2.3 Proximate Analysis

The dry matters contents, crude protein, crude fat and ash were determined in accordance with the standard methods of the AOAC [17]. Dry matters were determined by drying in an oven at 105℃ for 24 h to constant weight. Crude protein determination involved the use of routine Kjeldahl nitrogen assay (N × 6.25). Crude fat was determined by exhaustively extracting samples in a soxhlet apparatus using hexane as solvent. Ash was determined by incinerating in a fumace at 550℃ for 6 h, then weighing the residue after cooling to room temperature in a dessiccator. The method described by Dubois et al. [18] was used for the total sugar contents analysis. Reducing sugar contents were determined according to the method of Bernfeld [19] using 3.5 dinitrosalycilic acid. The total phenolic compound was determined according to the spectrophotometric method described by Swain and Hillis [20] using the Folin-Ciocalteu reagent.

2.4 Mineral Analysis

Magnesium, calcium, copper, potassium and zinc were quantitatively determined from the digest using strong acids and the atomic absorption spectrophotometer with appropriate hollow cathode lamps [17].

2.5 Functional Properties

2.5.1 Water absorption capacity (WAC) and solubility index (WSI)

The water absorption capacity (WAC) is an indispensable technological parameter allowing to control the consistency of the dough. The solubility corresponds to the ability of a powder to rehydrate under predetermined conditions. It is therefore an essential criterion in the control of the quality of the powders intended to be reincorporated in the aqueous phase.The water absorption capacity (WAC) and solubility index (WSI) of flours from yam (*D. alata,* cv Azaguié) tubers were evaluated according to Philips et al. [21] and Anderson et al. [22] methods, respectively. The flour from yam tubers (1 g) were each weighed into a centrifuge tube and 10 mL distilled water added. The content of the centrifuge tube was shaken for 30 min in a KS 10 agitator. The mixture was kept in a water-bath (37℃) for 30 min and centrifuged (Ditton LAB centrifuge, UK) at 5000 rpm for 15 min. The resulting sediment (*M2*) was weighed and then dried at 105℃ to constant weight (*M1*). The WAC was then calculated as follows:

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

While the WSI was calculated using the following equation:

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

2.5.2 Oil absorption capacity and hydrophilic-lipophilic index

The oil absorption capacity (OAC) of flours was assayed according to the method of Sosulski [23]. One (1) g of flour (*M0*) was 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 (*M1*) was weighed and the OAC was then calculated as follows:

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

While hydrophilic-lipophilic index (HLI) was determined as the ratio of WAC to that of OAC [24].

2.6 Bulk Density

The bulk density of a powder corresponds to the ratio between the mass of powder and the volume of solid including the closed intraparticle pores.The method of Narayana and Narasinga [25] was used to determine the bulk density of yam flour samples. A 50 g flour sample was put into a 100 ml measuring cylinder. The cylinder was tapped continuously on a laboratory bench until a constant volume was obtained. The bulk density (g/cm^3) was calculated as weight of flour (g) divided by flour volume (cm^3).

2.7 Wettability

It reflects the ability of a powder to absorb water after it has been deposited on the surface of a liquid. The wettability was determined by Onwuka method [26]. The flour sample (1 g) was added into a 25 ml graduated cylinder with a diameter of 1 cm. A finger was placed over the open end of the cylin0der, it was inverted and clamped at a height of 10 cm from the surface of a 600 ml beaker containing 500 ml of distilled water. The finger was then removed to allow the test material to be dumped. The wettability is the time required for the sample to become completely wet.

2.8 Foam Capacity and Foam Stability

The foam capacity corresponds to the ability to stabilize an air / water interface and therefore to increase the volume of a product. Foam stability is defined by the time elapsed before the foam collapses. The foam capacity (FC) and stability (FS) of flours were studied by the method of Coffman and Garcia [27]. Three (3) g of flour was transferred into clean, dry and graduated (50 ml) cylinders. The flour samples were gently leveled and the volumes noted. Distilled water (30 ml) was added to each sample; the cylinder was swirled and allowed to stand for 120 min while the change in volume was recorded every 10 min.

