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CHARCOAL-BASED CONSERVATION METHODS' IMPACT ON SOME FUNCTIONAL PROPERTIES OF FLOURS OF THREE PLANTAIN VARIETIES (*Musa sp.*)

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Abstract: *The plantain contributes significantly to food security in sub-Saharan Africa. However, the sector is faced with several difficulties, in particular the lack of inexpensive conservation techniques accessible to all. In response, a conservation method combining charcoal and polyethylene bags was tested on the SACI, Big-Ebanga, and Orishélé varieties, harvested at the mature stage. The water and oil absorption capacity and the solubility index were determined according to standard methods. The results indicated a significant increase in these properties during storage. The water and oil absorption capacity and solubility index of fruit flour preserved in a control environment without polythene and charcoal are between 197.35% and 242.21%, 30.56% and 59.80%, and between 29.19% and 43.7 2%, respectively. Plantain bananas stored in a control environment consisting of charcoal-free polyethylene packaging recorded water and oil absorption capacities and solubility index of between 214.12% and 241.19%, 35.86% and 59.21% then between 35.29% and 44.27%, respectively. Fruit flours packed in polythene bags containing dry or moistened solid charcoal or dry or moistened charcoal powder have recorded water and oil absorption capacities and solubility between 215.11% and 241.14%, 35.90% and 59.51% and between 35.32% and 43.72%, respectively. Charcoal preservation can be a solution approach to the problem of post-harvest loss.*

Keywords: *Plantain flours, functional parameters, storage, polyethylene.*

1. Introduction

Plantain is one of the main food sources of significant income for producing countries [1]. The plantain is cultivated in more than 120 countries for an area of about 10 million hectares and a world production of nearly 106 million tons per year [2]. This makes it the second food crop in the world after cereals and the fourth cultivated food crop in the world after rice, wheat, and maize [3]. Plantains are consumed in different forms of food depending on the state of maturity of the available bananas, including fries, boiled, roasted, mashed, etc. [4]. Its average annual consumption per person in Côte d'Ivoire is around 75 kg [5]. Plantain is a foodstuff characterized by a high carbohydrate content (more than 28 g per 100 g).

Although plantain is in high demand and sells very well on the Ivorian market, its expansion faces several constraints. The most missing is the absence of conservation methods using inexpensive, practical, and accessible techniques,

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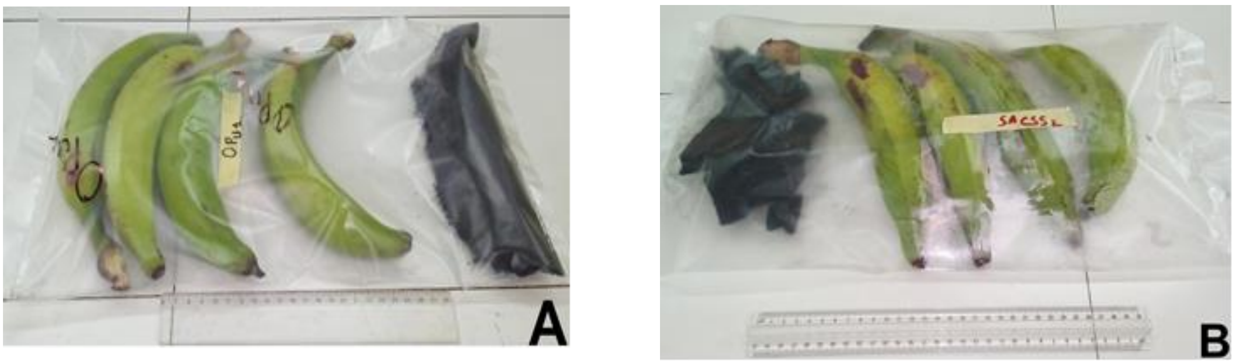
resulting in a lasting positive impact on food security. In fact, under normal ambient temperature conditions (30°C), the plantain ripens between 5 and 9 days after harvest, when physiological maturity is reached. Temperature, oxygen, carbon dioxide (CO2), and ethylene are factors that influence the ripening process of banana fruits. Ethylene is the hormone that initiates all the processes involved in fruit ripening [6]. Upon maturity, the fruit enters a period of senescence, which results in cellular disorganization and death. Knowing that charcoal has been known for a long time for its ability to adsorb gases, it was used in this study to slow down fruit ripening by ethylene absorption. The objective of this work is to evaluate the impact of charcoal-based preservation methods on some functional parameters of plantain bananas.

2. Matherials and methods

Material

The plantain bananas that were the subject of this study come from a plantation in the locality of Azaguié, about 50 km from Abidjan in Côte d'Ivoire. These are three cultivars, namely Big-Ebanga, SACI, and Orishèlé. The fruits were harvested at optimum maturity according to the method described by Gnakri and Kamenan [7] and Kouadio et al. [8]. It corresponds to 70 days for the Orishélé variety and 80 days for those of SACI and Big-Ebanga. As part of this study, 68 bunches were harvested including 25 bunches of the Orishélé variety, 26 bunches of Big-Ebanga, and 17 bunches of SACI. The preservation method consisted of packing four (4) plantain fingers in plastic bags containing either solid dry or moistened solid charcoal, or dry or moistened charcoal powder (Figure 1). The wet charcoal powder used was extracted from a mixture of dry charcoal powder moistened to 1/5 (V/V) of its volume. Solid coals immersed in water for a few seconds constituted the moistened solid coals used. The dimensions of the packaging bags were a function of the size of the plantain bananas and the mass of charcoal used according to the mass of the fingers of the plantain bananas. That is 7g of charcoal for 100g of plantain. Hermetically sealed packages were stored at a temperature of 28°C.



