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Effects of Charcoal Preservation Methods on the Biochemical Parameters of Three Varieties of Plantain (*Musa ssp*)

Sabli Loh Tinnde Charles [a], Wohi Maniga [b*], Coulibaly Souleymane [c] and Kouadio N'guessan Eugene Jean Parfait [a]

[a] *Department of Biochemistry and Food Technology, Nangui Abrogoua University, Abidjan, Côte d'Ivoire.*
[b] *Department of Biochemistry-Genetics, University Peleforo Gon Coulibaly Korhogo, Côte d'Ivoire.*
[c] *Formerly Laboratory of Food Technology, National Center for Agronomic Research, Côte d'Ivoire.*

Authors' contributions

This work was carried out in collaboration among all authors. Authors CS and KNEJP designed the study. Authors WM and SLTC managed the analyses of the study, performed the statistical analysis, wrote the protocol, wrote the first draft of the manuscript and managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: To contribute to solving plantain post-harvest losses, six preservation methods combining charcoal and polyethylene bags were experimented on three different varieties of plantain (*SACI, Big-Ebanga, and Orishele*).
Place and Duration of Study: This work was carried out at the Biocatalysis and Bioprocesses Laboratory of Nangui Abrogoua University in Abidjan and the Food Technology Laboratory of the National Center for Agronomic Research in Côte d'Ivoire.
Methodology: Some Biochemical parameters of these fruits are monitored to know the effects of these preservation methods during storage.
Results: The outcomes indicate an average shelf green life extension of up to 30 days for fruits preserved in polyethylene containing charcoal, while fruits preserved in polyethylene without charcoal have only 24 days on average. The control test (fruits stored in the open air) showed an average shelf green life of 12 days. During storage, total carbohydrate levels increase and values

**Corresponding author: Email: wmaniga@yahoo.fr;*

range from 92.49% to 70.05%. Those of total sugars also increase and the levels evolve from 0.47 to 30.83 g/100 g DM. On the other hand, there is a decrease in starch levels (42.66 and 64.05 mg/100g DM).

Conclusion: Charcoal can extend the shelf green life of plantain bananas for up to a month. These methods can be recommended to actors in the sector to reduce post-harvest losses.

Keywords: Plantain; conservation; charcoal; polyethylene.

1. INTRODUCTION

Plantain is one of the main sources of staple food for more than 100 million people in sub-Saharan Africa, where it contributes significantly to food security [1]. It also represents a significant source of income for producing countries. It is the second food crop in the world after cereals and the fourth cultivated food crop in the world after rice, wheat, and maize [2]. Nearly 75% of the world's plantain production is harvested in Africa [3]. In Côte d'Ivoire, with a production of around 1.9 million tones, plantain ranks fourth among foodstuffs in terms of consumption after rice, cassava and yam [4].

Plantain is characterized by a high carbohydrate contents, with levels above 28 g / 100 g. These contents corresponding to values ranging from 89 to 90.52 Kcal/100 g of dry matter [5] are the main energy source for consumers. Although plantain demand is high in the Ivorian markets, its expansion faces several constraints such as the lack of improved production techniques, ineffective post-harvest processing techniques and preservation techniques, which are very expensive, therefore not accessible to every actor in the sector [6]. All these constraints lead to low yields and high losses (up to 40%) of production [7]. Facing these constraints, production with better cultivation techniques and especially preservation through inexpensive, practical and accessible techniques are necessary, for a sustainable positive impact on plantain availability all year round.

In fact, storage temperature, oxygen, carbon dioxide and ethylene contains are the main factors, which influence banana ripening process. Ethylene initiates all the processes involved in fruits ripening [8]; for this reason preservation technics have been worked out, to slowing down ethylene production so that to extend shelf green life. Some traditional methods such as storage in pits, under foliage, under shelters [9] are commonly used. Modern or so-called improved methods of preserving plantain in a fresh state, including coating, cold, modified or controlled atmosphere, irradiation and special packaging [10], allow to store the fresh plantain for up to 60 days. A few of these methods seemed to be ineffective, difficult to implement and too expensive for common operators in the plantain sector and consumers. However, it seems easier to achieve modified atmospheres by using polyethylene bags [11]. For preservation the greatest difficulty is the too high level of chemical equipment requirement, which is very expensive and difficult to access.

Charcoal good adsorption capability is well known for very long time; it therefore has been used in many fields, in particular for water or gas purification. It could be used for ethylene absorption and slow down fruit ripening. The main objective of this work is to contribute to reduction of post-harvest losses of plantain, by developing a practical, inexpensive and accessible method of preserving plantain in a green state using charcoal.

2. MATERIALS AND METHODS

2.1 Materials

The plantain were harvested at the green ripe stage in an experimental plantation (Fig. 1) of the National Center for Agronomic Research (CNRA), located in Azaguié, in south-east of Côte d'Ivoire, about 50 km from Abidjan. These are three cultivars, namely *Big-Ebanga*, *SACI, Orishele* (Fig. 2).

