

Effect of Improved Shelter on the Storage of Plantain (*Musa Paradisiaca* AAAB) Cultivar FHIA 21: Green Self-life and Physicochemical Parameters

BROU Koffi Siméon^{1,*}, KANE Fako², DJINA Yves², TANO Kablan¹

¹Laboratory of Food Biochemistry and Tropical Product Technology, Departement of Food Science and Technology, Nangui ABROGOUA University, Abidjan, Côte d'Ivoire

²Biocatalysis and Bioprocesses Laboratory, Department of Food Science and Technology, Nangui ABROGOUA University, Abidjan, Côte d'Ivoire

*Corresponding author: broukofi2007@yahoo.fr

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Abstract Plantain (*Musa paradisiaca* L.), like most tropical fruits, is highly perishable. The aim of this study was to contribute to the reduction of post-harvest losses of plantain through storage under improved shelter to delay ripening. The study determined the effectiveness of improved shelter on the green self-life (GSL) of plantains and on evolution in the biochemical characteristics of FHIA 21 plantain fruits during storage. Plantain cultivar FHIA 21 harvested on days 80, 85, 90, 95, 100 and 105 after flower emergence was stored in the improved shelters and covered or not with dry plantain leaves. Green lifetimes and biochemical characteristics were determined using reference methods. Analysis of the results shows that the GLS of plantains at different stages of maturity varies from 12 to 27 days for plantains not covered with dry leaves and from 13 to 30 days when they are covered and when the ripe fingers are removed from the batches. Similarly, the GSL varies between 10 and 26 days for uncovered bananas and between 12 and 29 days for those covered with dry leaves when the ripe fingers are not removed from the batches. Biochemical analyses show a loss of firmness and a decrease in pH and starch levels during storage. However, there was an increase in the percentage of mass loss, dry matter and total and reducing sugars. Improved shelters made it possible to extend the GSL of plantain bananas.

Keywords: Green self-life, Improved Shelter, Plantain, Post-harvest losses, Storage

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1. Introduction

Plantain bananas are musaceous plants grown mainly for their fruit and contribute to food security [1]. Plantain is a major starchy staple food for populations in production areas [2]. Plantain also represents a substantial source of income for many rural and urban populations.

The plantain variety most widely grown in Côte d'Ivoire is the Horn type, in particular the Horn 1 variety. It accounts for around 90% of national production [3]. This variety is highly susceptible to black stripe disease (MRN). To combat this disease, disease-resistant tetraploid plantain hybrids have been developed to boost productivity [4]. With this in mind, a high-yielding tetraploid plantain hybrid variety, FHIA 21, was developed to control black stripe disease caused by *Mycosphaerella fijiensis*, another major constraint to plantain cultivation [5]. As part of the drive to improve plantain productivity in Côte d'Ivoire, this variety was

selected and included in a national dissemination programme [6].

During the period of abundance, excess production leads to numerous losses, particularly in connection with the transport and storage of plantain. Post-harvest losses are enormous, sometimes reaching 40% of production [7]. Storing plantain fresh therefore poses problems that limit its use and availability. However, a number of studies have proposed appropriate solutions, including storing organs at temperatures between 8°C and 12°C, and modifying the atmosphere inside warehouses [8]. The work of [9], for example, showed that plantain bananas wrapped in plastic packaging and stored at temperatures around 13.5°C increased their green life by 19 days. In China, [10] showed that pre-treating plantains by washing with chlorinated water and wrapping them in polyethylene bags increased their shelf life by more than 60 days in cold storage (at temperatures of 10-15°C). Other conservation techniques are commonly used in the West: reducing O₂ levels and increasing those of CO₂ in warehouses; refrigeration of organs by icing, modulation

of vapour pressures, or of the cooling speeds of refrigeration chambers, etc [8,9,10,11].

Although these methods are effective, they are expensive and out of reach for many farmers, who make up the majority of Ivorian growers. Under normal temperature conditions, plantain, like most tropical fruits with a high respiration rate, ripens between the fifth and ninth day after harvest [12]. This is attributed to unsuitable storage conditions and failure to observe care rules during various post-harvest operations, such as transport, handling, and display at markets [13]. Given the above, preserving plantain in Côte d'Ivoire remains a major issue that must be resolved if this crop is to contribute to food security. Therefore, the conservation problem remains almost unresolved, and devising new, practical techniques accessible to all farmers is imperative.

The aim of this study is to develop a method of preserving plantain that is accessible to all (producers and traders) through the use of improved shelters in order to help reduce post-harvest losses. The use of improved shelters (IS) is a simple and easy method of post-harvest preservation that can be used by plantain sector operators.