A: Fruit of plantain bananas stored in packages containing coal powder;

B: Plantain banana fruit stored in packages containing solid coal

Fig 1: Conservation methods for the fruits of the plantains studied

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Method

Flour production technology

For flour production, 600 g of each plantain sample was peeled using a stainless-steel knife. The pulp obtained was washed and cut into slices (about 1 cm thick). These slices were dried in a ventilated oven (MEMMERT, 854 Scwachbach, West Germany) at 45°C for 48 hours and then ground. The grinding was passed through a 200 um mesh sieve to obtain the flour.

Determination of water absorption capacity and water solubility index

The water absorption capacity and the water solubility index of the plantain flours were respectively determined according to the methods of Phillips et al. [9] and Anderson et al. [10]. One (1) g of plantain flour (m0) was dissolved in 10 ml of distilled water in a centrifuge tube. This mixture was stirred for 30 min and then kept in a water bath (Water bath HH-W600, China) at 37° C for 30 min. It was then centrifuged (Sigma 3-16P) at 4200 rpm for 20 min. The pellet obtained (m2) was weighed, and then dried (Biobase BOV-D70, China) at 105°C in an oven until a constant mass (m1) was obtained. The water absorption capacity and water solubility index were calculated according to the formula below.

$$\text{Water absorption capacity}\ (\%) = \frac{(m_2 - m_1)}{m_1} \times 100 \quad (1)$$

$$\text{Water solubility index}\ (\%) = \frac{(m_0 - m_1)}{m_0} \times 100 \quad (2)$$

m_0: mass of the sample taken
m_1: dry mass of the sample after passing through the oven
m_2: mass of the fresh pellet after centrifugation

Determination of oil absorption capacity

The oil absorption capacity of flour has been determined according to the method described by Sosulski [11]. A quantity of 1g of plantain flour (m0) was dissolved in 10 ml of oil. The mixture was agitated for 30 min at room temperature using a mechanical agitator (Vortex Genie K550-Ge, United States) and then, centrifuged (Sigma 3-16p, Germany) at 4200 rpm for 12 min. The pellet obtained was weighed (m1). The oil absorption capacity was calculated using the following formula:

$$\text{Oil absorption capacity}\ (\%) = \frac{(m_1 - m_0)}{m_0} \times 100 \quad (3)$$

m_0: mass (g) of the sample taken
m_1: mass (g) of the fresh pellet of the sample after centrifugation

Statistical analysis

Statistical analysis of the data was carried out using the IBM SPSS STATISTICS 21 software. The comparison of the means was made according to the Tukey test at the 5% threshold.

3. Results and discussion

Water absorption capacity

The water absorption capacity of the SACI variety (Table 1) which was initially 197.35% increased ($p \leq 0.5$) during storage to reach, after 30 days, 218.13% for Sassi in polythene bags containing dry solid charcoal (SACSS), 215.11% for Sassi in polythene bags containing wet solid charcoal (SACSH), 216.71% for Sassi in polythene bags containing dry powdered charcoal (SACPS) and 217.05% for Sassi in polythene bags containing wet charcoal powder (SACPH). Those of the control samples that are Sassi without packaging (SA) and Sassi in polythene bags without carbon (SSC), whose respective storage

times were 12 days and 24 days, recorded 213.90% and 214.12%, at the end of storage.
For the Big-Ebanga variety (Table 2), the values of the water absorption capacity of the fruits increased (p ≤ 0.5) as well and went from day 0 to day 30 from 230.48% to 240 .43% for Big-Ebanga in polythene bags containing dry solid charcoal (BCSS), 240.74% for Big-Ebanga in polythene bags containing wet solid charcoal (BCSH), 240.79% for Big-Ebanga in polythene bags containing dry powdered charcoal (BCPS) and 241.14% for Big-Ebanga in polythene bags containing wet charcoal powder (BCPH). The BCPH (241.14%) recorded the highest water absorption capacities while those of the BCSS (240.74%) were the lowest. In addition, the control fruits of this variety that are Big-Ebanga without packaging (B) whose storage time was 12 days and Big-Ebanga in polythene bags without carbon (BSC) whose storage time was 24 days have obtained, respectively, at the end of storage, flours whose water absorption capacity was 242.21% and 241.19%.
As for the fruits of the Orishélé variety (Table 3), the water absorption capacity increased (p ≤ 0.5), and the rates varied from day 0 to day 30 from 213.85% to 222, 59% for Orishele in polythene bags containing dry solid charcoal (OCSS), 222.31% for Orishele in polythene bags containing wet solid charcoal (OCSH), 222.71% for Orishélé in polythene bags containing dry powdered charcoal (OCPS) and 222.51% for Orishélé in polythene bags containing wet charcoal powder (OCPH). At day 30, fruits of OCSH (222.31%) had the lowest rate of water absorption capacity and those of OCPS (222.71%) had the highest rate. On the other hand, the control fruits of this variety have obtained, after respective conservation periods of 12 days for Orishélé without packaging (O) and (24) days for Orishélé in polythene bags without carbon (OSC), flours whose water absorption capacities were 221.26% and 221 .61%.
These rates are higher than those of Sylvain et al. [12] who obtained rates whose highest value was 180.29% for plantain flour. The statistical analysis results indicated a significant difference (p ≤ 0.5) between the values of the water absorption capacity of the flours of the fruits from one storage environment to another.
The high water absorption capacity could also be the result of the synthesis of hydrophilic constituents (amino acid, amylose, amylopectin) during ripening ([13], [14]), which contributed to increase the sites of interaction with water ([15], [16]). Furthermore, Diallo et al. [17] showed that the size of the starch grains and the high carbohydrate content in flour could promote greater water absorption. These high water absorption capacities of flours suggest that they can be incorporated with water, hence used in the formulation of certain foods such as sausages, pasta, and baked goods [18].