2.2 Methods

2.2.1 Sampling

The plantain bunches are harvested respectively 70 days for the *Orishele* variety and 80 days for the *SACI* and *Big-Ebanga* varieties after the inflorescence appearance, thus corresponding to the optimal maturity of the fruits according to the method of determining the cutting point described by Gnakri and Kamenan [12]. The different plantain variety fingers are packed and hermetically sealed in polyethylene plastic bags (11 µm thick), containing either dry charcoal pieces or with water-wetted charcoal pieces, or dry charcoal powder or with water-wetted charcoal powder. The water-wetted charcoal powder is obtained by mixing charcoal powder and water in proportions of 1/5 (one volume of water per five volume of charcoal powder). Water-wetted charcoal pieces are obtained by immersion in water for one minute. The sizes of packaging bags and the charcoal mass are determined as follows: a 11cm long bag for a 8cm long finger and 5g of charcoal for 100g of plantain. Samples are taken every four days from the day of harvest, which also corresponds to day 0 of storage (beginning of storage), until the end of green life. The fruits are stored at room temperature (28°C). The different preservation batches are constituted as follows:

- Batch 1 or control batch: plantain samples preserved with no packaging.
- Batch 2: plantain samples preserved in packaging without charcoal.
- Batch 3: plantain samples preserved in packages with dry charcoal powder.
- Batch 4: plantain samples preserved in packages with water-wetted charcoal powder.
- Batch 5: plantain samples preserved in packages with dry charcoal pieces.
- Batch 6: plantain samples preserved in packages with water-wetted charcoal pieces.
- The batches 2, 3, 4, 5 and 6 contained 40 bags each. The sampling was carried out during the storage process for the determination of physicochemical parameters.

Fig. 1. Experimental plot for taking the samples studied in the Azaguié area in Côte d'Ivoire

Fig. 2. Plantain varieties studied at physiological maturity
A: Orishele variety; B: Big-Ebanga variety; C: SACI variety

2.2.2 Determination of green lifetime

The green lifetime is determined according to the colorimetric scale defined by Wainwright and Hughes [13]. It consisted in examining visually plantain's skin color. For each sample, the green lifetime corresponds to the elapsed time between harvested plantain at mature green stage and ripening start, when the color of the skin changes to the yellow-green.

2.2.3 Determination of starch levels

The starch levels are determined according to the Faithful [14] method that was modified by Abu et al. [15]. A quantity of 1 g of dried plantain flour is dispersed in 10 mL ethanol (10% v/v). After stirring for 30 min using a stirrer (J.P. SELECTA), the mixture is centrifuged at 3000 rpm for 5 min. The supernatant is decanted and the paste is washed with 10 ml, sulfuric acid solution (1 M) and centrifuged during 5 min. The paste is dispersed in 50 ml sulfuric acid (1 M) and heated in a boiling water bath during 45 min. After 10 min cooling, the liquids are poured into a 100 ml flask and completed with distilled. Then 10 ml of this solution is poured into a flask and completed to 100 ml with distilled water. The glucose in the hydrolysate is quantified according to the method of Dubois et al. [16] for total sugars. The starch content is calculated with following formula:

Starch content (%) = 0.9 × glucose level

2.2.4 Determination of total carbohydrate levels

Total carbohydrates levels are measured according to the method of Dubois et al. [16]. A quantity of 2 g of dried plantain flour is poured into a 250 ml flask. 40 ml of lukewarm distilled water is then added. After stirring for solution homogenization, 3 ml of concentrated hydrochloric acid (12 N) are added to the mixture, which is then boiled during 3 h. The solution is cooled and neutralized with 6 N sodium hydroxide, when the color of 3 phenolphthalein drops change to pink. The obtained solution is centrifuged at 3000 rpm for 15 min. The supernatant is transferred to a 200 ml flask and the volume is completed with distilled water. 0.2 ml of this extract is mixed with 1.8 ml distilled water and 1 ml DNS. The whole was incubated for 10 min in a boiling water bath. Finally, 17 ml of distilled water are added to it. The tubes are smoothly agitated and cooled down to room temperature. The optical density is determined on a spectrophotometer (Thermo Fisher scientific, Madison WI 53711 USA) at 546 nm against a control containing no sugar extract.

2.2.5 Extraction and determination of ethanosoluble sugars

2.2.5.1 Extraction of ethanosoluble sugars

Plantain sugars are extracted according to the method described by Martinez-Herrera et al. [17]. One gram of dried plantain pulp is ground in 10 ml ethanol (80% v/v). The grinding obtained is centrifuged for 30 minutes at 3000 rpm. The supernatant is collected in a graduated cylinder. The pellet is taken up with 10 ml ethanol and centrifuged twice. The supernatant is then added to the first part. The whole supernatant is the extract which is used for the determination of total sugars.

2.2.5.2 Determination of total sugar

Total sugars are determined according Dubois et al. [16] method using phenol. A volume of 0.1 mL of extract is diluted in 0.9 mL distilled water, then 1 mL phenol (5% w/v) is added to the mixture. The mixture is homogenized and put in a boiling water bath, after adding 2 mL concentrated sulfuric acid, then cooled for 5 minutes at room temperature. The Optical Density is determined at 490 nm on a spectrophotometer (PG INSTRUMENTS, England) versus a control containing all products, except the extract. The indicated Optical Density is converted into total sugars by using the calibration curve obtained from a glucose solution (1 mg/mL).

2.2.6 Statistical analysis

Statistical analysis of the data are performed using IBM SPSS Statistics 21.0 software. The averages of biochemical parameters data undergo a variance analysis (ANOVA) in order to know the effects of preservation methods on the properties. Tukey's test is used to compare parameter values that differ significantly from each other at the threshold of 5%.

