MARKET CHARACTERISTICS OF BANANA HYBRIDS RESISTANT TO BLACK SIGATOKA

by

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ABSTRACT

Fourteen varieties of banana hybrids resistant to Black Sigatoka were stored at 20^{o}C. Data from the different assessments performed on hybrids were compared against those of “Grand Naine” (Control). Determination of shelf life of varieties was based on non- microbiological characterization of fruits (pH, total soluble solids (TSS), cutting force and respiration), determination of mechanical properties (stack and impact resistance) and characterization of processing properties (yield, moisture content, moisture absorption and fat absorption) at different stages of fruit maturity: green (1&2), mature green (3&4), mature (5&6) overripe (7). None of the hybrids considered measured up to the Control at every maturity stage. In the green stage (1&2) “TMB2x 9128-3”, “FHIA-23”, “PV 03-44”, “PV 42-81” presented interesting characteristics, such as higher TSS and higher mechanical strength compared to the Control. At the mature state (5&6) “FHIA-17”, “SH 3640” and “TMB2x 9128-3” were the varieties that showed improved performance in storage time, pH, TSS, shear strength, and resistance to damage compared with the control. In the state of overripe (7) “PA 03-22”, “FHIA-02” and “PV 42-81” also had good performances in the different evaluations. In summary, no single variety showed characteristics that could make them suitable replacements of the control (Grand Naine). Instead, data suggests that some of the hybrids could be reasonable replacements at specific stages of maturity. For example, at the green stage (1&2), “FHIA-23” could be a good replacement, while the “SH 3640” and “FHIA-17” could work for the mature stage (5&6).

RESUMEN

Catorce variedades de guineos híbridos resistentes a la Sigatoka Negra fueron almacenados a 20^{o}C. Datos de las diferentes evaluaciones realizadas a los híbridos se compararon contra los datos obtenidos para "Grand Naine" (Control). La determinación de la vida útil de cada variedad se basó en la caracterización no microbiológica de los frutos (pH, sólidos solubles totales (TSS), fuerza de corte y respiración), determinación de propiedades mecánicas (resistencia a estibamiento e impacto) y caracterización de propiedades para procesamiento (rendimiento, contenido de humedad, absorción de humedad y absorción de grasa) durante las diferentes etapas de maduración de la fruta: verde (1&2), verde maduro (3&4), maduro (5&6) sobre maduro (7). Ninguno de los híbridos considerados superó al Control en todas las etapas de maduración. En la etapa verde (1&2) "TMB2x 9128-3", "FHIA-23", "PV 03-44" y "PV 42-81" presentaron características interesantes tales como TSS más altos y resistencia mecánica más elevada comparadas con la control. En el estado maduro (5&6) "FHIA-17", "SH 3640" y "TMB2x 9128-3" fueron las variedades que presentaron desempeños superiores en tiempos de almacenamiento, pH, TSS, fuerza de corte y resistencia al daño comparados con la variedad control. En el estado sobre maduro (7) "PA 03-22", "FHIA-02" y "PV 42-81" también tuvieron buenos desempeños en las diferentes evaluaciones. En resumen, ninguna de las variedades evaluadas presentó características que la hubiesen hecho remplazos adecuados del Control. En vez, los datos sugieren que algunos de los híbridos podrían ser remplazos razonables en etapas de maduración específicas. Por ejemplo, en la etapa verde (1&2), "FHIA-23" podría ser un buen reemplazo, mientras que "SH 3640" y "FHIA-17" podrían funcionar para la etapa maduro (5&6).

DEDICATION

To my parents Gladys and Jose Manuel

and

my brothers Juan y Natalia,

for their support in the distance. I love you.

To God

for giving me the strength to believe that everything is possible.

To my family, friends and all other who made this experience memorable.

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TABLE OF CONTENTS

ABSTRACT II
RESUMEN III
DEDICATION V
ACKNOWLEDGEMENTS VI
TABLE LIST IX
FIGURE LIST X
APENDIX LIST XI
1 INTRODUCTION 1
1.1 OBJECTIVES 1
1.1.1 Primary Objective 1
1.1.2 Secondary Objectives 2
2 LITERATURE REVIEW 3
2.1 HISTORY 3
2.2 NUTRITIONAL VALUES AND CHEMICAL COMPOSITION 4
2.2.1 Carbohydrates 5
2.2.2 Fiber 5
2.2.3 Protein 5
2.2.4 Fat 6
2.2.5 Vitamins 6
2.2.6 Minerals 6
2.3 CLASSIFICATION 7
2.4 FARMING CHARACTERISTICS 8
2.5 PLANT GROWTH AND STRUCTURE 8
2.6 PESTS AND DISEASES 9
2.7 FRUIT POST-HARVEST PARAMETERS 10
2.7.1 Starch to Sugar Conversion 10
2.7.2 Pulp/Peel Ratio 11
2.7.3 Moisture content 11
2.7.4 Pulp's Strength (Firmness) 11
2.7.5 Total Soluble Solids 12
2.7.6 pH 12
2.7.7 Respiration Rate 13
3 MATERIALS AND METHODS 14
3.1 FRUIT SAMPLING 14
3.2 NON MICROBIOLOGICAL SHELF LIFE TESTS 14
3.2.1 Maturity Index Determination 14
3.2.2 Cut Strength 15
3.2.3 pH 16
3.2.4 ºBrix (Total soluble solids) 16
3.2.5 Respiration Rates 17
3.3 MECHANICAL PROPERTIES 18
3.3.1 Impact 18
3.3.2 Stack Height 19

3.4 PROCESSING CHARACTERISTICS: 19
3.4.1 Pulp Yield 19
3.4.2 Moisture Absorption 20
3.4.3 Fat Absorption 20
3.4.4 Statistical Analysis 21

4 RESULTS AND DISCUSSION 22

4.1 EFFECT OF RELATIVE HUMIDITY 22
4.2 STORAGE TIME AND MATURATION STAGE 25
4.3 NON MICROBIOLOGICAL SHELF LIFE TESTS 29
4.3.1 Total soluble solids 29
4.3.2 pH 31
4.3.3 Weight loss 34
4.3.4 Cut strength 36
4.3.5 Respiration rates 38
4.4 PROCESSING CHARACTERISTICS 41
4.4.1 Fat absorption 41
4.4.2 Moisture absorption 43
4.4.3 Moisture content 46
4.4.4 Pulp yield 48
4.5 MECHANICAL PROPERTIES 50
4.5.1 Impact 50
4.5.2 Stack 54

5 CONCLUSIONS 59

6 REFERENCES 62

APPENDIX 1: AUTHOR'S OBSERVATIONS ON HYBRIDS 67

APPENDIX 2: MECHANICAL DAMAGE IMPACT: EFFECT DURING STORAGE. 70

APPENDIX 3: COMPARATIVES SUMARY TABLES 74

TABLE LIST

Table 1: Nutritional values for plantain and banana 4
Table 2: Impact assessment: estimated height and equivalences. 19
Table 3: Stack assement : estimated stack height and equivalences. 19
Table 4: Time in days that fruits remained at the different maturation stages. 26
Table 5: Total soluble solids at the different maturity stages. 29
Table 6: pH at the different maturity stages. 31
Table 7: Weight loss percentage at the different maturity stages. 35
Table 8: Cut strength at the different maturity stages. 37
Table 9: Values of CO_2 (mL CO_2/kg.h) reported in papaya. 38
Table 10: Average value of CO_2 rate at the different maturity stages. 39
Table 11: Fat absorption at the different maturity stages. 42
Table 12: Moisture absorption at the different ripening stages. 44
Table 13: Moisture content at the different ripening stages. 46
Table 14: Yield at the different ripening stages. 49
Table 15: Deformation (in mm) from an equivalent drop of 5 ft (v= 6 m/s). 51
Table 16: Deformation (in mm) from an equivalent drop of 5 ft (v= 8 m/s). 52
Table 17: Deformation (in mm) from an equivalent drop of 5 ft (v= 10 m/s). 53
Table 18: Stack at the different maturation stages (Force=1.5kg) 55
Table 19: Stack at the different maturation stages (Force=3.0kg) 56
Table 20: Stack at the different maturation stages (Force=4.5kg) 57
Table 20: Comparative summary at green stage (1&2). 74
Table 21: Comparative summary at mature stage (5&6). 75
Table 22: Comparative summary at overripe stage (7). 76

FIGURE LIST

Figure 1: Probable origins of the cultivation of plantain and banana 3
Figure 2: Illustration of a banana plant. 9
Figure 3: Respiration rate of climacteric fruit. 13
Figure 4: Commercial hedonic Maturity Scale. 15
Figure 5: Texture Analyzer TA-XT2. 16
Figure 6: Implement used to measure cut strength 16
Figure 7: Digital Refractometer Model PA202 17
Figure 8: Implement used to inflict damage. 18
Figure 9: Pictures of impact assessment and the effect in the fruit during maturation.......... 73

APENDIX LIST

APPENDIX 1: AUTHOR'S OBSERVATIONS ON HYBRIDS 67

APPENDIX 2: MECHANICAL DAMAGE IMPACT: EFFECT DURING STORAGE 70

APPENDIX 3: COMPARATIVES SUMARY TABLES 74

1 INTRODUCTION

Puerto Rico's plantain and banana production for the fiscal year 2008-2009 represented 13.36% of the total agricultural production; generating $94.97 million in income and propelling these crops to first place in importance in the agro sector (Department of Agriculture, 2009). These crops are cultivated in different municipalities around the island, but the best, known for its quality and production level are Yabucoa, Maunabo, Corozal, San Lorenzo, Salinas, and San Sebastian (Cortes & Gayol, 2004).

The plantain and banana production in the island is threatened by fungus ***Mycosphaerela fijensis***, which was discovered in the island in 2004 (Ortiz-Alvarado & Díaz, 2005). This fungus causes a disease known as Black Sigatoka which is devastating to plants (Alamo et al, 2007). The affected leaves reduce their ability to photosynthesize; further affecting the quality of its fruits (Almodóvar et al, 2001).

In an effort to maintain local production, the USDA Tropical Agricultural Research Station (TARS) initiated a three year project to evaluate the agronomic characteristics of several banana hybrids resistant to Black Sigatoka.

1.1 Objectives

1.1.1 Primary Objective

Evaluate the market fresh characteristics of these banana hybrids (***Musa acuminata***), to determine their potential use.

1.1.2 Secondary Objectives

1. To characterize the ripening performance of hybrids under storage at 20 ^{o}C.
2. To determine the shelf life of hybrids using non microbiological tests and to compare them against commercially available varieties.
3. To determine fat and moisture absorption of hybrids during processing.

2 LITERATURE REVIEW

2.1 History

Banana cultivation originated in Southeast Asia, specifically in the regions of India, Malaysia, Indonesia and Papua New Guinea (Figure 1). It spread out to America during the period of the conquerors; initiating with the first plantations in the island of Hispaniola in Santo Domingo (Hernández, 2005). Initially, the plant leaves were used as fiber or wrapping material and only some specific fruits were used as food, since they presented seeds in the pulp that faded away with its propagation to the rest of the American continent (Cortes, 1994).

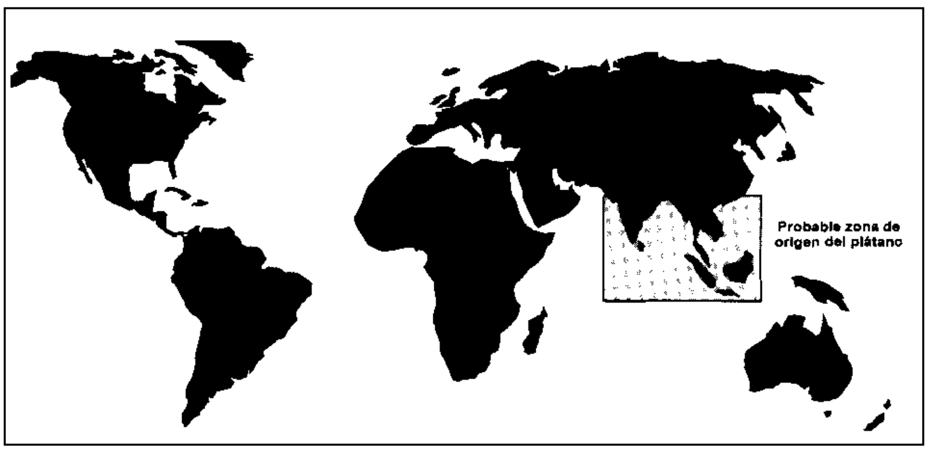

Figure 1 Plausible origins of the cultivation of plantain and banana

Bananas include a wide variety of species and hybrids of the *Musa* gender and the *Musaceae* family. In countries such as Japan, Pakistan and Burma, the only species that exist are *M. basjoo Sieb, M. Ornata & M. textilis* which are used for ornament and fiber. Currently, cultivation of banana species is one of the most developed crops in tropical regions all around the world and considered the fourth most important agricultural product.

2.2 Nutritional Values and Chemical Composition

Table 1 compares the nutritional composition of bananas with other starchy staples and fruits of economic importance worldwide.

Table 1-Nutritional values for plantain and banana (per 100g raw edible) from the USDA database (http://www.nal.usda.gov)

	Banana	Plantain	Sweet Potato	Potato	Cassava	Apple
Energy (Kcal)	92	122	105	79	160	59
Water (g)	74.26	65.28	72.84	8.96	59.68	83.93
Protein (g)	1.03	1.3	1.65	2.07	1.36	0.19
Carbohydrate (g)	23.43	31.89	24.28	17.98	38.05	15.25
Fat (g)	0.48	0.37	0.30	0.10	0.28	0.36
Monounsaturated fats	0.041	0.032	0.011	0.002	0.075	0.015
Polyunsaturated fats (g)	0.089	0.069	0.132	0.043	0.048	0.105
Saturated fats (g)	0.185	0.143	0.064	0.026	0.074	0.058
Calcium (mg)	6	3	22	7	16	7
Iron (mg)	0.31	0.6	0.59	0.76	0.27	0.18
Potassium (mg)	396	499	204	543	271	115
Sodium (mg)	1	4	13	6	14	0
Vitamin C (mg)	9.1	18.4	22.7	19.7	20.6	5.7
Thiamin (mg)	0.045	0.052	0.066	0.088	0.087	0.017
Riboflavin (mg)	0.100	0.054	0.147	0.035	0.048	0.014
Niacin (mg)	0.540	0.686	0.674	1.484	0.854	0.077
Vitamin A (IU)	81	1127	20063	0	25	53

The banana pulp is composed essentially from sugars that are easily digested by the human organism. For every 100g of banana, there are approximately 70g of water, 27g carbohydrates, and 1.5g of vitamins, 0.3g of fat and some 1.2g of protein. Different from plantains, bananas are characterized by their high water and sugar contents, since during the ripening period, the starch is hydrolyzed to much simpler carbohydrates such as fructose and glucose; making them appropriate for consumption as a fresh fruit or in desserts (Sharrok & Lusty, 1999). They are also recommended for people who need great amounts of glucose and require high levels of sugar in the bloodstream such as people who spend a lot of energy in sports or heavy labor (Wolever et al., 1991).

Aside from its high nutritional characteristics, bananas have also been recommended for therapeutic use in geriatric patients and children to treat peptic ulcers, infant diarrheas and intestinal disorders where carbohydrate absorption is limited (Sharrok & Lutsy, 1999).

2.2.1 Carbohydrates

Banana starch typically has an amylose/amylopectin ratio of 1/5. Only a 1.3% of the total dry masses are sugars when the fruit is still green, and in the mature fruit the levels of this nutrient increase to 1.7%. The conversion of these complex starches into sugars becomes evident during the ripening phases of the fruit, where the external part of the fruit changes from green to yellow as the levels of soluble solids in the pulp increase (Dadzie, 1998).

2.2.2 Fiber

Other polysaccharides present in bananas are cellulose, some peptic substances and hemicelluloses. Green fruits contain approximately 3.5% of dry mass which makes them excellent sources of dietary fiber. The ripening process slightly affects the fiber content in bananas, but the main change in fiber content is the result of boiling and frying processes used to conserve the banana or plantain (Ahenkora et al., 1996).

2.2.3 Protein

Total protein content is around 3.5% (db) in ripe or green pulp since ripening does not significantly change it. Protein content can decrease by about 50% when boiled or fried (Ahenkora et al., 1997). As a starchy staple food, banana supplies about 1g protein/100g edible portion (**Table 1**). In terms of amino acid contents, there are significant amounts of arginine, glutamine and asparagine; included in the group of the seven essentials amino acids in human nutrition (Sharrok &Lutsy, 1999).

2.2.4 Fat

Fat content in bananas is very low, roughly 0.5% (db). Such amount is not considered a significant source of energy. Total fat content increases during ripening of the fruit. The composition of fatty acids, especially within the phospholipid fractions, has been observed to change with a decrease in their saturation, but still, they do not add any nutritional significance (Ogazi, 1996).

