International Journal of Agronomy and Agricultural Research (IJAAR)
ISSN: 2223-7054 (Print) 2225-3610 (Online)
http://www.innspub.net
Vol. 10, No. 6, p. 6-18, 2017

RESEARCH PAPER OPEN ACCESS

Effect of the stage of maturity on the green self-life and the biochemical parameters of plantain (*Musa* AAB, var. *Horn 1*) stored in the improved shelter

Brou Koffi Siméon[1], Yao N'zué Benjamin[2], Kouamé Akissi Françoise[1], Yué Bi Yao Clément[1], Kouamé Fils David Vincent[3], Edi Edi Janequin[3], Tano Kablan[*1]

[1]*UFR of Food Science and Technology, University Nangui Abrogoua, Abidjan, Côte d'Ivoire*

[2]*UFR of Agroforestery, University Jean Lorougnon Guede of Daloa, Côte d'Ivoire*

[3]*Institut of Ivorian Tropical Technology (I2T), Abidjan, Côte d'Ivoire*

Article published on June 24, 2017

Key words: Plantain, Storage, Improved shelter, Green self-life (GSL), Post-harvest loss

Abstract

A study has been conducted in order to determine the efficacy of the improved shelters to retard the plantain ripening to reduce the post-harvests losses. Variety of plantain *Horn 1* harvested at 65, 70, 75, 80, 85 and 90 days after floral apparition have been stored in the improved shelter and covered or not by dried leaves of plantain. The green self-life (GSL) was determined when the ripe fingers are withdrawn or maintained in the batches. The physicochemical changes were measured in terms of the loss of mass, firmness of pulp, dry matter, pH, titratable acidity (TA), total soluble solids (TSS), total sugars (TS) and reducing sugars (RS) fruit. The results of GSL of plantain range from 15 to 36 days for plantains non-covered by dried leaves and from 15 to 38 days when they are covered and when the ripe fingers are removed from the batches. Similarly, the GSL oscillates between 14 and 29 days for non-covered plantain and between 15 and 31 days for those covered with dried leaves when the ripe fingers are not removed from the batches. Concerning the GSL of the control samples stored outdoors, it is included between 4 and 9 days. The samples stored in improved shelter have higher GSL as control samples stored outdoors. The results of biochemical analysis show a decrease of firmness and pH during storage. However, we notice an increasing of percentage of loss of mass, dry matter, total and reducing sugars, titratable acidity, total soluble solids (TSS). The analysis of the data revealed that the improved shelters significantly prolonged the GSL of the fruit.

* **Corresponding Author:** Tano Kablan ✉ pasqual_kab@hotmail.com

Introduction

Plantains are mainly grown for their fruit and contribute to food safety (Nkedah, 2001). Plantain is one of the most important crops in the world (Odah *et al.,* 2013). Plantain is a basic food for people in the production areas (Gire, 1994). It occupies the 4th rank of the food products in terms of consumption after wheat, corn and rice (FAO, 2009). Banana is also a substantial source of income for many rural and urban populations. The association of cultures is the main form of production of plantain (Nkendah and Akyeampong, 2003). Monoculture rarely is carried out on small surfaces. The production of banana in the world is estimated at about 106 millions tons annually, of which 18.127 millions tons of plantain (Lescot, 2006). The annual production of plantain in Côte d'Ivoire is about 1.5 million tons that places it in the third place of the food products after the yam and rice (Ducroquet, 2002; FAO, 2009).

During this period of abundance, excess production causes many losses particularly related to transportation and storage methods of plantain. The post-harvests losses are a lot and sometimes reached 40 % of production, that represent 640000 tons in 2012 (ANADER, 2013). Thus, conserving plantain in fresh form causes problems limiting the duration use and availability. However, many studies have allowed proposing appropriate solutions, including organ storage at some temperatures between 8°C and 12°C, and modified atmosphere in the interior of the warehouses (Varoquaux *et al.,* 2002). The works of Narayana *et al.* (2002) showed that the plantain wrapped in plastic packaging and stored at temperatures about 13.5°C lengthened their duration of GSL of 19.33 days. In China, Chen *et al.* 2000) showed that the pre-treatment of plantain by washing with chlorinated water and their packaging in polyethylene bags were increasing their shelf-life more than 60 days in cold room (of temperatures of 10 to 15°C). Other technical storage are commonly used in West such as reduction of the O_2 contents and increase those of CO_2 in the warehouses; organs refrigeration by icing, modulation of vapor pressures, or cooling speed of refrigerated systems etc. (Chamara *et al.,* 2000; Varoquaux *et al.,* 2002).

These methods despite their efficacy are onerous and out of reach for many farmers who constitute the majority of Ivorian's producers. In normal conditions of temperature, plantain as the majority of tropical fruits at high breathing matures between 5th and the 9th day after harvest (Yao, 2015). This situation is attributed to a non-adapted storage and non-compliance with rules in care of various post-harvests operations such as transportation, handling and the flaunt on the markets (Guillemot, 1976). In view of the above, the problem of storage in Côte d'Ivoire plantain remains a major constraint that we must be solve so that food can reach it aim in achieving food safety (security) of populations. So the problem of storage still on, and the necessity to create news technical practical and accessible to all farmers thus proves unavoidable.

Then study aims to put in evidence a storage method of plantain accessible to all (producers and traders) through the using of improved shelters to contribute the reduction of post-harvest losses. This study proposes to follow certain biochemical parameters of plantains during storage in the improved shelters.

Materiel and methods

Material

Vegetable material

Plantain (*Musa* sp.) of variety *Horn 1* (*Musa* AAB) was used in this study. The bunches were harvested in Tiassalé (Taboitien) (Côte d'Ivoire), town situated to 125 km to Abidjan, with geographic coordinate to 5°53′54″North latitude and 4°49′42″West longitude. Tiassalé is located in Agnéby-Tiassa region.

