PLANTAIN HYBRIDS: FRESH MARKET AND PROCESSING CHARACTERISTICS

By

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ABSTRACT

In 2004, the presence of a fungus known as *Mycosphaerella fijiensis* that causes the disease Black Sigatoka, was detected on plantain leaves in Puerto Rico. This situation motivated this study on the potential use of Black Sigatoka-resistant hybrids in Puerto Rico. To achieve this characterization, chemical tests were performed, including pH and °Brix determination. Additional tests were conducted to determine resistance to mechanical damage, storage time, yield, pulp and peel color change, force needed for cutting and peeling, and processing properties. Results were analyzed using ANOVA (P = 0.05) and means compared with the Tukey test. Performance of plantain hybrids varied with maturity stage. At the green stage, best performances were exhibited by PITA 16, CRBP 39 and PV 42-81. At the mature stage, best performances were observed in SH 3640, PITA 16 and PV 42-320. At the overripe stage, hybrids that outperformed the Control were CRBP 39, PV 42-81 and FHIA-21. In conclusion, PITA 16 and CRBP 39 were the two varieties that exhibited quality characteristics similar or superior to the Control (Maricongo) in more than one maturity stage.

RESUMEN

En el año 2004, se detectó en Puerto Rico la presencia de un hongo conocido como *Mycosphaerella fijiensis* causante de la enfermedad Sigatoka Negra, que afecta las hojas de plátanos. Esta situación motivó este estudio para determinar el uso potencial de híbridos resistentes a la Sigatoka Negra en Puerto Rico. Para lograr la caracterización se realizaron pruebas químicas, incluyendo determinación de pH y ºBrix. Pruebas adicionales se realizaron para determinar la resistencia a daño mecánico, tiempo de almacenamiento, rendimiento, cambio en el color de pulpa y cáscara, fuerza para corte y pelado y propiedades de procesamiento. Los resultados se analizaron utilizando ANOVA (P=0.05), y usando la prueba de Tukey para el análisis de las medias. El desempeño de los híbridos de plátano varió de acuerdo al nivel de maduración. En estado verde, el mejor desempeño fue observado en PITA 16, CRBP 39 y PV 42-81. En estado maduro, las variedades SH 3640, PITA 16 y PV 42-320, fueron las que mejor desempeño tuvieron. En estado sobre maduro, los híbridos que superaron al Control fueron CRBP 39, PV 42-81 y FHIA-21. En conclusión, PITA 16 y CRBP 39 fueron las dos variedades que exhibieron características de calidad similares o superiores al Control (Maricongo) en más de un estado de maduración.

DEDICATION

To God,

Who strengthens me.

To my angel,

Carolina Isabel.

To my family.

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I thank God for being present in my life and always giving me the strength to go forward.

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1. INTRODUCTION

Plantain (*Musa* species) is one of the most important cash crops in Puerto Rico's agricultural economy (Cortés-Perez and Gayol, 2005). This fruit is easy to propagate and cultivate. In addition, it has important nutritional properties, such as high level of potassium and carbohydrates. It is low in fat and a good source of fiber, vitamins C, B6 and A (Pérez, 2009). The plantain tree is a tall plant grown in tropical regions, like Puerto Rico. Around the world, plantain is one of the most important crops, as it occupies the fourth place in consumption after rice, wheat and corn (Comisión Veracruzana de Comercialización Agropecuaria, 2005). Plantains form part of the Puerto Rican heritage and their production generates a source of income and employment for the island. For the fiscal year 2008-2009, the report of *Value Distribution of Agricultural Production in Order of Economic Importance of the First Ten Enterprises*, plantain ranked second place and generated $76,917 thousand dollars to the agricultural production in Puerto Rico (Puerto Rico Department of Agriculture, 2009).

In 2004, the presence of fungus *Mycosphaerella fijiensis* was detected in western Puerto Rico (Añasco), (Alvarado-Ortiz, 2005). This microorganism causes a disease called Black Sigatoka that affects the plant leaves. It is an aggressive and destructive pathogen, leading to yield loss, thus impacting Puerto Rico's agricultural economy. The disease can be controlled by the applications of fungicides, but the high cost of such pesticide acquisition and application is not feasible for the industry. An alternative solution is the production of hybrids resistant to this devastating disease, thus guaranteeing the supply of the fruit to the market.

In 2008, the USDA's Tropical Agricultural Research Station (TARS) initiated a study to evaluate the agronomic characteristics of Black Sigatoka resistant hybrids. The study included internationally available hybrids as well as the locally available “Maricongo” variety. Yet, a complete assessment of the hybrids’ potential requires an evaluation of the fruit’s characteristics for fresh market and processing characteristics.

1.1 Objectives

1.1.2 Primary Objectives

Determine the potential use of the Black Sigatoka resistant hybrids by evaluating their fresh market and processing characteristics.

1.1.3 Secondary objectives

1. To evaluate their chemical properties, including pH and soluble solids content.
2. To characterize the physiological maturation process during storage; changes in pulp and peel color, yield, peeling and cutting force.
3. To evaluate processing properties (specifically fat and moisture absorption).
4. To evaluate mechanical damages (stack and impact).

2. LITERATURE REVIEW

2.1 Plantain

Plantain (**Table 1**) production in Puerto Rico has been extensively investigated (Rivera-Aveillez, 1984). The crop can grow in acid soils, with a low fertility and inclined soils. To ensure a good harvest, soil type, plant variety, planting season and fertilization practices must be considered. Optimum production conditions include deep soils with good drainage, with pH ranging from 4.5 to 7 and rich in potassium.

Table 1: Taxonomic classification of plantain

Class:	Monocotyledonous
Order:	Escitaminales (6 familias)
Family:	Musaceas (3 subfamilias)
Subfamily:	Musoideae
Genera:	Musa (5 regiones)

Source: Nieves-Silva, 2007

With respect to planting season, plantains require warm climates (average temperature of 26 to 27°C). According to Quiñones (2007), "growth stops at temperatures below 18°C and damage occurs at temperatures below 13°C and above 45°C". Planting season affects the production, fruit size and consequently farmer income. According with Rivera-Aveillez (1984), to standardize production, "it is recommended to plant during the first two weeks of January, July, September, November and December". Commercially available varieties ("Maricongo", "Enano común" and "Harton") in Puerto Rico are of the horn ("Cuerno") type. These are the varieties recommended by the Agricultural Extension Service (Rivera-Aveillez, 1984) to cultivate in Puerto Rico. Currently, the "Maricongo" variety accounts for about 90% of the plantain production in the island while the “Enano común” and “Harton” represent the remaining 10%.

2.2 Diseases

Plantain has achieved excellent acceptance by Puerto Rican consumers. Thus, diseases that affect fruit availability can greatly impact the economy as well as consumer expectations. Following is a brief description of some of the most important diseases found today.

- Yellow sigatoka (*Mycosphaerella musicola*) - This disease, which can appear any time of the year, can be found in most plantain growing areas. The sources of infection are water and wind; conidia cause the infection through water, and Ascospores causes the infection through wind. Ascospores produce spots in plantain leaves, and can be dispersed by the wind and infect new plantations (Alvarado-Ortiz, 2005).
- Black sigatoka (*Mycosphaerella fijiensis*) - This disease can affect the plantain leaf. The main sources of infection are plantations with poor management practices. Like in yellow sigatoka, Ascospores are the primary source of infection. Conidia is also associated with this infection and for this reason it is extremely important to take high relative humidity under consideration (Alvarado-Ortiz, 2005).
- Cordana leaf spot (*Cordana musae*) – This infection is common in plantations in humid areas. The infections occur in the margins and large portion of plantain leaves (Alvarado-Ortiz, 2005). This pathogen infects wounded and weakened tissue and it is caused by poor management and operation practices of plantations.
- Cigar-end rot – This disease tends to infect dwarf plantain (“plátano enano”) and affects fruit quality. Symptoms include necrosis and early maturity. (Alvarado-Ortiz, 2005).

- Banana streak virus (BSV) – This is the most common disease that occurs in fruits under storage or fruits growing in low temperature conditions. Symptoms include the presence of yellow striate and diamond-shaped lines along the leaves. There appears a darker color on infected tissues, colors such as dark brown or black (Alvarado-Ortiz, 2005).

2.3 Characteristics

Plantains are considered an important agricultural crop in the world (Comisión Veracruzana de Comercialización Agropecuaria, 2005). The Agricultural Experiment Station of the University of Puerto Rico recommends the production of the Maricongo variety, in Puerto Rico. This is an interspecific cross between clones of “Guayamero” and “Dominico-Harton” (AAB). These hybrids produce a good number of fruits per cluster and fruit size is acceptable by consumers, (Nieves-Silva, 2007). Plantains are considered giant plants that can grow approximately 10 to 17 feet tall, depending on the variety. Plantain plants have very large leaves; the stem is a rhizome, starchy and underground. Each group of flowers forms a cluster of fruits called hand or "mano” that contain 3 to 20 fruits, depending on the variety. Fruits are oblong and fruit size varies between varieties. During fruit development, plants bend due to their weight; determining the shape of the bunch. Plantains are polymorphic and may contain from 5 to 20 hands each with 3 to 20 fruits of greenish yellow, yellow, yellow-red or red color. The edible part of the plantain is the pulp. Commercial quality plantains should be green when unripe, whole, firm, free from rotting or deterioration, clean (not visible damage), exempt from pests, free from peel damage, without folds or fungal attacks, free from malformation, exempt of chill injury and free from abnormal external moisture (Infoagro, 2009).