The general objective of this study is to contribute to the reduction of post-harvest losses by preserving plantain bananas at different stage maturity under improved shelters.

Specifically, the aim is to:

- 1) determine the green self-life (GLS) for each maturity stage of plantains stored under improved cover;
- 2) determine changes in physico-chemical parameters during the storage of plantains under improved cover at different maturity stages

2. Material and Methods

2.1. Material

2.1.1. Plant Material

The work in this study was carried out on plantain (*Musa* sp) of the variety FHIA 21 (*Musa paradisiaca* AAAB). The bunches were harvested in Azaguié (Côte d'Ivoire), a town located about 40 km from Abidjan, at latitude: 5° 37' 60" N and longitude: 4° 4' 60" W. Azaguié is located in the Agnéby-Tiassa region.

2.1.2. Technical Equipment

Improved shelters and dry plantain leaves were used to preserve the fruits of plantains of the FHIA 21 variety. The shelters were built of 10 cm thick straw around the perimeter and the straw roof was 15 cm thick. The shelter is 5 m long, 3 m wide and 2.5 m high. The shelter contains two shelves, each 3 m long and 0.75 m wide. Each shelf compartment is 0.75 m wide, 1 m long and 0.5 m high.

2.2. Methods

2.2.1. Treatment

Plantain FHIA 21 bunches harvested 80, 85, 90, 95, 100 and 105 days after emergence of the floral axis were carefully transported to the laboratory in a truck lined with dry lantana leaf to protect the fingers from injury. The fruits were detached from the bunches or not and stored in

the improved shelter at a rate of 12 bunches for each batch.

The temperature of experience into improved shelters is $26.83 \pm 2.44^\circ\text{C}$ against $29.51 \pm 2.72^\circ\text{C}$ on the outside of shelters.

The relative humidity recorded in the improved shelter is $98.80 \pm 1.03\%$ and those measured outside of shelters is $89 \pm 11.39\%$.

2.2.2. Storage Sampling

Four batches were made up for each stage of ripeness. One hand-cut batch was covered with dry banana leaf. The second hand-cut batch was not covered with dry banana leaf. The third batch was stored and covered with dry banana leaf. The fourth batch was not covered with dry banana leaf.

Storage was carried out in the improved shelter. Work was carried out on 48 bunches for each stage of maturity at harvest (SMH) or flowering-cutting interval (FCI). Every two (02) days, the batches were inspected and the number of ripe fingers counted to determine the GSL. The experiment was carried out in triplicate.

2.2.3. Determination of Green Shelf Life (GSL)

The green self-life (GLS) of the plantains studied was evaluated by the time elapsing from the start of storage, when the bananas are completely green, until the fingers are de-vitrified. The GSL is reached when a sub-lot has at least 50% ripe fingers. Two methods of determining GSL were adopted, namely the removal of ripe fingers and the retention of ripe fingers from different batches.

2.2.4. Physical Parameters

2.2.4.1. Fruit Mass Loss

Measurement of mass loss during ripening was used to determine the amount of water lost through transpiration during storage [14]. The plantain bunches or the fingers detached from the stem of each bunch were weighed periodically each week. A mechanical laboratory balance was used for this purpose. Mass loss was evaluated as a percentage loss of the initial mass for each diet.

2.2.4.2. Pulp Firmness

Firmness was measured using a portable penetrometer (model FT 327, Milan, Italy). The tip of the penetrometer fitted with a Salter 0-10 kg electronic force indicator was placed in the middle of the banana. The force required for an 8 mm diameter tip to penetrate the pulp is measured. The value recorded is the maximum force for the pulp to yield to the tip. It is usually expressed in kilogram-force (kgf) or Newton (N) where $1 \text{ kgf} = 9.80665 \text{ N}$ [15].

2.2.5. Chemical Parameters

2.2.5.1. Hydrogen Potential (pH)

The pH of the samples was measured using a digital pH meter (HANNA HI2211, Romania). Ten grams (10 g) of plantain pulp were ground in 50 ml of distilled water. The pulp was centrifuged at 3000 rpm for 30 min. The supernatant was collected in a jar and the pH was read on a digital screen by immersing the pH meter electrode directly in the solution.

2.2.5.2. Dry Matter Content

The dry matter content was determined using an electronic moisture meter (Mettler Toledo MJ33, Switzerland). 5 g of each sample was weighed and spread out in the tray of the apparatus and resealed. The drying temperature was 150°C. At the end of the drying process, an audible beep indicated the end of the operation and the value was recorded on the instrument's screen, indicating the value of the dry matter content.