Refined palm oil absorption capacity
The refined palm oil absorption capacity of SACI variety fruit flour (Table 4) increases (p ≤ 0.5) during storage. The rate observed at the start of storage (day 0) is 30.56%. After 30 days of storage, this rate reached 36.13% for SACSS, 36.26% for SACSH, 35.90% for SACPS, and 36.82% for SACPH.
The highest refined palm oil absorption capacities of the SACI variety at day 30 were those of the fruits of SACPH (36.83%) and SACSH (36.26%), while the lowest rates were obtained from the fruits of the SACPS (35.90%). The control samples SA and SSC whose respective storage times were 12 days and 24 days

recorded respective rates of 36.79% and 35.86%, at the end of storage.

Table 1:
Evolution of the water absorption capacity (WAC) of the *SACI* variety in six storage environments

Storage time (Day)	WAC of SA (%)	WAC of SACSS (%)	WAC of SACSH (%)	WAC of SACPS (%)	WAC of SACPH (%)	WAC of SSC (%)
D0	197.35 ± 0.57^{aA}					
D4	201.63 ± 0.03^{bF}	198.02 ± 0.04^{aB}	198.82 ± 0.03^{aE}	197.98 ± 0.02^{aA}	198.09 ± 0.05^{aC}	198.70 ± 0.06^{aD}
D8	206.73 ± 0.02^{cF}	198.85 ± 0.04^{aA}	199.12 ± 0.02^{bB}	199.44 ± 0.02^{bC}	203.21 ± 0.08^{bE}	199.72 ± 0.07^{bD}
D12	213.90 ± 0.14^{dE}	200.34 ± 0.02^{abA}	201.04 ± 0.02^{cC}	201.03 ± 0.02^{cC}	207.72 ± 0.04^{cD}	200.47 ± 0.05^{cB}
D16		202.41 ± 0.03^{bcA}	204.67 ± 0.02^{dB}	202.26 ± 1.12^{dA}	212.64 ± 0.06^{dC}	201.78 ± 0.06^{dA}
D20		205.15 ± 0.05^{cB}	207.47 ± 0.03^{eC}	203.41 ± 0.03^{eA}	213.72 ± 0.04^{eE}	209.13 ± 0.09^{eD}
D24		209.85 ± 0.03^{dC}	209.81 ± 0.04^{fB}	206.45 ± 0.03^{fA}	215.01 ± 0.05^{fE}	214.12 ± 0.08^{fD}
D28		212.11 ± 0.02^{eC}	211.62 ± 0.18^{gB}	209.06 ± 0.03^{gA}	216.24 ± 0.02^{gD}	
D30		218.13 ± 0.02^{fB}	215.11 ± 0.02^{hA}	216.71 ± 0.03^{hAB}	217.05 ± 0.05^{hAB}	

These values are the means of three determinations for each parameter. The means ± standard deviation, assigned different lowercase letters in the same column indicate a significant difference ($p < 0.05$) between the storage days according to Tukey. Means ± standard deviation with different capital letters in the same row indicates a significant difference between storage media according to Tukey.
WAC: water absorption capacity; **SA:** *SACI* without packaging; **SACSS**: *SACI* in polythene bags containing dry solid carbon; **SACSH**: *SACI* in polythene bags containing wet solid carbon; **SACPS**: *SACI* in polythene bags containing dry powdered charcoal; **SACPH**: *SACI* in polythene bags containing wet powdered charcoal; **SSC**: *SACI* in polythene bags without carbon.

Table 2:
Evolution of the water absorption capacity (WAC) of the *Big-Ebanga* variety in six storage environments