2.4 Quality

Plantains and bananas belong to the family of musaceas, but have different nutritional characteristics (**Table 2**). Although they look like green bananas, and indeed are close relatives, plantains are starchy rather than sweet, thus, considered as vegetables by consumers. Plantains, on average, are 65% moisture content and bananas are 83%. Bananas are typically consumed raw (uncooked), while the green and yellow plantains are usually processed by either boiling, frying or baking. Another difference is the size; plantains are usually larger than bananas. The banana peel is thin compared to plantains, which makes banana easier to peel. Another characteristic used to differentiate bananas and plantains is their color. Both exhibit green peel in unripe stage, but as fruits ripen, they turn different shades of yellow (Grab, 2006).

Shelf life is the time period where the fruit has a specific quality under specific conditions of storage. During this storage period, plantains present chemical and physical changes which contribute to the quality of the fruit and acceptance by consumer. Color of the plantain's pulp and peel are very important factors that influence consumer's acceptance and quality determination. Plantain color and physical damage can be a signal of a possible contamination, deterioration or maturity, (Dadzie and Orchard, 1997). In almost every plantain, pulp color is light yellow when it is not mature at all. During the storage period, the pulp shows a change of color from light yellow to yellow or orange-yellow. Changes in pulp color and peel color help to determine the physiological maturity of plantains. Changes in weight arise simultaneously with other visual changes in the fruit, such as, reduction in size, change in shape, volume, and peel color (Dadzie and Orchard, 1997). Extrinsic factors, such as temperature, humidity and age at harvest, can significantly affect fruit characteristics.

Table 2: Nutritional value of plantains without peel

Component (wet basis)		Quiñonez, 2007 (per 100 g of plantain without peel)
Water (%)		75.7
Proteins (%)		1.1
Lipids (%)		0.2
Carbohydrates	Total (%)	22.2
	Fiber (%)	0.6
Vitamins (per 100g)	A (IU)	190
	B1 (mg)	0.05
	B2 (mg)	0.06
	B6 (mg)	0.32
	Nicotinic acid (mg)	0.6
	Panthotenic acid (mg)	0.2
	C (mg)	10
Other organic components (per 100g)	Malic acid (mg)	500
	Citric acid (mg)	150
Minerals (per 100g)	Oxalic acid(mg)	6.4
	Sodium (mg)	1
	Potassium (mg)	420
	Calcium (mg)	8
	Magnesium (mg)	31
	Manganese (mg)	0.64
	Iron (mg)	0.7
	Copper (mg)	0.2
	Phosphorous (mg)	28
	Sulfur (mg)	12
	Chlorine (mg)	125
Calories (kcal per 100g)		85

Characterization of plantains enables knowledge of the internal quality of fruit, helps to minimize losses, and supports fruit quality improvement and innovation of new products. From studies in Africa, maturing plantains tend to exhibit a reduction of carbohydrates and sugars, an increase in the pulp/peel relationship and a reduction in fruit weight (Arcila et al., 2002).

The peel has more fiber than the pulp, but investigations have not observed an increase in concentration of fiber in whole plantain as it matured. The pulp tends to have more starch while unripe (green) and peels have high starch content in green and mature plantains (Arcila et al., 2002). Starch is transformed as it matures and its degradation is higher in pulp than in the peel. The starch content in both parts (peel and pulp) is inversely proportional to the content of total sugars.

In varieties such as Dominican-Harton, decreases in fresh weight of fruits during ripening have been observed influenced by factors such as, climate, location and state of maturation. In terms of total soluble solids or °Brix, it was determined that sugar is the major component of the total soluble solids. Degrees Brix is used as a criteria for establishing standards of maturity of some fruits and eating quality, and is often better related with total soluble solids (TSS) (Arcila et al., 2002). The most important change associated with fruit ripening is the degradation of starch into glucose that affects the texture and flavor of the fruit. The amount of sugar increases as plantains mature. Mechanical damage is one of the main problems found in plantains during storage. Mechanical damage may affect consumer acceptance and increase susceptibility to infection by various diseases caused by fungus or molds. It affects physical appearance of the plantain by producing black and soft areas. This particular situation occurs when plantains suffer physical abuse or are placed under pressure. Resistance to mechanical damage of plantains depends on the variety (Medicott, 2009).

Díaz et al. (1999) compared four plantain varieties including Dominico-Harton, Bouroukou, Bluggoe and FHIA 21. These researchers investigated the change in moisture and fat absorption of these four varieties during the frying process at different temperatures. At all three temperatures, moisture content decreased as the fat absorption increased. For example, average moisture contents over all varieties were 96g kg $^{-1}$ (wb) at 145°C, 47.6 g kg $^{-1}$ (wb) at 165°C and 11.9 g kg $^{-1}$ (wb) at 185°C. In terms of variations by variety, the order was: Bluggoe, FHIA 21, Dominico-Harton and Bouroukou in descending order of fat absorption values. This was true for all the temperatures and processing times considered.

2.5 Market Potential

Puerto Rico's plantain industry fully supports the demand of fresh plantain in the island (Cortés-Pérez, 2004). The quality of fresh plantains is based in their green color and size. These are the main characteristics consumers seek. In Puerto Rico, plantains are used for the preparation of typical dishes including "mofongo", "tostones", "piñon", "pastelón de plátano maduro" and "plátano hervido".

The plantain is a fruit with high processing potential. In Puerto Rico, the majority of plantain-containing dishes use the fresh fruit. Modern consumer trends, however, call for the availability of processed convenience products. In Puerto Rico, these products have been imported from foreign countries (Cortés-Pérez, 2004). One of many established product currently manufactured in Puerto Rico are the plantain chip (**Figure 1**). The economy of Puerto Rico supports this production informally.

Figure 1: Plantain chips or "platanutres"

Plantain chips are crunchy snacks locally known as ¨platanutres¨. This product is prepared by peeling the plantain, then cutting it in thin slices and frying in hot oil until it becomes golden in color. The thin slices must be drained to eliminate excess oil (ITDG, 2008). Seasonings and spices can be added to provide different flavors; the most common are salt and garlic.

3. Materials and Methods

3.1 Sample Collection and Preparation

In this experiment we studied seven hybrids (SH 3640, PITA 16, CRBP 39, PV 42-320, PV 42-81, FHIA-01 and FHIA-21) and one Control (Maricongo). The experiment was conducted at the facilities of the Food Science and Technology Program and the Agro-Industrial Innovation and Technology Center of the University of Puerto Rico, Mayagüez Campus. Fruits were harvested at the Isabela facilities of the USDA-TARS on Mondays, Wednesdays and Fridays as they became available. Each variety was tested in two blocks namely, the first (2009) and the second (2010) accessions. Harvested fruit was labeled, placed in cardboard boxes and transported to University facilities for evaluation. The fruit was stored and processed in a room where the temperature was maintained at 20°C. Samples were transferred to tables and trays, and classified according to variety. Each crop was coded, for proper identification, with a number that included the date of harvest. On evaluation days, tests (Hedonic commercial maturity scale, peel and pulp color, pH, °Brix, cut strength, weight loss, peeling force, impact resistance, stack resistance, yield, moisture absorption and fat absorption) were performed on available varieties, as appropriate.

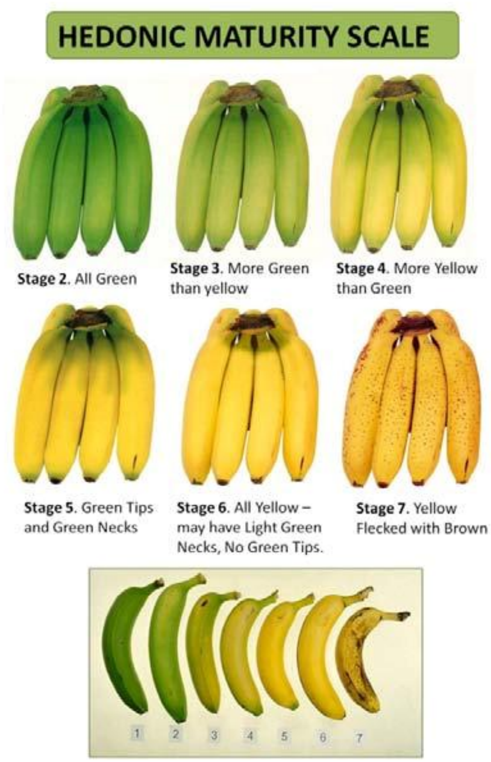
3.2 Sample Evaluation

Tests of hedonic commercial maturity index peel and pulp color, pH, °Brix, cut strength and weight loss 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

Three samples were randomly taken from the sample pool and compared to the hedonic commercial maturity scale (**Figure 2**). Tests were performed on storage days 0, 5, 9, 14, 19, 23, 28 and 33. To determine the maturity index, samples were compared to the hedonic color scale. The average of the three samples was reported as the maturity index for the sample day. With this scale it is possible to compare hybrids, determine the degree of ripeness and estimate the changes of the fruit during storage.

Figure 2: Hedonic commercial maturity scale



3.2.2 Peel and Pulp Color

A Hunterlab Miniscan colorimeter was used for the peel and pulp color tests. The peel and pulp color tests were performed on storage days 0, 5, 9, 14, 19, 23 and 33. Three measurements of peel color were taken from the middle of the fruit. The colorimeter was configured to register *L*, *a* and *b* parameters for a 10° observed and D65 illuminant. For pulp color, a ½" ring of fruit was cut from the lower ¼ of each sample, peeled and used for color determination. The peeled ring was saved for the pH and soluble solids (°Brix) tests.

3.2.3 pH

pH was measured in duplicate with a previously calibrated potentiometer (Accumet Basic AB15). The pH meter was previously standardized using 4.0, 7.0 and 10.0 standard solutions. The remaining macerated sample was kept for the °Brix measurement. Test following the AOAC method 10.041/84.