2.2.5.3. Total and Reducing Sugars and Starch Content of Plantain

The total sugar content was determined using the method described by [16] using phenol. The reducing sugar content was determined according to the method described by [17] using deoxy-nitrosalicylic acid (DNS). The starch content was determined using the method of [18] modified by [19].

2.2.3. Statistical Analysis

The results were analysed using Stastica 7.1 software. The two-factor analysis of variance (ANOVA) and Duncan's test were used to compare the variables analysed for bananas during storage. Differences were considered significant for values of $P \leq 0.05$.

3. Results and Discussion

3.1. Results

3.1.1. Influence of the Storage Method on the Green self-life of the FHIA 21 Variety

The results of the effect of improved shelter on the green life of plantains of cultivar FHIA 21 and controls stored in the open are presented in Table 1. Analysis of the data revealed that the improved shelters significantly prolonged the green life of the fruit during storage compared with the control. The experimental temperature inside the improved shelters was $26.83 \pm 2.44^\circ\text{C}$ compared with $29.51 \pm 2.72^\circ\text{C}$ outside the shelters. The relative humidity recorded in the improved shelters was $98.80 \pm 1.03\%$ and that measured outside the shelters was $89 \pm 11.39\%$. Statistical analysis showed significant differences ($P \leq 0.05$) between the different stages of maturity at harvest and between the method of preserving the different stages of maturity when the ripe fingers were removed from the batches.

Table 1 shows the green life of FHIA 21 fruit with the removal of ripe fingers stored under improved shelter. For samples in hand covered with dry plantain leaves, the GSL ranged from 13.3 to 30.3 days, and from 12.0 to 27.6 days for uncovered banana samples in hand (Table 1). The GLS of plantains in covered hands is higher than that of plantain samples in uncovered hands, whatever the overall stage of ripeness.

Table 1. Green life of plantains of the FHIA 21 variety according to maturity stage and storage method with or without removal of ripe fingers

Storage mode	Maturity stage (Flowering-cutting interval (FCI) in days)					
	80	85	90	95	100	105
Removing ripe fingers in the batches						
MNR	27,6 ± 0,6 bF	23,3 ± 0,6 cE	22,0 ± 0,0 dD	19,3 ± 2,5 bcC	12,0 ± 0,0 bB	13,3 ± 0,6 bcA
MR	30,3 ± 0,6 bE	25,7 ± 1,2 dD	23,7 ± 0,5 cC	21,7 ± 0,6 cB	14,0 ± 1,0 cA	13,3 ± 0,6 bcA
RNM	26,3 ± 4,6 bC	20,3 ± 0,6 bB	18,0 ± 1,0 bB	17,3 ± 0,6 bB	13,0 ± 1,0 bcA	12,7 ± 0,6 bA
RR	28,0 ± 1,7 bD	23,3 ± 0,6 cC	20,3 ± 1,5 cB	19,3 ± 0,5 bcB	13,7 ± 0,6 cA	14,3 ± 1,2 cA
Control	8,0 ± 1,0 aE	7,4 ± 0,5 aDE	6,6 ± 0,8 aD	5,6 ± 0,5 aC	5,2 ± 0,4 aBC	4,6 ± 0,5 aA
Maintaining ripe fingers in the batches						
MNR	26,6 ± 0,6 dD	21,7 ± 1,2 bC	20,7 ± 1,2 cC	17,7 ± 1,2 cdB	11,0 ± 1,0 bA	10,3 ± 0,5 bA
MR	29,3 ± 1,5 eD	24,0 ± 2,6 cC	21,3 ± 1,5 cBC	18,7 ± 1,5 dB	12,3 ± 1,2 bA	12,3 ± 0,6 cA
RNR	22,3 ± 0,6 bB	19,7 ± 0,6 bB	14,3 ± 4,0 bA	13,3 ± 0,6 bA	12,0 ± 1,0 bA	11,0 ± 1,0 bA
RR	24,7 ± 0,6 cD	20,0 ± 0,0 bC	15,7 ± 1,2 bB	16,3 ± 1,2 cB	12,7 ± 0,6 bA	13,0 ± 0,0 cA
Control	8,0 ± 1,0 aE	7,4 ± 0,5 aDE	6,6 ± 0,8 aD	5,6 ± 0,5 aC	5,2 ± 0,4 aBC	4,6 ± 0,5 aA

Means ($n = 6$) ± standard deviation followed by the same lower-case letter in a column for a storage method and by the same upper-case letter in a row are not significantly different at the 5% threshold according to Duncan's test. MNR = uncovered hand, MR = covered hand, RNR = uncovered diet, RR = covered diet, FCI = flowering-cutting interval

The GSL ranged from 13.7 to 28.0 days for covered bunches and from 12.7 to 26.3 days for uncovered bunches. The different GSL of covered bunches are higher than those of uncovered bunches in all the different maturity stages studied.