Storage time (Day)	WAC of B (%)	WAC of BCSS (%)	WAC of BCSH (%)	WAC of BCPS (%)	WAC of BCPH (%)	WAC of BSC (%)
D0	230.48 ± 0.09^{aA}					
D4	$234,53 \pm 0.02^{bF}$	230.77 ± 0.01^{aD}	229.65 ± 0.02^{aA}	231.02 ± 0.02^{aE}	230.74 ± 0.02^{aC}	230.64 ± 0.01^{aB}
D8	$237,95 \pm 0.01^{cF}$	232.31 ± 0.03^{bD}	230.26 ± 0.03^{bA}	232.17 ± 0.02^{bC}	231.12 ± 0.02^{bB}	232.54 ± 0.01^{bE}
D12	242.21 ± 0.03^{dF}	232.89 ± 0.02^{cC}	231.31 ± 0.02^{cA}	232.36 ± 0.01^{cB}	233.07 ± 0.01^{cD}	233.73 ± 0.02^{cE}
D16		235.92 ± 0.03^{dD}	233.12 ± 0.15^{dA}	233.21 ± 0.03^{dB}	233.21 ± 0.02^{dB}	234.59 ± 0.01^{dC}
D20		237.06 ± 0.01^{eE}	235.16 ± 0.01^{eB}	235.18 ± 0.02^{eC}	236.54 ± 0.01^{eD}	235.03 ± 0.02^{eA}
D24		237.83 ± 0.01^{fB}	237.51 ± 0.02^{fB}	236.81 ± 0.02^{fA}	239.23 ± 0.02^{fC}	241.19 ± 0.03^{fD}
D28		238.09 ± 0.02^{gA}	239.91 ± 0.03^{gC}	239.52 ± 0.02^{gB}	241.03 ± 0.03^{gD}	
D30		240.43 ± 0.04^{hA}	240.74 ± 0.02^{hB}	240.79 ± 0.06^{hB}	241.14 ± 0.02^{hC}	

These values are the means of three determinations for each parameter. The means ± standard deviation, assigned different lowercase letters in the same column indicate a significant difference ($p < 0.05$) between the storage days according to Tukey. Means ± standard deviation with different capital letters in the same row indicates a significant difference between storage media according to Tukey.
WAC: water absorption capacity; **B:** *Big-Ebanga* without packaging; **BCSS**: *Big-Ebanga* in polythene bags containing dry solid charcoal; **BCSH**: *Big-Ebanga* in polythene bags containing wet solid charcoal; **BCPS**: *Big-Ebanga* in polyethylene bags containing dry powdered charcoal; **BCPH**: *Big-Ebanga* in polyethylene bags containing wet powdered charcoal; **BSC**: *Big-Ebanga* in polyethylene bags without carbon

Table 3:
Evolution of the water absorption capacity (WAC) of the *Orishele* variety in six storage environments

Storage time (Day)	WAC of O (%)	WAC of OCSS (%)	WAC of OCSH (%)	WAC of OCPS (%)	WAC of OCPH (%)	WAC of OSC (%)
D0	213.85 ± 0.01^{aA}					
D4	217.24 ± 0.01^{bE}	214.51 ± 0.01^{aD}	214.14 ± 0.03^{aC}	214.03 ± 0.05^{aB}	213.31 ± 0.04^{aA}	214.02 ± 0.02^{aB}
D8	219.45 ± 0.12^{cE}	214.64 ± 0.05^{bB}	214.82 ± 0.05^{bC}	215.17 ± 0.02^{bD}	214.38 ± 0.19^{bA}	214.43 ± 0.14^{bA}
D12	221.26 ± 0.02^{dF}	216.57 ± 0.02^{cE}	215.81 ± 0.02^{cC}	215.92 ± 0.02^{cD}	214.96 ± 0.03^{cB}	214.89 ± 0.02^{cA}
D16		217.72 ± 0.02^{dE}	217.01 ± 0.02^{dC}	217.10 ± 0.01^{dD}	216.02 ± 0.02^{dB}	215.83 ± 0.05^{dA}
D20		219.01 ± 0.01^{eE}	217.24 ± 0.02^{eC}	217.37 ± 0.01^{eD}	216.44 ± 0.01^{eA}	216.94 ± 0.03^{eB}
D24		219.91 ± 0.01^{fD}	219.13 ± 0.03^{fC}	21761 ± 0.05^{fB}	217.15 ± 0.02^{fA}	221.61 ± 0.02^{gE}
D28		220.04 ± 0.01^{gB}	220.39 ± 0.01^{gD}	219.123 ± 0.01^{gA}	220.31 ± 0.04^{gC}	
D30		222.59 ± 0.01^{hC}	222.31 ± 0.01^{hA}	222.71 ± 0.02^{hD}	222.51 ± 0.01^{hB}	

These values are the means of three determinations for each parameter. The means ± standard deviation, assigned different lowercase letters in the same column indicate a significant difference (p < 0.05) between the storage days according to Tukey. Means ± standard deviation with different capital letters in the same row indicates a significant difference between storage media according to Tukey.
WAC: water absorption capacity; **O:** *Orishele* without packaging; **OCSS**: *Orishele* in polythene bags containing dry solid charcoal; **OCSH**: *Orishele* in polythene bags containing wet solid charcoal; **OCPS**: *Orishele* in polyethylene bags containing dry powdered charcoal; **OCPH**: *Orishele* in polyethylene bags containing wet powdered charcoal; **OSC**: *Orishele* in polyethylene bags without carbon