Technical material

For storage of plantain fruits of variety *Horn 1*, the improved shelter and the dried leaves of banana tree have been used. The shelter was built in straw for the circumference of 10 cm of thickness and the straw in roof has of thickness 15 cm. The shelter has following dimensions: 5 m of length, 3 m of width and 2.5 m high. The shelter contains two shelf lengths of 3 m and of width 0.75 m. Each lodge has a dimension of 0.75 m of width, 1 m of length and 0.5 m of high.

Methods

Treatment

Some bunches of plantain cultivar *Horn 1* harvested 65, 70, 75, 80, 85 and 90 days after floral apparition were carefully transported to the laboratory of Institute of Ivorian Tropical Technology (I2T) in a truck lined with dried leaves of banana tree to preserve the fingers of all injuries. The fruits were detached from the bunch or not have stored in the improved shelter due to 12 bunches for each batch.

Storage sampling

For each stage of maturity, four batches were created. A batch cutting by hand was covered with dried banana leaves. The second batch cutting by hand wasn't covered with dried banana leaves. The third batch in bunch was stored and covered with dried banana leaves. The fourth batch in bunch wasn't covered with dried banana leaves. Storagehas been carried out in improved shelter. Studies concerned 48 bunches for each stage of maturity during harvest. Each two (02) days, the batches are inspected and the numbers of ripe fingers are counted to determine the GSL. The experiment has been done in triplicate.

Determination of the green self life (GSL)

The GSL of plantain bunches studied has been evaluated by the time running at the beginning of storage where the bananas are totally green to paint removal fingers. The GSL is reached when under batch of ripe at least 50% of ripe fingers. Two methods of determination of the GSL have been adopted such as the remove of ripe fingers and those which maintain ripe fingers for differents batches.

Physical parameters

Loss of mass of fruits

The loss of mass during the ripening was measured using the method of Proulx *et al. (*2005). Mass loss was determined during the storage period by monitoring the mass of the 10 bunches. Plantain bunches were weighed periodically every week. A mechanical laboratory balance was used for this purpose. Mass loss was expressed as percentage of the loss of mass with respect to the initial mass for each bunch and was determined in triplicate.

Firmness of pulp

Firmness was measured using a portable penetrometer (model FT 327, Milan, Italy).

In the middle part of plantain pulp, we place the tip of the penetrometer equipped by an electronic force indicator Salter from 0 to 10 kg. The necessary force is measured so that an end 8 mm in diameter penetrates in pulp. The recorded value is the maximum force for the pulp give way to the tip. It is usually expressed of kilogram-force (kgf) or Newton (N) with 1 kgf = 9.80665 N (Dadzie and Orchard, 1997).

Chemical parameters

Dry matter content was determined by an electronic humidimeter (Mettler Toledo MJ33, Switzerland). Indeed, 5 g of each sample were weighed and spread out in the plate of the apparatus and closed. The temperature of desiccation is of 150°C. At the end of the drying a beep sound indicates the end of the operation and the value is recorded on the screen of the apparatus indicating the value of the dry matter content. The hydrogen potential (pH) of the samples was measured with a digital pH-meter (HANNA HI2211, Romania).Ten grams (10 g) of the banana pulp are crushed in 50 mL of distilled water. The homogenate is centrifuged at 3000 towers/min for 30 min. The supernatant is collected in a jar, the pH is read on a digital screen while directly by immersing the electrode of the pH-meter in to solution. Titratable acidity was determined according to the method A.O.A.C (2000).

The total soluble solids (TSS) expressed in brix degree (°Brix) was measured with a portable refractometer equipped with a corrector of temperature (model FG103/113, Milan, Italy). A drop of the juice obtained after grinding banana pulp is deposited on the refractometer prism. Reading is performed by pointing the refractometer toward a source of light. The method described by Dubois *et al.* (1956) using the phenol-sulfuric was used for the total sugars contents analysis. Reducing sugars contents were determined according to the method of Bernfeld (1955) using 3.5-dinitro-salicylic acids. All determinations were performed in triplicates

Statistical analysis

Analysis of the data was carried out using Stastica 7.1 software.

The analysis of the variance with two factors (ANOVA) and the test of Duncan were realised to compare the variables analysed on plantain during the storage. The differences were considered significant for values of $P \leq 0.05$.

Results and discussion

Green self-life (GSL) with withdrawal and with maintenance of the ripe fingers

The results of effect of the improved shelter on the green self-life (GSL) of plantain of the cultivar *Horn 1* and the control stored with the air are presented in Table 1.

Table 1. Green life duration of the variety *Horn 1* preserved in the improved shelters with withdrawal of ripe fingers and maintenance of ripe fingers.

Mode of	Stage of maturity (Interval Flowering – Cut (IFC) (day))					
storage	65	70	75	80	85	90
	Withdrawal of the ripe fingers of the batches					
MNR	36.0±1.0 aG	33.0±2.6 aH	25.6±0.5 abI	23.0±1.0 dJ	19.6±1.2 eK	15.0±1.0 fL
MR	38.3±1.5 bM	29.3±0.6 bN	27.0±1.7 bO	24.0±1.0 dP	18.6±0.6 eQ	16.3±0.6 fR
RNR	30.0±1.0 cS	26.3±1.2 bT	24.0±0.0 aU	23.0±1.7 dU	19.3±1,5 eV	15.3±0.6 fW
RR	31.0±1.0 cI	29.0±1.0 bIJ	27.6±1.5 bJ	24.0±1.0 dN	20.0±1.7 eO	15.3±0.6 fP
	Maintenance of the ripe fingers of the batches					
MNR	29.6±1.0 aG	27.6±2.5 bH	24.0±1.7 cI	21.0±0.8 aJ	18.0±0.5 eK	14.0±0.5 aL
MR	31.0±1.8 aM	29.2±3.8 bM	25.4±2.5 cO	22.0±0.7 bP	16.0±1.0 dQ	15.0±0.7 bcQ
RNR	29.6±0.9 aR	24.4±2.9 bS	24.6±1.3 cS	22.0±0.7 bT	18.0±0.7 eU	14.2±0.5 abV
RR	30.0±1.2 aW	27.4±5.0 bW	27.2±3.8 cW	21.8±0.4 abX	19.0±1.0 eX	15.4±0.6 cY
Control	9.0±0.7 F	7.8±0.8 E	6.6±0.5 D	5.8±0.4 C	5.0±0.0 B	4.2±0.4 A

The means (N = 6) followed by the same small letter in a column and of the same capital letter on a line are not significantly different with the threshold from 5 % according to the test of Duncan.