2.2.5 Vitamins

Bananas are good and important sources of vitamins A (carotene), B (thiamin, niacin, and riboflavin) and C (ascorbic acid). Processing and cooking them will affect their vitamin content. Bananas eaten ripe provide a better source of vitamins than cooked bananas. In their raw state, plantains are richer in vitamin C than bananas. However, some varieties of cooking bananas have a deeper yellow or orange flesh similar to plantains. When ripe, these yellow pulp bananas may contain up to 400 times more beta-carotene than white-fleshed varieties (Ahenkora et al., 1997).

2.2.6 Minerals

Uncooked bananas are low in calcium, iodine and iron, but high in potassium (approximately 400mg for every 100g of pulp). It has been shown that there are changes in the mineral content of bananas during maturation.

The magnesium (Mg) content of banana decreases with ripening while zinc (Zn) and manganese (Mn) increase. The decrease of Mg could be attributed to the conversion of chlorophyll (green pigment in unripe banana) into carotenoids (yellow color) which is responsible for color of ripe fruits (Adeyemi & Oladiji, 2009).

Bananas do not contain significant levels of toxic components, but contain high levels of serotonin and other biogenic amines. Dopamine is responsible for the enzymatic browning of the fruit. Some studies have attempted to link the biogenic amines present in bananas to a disorder denominated endomyocardial fibrosis (EMF) (Foy & Parratt, 1960). Results have not confirmed that the amounts consumed by humans through these foods could be sufficiently high for them to be related to such disease.

As a product of exportation, it significantly contributes to the economy of countries with low gross income, such as Ecuador, Honduras, Guatemala and others; being the most exported fresh fruit worldwide (Arias et al., 2004). In Puerto Rico, banana cultivation is one of the most important contributors to agricultural economy, but its production is destined for local consumption only (Cortes & Gayol, 2004).

2.3 Classification

Commercially, banana is known as a yellow colored fruit which is sold and consumed fresh or without the need for cooking. They are classified into two large groups. The first one, denominated *Simmonds,* has some varieties belonging to the species *M. accuminata Sucrier* that are found distributed mainly in Malaysia, Indonesia, Philippines, Southeast India, Colombia and Brazil. The plants are relatively small but strong, and produce small, dark brown bananas of very thin peel, sweet pulp and almost wax free.

The second group, called *Gros Michel*, includes various species of *M. Cavendishii* and is found in the regions of Birmania, Thailand, Malaysia, Jamaica, Costa Rica, Hawaii and Australia. These were also previously cultivated in Central Africa, Latin America and the Caribbean. Plants in this group are much taller with much larger and yellower fruits. This group includes some outstanding varieties such as: *Draft Cavendish, Giant Cavendish, Bungulan, Robusta, Valery and Buggoe, banana of Hawaii,* and *Mysore* among others. Some of these subspecies have been created by genetic manipulations in the struggle to prevent and avoid plagues from attacking the crop to be harvested.

One of the most important and devastating diseases is *Black Sigatoka* caused by the ***Mycosphaerela fijensis*** fungus. This was first detected in the island of Java in 1902 and it spread rapidly into India and South America (Morton, 1997). Regardless of the efforts made worldwide by banana's largest producers, the attack of such plague is still devastating. The costs of eradicating the fungus in crops are very high. This is why efforts are now being focused in the development of new species (i.e., hybrids) of bananas. Some of these hybrids have been introduced into some countries with great success.

2.4 Farming Characteristics

According to previous investigations in Puerto Rico, on the production of large volumes of banana, the crop requires acidic soils (pH between 4.5 and 7.0), with low fertility, inclined and with good drainage. It has been also observed that its production is based on the rain seasons and is generally performed during the first weeks of January, July, September, November and December (Rivera, 1914).

2.5 Plant Growth and Structure

Banana plants grow from an underground stem called a corm. The corm sends up a shoot called a sucker that grows onto a mother plant that dies after giving fruit. Differences between varieties of banana are evident in the structure of the plant: leaves and trunk (mostly rolled leaf). The banana fruit grow in hanging clusters, with up to 20 fruit to a tier (hand), 3 – 20 tiers to a bunch, every bunch can weigh from 30-50kg, and the fruit averages 125g each (Morales-Osorno et al., 1998).

Figure 2 Illustration of a banana plant.

In terms of nutritional requirements for improved production, bananas need high levels of nitrogen and potassium, as well as low levels of phosphorus and magnesium. Variations in potassium availability cause different effects in crops: from late blooming to a reduction in the number of banana bunches and fruit sizes. Potassium plays an important role in the plant´s resistance to plagues, increases the quality of the soluble solids and affects vitamin C content, fruit color and the lifespan of the peel after harvested (Padilla, 2009).

2.6 Pests and Diseases

Bananas are susceptible to a wide range of pests and diseases that are highly aggressive or very contagious and easily spread. Once these are established they are persistent and practically impossible to eradicate.

Dry weather favors many types of insect and viral diseases in banana, and they are more common where banana plants are grown together in large numbers (monocultures) rather than where planted in small numbers and spatially separated. The most significant disease of bananas is the black leaf streak, also called black sigatoka, caused by the fungus

Mycosphaerela fijensis. It is globally distributed and epidemic in many locations. Bunch yield loss can be significant (Escalona-Laborem et al., 2001). Researchers worldwide are continually working to develop disease-resistant varieties, to reduce the attacks and reduce the cost of the disease management.

2.7 Fruit Post-Harvest Parameters

Evaluation of the physical and chemical quality parameters is essential for its commercialization. These depend on the characteristics of the bunch and individual fruits at the time of the harvest; as well as the post-harvest characteristics (Garcia-Osuna, et al., 2008). Some of the most important post-harvest characteristics are: color of the peel and pulp, pH, total solids and firmness. Other chemical characteristics of interest include transformation ratio of starch into sugar, changes in the pulp/peel relation, changes in moisture content of the pulp, and changes in respiration rates that determine the shelf-life of the fruit and its uses in the market (Dadzie & Orchrad, 1997).

2.7.1 Starch to Sugar Conversion

One of the most important chemical changes of the ripening process of bananas is the hydrolysis of starch which results in an increase of sugar content in the pulp (i.e., sucrose, glucose and fructose). This process is responsible for the intensity of sweetness of the fruit and is completed when it reaches full maturity period. In bananas, starch level in the unripe fruit are around 20% and decline to 1-2% in fully ripe fruit, while at the same time the soluble sugar increases from less than 1% to around 20%. During ripening the sugar content are in the approximate ratio 20:15:65 (glucose: fructose: sucrose) and only traces of other sugars are found. High sugar content in ripe banana is unusual in a fresh fruit.

2.7.2 Pulp/Peel Ratio

The pulp/peel ratio is a good indicator of banana ripeness. This relation means deeper pulp penetration into the fruit and low firmness. It relates to changes in fruit water content and sugar level in the pulp, thus, contributing to a differential gradient in the osmotic pressure (Dadzie & Orchrad, 1997). Some studies determine that the pulp/peel ratio has a negative correlation with fruit weight but a positive one with fruit diameter and storage time (Asoegwu, 1995).

2.7.3 Moisture content

Water loss is a main cause of deterioration, resulting in quantitative losses in weight, appearance, texture and nutritional quality. The moisture rate loss is influenced by different factors, such as surface to volume ratio, surface injuries, maturity stage, temperature, relative humidity, air movement, and atmospheric pressure (De Villiers, 2005).

Investigations evaluating weight loss in ripening under different moisture conditions (95%) and (30-40%) obtained weight losses in the order of 2% to 14% over 15 days of storage. Usually, there is an increased water loss associated with changes by degenerative diseases of the fungal attack. At the late stages of maturation the peel is aged and weight loss is greatly influenced by transpiration (Finger et al., 1995).

2.7.4 Pulp's Strength (Firmness)

Firmnes and hardness, are mesasures of the pressure requiered to penetrate the fruit, or the deformation caused by exerting pressure on the fruit. Firmnes is an important textural atribute related to the readiness of crops for harvest and a quality indicator during storage for fresh market (Asoegwu, 1995).

Different techniques exist for measuring the strength of a material based on mechanical properties. Penetration and puncture tests, for example, measure the force that opposes an object perforating a biological material. Other tests measure the force required to compress to certain depth or the resulting deformation when subject to a given force (Buitrago, 2004). Determination of such properties is necessary for the development of mechanized harvesting processes, as well as, transportation and shipping and handling protocols to avoid undesired changes in flavor and appearance of the fruit (Velásquez, 2005).

Asoegwu (1995) determined that fruit firmness decreased as pulp/peel ratio, fruit water content and days of storage increased while fruit weight correlated positively with firmness at harvest.

2.7.5 Total Soluble Solids

Bananas contain many water soluble compounds (e.g., sugar, acids, vitamins, some amino acids and other peptic substances) comprising, as a whole, what are known as soluble solids. Soluble solids increase during the ripening process, but don't vary according to the fruit location in the bunch (Arcila, 2002). These changes depend on storage temperature, fruit age and hybrid variety. In some varieties, total soluble solids increase from 0% to approximately 13% and decline after reaching maturation (Dadzie, 1998).

2.7.6 pH

pH is a measurement of the acidity of a product. In the case of bananas, this parameter is also an indicator of the post-harvest quality of the fruit since the balance between acids and sugars significantly determines taste. In banana hybrids, there is a decrease in pulp pH during ripening, followed by an increase at the latest stages of maturation. In new varieties (e.g., FHIA- 01 and FHIA-02), pulp pH decreases from initial values of 6.0 and 5.70 in green fruit, to around 4.50 and 4.40 at maturation, followed by a slow increase to 4.9 and 5.2 when the fruits fully matures (Dadzie, 1998).

2.7.7 Respiration Rate

Respiration is a naturally-occurring process in harvested produce such a plant´s or other products. This process includes the decomposition of the complex components present in the fruit such as starch, sugars and organic acids, into simple molecules such as carbon dioxide and water.

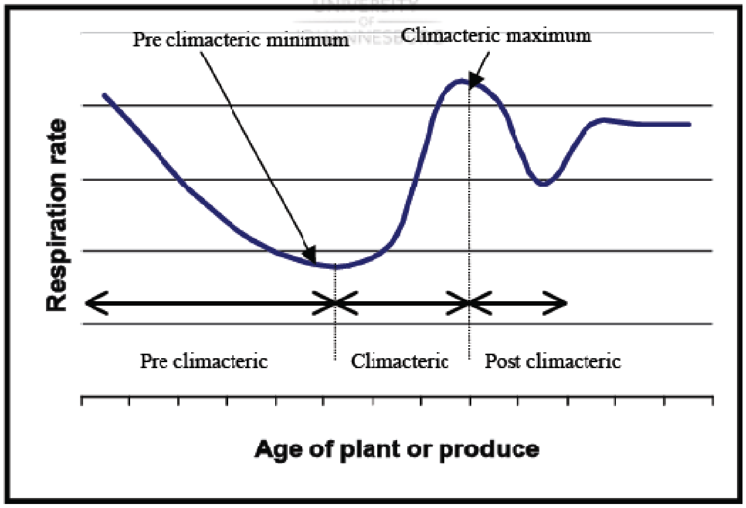

Figure 3 Respiration rate of climacteric fruit.

After harvest, climacteric respiration of the fruit stays constant or shows a slight decline until a minimum (the pre-climacteric minimum) is reached. Up to this minimum the produce is still in the pre-climacteric phase. This point is usually the stage where produce start ripening. An increase in the respiration rate is later reached until the climacteric peak is reached; this period is known as the climacteric phase. This climacteric phase is followed by a second decrease in the respiration rate known as the post climacteric phase. As an example, De Villieris (2005) reported that, in two days, a respiration rate of about 20ml CO_2/kg/h in hard green bananas increased to 125ml CO_2/(kg*h) at the climacteric peak. This rate may then fell to 100ml CO_2/ (kg*h) as ripening advanced to its final stages.

3 MATERIALS AND METHODS

3.1 Fruit Sampling

Banana hybrid samples were obtained from the USDA-TARS facility in Isabela, Puerto Rico. Harvested fruits were labeled, boxed and transported to the Food Processing Laboratory of the University of Puerto Rico at Mayagüez and stored at 20^{o}C until evaluated. A total of 14 hybrids were considered. Each variety was tested in two blocks namely, the first (2009) and the second (2010) accessions. Sample collection and transport took place on Mondays, Wednesdays and Fridays as fruit became ready to harvest.

3.2 Non Microbiological Shelf Life Tests

The following tests were performed every four days until overripe. Three samples were randomly picked form the pool of stored fruit, on each sampling day, and subjected to the following sequence of tests.

3.2.1 Maturity Index Determination

This test assesses the changes in appearance of the fruit during storage using the seven points scale established by industry for the classification of the product at the commercial level (Dadzie and Orchrad, 1997). On each evaluation day, each sample was compared against the commercial hedonic scale (Figure 4) to determine the maturity index. Data was recorded per sample. The average value over three samples was presented as the score for the storage day.

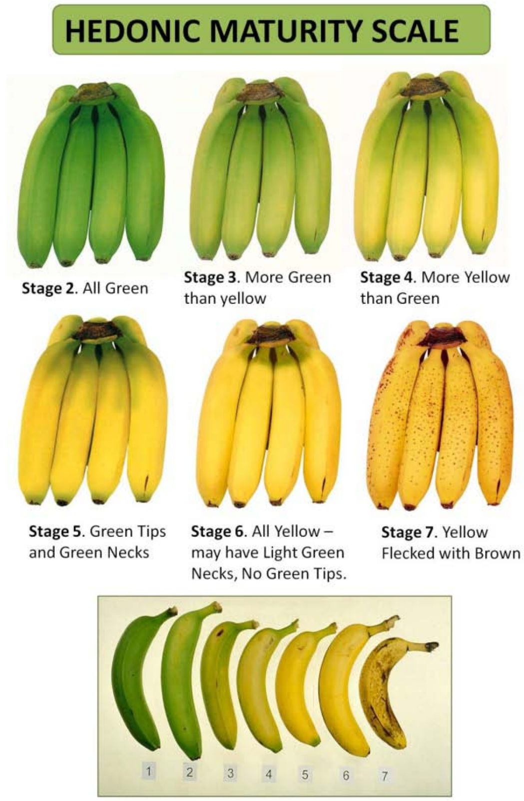

Figure 4 Commercial hedonic maturity scale.

3.2.2 Cut Strength

This measurement was performed using a Texture Analyzer TA-XT2 (Texture Technologies – Figure 5) equipped with the implement TA-45 (Figure 6) and configured to measure force in compression (1 cm distance) at a test speed of 1 cm/s. Cut strength was measured on the long segment of the cut sample. The peel was removed on one side to expose the pulp and the fruit placed in position under the implement before starting the test. Duplicate measurements were made per sample. Data was averaged and presented as the value for the storage day.

Figure 5 Texture Analyzer TA-XT2.

Figure 6 Implement used to measure cut strength

3.2.3 pH

pH measurement was performed using a portable pH meter (Accumet Basic AB15, Fisher Scientific) previously standardized with buffer solutions of pH 4, 7 and 10 at constant temperature (20ºC). The electrode was placed inside the sample previously homogenized in a porcelain mortar using a pestle. Measurements were taken in duplicate on each sample, averaged and presented as the value for the storage day.

3.2.4 ºBrix (Total soluble solids)

Total soluble solids were determined with a Palm Abbe Digital Refractometer Model PA202 (Figure 7) as described in method AOAC 93, 1290 (AOAC, 1990). About three grams of pulp sample were mashed until a homogenous mass was obtained. A drop was then taken from the mashed sample and placed in the refractometer. Two measurements for each sample were taken, averaged and reported as the value for the storage day.

Figure 7 Digital Refractometer Model PA202

3.2.5 Respiration Rates

Nine samples were randomly picked from the pool of samples and used for this test. These samples were tested on every evaluation day for 30 days or until the fruit was overripe. Three samples were labeled, weighed and placed into each of the three 1-gallon glass jars. Jars were hermetically sealed with a cap equipped with a septum for headspace sampling and stored at 20ºC for one hour. A 10 ml syringe was inserted into the septum and the collected air sample was analyzed using a gas analyzer (Servomex Food Package Analyzer) to measure the CO_2 concentration. Fruit samples were returned to storage until the next sampling day. Carbon dioxide and nitrogen standards were used for equipment calibration.