For the Big-Ebanga variety (Table 5), the refined palm oil absorption capacity observed on day 0 was 45.45%. This rate increased (p ≤ 0.5) and reached, after 30 days of storage, respective rates of 49.49% for BCSS, 49.32% for BCSH, 49.13% for BCPS, and 48.91 % for BCPH. BCSS flours obtained the highest rate of refined palm oil absorption capacity (49.49%) while BCPH flours (48.91%) and BCPS flours (49.13%) recorded the lowest rates. In addition, the control fruits of this variety were obtained at the end of conservation flours with refined palm oil absorption capacity of 49.31% for the B and 49.17% for the BSC.
As for the Orishélé variety (Table 6), the absorption capacity of refined palm oil which was 50.41% on day 0 increased (p ≤ 0.5) to respectively reach 59.51% for the OCSS, 58.38% for OCSH, 58.07% for OCPS and 58.13% for OCPH, after 30 days of storage. The fruits of the OCSS (59.51%) presented the highest refined palm oil absorption capacities while the lowest rates were obtained by the OCPS (58.07%). On the other hand, the control fruits of this variety were obtained after respectively 12 days (O) and 24 days (OSC) of conservation of the flours whose refined palm oil absorption capacities were 59.80% and 59.21%.
Statistical analysis indicates a significant difference (p ≤ 0.5) between the values of the refined palm oil absorption capacity of fruits from one storage environment to another.
The increase in oil absorption capacity during storage could be attributed to the increase in protein content, which increases the hydrophobicity of flour [13]. Indeed, the oil absorption capacity is the capacity of a protein to absorb and maintain oil in its structure. It can therefore be influenced by the lipophilic nature of proteins [19]. These results are lower than that (85.9%) obtained by Medoua [20] on yam flours (*Dioscorea dumetorum*) kept

for 2 days and then dehydrated in an oven at 45°C. flour with high oil absorption capacity assumes that it has good lipophilic constituents and can therefore be suitable for the production of sausages, cakes, and donuts [21].

Table 4:
Evolution of the refined palm oil absorption capacity (RPOAC) of the *SACI* variety in six storage environments

Storage time (Day)	RPOAC of SA (%)	RPOAC of SACSS (%)	RPOAC of SACSH (%)	RPOAC of SACPS (%)	RPOAC of SACPH (%)	RPOAC of SSC (%)
D0	30.56 ± 0.01^{aA}					
D4	31.05 ± 0.63^{aF}	30.87 ± 0.06^{aD}	30.76 ± 0.11^{aB}	31.07 ± 0.03^{aA}	31.17 ± 0.02^{aC}	30.52 ± 0.02^{aE}
D8	33.42 ± 0.39^{bE}	31.14 ± 0.22^{abC}	30.85 ± 0.12^{abB}	31.40 ± 0.27^{abA}	31.64 ± 0.38^{abA}	30.74 ± 0.23^{aD}
D12	36.79 ± 0.12^{cF}	31.41 ± 0.09^{bcE}	31.476 ± 0.43^{bcA}	31.73 ± 0.12^{bcC}	32.06 ± 0.03^{bB}	31.28 ± 0.23^{bD}
D16		31.65 ± 0.09^{cD}	32.07 ± 0.25^{cC}	31.92 ± 0.09^{cA}	32.28 ± 0.14^{bB}	31.59 ± 0.16^{bD}
D20		33.95 ± 0.32^{dA}	34.29 ± 0.06^{dB}	34.31 ± 0.27^{dC}	34.36 ± 0.02^{cD}	33.94 ± 0.13^{cA}
D24		34.49 ± 0.15^{eA}	34.71 ± 0.32^{deB}	34.51 ± 0.03^{dA}	34.87 ± 0.35^{cdC}	35.86 ± 0.05^{eD}
D28		34.72 ± 0.09^{eC}	35.09 ± 0.22^{eA}	34.57 ± 0.04^{dA}	35.36 ± 0.12^{dB}	
D30		36.13 ± 0.13^{fB}	36.26 ± 0.06^{fC}	35.90 ± 0.08^{eB}	36.82 ± 0.52^{eA}	

These values are the means of three determinations for each parameter. The means ± standard deviation, assigned different lowercase letters in the same column indicate a significant difference ($p < 0.05$) between the storage days according to Tukey. Means ± standard deviation with different capital letters in the same row indicates a significant difference between storage media according to Tukey.

RPOAC: refined palm oil absorption capacity; **SA:** *SACI* without packaging; **SACSS**: *SACI* in polythene bags containing dry solid carbon; **SACSH**: *SACI* in polythene bags containing wet solid carbon; **SACPS**: *SACI* in polythene bags containing dry powdered charcoal; **SACPH**: *SACI* in polythene bags containing wet powdered charcoal; **SSC**: *SACI* in polythene bags without carbon.

Table 5:
Evolution of the refined palm oil absorption capacity (RPOAC) of the *Big-Ebanga* variety in six storage environments