MNR = non covered hand, MR. = covered hand, RNR = mode not covered, RR = covered mode, IFC = interval flowering-cut.

The analysis of the data revealed that the improved shelters significantly ($P \leq 0.05$) prolonged the green self-life of the fruit during storage compare to the control.

The temperature of experience into improved shelters is 26.83±2.44°C against 29.51±2.72°C on the outside of shelters.

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

The storage temperature inside the improved shelters (26°C) and the high relative humidity permited to prolong the green self-life of plantains beyond two weeks. These results are similar with those of Hailu *et al.* (2013) stipulating that a temperature of 25°C and a relative humidity ranging between 85 et 95% permit to store plantain about three weeks. Indeed, they show that a temperature of 25°C would shorten the pre-climateric time and increase the climateric peak and the quality of fruit would change because of the metabolic modification during maturation. Thus, Pesi (2004) reports that a temperature superior to 30°C would induce the increase of the ethylen synthesis to begin the fruit maturation.

According to Gowen (1995), a weak relative humidity lead to a great loss of water and the softening of fruit tissues and consequently the pre-climaterical time will be short. Indeed, the green self-life of plantain of variety *horn 1* with the withdrawal or the maintenance of ripe fingers stored under improved shelter are represented in Table 1.

Table 2. Evolution of the dry matter rate of the various levels of maturity of plantain during the storage.

		Dry matter (%) Self-life (day)			
Variety	IFC	Day 0	Day 7	Day 14	Day 21
	65	38.04±0.01 aA	38.18±0.01 aB	39.59±0.01 aC	38.26±0.01 aD
	70	38.64±0.01 bE	40.30±0.00 bF	40.64±0.01 bG	39.24±0.01 bH
Horn 1	75	38.43±0.02 cI	40.21±0.01 cJ	40.96±0.01 cK	40.80±0.00 cL
	80	39.13±0.01 dM	39.36±0.01 dN	39.50±0.06 dO	37.80±0.01 dP
	85	39.63±0.01 eQ	39.59±0.02 eQ	40.29±0.01 eR	37.53±0.05 eS
	90	38.25±0.06 fT	39.25±0.06 fU	41.11±0.01 fV	39.96±0.01 fW

The means (N = 3) ± SD followed by the same small letter in a column and of the same capital letter on a line are not significantly different with the threshold from 5 % according to the test of Duncan. IFC = interval flowering-cut.

The results show that the GSL of bananas in covered hands is higher than those of bananas in hands not covered as a whole. The GSL of plantain is higher when the ripe fingers are withdrawn in the batches compared to the batches where the ripe fingers are maintained (Table 1). We notice that the GSL of plantain in covered hands or bunches is higher than that of plantain in hands or bunches not covered as a whole whatever the stage of maturity when the ripe fingers were withdrawn or maintained (Table 1).

As regard the samples in bunches with the withdrawal the ripe fingers, the various GSL of bananas in covered bunches are higher than those of the bunches not covered as a whole with the stage of maturity studied. Concerning the bunches samples when the ripe fingers are maintained the ripe fingers, the various GSL of plantain in covered bunches are higher than those of the bunches not covered as a whole with the studied of stages of maturity.

Table 3. Evolution of the pH of the various levels of maturity of plantain during the storage.

		pH Self-life (day)			
Variety	IFC	Day 0	Day 7	Day 14	Day 21
	65	6.73±0.05 aA	6.39±0.12 aA	5.59±0.06 aB	5.18±0.01 aB
	70	6.56±0.02 bC	5.96±0.01 bD	5.35±0.10 bDE	5.09±0.01 bE
Horn 1	75	6.57±0.01 bF	5.95±0.03 bG	5.30±0.01 bGH	5.10±0.01 bH
	80	6.72±0.01 aI	6.36±0.03 cIJ	6.13±0.05 cJK	5.30±0.05 cK
	85	6.69±0.01 aL	6.11±0.03 dM	5.47±0.02 dM	5.33±0.01 dM
	90	6.78±0.01 cN	6.55±0.05 eN	6.04±0.03 eP	5.78±0.01 eP

The means (N = 3) followed by the same small letter in a column and of the same capital letter on a line are not significantly different with the threshold from 5 % according to the test of Duncan. IFC = interval flowering-cut.

For the samples covered with dried leaves, the GSL is practically higher for the samples preserved in hand than those preserved in bunches. Also, the GSL decreases when the stage of maturity increases when the ripe fingers are withdrawn. As regard the samples covered with dried leaves, the GSL is practically higher for the samples preserved in hand than those preserved in bunches in the whole of the stage of maturity when the ripe fingers are maintained. The effect of covering over the shelf life of the plantain revealed that all the bananas in hands or bunches covered, caused a significant lengthening of the shelf life of those. The best results were obtained with bananas in hands covered as a whole. Similar results were obtained by Varoquaux *et al.* (2002). These same observations were reported by Sugri and

Johnson (2009) who in their study of four varieties of plantain (*Apem, Apentu, Oniaba* and *Asamienu*) in Ghana, covered the fruit with sawdust in jute bags humidified and obtained GSL ranging from 15 to 28 days during the preclimacteric phase.

Table 4. Evolution of the assayable acidity of the various levels of maturity of plantain during the storage.