3. RESULTS AND DISCUSSION

3.1 Green Lifetime

In terms of shelf life, the control fruits kept in the open air without packaging had a green shelf life of 12 days. That of fruits packed in polythene bags without charcoal is 24 days while those packed in the presence of charcoal have reached 30 days of green life.

The results obtained show an influence of charcoal on the green life of the fruits of the three varieties of plantain, namely *SACI, Big-Ebanga and Orishélé*. In fact, charcoal has the property of absorbing gases, certain dissolved bodies and solvents [18]. This charcoal adsorption capacity is determined by the surface area of receptive sites on the walls of the charred wood vessels [19]. The extension of the pre-climatic phase of the fruits of the plantain bananas packed in polyethylene bags containing charcoal could be explained by the adsorption by the charcoal of the ethylene produced by the fruits in the packaging during the conservation. It is a transfer of ethylene to the surface of the carbon. The particles of the fluid penetrate inside the pores by a concentration gradient to settle on the surface of the pores [20]. Note that powdered carbon has a large external surface and a low depth of diffusion which generates a faster adsorption rate. Unlike solid coal, characterized by a large internal surface and a relatively small external surface. As a result, the adsorption kinetics are slow [21]. In addition, the 30-day period marks the start of ripening of at least one finger of the plantains stored in the polyethylene bag containing charcoal. But, beyond this date, ripening was faster for fruits in wet charcoal than those in dry charcoal. Indeed, Groszek and Aharoni [22] showed by microcalorimetry that the presence of water induced increases in the temperature of the carbon due to the chemisorption of water on the surface of the carbons and therefore to a lowering of its adsorption capacity [23,24]. This could explain the rapid ripening of fruits packed in polythene bags containing wet charcoal compared to those packed in polythene bags containing dry charcoal. The conservation of fruits in polyethylene bags would modify the composition of the atmosphere inside these bags by reducing exchanges with the external environment. This will result in a decrease in the oxygen level and a naked increase in CO2 and the humidity level. The CO2 and humidity levels produced during storage help keep the plantain green and firm longer, while reducing the effect of ethylene [25]. This is what explains the extension of the green life of packaged fruit compared to that of fruit stored in the open air without packaging.

3.2 Starch

The starch levels of the three plantain varieties fruits *SACI* (Table 1), *Big-Ebanga* (Table 2), and *Orishele* (Table 3) decreased significantly ($p \leq 0.05$) during storage in all preservation environments. The results also indicate a significant difference ($p \leq 0.5$) between the starch values of the fruits from one storage environment to another.

The starch level of *SACI* variety recorded on day 0 is 77.31%. After 30 days of storage, the lowest starch level is observed in *SACI* packed in polythene bags containing wet charcoal powder (SACPH) with a value of 34.52%. Fruits from *SACI* packed in polythene bags without charcoal (SSC) have a starch level of 48.52% after 24 days of storage.

The starch rate of the *Big-Ebanga* variety went from 81.349% on day 0 to reach the lowest rate which is 39.73% obtained by *Big-Ebanga* packed in polythene bags containing wet charcoal powder (BCPH), after 30 days of storage. After 24 days of storage, the *Big-Ebanga* packed in polythene bags without charcoal (BSC) have a starch level of 47.24%.

The starch level of the Orishele variety is 78.66% on day 0. After 30 days of storage, lowest starch level is observed in Orishele packed in polythene bags containing wet solid charcoal (OCSH) with 50.26%. Orishele packed in polythene bags without charcoal (OSC) have 58.84% of starch rate at the end of green life (24 days).

The decrease in starch levels during ripening is also observed by Belalcázar et al. [26] on the fruits of the plantain "Dominico harton" clone (80% to 69%) and also by Assemand et al., [27] on *Orishele* (79.63% to 59.13%) and *Agnrin* (80.85% to 56.92%) varieties fruits. This decrease of starch levels are due to its conversion in soluble sugars during the ripening process of the fruit [28,29]. Indeed, during ripening, α and β-amylases catalyze starch degradation, thus releasing glucose, maltose and maltodextrins [30].

3.3 Total Carbohydrates

The total carbohydrate content of plantains *SACI* (Table 4), *Big-Ebanga* (Table 5) and *Orishele* (Table 6) varieties fruits decreased significantly ($p \leq 0.5$) during storage for each storage environment. The results also indicate a significant difference ($p \leq 0.5$) between the total carbohydrate values of these fruits from one storage environment to another.

The total carbohydrate level of the *SACI* variety fruits on day 0 is 89.41%. This value decreases during storage to the lowest, which is 73.19% recorded among *SACI* packed in polythene bags containing dry powdered charcoal SACPS at the end of storage (30 days). The total carbohydrate level recorded for SSC is 76.68% after 24 days of storage.

The total carbohydrate levels of the *Big-E*banga variety fruits also decreases from day 0 to day 30 from 92.49% to 74.21% (*Big-Ebanga* packed in polythene bags containing dry powdered charcoal (BCPS)). After 24 days, the BSC have a level of 76.20%.

Total carbohydrate levels of fruits of the *Orishele* fruit ranges from day 0 to day 30 from 91.43% to 70.05% (*Orishele* packed in polythene bags containing dry powdered charcoal (OCPS)). OSC have a level of 75.27% at the end of green life (24 days).