Storage time (Day)	RPOAC of B (%)	RPOAC of BCSS (%)	RPOAC of BCSH (%)	RPOAC of BCPS (%)	RPOAC of BCPH (%)	RPOAC of BSC (%)
D0	45.45 ± 0.03^{aA}					
D4	46.64 ± 0.06^{abE}	45.42 ± 0.14^{aC}	45.33 ± 0.09^{aBC}	45.21 ± 0.01^{aAB}	45.07 ± 0.08^{aA}	45.58 ± 0.03^{aD}
D8	48.70 ± 0.03^{bD}	47.31 ± 0.01^{bC}	45.69 ± 0.57^{aA}	47.12 ± 0.03^{bC}	46.11 ± 0.07^{bB}	47.48 ± 0.05^{bC}
D12	49.31 ± 0.02^{bD}	47.45 ± 0.05^{cB}	47.18 ± 0.06^{cA}	47.16 ± 0.03^{bA}	47.21 ± 0.02^{cA}	47.75 ± 0.06^{cC}
D16		48.30 ± 0.01^{dD}	47.32 ± 0.02^{cA}	48.21 ± 0.09^{cC}	48.16 ± 0.03^{dB}	48.33 ± 0.01^{dD}
D20		48.61 ± 0.03^{eE}	48.08 ± 0.02^{dA}	48.39 ± 0.02^{dC}	48.30 ± 0.02^{dB}	48.51 ± 0.01^{eD}
D24		49.21 ± 0.01^{fC}	49.22 ± 0.04^{eC}	48.56 ± 0.06^{eB}	48.44 ± 0.05^{dA}	49.17 ± 0.08^{fC}
D28		49.51 ± 0.01^{gA}	49.31 ± 0.01^{eA}	49.07 ± 0.06^{fA}	49.06 ± 0.09^{eA}	
D30		49.49 ± 0.03^{gA}	49.32 ± 0.05^{eA}	49.13 ± 0.03^{fA}	48.91 ± 0.55^{fA}	

These values are the means of three determinations for each parameter. The means ± standard deviation, assigned different lowercase letters in the same column indicate a significant difference ($p < 0.05$) between the storage days according to Tukey. Means ± standard deviation with different capital letters in the same row indicates a significant difference between storage media according to Tukey.

RPOAC: refined palm oil absorption capacity; **B:** *Big-Ebanga* without packaging; **BCSS**: *Big-Ebanga* in polythene bags containing dry solid charcoal; **BCSH**: *Big-Ebanga* in polythene bags containing wet solid charcoal; **BCPS**: *Big-Ebanga* in polyethylene bags containing dry powdered charcoal; **BCPH**: *Big-Ebanga* in polyethylene bags containing wet powdered charcoal; **BSC**: *Big-Ebanga* in polyethylene bags without carbon

Table 6:
Evolution of the refined palm oil absorption capacity (RPOAC) of the *Orishele* variety in six storage environments

Storage time (Day)	RPOAC of O (%)	RPOAC of OCSS (%)	RPOAC of OCSH (%)	RPOAC of OCPS (%)	RPOAC of OCPH (%)	RPOAC of OSC (%)
D0	50.41 ± 0.02^{aA}					
D4	55.19 ± 0.02^{bB}	50.73 ± 0.04^{aA}	50.87 ± 0.58^{aA}	50.77 ± 0.10^{aA}	50.81 ± 0.05^{aA}	50.99 ± 0.51^{aA}
D8	57.11 ± 0.03^{cC}	51.56 ± 0.02^{bAB}	51.84 ± 0.02^{bAB}	51.45 ± 0.52^{bA}	51.93 ± 0.08^{bAB}	52.05 ± 0.07^{bB}
D12	59.80 ± 0.02^{dF}	56.30 ± 0.03^{cE}	55.52 ± 0.03^{cB}	56.02 ± 0.02^{cC}	55.12 ± 0.02^{cA}	56.21 ± 0.02^{cD}
D16		56.49 ± 0.02^{dD}	56.36 ± 0.01^{dC}	56.11 ± 0.02^{cB}	55.31 ± 0.03^{dA}	56.61 ± 0.02^{cE}
D20		57.13 ± 0.01^{eD}	56.70 ± 0.02^{dC}	56.32 ± 0.02^{cB}	56.11 ± 0.02^{eA}	57.33 ± 0.01^{dE}
D24		58.52 ± 0.02^{fD}	58.22 ± 0.01^{eC}	57.32 ± 0.02^{dB}	57.21 ± 0.01^{fA}	59.21 ± 0.02^{eE}
D28		58.75 ± 0.02^{gD}	58.28 ± 0.02^{eC}	57.62 ± 0.01d^{eA}	58.12 ± 0.02^{gB}	
D30		59.51 ± 0.02^{hD}	58.38 ± 0.02^{eC}	58.07 ± 0.01^{eA}	58.13 ± 0.01^{hB}	

These values are the means of three determinations for each parameter. The means ± standard deviation, assigned different lowercase letters in the same column indicate a significant difference ($p < 0.05$) between the storage days according to Tukey. Means ± standard deviation with different capital letters in the same row indicates a significant difference between storage media according to Tukey.

RPOAC: refined palm oil absorption capacity; **O:** *Orishele* without packaging; **OCSS**: *Orishele* in polythene bags containing dry solid charcoal; **OCSH**: *Orishele* in polythene bags containing wet solid charcoal; **OCPS**: *Orishele* in polyethylene bags containing dry powdered charcoal; **OCPH**: *Orishele* in polyethylene bags containing wet powdered charcoal; **CSO**: *Orishele* in polyethylene bags without carbon

Solubility index

The solubility index of flours from the fruits of the three plantain varieties SACI (Table 7), Big-Ebanga (Table 8), and Orishélé (Table 9) increases significantly ($p \leq 0.05$) during storage in all storage conditions for this study. The results also indicate a significant difference ($p \leq 0.5$) between the values of the fruit solubility index from one storage condition to another. The solubility index of the SACI variety recorded on day 0 is 29.19%. This rate increases and passes respectively, after 30 days of storage, to 35.91% for SACSS, 36.35% for SACSH, 35.32% for SACPS, and 36.35% for SACPH. The highest solubility indices of the SACI variety, after 30 days of storage, are obtained by the SACPH (36.35%) and SACSH (36.35%) flours. SACPS fruit flour (35.32%) recorded the lowest solubility index. The SA and SSC control samples, whose respective storage times were 12 days and 24 days, recorded rates of 35.22% and 35.29% at the end of storage.