		Titratable acidity ((mEq / 100 g f. m.) Self-life (day)			
Variety	IFC	Day 0	Day 7	Day 14	Day 21
	65	4.82±0.53 abA	11.50±0.50 aB	19.50±0.00 bC	25.20±0.26 aD
	70	4.77±0.66 abE	13.17±0.29 bcF	17.67±0.29 aG	24.85±0.30 aH
Horn 1	75 abJ	6.17±0.58 cI	12.50±1.50	19.17±0.29 bK	25.67±0.29 aL
	80	4.50±0.50 aM	14.17±0.29 cN	21.00±0.50 cO	32.17±0.76 cP
	85	5.83±0.76 bcQ	13.17±0.76 bcR	26.67±0.58 eS	30.83±0.58 bT
	90	6.67±0.29 cU	11.50±0.50 aV	22.00±0.50 dW	32.00±0.00 cX

The covering of the fruits, enables them to retain a good quantity of moisture which tends to keep them fresh. It is one of the reasons which would explain the higher GSL of covered plantain than not covered plantain. Similar results were reported by Narayana *et al.* (2002) on bananas stored in hermetically sealed bags. Our results of green self-life of differents maturity stages are widely superior to those of Yao *et al.* (2014) on the storage of plantains with the use of the polyethylenes sachets of 14 and 18 days of storage.

The shrinking of the ripe fruits of the batches showed a beneficial effect on the GSL. The withdrawal of ripe fingers permit to reduce considerably the action of ethylene which induces the ripening of the stored fruits and increase their GSL compared to the batches where the ripe fingers were maintained.

Table 5. Evolution of total soluble solids of the various levels of maturity of plantain during the storage.

		Total soluble solids (°Brid) Self-life (day)			
Variety	IFC	Day 0	Day 7	Day 14	Day 21
	65	4.83±0.15 aA	7.90±0.10 aB	14.36±0.15 aC	25.33±0.15 aD
	70	4.60±0.05 bE	7.90±0.10 aF	15.20±0.05 bG	25.56±0.15 aH
Horn 1	75	4.96±0.05 aI	7.40±0.10 bJ	15.96±0.05 cK	28.26±0.15 bL
	80	5.76±0.15 cM	8.13±0.05 cN	16.36±0.15 dO	28.33±0.15 bcP
	85	5.86±0.05 cQ	8.33±0.11 dR	16.96±0.05 eS	28.56±0.15 cT
	90	6.86±0.11 dU	9.10±0.20 eV	19.20±0.17 fW	29.93±0.11 dX

The means (N = 3) followed by the same small letter in a column and of the same capital letter on a line are not significantly different with the threshold from 5 % according to the test of Duncan. IFC = interval flowering-cut.

The shrinking of the ripe fruits is considered an inhibitor effect on the action of ethylene on ripening to decrease the respiratory rate. This result was reported by Sisler and Serek (1997) who during their studies applied an inhibitor of ethylene action, 1-methyl-cyclopropene (MCP) as having an inhibitory effect on the maturation of the fruits to extend the shelf life of tomatoes.

The GSL of the control stored in air oscillate between 4.2±0.4 and 9.0±0.7 days. They are all lower than those of bananas stored in the improved shelters. However, we notice that the GSL is higher at levels of the stages of maturity of 65, 70 and 75 when the ripe fingers are withdrawn or maintained in the batches (Table 1).The statistical analysis showed significant differences ($P \leq 0.05$).

The GSL of the *Horn 1* variety studied decreases when the maturity stages increase. Indeed, the GSL depends on the age at harvest of fruit and vegetable. According to Julien *et al.* (2001) reported that there was a decreasing relationship between the GSL of fruits and their age at harvest, which would justify the low GSL of the plantains studied at the advanced stage of maturity. The highest GSL were observed with early stages of maturity for the variety Horn1 studied while those of the advanced stages of maturity were short.

Table 6. Evolution of the total sugar rate of the various levels of maturity of the bananas plantain during the storage.

		Total sugar (%) Self-life (day)			
Variety	IFC	Day 0	Day 7	Day 14	Day 21
	65	4.42±0.02 cA	14.8 9±0.01 fB	20.71±0.01 fC	26.96±0.02 dD
	70	4.52±0.02 dE	14.54±0.01 dF	19.86±0.02 eG	25.96±0.02 cH
Horn 1	75	4.80±0.10 eJ	14.77±0.01 eK	19.41±0.01 cL	25.89±0.01 cM
	80	3.11±0.01 aN	11.70±0.01 aP	17.53±0.03 aQ	24.73±0.02 bR
	85	3.05±0.01 aS	12.65±0.01 cT	18.91±0.01 bU	24.70±0.01 bV
	90	3.34±0.01 bW	12.02±0.01 bX	19.51±0.01 dY	23,97±0.18 aZ

The means (N = 3) followed by the same small letter in a column and of the same capital letter on a line are not significantly different with the threshold from 5 % according to the test of Duncan. IFC = interval flowering-cut.

The results obtained are similar to those obtained by Kouadio *et al.* (2013) in their study on the determination of the optimal cutting point for fruits of the plantain hybrids *PITA 3*, *PITA 8* and the plantain varieties *Lorougnon* and *Horn 1*. According to N'da *et al.* (1997), the shelf life depends enormously on the interval flowering-cut (IFC) or stages of maturity of the fruits at harvest. These authors argue that the higher the stage of maturity was the more the possibilities of storage and marketing of the fruits in a consumable state decrease. In comparison with the results of the GLD of the different stages of maturity, plantains should be harvested at IFC 65, 70 and 75, thus giving a long shelf life.

The GSL are higher in the samples preserved under improved shelter whatever the mode of storage than those stored at the free air. The statistical analysis reveals significant differences ($P \leq 0.05$) between the mode of storage and between the various stages of maturity to harvest. In short, the GSL the most higher were observed in the samples covered with sheets dried leaves of plantain trees where the ripen fingers were retired.

Physical parameters

Firmness

The firmness of the plantain decreases, in general, during storage, whatever the various levels of maturity (Fig 1). Plantain of the various interval flowering-cut (IFC) or stages of maturity have firmness varying of 60.81±0.01N with 65.70±0.10N day 0 and 16.72±0.01 to 20.59±0.00N the day 21. The evolution of the loss firmness of plantain of the various IFC preserved, is similar as a whole and present significant differences at the threshold in 5% after 21 days of storage at the ambient temperature of the shelter and between the various studied stages of maturity.

Concerning the firmness evolution, we notice a significant difference between the six stages of maturity on the one hand and between the shelf life on the other hand. Indeed, we noticed a significant reduction during storage of day 0 to day 21. This firmness loss could be explained by the transpiration of the fruits during storage. As, should it be added as during maturation, the firmness loss is the consequence of the hydrostatic pressure of the parenchymatous cells of the fruit (Chaïb, 2007).