For samples of plantains in uncovered hands, GSL ranged from 12.0 to 27.6 days, while those for samples in

uncovered bunches varied from 12.7 to 26.3 days. GSL are significantly different. They are higher with samples in uncovered hands than with samples in diets not covered with dry leaves.

The GSL of plantains in hand is higher than that of plantains stored in diets. Similarly, the GSL of covered plantain samples is higher than that of uncovered plantain

samples. Thus, plantain must be kept in hand and covered to prolong green life. Also, GSL decreases as maturity stage increases. GSL is highest at maturity stages 80, 85, 90 and 95. The GSL of the air-preserved controls range from 4.6 to 8.0 days. They are all lower than those of plantains stored in improved shelters.

Table 1 shows the green life of plantains of the FHIA 21 variety with the maintenance of ripe fingers stored under improved shelter. Statistical analysis revealed significant differences ($P \leq 0.05$) between storage methods and between different stages of maturity at harvest.

The self life of samples covered with dry plantain leaves ranged from 12.3 to 29.3 days (Table 1). For uncovered plantain samples, the self life ranged from 10.3 to 26.6 days. The GSL of covered bunch samples is higher than that of uncovered bunch samples overall.

For uncovered bunches of bananas, the GSL s range from 10.3 to 26.6 days, and for uncovered bunches, they range from 11.0 to 22.3 days. The GSL s are higher for uncovered bunches than for covered bunches in all IFCs studied, regardless of the stage of ripeness. For samples covered with dry leaves, the GSL is higher for samples stored in bunches than for those stored in bunches in all FCI.

The GSL s are higher in samples stored under improved shelter, regardless of the storage method, than in those stored in the open air. Also, all GSL s for plantains stored under improved shelter are significantly higher than those for plantains stored in the open air. In summary, the highest GSL s were observed in samples covered with dry plantain leaves where the ripe fingers had been removed.

As for samples in bunches, the GSL ranges from 12.7 to 24.7 days for covered plantain samples and from 11.0 to 22.3 days for uncovered plantain samples. The different

GSL s for covered bunches of plantains are higher than those for uncovered bunches in all the FCI.

3.1.2. Firmness

The firmness of plantains generally decreases during storage, regardless of the different maturity levels (Figure 1). Plantains from the different FCI had firmnesses ranging from 54.92 to 57.21 N on day 0 and from 16.34 to 22.88 N on day 21. Statistical analysis revealed a significant difference ($P \leq 0.05$) between the different FCI on day 0. On the 21st day of storage, it showed differences between the different FCI studied. The loss of firmness of the plantains from the different preserved FCI was similar overall and showed significant differences at the 5% threshold after 21 days of storage at room temperature and between the different maturity stages studied.

3.1.3. Loss of mass

The loss of mass of plantains increases rapidly during storage under improved cover (Figure 2). The different maturity stages of bananas showed no significant difference in mass loss from day 0 to day 7 of storage. The percentage loss in mass of plantains of the different maturity stages at harvest increases significantly from day 7 to day 21. It ranged from $3.67 \pm 0.47\%$ on day 7 to $27.96 \pm 0.06\%$ on day 21. Statistical analysis showed that there was a significant difference in plantain mass loss at the different FCI on day 7 of storage. There was also a significant difference between the six harvest dates on days 14 and 21 of storage at the experimental temperature.