Concerning the solubility index of the Big-Ebanga variety, it evolved from 37.26% on day 0 to reach respectively, after 30 days of storage, rates of 43.11% for BCSS, 43.81% for BCSH, 44.25% for BCPS and 43.24% for BCPH. The highest solubility index was obtained by BCPS (44.25%) and the lowest rate was obtained by BCSS (43.11%). Furthermore, the control fruits of this variety obtained flours whose solubility indices were 43.72% and 44.27% for B and BSC respectively.

The solubility index of the Orishelé variety recorded on day 0 was 31.65%. This rate increased respectively, after 30 days of storage, to 39.31% for OCSS, 37.84% for OCSH, 39.13% for OCPS, and 39.12% for OCPH. OCSS flours (39.31%) obtain the highest solubility index of the Orishelé variety, after 30 days of storage.

Table 7:
Evolution of the solubility index (SI) of the SACI variety in six storage environments

Storage time (Day)	SI of SA (%)	SI of SACSS (%)	SI of SACSH (%)	SI of SACPS (%)	SI of SACPH (%)	SI of SSC (%)
D0	29.19 ± 0.01^{aA}					
D4	30.35 ± 0.08^{bD}	29.51 ± 0.01^{aB}	29.42 ± 0.06^{aB}	29.71 ± 0.03^{aC}	29.81 ± 0.02^{aC}	29.16 ± 0.02^{aA}
D8	33.18 ± 0.19^{cC}	31.77 ± 0.22^{bAB}	31.65 ± 0.03^{bAB}	31.99 ± 0.24^{bAB}	32.28 ± 0.38^{bB}	31.38 ± 0.23^{bA}
D12	35.22 ± 0.12^{dC}	32.05 ± 0.09^{bcA}	32.14 ± 0.39^{bcA}	32.19 ± 0.04^{bcAB}	32.69 ± 0.03^{bcB}	31.93 ± 0.23^{cA}
D16		32.29 ± 0.09^{bcA}	32.71 ± 0.25^{bcdC}	32.55 ± 0.10^{cAC}	32.83 ± 0.08^{bcC}	32.23 ± 0.16^{cdA}
D20		32.59 ± 0.32^{cdA}	32.94 ± 0.06^{bcdA}	32.95 ± 0.28^{dA}	33.00 ± 0.02^{cdA}	32.58 ± 0.13^{dA}
D24		33.14 ± 0.15^{dA}	33.16 ± 0.30^{cdA}	33.15 ± 0.03^{dA}	33.51 ± 0.35^{deA}	35.29 ± 0.03^{fB}
D28		33.34 ± 0.06^{dA}	33.59 ± 0.03^{dB}	33.21 ± 0.04^{dA}	33.89 ± 0.11^{eC}	
D30		35.91 ± 0.64^{eA}	36.35 ± 1.19^{eA}	35.32 ± 0.08^{eA}	36.35 ± 0.39^{fA}	

These values are the means of three determinations for each parameter. The means ± standard deviation, assigned different lowercase letters in the same column indicate a significant difference ($p < 0.05$) between the storage days according to Tukey. Means ± standard deviation with different capital letters in the same row indicates a significant difference between storage media according to Tukey.

SI: solubility index; **SA:** *SACI* without packaging; **SACSS**: *SACI* in polythene bags containing dry solid carbon; **SACSH**: *SACI* in polythene bags containing wet solid carbon; **SACPS**: *SACI* in polythene bags containing dry powdered charcoal; **SACPH**: *SACI* in polythene bags containing wet powdered charcoal; **SSC**: *SACI* in polythene bags without carbon.

Table 8:
Evolution of the solubility index (SI) of the *Big-Ebanga* variety in six storage environments.

Storage time (Day)	SI of B (%)	SI of BCSS (%)	SI of BCSH (%)	SI of BCPS (%)	SI of BCPH (%)	SI of BSC (%)
D0	37.26 ± 0.06^{aA}					
D4	40.79 ± 0.07^{bF}	38.91 ± 0.06^{aC}	38.50 ± 0.01^{aB}	39.08 ± 0.02^{aD}	39.12 ± 0.03^{aE}	38.42 ± 0.02^{aA}
D8	41.85 ± 0.03^{cB}	39.42 ± 0.57^{aA}	39.15 ± 0.03^{bA}	39.23 ± 0.01^{aA}	39.65 ± 0.04^{bA}	39.17 ± 0.01^{bA}
D12	43.72 ± 0.07^{dF}	40.12 ± 0.01^{bD}	39.61 ± 0.05^{cC}	39.32 ± 0.06^{aA}	40.59 ± 0.04^{cE}	39.43 ± 0.02^{bB}
D16		40.30 ± 0.01^{bD}	39.92 ± 0.05^{dB}	39.54 ± 0.06^{aA}	40.91 ± 0.09^{dE}	40.07 ± 0.02^{cC}
D20		41.09 ± 0.05^{cC}	40.27 ± 0.02^{eA}	40.58 ± 0.09^{bB}	41.04 ± 0.01^{eC}	41.43 ± 0.02^{dD}
D24		41.41 ± 0.08^{cC}	40.73 ± 0.02^{fB}	40.61 ± 0.15^{bcA}	41.71 ± 0.03^{fD}	44.27 ± 0.56^{eE}
D28		42.08 ± 0.01^{dB}	41.12 ± 0.04^{gA}	41.17 ± 0.04^{cA}	42.07 ± 0.05^{gB}	
D30		43.11 ± 0.06^{eA}	43.81 ± 0.06^{hAB}	44.25 ± 0.58^{dB}	43.24 ± 0.03^{hA}	