Authors such as Assemand et al. [27] also observed decreases in total carbohydrate levels of plantain varieties such as *Orishele* (93.41% to 91.95%) and *Agnrin* (94.96% to 93.22%) during storage. This decrease in total carbohydrate levels is due to starch conversion in sugars under the action of some enzymes such as endo-1,4-ß-D-glucanases, polygalacturonases, pectate lyases and pectin esterases and expansins [31] which degrade the cell wall [32], during ripening.

3.4 Total Sugars

The total sugars levels of following plantain varieties fruits: *SACI* fruits (Table 7), *Big-Ebanga* fruits (Table 8) and *Orishele* fruits (Table 9) increase significantly ($p \leq 0.05$) depending on the days of storage for each storage environment.

Concerning *SACI* variety, the total sugars rate observed on day 0 is 0.74%. This value changes during storage to reach, at 30 days of storage, 28.16% (SACPH). The SSC record a level of 21.33% on day 24.

The total sugars levels of *Big-Ebanga* variety also increases from day 0 to day 30 from 0.62% to 29.82% for BCSS, 30.13% for BCSH, 30.83% for BCPS and 30.84% for BCPH. Those of BSC at the end of green life (24 days) is 31.43%. At 30 days of storage, the fruits of BCSS (29.82%) and BCSH (30.13%) record the lowest total sugar rate while the highest is that of BCPS (30.83%).

The total sugars levels of *Orishele* variety varies from day 0 to day 30 from 0.47% to 25.87% (OCPH). This level is 20.26% for OSC after 24 days of storage.

The total sugars levels of these plantain varieties vary significantly ($P \leq 0.05$) during storage from one conservation environment to another. Collin and Dalnic [33] also observed the increase in total sugar levels (0.466 to 30.830 g / 100 g DM) during plantain storage, but these levels are slightly higher than those of *Orishele* variety (0. 5% to 22.56%). Belalcázar et al. [26] also observed the same evolution in plantain "Dominico harton" clone (0.75% 23.70%). Similar to total carbohydrates, the increase in total sugars is due to starch degradation during storage by the same process. Furthermore, according to Dorais et al. [34] factors such as mineral content water availability, irrigation, fertilization and climatic conditions con influence fruit sugar levels.

Table 1. Evolution of the starch levels of *SACI* variety fruits in six different storage environment

Green life (Day)	Starch of SA (%)	Starch of SACSS (%)	Starch of SACSH (%)	Starch of SACPS (%)	Starch of SACPH (%)	Starch of SSC (%)
0	77.31 ± 0.00^{aA}					
4	72.89 ± 0.01^{bA}	77.30 ± 0.01^{aE}	77.12 ± 0.00^{aC}	77.05 ± 0.00^{aB}	77.18 ± 0.05^{aD}	77.27 ± 0.00^{aE}
8	59.57 ± 0.00^{cA}	72.39 ± 0.00^{bE}	71.73 ± 0.00^{bD}	71.21 ± 0.00^{bC}	70.14 ± 0.00^{bB}	72.75 ± 0.00^{bF}
12	37.69 ± 0.00^{dA}	70.81 ± 0.00^{cD}	71.17 ± 0.01^{cE}	70.09 ± 0.10^{cB}	70.14 ± 0.00^{bB}	70.46 ± 0.00^{cC}
16		65.67 ± 0.36^{dAB}	66.46 ± 0.55^{dB}	65.31 ± 0.85^{dAB}	63.28 ± 1.78^{cAB}	62.52 ± 0.00^{dA}
20		60.21 ± 0.00^{eC}	61.07 ± 0.00^{eE}	60.65 ± 0.00^{eD}	58.87 ± 0.00^{dB}	58.21 ± 0.00^{eA}
24		51.49 ± 0.00^{fC}	55.79 ± 0.00^{fE}	51.61 ± 0.00^{fD}	49.60 ± 0.00^{eB}	48.52 ± 0.00^{fA}
28		45.25 ± 0.00^{gC}	48.09 ± 0.00^{gE}	47.51 ± 0.00^{gD}	43.51 ± 0.00^{fA}	
30		37.06 ± 0.00^{hD}	39.71 ± 0.01^{hE}	36.39 ± 0.00^{hC}	34.52 ± 0.00^{gA}	

These values are the averages of 3 determinations for each parameter. Values ± SD, with different lowercase letters in the same column indicate a significant difference ($p < 0.05$) between storage days according to Tukey. Values ± SD with different capital letters in the same line indicate a significant difference between storage media according to Tukey.
SA: SACI no packaging; SACSS: SACI packed in polythene bags containing dry solid charcoal; SACSH: SACI packed in polythene bags containing wet solid charcoal; SACPS: SACI packed in polythene bags containing dry powdered charcoal; SACPH: SACI packed in polythene bags containing wet charcoal powder; SSC: SACI packed in polythene bags without charcoal

Table 2. Evolution of the starch levels of the *Big-Ebanga* variety fruits in six different storage environment