The respiration rate was calculated as milligrams of CO_2 per kilogram per hour on a fresh weight basis using a conversion factor of 1.84 (density of CO_2 at 20ºC), as in the following equation (Kader, 1992).

$$\mathrm{CO_2\ Production} = \frac{\mathrm{(Equipment\ Reading) * (Headspace\ Volume)}}{\mathrm{(Fruit\ Mass) * (Storage\ Time\ in\ Jar)}} * 1.84$$

$$\text{Head space (mL)} = \text{Jar volume (mL)} - \text{fruit volume (mL)}$$

3.3 Mechanical Properties

Each of the following two tests were performed on three samples (six in total) randomly picked from the pool of stored fruits, on days 1, 10 and 20. Samples were damaged and kept for observation until overripe. Damage was achieved using the previously described Texture Analyzer equipped with the implement shown in Figure 8 and configured as specified on each test.

Figure 8 Implement used to inflict damage.

On each test, three different levels of damage (A, B, C) were inflicted on the samples. Damage location was different for each level of damage on each fruit in order to consider the variability on the degree of ripeness of sampled fruits. Damage levels were administered following the arrangement shown below.

Sample 1	Sample 2	Sample 3
A B C	C A B	B C A

3.3.1 Impact

This test attempts to estimate the effect of the impact resulting from dropping the fruit from a given height (Velásquez, 2006). To inflict the damage level, the equipment was configured to measure distance in compression at a force of 1.48N. This force assumes a typical fruit weight of about 1/3 lb (150 grams). Test speed for each point (A, B & C) should be assumed as per the parameters on Table 2.

Table 2 Impact assessment: estimated height and equivalences.

Test Condition	Fall Height (ft)	Equivalent Velocity (m/s)
A	5	6
B	10	8
C	15	10

3.3.2 Stack Height

This test attempts to estimate the degree of damage resulting from stacking bananas. To inflict the damage level, the equipment was configured to measure distance in compression and set the force as configured on Table 3. Test speed was fixed to 1 mm/sec and force holding time was 5 seconds.

Table 3 Stack assessment: estimated stack height and equivalences.

Test Condition	Stack Height (fruits)	Force (kilograms)
A	10	1.5
B	20	3.0
C	30	4.5

3.4 Processing Characteristics:

On each testing day (0, 8, 14 and 21), three samples were randomly picked from the pool of stored fruit and used for the following sequence of tests.

3.4.1 Pulp Yield

Using a laboratory scale (Mettler PC 16), each picked sample was weighed. Afterwards, each sample was peeled and the pulp was weighed. The pulp yield was calculated using the following equation.

$$\text{Yield}\,(\%) = \frac{\text{pulp weight}}{\text{fruit weight}} \times 100$$

Data from all samples was averaged and presented as the yield for the storage day. Once the pulp yield was calculated, the naked pulp was cut into three equal segments; two segments of each fruit were used the following tests. The remaining portion was dried and stored for future testing.

3.4.2 Moisture Absorption

First, the sample was cut in half and both fruit pieces were weighed. One of the pieces was placed in boiling water (100^{o} C) for ten minutes, removed, drained, cooled and weighed again. Both pieces were then placed in an oven at 100^{o}C for 24 hours, removed from the oven, cooled in a dissecator and weighed. To determine moisture content of fresh fruit, moisture content of boiled fruit and moisture absorption, the following relations were used.

$$Moisture\ content\ \ of\ fresh\ fruit = \frac{Fresh\ wet\ weigth\ \ - Fresh\ dry\ weight}{Fresh\ \ sample\ dry\ weight}$$

$$Moisture\ content\ \ of\ boiled\ fruit = \frac{Boiled\ wet\ weigth\ \ - Boiled\ dry\ weight}{Boiled\ \ dry\ weight}$$

$$Moisture\ absorption = Boiled\ wet\ weigth - Fresh\ wet\ weight$$

3.4.3 Fat Absorption

First, the sample was cut in half and both fruit pieces were weighed, one piece was immersed in oil heated to 375^{o}F for five minutes. The sample was removed, drained, cooled and weighed (Rodríguez-Pérez et al., 2007). To analyze fat content, the applicable AOAC Soxhlet method was used, with the XT14 Fat Extractor (Ankom). The following metrics were calculated.

$$Fat\ content\ \ of\ fresh\ fruit = \frac{Fat\ weigth}{Fresh\ sample\ weigth}$$

$$Fat\ content\ of\ fried\ fruit = \frac{Fat\ weigth}{Fried\ sample\ weight}$$

$$Fat\ absorption = Fat\ contet\ fried - Fat\ content\ fresh$$

3.4.4 Statistical Analysis

Non microbiological shelf life and processing characteristics tests data were submitted to an analysis of variance (ANOVA) using Info Stat V.3.0. The Tukey test ($p<0.05$) was used to evaluate differences between varieties.

4 RESULTS AND DISCUSSION

4.1 Effect of Relative Humidity

This experiment evaluated 14 different varieties of banana hybrids (*Musa spp*) resistant to Black Sigatoka, using Grand Nain as control to compare their characteristics and identify hybrids that could replace the commercial variety (Grand Nain). Through the development of this research, we used two different laboratory facilities while maintaining the same storage temperature conditions (20^{o}C). The first laboratory facility had limited access and was smaller compared to the second, allowing the storage to keep high humidity conditions. In the second laboratory, frequent personnel access and equipment installation were factors which might have affected the relative humidity. Apparently, this difference in relative humidity conditions affected fruit storage time (days of storage) of the different harvests seasons. As an example, consider the pH curve for variety FHIA-17 shown in Figure 9. Fruits form the first harvest lasted 33 days under storage while those from the second harvest lasted only 19 days. Yet, they both went through the same maturity stages.

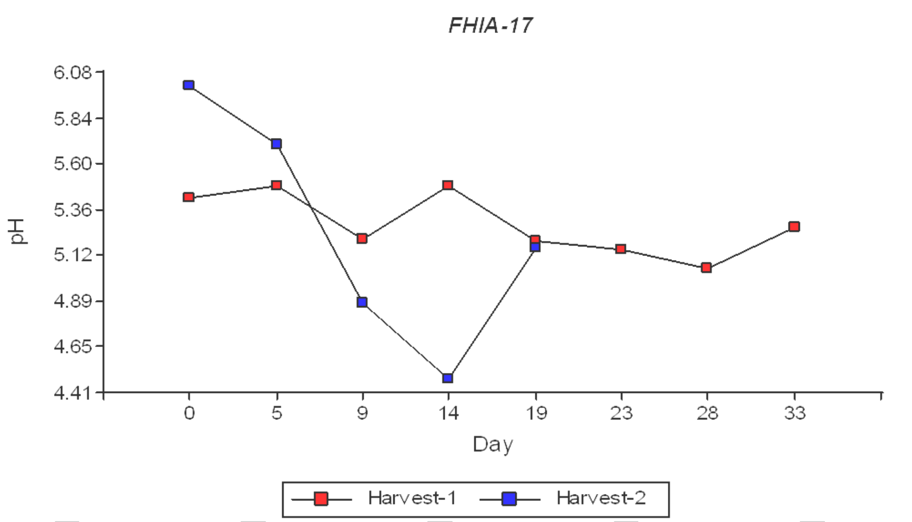

Figure 9 Changes in fruit pH during maturation in days of FHIA-17.

Given this difference in ripening time, the use of storage time as comparison base did not seem appropriate. Instead, analysis of data was performed using the commercial maturity hedonic scale as the base to compare the different characteristics at the same ripening stage.

As previously described in Figure 4 of the Materials and Methods section, the commercial hedonic scale defines 7 stages of maturation based on peel color. At stages 1 to 3, banana is not usually eaten like fruit, because it is green, very hard, astringent, and rich in starch. At stage 7, banana is overripe and has a soft texture (Berthe & Parfait, 2008).

Figure 10 shows, again, the performance of the pH curves for the two harvests of variety FHIA-17 using the hedonic scale as base for comparison. Such data management allows for a more fair comparison since the consumer would expect fruits at the same ripening stage to have similar characteristics.

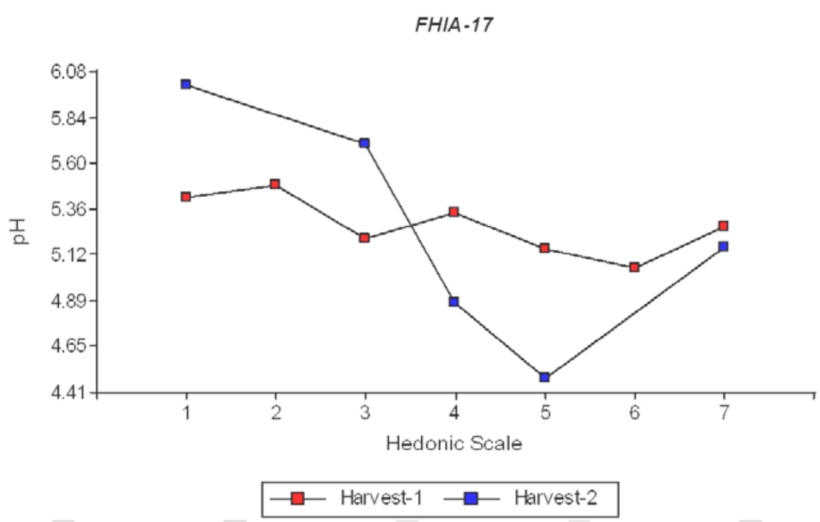

Figure 10 Changes in fruit pH during maturation of variety FHIA-17.

As mentioned before, though the temperature was kept constant in both laboratory facilities, there was a change in the performance of fruits which was associated to differences in relative humidity (RH). The effect of relative humidity during storage in the composition of different fruits (e.g., kiwifruit, apples) has been studied (Berthe and Parfait, 2008; Soltani et al., 2010; Dadzie, 1998; Ullah et al., 2006). For example, Baños et al. (2000) studied the role of relative humidity on *Botrytis cinerea* incidence during early storage of kiwifruit and concluded that weight loss increased as RH decreased and firmness increased at the highest levels of RH.

RH is used as a method to control water loss for different fruits since high RH reduces the vapor pressure difference between the air and the moisture content of the fruit. Usually, for the storage of fruits, RH must be in a range from 90% to 95%. Values below this range can cause weight loss and help accelerate the ripening process. RH values close 100% may cause growth of microorganisms causing a higher deterioration in the fruit (Shudeer et al., 2007).

Previous studies (Dadzie, 1998) relate changes in peel color to the ripening stage of banana and, generally, these comparisons are made visually. According to Dadzie (1998), when bananas are stored under low humidity and high temperature, the peel may remain green, but internally, the fruit has started the ripening process. In some cases, peel color does not reflect the internal status, and a combination of several parameters such as color charts, respiratory changes during ripening, firmness changes, pH and total soluble solids, can be used to better assess the maturity index. Yet, though it might be important to use a combination of external and internal ripening indicators to assess the maturity stage, characterizations of hybrids has traditionally been done using the commercial maturity scale to compare the characteristics (internal or external) of fruits (Dadzie, 1998). For example, Dadzie (1998) reported changes in total soluble solids (TSS) content during ripening of Grand Naine and Williams bananas compared to FHIA-01 and FHIA-02 using a hedonic maturity scale to compare between varieties.

4.2 Storage time and maturation Stage

Table 4 shows the number of storage days that each variety remained at the various stages of the commercial hedonic scale. To facilitate analysis of collected data at the different stages of the commercial maturity hedonic scale, data were grouped as follow: green (stages 1 & 2), mature green (stages 3 & 4), mature (stages 5 & 6) and overripe stage (7). Columns "Harvest 1" (2009) and "Harvest 2" (2010) show the time in days that the variety remained at the maturity stage on each of the two different seasons. The "Average" column shows the mean value of the previous two columns.

Some entries in the table show "0". These values mean that the variety went through the maturity stage too quickly for the testing schedule to detect the particular stage. For example, when the PA 03-22 fruit was received at the laboratory on day 0, it was green. As testing began on Day 1, the fruit had already matured and appeared to be at the mature-green stage (3&4). The same performance was presented by other varieties at other maturity stages and reported as 0 in the Table. For example, Grand Nain, went from ripening stages green (1&2)on one sampling day to mature (5&6) on the next. Again, it must be noted that observations were performed based on the established itinerary, therefore, this does not suggest that varieties skipped maturity stages, but rather that the stage happened so fast that those stages were not captured by the two to three day interval of the sampling schedule.

Table 4 Time in days that fruits remained at the different maturation stages.

Variety	Hedonic Scale														
	1 &2			3 & 4			5 & 6			7			Total		
	Harvest 1	Harvest 2	Average	Harvest 1	Harvest 2	Average	Harvest 1	Harvest 2	Average	Harvest 1	Harvest 2	Average	Total Harvest 1	Total Harvest 2	Total Average
**Grand Nain	4	5	4.5	0	5	2.5	9	5	7	5	4	4.5	18	19	18.5
FHIA-01	4	5	4.5	4	5	4.5	4	0	2	3	4	3.5	15	14	14.5
FHIA-02	5	5	5	5	9	7	4	5	4.5	14	5	9.5	28	24	26
FHIA-17	5	5	5	8	5	6.5	10	5	7.5	10	4	7	33	19	26
FHIA-18	9	3	6	4	4	4	10	4	7	5	3	4	28	14	21
FHIA-23	17	5	11	10	5	7.5	9	4	6.5	11	0	5.5	47	14	30.5
PA 03-22	0	0	0	5	5	5	0	5	2.5	19	14	16.5	24	24	24
PA 12-03	5	9	7	17	0	8.5	6	4	5	0	6	3	28	19	23.5
PV 03-44	5	9	7	9	0	4.5	0	0	0	5	1	3	19	10	14.5
PV 42-320	5	14	9.5	9	0	4.5	5	9	7	0	5	2.5	19	28	23.5
PV 42-53	9	9	9	6	4	5	0	0	0	9	5	7	24	18	21
PV 42-81	5	5	5	5	4	4.5	0	4	2	14	5	9.5	24	18	21
SH 3640	9	4	6.5	4	10	7	11	4	7.5	4	1	2.5	28	19	23.5
TMB2x 9128-3	9	9	9	4	0	2	5	4	4.5	5	1	3	23	14	18.5
Yangambi	4	4	4	5	4	4.5	9	0	4.5	6	6	6	24	14	19
Total	6.3	6.1	6.2	6.3	4.0	5.2	5.5	3.5	4.5	7.3	4.3	5.8	25.5	17.9	21.7

The control remained at the green stage (1&2) for 4.5 days. Similar performance was presented by the varieties FHIA-01, FHIA-17, FHIA-02, SH 36-40 and PA 12-03. At the same stage TMB2x, PV 42-53 and PV 42-320 fell in the “7 to 10 days” group, thus, performing better than the control. FHIA-23 was the best performer with more than 11 days at the green stage. Thus, in terms of storage time for the green banana fresh market, any of varieties TMB2x, PV 42-53, PV 42-320 or FHIA-23, outperforms the control. This longer storage time can have a positive economic impact for the food service industry.

For the mature stage (3&4) the control remained for 2.5 days and the only variety which showed a similar performance was TMB2x. All other varieties outperformed the control in storage time at the mature-green stage, with varieties PA 12-03, PA 03-22 and FHIA-23 lasting between 7 and 10 days. This maturity stage is the appropriate one for distribution and retail of fresh mature bananas. Thus, longer storage time implies lower losses for retail establishments.

At the mature stage (5&6) the control variety remained 7 days; performance similar to that shown by PV 42-320, FHIA-23, PA 12-03, FHIA-02 and TMB2x. Only FHIA-17 and SH 3640 lasted between 7 to 10 days. Longer shelf life at this stage reduces potential loses for retail establishments and consumers.

Finally, in the overripe, stage (7) the control lasted for 4.5 days, similar to FHIA-23, PV 42-53 and FHIA-17. At this stage, only variety PA 03-22 remained more than 10 days while FHIA-02 and PV 42-81 lasted between 4 and 7 days.

Compared to the control, in terms of storage time, the following varieties presented interesting performances. FHIA-23 remained longer in stages green and mature green, thus, it has potential interest for consumption as green (cooked) or processed. The storage times for the other two stages, mature and overripe, are similar to the control and could indicate that the fruit could accommodate well to the current fresh market expectations.

FHIA-02 performs similarly to the control for the green, mature-green and mature stages, but last longer at the overripe stage. This data can indicate that this variety could also accommodate well to the current expectations of the fresh market. Similarly, FHIA-17 behaves much like the control, but lasts longer in the mature stage.