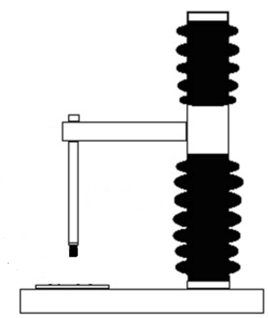
3.2.4 Total soluble solids (°Brix)

For °Brix determination, the fruit ring used for pulp color measurement was macerated and collected in a beaker. A sample was placed in a digital refractometer Pa202 (**Figure 3**) to determine ºBrix. Duplicate measurements for ºBrix were taken. Test following the AOAC 932.12/90.

Figure 3: Digital Refractometer (model MiscoMan Pa202) used to determine °Brix

3.2.5 Cut Strength

Figure 4: Texture analyzer (Texture Technologies) configured for the cut strength test.



The peel of collected samples was removed and the pulp was exposed for the cut strength test. The reading was taken on storage days 0, 5, 9, 14, 19, 23, 28 and 33. The texture analyzer (Texture Technologies) is shown in **Figure 4**. It was configured to measure force in compression (versus 1 cm distance) at a test speed of 1 cm/sec. For this test the necessary equipment is a knife blade probe. Measurements for cut strength were taken in duplicate. We determined the force required to peel the plantains using the slope of the data.

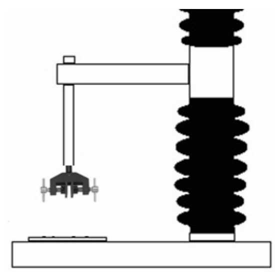
3.2.6 Weight loss

For this test we used the same three samples of each variety during the sampling. The samples were weighed according hybrids maturing. We took the initial weight of the hybrids and continued to take their weight every two days. With the data obtained and using the following equation was determined weight loss.

$$Weight\ Loss = \left|\frac{Final\ weight - Initial\ weight}{Final\ weight}\right| x\ 100$$

3.2.7 Peeling force

Figure 5: Texture analyzer with tensile grip for the peelability test.



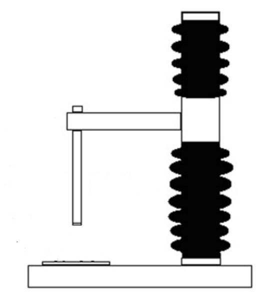
The texture analyzer (**Figure 5**) was configured to measure force in tension (versus 1 cm distance) at test speed of 1 cm/sec. Measurements were made on storage days 0, 7, 14, 21, 28 and 35. Before testing, the peel was cut longwise in three sections and short portion of the peel was removed. The removed portion was clamped with the analyzer grips so the equipment could pull the peel and take the readings. The slope of the curve determined the peel force of the fruit. For each sample, two readings were taken to determine peel force.

3.3 Mechanical properties

Mechanical tests were performed every 10 days until overripe. Three samples were randomly picked from the pool of stored fruit, on each sampling day, and subjected to the following sequence of tests.

3.3.1 Impact resistance test

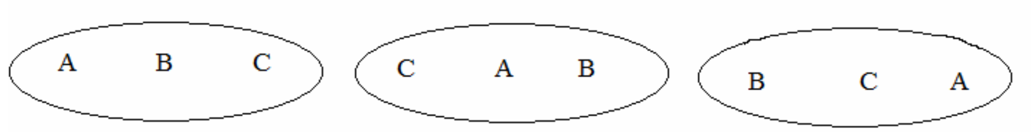
Figure 6: Texture analyzer configured to perform stack and impact test.



A Texture analyzer is used to inflict mechanical damage to fruits on sampling days (**Figure 6**). Damage readings were performed on 2, 9, 16, 23 and 30 days, to different samples of each variety, starting from their second day of harvest. For both tests the necessarily equipment is a 10 mm OD aluminum cylinder.

In the impact test, the plantain was hit at different speeds on three locations (labeled A, B and C) (**Figure 7**). Each test speed represents a given drop height for a 150 g (0.33 lbs) load. The compressive force was set constant at 1.48 N. The first hit was labeled with the letter A and represented a drop height of 5 feet (velocity of 6 m/s), letter B corresponds to a height of 10 feet (velocity of 8 m/s) and letter C to 15 feet (velocity of 10 m/s). Pictures were taken to determine the mechanical damage in hybrids at 10, 20 and 30 days after impact damage. Samples of each variety were struck with the three different speeds in the following order (**Figure 7**).

Figure 7: Order of the different speed to determine damage level in impact test.



3.3.2 Stack resistance test

The stack test attempts to simulate damage caused by stacking fruit in a pile of various heights, the height of the stack determining the force. Readings were taken 2, 9, 16, 23 and 30 days after harvest. The texture analyzer was set to measure distance in compression and configured with test speed of 1mm/sec and force holding time of 5 seconds. The applied force for each test condition appears in **Table 3**. In the stack test, the plantain was hit at different force (kg) on three locations (labeled A, B and C) (**Figure 7**).

Table 3: Height and force for stack test.

Stack height (fruits)	Force (kilograms)
10	1.5 kg
20	3.0 kg
30	4.5 kg

3.4 Processing tests

Processing tests (yield, peeling force, moisture absorption and fat absorption) were performed every 7 days until overripe. Three samples were randomly picked from the pool of stored fruit, on each sampling day, and subjected to the following sequence of tests.

3.4.1 Pulp yield

The whole plantain sample is weighed on a scale (Mettler PC 16). The peel was removed and the pulp weighed again. The following formula was used to calculate the yield of the pulp.

$$Yield = \frac{pulp\ weight}{fruit\ weight}$$

After calculating pulp yield, the plantain is cut in three pieces of equal size; one piece for each for the following tests. The three pieces were used in tests of fat and moisture absorption. The third portion was saved for future study.

Each test piece was further cut in two equal portions; the control and treated sample, respectively. Tests were performed at 0, 7, 14, 21, 28 and 35 days.

3.4.2 Moisture Absorption

The treated sample was boiled in water for 10 minutes, removed from the water, drained and cooled. Weights of the boiled and control pieces were collected and registered before drying both pieces in an oven at 100ºC for 24 hrs. Dried samples were cooled in a dessicator before weighing. Moisture absorption was estimated with the following equations (**Table 4**).

Table 4: Formulas to calculate moisture of fresh fruit, boiled fruit and moisture absorption

Metric	Formula
Moisture content of fresh fruit (db)	$\frac{FreshWet - FreshDry}{FreshDry}$
Moisture content of boiled fruit (db)	$\frac{BoiledWet - BoiledDry}{BoiledDry}$
Moisture absorption	$BoiledWet - FreshWet$

3.4.3 Fat absorption

Control and treated samples were weighed and the data was recorded. The treated samples was placed in heated oil at 375ºF for 5 minutes, drained and cooled. The treated samples were weighed again. Fat absorption of of both samples was determined the following AOAC method 920.39 or equivalent. Fat absorption was calculated using the following equations (**Table 5**).

Table 5: Equations to calculate fat content of fresh, fried fruit and fat absorption

Metric	Formula
Fat content of fresh fruit (db)	$\frac{FatWeight}{FreshSampleWeight}$
Fat content of fried fruit (db)	$\frac{FatWeight}{FriedSampleWeight}$
Fat absorption	$FatContentFried - FatContentFresh$

3.5 Experimental Design

This research was conducted as a completely randomized design. Results for different parameters were analyzed by analysis of variance using the statistical program Infostat ($P = 0.05$). Means were compared with the Tukey test when appropriate. Two hypotheses were postulated; H_o: $\mu_1 = \mu_2 = \mu_3 = ... = \mu_n$ and the H_a: at least one μ is different. For this investigation we used two replications (harvest 1 and harvest 2).

We used the same three samples for testing maturity hedonic scale, peel and pulp color, pH and °Brix. For the weight loss we used the same three samples for each variety during sampling period. We used three other samples for impact tests and stack. For processing tests (yield, peel force, fat and moisture absorption) were used three other samples. There were three repetitions for each test, except for pH and Brix testing, in which only two repetitions were performed.

4. RESULTS

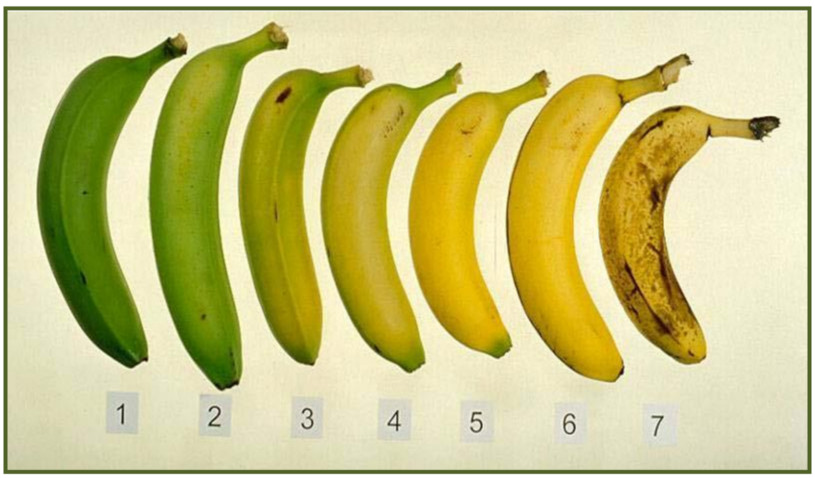
4.1 Environment and relative humidity

This investigation included fruits from two harvest season. At some point through the study, samples had to be moved from one lab to another. Although temperature was controlled (20ºC) in both environments, results show that varieties didn't mature or lasted the same time at the various locations.