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

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

2.9 Statistical Analysis

All analyses in this study were threefold. In each case a mean value and standard deviation were calculated. Statistical analyses of the data were performed using software Statistica 7.1. Comparisons between the dependent variables were determined using variance analysis (ANOVA) and the Duncan test. Statistical significance was set at $P \leq 0.05$.

3. RESULTS AND DISCUSSION

3.1 Proximate Composition

The proximate composition of yam flour « Azaguié » during the post-harvest conservation is presented in Table 1. Statistical analysis showed significant differences ($P \leq 0.05$) between the means of variables estimated except for lipid content. Dry matter of yam flour « Azaguié » increased from 88.73 ± 0.15 to 92.67 ± 0.12% during the 6 month of storage. This observation is similar to what was reported by Otegbayo et al. [12] who noted variation from 25.32% to 26.72% of yam (*D. alata*) and 34.83% to 41.77% of yam (*D. rotundata cayenensis*). Dry matter increase was due to the loss of water by tubers during storage. This phenomenon was caused by the setting up of the germination process that requires a strong increase of the respiratory intensity and perspiration acceleration [28].

Total and reducing sugars contents were ranged from 2.90 ± 0.15 to 5.60 ± 0.14 g / 100 g dm and from 0.71 ± 0.03 to 2.01 ± 0.02 g / 100 dm, respectively. These values were lower than those reported with yam "Kponan" (*D. cayenensis-rotundata*) flours (6.51 ± 0.09 for total sugars and 3.82±0.24 for reducing sugars) [29]. Total and reducing sugars increase could be attributed to hydrolysis of starch by the amylolytic enzymes present in the tuber starch [30]. The presence of reducing sugars in flour may cause caking and damping during their storage because of sugar's hygroscopic property. However, yam is desirable in bakery products like bread and cake where the tenderising effects positively affect texture and where sugars serve as substrate for fermentation of the dough [31].

Protein content of yam « Azaguié » (*D. alata*) decreased from 8.59 ± 0.39 to 6.90 ± 0.30 g / 100 g dm. The protein value reported in this work was higher than the value (5.7- 8.3%) reported by Udensi et al. [32] with different varieties for (*D. alata*). The decrease of protein content during conservation could be explained by reduction of the protein synthesis capacity as well as proteolysis initiated by the proteases [33].

Ash content of yam flour decreased from 3.20 ± 0.10 to 2.60 ± 0.10 g / 100 g dm. 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 [34]. Decrease in ash content may be due to the involvement of minerals in the tuber phenomenon of respiration and metabolic processes in the bud [33,35]. Values were in agreement with those reported by Amani and Kamenan [36]. They recorded in whole tubers of yams (*D. alata*) cv « Florido », « Bètè-bètè » (*D. cayenensis-rotundata*) cv « Kponan » and « Krenglè » respective rates of 3.3%; 3.4%; 2% to 2.9%.

Phenolic compound content ranged from 437.09 ± 15.25 to 99.55 ± 13.36 mg / 100 dm. Changes in phenolic compounds exhibited during post-harvest storage were attributed to the role of phenolic compounds in the morphogenesis of the stems formed on the tuber [37]. Similar change was recorded by Medoua et al. [37] who noted reduction of total phenols from 318 to 248.4 mg / 100 g dry weight after 56 days of storage in *D. dumetorum*.