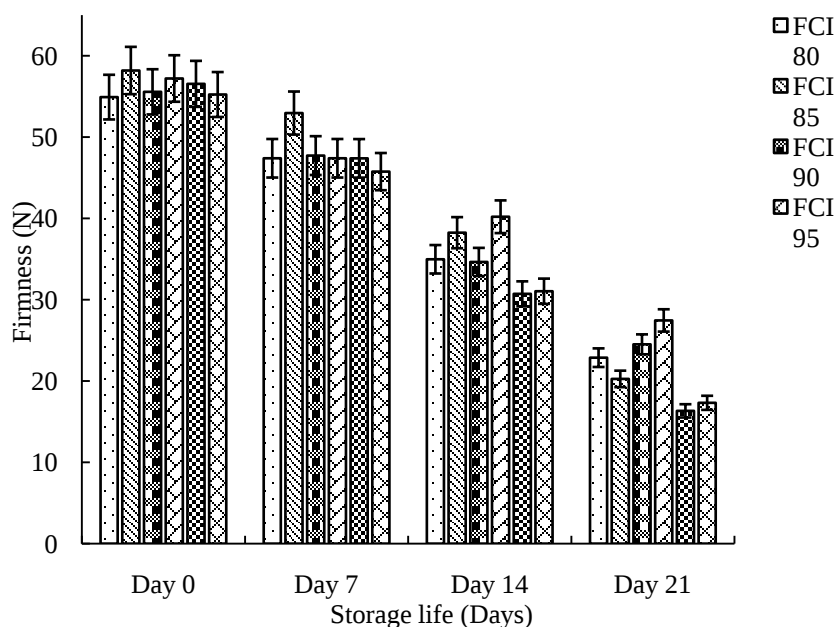


Figure 1. Evolution of the firmness of plantains of the FHIA 21 variety at different maturity stages during storage. Histograms of the means $\pm$ SD surmounted by the same letter are not statistically different at the 5% threshold according to Duncan's test. FCI: flowering-cutting interval or harvest date

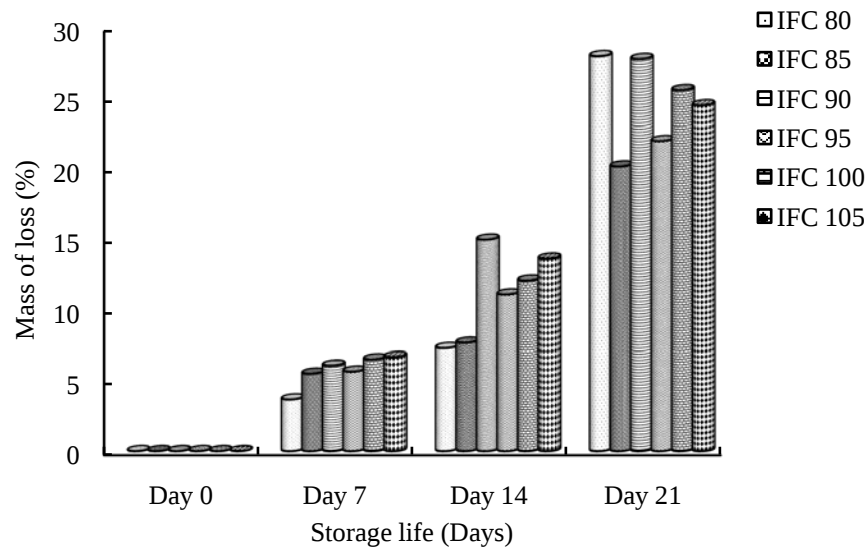


Figure 2. Evolution of the percentage loss of mass of the variety FHIA 21 at different stages of maturity during storage. The histograms of the means $\pm$ SD surmounted by the same letter are not statistically different at the 5% threshold according to Duncan's test. FCI: flowering-cutting interval or harvest date

Table 2. Evolution of the dry matter content of the different maturity stages of FHIA 21 plantains during storage

		Dry matter (%)			
		Storage life (days)			
Variety	FCI Day 0	Day 7	Day 14	Day 21	
FHIA 21	80	34,52 $\pm$ 0,15 cA	36,62 $\pm$ 0,02 dC	37,05 $\pm$ 0,19 dC	35,90 $\pm$ 0,27 cB
	85	33,80 $\pm$ 0,07 bA	33,54 $\pm$ 0,12 aA	34,68 $\pm$ 0,08 bB	34,89 $\pm$ 0,31 bB
	90	33,83 $\pm$ 0,05 bA	36,18 $\pm$ 0,09 cC	36,01 $\pm$ 0,10 cC	34,18 $\pm$ 0,18 aB
	95	33,53 $\pm$ 0,11 bA	34,43 $\pm$ 0,05 bB	36,49 $\pm$ 0,39 cC	36,98 $\pm$ 0,18 dC
	100	33,07 $\pm$ 0,23 aA	33,66 $\pm$ 0,13 aB	33,91 $\pm$ 0,13 aC	38,05 $\pm$ 0,21 eD
	105	35,31 $\pm$ 0,09 dB	34,14 $\pm$ 0,25 bA	34,92 $\pm$ 0,13 bB	35,78 $\pm$ 0,09 cC

Means ($n = 3$) $\pm$ SD followed by the same lower case letter in a column and the same upper case letter in a row are not significantly different at the 5% threshold according to the test of Duncan. FCI = Flowering-Cutting Interval (day).