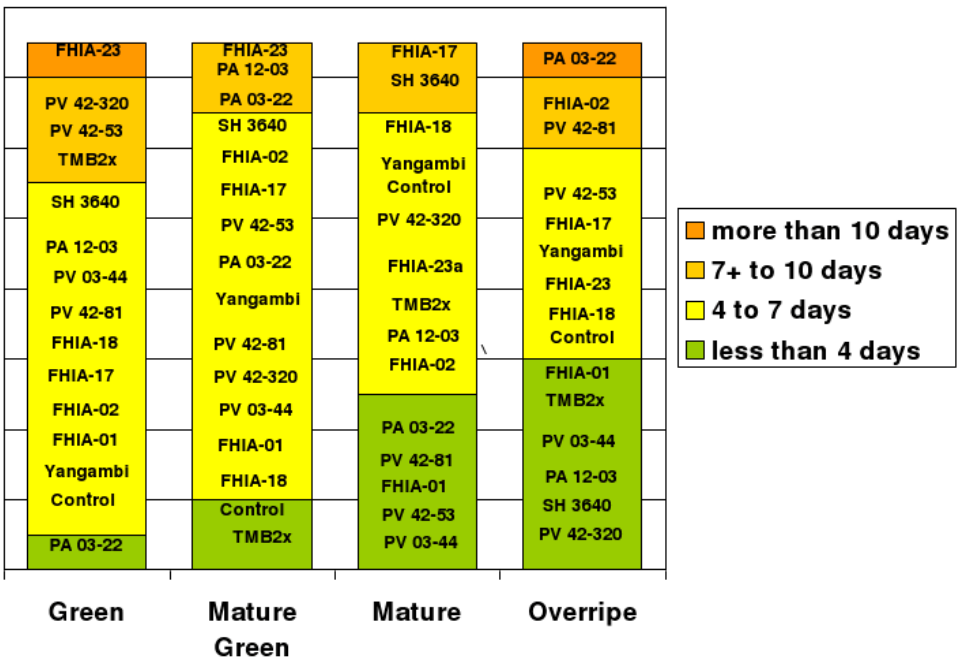

Figure 11 Time in days that fruits remained at the different maturation stages.

Figure 11 presents the "Average" data from Table 7 in groups (less than 4 days, 4 to 7 days, 7+ to 10 days and more than 10 days) to facilitate a visual comparison of the performance of varieties. It must be stressed that, though groups represent the average of two harvests for each variety, the division in groups does not imply statistical significance.

4.3 Non microbiological shelf life tests

4.3.1 Total soluble solids

Table 5 Total soluble solids at the different maturity stages.

Variety	1-2	3-4	5-6	7
*Grand Nain	5.35^{ABC}_{a}	------	15.28^{A}_{b}	16.25^{A}_{b}
FHIA-01	5.62^{ABCD}_{a}	13.95^{AB}_{b}	19.98^{AB}_{c}	20.33^{ABC}_{c}
FHIA-02	5.15^{ABC}_{a}	10.70^{A}_{b}	22.20^{AB}_{c}	17.01^{AB}_{c}
FHIA-17	3.37^{A}_{a}	14.37^{AB}_{b}	17.68^{AB}_{b}	19.73^{ABC}_{b}
FHIA-18	6.69^{ABCDE}_{a}	13.47^{AB}_{b}	21.59^{AB}_{c}	20.60^{ABCD}_{c}
FHIA-23	4.75^{AB}_{a}	10.81^{A}_{b}	17.83^{AB}_{c}	18.57^{ABC}_{c}
PA 03-22	------	9.23^{A}_{a}	------	22.37^{BC}_{b}
PA 12-03	9.38^{ABCDEF}_{a}	16.48^{AB}_{a}	19.47^{AB}_{a}	21.06^{ABC}_{b}
PV 03-44	11.08^{CDEF}_{a}	15.69^{AB}_{ab}	------	23.51^{C}_{c}
PV 42-320	12.34^{EF}_{a}	13.59^{AB}_{a}	21.85^{AB}_{b}	23.70^{C}_{b}
PV 42-53	11.56^{DEF}_{a}	21.74^{AB}_{b}	22.32^{AB}_{b}	21.60^{ABC}_{b}
PV 42-81	10.67^{BCDEF}_{a}	18.74^{AB}_{b}	------	23.34^{C}_{b}
SH 3640	8.23^{ABCDEF}_{a}	15.92^{A}_{a}	17.68^{AB}_{b}	17.79^{ABC}_{b}
TMB2x 9128-3	12.74^{F}_{a}	17.91^{AB}_{ab}	22.91^{B}_{b}	22.60^{BC}_{b}
Yangambi	8.74^{ABCDEF}_{a}	12.38^{AB}_{a}	19.72^{AB}_{b}	20.82^{ABC}_{b}

*Control Variety. ; --- No Data.
Values with the same superscript in the same column are not significantly different between varieties. Values with the same subscript in the same row are not significantly different between hedonic scales.

Ripe banana is essentially a sugar rich, easily-digestible pulp. Bananas contain many water soluble compounds (e.g., sugar, acids, vitamins, amino acids and other peptic substances), known as total soluble solids (TSS) (Arcila, 2002). Starch in the green fruit is converted to sugars (fructose and very small quantities of maltose) (Soltani et al., 2010). Since the amount of TSS increases as the fruit ripens, it can be used as a maturity index. The refractometer is the instrument used to estimate the total soluble solids contents in fruits (measured in degrees ^{o}Brix). Since most TSS in fruits are sugar degrees ^{o}Brix is used as an index of the sugar content as ripening progresses (Fernandez et al., 1997; Zhag et al., 2005; and Dadzie, 1998).

In Table 5, as mentioned earlier, the “-----“ mean that the variety jumped quickly through the maturation stage and the sampling schedule did not capture data for that stage. Data in the Table agreed with information reported in terms of increase in TSS as maturation progresses. This performance was exhibited by all varieties.

At the green stage (1&2), TSS for the control was 5.35%. This value is consistent with that reported by Dadzie et al. (1998). No significant differences were found between the control and all other varieties, except PV 42-320, PV 42-53, and TMB2x 9128-3, which resulted in higher values. Green stage bananas are typically used for flour production or cooking. High levels of solids at this stage imply higher caloric content and higher flour yield compared to the control.

The mature green stage (3&4) is the transition between green and the mature banana. As shown in Table 3, no data could be collected for the control at stage (3&4). Thus, no comparisons can be made between the control and other varieties. Yet, data shows no significant differences in TSS content of hybrids.

At the mature stage (5&6), the control had an average value of 15.28%, similar to all other varieties, except TMB2x 9128-3 which was significantly higher (22.91%). Dadzie (1998) reported values of 13%, 10%, and 10% for the Grand Nain, FHIA-01 and FHIA-02, respectively. These values are lower than the results of this study. The fact that no significant differences were found between control and most hybrids implies that any of such varieties could provide similar caloric content as the control when consumed as fresh fruit or as an ingredient of further processed products.

At the overripe stage (7), the value for the control (16.25%) is not significantly different than at the mature stage (5&6). Compared to the other varieties, significant difference was only found between the control and PA 03-22 (22.37%), PV 03-44 (23.51%), PV 42-320 (23.70%), PV 42-81 (23.34%) and TMB2x 9128-3 (22.60%). Since ripening increases sugar content in fruit (Fernandez et al., 1997; Zhag et al., 2005; Dadzie, 1998), higher TSS values for these varieties imply higher sugar content when compared to the control, thus, higher caloric content.

4.3.2 pH

Table 6 pH at the different maturity stages.

Variety	1-2	3-4	5-6	7
*Grand Nain	6.03^{B}_{b}	------	5.51^{D}_{a}	5.66^{F}_{a}
FHIA-01	5.87^{AB}_{b}	4.90^{AB}_{b}	4.37^{AB}_{a}	4.59^{A}_{a}
FHIA-02	5.58^{AB}_{b}	4.83^{AB}_{a}	4.6^{ABC}_{a}	5.02^{ABCDE}_{ab}
FHIA-17	5.65^{AB}_{b}	5.10^{AB}_{a}	5.06^{CD}_{a}	5.27^{DE}_{ab}
FHIA-18	5.16^{A}_{c}	4.48^{A}_{ab}	4.17^{A}_{a}	4.66^{AB}_{b}
FHIA-23	5.50^{AB}_{a}	5.38^{AB}_{a}	5.14^{CD}_{a}	5.40^{E}_{a}
PA 03-22	------	4.96^{AB}_{a}	------	4.72^{ABC}_{a}
PA 12-03	5.86^{AB}_{b}	4.97^{AB}_{a}	4.95^{CD}_{a}	4.77^{ABCD}_{a}
PV 03-44	5.46^{AB}_{a}	5.33^{AB}_{a}	------	5.03^{ABCDE}_{a}
PV 42-320	5.72^{AB}_{a}	5.63^{B}_{a}	4.69^{ABC}_{a}	4.72^{ABC}_{a}
PV 42-53	5.54^{AB}_{b}	4.82^{AB}_{b}	4.66^{ABC}_{a}	4.80^{ABC}_{a}
PV 42-81	5.26^{AB}_{b}	4.77^{AB}_{a}	------	4.57^{A}_{a}
SH 3640	5.95^{AB}_{a}	5.01^{AB}_{a}	4.91^{BC}_{a}	4.70^{ABC}_{b}
TMB2x 9128-3	5.28^{AB}_{a}	4.98^{AB}_{a}	4.96^{CD}_{a}	5.17^{CDE}_{a}
Yangambi	5.22^{AB}_{a}	5.32^{AB}_{a}	5.10^{CD}_{b}	5.09^{BCDE}_{a}

*Control Variety. ; --- No Data.
Values with the same superscript in the same column are not significantly different between varieties. Values with the same subscript in the same row are not significantly different between hedonic scales

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Pulp pH is another quality attribute for assessing fruit maturity. According to Caussiol (2006), at the green stage, pulp pH is between 5.4 and 6.0. A glance at Table 4 suggests that values for the control are similar to those reported by Caussiol (2006), but hybrids have lower values.

In banana flesh the main acids are malic, citric and oxalic acids. While the first two acids are responsible for the tartness in the unripe banana, oxalic acid contributes to astringent taste of the fruit (Seymour, 1993). Siriboon et al. (2006) found that as the fruit ripens these acids were reduced and the taste change; mainly from the increasing in sugars from starch degradation. Organics acids are important for maintaining the sugar-acid balance which helps provide a pleasing fruit taste during ripening (Loesoecke, 1950). Pulp pH is often high while the titrable acidity is low at the green stage. TSS increases, pH decreases and acidity increases as ripening progresses (Piña et al., 2006). Arcila et al. (2002) reported that the malic acid content increases during maturation, and decreases at the overripe stage 7. The magnitude of pH changes depends on variety. Generally, the pH is when high fruits are green, but as ripening progresses pH drops. The decrease in organic acids in the pulp is related to the respiration process (conversion to sugar) (Saavedra et al., 2006; Arcila et al., 2002; Causiol, 2006).

Table 6 shows pH data according to the commercial hedonic scale. Again, some entries in the Table show “-----“. This means that the variety went through the stage quickly and data could not be detected by the sampling schedule. Data in the Table, in general, agrees with Dadzie (1997) reports on pH decrease as maturity progresses. The performance of hybrids FHIA-23, PV 03-44, PV 42-320 and TMB2x 9128-3, however, did not follow such trend as no significant differences were found between the maturity stages.

At the green stage (1&2) the control had a pH value of 6.03. This value is only significantly higher compared to FHIA-18 (5.16). Dadzie (1998) reported Grand Nain pH of 5.80 and 5.40 for stages 1 and 2, respectively, and pH of 6.00 and 5.70 for FHIA-01 and FHIA-02, respectively. Dadzie's values for the Grand Nain are lower than those found in this study, but values for the FHIA varieties are similar.

The mature green stage (3&4) is the transition between green and the mature banana. As shown in the Table 6 no data could be collected for the control at stage (3&4). Thus no comparisons can be made between the control and other varieties. Yet, data shows no significant differences among varieties, except for varieties FHIA-18(4.48) and PV 42-320 (5.63), where a significant difference was found.

At the mature stage (5&6) pH of the control variety (5.51) is significantly lower than for the green (1&2) stage. Compared to hybrids this value is significantly higher than for FHIA-01 (4.37), FHIA-02 (4.6), FHIA-18 (4.17), PV 42-320 (4.69), PV 42-53 (4.66) and SH 3640 (4.91). Dadzie (1998) reported values of approximately 5.5 for the Grand Nain and 4.5 for FHIA-01 and FHIA-02. These values agree with those found in this study.

Dadzie (1998) reported a pH increase during the final stages of maturity. Results in Table 4 show a slight increase in pH from stage (5&6) to stage 7 for the control variety. Though the observed change is statistically insignificant, it agrees with the trend observed by Dadzie.

Such trend, however, was found significant for varieties such as FHIA-18, SH 36-40 and Yangambi. A comparison of the control pH (5.66) with the other varieties shows that the control has significantly higher values than any other variety (4.59 – 5.40).

4.3.3 Weight loss

Previous studies (Siriboon et al., 2006; Dadzie, 1998) showed that percent weight loss increased continuously during ripening due to high storage temperature (30^{o}C). Other changes and chemicals reactions such as appearance, texture and nutritional qualities were also related to storage temperature. Due to the large amounts of energy required for the maturation process in the fruit, starch turns into sugar and used as energy. Excess of energy produced from the respiration process is released from the fruit as water vapor and causes weight loss (Siriboon et al., 2006).

Banana peel has stomata and continues gas exchange through maturation. Piña et al. (2006) found a relationship between the thicknesses of the peel and weight loss. This relation is visible in the change of weight in FHIA-23 between the green and the mature stages. They reported a weight loss at the mature stage for FHIA-23 (21.43 %), FHIA-17 (17.15%), and FHIA-01 (13.97%) during storage at 28±2 ^{o}C and 68% HR and concluded that the rate of postharvest water loss depends primarily on the external vapor pressure deficit.

For this study, weight loss was calculated as the difference between the weight of the fruit on the day of the assessment and the weight expressed as percentage of initial weight. Table 7 shows the percent weight loss of varieties according to the maturity stage. Missing values in the Table 7 mean that the variety passed through the maturity stage too quickly for the testing schedule to detect the stage.

Table 7. Weight loss percentage at the different maturity stages.

Variety	1-2	3-4	5-6	7
*Grand Nain	$16.62\,^{C}_{a}$	$17.22\,^{D}_{a}$	$27.31\,^{B}_{ab}$	$38.29\,^{D}_{b}$
FHIA-01	$2.21\,^{AB}_{a}$	$10.09\,^{ABC}_{b}$	$13.47\,^{A}_{bc}$	$20.92\,^{ABC}_{c}$
FHIA-02	$7.01\,^{B}_{a}$	$10.48\,^{ABCD}_{a}$	$18.88\,^{AB}_{b}$	$27.91\,^{BCD}_{c}$
FHIA-17	$4.87\,^{AB}_{a}$	$13.03\,^{BCD}_{b}$	$15.85\,^{A}_{bc}$	$22.27\,^{ABC}_{c}$
FHIA-18	$3.86\,^{AB}_{a}$	$10.32\,^{ABC}_{b}$	$16.36\,^{A}_{c}$	$25.08\,^{ABC}_{d}$
FHIA-23	$6.93\,^{B}_{a}$	$14.24\,^{CD}_{b}$	$14.18\,^{A}_{b}$	$20.52\,^{ABC}_{c}$
PA 03-22	------	$7.53\,^{ABC}_{a}$	------	24.93^{ABC}_{b}
PA 12-03	0.78^{A}_{a}	$4.08\,^{A}_{a}$	$14.49\,^{A}_{b}$	$17.74\,^{ABC}_{b}$
PV 03-44	$3.17\,^{AB}_{a}$	$9.96\,^{ABC}_{b}$	------	$19.12\,^{ABC}_{c}$
PV 42-320	$2.66\,^{AB}_{a}$	$9.57\,^{ABC}_{b}$	$14.05\,^{A}_{b}$	$14.71\,^{A}_{b}$
PV 42-53	$2.44\,^{AB}_{a}$	$9.74\,^{ABC}_{b}$	------	$19.13\,^{ABC}_{c}$
PV 42-81	$3.93\,^{AB}_{a}$	$6.74\,^{AB}_{a}$	------	$18.46\,^{ABC}_{b}$
SH 3640	$2.59\,^{AB}_{a}$	$8.29\,^{ABC}_{ab}$	14.32^{A}_{bc}	$18.73\,^{ABC}_{c}$
TMB2x 9128-3	$4.89\,^{AB}_{a}$	$12.23\,^{BCD}_{b}$	$15.99\,^{A}_{b}$	$29.21\,^{CD}_{c}$
Yangambi	$2.97\,^{AB}_{a}$	9.28^{ABC}_{b}	$13.83\,^{A}_{c}$	16.88^{AB}_{c}

*Control Variety. ; --- No Data.
Values with the same superscript in the same column are not significantly different between varieties. Values with the same subscript in the same row are not significantly different between hedonic scale

At the green stage (1&2) the control presents the highest value in weight loss percentage 16.62%. This value is significantly higher than for all varieties (ranged from 0.78% to 7.0%).

At the mature green stage (3&4), the value for the control (17.22%) is the highest average weight loss compared to hybrids, yet, this value was not significantly different than for FHIA-02 (10.48%), FHIA-17 (10.03%), FHIA-23 (14.84%), and TMB2x 9128-3 (15.99%). The best performer at this stage was PA 12-03 with an average weight loss of 4.08%.