Previous studies suggest that the relative humidity should be controlled in a range of 90 – 95% (Dadzie and Orchard, 1997) in order to prevent premature ripening and water loss. This occurs because, at high relative humidity in the environment, the vapor pressure difference between the fruit and the environment is smaller. Ullah et al., (2006) investigated the effect of high humidity and water on the storage life and quality of bananas. They found that, when the relative humidity is 100%, a delay occurs in the ripening and maturation processes of banana. These findings support the hypothesis that the observed difference in storage time between harvests was due to variations in the relative humidity of the lab environments. Since fruits form the two harvest seasons didn't last the same time, an alternative to storage time had to be used as the base for comparison.

The commercial maturity scale (**Figure 8**) is a hedonic scale that identifies 7 stages of maturity based on the color and appearance of fruits. Though fruits of the same variety didn't ripe at the same rate, they, in general, did exhibit the various maturity stages. Thus, the commercial maturity scale could be used for the analysis. The use of this scale will also allow for comparisons among varieties that, naturally, have different storage times. Dadzie and Orchard (1997), working with plantains and bananas, used the maturity scale as the basis for comparisons between hybrids. Ngoh et al., (2007) used the stage of maturity to assess the potential of carotenoids from plantains and bananas harvested in Cameroon. Agoreyo (2010) conducted a study to determine the enzymatic activity of phosphatase and alkaline phosphatase in ripening of plantain *Musa paradisiaca* L, and used the color scale. Thus, analysis based on maturity levels is an alternative to storage time because it allows for a fair comparison of fruits.

Figure 8: Hedonic commercial maturity scale



In this study, some varieties matured faster than others. Thus, observations at each maturation stage couldn't be achieved with an established testing schedule. Also, aside from the assumption that the relative humidity made some plantains cultivars mature faster than others, factors such as insect damage, physical damage, scars and decay, may have caused the varieties ripen very quickly (Morelli and Kader, 2005).

Some hybrids matured very fast and appeared to skip stages of maturity based on the pre-established sampling plan. As a consequence, no sufficient data was available for a stage by stage analysis of cultivars. In order to make inferences, it was necessary to group the 7-point commercial scale to a reduced 4-point scale. **Figure 9** shows the reduced maturity scale where groups were made according to similarity of color and ripening stage (i.e., 1-2 = Green, 3-4 = Mature Green, 5-6 = Mature, 7 = Overripe).

Figure 9: Commercial maturity scale modified to analyze the results

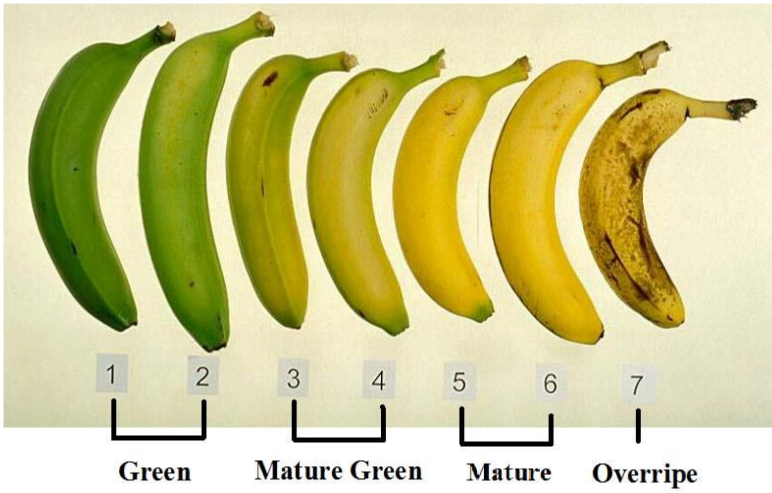
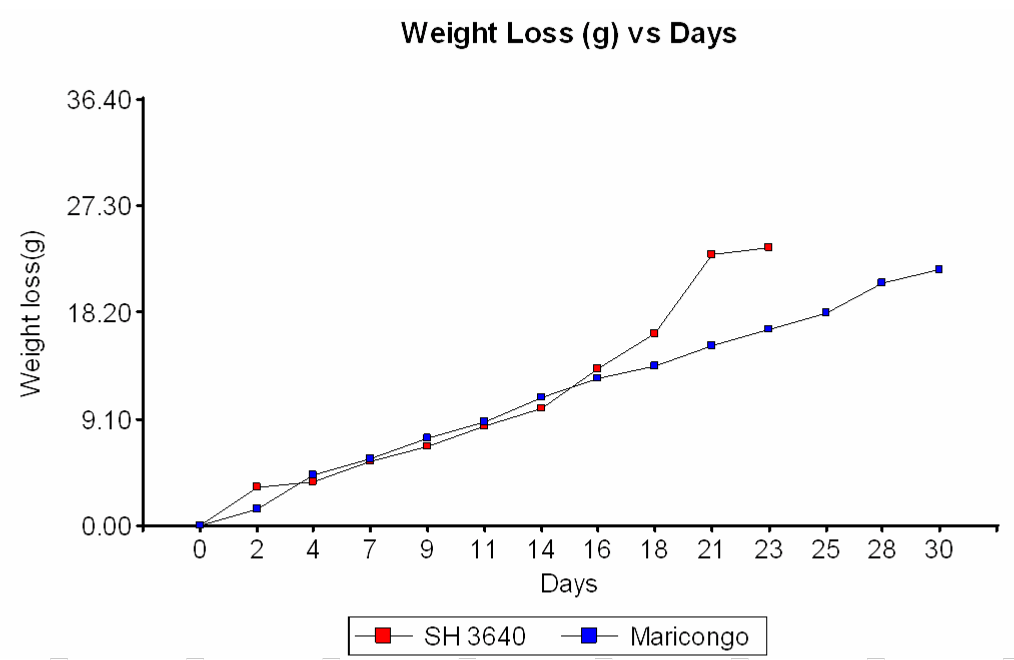
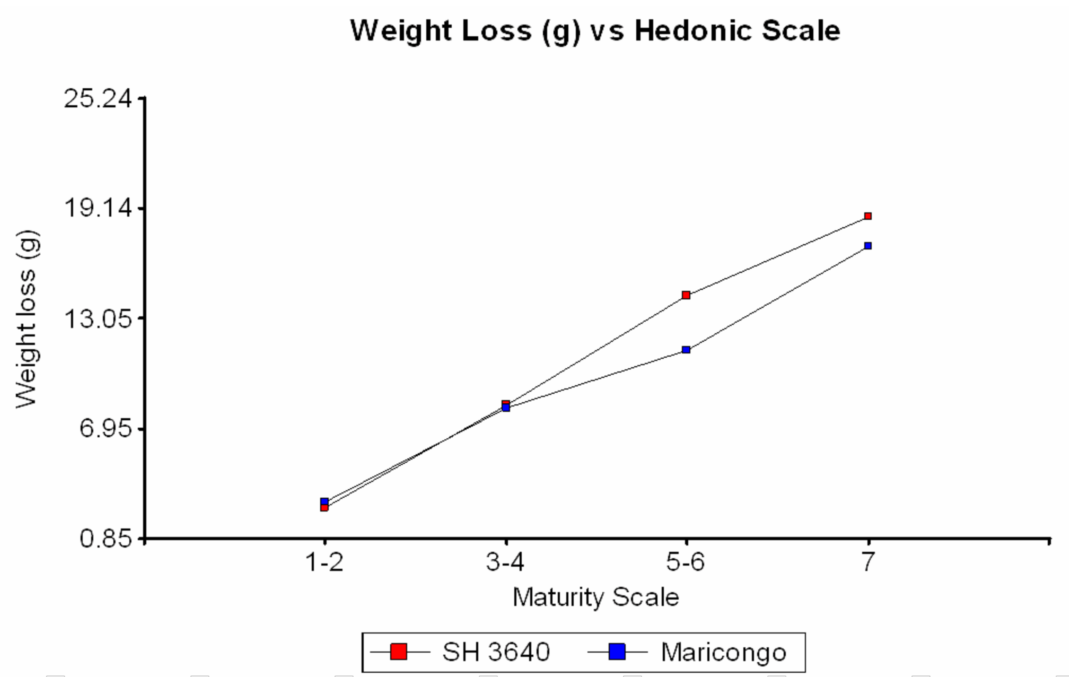


Figure 10: Weight loss test analyzed under maturing days of varieties SH 3640 vs Control



As an example of the previous discussion, consider the data on **Figures 10** and **11**. **Figure 10** compares the weight loss among varieties SH 3640 and Maricongo (Control) during storage. As it can be seen, a comparison of varieties along storage time would yield an excess of Maricongo data that has nothing to compare against from days 23 to 30 of storage. In contrast, when grouping by maturation stages, all data can be used for the analysis (**Figure 11**).

Figure 11: Weight loss test analyzed under the modified maturity stages of varieties SH 3640 vs Control



4.2 Storage Time and Maturation Stage

Table 6 presents the duration (in days) of each variety per stage of the modified commercial maturity scale, this is, the days that varieties lasted at each level of maturity and an average modified of these values. From the table, it's also possible to determine which varieties lasted longer than the Control at various stages of maturation. Each entry for H1 (first harvest season) and H2 (second harvest season) represents the time that a sample of 3 fruits from each variety lasted on the particular maturation stage. The column labeled "Average" correspond to the arithmetic average of H1 and H2.