3.2 Minerals

Minerals are important to diet because of their physiological and metabolic function in the body. The result presented in Table 2 showed the mineral evolution of the yam flours during the post-harvest conservation from yam tubers. Generally, the mineral contents decreased significantly ($P \leq 0.05$) with the conservation time. Within this flour, calcium content varied from 56.82 ± 1.05 to 50.13 ± 0.64 mg / 100 g dm. Copper content ranged from 1.77 ± 0.04 to 0.97 ± 0.04 mg / 100 g dm. Potassium content decreased from 698.02 ± 3.67 to 567.99 ± 2.77 mg / 100 g dm. Magnesium content varied from 86.53 ± 2.16 to 80.88 ± 2.53 mg / 100 g dm. Zinc content ranged from 3.15 ± 0.05 to 1.11 ± 0.03 mg / 100 g dm. Decrease of all minerals content during the post-harvest conservation would be caused by their transfer towards the bud for the metabolic process entailed by germination [35]. This observation is similar to what was reported by Djè et al. [30] who noted a decrease of minerals (magnesium, calcium and zinc) during the post-harvest conservation of yam flour from different parts (distal, median, proximal) of tubers.

3.3 Functional Properties

In this study, the change in conservation time led to a significant ($P \leq 0.05$) variation in the functional properties of yam flour « Azaguié » as shown in Table 3. The Water absorption characteristic represents the ability of a product to associate with water under conditions where water is limiting e.g. dough and pastes [38]. Water absorption capacity (WAC) is important to certain product characteristics, such as the moistness of the product, starch retrogradation, and subsequent product scaling [39]. The WAC of the flour ranged from 265.74 ± 1.91 to 302.61 ± 2.16%, indicating that flour from tubers during the post-harvest conservation has higher WAC. According to Diallo et al. [40], flour with high WAC can add more water to the dough and improve maneuverability. Therefore, it is useful in baking property. The range of WAC observed for flour sample analyzed is higher compared to those of flours from yam (*Dioscorea dumetorum*) (182.3 ± 4.1 to 390.7 ± 4.4%) during 56 days post-harvest conservation [41].

Oil absorption is an important property in food formulations because fats improve the flavour and mouthfeel of foods [42]. In this study, the oil absorption capacity (OAC) ranged from 35.87 ± 0.45 to 40.13 ± 0.40%. These values were lower than those obtained for yam (*D. dumetorum*) flour (72.3 ± 1.9 t0 94.8 ± 2.4%) [41]. The variation in OAC depends on the presence of non-polar side chains, which bind the hydrocarbon side chain of oil. 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 [43]. The increase in protein also enhances the hydrophobicity and exposed more the polar amino acid to the fat [44]. Thus, the decrease in protein in yam « Azaguié » flours would tend to reduce the hydrophobicity, and thereby causing a low fat binding to protein. The oil absorption capacity of the protein is required in ground meat formulations, meat replacers and extenders, doughnuts, pancake, baked food and soups. [45].

Ease of dispersibility or wettability is important in food formulations. Wettability of protein is affected by surface polarity, topography, texture and area and by the size and microstructure of the protein particles, but not necessarily by the amount of native structure. Wettability among the samples ranged from 50 ± 2 to 87 ± 2 sec. These values are lower at 120 dry which would mean that these flours are wettable [46]. Values obtained are higher than those recorded by Udensi et al. [32] for different flour varieties of *D. alata* (27-35 secs).

Table 1. Evolution of biochemical parameters of the yam flour « Azaguié » during the post-harvest conservation of yam tubers

Parameters	Conservation time (months)			
	0	2	4	6
Dry matter (%)	88.73 ± 0.15[a]	90.10 ± 0.23[b]	91.60 ± 0.26[c]	92.67 ± 0.12[d]
Proteins (g/100 g dm)	8.59 ± 0.39[a]	7.91 ± 0.32[b]	7.41 ± 0.25[bc]	6.90 ± 0.30[c]
Lipids (g/100 g dm)	0.30 ± 0.01[a]	0.30 ± 0.01[a]	0.30 ± 0.01[a]	0.30 ± 0.01[a]
Total sugar (g/100 g dm)	2.90 ± 0.15[a]	3.42 ± 0.13[b]	4.39 ± 0.17[c]	5.60 ± 0.14[d]
Reducing sugars (g/100 g dm)	0.71 ± 0.03[a]	1.21 ± 0.05[b]	1.60 ± 0.06[c]	2.01 ± 0.02[d]
Ash (g/100 g dm)	3.20 ± 0.10[a]	3.01 ± 0.06[b]	2.81 ± 0.06[c]	2.60 ± 0.10[d]
Phenolic compounds (mg/100 g dm)	437.09 ± 15.25[a]	306.33 ± 14.85[b]	197.36 ± 14.65[c]	99.55 ± 13.36[d]

dm: Dry matter

The obtained values are averages ± standard deviation of triplicate determinations. Means within the same row with different superscript are significantly (p≤0.05) different