In the mature stage (5&6) significant differences were found between the control (27.31%) and all varieties, with the exception of FHIA-02 (18.88%). The best performance was exhibited by FHIA-01 (13.47%). Finally, at the overripe stage (7), the average weight loss for the control (38.29%) was the highest. Similar performance (no significant difference) was only observed in FHIA-02 (27.91%) and TMB2x 9128-3 (29.21%).

In the case of weight loss, all the chemical transformations in the fruit can be related to this parameter. The relationship between the initial weight and its change through the ripening stages is related to the final composition of the fruit. In general, the best performance in this assessment was shown for PA 12-03. In terms of weight loss its low values help increase the yield at the different stages.

4.3.4 Cut strength

Tissue softening accompanies the ripening of many fruits and initiates the irreversible deterioration (Marriott, 1980). The production of ethylene during storage is essential to promote the proper cell wall hydrolysis sequence required for normal fruit softening. Bananas are climacteric fruits. As they mature, the pulp softens rapidly and become much more susceptible to mechanical damage (De Villieris, 2005).

Chitarra (1998) described the effect of cuts and injuries on plants, and states that injuries rupture the cells and modify their permeability. As a consequence, there is acceleration on the ethylene synthesis and respiration. When the bananas suffer cuts, the fatty acids react with the oxygen (lypoxigenases) and form dark pigmentations in the fruit (hydroperoxidases).

Chavez et al. (2000) determined the plastic deformation and cut resistance in blackberries at different maturation stages. They define cut resistance as the maximum force to break a material. Data obtained suggested that the required force to cut the fruit decreases according to the maturity stage (green stage 2.536kg; overripe stage 0.557kg).

Table 8 Cut strength at the different maturity stages.

Variety	1-2	3-4	5-6	7
*Grand Nain	429.15^{ABCD}_{c}	------	298.26^{C}_{b}	123.87^{D}_{a}
FHIA-01	263.54^{A}_{b}	214.41^{AB}_{b}	81.37^{A}_{a}	41.99^{AB}_{a}
FHIA-02	654.07^{EF}_{d}	437.83^{BC}_{c}	196.38^{ABC}_{b}	32.95^{A}_{a}
FHIA-17	529.47^{CDEF}_{c}	308.47^{AB}_{b}	89.50^{A}_{a}	98.72^{CD}_{a}
FHIA-18	666.59^{F}_{c}	295.89^{AB}_{b}	144.21^{AB}_{a}	36.90^{AB}_{a}
FHIA-23	591.62^{DEF}_{c}	346.60^{ABC}_{b}	96.18^{AB}_{a}	105.80^{CD}_{a}
PA 03-22	------	283.76^{A}_{a}	------	51.38^{ABC}_{b}
PA 12-03	306.38^{AB}_{b}	199.30^{AB}_{ab}	233.89^{BC}_{b}	42.24^{AB}_{a}
PV 03-44	654.70^{EF}_{c}	303.56^{AB}_{b}	------	92.71^{A}_{a}
PV 42-320	535.79^{CDEF}_{c}	232.21^{AB}_{b}	108.52^{AB}_{ab}	82.28^{ABCD}_{a}
PV 42-53	487.95^{BCDEF}_{b}	163.41^{A}_{a}	64.07^{A}_{a}	61.05^{ABC}_{a}
PV 42-81	453.15^{ABCDE}_{c}	248.21^{AB}_{b}	------	70.39^{ABCD}_{a}
SH 3640	338.71^{ABC}_{b}	175.56^{A}_{a}	112.60^{AB}_{a}	99.53^{CD}_{a}
TMB2x 9128-3	489.69^{BCDEF}_{c}	358.42^{ABC}_{b}	69.32^{A}_{a}	52.11^{ABC}_{a}
Yangambi	618.85^{DEF}_{b}	596.63^{C}_{b}	117.64^{AB}_{a}	38.22^{AB}_{a}

*Control Variety. ; --- No Data.
Values with the same superscript in the same column are not significantly different between varieties. Values with the same subscript in the same row are not significantly different between hedonic scales

Table 8 shows average cut strength values for the different varieties at the various ripening stages. Cut strength was determined as the force in grams required to cut the pulp. Data show a decreasing trend as fruit ripens. This agrees with the performance reported in the literature. As mentioned earlier, missing values in Table 8 mean that the variety jumped quickly through the maturation stage and the sampling schedule did not capture data for that stage.

At the green stage (1&2), significant differences were found between the control (429.15) and varieties FHIA-02 (654.07), FHIA-18 (666.59) and PV 03-44 (654.70).

The mature green stage (3&4) is the transition between green and the mature banana. As shown in Table 8, no data could be collected for the control at stage (3&4). Thus, no comparisons can be made between the control and other varieties.

In the mature stage (5&6) no significant differences were found between the control (298.26) and varieties FHIA-02 (196.38) and PA 12-03 (233.89). Values of other varieties were significantly lower compared to the control.

Finally, at the overripe stage (7) no significant differences were found between the control (123.87), FHIA-17 (98.72), FHIA-23 (105.80), PV 42-320 (82.28), PV 42-81 (70.39), SH 3640 (99.53). Values of the other varieties were significantly lower compared to the control.

4.3.5 Respiration rates

Respiration is a complex biochemical process which involves the exothermic transformation of potential energy into kinetic energy. In the presence of oxygen, carbohydrates are oxidized to carbon dioxide and water (Alvarado et al., 2005). Previous studies confirm the climacteric performance of bananas and describe the respiration process in different phases. On the beginning stages of ripening (from green to green mature), the fruit develops its fundamental characteristics. In the second half of the maturation process (mature to overripe), fruit quickly develop their flavor and aroma and increase the production of CO_2 (Coba & Guanoluisa, 1988). Respiration rate can vary depending on the type of hybrid/cultivar because some varieties suffer from premature ripening. Gayosso-Garcia et al. (2010) reported respiration rate data for papaya at different stages of maturation (Table 9).

Table 9 Values of CO_2 (mL CO2/kg.h) reported in papaya.

Maturity stage	CO_2 (mL CO_2/kg.h)
0-25% yellow	7.94
>25 and 50% yellow	11.51
>50 and 75% yellow	14.8
>50 and 75% yellow	15.41

Data in Table 10 show the average respiration rate in mg CO_2/ (kg*h) of samples at the different maturity stages. As mentioned earlier, missing entries mean that the fruit went too quickly through the particular stage that data could not be captured with the established sampling schedule.

Data in the table agrees with literature reports in terms of increase CO_2 production as maturation progresses. This generalized tendency was not statistically significant for some varieties (FHIA-17, PA 03-22, PA 12-03 and PV 03-44). Also, varieties such as SH 3640 and TMB2x 9128-3 show a significant decrease in respiration rate as they moved from mature (5&6) to overripe (7).

Table 10 Average value of CO_2 rate at the different maturity stages.

Variety	**1-2**	**3-4**	**5-6**	**7**
*Grand Nain	36.54^{AB}_{a}	50.80^{ABCD}_{a}	66.99^{ABC}_{a}	154.48^{AB}_{b}
FHIA-01	69.45^{BC}_{a}	99.74^{BCD}_{a}	107.69^{ABC}_{ab}	176.58^{AB}_{b}
FHIA-02	0.00^{A}_{a}	32.03^{AB}_{b}	66.36^{ABC}_{c}	91.27^{AB}_{c}
FHIA-17	0.00^{A}_{a}	0.00^{A}_{a}	2.82^{A}_{a}	46.22^{AB}_{a}
FHIA-18	99.45^{C}_{a}	123.96^{CD}_{ab}	171.26^{C}_{ab}	202.18^{B}_{b}
FHIA-23	10.10^{A}_{a}	17.84^{A}_{a}	76.26^{ABC}_{a}	178.40^{AB}_{b}
PA 03-22	------	53.67^{ABC}_{a}	67.91^{ABC}_{a}	67.57^{AB}_{a}
PA 12-03	53.64^{ABC}_{a}	67.46^{ABCDE}_{a}	76.55^{ABC}_{a}	81.52^{AB}_{a}
PV 03-44	37.70^{AB}_{a}	44.12^{AB}_{a}	45.39^{AB}_{a}	93.42^{AB}_{a}
PV 42-320	2.85^{A}_{a}	30.24^{AB}_{ab}	69.90^{ABC}_{bc}	93.13^{AB}_{c}
PV 42-53	5.00^{A}_{a}	62.00^{ABCDE}_{b}	87.62^{ABC}_{c}	------
PV 42-81	5.21^{A}_{a}	75.61^{ABCD}_{b}	116.14^{BC}_{bc}	138.99^{AB}_{c}
SH 3640	33.83^{AB}_{a}	59.69^{ABC}_{a}	171.84^{C}_{b}	85.74^{AB}_{a}
TMB2x 9128-3	160.26^{D}_{a}	148.82^{D}_{b}	295.86^{D}_{c}	33.93^{A}_{a}
Yangambi	7.56^{A}_{a}	68.86^{ABCDE}_{b}	78.14^{ABC}_{b}	------

*Control Variety. ; --- No Data.
Values with the same superscript in the same column are not significantly different between varieties.
Values with the same subscript in the same row are not significantly different between hedonic scales

Data in Tables 10 show the average value of mg CO_2/kg.h of samples trough the different maturity stages. As mentioned earlier, missing entries mean that the fruit passed too quickly through the particular stage and data could not be captured with the established sampling schedule.

At the green stage (1&2), significant differences were found between the control (36.54 mg CO_2/kg*h) and FHIA-18 (99.45 mg CO_2/kg*h) and TMB2x 9128-3 (160.26 mg CO_2/kg*h). Respiration rate for all other varieties ranged from 0.00 mg CO_2/kg*h (FHIA-02 and FHIA-17) to 66.45 mg CO_2/kg*h (FHIA-01). Comparing data obtained for papaya at the same stage (green) the production of CO_2 (7.94 mL CO_2/kg.h = 14.61 mg CO_2/kg*h) with data obtained in this study, it can be seen that the respiration rate of the Control is about twice as much than that of papaya.

At the mature green stage (3&4), significant difference was observed between the control (50.80 mg CO_2/kg*h) and TMB2x 9128-3 (148.82 mg CO2/kg.h). For the rest of the hybrids CO_2 average values ranged from 0.00 mg CO_2/kg*h (FHIA-17) to 123.96 mg CO_2/kg*h (FHIA-18).

At the mature stage (5&6), significant differences were found between the control (66.99 mg CO_2/kg*h) and TMB2x 9128-3 (295.86 mg CO_2/kg*h). For the rest of the varieties respiration rate averages ranged from 2.82 (FHIA-17) to 171.84 mg CO_2/kg*h (SH 3640). Some hybrids differed significantly among each other within this range, but were not different to the control.

At the final stage of maturity (7), no significant differences were found between the control and all the varieties. At this stage the highest value for the rate value of mg CO_2/kg*h was exhibited by PV42-81 (138.99 mg CO_2/kg*h). For the rest of the varieties, respiration rate ranged between 33.93 mg CO_2/ kg*h (TMB2x 9128-3) and 202.18mg CO_2/kg*h (FHIA-18).

4.4 Processing characteristics

4.4.1 Fat absorption

This test was conducted to determine the amount of oil absorbed by the different varieties according to their ripening stage. Previous investigations (Diaz et al., 1999) show that the oil uptake appears to be linked to the starch content of the fruit, and variety, irrespective of processing time or temperature. Oil uptake in the case of banana, does not appear to be correlated to the raw material water content as it was previously described for potato chips production and cassava chips (Diaz et al., 1999).

For this study, the amount of absorbed oil was calculated as the difference in fat content (%) of the treated sample (fried for 5 minutes at 350 ^oF) and the fat content of the fresh fruit (without treatment). Data is shown in Table 11. As mentioned earlier, missing entries mean that the fruit passed too quickly through the particular stage and data could not be captured with the established sampling schedule.

Tran et al. (2006) found that oil absorption in potato chips ranged from 35% to 42%. Compared to the values obtained for the different varieties considered in this study, it can be seen that with few exceptions, bananas absorb less oil than potatoes. Diaz et al. (1999) concludes that oil uptake appears to be influenced by apparent density and starch content, with oil content falling as the starch content and apparent density increase.

Fat absorption for the control variety ranged between 5.35% and 30.91% as maturation progressed. Such variation was found to be statistically significant at the latter stages of maturity. A similar pattern was observed for all hybrids, with the exception of FHIA-17, FHIA-18, PV 42-81, and TMB2x 9128-3 where no significant differences were found between maturity stages.

Table 11 Fat absorption at the different maturity stages.

Variety	1-2	3-4	5-6	7
*Grand Nain	5.33_{a}^{AB}	------	12.18_{a}^{A}	30.91_{b}^{A}
FHIA-01	6.42_{a}^{AB}	------	22.50_{ab}^{A}	34.88_{b}^{A}
FHIA-02	3.44_{a}^{AB}	------	13.76_{b}^{A}	24.37_{c}^{A}
FHIA-17	2.72_{a}^{AB}	5.65_{a}^{A}	11.96_{a}^{A}	14.83_{a}^{A}
FHIA-18	3.69_{a}^{AB}	7.43_{a}^{A}	14.41_{a}^{A}	16.55_{a}^{A}
FHIA-23	2.82_{a}^{AB}	10.98_{a}^{A}	32.85_{b}^{A}	60.96_{c}^{A}
PA 03-22	------	5.17_{a}^{A}	------	41.73_{b}^{A}
PA 12-03	7.49_{a}^{B}	15.26_{a}^{A}	32.56_{b}^{A}	------
PV 03-44	2.42_{a}^{AB}	7.34_{a}^{A}	------	45.19_{b}^{A}
PV 42-320	------	6.29_{a}^{A}	28.44_{b}^{A}	------
PV 42-53	3.52_{a}^{AB}	------	11.60_{a}^{A}	27.23_{b}^{A}
PV 42-81	3.71_{a}^{AB}	8.29_{a}^{A}	26.64_{a}^{A}	13.64_{a}^{A}
SH 3640	4.65_{a}^{AB}	10.72_{a}^{A}	26.18_{b}^{A}	------
TMB2x 9128-3	1.29_{a}^{A}	5.55_{a}^{A}	4.04_{a}^{A}	20.84_{a}^{A}
Yangambi	4.58_{a}^{AB}	11.67_{ab}^{A}	23.68_{ab}^{A}	28.45_{b}^{A}

*Control Variety. ; --- No Data.
Values with the same superscript in the same column are not significantly different between varieties. Values with the same subscript in the same row are not significantly different between hedonic scales

At the green stage (1&2), no significant differences were found between the control and all the varieties in terms of fat absorption. Fat absorption at green stage ranged to 1.29% for TMB2x 9128-3 to 7.49% for PA 12-03. The control variety fell on the high end of the range with 5.33%.

The mature green stage (3&4) is the transition between green and the mature banana. As shown in the Table no data could be collected for the control at stage (3&4). Thus no comparisons can be made between the control and other varieties. Yet, data shows no significant differences among varieties.

At the mature stage (5&6), no significant differences were found between the control and all the varieties. Fat absorption ranged between 4.04% for Yangambi to 32.85% for FHIA-23. Fat absorption for the control was 12.18%. A similar pattern was observed at overripe stage (7), where no significant differences were found between hybrids and the control. Samples of this stage (7) exhibited more noticeable changes in the color of the surface crust; typical of caramelization processes.

4.4.2 Moisture absorption

During cooking, banana absorbs water in an amount that depends on process time and variety. Dadzie et al. (1997) state that good cooking qualities of a hybrids depend on low water absorption potential, high initial pulp firmness, high percentage of dry matter and low moisture content. The free space left in the cells is occupied by water. The amount of water absorbed depends of their initial moisture; initial composition and maturity stage (Siriboon et al., 2006).

Data in Table 12 show the percentage of water absorbed by samples calculated as the difference between the water content of treated samples (boiled in water for 10 min) and the moisture content of the fresh fruit (without treatment). As mentioned earlier, missing entries mean that the fruit passed too quickly through the particular stage and data could not be captured with the established sampling schedule.

Table 12 Moisture absorption at the different ripening stages.