Similarly, respiration and ethylene synthesis are two phenomena that support the metabolic reactions such as the decomposition of chlorophyll and the enzymatic hydrolysis of the cellular wall inducing the fruits firmness loss. These results are in agreement with those mentioned by Fisher and Bennet (1991) and Ketsa and Daengkanit (1999) who showed that the activity of the parietal hydrolases of certain enzymes would increase during the maturation of the melon fruit with the synthesis of ethylene.

According to works of Djioua (2010), during the pre-climacteric phase, the activities of the degradation enzymes of the cellular walls of the climacteric fruits are weak. These activities increase quickly during the climacteric phase coinciding with the increased phase of the breathing of the fruit. However, all these authors showed that certain phenomena responsible for the softening of the fruit such as the loss of turgescence are independent of ethylene.

Table 7. Evolution of the reducing sugar content of the various levels of maturity of plantain during the storage.

		Reducing sugar (%) Self-life (day)			
Variety	IFC	Day 0	Day 7	Day 14	Day 21
	65	1.45±0.12 dA	6.50±0.05 cB	12.82±0.59 eC	15.57±0.58 cD
	70	0.99±0.01 cE	5.42±0.03 bF	11.97±0.01 dG	15.06±0.56 cH
Horn 1	75	0.94±0.01 cJ	5.19±0.01 aK	10.14±0.01 cL	12.45±0.12 aM
	80	0.82±0.02 bN	6.91±0.01 dP	8.82±0.03 aQ	12.84±0.01 aR
	85	0.51±0.00 aS	7.02±0.01 eT	9.49±0.01 bU	12.93±0.01 aV
	90	0.52±0.00 aW	8.63±0.02 fX	10.17±0.01 cY	13.96±0.01 bZ

The means (N = 3) followed by the same small letter in a column and of the same capital letter on a line are not significantly different with the threshold from 5 % according to the test of Duncan. IFC = interval flowering-cut.

Loss of mass

The loss of mass of plantain increases quickly during their storage under improved shelter (Fig 2). The various stages of maturity or interval flowering-cut (IFC) of plantain do not present any significant difference in loss of mass of day 0 at day 7 of storage. The percentage of mass loss of plantain of the various stages of maturity to harvest increases significantly day 7 at day 21.

The analysis showed that there is no significant difference between the losses of mass of plantain to the various IFC at the 7th day of storage. However, the difference is significant between the six stages of maturity at 14th and the 21st day of storage at the temperature of the experiment. Mass loss of plantain is high during the storage. For the loss of mass, it strongly increases during storage of the different stages of maturity whatever is the shelf life.

This situation of mass loss can be explained by the fact that the fruits stored at the high temperature perspire a lot and release water. Tano *et al.* (2007) showed that the mass loss is the result of the breathing of the fruits. According to these authors, the respiration of the fruit and vegetables increase with the temperature, which increases transpiration. However, this water rejected by the fruits during breathing is not renewed because the fruit is detached from the tree; it thus follows a mass loss (Chen and Paul, 1989; Yao *et al.,* 2011). The covering of plantain with dry leaves of banana permit to increase the humidity relative around the fruit while, decreasing the transpiration of stored bananas.

Chemical parameters

Dry matter

The dry matter rates of the various stages of maturity of plantain of the variety *Horn 1*, vary significantly with the threshold of 5% during the post-harvest storage (Table 2).

Indeed, at the 21st day of storage of the variety *Horn 1*, these rates are included between 37.53±0.05% and 40.80±0.00% whereas at the beginning, they oscillated between 38.04±0.01% and 39.63±0.01%. The dry matter rates of each stage of maturity increase of day 0 to day 14.The dry matter rate increases when the stage maturity increases. The dry matter content differ significantly ($P \leq 0.05$) according to the stage and shelf life various from maturity.

As far as concerned the dry matter rate, there is a significant increase during storage on the level of the stages of maturity and shelf life ago of the plantain. The rates of dry matter vary from 37.533 % to 40.956 %. These results are similar to those reported by Maniga *et al.*. (2015) and Coulibaly (2008) on different plantain cultivars. However, the increase in the dry matter rate is related to the water loss provoke by the breathing of the fruits during storage.

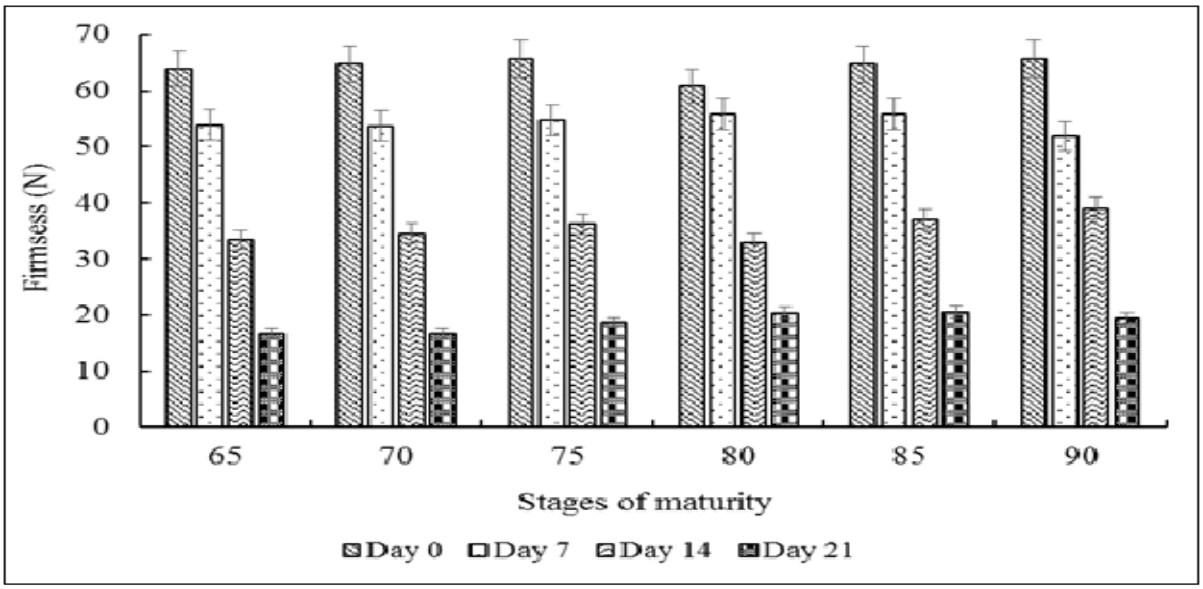

Fig. 1. Histogram of the evolution of the firmness of the plantain of the variety Horn 1 at various stages of maturity during the storage.