Green life (Day)	Starch of B (%)	Starch of BCSS (%)	Starch of BCSH (%)	Starch of BCPS (%)	Starch of BCPH (%)	Starch of BSC (%)
0	81.35 ± 0.00^{aA}					
4	78.10 ± 0.00^{bA}	79.91 ± 0.00^{aF}	79.35 ± 0.00^{aE}	79.03 ± 0.00^{aB}	79.252 ± 0.00^{aD}	79.11 ± 0.00^{aC}
8	69.57 ± 0.00^{cA}	72.15 ± 0.00^{bE}	71.15 ± 0.00^{bD}	71.08 ± 0.00^{bC}	71.033 ± 0.00^{bB}	73.12 ± 0.00^{bF}
12	41.94 ± 0.00^{dA}	64.56 ± 0.00^{cF}	63.51 ± 0.00^{cE}	61.49 ± 0.00^{cC}	61.066 ± 0.00^{cB}	62.48 ± 0.00^{cD}
16		58.60 ± 0.00^{dE}	56.43 ± 0.17^{dC}	53.37 ± 0.00^{dB}	51.180 ± 0.00^{dA}	57.07 ± 0.00^{dD}
20		53.20 ± 0.00^{eE}	51.81 ± 0.00^{eD}	49.19 ± 0.00^{eB}	49.170 ± 0.00^{eA}	51.32 ± 0.00^{eC}
24		49.16 ± 0.00^{fE}	47.15 ± 0.00^{fC}	45.53 ± 0.00^{fB}	45.445 ± 0.00^{fA}	47.24 ± 0.00^{fD}
28		44.18 ± 2.88^{gAB}	43.18 ± 0.00^{gAB}	41.17 ± 0.00^{gAB}	41.019 ± 0.00^{gA}	
30		40.20 ± 0.01^{hC}	42.45 ± 0.00^{hD}	40.04 ± 0.00^{hB}	39.728 ± 0.00^{hA}	

These values are the averages of 3 determinations for each parameter. Values ± SD, with different lowercase letters in the same column indicate a significant difference ($p < 0.05$) between storage days according to Tukey. Values ± SD with different capital letters in the same line indicate a significant difference between storage media according to Tukey.
B: Big-Ebanga no packaging; BCSS: Big-Ebanga packed in polythene bags containing dry solid charcoal; BCSH: Big-Ebanga packed in polythene bags containing wet solid charcoal; BCPS: Big-Ebanga packed in polythene bags containing dry powdered charcoal; BCPH: Big-Ebanga packed in polythene bags containing wet charcoal powder; BSC: Big-Ebanga packed in polythene bags without charcoal

Table 3. Evolution of the starch levels of the *Orishele* variety fruits in six different storage environment

Green life(Day)	Starch of O (%)	Starch of OCSS (%)	Starch of OCSH (%)	Starch of OCPS (%)	Starch of OCPH (%)	Starch of OSC (%)
0	78.56 ± 0.00^{aA}					
4	77.68 ± 0.00^{bF}	76.84 ± 0.00^{aD}	76.26 ± 0.00^{aC}	75.06 ± 0.00^{aA}	76.03 ± 0.00^{aB}	76.94 ± 0.00^{aE}
8	65.78 ± 0.00^{cA}	71.84 ± 0.00^{bF}	71.58 ± 0.00^{bE}	70.72 ± 0.00^{bC}	70.21 ± 0.00^{bB}	71.56 ± 0.00^{bD}
12	54.69 ± 0.00^{dA}	68.54 ± 0.00^{cE}	68.54 ± 0.00^{cE}	67.57 ± 0.05^{cD}	65.28 ± 0.00^{cB}	67.29 ± 0.00^{cC}
16		64.48 ± 0.00^{dD}	64.52 ± 0.00^{dE}	63.87 ± 0.00^{dA}	64.11 ± 0.00^{dB}	64.28 ± 0.00^{dC}
20		61.51 ± 0.00^{eB}	61.43 ± 0.00^{eB}	61.24 ± 0.00^{eB}	60.22 ± 0.00^{eA}	60.86 ± 0.58^{eAB}
24		58.14 ± 0.00^{fD}	57.15 ± 0.00^{fC}	57.02 ± 0.00^{fB}	56.43 ± 0.00^{fA}	58.84 ± 0.00^{fE}
28		54.43 ± 0.00^{gD}	54.01 ± 0.00^{gB}	54.13 ± 0.00^{gC}	52.61 ± 0.00^{gA}	
30		51.14 ± 0.01^{hD}	50.26 ± 0.00^{hA}	51.07 ± 0.00^{hC}	50.66 ± 0.00^{hB}	

These values are the averages of 3 determinations for each parameter. Values ± SD, with different lowercase letters in the same column indicate a significant difference ($p < 0.05$) between storage days according to Tukey. Values ± SD with different capital letters in the same line indicate a significant difference between storage media according to Tukey.

O: Orishele no packaging; OCSS: Orishele packed in polythene bags containing dry solid charcoal; OCSH: Orishele packed in polythene bags containing wet solid charcoal; OCPS: Orishele packed in polythene bags containing dry powdered charcoal; OCPH: Orishele packed in polythene bags containing wet charcoal powder; OSC: Orishele packed in polythene bags without charcoal

Table 4. Evolution of the carbohydrates levels of the *SACI* variety fruits in six different storage environment