Variety	1-2	3-4	5-6	7
*Grand Nain	$31.51\,^{AB}_{a}$	------	$38.53\,^{AB}_{a}$	$61.25\,^{A}_{a}$
FHIA-01	$39.37\,^{AB}_{a}$	------	$41.64\,^{AB}_{a}$	$42.78\,^{A}_{a}$
FHIA-02	$30.62\,^{AB}_{a}$	------	$50.72\,^{AB}_{a}$	$50.91\,^{A}_{a}$
FHIA-17	$31.67\,^{AB}_{a}$	$35.59\,^{A}_{ab}$	$36.37\,^{A}_{ab}$	$68.05\,^{A}_{b}$
FHIA-18	$45.64\,^{B}_{a}$	$44.63\,^{A}_{a}$	$56.78\,^{AB}_{a}$	$60.02\,^{A}_{a}$
FHIA-23	$36.18\,^{AB}_{a}$	$50.28\,^{A}_{a}$	$46.43\,^{AB}_{a}$	$48.69\,^{A}_{a}$
PA 03-22	------	$37.63\,^{A}_{a}$	------	$48.25\,^{A}_{a}$
PA 12-03	$43.55\,^{B}_{ab}$	$34.54\,^{A}_{a}$	$66.56\,^{AB}_{b}$	------
PV 03-44	$26.28\,^{AB}_{a}$	$28.15\,^{A}_{a}$	------	$43.72\,^{A}_{a}$
PV 42-320	------	$33.52\,^{A}_{a}$	$46.56\,^{AB}_{a}$	------
PV 42-53	$29.33\,^{AB}_{a}$	------	$43.35\,^{AB}_{a}$	$52.41\,^{A}_{a}$
PV 42-81	$38.03\,^{AB}_{a}$	$57.32\,^{A}_{ab}$	$85.92\,^{B}_{b}$	$43.85\,^{A}_{a}$
SH 3640	$5.85\,^{A}_{a}$	$26.15\,^{A}_{b}$	$70.92\,^{AB}_{c}$	------
TMB2x 9128-3	$28.44\,^{AB}_{a}$	$27.46\,^{A}_{a}$	$60.43\,^{AB}_{ab}$	$79.08\,^{A}_{b}$
Yangambi	$30.31\,^{AB}_{a}$	$59.32\,^{A}_{a}$	$32.33\,^{A}_{a}$	$56.32\,^{A}_{a}$

*Control Variety. ; --- No Data.
Values with the same superscript in the same column are not significantly different between varieties.
Values with the same subscript in the same row are not significantly different between hedonic scales

Comparison of water absorption data between maturity stages of varieties shows no significant difference with the exception of FHIA-17, PA 12-03, PV 42-81, SH 3640 and TMB2x 9128-3. The previously mentioned hybrids absorbed significantly more water at the mature (5&6) and overripe stages (7) compared to the green stage. For example, SH 3640 went from 5.85% water absorption at the green stage (1&2) to 70.92% at the mature stage (5&6).

A study on banana starch found that the moisture absorption is a function of exposure time. Banana starch is hydrophilic and absorbs moisture from the atmosphere (Duangdao et al., 2002). During ripening, starch breaks down into sugars. Starch content in banana declines from 20-23% in unripe fruit to 1-2% at the overripe stage (Payasi et al., 2007).

Several authors (Forsyth, 1980; Agarvante et al., 1990; Kojima et al., 1994) suggested that the degradation of peptic and hemicellulosic polysaccharides and starch are the main reason for the pulp softening. Other investigations showed that the decrease on starch content is accompanied by an increase in TSS and increase in α-amylase; one of the reasons for the fruit softening (Payasi et al., 2007).

At the green stage (1&2) no significant differences were found between the control and all other varieties. Though water absorption for SH 3640 was 5.85%, the average values for all other varieties ranges between 26.28% and 45.64%. However, no significance difference was found between varieties and the control at this maturity stage. Water absorption at this stage is of commercial importance for the food service industry in Puerto Rico where green bananas are boiled and served as a side dish. It could also have implications of products made with green banana flour.

The mature green stage (3&4) is the transition between green and the mature banana. As shown in the Table no data could be collected for the control at stage (3&4). Thus, no comparisons can be made between the control and other varieties. Yet, data shows no significant differences among varieties.

At the mature stage (5&6), Yangambi had the lowest water absorption capacity (32.33%) while PV 42-81 had the highest (85.92%). Significant difference was found in the water absorption capacity of these two hybrids, but no difference was found between these two, or any other hybrid, and the control. Water absorption for the control (38.53%) fell in the lower end of the range at this stage.

At the final stage of maturity (7) average water absorption for the control increases considerably from 38.53% to 61.25%. The lack of significance between these values indicates the degree of variability, probably introduced by the need to group maturity stages for the analysis. Such a marked difference is only exhibited by FHIA-17 (36.37% to 68.05%) and Yangambi (32.33% to 56.32%). The observed change of most other varieties ranged from 1 to 10%. An interesting performance is that for PV 42-81 where moisture absorption when down from 85.92% to 43.85%.

4.4.3 Moisture content

Table 13 Moisture content at the different ripening stages.

Variety	1-2	3-4	5-6	7
*Grand Nain	0.75_{a}^{CD}	------	0.75_{a}^{CDE}	0.75_{a}^{AB}
FHIA-01	0.74_{ab}^{BCD}	------	0.71_{a}^{ABCD}	0.75_{b}^{AB}
FHIA-02	0.71_{a}^{ABC}	------	0.69_{a}^{AB}	0.74_{a}^{AB}
FHIA-17	0.77_{a}^{D}	0.77_{a}^{DE}	0.77_{a}^{E}	0.79_{b}^{BC}
FHIA-18	0.71_{a}^{ABC}	0.73_{a}^{BCDE}	0.72_{ab}^{ABCD}	0.80_{b}^{BC}
FHIA-23	0.77_{a}^{D}	0.78_{a}^{E}	0.80_{ab}^{E}	0.83_{b}^{C}
PA 03-22	------	0.70_{a}^{ABC}	------	0.74_{b}^{AB}
PA 12-03	0.68_{a}^{A}	0.67_{a}^{A}	0.76_{b}^{DE}	------
PV 03-44	0.68_{a}^{A}	0.68_{a}^{AB}	------	0.70_{a}^{A}
PV 42-320	------	0.70_{a}^{ABC}	0.70_{a}^{ABC}	------
PV 42-53	0.72_{a}^{ABC}	------	0.70_{a}^{AB}	0.74_{a}^{AB}
PV 42-81	0.68_{a}^{A}	0.68_{a}^{AB}	0.69_{a}^{A}	0.78_{b}^{BC}
SH 3640	0.74_{a}^{BCD}	0.75_{a}^{CDE}	0.75_{a}^{BCDE}	------
TMB2x 9128-3	0.70_{a}^{AB}	0.70_{a}^{ABC}	0.73_{b}^{ABCD}	0.72_{ab}^{AB}
Yangambi	0.74_{a}^{BDC}	0.72_{a}^{ABCD}	0.75_{a}^{CDE}	0.72_{a}^{AB}

*Control Variety. ; --- No Data.
Values with the same superscript in the same column are not significantly different between varieties.
Values with the same subscript in the same row are not significantly different between hedonic scales

Moisture content is an important parameter in processing of the banana. The use of green and ripe banana flour has an increasing impact in the food industry. Ripe Banana flour has been investigated as an additive to replace wheat flour due their low water retention and good viscosity makes it a good ingredient in children's formula too. Many studies confirm that the use of the modified flour of banana has an increasing use in the bakery industry due their high potassium and carbohydrate contents (Debabandya et al., 2010).

Table 13 presents the moisture content data for all the varieties evaluated in this study. As mentioned earlier, missing entries mean that the fruit passed too quickly through the particular stage and data could not be captured with the established sampling schedule.

Data in the table shows moisture content of 0.75 for the control at every stage of maturity. This constant moisture performance was also exhibited by FHIA-02 (0.69-0.74), PV 03-44 (0.68-0.70), PV 42-320 (0.70), PV 4253 (0.70-0.74), SH 3640 (0.74-0.75) and Yangambi (0.72-0.75). Other varieties exhibited a significant increase in moisture content as maturation progressed; particularly at the overripe stage.

At the green stage (1&2) significant differences were found between the control (0.75) and PA12-03 (0.68), PV 03-44 (0.68), PV 4281 (0.68) and TMB2x 9128-3 (0.70). The moisture content range for varieties similar to the control was 0.71 to 0.77. Data obtained fall on similar ranges than those reported by Madrigal et al. (2007) and Dadzie (1998). They reported moisture contents of 78.17% for FHIA-17, 79.83% for FHIA-23, 74.05% for Grand Naine and 76.21% for FHIA-02. Moisture content is of commercial importance for the processing industry. Bananas are used to produce flour and to incorporate into products such as soups, jam, jelly and bakery products (Debabandya et al., 2010).

The mature green stage (3&4) is the transition between green and the mature banana. As shown in the Table no data could be collected for the control at stage (3&4). Thus, no comparisons can be made between the control and other varieties. Yet, data shows that significant differences were found among some of the varieties. Moisture content at this stage ranged between 0.67 (PA 12-03) to 0.78 (FHIA-23).

At the mature stage (5&6), significant differences were found between the control and varieties FHIA-02 (0.69), PV 42-81 (0.69) and PV 42-53 (0.70). Moisture content at this stage for varieties similar to the control ranged between 0.70 (PV 42-320) to 0.80 (FHIA-23). At the overripe stage (7) moisture content for varieties similar to the control (0.75) ranged from 0.70 (PV 03-44) to 0.80 (FHIA-18). Significant differences were only with FHIA-23 has presented a moisture content of 0.83 higher than the control found between the control and the hybrids. Moisture content varies ranging from 0.02 to 0.05.

4.4.4 Pulp yield

The relation pulp/peel is a good indicator of maturation in banana since pulp to peel ratio increases with maturation. Piña et al. (2006) found that the increase in pulp/peel ratio is related to differences in sugar concentration between the two tissues. The greater concentration of sugars in the pulp compared to the peel leads to moisture transfer to the peel to the pulp. Stover and Simmonds (1987) explained such moisture transfer in terms of an osmotic pressure differential and reminds that the peel also losses water trough respiration.

Data in Table 14 show the pulp fraction (yield) of samples calculated as the relation between the weight of the pulp and the weight of the fruit. As mentioned earlier, missing entries mean that the fruit passed too quickly through the particular stage and data could not be captured with the established sampling schedule.

Table 14 Yield at the different ripening stages.

Variety	1-2	3-4	5-6	7
*Grand Nain	0.51_{a}^{ABCD}	------	0.60_{a}^{A}	0.62_{a}^{A}
FHIA-01	0.47_{a}^{ABC}	------	0.54_{b}^{A}	0.63_{c}^{A}
FHIA-02	0.54_{a}^{BCDE}	------	0.56_{a}^{A}	0.69_{b}^{AB}
FHIA-17	0.56_{a}^{CDE}	0.64_{b}^{BCD}	0.71_{bc}^{BC}	0.78_{c}^{AB}
FHIA-18	0.43_{a}^{A}	0.56_{ab}^{AB}	0.63_{bc}^{B}	0.73_{c}^{AB}
FHIA-23	0.59_{a}^{DE}	0.64_{a}^{BCD}	0.70_{b}^{BC}	0.77_{c}^{AB}
PA 03-22	------	0.65_{a}^{BCD}	------	0.74_{b}^{AB}
PA 12-03	0.44_{a}^{AB}	0.59_{b}^{ABC}	0.77_{c}^{C}	------
PV 03-44	0.53_{a}^{BCDE}	0.66_{ab}^{CD}	------	0.76_{b}^{AB}
PV 42-320	------	0.49_{a}^{A}	0.59_{b}^{A}	------
PV 42-53	0.53_{a}^{BCDE}	------	0.59_{b}^{A}	0.75_{c}^{AB}
PV 42-81	0.49_{a}^{ABC}	0.55_{ab}^{AB}	0.57_{bc}^{A}	0.65_{c}^{AB}
SH 3640	0.52_{a}^{ABCD}	0.53_{a}^{A}	0.62_{b}^{AB}	------
TMB2x 9128-3	0.49_{a}^{ABC}	0.51_{a}^{A}	0.62_{b}^{AB}	0.66_{b}^{AB}
Yangambi	0.61_{a}^{E}	0.70_{ab}^{D}	0.80_{b}^{C}	0.81_{b}^{B}

*Control Variety. ; --- No Data.
Values with the same superscript in the same column are not significantly different between varieties. Values with the same subscript in the same row are not significantly different between hedonic scales

At the green stage (1&2) significant differences were found between the control (0.51) and Yangambi (0.61). Yield ranged from 0.43 (FHIA-18) to 0.61 (Yangambi).

The mature green stage (3&4) is the transition between green and the mature banana. As shown in the Table no data could be collected for the control at stage (3&4). Thus, no comparisons can be made between the control and other varieties. Significant differences were found between varieties with yield values ranging between 0.49 (PV 42-320) and 0.70 Yangambi.

At the mature stage (5&6), significant differences were found between the control (0.60) and FHIA-17 (0.71), FHIA-18 (0.63), FHIA-23 (0.70), PA 12-03 (0.77) and Yangambi (0.80). For the varieties where no significant differences were found, yield values ranged between 0.54 (FHIA-01) and 0.62(SH 3640 and TMB2x 9128-3).

At the final stage of maturity (7), significant difference was found between the control (0.62) and Yangambi (0.81). For the rest of the varieties, yield values ranged between 0.63 (FHIA-01) and 0.78 (FHIA-23).

4.5 Mechanical properties

4.5.1 Impact

Fruit softening is a complex process that involves loosening of cell wall mediated by expansions and depolymerization by poligalacturonase or other hydrolytic enzymes (Brumell et al., 1996). This relates to changes in cell wall components and starch degradation. Starch granules packed into the flesh tissue of greens bananas account for the hardness. During storage, starch is hydrolyzed into sugars, increasing the permeability of cell walls in the peel. This allows for the pass (in or out) of water and nutrients. As starch degrades, pulp firmness decreases steadily during storage (Seymour, 1993). Saavedra et al. (2007) define impact as the collision of the fruit against solid surfaces or other fruits. This parameter is important in harvest, transportation and commercialization.

The mechanical damage is one of the most common causes of quality deterioration during harvest, storage, handling in fruits. Impact as defined as transitory movements caused by abrupt acceleration or deceleration causing the dissipation of energy and consequent damage to the fruit (Garcia et al., 1988). Effects of this damage are related loss of internal quality, flavor and nutritional value in limes (Durigan et al., 2005).

Table 15 Deformation (in mm) from an equivalent drop of 5 ft. (v= 6 m/s).

Variety	**1-2**	**3-4**	**5-6**	**7**	**Stage at peel breakage**
*Grand Nain	$2.77\,{}^{A}_{a}$	------	$5.62\,{}^{AB}_{a}$	$2.64\,{}^{A}_{a}$	5&6
FHIA-01	$2.27\,{}^{A}_{a}$	------	$5.12\,{}^{AB}_{b}$	------	5&6
FHIA-02	$0.95\,{}^{A}_{a}$	------	$13.34\,{}^{B}_{b}$	$11.52\,{}^{A}_{b}$	5&6
FHIA-17	$1.36\,{}^{A}_{a}$	$2.47\,{}^{A}_{ab}$	$5.47\,{}^{AB}_{c}$	$4.94\,{}^{A}_{bc}$	7
FHIA-18	$1.88\,{}^{A}_{a}$	$2.98\,{}^{A}_{a}$	$6.23\,{}^{AB}_{a}$	$14.17\,{}^{A}_{b}$	5&6
FHIA-23	$3.61\,{}^{A}_{a}$	$2.83\,{}^{A}_{a}$	$3.44\,{}^{A}_{a}$	$4.92\,{}^{A}_{a}$	7
PA 03-22	------	$1.58\,{}^{A}_{a}$	------	$9.73\,{}^{A}_{b}$	7
PA 12-03	$2.10\,{}^{A}_{a}$	$4.74.{}^{A}_{a}$	$7.44\,{}^{AB}_{a}$	------	5&6
PV 03-44	$2.02\,{}^{A}_{a}$	------	------	$7.56\,{}^{A}_{a}$	7
PV 42-320	$6.06\,{}^{A}_{a}$	$1.91\,{}^{A}_{a}$	$4.51\,{}^{AB}_{a}$	$6.16\,{}^{A}_{a}$	7
PV 42-53	$1.91\,{}^{A}_{a}$	------	$5.65\,{}^{AB}_{ab}$	$11.13\,{}^{A}_{b}$	7
PV 42-81	$1.76\,{}^{A}_{a}$	$2.33\,{}^{A}_{a}$	------	$6.08\,{}^{A}_{b}$	7
SH 3640	$1.39\,{}^{A}_{a}$	$3.70\,{}^{A}_{ab}$	$8.47\,{}^{AB}_{b}$	------	5&6
TMB2x 9128-3	$1.56\,{}^{A}_{a}$	$2.94\,{}^{A}_{a}$	$5.22\,{}^{AB}_{b}$	$8.61\,{}^{A}_{c}$	7
Yangambi	$1.66\,{}^{A}_{a}$	$2.34\,{}^{A}_{a}$	$5.39\,{}^{AB}_{a}$	$5.10\,{}^{A}_{a}$	7

*Control Variety. ; --- No Data.
Values with the same superscript in the same column are not significantly different between varieties. Values with the same subscript in the same row are not significantly different between hedonic scales

Candida et al. (2009) evaluated the visual and chemical quality of tangerines after mechanical damage. Tangerines were submitted to different degrees of impact by letting the fruit fall from 40, 60, 80 or 100-cm heights. Results showed that fruit injured by impact possibly have suffered rupture of the internal tissues, responsible of the exposition of the ascorbic acid to oxygen accelerating degradation.