Hydrogen potential (pH) and Titratable acidity (TA)

Table 3 presents the variation of the pH of plantain of variety *Horn 1*, collected at the various stages of maturity and stored under improved shelter. Whatever the various stages of maturity, the pH decreases significantly ($P \leq 0.05$) during the storage. The values of pH of the various stages of maturity of the studied variety of plantain increase significantly when the stages of maturities increase.

Titratable acidity increases, in general, in the plantain of the various collected stages of maturity then preserved under improved shelters (Table 4). The values of the titratable acidity of the levels of maturity to the harvest of the variety *Horn 1* vary 4.77±0.66mEq/100g of matter fresh and 6.67±0.29mEq/100g of fresh matter (day 0).

At the 21st day of conservation these values are included/understood between 24.85±0.30mEq/100g and 32.00±0.00mEq/100g. Whatever the stage of maturity and the time of conservation, acidity increases significantly ($P \leq 0.05$) during storage.

We notice a reduction in the hydrogen potential (pH) during storage. The differents pH (5.09–6.78) are similar to those of Maniga *et al.,* (2015). This variation of pH observed of the plantain studied would be related to the rates of acids in the pulp of these plantains. Indeed, the amylolytic water and enzymes (α and β and α-1,4 and α-1,6-glucosidases) present in the fruits would support the decomposition of glucidic polymers in simpler glucidic molecules, facilitating their conversion into organics acids (Hsiao and Siebert, 1999).

The increase in titratable acidity in pulp on the level of the various stages of maturity of the stored plantain would result from the synthesis of the organic acids during storage. According to works of Satyan and Patwardhan, (1984) and of Inaba and Nakamura, (1988), the titratable acidities increase in the pulp of plantain would be the fact of the production of the organic acids during storage, in particular citric, malic and oxalic acids (N'gazoua *et al.,* 2010).

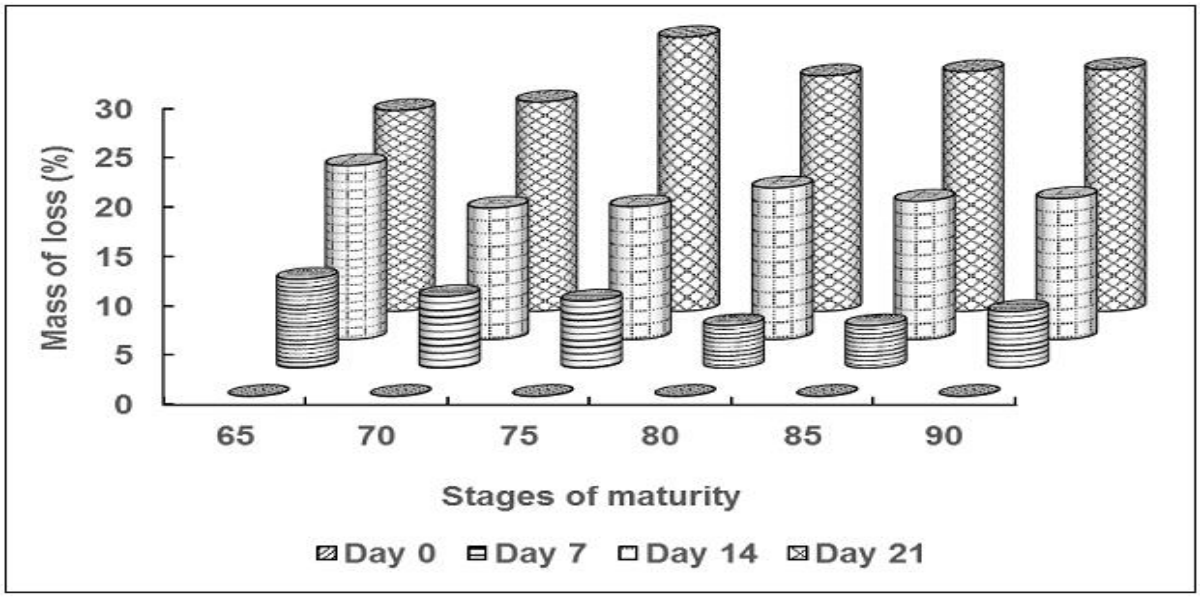

Fig. 2. Histogram of the loss of mass of the variety Horn 1 at various stages of maturity during the storage.

Total soluble solids, Total sugars and Reducing sugars

The content of total soluble solids (TSS) increases during the storage of plantain of variety *Horn 1 the studied*. The TSS content increases when the maturity stages of plantain increase (Table 5). However, the TSS content of plantain harvested at the differents stages of maturity and preserved under improved shelters are significantly different ($P \leq 0.05$). The TSS increases in general in plantain during the shelf life.

The total sugars content increases during the storage of the plantain under shelter improved as a whole (Table 6). The total sugar rates of the plantain studied decrease when the stages of maturity increase (Table 6). Total sugar contents decrease according to the stages of maturity. The statistical analysis showed significant differences ($P \leq 0.05$) of the rates of total sugars between the various stages of maturity to the harvest and during the shelf life. The total sugar rates decrease according to the stages of maturity and increase during the shelf life.

The rate of reducing sugars of the various stages of maturity of the collected plantain of the studied variety increases significantly during the storage. On the other hand, these rates decrease when the stages of maturity increase (Table 7).