Green life (Day)	Carbohydrates of SA (%)	Carbohydrates of SACSS (%)	Carbohydrates of SACSH (%)	Carbohydrates of SACPS (%)	Carbohydrates of SACPH (%)	Carbohydrates of SSC (%)
0	89.41 ± 0.79^{aA}					
4	85.69 ± 2.78^{aA}	88.92 ± 0.68^{aA}	88.61 ± 1.037^{aA}	88.48 ± 1.15^{aA}	88.39 ± 1.15^{aA}	88.62 ± 0.97^{aA}
8	78.87 ± 3.89^{bA}	87.19 ± 0.34^{abB}	87.04 ± 0.354^{abB}	86.84 ± 0.47^{abB}	87.05 ± 0.01^{abB}	87.39 ± 0.21^{abB}
12	73.26 ± 0.11^{bA}	85.00 ± 1.83^{bB}	83.95 ± 3.250^{bB}	85.82 ± 0.61^{bB}	83.85 ± 3.21^{bB}	84.68 ± 1.95^{bB}
16		79.67 ± 1.01^{cA}	79.18 ± 0.997^{cA}	79.38 ± 1.28^{cA}	78.32 ± 1.51^{cA}	79.57 ± 1.02^{cA}
20		78.10 ± 0.44^{deA}	77.39 ± 1.042^{dfA}	77.57 ± 0.42^{deA}	77.36 ± 0.61^{cA}	78.49 ± 0.35^{deA}
24		76.91 ± 0.82^{efA}	77.06 ± 0.240^{efgA}	76.73 ± 0.48^{eA}	76.03 ± 0.76^{cdA}	76.68 ± 0.87^{efA}
28		74.59 ± 1.01^{fgA}	74.44 ± 1.068^{fgA}	74.23 ± 0.95^{fA}	74.39 ± 0.93^{cdA}	
30		73.55 ± 0.07^{gB}	73.36 ± 0.132^{gAB}	73.19 ± 0.07^{gA}	73.24 ± 0.06^{dA}	

These values are the averages of 3 determinations for each parameter. Values ± SD, with different lowercase letters in the same column indicate a significant difference ($p < 0.05$) between storage days according to Tukey. Values ± SD with different capital letters in the same line indicate a significant difference between storage media according to Tukey.

SA: SACI no packaging; SACSS: SACI packed in polythene bags containing dry solid charcoal; SACSH: SACI packed in polythene bags containing wet solid charcoal; SACPS: SACI packed in polythene bags containing dry powdered charcoal; SACPH: SACI packed in polythene bags containing wet charcoal powder; SSC: SACI packed in polythene bags without charcoal

Table 5. Evolution of the carbohydrates levels of the *Big-Ebanga* variety fruits in six different storage environment

Green life (Day)	Carbohydrates of B (%)	Carbohydrates of BCSS (%)	Carbohydrates of BCSH (%)	Carbohydrates of BCPS (%)	Carbohydrates of BCPH (%)	Carbohydrates of BSC (%)
0	92.49 ± 1.73^{aA}					
4	89.26 ± 1.19^{aA}	89.96 ± 1.35^{aA}	89.96 ± 1.40^{aA}	89.96 ± 0.01^{aA}	91.02 ± 0.00^{aA}	91.02 ± 0.14^{aA}
8	80.94 ± 5.54^{bA}	87.32 ± 1.22^{abAB}	87.97 ± 0.72^{abB}	88.21 ± 0.01^{bB}	88.12 ± 0.00^{bB}	88.38 ± 0.05^{bB}
12	74.63 ± 0.01^{bA}	85.98 ± 0.57^{bB}	85.32 ± 1.04^{bB}	86.03 ± 0.01^{cB}	85.42 ± 0.09^{cB}	86.44 ± 0.09^{cB}
16		81.61 ± 1.88^{cA}	81.82 ± 1.49^{cA}	83.09 ± 0.01^{dA}	83.02 ± 0.00^{dA}	83.13 ± 0.01^{dA}
20		77.97 ± 1.66^{dA}	78.05 ± 1.29^{dA}	79.05 ± 0.01^{eA}	78.57 ± 0.14^{eA}	79.46 ± 0.14^{eA}
24		76.14 ± 0.30^{deB}	76.07 ± 0.05^{deB}	75.65 ± 0.07^{fA}	75.58 ± 0.06^{fA}	76.20 ± 0.01^{fB}
28		75.33 ± 0.58^{deA}	75.08 ± 0.49^{eA}	75.31 ± 0.00^{gA}	75.01 ± 0.01^{gA}	
30		74.51 ± 0.00^{eD}	74.41 ± 0.01^{eC}	74.21 ± 0.00^{hA}	74.31 ± 0.01^{hB}	

These values are the averages of 3 determinations for each parameter. Values ± SD, with different lowercase letters in the same column indicate a significant difference ($p < 0.05$) between storage days according to Tukey. Values ± SD with different capital letters in the same line indicate a significant difference between storage media according to Tukey.

B: Big-Ebanga no packaging; BCSS: Big-Ebanga packed in polythene bags containing dry solid charcoal; BCSH: Big-Ebanga packed in polythene bags containing wet solid charcoal; BCPS: Big-Ebanga packed in polythene bags containing dry powdered charcoal; BCPH: Big-Ebanga packed in polythene bags containing wet charcoal powder; BSC: Big-Ebanga packed in polythene bags without charcoal

Table 6. Evolution of the carbohydrates levels of the *Orishele* variety fruits in six different storage environment