Table 2. Evolution of some minerals in yam flour « Azaguié » during the post-harvest conservation of yam tubers

Minerals (mg / 100 g dm)	Conservation time (months)			
	0	2	4	6
Calcium	56.82 ± 1.05[a]	53.66 ± 0.92[b]	53.19 ± 0.70[b]	50.13 ± 0.64[c]
Copper	1.77 ± 0.04[a]	1.18 ± 0.03[b]	1.00 ± 0.03[c]	0.97 ± 0.04[c]
Potassium	698.02 ± 3.67[a]	618.42 ± 2.52[b]	606.19 ± 2.16[c]	567.99 ± 2.77[d]
Magnesium	86.53 ± 2.16[a]	82.70 ± 2.27[b]	81.99 ± 2.23[b]	80.88 ± 2.53[c]
Zinc	3.15 ± 0.05[a]	1.40 ± 0.05[b]	1.19 ± 0.10[c]	1.11 ± 0.03[c]

dm: Dry matter

The obtained values are averages ± standard deviation of triplicate determinations. Means within the same row with different superscript are significantly (p≤0.05) different

Water solubility index (WSI) reflects the extent of starch degradation [47]. The WSI of flour from yam tuber « Azaguié » decreased from 40.17 ± 0.25 to 30.83 ± 0.40% during the post-harvest conservation. WSI indicates that post-harvest conservation had more profound effects on starch degradation. Similar observations were recorded by Hsu et al. [48] and Medoua et al. [41] when using yam (*Dioscorea spp*) flour (9.26 ± 0.11 to 15.31 ± 0.85%) and yam (*D. dumetorum*) flour (15.0 ± 0.1 to 14.8 ± 0.4%), respectively.

The hydrophilic-lipophilic index (HLI) varied from 8.44 ± 0.12 to 6.62 ± 0.11. HLI variation would be related to the different variations of the WAC and OAC during the post-harvest conservation of yam tubers. The values obtained in this study are higher than those reported by Medoua *et al.* [41] for (*D. dumetorum*) flour (2.5 ±0.1 to 4.1 ± 0.1), suggesting that yam « Azaguié » flour has more affinity for water than for oil.

The bulk density of flour from yam tuber « Azaguié » ranged from 1.14 ± 0.02 to 0.76 ± 0.01 g / cm^3. The values obtained were higher than those found by Udensi et al. [32] (0.64 - 0.76 g / cm^3). High bulk density increases the rate of dispersion [49], which is important in the reconstitution of yam flours in hot water to produce yam *fufu* dough. According to Bello and Okezie [50], bulk density of a good material is also important in relation to its packaging.

The foaming properties of proteins, the ability to form stable and consistent foams are important in preparing cakes and desserts [51]. Indeed, the foams are used to improve the texture, consistency and appearance of food [29]. In our study, the foaming capacity (24.41 ± 0.94 to 18.80 ± 0.63%) and foam stability (Fig. 1) decreased during the post-harvest conservation of yam tubers. This variation may be due to protein denaturation during post-harvest conservation. Moreover, according to Halling [52], the protein concentration would play on the formation and stability of foams. Similar variations were recorded by Koné et al. [29] when using yam « Kponan » flour (25.80 to 13.32 %) during the cooking water of yam tubers.