The statistical analysis revealed significant differences ($P \leq 0.05$) between the reducing sugars contents in the plantain of the various stages of maturity preserved under improved shelters. The reducing sugar rates decrease according to the stages of maturity and increase during the shelf life.

Concerning, the rate of total solids soluble (TSS), total sugars and reducing sugars, they increases as a whole during storage. The increase in soluble sugars (TSS) would be due to the synthesis by the sucrose phosphate synthase starting from galactose released by the hydrolytic enzymes of the cellular wall (Gomez and Cordenunsi, 2002). With regard to the variation of total and reducing sugar rates of the plantains preserved at various stages of maturity would be the result of the increasing hydrolysis of the glucides by the glycosidases during the conservation.

The increase in the rates of total sugars and reducers of bananas is dependent on the hydrolysis of the starch by the amylolytic enzymes present in pulp (Brady, 1978; Happi *et al.* 2008). Indeed, Lii *et al.* (1982) showed that during ripening plantain, the starch contents decrease strongly by stage 1 of ripening at the stage 9, which increases consequently the contents of total and reducing sugar and that of TSS.

Conclusion

The plantain varity *Horn 1* storage under improved shelter made it possible to prolong significantly their green self-life. This GSL is 15 to 38 days when the ripe fingers are withdrawn from the batches and 14 to 31 days when the ripe fingers are maintained in the batches. The storage method the most indicated is the covering plantain with sheets dry followed withdrawal of the ripe fingers of the batches. According to the different GSL of the differents stages of maturity, plantains should be harvested to the stages of maturity 65, 70 and 75 which give a long self-life. The evolution study of the physicochemical characteristics during storage period, showed a significant difference between the biochemical composition of the samples according to the stages of maturity and the shelf life.

Acknowledgement

This work is integrated within the framework of the project "Seeks the best methods of conservation of plantain (Musa AAB) in a green state" initiated by West Africa Agricultural Productivity Programme (WAAPP), carried out by the Institute of Ivorian Tropical Technology (I2T) under the supervision and the coordination of the Agricultural Council and Research of Interprofessional Funds (FIRCA) and financed by the World Bank.We are deeply grateful to them.

References

ANADER (Agence Nationale pour le Développement Rural). 2013. Etude de la filière banane plantain en Côte d'Ivoire, 66.

AOAC. 2000. Official method 942.15 (17th Edn). Acidity (Titratable) of fruit products read with A.O.A.C official method 920. 149, Preparation of test sample. Washington D. C.

Bernfeld P. 1955. Amylase β and α (Assay method), in methods in enzymology I. Colowick and Kaplan, Ed. New York: Academic press, 149-154.

Brady CJ. 1987. Fruit ripening. Annual Review Plant Physiology **38,** 155-178.

Chaib J. 2007. Caractérisation des déterminants génétiques et moléculaires de composantes de la texture du fruit de tomate. Thèse de Doctorat, Ecole Nationale Supérieure Agronomique de Montpellier, France, 143.

Chamara D, Illeperuma K, Theja Galappatty P, Sarananda KH. 2000. Modified atmosphere packaging of 'Kolikuttu' bananas at low temperature. Journal of Horticultural Science and Biotechnology **75(1),** 92-96.

Chen W, Wu Z, Su M, Zhu J. 2000. Technologie post-récolte, transport et commercialisation des bananes en Chine. Agrociencia (Mexique) **36(2),** 169-180.

Chen NJ, Paull RE. 1989. Waxing and plastic wraps influence water loss from paraya fruit during storage and ripening. Journal of the American Society for Horticultural Science **114,** 937-942.

Coulibaly S. 2008. Caractérisation physico-chimique, rhéologique et analyse des fruits de quelques cultivars de bananier (*Musa* AAB, AAAA, AAAB). Thèse de Doctorat, Université d'Abobo-Adjamé, Côte d'Ivoire, 171.

Dadzie BK, Orchard JE. 1997. Évaluation post-récolte des hybrides de bananiers et bananiers plantain: critères et méthodes. Guides techniques INIBAP 2, 77.

Dick E. 2006. Contribution à l'étude de la physiologie du mûrissement, de l'entreposage et de la conservation de la banane plantain après récolte. Thèse de Doctorat d'Etat, Université de Cocody-Abidjan, Côte d'Ivoire, 243.

Djioua T. 2010. Amélioration de la conservation des mangues 4ème gamme par application de traitements thermiques et utilisation d'une conservation sous atmosphère modifiée. Thèse de doctorat, Université d'Avignon et des Pays de Vaucluse, France, 169.

Dubois M, Gilles KA, Hamilton JK, Rebers PA, Smith F. 1956. Colorimetric method for determination of sugars and related substances. Analytical Chemistry **28,** 350–356.

Ducroquet H. 2002. L'agriculture ivoirienne à la luope (1). Le professionnel agricole **3,** 10-12.

Happi ET, Wathelet B, Paquot M. 2008. Changements texturaux et biochimiques des fruits du bananier au cours de la maturation. Leur influence sur la préservation de la qualité du fruit et la maîtrise de la maturation. Biotechnologie, Agronomie, Société, Environnement **12(1),** 89-98.

FAO. 2009. Food and Agriculture Organization of the United Nations, Rome. Productions 2008. FAOSTAT, FAO Statiscal Databases. Downloaded from http://faostat.fao.org on 18/7/2013.

Fisher R, Bennett A. 1991. Role of cell wall hydrolases in fruit ripening. Annual Review of Plant Physiology and Plant Molecular Biology **42,** 675-703.

Gire A. 1994. Relation entre la résistance partielle du bananier à *Cercospora figiensis* et une composante cellulaire constitutive de nature polyphénolique. Mémoire de (DEA), Université Montpellier II, France, 14.

Gomez M, Lajalo F, Cordenunsi B. 2002. Evolution of soluble sugars during ripening of papaya fruit and its relation to sweet taste. Journal of Food Science **67(1),** 442-447.

Gowen S. 1995. Ripening and biochemistry of the fruit. In: Chandler S, Ed. Bananas and plantains. Chapman and Hall, London, UK, 567.