Green life (Day)	Carbohydrates of O (%)	Carbohydrates of OCSS (%)	Carbohydrates of OCSM (%)	Carbohydrates of OCPS (%)	Carbohydrates of OCPM (%)	Carbohydrates of OCEM (%)
0	91.43 ± 1.17^{aA}					
4	89.02 ± 0.52^{bA}	90.23 ± 0.02^{aA}	89.49 ± 1.15^{aA}	89.36 ± 1.27^{aA}	90.14 ± 0.05^{aA}	89.63 ± 1.05^{aA}
8	82.85 ± 0.65^{cA}	86.54 ± 1.01^{bB}	87.24 ± 0.81^{aB}	86.21 ± 0.95^{bB}	86.23 ± 0.94^{bB}	86.22 ± 1.06^{bB}
12	71.42 ± 0.05^{dA}	84.37 ± 1.16^{bB}	84.41 ± 1.22^{bB}	83.34 ± 1.12^{bB}	83.93 ± 0.71^{cB}	83.97 ± 2.36^{bB}
16		81.00 ± 0.38^{cA}	80.53 ± 0.70^{cA}	79.79 ± 1.40^{cA}	79.69 ± 1.34^{dA}	80.09 ± 1.06^{cA}
20		77.63 ± 1.05^{dA}	77.25 ± 0.88^{dA}	76.91 ± 0.79^{cdA}	76.19 ± 0.91^{eA}	77.52 ± 0.76^{cdA}
24		75.14 ± 0.99^{eA}	75.14 ± 0.65^{dA}	74.33 ± 0.62^{deA}	73.56 ± 0.72^{fA}	75.27 ± 0.74^{deA}
28		73.11 ± 0.96^{efA}	72.25 ± 1.11^{eA}	71.92 ± 1.63^{efA}	72.01 ± 0.85^{fgA}	
30		71.18 ± 0.09^{fC}	71.15 ± 0.02^{eBC}	70.05 ± 0.03^{fA}	71.11 ± 0.00^{gB}	

These values are the averages of 3 determinations for each parameter. Values ± SD, with different lowercase letters in the same column indicate a significant difference ($p < 0.05$) between storage days according to Tukey. Values ± SD with different capital letters in the same line indicate a significant difference between storage media according to Tukey.

O: Orishele no packaging; OCSS: Orishele packed in polythene bags containing dry solid charcoal; OCSH: Orishele packed in polythene bags containing wet solid charcoal; OCPS: Orishele packed in polythene bags containing dry powdered charcoal; OCPH: Orishele packed in polythene bags containing wet charcoal powder; OSC: Orishele packed in polythene bags without charcoal

Table 7. Evolution of the total sugars levels of the *SACI* variety fruits in six different storage environment

Green life (Day)	Total sugars of SA (%)	Total sugars of SACSS (%)	Total sugars of SACSH (%)	Total sugars of SACPS (%)	Total sugars of SACPH (%)	Total sugars of SSC (%)
0	0.74 ± 0.04^{aA}					
4	7.26 ± 0.03^{bB}	1.66 ± 0.03^{aA}	1.70 ± 0.20^{aA}	2.43 ± 0.31^{aA}	2.63 ± 0.25^{aA}	1.85 ± 0.04^{aA}
8	16.05 ± 0.04^{cB}	5.87 ± 0.03^{bA}	5.93 ± 0.02^{bA}	6.33 ± 0.26^{bA}	6.24 ± 0.03^{bA}	6.25 ± 0.32^{bA}
12	27.16 ± 0.04^{dD}	11.96 ± 0.04^{cA}	11.96 ± 0.03^{cAB}	11.81 ± 0.02^{cC}	12.08 ± 0.01^{cB}	12.10 ± 1.83^{cAB}
16		16.24 ± 0.03^{dAB}	16.12 ± 0.03^{dBC}	17.15 ± 0.04^{dAB}	16.57 ± 0.25^{dC}	17.23 ± 0.03^{dA}
20		19.32 ± 0.03^{eAB}	19.66 ± 0.03^{eBC}	20.13 ± 0.03^{eA}	19.84 ± 0.03^{eCD}	20.13 ± 0.04^{eD}
24		21.33 ± 0.03^{fA}	21.23 ± 0.02^{fA}	21.54 ± 0.03^{fA}	20.79 ± 0.02^{fB}	21.33 ± 0.25^{fA}
28		25.12 ± 0.02^{gA}	25.42 ± 0.03^{gA}	25.36 ± 0.03^{gA}	26.03 ± 0.02^{gA}	
30		27.91 ± 0.05^{hB}	27.79 ± 0.24^{hA}	27.70 ± 0.25^{hB}	28.16 ± 0.03^{hB}	

These values are the averages of 3 determinations for each parameter. Values ± SD, with different lowercase letters in the same column indicate a significant difference (p < 0.05) between storage days according to Tukey. Values ± SD with different capital letters in the same line indicate a significant difference between storage media according to Tukey

SA: SACI no packaging; SACSS: SACI packed in polythene bags containing dry solid charcoal; SACSH: SACI packed in polythene bags containing wet solid charcoal; SACPS: SACI packed in polythene bags containing dry powdered charcoal; SACPH: SACI packed in polythene bags containing wet charcoal powder; SSC: SACI packed in polythene bags without charcoal

Table 8. Evolution of the total sugars levels of the *Big-Ebanga* variety fruits in six different storage environment