A quick observation of **Table 6** data suggests that, considering all varieties together, the first harvest lasted more than the second harvest for all stages of maturity. Also, fruits stayed longer at stage 1-2 (green), than at stage 3-4 (mature-green) and less time at stage 5-6 (mature). It also appears that fruits stayed longer at stage 7 (overripe) compared to stage 5-6, but that is easily explained by considering that the fruit enters this stage as black spots start appearing in the peel and ends when the fruit rots. **Table 6** also shows that some varieties (CRBP 39 and PV 42-81) have values of "0" storage time. This means that, according to the sampling schedule, these varieties went through that stage between the two or three day interval of the sampling schedule and no observation could be taken.

In terms of significant difference, at stage 1-2 (green), the only hybrid that lasted longer than the Control was PITA 16 ("Average" = 18 days). This observation suggests that PITA 16 can have potential economic benefit for the green fresh or processing markets. There was no evidence to suggest significant difference among varieties at the other stages of maturity. Corresponding to the overall storage time, varieties lasted the same as the Control, except for FHIA 01, with an average storage time of 10 days, and PITA 16 that lasted an average of 27.5 days.

Figure 12 is a graphic representation of "average" data from **Table 7**. Each color grouping includes varieties that tended to last about the same amount of time at each stage of maturation (i.e., gray = less than 4 days, blue = 4 to 7 days, green = 7 + to 10 days and purple = more than 10 days). This information allows for a quick comparison of hybrids to determine how they performed against the Control.

Table 6: Duration (days) of each variety per stage of the (modified) commercial maturity scale.

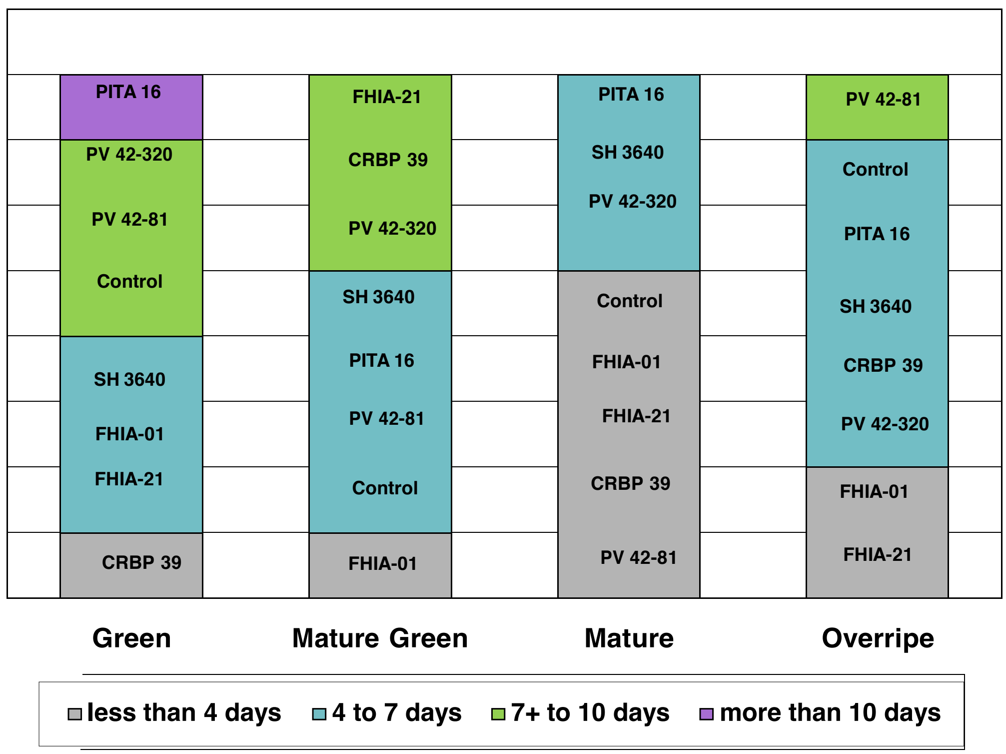
Varieties	Modified Hedonic Scale														
	1 or 2			3 or 4			5 or 6			7			Total		
	2009	2010	Avg*	2009	2010	Avg*	2009	2010	Avg*	2009	2010	Avg*	2009	2010	Avg*
SH 3640	7	3	5^{a}	5	6	5.5^{a}	3	6	4.5^{a}	7	4	5.5^{a}	22	19	16^{ab}
PITA 16	19	17	18^{c}	4	4	4^{a}	6	3	4.5^{a}	7	4	5.5^{a}	36	28	27.5^{c}
CRBP 39	4	3	3.5^{a}	15	4	9.5^{a}	0	0	0^{a}	0	10	5^{a}	19	17	18^{ab}
PV 42-320	9	8	8.5^{b}	8	9	8.5^{a}	4	4	4^{a}	6	3	4.5^{a}	27	24	21.5^{bc}
PV 42-81	8	8	8^{b}	5	3	4^{a}	0	0	0^{a}	12	5	8.5^{a}	25	16	20.5^{ab}
Maricongo (control)	9	7	8^{b}	4	4	4^{a}	4	3	3.5^{a}	12	2	7^{a}	29	16	19^{b}
FHIA-21	5	3	4^{a}	8	11	9.5^{a}	3	0	1.5^{a}	0	5	2.5^{a}	16	19	16^{ab}
FHIA-01	4	4	4^{a}	2	3	2.5^{a}	7	0	3.5^{a}	2	5	3.5^{a}	15	12	10^{a}
All	8.1	6.6	7.4	6.4	5.5	5.9	3.4	2	2.7	5.8	4.8	5.3	23.6	18.9	18.5

2009 =First harvest season 2010 =Second harvest season

*Values with different superscript along the same column are significantly different ($p < 0.05$)

By observing the values presented in the figure, we can determine that variety PITA 16 lasts longer than the Control in the mature green stage, and as well as the Control in the other two stages. According to the results, PITA 16 seems to be superior in terms of storage time. PV 42-320 is similar to the Control when it's green, but lasts longer as green-mature and mature. Therefore, it has advantages over the Control for this market.

Figure 12: Number of days in which the varieties lasted at each stage of the modified maturity scale compared to Control.



Maricongo, PV 42-81 and PITA 16 lasted about the same time at the mature-green stage. A longer storage time at this maturation stage implies that the distributor or retailer of fresh mature plantains has more time to move the product without the risk of losses due to maturation. The PV 42-81 is good as the Control for stages 1 through 6, in terms of storage time, but lasts more days in the overripe stage of overripe.

At maturity scale 5-6, the hybrids that lasted longer were PITA 16, SH 3640 and PV 43-320, follow by the Maricongo and FHIA-01. The difference in storage time between these hybrids was not substantial. At this stage, only PITA 16, SH 3640 and PV 43-320 would accommodate the consumer expectations for storage time of fresh mature plantains. The variety FHIA-21 lasted as long as the Control in mature stage, but lasts longer in mature-green stage. This could be an advantage as it gives more time for traders to move the product. However, it last few days at the green stage and rushes through the overripe stage. Thus, compared to the Control, FHIA 21 has a substantially shorter storage life.

The longer lasting varieties at stage 7 were PV 42-81 and Maricongo. All other varieties lasted substantially less than the Control. Thus, only PV 42-81 can accommodate to the consumer expectation for overripe fresh plantains.

With maturation, begins a process where dry matter accumulates and physical and chemical changes give rise to decomposition. As plantains enter the overripe stage, many varieties began to experience changes in their weight, peel and pulp thickness, respiration rate, color and aroma. These changes are dependent on external factors such as temperature and relative humidity, as well as on the type of hybrid/cultivar.

4.3 Cut Strength

According to Dadzie and Orchard (1997), no significant changes occur in the firmness of bananas and plantains in early stages of maturation. In advanced maturation stages, however, significant changes will occur and, therefore, a decrease in the required cutting force can be observed. They also noted that pulp cut strength vary between hybrids and cultivars. Barrera et al., (2010), in a study with Dominico-Harton, concluded that firmness and cutting force decreases as plantains mature.

This softening behavior seems to be typical of fruits other as well. For example, a study to determine physico-mechanical properties of orange peel and pulp under ambient and refrigerated conditions (Singh and Reddy, 2005) showed a reduction in cutting force with storage time.

Table 7 presents the cutting force for the different varieties according to the maturity stages. Data entries "ND" mean the value is missing. This happened because fruits ripened so fast that the sampling schedule couldn't capture the particular maturity stage for that variety.

Data show agreement with literature reports in terms of cutting force reduction with maturity. For the Control, significant changes in force are observed at each stage of maturation; decreasing from 736.45g/mm at the green stage (1-2) to 126.85g/mm at the mature stage (5-6). Other varieties exhibited a similar behavior; of significantly decreasing cutting force with maturity.

At the green stage (1-2), cutting force ranged between 263.54g/mm and 646.83g/mm. Significant differences, however, were found between the Control (736.45g/mm) and SH 3640 (338.71g/mm), PV 42-81 (453.15g/mm) and FHIA-01 (263.54g/mm). Significant differences at green stage (1-2) imply differences in the cutting force of fruits are due to variety.

The mature green stage (3-4) is a transition period where the fruit is not suitable for the green market or the mature market. Significant differences were found between the Control (388.38g/mm) and SH 3640 (175.56g/mm) and PITA 16 (179.25g/mm). Cutting force for this stage ranged between 175.56g/mm and 352.60g/mm.

At maturity stages 5-6 the cultivar found to be significantly different to the Control (126.85g/mm) was FHIA-21 (250.96g/mm). This implies that FHIA-21 will have higher cutting force than the Control.

At stage 7 significant differences were observed between Maricongo (113.16g/mm) and PV 42-81 (70.39g/mm), FHIA-21 (49.29g/mm) and FHIA-01 (41.99g/mm). Other varieties had similar cutting force (79.51g/mm to 99.53g/mm) to the Control. Fruit at this stage is typically used for cooking and processing.