Guillemot J. 1976. Le bananier plantain en Côte d'Ivoire. Fruits **31,** 684-687.

Hailu M, Workneh TS, Belew D. 2013. Review on postharvest technology of banana fruit. African Journal of Biotechnology **12(7),** 635-647.

Hsiao C, Siebert K. 1999. Modeling the inhitory effects of organic acids on bacteria. International Journal of Food and Microbiology **45(3),** 189-201.

Inaba A, Nakamura R. 1988. Numerical expression for estimating the minimum ethylene exposure time necessary to induce ripening in banana fruit. Journal of American Society of Horticol Science **113(4),** 561-564.

Jullien A, Malézieux É, Michaux-Ferrière N, Chillet M, Ney B. 2001. Within-bunch variability in banana fruit weight. Importance of development lag between fruits (Musa spp. AAA group cv. Grande Naine (Cavendish subgroup). Annals of Botany **87,** 101–108.

Ketsa S, Daengkanit T. 1999. Firmness and activities of polygalacturonase, pectinesterase, β-galactosidase and cellulase in ripening durian harvested at different stages of maturity. Scientia Horticultuarae **80,** 181-188.

Kouadio KKA, Coulibaly S, Soro LC, Ocho AAL. 2013. Determination of the optimal point of cut fruit of plantain hybrids PITA 3, PITA 8 and varieties of plantain Lorougnon and Horn 1. International Journal of Agriculture and Food Science **3(1),** 16-21.

Lepengué NA, Mouaragadja I, Dick E, Mbatchi B, Ake S. 2010. Amélioration de la durée de conservation des bananes plantain aux températures ambiantes. International Journal of Biology Chemistry and Sciences **4(3),** 730-737.

Lescot T. 2006. Estimation de la production et du commerce bananier mondial. FruiTrop **140,** 6–9.

Lii C, Chang SM, Young YL. 1982. Investigation of the physical and chemical properties of banana starches. Journal of Food Science **47,** 1493-1497.

Maniga W, Coulibaly S, Yao NB, Thiemele DFE, Tano K. 2015. Nutritional and anti-nutritional compositions of 9 local cultivars of plantain (*Musa* spp.) cultivated in Côte d'Ivoire. International Journal of Development Research **5(12),** 6116-6124.

Narayana CK, Mustafa MM, Sathiamoorthy S. 2002. Influence de l'emballage et du stockage sur la durée de vie et la qualité des bananes de la variété Karpuravalli. Indian Journal of Horticulture **59(2),** 113-117.

N'da AA, Lassoudière A, Tchango TJ. 1997. La banane plantain: importance du stade de récolte dans la filière et quelqeus aspects de la conservation. Fruits, **51(6)**, 397-406.

N'ganzoua KR, Camara B, Dick E. 2010. Evaluation des changements physico-chimiques caractérisant le mûrissement au cours de l'entreposage de trois variétés de bananes *Musa* spp. (AAB, cv. Corne 1; AAA, cv. Poyo et AA, cv. Figue Sucrée). Sciences & Nature **7(2),** 155–163.

Nkendah R, Akeyeampong E. 2003. Données socioéconomiques sur la filière plantain en Afrique Centrale et de l'Ouest. Infomusa **12(1),** 8-13.

N'kendah R. 2001. L'essor du marché de plantain au Cameroun: une alternative de lutte contre la pauvreté. Proposition de recherche. Document CRBP N° 230/CRBP/2001.

Odah K, Aziadekey M, Tozo K, Akpavi S, Koukouma R, Guelly A, Kokou K, Assignon K, Akogo Y, Aidam A, Akpagana K, Kenny L, Ait-Oubahou A, Zinsou C, Gbeassor M. 2013. La diversité génétique des bananiers plantains cultivés dans la zone Ouest de la Région des Plateaux au Togo. International Journal of Biological and Chemical Sciences **7(5),** 1910-1918.

Pesis E. 2004. Respiration and ethylene. International Research and Development on Postharvest Biology and Technology. Israel: The Volcani Center.

Proulx E, Cecilia M, Nunes N, Emond JP, Brecht JK. 2005. Quality attributes limiting papaya postharvest life at chilling and non-chilling temperatures. Proceedings of the Florida State Horticultural Society **118,** 389-395.

Satyan SH, Patwardhan MV. 1984. Purification and regulatory properties of phosphoenolpyruvate carboxylase from banana fruits of Dwarf Cavendish. Journal of Food Sciences and Technology **21,** 135-138.

Sisler EC, Serek M. 1997. Inhibitors of ethylene responses in plants at the receptor level: Recent developments. Physiologia Plantarum, **100(3)**, 577-582.

Sugri I, Johnson PNT. 2009. Effect of two storage methods on the keeping and sensory qualities of four plantain varieties. African journal of Food Agriculture Nutrition and Development **9(4),** 1091-1109.

Tano K, Oulé MK, Doyon G, Lencki RW, Arul J. 2007. Comparative evaluation of the effect of storage temperature fluctuation of modified atmosphere packages of selected fruit and vegetables. Postharvest Biology and Technology **46,** 212–221.

Varoquaux P, Gouble B, Ducamp MN, Self G. 2002. Méthode permettant d'optimiser l'emballage des fruits sous atmosphère modifiée. Fruits **57(5-6),** 313-322.

Yao KA. 2015. Contribution à la réduction des pertes post-récoltes de la banane plantain (*Musa* AAB) et du manioc (*Manihot esculentus* Crantz) par des approches technologiques de conservation et de transformation. Thèse unique de Doctorat, Université Félix Houphouet Boigny, Côte d'Ivoire, 149.

Yao KA, Koffi DM, Irié ZB, Niamké SL. 2014. Conservation de la banane plantain (*Musa* AAB) à l'état vert par l'utilisation de films de polyéthylène de différentes épaisseurs. Journal of Animal and Plant Sciences **23(3),** 3677-3690.

Yao NB, Tano K, Assemand EF, Nevry KR, Bédié KG, Amani G. 2011. Effect of the maturity stage and storage temperature on the posharvest quality of *Carica papaya* L. variety Solo 8. Fresh Produce **5(1),** 15-21.