3.1.4. Dry Matter

The dry matter content of the different maturity stages of plantains of the FHIA1 variety studied varied significantly at the 5% threshold during post-harvest storage. The dry matter content values increase significantly over the storage period and the various harvest dates (Table 2). On day 0, these values ranged from $33.07 \pm 0.23\%$ to $35.31 \pm 0.09\%$. On day 21 of storage, these values reach proportions of $34.18 \pm 0.18\%$ and $38.05 \pm 0.21\%$. These rates increase from day 0 to day 14 of storage and decrease from day 14 to day 21 of storage. The highest dry matter content was observed with FCI 105 on day 0 and at the end of storage (day 21) the highest dry matter content was observed with FCI 100 plantains. However, the dry matter contents differed

significantly according to storage duration and the different maturity stages.

3.1.5. Hydrogen Potential (pH)

Table 3 shows the pH of plantains harvested at different maturity levels and stored in the improved shelter. For all the different FCIs, the pH decreased significantly ($P \leq 0.05$) during storage. The pH values varied between 6.17 ± 0.01 (day 0) and 4.83 ± 0.01 (day 21) for all plantains during the storage period. Statistical analysis revealed significant differences ($P \leq 0.05$) between the pH values of the different maturity levels at harvest of the plantains. However, FCI 85 had the highest pH values at day 0, compared with 4.90 for FCI 90 at day 21. The pH decreases in all six FCIs during storage as a function of the different stages of maturity and storage time.

Table 3. Evolution of the pH of the different maturity stages of FHIA 21 plantains during storage

		pH			
Storage life (days)					
Variety	FCI	Day 0	Day 7	Day 14	Day 21
FHIA 21	80	5,90 ± 0,07 bB	5,88 ± 0,03 dB	4,69 ± 0,04 bA	4,88 ± 0,18 aA
	85	6,17 ± 0,01 dD	5,94 ± 0,0 eC	4,97 ± 0,00 dB	4,84 ± 0,03 aA
	90	5,96 ± 0,00 cD	5,87 ± 0,03 dC	4,66 ± 0,02 bB	4,90 ± 0,03 aA
	95	5,82 ± 0,01 aC	5,77 ± 0,02 cC	4,60 ± 0,02 aB	4,84 ± 0,06 aA
	100	5,81 ± 0,01 aD	5,51 ± 0,0 2aC	5,12 ± 0,02 eB	4,91 ± 0,02 aA
	105	5,96 ± 0,01 cD	5,71 ± 0,01 bC	4,93 ± 0,01 cB	4,83 ± 0,01 aA

Means (n = 3) ± SD followed by the same lower case letter in a column and the same upper case letter in a row are not significantly different at the 5% threshold according to the test of Duncan. FCI = Flowering-Cutting Interval (day).

Table 4. Evolution of total sugar levels in the different maturity stages of FHIA 21 plantains during storage

		Total sugar content (%)			
Storage life (days)					
Variety	FCI	Day 0	Day 7	Day 14	Day 21
FHIA 21	80	3,46 ± 0,06 bA	11,72 ± 0,01 aB	27,09 ± 1,04 dC	28,97 ± 1,06 bD
	85	3,22 ± 0,00 aA	14,72 ± 0,01 eB	25,46 ± 0,02 bcC	27,25 ± 0,96 aD
	90	3,43 ± 0,06 bA	13,86 ± 0,02 dB	27,84 ± 1,06 dC	29,29 ± 1,39 bD
	95	3,26 ± 0,02 aA	13,27 ± 0,03 bB	25,87 ± 0,12 cC	27,81 ± 2,11 abD
	100	3,27 ± 0,03 aA	11,69 ± 0,02 aB	24,65 ± 0,17 bcC	28,71 ± 1,73 bD
	105	3,25 ± 0,01 aA	13,72 ± 0,04 cB	23,36 ± 0,34 aC	27,20 ± 0,29 abD

Means (n = 3) ± SD followed by the same lower case letter in a column and the same upper case letter in a row are not significantly different at the 5% threshold according to the test of Duncan. FCI = Flowering-Cutting Interval (day).