Table 1: Cut strength at the different maturity stages.

Varieties	1-2	3-4	5-6	7
SH 3640	338.71^{AB}_{b}	175.56^{A}_{a}	112.60^{A}_{a}	99.53^{CD}_{a}
PITA 16	593.87^{CD}_{b}	179.25^{A}_{a}	96.46^{A}_{a}	79.51^{ABCD}_{a}
CRBP 39	627.40^{CD}_{c}	327.22^{AB}_{b}	ND	80.33^{ABCD}_{a}
PV 42-320	535.79^{BCD}_{c}	232.21^{AB}_{b}	108.52^{A}_{ab}	82.28^{BCD}_{a}
PV 42-81	453.15^{ABC}_{c}	248.21^{AB}_{b}	ND	70.39^{ABC}_{a}
Maricongo^{++}	736.45^{D}_{c}	388.38^{B}_{b}	126.85^{A}_{a}	113.16^{D}_{a}
FHIA-21	646.83^{CD}_{c}	352.60^{AB}_{b}	250.96^{B}_{b}	49.29^{AB}_{a}
FHIA-01	263.54^{A}_{b}	214.41^{AB}_{b}	81.37^{A}_{a}	41.99^{A}_{a}

*** 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.
$^{++}$ = Control plantain
ND = No Data

Results presented in **Table 7**, agrees with results reported by Chavez et al., (2000) for blackberries. These researchers reported a decrease in cutting force with maturation, a behavior typical of maturing fruit (**Table 8**).

Table 8: Values of cutting force (g) on blackberries by Chavez et al., (2000)

Treatments	Cutting force (g)
Green 50%	2378 [a]
Red at 60 %	368 [b]
Red at 90% and 10% black	320 [b]
Black at 90%	287 [b]
Black at 98%	248 [b]
Values with the same letter in the same column are not significantly different between treatments. (Tukey, 0.05)	

4.4 Total soluble solids

Total soluble solids (TSS) are compounds such as sugars, acids, vitamins and pectin found in fruits and vegetables (Dadzie, 1998). Soluble solids tend to increase as these foods mature. The starch content of a plantain during the green stages is high and it will decrease as the fruit ripens (Sakyi-Dawson et al., 2008).

As a result of chemical reactions, starch will degrade to form sugars (glucose, fructose and sucrose) and soluble solids will increase (Arrieta et al., 2006). As plantains ripen, synthesis of starch occurs and sugar levels rise, therefore, sugar content in the fruit can be used as an indicator of physiological maturity (Walteros et al., 2002). According to Potter and Hotchkiss (1995) soluble solids in fruits are mostly sugar and the concentration can be estimated with a refractometer. This device measures the ability of liquids containing solids to bend or refract a light beam. Light deviation (measured in degrees Brix) is proportional to the concentration of the solution.

Studies performed to determine shelf life of green plantain (Dominico-Harton) in different environments (packed and unpacked) tried to explain how TSS varied depending on the environment (bags) and storage time. Samples exposed to the various environmental conditions showed significant differences in degrees Brix during storage (Walteros et al., 2002). Another study with Dominico-Harton grew fruits at different locations. Results showed significant differences in TSS according to locations at green and mature stages (Arcila et al., 2002). According to Barrera et al., (2010) in a study with Dominico-Harton in an organic versus traditional system, increases in TSS values with maturity were also observed. They found a significant increase on TSS between maturation stages, specifically in the traditional system. They suggested that this happens because plantain has more enzymatic activity under this condition.

Table 9: Total soluble solids at the different maturity stages.

Varieties	1-2	3-4	5-6	7
SH 3640	8.23^{AB}_{a}	15.92^{A}_{b}	17.68^{AB}_{b}	19.79^{A}_{b}
PITA 16	11.75^{B}_{a}	19.84^{A}_{b}	23.57^{B}_{b}	24.45^{AB}_{b}
CRBP 39	5.93^{AB}_{a}	16.29^{A}_{b}	ND	20.74^{A}_{b}
PV 42-320	12.34^{B}_{a}	13.59^{A}_{a}	21.85^{B}_{b}	23.70^{AB}_{b}
PV 42-81	10.67^{AB}_{a}	18.74^{A}_{b}	ND	23.34^{AB}_{b}
Maricongo[++]	6.67^{AB}_{a}	19.45^{A}_{b}	24.32^{B}_{b}	31.21^{C}_{c}
FHIA-21	4.58^{A}_{a}	12.69^{A}_{a}	13.38^{A}_{a}	26.02^{BC}_{b}
FHIA-01	5.62^{AB}_{a}	13.95^{A}_{b}	19.98^{AB}_{c}	20.33^{A}_{c}

*** 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.
[++] = Control plantain
ND = No Data

Table 9 presents degrees Brix data (TSS) for the different varieties according to maturity stages. Data entries "ND" mean the value is missing. This happened because fruits ripen so fast that the sampling schedule couldn't capture the particular maturity stage for that variety.

Data shows agreement with literature reports in terms of TSS increase with maturity. For the Control, significant changes in TSS are observed at each stage of maturation; increasing from 6.67% at the green stage (1-2) to 24.32% at the mature stage (5-6) to 31.21% at the overripe stage (7). Other varieties exhibited the similar behavior of significantly increasing soluble solids with maturity. Again, this behavior is not exclusive of plantains. Bouchra et al., (2008) made a study with clementine tangerines to estimate juice quality changes during maturation. They analyzed TSS values of tangerines juice according to maturity. They found TSS increased from 7.9% to about 13.70% according storage time.

Dadzie (1998) evaluates TSS content during ripening of four varieties (Grande Naine and Williams bananas compared to FHIA-01 and FHIA-02). He found that, at green stage, total soluble solids contents were similar in all varieties, and increased as ripening progresses. Dadzie (1998) found that TSS increased from 0% at green stage to approximately 13% at maturation in Grande Naine. In Williams, TSS increased from 0% to approximately 13.5%. In contrast, TSS in FHIA-01 increased from 0% at green the stage to 12% at maturation, while in FHIA-02 they increased to 11%.

At the green stage (1-2), TSS ranged between 4.58% and 12.34%. No significant differences were found between the Control (6.67%) and other varieties. Significant differences, however, were found between FHIA-21 (4.58%) and PITA 16 (11.75%) as well as PV42-320 (12.34%). Significant differences, at green stage (1-2) imply differences in the caloric content of fruits and flour yield depending on the used variety.

The mature green stage (3-4) is a transition period where the fruit is not suitable for the green market or mature market. No significant differences were found between the Control (19.45%) and other varieties. TSS for this stage ranged between 12.69% and 19.84%.

At maturity stages 5-6 the cultivar that demonstrated to be significantly different from the Control (24.32%) was FHIA-21 (13.38%). This implies that FHIA-21 will have lower caloric content than the Control at this maturity stage. However, at stage 7, no significant difference was observed between Maricongo (31.21%) and FHIA-21 (26.02%). Other varieties had significantly lower TSS (19.79% to 24.45%) than the Control. Fruit at this stage is typically used for cooking and processing. Again, lower TSS implies low caloric content which is aligned with current trends to fight obesity.

4.5 pH

pH testing determines alkalinity or acidity of fruits as they mature and serves as an indicator of hygienic conditions and maturity stage (North Carolina Department of Agriculture and Consumer Services, 2007). **Table 10** includes pH values obtained for different varieties. Data entries “ND” mean the value is missing. This happened because fruits ripened so fast that the sampling schedule couldn’t capture the particular maturity stage for that variety.

In general, pH values tend to decline as maturation progresses. This is contrary to TSS data, which increased with ripening, and agrees with information reported in literature. Arcila et al., (2002) found, in a study with the Dominico-Harton, that pH decreases as plantains ripen. Arrieta et al., (2006) in a study with Papocho in advanced levels of maturity, found that acidity increased (pH values decreased) as plantains matured. Barrera et al., (2010) in study with Dominico-Harton in an organic versus traditional system reported a decrease in pH values as plantains ripen. They suggested that this behavior is related to green color loss and the presence of other pigments (carotenes and xanthophylls). They mention that pH values are related to starch degradation into reducing sugars or their conversion to pyruvic acid.

Table 10 data shows significant differences in pH as maturity progresses. Control pH went down from 5.83 at the green stage (1-2) to about 4.40 at mature stage (5-6). Other varieties showed similar behavior. The greatest change was exhibited by FHIA-21, where pH dropped from 6.48 to 4.27.

At green stage (1-2), no significant differences were found between de Control (5.83) and other varieties (range 5.26 to 6.48). At green and green-mature stages, pH values tend to decrease due to an increase of organic acid solutions (Álvarez-Herrera et al., 2009).

Similar behavior was observed at the mature stage (5-6), where the Control had pH of 4.40 and the range was 4.37 to 5.03. Significant differences were only found at the mature green stage (3-4) between the Control (4.69) and PV 42-320 (5.63).

At the overripe stage (7), pH of the Control (4.27) was significantly lower than SH 3640 (4.70), CRBP 39 (4.79), PV 42-320 (4.72) and PITA 16 (4.74).

Dadzie (1998) reported a decrease in pulp pH during ripening. At green stage, FHIA-01 and FHIA-02 had pH values of 6.00 and 5.70, respectively; that decreased to 4.50 and 4.40 at maturation. A small increase was observed as fruits overripe (4.90 and 5.20). Green Grand Naine and Williams fruits had an initial pulp pH value of 5.80 that decreased slowly to 5.50 and 5.60. pH tends to show a slow increase at mature green stage, but decreases as plantain reaches overripe stage (Dadzie, 1998). In the same study, but with FHIA-03, pulp pH also decreased with maturation, but had slight increase after the mature stage (green 5.00; mature 4.50 and overripe 4.8).