Table 3. Evolution of the functional properties of yam flour « Azaguié » during post-harvest conservation of yam tubers

Functional properties	Conservation time (months)			
	0	**2**	**4**	**6**
WAC (%)	265.74 ± 1.91[a]	280.53 ± 2.71[b]	288.86 ± 6.85[c]	302.61 ± 2.16[d]
WSI (%)	40.17 ± 0.25[a]	37.87 ± 0.25[b]	34.23 ± 0.25[c]	30.83 ± 0.40[d]
OAC (%)	35.87 ± 0.45[a]	36.80 ± 0.30[b]	38.10 ± 0.20[c]	40.13 ± 0.40[d]
IHL	8.44 ± 0.12[a]	7.85 ± 0.19[b]	7.36 ± 0.04[c]	6.62 ± 0.11[d]
bulk density (g/cm^3)	1.14 ± 0.02[a]	1.02 ± 0.04[b]	0.91 ± 0.04[c]	0.76 ± 0.01[d]
wettability (sec)	50 ± 2[a]	60 ± 3[b]	72 ± 3[c]	87 ± 2[d]
Foaming capacity (%)	24.41 ± 0.94[a]	21.42 ± 0.46[b]	20.09 ± 0.25[c]	18.80 ± 0.63[d]

The obtained values are averages ± standard deviation of triplicate determinations. Means within the same row with different superscript are significantly (p≤0.05) different

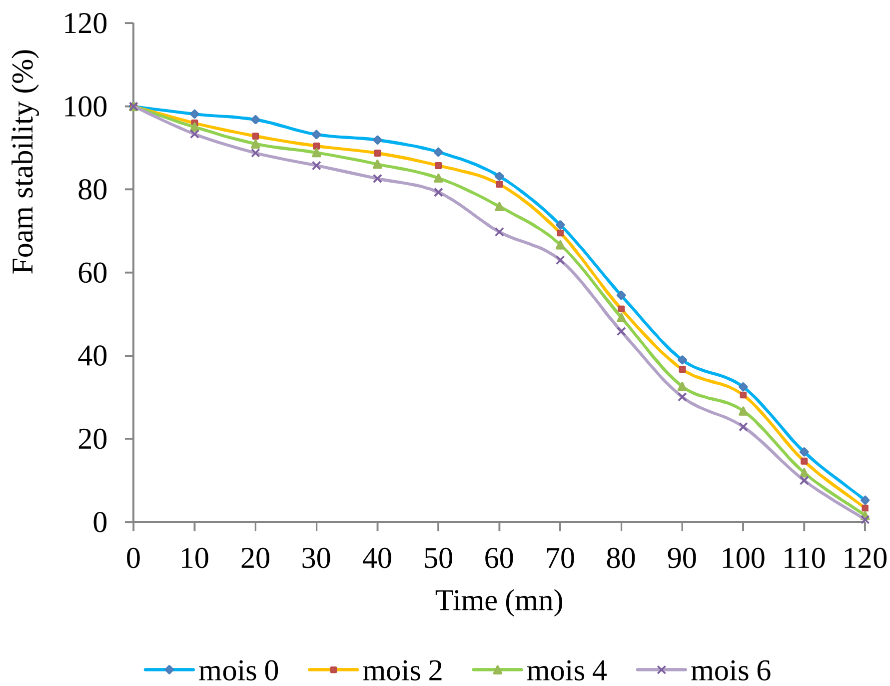

Fig. 1. Evolution of the foam stability of yam flour « Azaguié » during post-harvest storage of yam tubers

4. CONCLUSION

After this study, it appears that except for lipids, the post-harvest conservation of yam variety « Azaguié » tubers had a significant influence on the biochemical parameters and functional properties of flour. In general, the dry matter, total and reducing sugars contents increased with the post-harvest conservation time. In contrast, protein, starch, phenolic compound, ash and minerals contents of yam flour decreased with the post-harvest conservation time of yam tubers. In addition, the water absorption capacity and oil as well as the wettability of flour increased. Conversely, bulk density, index of solubility, foaming capacity and foam stability flour decreased with the post-harvest conservation time of yam tubers. The results suggest that, for the use of yam « Azaguié » flour as ingredient in food formulation, it is necessary to take into consideration the state of the tubers. Thus, this study gives us information on the choice of yam tubers for the use of flour in food technology.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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