Data in Tables 16, 17 and 18 show the average distance that fruits compressed when subjected to a force of 1.48N at a velocity of 6m/s, 8m/s and 10m/s, respectively. As mentioned earlier, missing entries mean that the fruit passed too quickly through the particular stage and data could not be captured with the established sampling schedule.

Tables 16, 17 and 18 include an additional column labeled "stage at peel breakage". It tells the maturity stage at which the peel broke while conducting the test.

Table 16 Deformation (in mm) from an equivalent drop of 10 ft. (v= 8 m/s).

Variety	1-2	3-4	5-6	7	Stage at peel breakage
*Grand Nain	3.08^{A}_{a}	------	6.88^{A}_{a}	2.53^{A}_{a}	5&6
FHIA-01	2.40^{A}_{a}	------	8.11^{A}_{a}	------	5&6
FHIA-02	0.99^{A}_{a}	------	13.90^{A}_{b}	10.88^{A}_{ab}	5&6
FHIA-17	1.52^{A}_{a}	2.57^{A}_{ab}	5.51^{A}_{c}	4.80^{A}_{bc}	7
FHIA-18	2.27^{A}_{a}	3.13^{A}_{a}	5.67^{A}_{a}	12.19^{A}_{b}	5&6
FHIA-23	3.25^{A}_{a}	2.68^{A}_{a}	3.35^{A}_{a}	4.67^{A}_{a}	7
PA 03-22	------	2.08^{A}_{a}	------	10.23^{A}_{b}	7
PA 12-03	1.45^{A}_{a}	3.49^{A}_{ab}	8.80^{A}_{b}	------	5&6
PV 03-44	1.81^{A}_{a}	------	------	7.63^{A}_{b}	7
PV 42-320	2.41^{A}_{a}	1.96^{A}_{a}	4.42^{A}_{ab}	6.23^{A}_{b}	7
PV 42-53	2.04^{A}_{a}	------	5.11^{A}_{ab}	7.83^{A}_{b}	7
PV 42-81	1.16^{A}_{a}	2.94^{A}_{b}	------	6.15^{A}_{c}	7
SH 3640	1.48^{A}_{a}	3.39^{A}_{ab}	8.48^{A}_{b}	------	5&6
TMB2x 9128-3	1.48^{A}_{a}	2.85^{A}_{a}	5.13^{A}_{a}	13.45^{A}_{b}	7
Yangambi	1.82^{A}_{a}	2.10^{A}_{a}	6.76^{A}_{a}	5.48^{A}_{a}	7

*Control Variety. ; --- No Data.
Values with the same superscript in the same column are not significantly different between varieties. Values with the same subscript in the same row are not significantly different between hedonic scales

An analysis of impact data showed that differences could be explains in terms of variety and maturity stage, but the effect of velocity was not significant (p> 0.05). A comparison of data between maturity stages for the control suggests that maturation does not influence the amount of compression resulting from impact at the different velocities. However, peel breakage does occur as stages 5&6 and on. Similar performance was only exhibited by FHIA-23 and Yangambi. For all other varieties compression distance increase as maturity progressed.

Table 17 Deformation (in mm) from an equivalent drop of 15 ft. (v= 10 m/s).

Variety	1-2	3-4	5-6	7	Stage at peel breakage
*Grand Nain	$2.36\,^{A}_{a}$	------	$5.48\,^{A}_{a}$	$2.17\,^{A}_{a}$	5&6
FHIA-01	$2.43\,^{A}_{a}$	------	$4.48\,^{A}_{b}$	------	5&6
FHIA-02	$1.16\,^{A}_{a}$	------	$6.02\,^{A}_{ab}$	$10.06\,^{A}_{b}$	5&6
FHIA-17	$1.57\,^{A}_{a}$	$2.48\,^{A}_{ab}$	$5.29\,^{A}_{c}$	$5.09\,^{A}_{bc}$	7
FHIA-18	$2.41\,^{A}_{a}$	$4.32\,^{A}_{a}$	$5.62\,^{A}_{a}$	$12.24\,^{A}_{a}$	5&6
FHIA-23	$4.79\,^{A}_{a}$	$2.89\,^{A}_{a}$	$3.66\,^{A}_{a}$	$4.88\,^{A}_{a}$	7
PA 03-22	------	$1.80\,^{A}_{a}$	------	$8.16\,^{B}_{b}$	7
PA 12-03	$1.98\,^{A}_{a}$	$2.87\,^{A}_{a}$	$7.61\,^{A}_{a}$	------	5&6
PV 03-44	$5.66\,^{A}_{a}$	------	------	$6.69\,^{A}_{a}$	7
PV 42-320	$1.82\,^{A}_{a}$	$2.26\,^{A}_{ab}$	$5.12\,^{A}_{bc}$	$5.68\,^{A}_{c}$	7
PV 42-53	$1.47\,^{A}_{a}$	------	$7.20\,^{A}_{a}$	$8.99\,^{A}_{a}$	7
PV 42-81	$1.25\,^{A}_{a}$	$3.42\,^{A}_{ab}$	------	$7.42\,^{A}_{b}$	7
SH 3640	$1.61\,^{A}_{a}$	$3.25\,^{A}_{ab}$	$5.84\,^{A}_{b}$	------	5&6
TMB2x 9128-3	$1.57\,^{A}_{a}$	$2.49\,^{A}_{a}$	$5.19\,^{A}_{b}$	$8.35\,^{A}_{c}$	7
Yangambi	$1.32\,^{A}_{a}$	$2.00\,^{A}_{a}$	$7.42\,^{A}_{a}$	$5.84\,^{A}_{a}$	7

*Control Variety. ; --- No Data.
Values with the same superscript in the same column are not significantly different between varieties. Values with the same subscript in the same row are not significantly different between hedonic scales

At the green stage (1&2), for all velocities (6m/s, 8m/s and 10m/s) no significant differences were found between the control and varieties in terms of average distance.

The mature green stage (3&4) is the transition between green and the mature banana. As shown in the Table no data could be collected for the control at stage (3&4). Since no data could be collected for the control, no comparisons can be made against it. However, a glance at the values obtained for the different hybrids suggest no significant differences among varieties for the difference velocities.

At the mature stage (5&6), no significant differences were found between the control and all the varieties for all the velocities (6m/s, 8m/s and 10m/s). The only significant difference was found between FHIA-02 (13.34) and FHIA-23 (3.44) at velocity 6m/s. Peel breakage started happening at this stage, independent of velocity, for the control, FHIA-01, FHIA-02,FHIA-18, PA 12-03 and SH 3640. Similarly, at the final stage of maturity (7), no significant differences were found between the control and all the varieties for all the velocities (6m/s, 8m/s and 10m/s).

Piña et al. (2006) reported penetration values at the mature stage for FHIA-17 (9.10 mm), FHIA-02 (8.61mm) and FHIA-23 (8.45 mm); giving them a classification of soft. They also observed a relation between the thickness of the peel and the amount of penetration in the fruit. The methodology used by Piña et al. (2006) differs from the one used in this study, but both evaluations measure the distance that the fruit yielded when subjected to a given force. It is interesting to note that the range of values obtained in this study is wider than the one reported by Piña et al. (2006). For example, at velocity 6 m/s, Table 10 reports values of 3.44 for FHIA-23, 5.47 for FHIA-17 and 13.34 for FHIA-02.

4.5.2 Stack

Stack damage is defined as the injuries caused by a specific pressure on the fruit or when the fruit is stored in containers or boxes and the pressure is produced by other fruits (Saavedra et al., 2007).

Saavedra et al. (2007) reported that weight loss on fruits that suffers mechanical damage (impact 15.19%; cutting 25.42%; scratching 22.97%; compression 12.82%) was higher compared to the fresh fruit (13.12%). Results showed that the bananas with mechanical damage had alterations in their normal skin color during ripening (dark color) this change negatively influences appearance fruit (Saavedra et al., 2007)

Table 18 Stack at the different maturation stages (Force=1.5kg)

Variety	1-2	3-4	5-6	7	Stage at peel breakage
*Grand Nain	1.69^{AB}_{a}	------	5.24^{A}_{a}	3.25^{A}_{a}	5&6
FHIA-01	5.60^{AB}_{b}	------	7.68^{AB}_{b}	------	5&6
FHIA-02	1.53^{AB}_{a}	------	19.81^{B}_{b}	9.61^{AB}_{a}	5&6
FHIA-17	1.69^{AB}_{a}	4.16^{A}_{ab}	5.51^{A}_{b}	6.86^{AB}_{b}	7
FHIA-18	2.90^{AB}_{a}	6.75^{A}_{ab}	11.06^{AB}_{bc}	15.05^{B}_{c}	5&6
FHIA-23	2.08^{AB}_{a}	4.89^{A}_{ab}	5.05^{A}_{ab}	8.52^{AB}_{b}	7
PA 03-22	------	2.62^{A}_{a}	------	11.46^{AB}_{b}	7
PA 12-03	2.07^{AB}_{a}	5.39^{A}_{a}	9.37^{AB}_{a}	------	5&6
PV 03-44	1.87^{AB}_{a}	------	------	8.84^{AB}_{b}	7
PV 42-320	6.06^{B}_{a}	1.83^{A}_{a}	5.50^{A}_{a}	11.99^{AB}_{b}	7
PV 42-53	1.19^{A}_{a}	------	10.57^{AB}_{b}	10.37^{AB}_{b}	5&6
PV 42-81	1.08^{A}_{a}	4.27^{A}_{a}	------	13.25^{AB}_{b}	7
SH 3640	1.72^{AB}_{a}	4.45^{A}_{ab}	7.19^{A}_{b}	------	5&6
TMB2x 9128-3	1.89^{AB}_{ab}	2.72^{A}_{a}	5.61^{A}_{ab}	9.06^{AB}_{b}	7
Yangambi	2.98^{AB}_{a}	4.06^{A}_{a}	9.28^{AB}_{a}	8.01^{AB}_{a}	5&6

*Control Variety. ; --- No Data.
Values with the same superscript in the same column are not significantly different between varieties. Values with the same subscript in the same row are not significantly different between hedonic scales

Data in Tables 18, 19 and 20 show the average distance that fruits compressed at the speed of 1mm/s and forces of 1.5Kg, 3.0Kg and 4.5Kg, respectively. As mentioned earlier, missing entries mean that the fruit passed too quickly trough the particular stage and data could not be captured with the established sampling schedule. Tables 16, 17 and 18 include an additional column labeled “stage at peel breakage”. It tells the maturity stage at which the peel broke while conducting the test.

A comparison on data on Tables 18, 19 and 20 shows that differences in compression distance from stacking were due variety, maturation stage and compression force ($p<0.05$). Evidence of this can be seen when comparing information presenting in the column labeled stage at peel breakage, as well as comparing values for a given varieties in the Tables 16, 17 and 18. In general terms, hybrids were more able to withstand compression forces of 1.5Kg than forces of 3.0Kg or 4.5Kg ($p<0.05$).

Table 19 Stack at the different maturation stages (Force=3.0kg)

Variety	1-2	3-4	5-6	7	Stage at peel breakage
*Grand Nain	5.51^{AB}_{a}	------	13.19^{A}_{a}	4.99^{A}_{a}	5&6
FHIA-01	12.39^{B}_{a}	------	20.66^{A}_{a}	------	5&6
FHIA-02	2.23^{A}_{a}	------	19.07^{A}_{b}	12.86^{AB}_{b}	5&6
FHIA-17	3.18^{A}_{a}	11.09^{A}_{a}	12.38^{A}_{a}	11.14^{AB}_{a}	7
FHIA-18	4.90^{AB}_{a}	9.12^{A}_{ab}	16.67^{A}_{b}	13.74^{AB}_{b}	5&6
FHIA-23	5.46^{AB}_{a}	8.63^{A}_{a}	9.82^{A}_{a}	12.59^{AB}_{a}	7
PA 03-22	------	3.92^{A}_{a}	------	18.73^{B}_{b}	7
PA 12-03	3.11^{A}_{a}	16.34^{A}_{b}	9.25^{A}_{ab}	------	3&4
PV 03-44	3.64^{A}_{a}	------	------	18.95^{B}_{b}	7
PV 42-320	2.41^{A}_{a}	3.25^{A}_{a}	9.78^{A}_{ab}	12.45^{AB}_{b}	7
PV 42-53	2.71^{A}_{a}	------	13.80^{A}_{b}	12.71^{AB}_{b}	5&6
PV 42-81	2.24^{A}_{a}	9.75^{A}_{b}	------	13.88^{AB}_{b}	7
SH 3640	2.78^{A}_{a}	10.79^{A}_{ab}	17.86^{A}_{b}	------	5&6
TMB2x 9128-3	3.08^{A}_{a}	6.00^{A}_{ab}	12.45^{A}_{b}	12.14^{AB}_{ab}	5&6
Yangambi	6.04^{AB}_{a}	14.41^{A}_{a}	15.69^{A}_{a}	11.04^{AB}_{a}	3&4

*Control Variety. ; --- No Data.
Values with the same superscript in the same column are not significantly different between varieties. Values with the same subscript in the same row are not significantly different between hedonic scales

In terms of peel breakage, for the control, it happened at stage 5&6 regardless of the applied force. In contrast, for TMB2x 9128-3 peel breakage occurs at stage 7 under 1.5Kg force and at stage 5&6 under 3.0Kg or 4.5Kg. For varieties PA 12-03 and Yangambi peel breakage started to showed up at stage 3&4 under 3.0Kg force.

For most varieties, at the various stack forces, compression distance increased with maturation. This implies that, as maturation progresses, the fruit is less able to withstand compression forces such as the ones associated with stacking of fruits one on top of the other. Unlike most varieties, the control showed no significant differences on compression distance with maturation at any of the compression forces considered in this study. The only hybrid exhibiting similar performance was Yangambi.

Table 20 Stack at the different maturation stages (Force=4.5kg)

Variety	1-2	3-4	5-6	7	Stage at peel breakage
*Grand Nain	6.53^{AB}_{a}	------	13.98^{AB}_{a}	3.70^{A}_{a}	5&6
FHIA-01	11.27^{B}_{a}	------	24.85^{B}_{b}	------	5&6
FHIA-02	3.79^{AB}_{a}	------	15.87^{AB}_{b}	14.06^{AB}_{b}	5&6
FHIA-17	3.73^{AB}_{a}	13.01^{A}_{ab}	16.30^{AB}_{b}	13.73^{AB}_{ab}	7
FHIA-18	8.39^{AB}_{a}	10.74^{A}_{a}	14.57^{AB}_{a}	15.77^{AB}_{a}	3&4
FHIA-23	4.85^{AB}_{a}	9.82^{A}_{ab}	12.86^{AB}_{ab}	16.04^{AB}_{b}	5&6
PA 03-22	------	7.19^{A}_{a}	------	19.83^{B}_{b}	3&4
PA 12-03	1.96^{AB}_{a}	15.03^{A}_{ab}	21.12^{AB}_{b}	------	3&4
PV 03-44	5.02^{AB}_{a}	------	------	23.91^{B}_{b}	7
PV 42-320	1.82^{A}_{a}	4.70^{A}_{a}	9.13^{A}_{ab}	14.47^{AB}_{b}	5&6
PV 42-53	4.25^{AB}_{a}	------	14.09^{AB}_{b}	12.34^{AB}_{b}	5&6
PV 42-81	3.70^{AB}_{a}	10.19^{A}_{ab}	------	13.60^{AB}_{ab}	3&4
SH 3640	3.82^{AB}_{a}	17.15^{A}_{b}	12.37^{AB}_{ab}	------	3&4
TMB2x 9128-3	4.09^{AB}_{a}	7.88^{A}_{a}	11.68^{AB}_{a}	11.87^{AB}_{a}	5&6
Yangambi	9.01^{AB}_{a}	13.69^{A}_{a}	17.05^{AB}_{a}	15.38^{AB}_{a}	3&4

*Control Variety. ; --- No Data.
Values with the same superscript in the same column are not significantly different between varieties.
Values with the same subscript in the same row are not significantly different between hedonic scales

At the green stage (1&2), no significant differences were found between the control and varieties for all the forces (1.5Kg, 3.0Kg and 4.5Kg). Compression distances ranged from 1.08 to 6.06 at 1.5Kg, 2.23 to 12.39 at 3.0Kg and 1.82 to 11.27 at 4.5 Kg.