González et al. (2004) reported pH data for loquat fruit (*Eriobotrya japonica Lindl.*) through ripening (green 5.6; light green 6.1; colored 7.4). Contrary to loquat fruit, plantain pH decreases with maturation, but the initial value for the green fruit is similar. It supports, however, the suggestion of using pH as a maturity indicator since pH changes with maturation.

Table 10: Percentage pulp pH at the different maturity stages.

Variety	1-2	3-4	5-6	7
SH 3640	5.95^{AB}_{b}	5.01^{AB}_{a}	4.91^{A}_{a}	4.70^{B}_{a}
PITA 16	5.48^{A}_{b}	4.67^{A}_{a}	4.74^{A}_{a}	4.74^{B}_{a}
CRBP 39	5.81^{AB}_{b}	5.07^{AB}_{a}	ND	4.79^{B}_{a}
PV 42-320	5.72^{A}_{b}	5.63^{B}_{b}	4.69^{A}_{a}	4.72^{B}_{a}
PV 42-81	5.26^{A}_{b}	4.77^{AB}_{a}	ND	4.57^{AB}_{a}
Maricongo++	5.83^{AB}_{b}	4.69^{A}_{a}	4.40^{A}_{a}	4.27^{A}_{a}
FHIA-21	6.48^{B}_{c}	5.14^{AB}_{b}	5.03^{A}_{b}	4.27^{A}_{a}
FHIA-01	5.87^{AB}_{b}	4.90^{AB}_{a}	4.37^{A}_{a}	4.59^{AB}_{a}

*** 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.
++ = Control plantain
ND = No Data

4.6 Weight loss

During plantain maturation, changes are observed in fruit weight, specifically moisture loss, increase in pulp weight and decreased in peel weight. As a result, the ratio pulp/peel increases. Pulp weight gain occurs because there is an increase in the percentage of water content. This is caused by hydrolysis of starch and the resulting osmotic pressure that promotes the passage of water from the peel to the pulp (Echeverry and Castellanos, 2002). Carvajal et al., (2002) reported an investigation with Dominico-Harton where significant weight loss was found as fruits matured. The change was attributed to moisture loss and transpiration that occurs through cuticles and stomata present in the peel of plantains.

Table 11 shows changes in plantain weight during maturation expressed as percentage lost from the initial weight. Data entries "ND" mean the value is missing. This happened because fruits ripened so fast that the sampling schedule couldn't capture the particular maturity stage for that variety. Data in **Table 11** show a tendency that agrees with reported literature in that weight loss as increases maturity progresses. Weight loss for the Control, for example, increased from 2.87% at the green stage to 17.08% at the overripe stage, and differences were statistically significant at every maturity stage. Similar weight loss increasing trends were registered by other varieties.

At each maturity stage, significant differences between the Control and other varieties were not evident. The only exceptions to this generalization are CRBP 39 at stage 3-4 and PITA 16 at stage 7 that had higher weight loss than the Control.

Plantain usage varies according maturity stage. For example, green plantains are good for the manufacture of chips and flour. At mature stages, it's possible to obtain plantain flour. At the green-mature stage, canned slices can be produced and at the overripe stage fruit can be made into jellies and marmalades (Dadzie and Orchard, 1997).

In a study to determine physico-mechanical properties of orange peel and pulp, results reflected a decrease in weight after at the first 17 days of storage. Oranges lost 19.4% of the initial weight under ambient conditions and 7.3 % under refrigerated conditions (Singh and Reddy, 2005).

4.7 Moisture content and absorption

Cooking or boiling cause plantains to absorb water and soften the pulp. Dadzie and Orchard (1997) stated that the amount of water absorbed depends of cooking time and variety. They suggest that ideal behavior for a high quality plantain is to absorb low amounts of water. Determination of moisture content of processed food offers information about shelf life and nutritional values. Food with a low moisture content tends to last more under storage. Moisture content is related to dry matter content and yield of fresh fruit (Zakpaa et al., 2010).

Table 11: Weight loss percentage at the different maturity stages.

Variety	1-2	3-4	5-6	7
SH 3640	2.59^{AB}_{a}	8.29^{A}_{ab}	14.32^{A}_{bc}	18.73^{A}_{c}
PITA 16	6.07^{B}_{a}	13.52^{BC}_{a}	18.80^{A}_{a}	41.46^{B}_{b}
CRBP 39	4.27^{AB}_{a}	16.92^{C}_{b}	ND	17.29^{A}_{b}
PV 42-320	2.66^{AB}_{a}	9.57^{AB}_{b}	14.05^{A}_{b}	14.71^{A}_{b}
PV 42-81	4.07^{AB}_{a}	7.13^{A}_{a}	ND	18.46^{A}_{b}
Maricongo^{++}	2.87^{AB}_{a}	8.13^{A}_{b}	11.29^{A}_{c}	17.08^{A}_{d}
FHIA-21	2.17^{AB}_{a}	10.23^{AB}_{b}	14.90^{A}_{bc}	21.75^{AB}_{c}
FHIA-01	2.04^{A}_{a}	9.29^{AB}_{b}	14.87^{A}_{bc}	20.36^{A}_{c}

*** 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.
$^{++}$ = Control plantain
ND = No Data

Also, moisture absorption is a parameter related to texture of fruits and vegetables. Dadzie (1998) suggests that factors affecting moisture absorption in plantain include amount of starch, variety and intensity of heat treatment (time and temperature). Pectin, cellulose and starch are the structural components that cause the pulp to get softer when subjected to a heat treatment, specifically, starch which is gelatinized.

Table 12: Moisture absorption at the different maturity stages.

Variety	1-2	3-4	5-6	7
SH 3640	5.85^{A}_{a}	26.15^{A}_{b}	70.92^{AB}_{c}	ND
PITA 16	26.58^{AB}_{a}	20.24^{A}_{a}	62.87^{AB}_{b}	57.17^{A}_{b}
CRBP 39	26.75^{AB}_{a}	23.97^{A}_{a}	ND	35.69^{A}_{a}
PV 42-320	ND	33.52^{AB}_{a}	46.56^{AB}_{a}	ND
PV 42-81	38.03^{B}_{a}	57.32^{B}_{ab}	85.92^{B}_{b}	43.85^{A}_{a}
Maricongo^{++}	11.40^{A}_{a}	25.67^{A}_{ab}	30.85^{A}_{ab}	48.61^{A}_{b}
FHIA-21	24.80^{AB}_{a}	32.89^{AB}_{a}	33.11^{A}_{a}	36.19^{A}_{a}
FHIA-01	39.37^{B}_{a}	ND	41.64^{A}_{a}	42.78^{A}_{a}

*** 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.
$^{++}$ = Control plantain
ND = No Data

Table 12 presents the percentages of moisture absorption of treated samples. Data entries "ND" mean the value is missing. This happened because fruits ripen so fast that the sampling schedule couldn't capture the particular maturity stages for that variety. Data in the **Table 12** agrees with reported literature in that water absorption increases, in general, as fruit ripens. The Control, for example, goes from 11.40% at the green stage (1-2) to about 30% at the mature stage (5-6) and 48.61% at the overripe stage (7). These changes were found to be statistically significant different. Interesting behavior was exhibited by CRBP 39 and FHIA-21 where no significant differences were found between the maturity stages.

Dadzie and Orchard (1998) reported moisture absorption data after 5 minutes of cooking for FHIA-04, FHIA-21, FHIA-22 and Cuerno at green stage and suggested that moisture absorption depends on cooking time, cultivar and starch content. Though they did not report data in starch content, they provided information on dry matter content. A summary of their findings is presented in **Table 13**. They noted that higher moisture absorption resulted in softer texture of the cooked product. Data in the **Table 13** suggests that higher moisture absorption might be related to lower dry matter content. Based on this observation, the authors concluded that good cooking qualities (i.e., firmer cooked product) are related to low moisture absorption, thus, high dry matter content.

Table 13: Values of moisture absorption (%) and dry matter content (Dadzie and Orchard, 1998)

Hybrid/Cultivar	Moisture absorption (%)	Dry matter content
FHIA-04	20%	34.29
FHIA-21	9%	35.02
FHIA-22	7%	36.43
Cuerno	7%	37.56

Zakpaa et al. (2010) reported the results of a study with flour from ripe french horn plantain grown in Ghana. They found moisture content of 3.14% (± 0.22%) lower than the 5.43% threshold for preservation of flour. Thus, moisture content impacts shelf life and nutritional values of foods. At maturity stage 1-2 the Maricongo absorbed significantly less moisture (11.40%) than PV 42-81 (38.03%) and FHIA-01 (39.37%). Moisture absorption for other varieties ranged from 5.85% to 26.75%. Green plantain is typically used for cooking and processing. Moisture absorption at this stage has important implications for the texture, caloric content and yield of products processed plantain or plantain flour. At maturity stages 3-4 and 5-6 significant differences were found between the Control and PV 42-81. At overripe stage (7) no significant differences were found among varieties.

Zakpaa et al., (2010) reported water absorption of 71% for plantain flour and stated that flours of ripe plantains should have lower absorption capacity. They attributed the difference to the fact that green plantain contains more starch from ripe plantain flour; which is high in sugars. Starch contains more –OH group than sugar, therefore, it is better suited to bind water molecules.

According to **Table 12**, water absorption increases with ripening. A possible explanation could have to do with the fact that this study evaluated whole pieces of fruit as opposed to flours. Contrary to flours, whole fruits cells are whole and can support water uptake.