Table 5. Evolution of the reducing sugar levels at different maturity stages of FHIA 21 plantains during storage

		Reducing sugar content (%)			
Storage life (days)					
Variety	FCI	Day 0	Day 7	Day 14	Day 21
FHIA 21	80	1,58 ± 0,01 fA	3,02 ± 0,14 dB	9,95 ± 0,02 eC	15,97 ± 0,01 eD
	85	0,88 ± 0,00 eA	3,05 ± 0,37 dB	9,60 ± 0,01 dC	15,16 ± 0,05 dD
	90	0,51 ± 0,01 cA	1,59 ± 0,05 abB	9,32 ± 0,00 bC	16,23 ± 0,00 fD
	95	0,54 ± 0,00 dA	1,34 ± 0,01 aB	9,57 ± 0,00 cC	14,09 ± 0,00 bD
	100	0,45 ± 0,01 bA	2,41 ± 0,00 cB	10,06 ± 0,01 fC	13,92 ± 0,00 aD
	105	0,33 ± 0,01 aA	1,82 ± 0,00 bB	8,66 ± 0,01 aC	14,86 ± 0,01 cD

Means (n = 3) ± SD followed by the same lower case letter in a column and the same upper case letter in a row are not significantly different at the 5% threshold according to the test of Duncan. FCI = Flowering-Cutting Interval (day).

3.1.6. Total Sugars

Total sugar levels increased in all bananas during storage under improved cover for the first 21 days (Table 4). Total sugar values increased from $3.22 \pm 0.00\%$ on day 0 to $29.29 \pm 1.39\%$ on day 21. This trend in total sugar content was similar for all the different stages of maturity at harvest and as a function of storage time. Statistical analysis showed significant differences in total sugar levels between the different stages of maturity at harvest and storage time.

3.1.7. Reducing Sugars

The levels of reducing sugars at the different stages of maturity at harvest in harvested plantains increased significantly during storage (Table 5). Reducing sugar levels ranged from $0.33 \pm 0.01\%$ on day 0 to $16.23 \pm 0.00\%$ on day 21. The highest values were obtained with

FCI 80, 85 and 90 on day 21. Statistical analysis revealed significant differences ($P \leq 0.05$) between reducing sugar levels in plantains at different maturity levels at harvest. However, reducing sugar levels differed according to maturity level and increased during banana storage.

3.1.8. Starch

Table 6 shows the evolution of starch levels in plantains harvested at different harvesting dates for the FHIA 21 variety. The starch levels for the different harvest dates for the FHIA 21 variety ranged from $85.78 \pm 1.59\%$ to $88.24 \pm 0.41\%$ on day 0. On day 21, starch levels ranged from $30.00 \pm 0.14\%$ to $37.87 \pm 0.17\%$. The starch levels for the different plantain harvest dates decreased significantly at the 5% threshold during storage and as a function of maturity levels. Statistical analysis showed significant differences between the starch content of the different harvest dates and the length of storage.

Table 6. Evolution of starch content at different maturity stages of FHIA 21 plantains during storage

		Starch content (%)			
Storage life (days)					
Variety	FCI	Day 0	Day 7	Day 14	Day 21
FHIA 21	80	88.19 ± 0.32 bA	81.57 ± 0.87 dB	57.48 ± 0.49 cC	37.87 ± 0.17 dD
	85	88.24 ± 0.41 b A	80.84 ± 0.23 cdB	60.39 ± 0.17 eC	37.62 ± 0.05 dD
	90	87.50 ± 1.40 abA	79.39 ± 0.18 cB	60.01 ± 0.16 eC	34.02 ± 0.10 cD
	95	87.23 ± 0.45 abA	77.75 ± 0.72 bB	58.78 ± 0.35 dC	33.96 ± 0.10 cD
	100	86.35 ± 1.68 abA	75.25 ± 1.09 aB	53.26 ± 0.11 bC	30.79 ± 0.96 bD
	105	85.78 ± 1.59 aA	73.87 ± 1.42 aB	51.62 ± 0.43 aC	30.00 ± 0.14 aD

Means ($n = 3$) $\pm$ SD followed by the same lower case letter in a column and the same upper case letter in a row are not significantly different at the 5% threshold according to the test of Duncan. FCI = Flowering-Cutting Interval (day).

3.2. Discussion

The results obtained in this work show that the improved shelter has a significant influence on the green self-life (GSL) and on evolution in the physico-chemical characteristics of plantain fruit during storage.