These values are the means of three determinations for each parameter. The means ± standard deviation, assigned different lowercase letters in the same column indicate a significant difference ($p < 0.05$) between the storage days according to Tukey. Means ± standard deviation with different capital letters in the same row indicates a significant difference between storage media according to Tukey.

SI: solubility index; **B:** *Big-Ebanga* without packaging; **BCSS**: *Big-Ebanga* in polythene bags containing dry solid charcoal; **BCSH**: *Big-Ebanga* in polythene bags containing wet solid charcoal; **BCPS**: *Big-Ebanga* in polyethylene bags containing dry powdered charcoal; **BCPH**: *Big-Ebanga* in polyethylene bags containing wet powdered charcoal; **BSC**: *Big-Ebanga* in polyethylene bags without carbon

Table 9:

Evolution of the solubility index (SI) of the *Orishele* variety in six storage environments

Storage time (Day)	SI of O (%)	SI of OCSS (%)	SI of OCSH (%)	SI of OCPS (%)	SI of OCPH (%)	SI of OSC (%)
D0	31.65 ± 0.08^{aA}					
D4	32.13 ± 0.09^{bCD}	32.22 ± 0.05^{aDE}	31.89 ± 0.15^{aBC}	31.86 ± 0.05^{aB}	32.41 ± 0.09^{aE}	31.35 ± 0.15^{aA}
D8	36.42 ± 0.01^{cE}	32.64 ± 0.03^{abCD}	32.46 ± 0.06^{abC}	32.05 ± 0.10^{aB}	32.70 ± 0.16^{aD}	31.54 ± 0.02^{abA}
D12	39.74 ± 0.05^{dC}	32.94 ± 0.02^{bB}	32.75 ± 0.16^{bB}	32.17 ± 0.05^{aA}	33.09 ± 0.25^{abB}	31.98 ± 0.36^{bcA}
D16		33.02 ± 0.06^{bB}	32.99 ± 0.10^{bB}	32.41 ± 0.08^{aA}	33.66 ± 0.33^{bC}	32.38 ± 0.16^{cA}
D20		36.21 ± 0.01^{cA}	36.18 ± 0.21^{cA}	36.10 ± 0.53^{bA}	37.02 ± 0.01^{cB}	35.91 ± 0.35^{dA}
D24		36.42 ± 0.02^{cdAB}	36.62 ± 0.17^{cBC}	36.73 ± 0.19^{cC}	37.04 ± 0.02^{cD}	38.21 ± 0.06^{dE}
D28		36.81 ± 0.07^{dAB}	36.75 ± 0.01^{cA}	37.02 ± 0.15^{cBC}	37.14 ± 0.05^{cC}	
D30		39.31 ± 0.51^{eB}	37.84 ± 0.56^{dA}	39.13 ± 0.03^{dB}	39.12 ± 0.79^{dB}	

These values are the means of three determinations for each parameter. The means ± standard deviation, assigned different lowercase letters in the same column indicate a significant difference ($p < 0.05$) between the storage days according to Tukey. Means ± standard deviation with different capital letters in the same row indicates a significant difference between storage media according to Tukey.

ISE: solubility index; **O:** *Orishele* without packaging; **OCSS**: *Orishele* in polythene bags containing dry solid charcoal; **OCSH**: *Orishele* in polythene bags containing wet solid charcoal; **OCPS**: *Orishele* in polyethylene bags containing dry powdered charcoal; **OCPH**: *Orishele* in polyethylene bags containing wet powdered charcoal; **CSO**: *Orishele* in polyethylene bags without carbon

The fruits of OCSH (37.84%) and OCPH (39.12%) recorded the lowest solubility indices. The control fruits of this variety recorded respective rates of 39.74% (O) and 38.21% (OSC).

Indeed, the solubility index shows the affinity of flours to disperse in water and to give a homogeneous solution [17]. It also reflects the extent of starch degradation and measures the quantity of soluble substances released from starch granules [22]. The high solubility index percentage observed for flours at the end of storage could be due to the degradation of starch and fibers by amylolytic enzymes [23]. The solubility index is used to determine the ability of a product to dissolve following centrifugation. The high solubility indices of flours show that they can be ideal for the preparation of infant foods [24].

4. Conclusion

Functional properties such as water and oil absorption capacity and solubility index of plantain fruit flours increase during storage. Flour from SACI, Big-Ebanga and Orishélé plantain varieties absorbs a large amount of water and oil. These flours have good availability to be used in pastry, bakery, and in the preparation of food porridges.

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