Green life (Day)	Total sugars of B (%)	Total sugars of BCSS (%)	Total sugars of BCSH (%))	Total sugars of BCPS (%)	Total sugars of BCPH (%)	Total sugars of BSC (%)
0	0.62 ± 0.03^{aA}					
4	7.24 ± 0.02^{bB}	2.14 ± 0.04^{aA}	3.23 ± 0.04^{aA}	2.81 ± 0.04^{aA}	2.56 ± 0.03^{aA}	2.32 ± 0.01^{aA}
8	18.06 ± 0.02^{cD}	6.23 ± 0.03^{bA}	7.15 ± 0.04^{bC}	8.04 ± 0.03^{bC}	8.60 ± 0.30^{bAB}	7.25 ± 0.03^{bBC}
12	29.63 ± 0.02^{dD}	10.65 ± 0.03^{cA}	11.15 ± 0.04^{cC}	10.86 ± 0.03^{cA}	11.65 ± 0.03^{cBC}	11.62 ± 0.04^{cAB}
16		15.25 ± 0.04^{dB}	16.04 ± 0.03^{dD}	16.34 ± 0.04^{dC}	16.59 ± 57.70^{dA}	16.24 ± 0.04^{dB}
20		18.36 ± 0.03^{eA}	17.88 ± 0.03^{eA}	18.33 ± 0.04^{eA}	18.73 ± 0.04^{eA}	19,.56 ± 0.03^{eA}
24		23.52 ± 0.04^{fAB}	24.16 ± 0.01^{fA}	23.75 ± 0.03^{fB}	23.58 ± 0.03^{fB}	24.12 ± 0.03^{fB}
28		25.13 ± 0.03^{gB}	26.22 ± 0.03^{gA}	26.76 ± 0.03^{gC}	25.83 ± 0.04^{gD}	
30		29.82 ± 0.04^{hA}	30.13 ± 0.04^{hA}	30.83 ± 0.04^{hB}	30.34 ± 0.04^{hB}	

These values are the averages of 3 determinations for each parameter. Values ± SD, with different lowercase letters in the same column indicate a significant difference (p < 0.05) between storage days according to Tukey. Values ± SD with different capital letters in the same line indicate a significant difference between storage media according to Tukey

B: Big-Ebanga no packaging; BCSS: Big-Ebanga packed in polythene bags containing dry solid charcoal; BCSH: Big-Ebanga packed in polythene bags containing wet solid charcoal; BCPS: Big-Ebanga packed in polythene bags containing dry powdered charcoal; BCPH: Big-Ebanga packed in polythene bags containing wet charcoal powder; BSC: Big-Ebanga packed in polythene bags without charcoal

Table 9. Evolution of the total sugars levels of the *Orishele* variety fruits in six different storage environment

Green life (Day)	Total sugars of O (%)	Total sugars of OCSS (%)	Total sugars of OCSH (%)	Total sugars of OCPS (%)	Total sugars of OCPH (%)	Total sugars of OSC (%)
0	0.47 ± 0.03^{aA}					
4	6.28 ± 0.05^{bB}	2.04 ± 0.03^{aA}	1.85 ± 0.04^{aA}	2.23 ± 0.16^{aA}	1.85 ± 0.04^{aA}	2.05 ± 0.04^{aA}
8	9.56 ± 0.03^{cE}	4.74 ± 0.03^{bA}	4.95 ± 0.03^{bD}	4.86 ± 0.03^{bBC}	5.05 ± 0.03^{bAB}	4.55 ± 0.02^{bC}
12	25.13 ± 0.03^{dC}	10.14 ± 0.04^{cA}	9.95 ± 0.03^{cAB}	10.23 ± 0.03^{cB}	10.58 ± 0.02^{cB}	10.75 ± 0.03^{cB}
16		15.14 ± 1.71^{dAB}	14.53 ± 0.03^{dC}	13.95 ± 0.03^{dBC}	14.64 ± 0.04^{dA}	14.25 ± 0.03^{dAB}
20		18.56 ± 0.03^{eAB}	17.96 ± 0.03^{eBC}	18.17 ± 0.02^{eA}	18.85 ± 0.04^{eC}	18.44 ± 0.03^{eAB}
24		20.17 ± 0.02^{eA}	19.66 ± 0.04^{fB}	20.23 ± 0.02^{fA}	20.34 ± 0.03^{fB}	20.26 ± 0.03^{fB}
28		22.34 ± 0.16^{fAB}	22.15 ± 0.02^{gB}	22.46 ± 0.03^{gA}	23.16 ± 0.03^{gB}	
30		25.66 ± 0.02^{gA}	25.24 ± 0.03^{hA}	25.54 ± 0.03^{hA}	25.86 ± 0.03^{hA}	

These values are the averages of 3 determinations for each parameter. Values ± SD, with different lowercase letters in the same column indicate a significant difference ($p < 0.05$) between storage days according to Tukey. Values ± SD with different capital letters in the same line indicate a significant difference between storage media according to Tukey

O: Orishele no packaging; OCSS: Orishele packed in polythene bags containing dry solid charcoal; OCSH: Orishele packed in polythene bags containing wet solid charcoal; OCPS: Orishele packed in polythene bags containing dry powdered charcoal; OCPH: Orishele packed in polythene bags containing wet charcoal powder; OSC: Orishele in polythene bags without charcoal

4. CONCLUSION

The different charcoal preservation methods used in this study allow an extension of the green life of the plantain until 30 days. Better still, these preservation methods have no negative impact on plantain biochemical composition. Overall, there is an increase of some biochemical parameters during the preservation of these fruits in these different storage environments. These preservation methods could be recommended to reduce post-harvest losses of plantain, especially since they are less expensive.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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