The study of GSL during storage revealed that fruit kept at $26.83 \pm 2.44^\circ\text{C}$ and a relative humidity of $98.80 \pm 1.03\%$ inside the improved shelters had a green self-life of between 12 and 30 days when the ripe fingers were removed from the batches and between 10 and 29 days when the ripe fingers were kept in the different batches. Our results of GSL of the different maturity stages are largely superior to those of [20] on the storage of plantains with the use of polyethylene bags which of 14 to 18 days of preservation. The GLS values for the different maturity stages obtained are similar to those reported by [21] on the preservation of plantain of the Horn 1 variety. The storage temperature inside the improved shelters (26°C) and relative humidity ($\text{RH} = 98\%$) extended the GSL of plantains to more than two weeks. These results are in agreement with those of [22] stipulating that a temperature of 25°C and RH of between 85 and 95% enable bananas to be kept for approximately three weeks.

In fact, they go on to say that a temperature of 25°C would shorten the pre-climacteric period and increase the climacteric peak, while fruit quality would change due to metabolic changes during ripening. Similarly, [23] reports that a temperature higher than 30°C induces an increase in ethylene synthesis to initiate fruit ripening. According to [24], a low RH favours high water loss and softening of fruit tissues, and consequently the pre-climacteric period will be short.

The study of changes in the physico-chemical characteristics of plantains of the Horn 1 cultivar showed significant variations between samples from the six maturity stages kept in improved shelters.

With regard to changes in firmness, there was a significant difference between the six maturity stages on the one hand, and between storage times on the other. In fact, there was a significant decrease during storage from day 0 to day 21. It should also be added that during ripening, loss of firmness is the result of hydrostatic pressure in the parenchymal cells of the fruit [25]. Similarly, respiration and ethylene synthesis are two phenomena that favour metabolic reactions such as chlorophyll degradation and enzymatic hydrolysis of the cell wall, leading to loss of fruit firmness. These results

are in agreement with those mentioned by [26] and [27] who showed that the activity of parietal hydrolases of certain enzymes increased during the ripening of melon fruit with the synthesis of ethylene. According to the work of [28], during the pre-climacteric phase, the activities of cell wall degradation enzymes in climacteric fruit are low. These activities increase rapidly during the climacteric phase, coinciding with the increased respiration of the fruit. However, all these authors have shown that certain phenomena responsible for the softening of the fruit, such as the loss of turgidity, are independent of ethylene.

As regards loss of mass, this increases sharply during the storage of the various FCIs, whatever the shelf life. This loss of mass can be explained by the fact that fruit stored at high temperature transpires more and therefore releases more water. Reference [29] have shown that mass loss is the result of fruit respiration. According to these authors, fruit and vegetable respiration increases with temperature, which increases transpiration. However, the water released by the fruit during respiration is not renewed because the fruit is detached from the tree, so mass is lost [30,31].

With regard to the dry matter content, there is a significant increase during storage in the maturity stages and shelf life of plantains. Dry matter levels ranged from 33.07% to 38.05%. These results are similar to those reported by [32] and [33] on different plantain cultivars. However, the increase in dry matter content is linked to water loss following respiration of the fruit during storage.

The hydrogen potential (pH) decreased during storage. The different pH values (4.83-6.17) obtained are similar to those of [32]. This variation in pH observed in the plantain bananas studied would be linked to the acid levels in the pulp of these plantains. Indeed, the water and amylolytic enzymes (α and β and α -1,4 and α -1,6-glucosidases) present in the fruits would favour the degradation of carbohydrate polymers into simpler carbohydrate molecules, facilitating their conversion into organic acids [34].

The variation in total and reducing sugar levels in plantains harvested and stored under improved cover at different harvest dates is thought to be the result of the increasing hydrolysis of carbohydrates by glycosidases during storage. The increase in total and reducing sugar levels in bananas depends on the hydrolysis of starch by amylolytic enzymes present in the pulp [35,36]. Indeed, [37] showed that during plantain ripening, starch content falls sharply from stage 1 of ripening to stage 7, which consequently increases total and reducing sugar content. These same observations were reported by [38] during their study on the evaluation of the physicochemical qualities of the fruit of home-grown bananas in Cameroon. The levels of total sugars and reducing sugars obtained are similar to those obtained by [39] and [40] on the Horn 1 and Orishélé varieties respectively.

4. Conclusion

The preservation of plantains of cultivar FHIA 1 under improved shelter significantly extended their green life. This green life was between 12 and 30 days when the ripe fingers were removed from the batches and between 10 and 29 days when the ripe fingers were kept in the batches.

The most suitable method of preservation is to cover the bananas with dry leaves. According to the various GSLs for the different maturity stages, plantains should be harvested at FCI 80, 85 and 90, which give a long shelf life. The study of changes in physico-chemical characteristics over the storage period showed a significant difference between the biochemical composition of samples as a function of FCI and storage time.

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