The mature green stage (3&4) is the transition between green and the mature banana. As shown in the Table no data could be collected for the control at stage (3&4). Since no data could be collected for the control, no comparisons can be made against it. However, a glance at the values obtained for the different hybrids suggest no significant differences among varieties for the different forces.

Results for stage (5&6) varied according to compression force. At 1.5Kg, significant difference was found between the control (5.24) and FHIA-02 (19.81). At forces 3.0Kg and 4.5Kg, no significant differences were found among varieties (ranges 9.25 to 20.66 and 9.13 to 24.85, respectively).

At the overripe stage 7, results also varied according to compression force. At 1.5 Kg, significant difference was found between the control (3.25) and FHIA-18 (15.05). At 3.0Kg, significant difference was found between the control (4.99) and PA 03-22 (18.73) as well as PV 03-44 (18.95). At 4.5Kg, significance difference was found between the control (3.70) and PV 03-44 (23.91). At this stage compression distances for the control fell on the lower end of the range.

5 CONCLUSIONS

Samples of 14 banana hybrids were collected, analyzed and compared to the Grand Naine (Control). Test included several chemical and physical evaluations to characterize their fresh and processing characteristics. A summary of the gathered results is presented in Tables 20 to 22 in Appendix 3 for the green, mature and overripe stage, respectively.

The first line of each Table presents the value obtained for the Control, on every test considered in the study, at the given maturity stage. For other varieties entries are “=”, “+” or “-“ depending on whether the particular variety yielded results the where not significantly different, greater or lower than the control, respectively. Entries “ND” mean that the value is missing.

Table 20 presents the data summary for the green stage. At this stage, the best performance was obtained from TMB2x 9128-3. This variety outperforms the Control in terms of storage time, TSS and resistance to mechanical damage. Yet, this variety has a considerably smaller diameter than the Control; which significantly affected pulp yield.

Other good performers at this maturity stage include FHIA-23, PV 03-44, PV 42-81 and PV 42-53. FHIA-23 lasted significantly longer than the Control and withstood better the mechanical damage, but had higher weight losses. PV 03-44 and PV 42-81 have similar quality characteristics to the Control, but have higher resistance to mechanical damage. On the other hand, they also have higher weight losses when compared to the Control. PV 42-53 has higher performance in terms of storage time, TSS and impact. For all the other tests, this variety showed similar performance to the Control.

Table 21 presents the data summary for the mature stage. At this stage, the best performance in storage time was presented from FHIA-17 and SH 3640 compared to the Control. FHIA-17 shows an interesting performance in terms of cut strength, yield, and resistance to a mechanical damage. SH 3640 presents lower values in pH, weight loss values and cut strength, but similar values in mechanical damage compared to the Control. At this stage TMB2x 9128-3 presented higher values in TSS and mechanical damage compared to the Control, in the rest of the tests this variety presented the same performance than the Control.

Table 22, presents the data summary for the overripe stage. At this stage the best performance was exhibited for PA 03-22, FHIA-02 and PV 42-81 in terms of storage time with higher values compared to the control. PA 03-22 also presented best performance in terms of TSS and mechanical damage, but lower values in pH, weight loss and cut strength. FHIA-02 present lower performances in terms of pH and cut strength compared to the control. PV 42-81, also presents high performance in pH and mechanical damage. FHIA-17 presents lower values in terms of pH and weight loss, but high performance in mechanical damage. PV 42-53 presents lower values compared to the Control in pH, weight loss, cut strength, and high values on the impact test.

In summary, no single variety showed characteristics comparable to the Control (Grand Naine) over all maturity stages. Varieties like PV 42-53 and PV 42-81 appear to be good candidates, but their mature stage (5&6) is too short. An alternative to a single replacement of the Control would be to select specific varieties for maturity stages. Under this scheme, a potential replacement for the Control at the green stage could be FHIA-23, while SH 3640 and FHIA-17 could work for the mature stage. Varieties worth noting for the mature stage are FHIA-23 and FHIA-18 because of their attractive appearance as ripe bananas.

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APPENDIX 1: AUTHOR'S OBSERVATIONS ON HYBRIDS

Varieties that exhibited good performance at the green stage (1&2):

- Varieties FHIA -17 and FHIA-01, showed similar performance in terms of storage time, ºbrix, pH, cut and resistance to mechanical damage. Both varieties also presented higher values in moisture content in comparison to the control. In terms of appearance, FHIA-01 at this stage exhibited black spots (normal, not fungus related) and FHIA-17 presented a yellower pulp (similar to plantain).
- FHIA-18 showed a good performance in comparison to the control in terms of storage time, ºbrix, pH, moisture content and resistance to mechanical damage, but higher values in respiration rates making their transition from green stage (1&2) to mature stage (3&4) short in comparison to the other varieties.
- PV 42-320, appears to be a good candidate to replace the control variety, but due the sampling schedule, data could not be collected for moisture absorption, fat absorption and moisture content.
- Yangambi presented similar behavior compared to the control and exhibited high resistance to mechanical damage. In appearance, however, this variety is considerably smaller than the control. It also had the highest performance in the yield test due its thin peel.
- PV 03-44, in terms of appearance, presented black spots. This variety also presented a marked angularity (as opposed to the typical rounded circumference of the fruit).

- PV 42-81 has a small size compared to the control, thus, it is not a suitable replacement for the control.

Varieties that exhibited good performance at the mature stage (5&6):

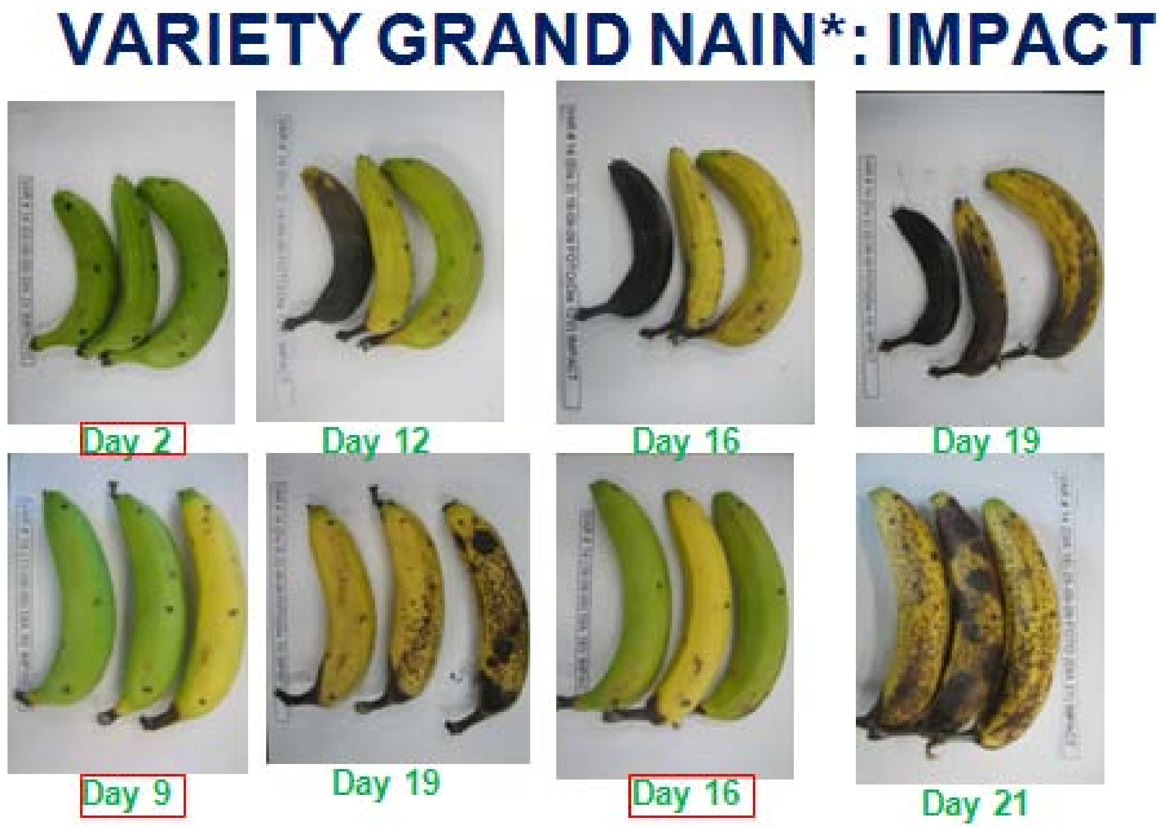
- PV 42-320, in terms of the physicochemical characteristics, had better performance than the control. In terms of appearance at this stage, dark spots started to appear as a consequence of the accelerated maturation process.
- SH 36-40, presented signs of (microbiological) deterioration at the peduncle, including black spots.
- TMB2x 9128-3 fruit do not ripen uniformly, this is, fruits have marked different sizes and, at this stage, some fruits appear to be in the green stage (1&2) and others at overripe stage (7).
- FHIA-17 presented an interesting performance in terms of storage time. Most of the other parameters evaluated in this study compared similarly to the control. In terms of appearance, however, darks spots appeared in the fruit at this stage.

Varieties that exhibited good performance at the overripe stage (7):

- PA 03-22 exhibited the best behavior at this stage in terms of physicochemical properties. In terms of appearance, this variety presented blacks spots in most the surface (indicator of fungi attack on the fruits). This fruit is also small compared to the control and, at the green stage, presents a series of cuts on the peel that could help to accelerate their maturation and deterioration.
- PV 03-44 presented random black spots in different areas on the surface that began at the green stage (1&2).

- PV 42-53, at his stage, presented big black spots on the ends of the fruit that began to appear at green mature stage (3&4).

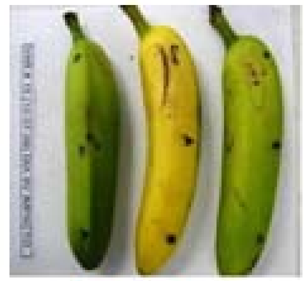
APPENDIX 2: MECHANICAL DAMAGE IMPACT: EFFECT DURING STORAGE.



VARIETY FHIA-02**: IMPACT

Day 2

Day 12



Day 9

Day 19

Day 16

Day 23

VARIEDAD FHIA 23*: IMPACT

Day 2 | Day 12 | Day 21 | Day 30 | Day 40

Day 9 | Day 19 | Day 28 | Day 37

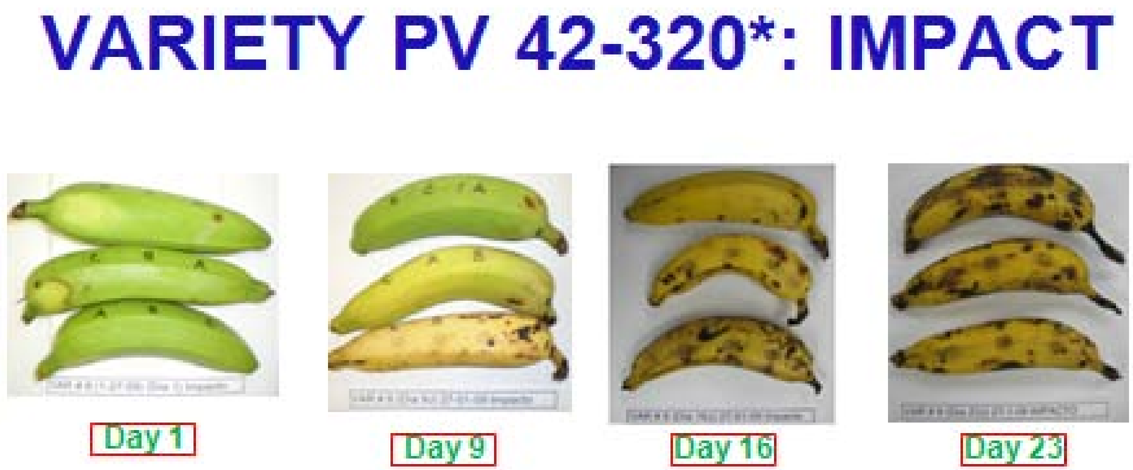


Figure 9 Pictures of impact assessment and the effect in the fruit during maturation.

APPENDIX 3: COMPARATIVES SUMARY TABLES

Table 21 Comparative summary at green stage (1&2).

Variety	Green (1&2)											
Test	Storage time	Brix	pH	Weight Loss	Cut Strength	Fat absorption	Moisture Absorption	Moisture content	Yield	Impact	Stack	Respiration
**Grand Nain	4 to 7	5.35	6.03	16.62	429.15	5.33	31.51	75	0.51	5&6	5&6	36.54
FHIA-01	=	=	=	-	=	=	=	+	=	=	=	=
FHIA-02	=	=	=	-	-	=	=	=	=	=	=	=
FHIA-17	=	=	=	-	=	=	=	+	=	+	+	=
FHIA-18	=	=	+	-	-	=	=	+	=	=	=	+
FHIA-23	+	=	=	-	=	=	=	=	=	+	+	=
PA 03-22	-	ND	ND	ND	ND	ND	ND	ND	ND	+	+	=
PA 12-03	=	=	=	-	=	=	=	-	=	=	=	=
PV 03-44	=	=	=	-	=	=	=	-	=	+	+	=
PV 42-320	+	+	=	-	=	ND	ND	ND	=	+	+	=
PV 42-53	+	+	=	-	=	=	=	=	=	+	=	=
PV 42-81	=	=	=	-	=	=	=	-	=	+	+	=
SH 3640	=	=	=	-	=	=	=	=	=	=	=	=
TMB2x 9128-3	+	+	=	-	=	=	=	-	=	+	+	+
Yangambi	=	=	=	-	=	=	=	=	+	+	=	=
"+" = higher values; "-" = lower values; "=" no significant difference ;ND = No Data.												

Table 22 Comparative summary at mature stage (5&6).

Variety	Mature (5&6)										
Test	Storage time	Brix	pH	Weight Loss	Cut Strength	Fat absorption	Moisture Absorption	Moisture content	Yield	Impact	Stack	Respiration
**Grand Nain	4 to 7	15.28	5.51	27.31	298.96	12.18	38.53	75	0.6	5&6	5&6	50.8
FHIA-01	-	=	-	-	-	=	=	-	=	=	=	=
FHIA-02	=	=	-	+	=	=	=	=	=	=	=	=
FHIA-17	+	=	=	=	-	=	=	=	-	+	+	=
FHIA-18	=	=	-	-	-	=	=	=	-	=	=	=
FHIA-23	=	=	=	-	-	=	=	=	-	+	+	=
PA 03-22	-	ND	ND	ND	ND	ND	ND	ND	ND	+	+	=
PA 12-03	=	=	=	-	=	=	=	=	-	=	=	=
PV 03-44	-	ND	ND	ND	ND	ND	ND	ND	ND	+	+	=
PV 42-320	=	=	-	-	-	=	=	=	=	+	+	=
PV 42-53	-	=	-	ND	ND	=	=	-	=	+	=	=
PV 42-81	-	ND	ND	ND	-	=	=	-	=	+	+	=
SH 3640	+	=	-	-	-	=	=	=	=	=	=	=
TMB2x 9128-3	=	+	=	-	-	=	=	=	=	+	+	+
Yangambi	=	=	=	-	-	=	=	=	+	+	=	=

"+" = higher values; "-" = lower values; "=" no significant difference ;ND = No Data.

Table 23 Comparative summary at overripe stage (7)**.**

Variety	Overripe (7)											
Test	Storage time	Brix	pH	Weight Loss	Cut Stregth	Fat absorption	Moisture Absorption	Moisture content	Yield	Impact	Stack	Respiration
**Grand Nain	4 to 7	16.25	5.66	38.29	123.87	30.91	61.25	75	0.62	5&6	5&6	154.48
FHIA-01	-	=	-	-	-	=	=	=	=	=	=	=
FHIA-02	+	=	-	=	-	=	=	=	=	=	=	=
FHIA-17	=	=	-	-	=	=	=	=	=	+	+	=
FHIA-18	=	=	-	-	-	=	=	=	=	=	=	=
FHIA-23	=	=	-	-	=	=	=	-	=	+	+	=
PA 03-22	+	+	-	-	-	=	=	=	=	+	+	=
PA 12-03	-	=	-	-	-	ND	ND	ND	ND	=	=	=
PV 03-44	-	+	-	-	-	=	ND	=	=	+	+	=
PV 42-320	-	+	-	-	=	ND	ND	ND	=	+	+	=
PV 42-53	=	=	-	-	-	=	=	=	=	+	=	=
PV 42-81	+	+	-	-	=	=	=	=	=	+	+	=
SH 3640	-	=	-	-	=	ND	ND	ND	ND	=	=	=
TMB2x 9128-3	-	+	-	+	-	=	=	=	=	+	+	=
Yangambi	=	=	-	-	-	=	=	=	-	+	=	=
"+" = higher values; "-" = lower values; "=" no significant difference ;ND = No Data.												