Table 14 presents the moisture content fraction of samples. Data entries “ND” mean the value is missing. This happened because fruits ripen so fast that the sampling schedule couldn’t capture the particular maturity stages for that variety. As seen in **Table 14**, with the exception of PITA 16, PV 42-81 and FHIA-01, maturation did not significantly affect moisture content. The Control, for example, goes from 0.59 at green stage (1-2) to 0.63 at overripe stage (7), but the changes were not statistically significant. Madrigal et al. (2008) presented data on several varieties of plantain (**Table 15).** Their results are somewhat higher than to those obtained in this study.

Table 14: Moisture content at the different maturity stages.

Variety	1-2	3-4	5-6	7
SH 3640	0.74^{D}_{a}	0.75^{E}_{a}	0.75^{C}_{a}	ND
PITA 16	0.70^{C}_{a}	0.71^{DE}_{a}	0.71^{BC}_{a}	0.77^{C}_{b}
CRBP 39	0.68^{BC}_{a}	0.64^{B}_{a}	ND	0.66^{A}_{a}
PV 42-320	ND	0.70^{CDE}_{a}	0.70^{BC}_{a}	ND
PV 42-81	0.68^{BC}_{a}	0.68^{BCD}_{a}	0.69^{BC}_{a}	0.78^{C}_{b}
Maricongo	0.59^{A}_{a}	0.59^{A}_{a}	0.61^{A}_{a}	0.63^{A}_{a}
FHIA-21	0.66^{B}_{a}	0.66^{BC}_{a}	0.67^{B}_{a}	0.69^{AB}_{a}
FHIA-01	0.74^{D}_{ab}	ND	0.71^{BC}_{a}	0.75^{BC}_{b}

*** 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.
$^{++}$ = Control plantain
ND = No Data

Table 15: Moisture content (%) of plantains at green stage (Madrigal et al., 2008)

Varieties	Moisture Content (%)
FHIA-17	78.17
FHIA-20	74.20
FHIA-23	79.83
“Plátano Macho”	72.22

According to **Table 14** data, at green stage (1-2), significant differences were found between the Control (0.60) and all other varieties (range from 0.66 to 0.74). Dadzie and Orchard (1998) suggested that a characteristic of good quality plantains is high dry matter content. In foods, dry matter equals the remaining portion after removing the moisture. Thus, the lower the moisture content, the higher the dry matter content of the fruit. From gathered data, and based on moisture content only, the Control would have the best quality rating of all varieties included in this study. The worst rating corresponds to FHIA-01.

At green mature stage (3-4) and mature (5-6) stage, significant differences were found between hybrids and the Control. Again, the Control showed the best quality characteristics by having lower moisture than other varieties. At overripe stage (7), the slight but insignificant increase in moisture content of the Control forces the statistical analysis to not reject the null hypothesis when measured against varieties CRBP 39 and FHIA-21

4.8 Fat absorption

Several countries, such as Puerto Rico, consume plantains as "tostones" (fried flattened slice of plantain), plantain chips and “mofongo” (fried mashed pieces of plantain). Determination of oil absorption gives information about which plantain variety will result in a product with a lower caloric content. **Table 16** presents average fat uptake as the difference of percent fat content between the fried and fresh product. The amount of oil absorbed depends of many factors such as oil temperature, frying time and degree of ripeness (Diaz et al., 1999).

Diaz et al., (1999) treated plantain samples (Dominico-Harton) at different temperatures and found how on initial phase (0 to 20 seconds) rapid moisture loss and considerable fat uptake. This is standard test for this kind of processing. They also found how yield falls as frying time increases. This same study reported that fat absorption increased as temperatures decreased and that there was a varietal effect. For example, at 185 ºC, fat content of Bluggoe, FHIA-21, Dominico-Harton and Bouroukou were 425, 350, 349, 275 g/kg for 2.5 minutes of frying. **Table 16** presents fat absorption data of the treated samples. Data entries "ND" mean the value is missing. This happens because fruits ripen so fast that the sampling schedule couldn't capture the particular maturity stages for that variety. Data in the **Table 16** agrees with reported literature in that fat absorption increases, in general, as fruit ripens (Diaz et al., 1999). The Control, for example, goes from 3.12% at the green stage (1-2) to about 4.67% at the green mature stage (3-4) and 12.02% at the mature stage (5-6). These changes were found to be statistically significant. Interesting behavior was exhibited by PV 42-81 and both FHIA where no significant differences were found even at the overripe stage (7).

Plantain is typically used for cooking and processing. Fat absorption has important implications for the texture, caloric content and yield of products processed plantain. Plantain with low fat absorption is more appropriated for people who have high blood pressure and heart disease (Zakpaa et al., 2010).

In terms of varietal differences at every maturity stage, data in the **Table 16** shows that evidence was not sufficient to reject the null hypothesis of "no difference".

Table 2: Fat absorption at the different maturity stages.

Variety	1-2	3-4	5-6	7
SH 3640	4.65^{A}_{a}	10.72^{A}_{a}	26.18^{A}_{b}	ND
PITA 16	10.53^{A}_{a}	11.69^{A}_{a}	28.81^{A}_{b}	36.40^{A}_{b}
CRBP 39	3.02^{A}_{a}	5.38^{A}_{a}	ND	31.97^{A}_{b}
PV 42-320	ND	6.29^{A}_{a}	28.44^{A}_{b}	ND
PV 42-81	3.71^{A}_{a}	8.29^{A}_{a}	26.66^{A}_{a}	13.63^{A}_{a}
Maricongo^{++}	3.12^{A}_{a}	4.67^{A}_{a}	12.02^{A}_{ab}	21.84^{A}_{b}
FHIA-21	2.95^{A}_{a}	5.34^{A}_{ab}	7.06^{A}_{ab}	20.44^{A}_{a}
FHIA-01	6.42^{A}_{a}	ND	22.50^{A}_{ab}	34.88^{A}_{b}

*** 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.
$^{++}$ = Control plantain
ND = No Data

Dadzie and Orchard (1997) show results about oil absorption of some plantain varieties. According to their data FHIA-21 (32.80 %) has the higher fat absorption, follow by Cuerno (25.00%) and FHIA-22 (17.35%) varieties on ripe stage. Data obtained by Dadzie and Orchard (1997) agrees with **Table 16**. **Table 16** shows similar behavior at ripen stage (5-6), except for varieties such as FHIA-21 and Control, which reported lower values at this stage (7.06 and 12.02 %).

4.9 Peel and pulp color (L, a, b, Hue and Chroma)

Color changes are due to several reasons, including the destruction of chlorophyll present in plantain and enzyme activity. Color change from green to yellow is related to changes of pH levels and oxidative damage suffered during maturation (Echeverry and Castellanos, 2002). Another factor influencing color change and deterioration of the peel is the appearance of black or dark spots (Rabsatt, 2010) shown in **Figure 13**. These changes have been attributed to the presence of a fungus of the genus *Colletotrichum* that causes a disease called anthracnose. This disease usually appears when the plantain overripe, particularly in wounds and openings in the peel (Morelli and Kader, 2005). It is very common in plantains, but also in mangoes, papaya, tomatoes, citrus fruits and beans.

Figure 13: Physical appearance of plantain with anthracnose during overripe stage

During maturation, plantains change color from green to yellow. These data permits to make an evaluation of maturity stage (Dadzie and Orchard, 1998). Color is a very important criterion of plantain quality, because indicates spoilage, infestation or contamination. For the fresh market, color represents an important visual attribute for consumers and traders alike.

Hunter *L*, *a* and *b* color scale is similar to the standard XYZ color scale. *L* or lightness runs from a minimum value of 0 (black) to a maximum value of 100 (white). The *a* and *b* parameters could been have positive or negative values; the larger the number (positive or negative), the more intense the color. Positive *a* indicate red while negative *a* indicate green. Positive *b* is yellow and negative *b* is blue.

Hue and Chroma are two of the three color parameters that define the universe of colors in the Munsell system. Hue is defined as the tone or shade of color (i.e., red, green, yellow) and

Croma indicates color saturation or intensity (Hernández et al., 2008). Hue values are reported in a scale that goes from 0 to 360º (or 0 to 2π radians) according to the scale shown in **Table 17**.

Table 17: Hue equivalencies

Color	Hue scale (radians)	Hue scale (degrees)
red	0 to 1.047	0 to 60
yellow	1.047 to 2.094	60 to 120
Green	2.094 to 3.142	120 to 180
cyan	3.142 to 4.189	180 to 240
blue	4.189 to 5.246	240 to 300
magenta	5.246 to 6.283	300 to 360

Hue and Chroma can be estimated in terms of the Hunter parameters *L*, *a* and *b* as follows.

$$Hue = TAN^{-1}\left(\frac{b}{a}\right)$$

$$Chroma = \sqrt{a^2 x\, b^2}$$

With these parameters (i.e., Hue, Chroma, *L*, *a* and *b*) it's possible to measure the changes in color occurred on pulp and peel as fruits mature (Hunter Lab Co, 2008). Data on *L*, *a* and *b* for the peel and pulp is presented in Appendix A. Hue and Chroma information is discussed here as they represent better the changes occurred in the fruits they matured. Each figure shows box-plots of data gathered for each variety on the specific color parameter. Several color coded box-plots are shown for each variety. Each box-plot represents the data for that particular variety at a different maturity stage.

In terms of pulp color, Hue data (**Figure 14**) suggest that samples are, in general terms, yellow, but to the red side of the yellow spectrum. It can be noted, however, that there are differences in Hue among varieties as well as among maturity stages. CRBP 39, FHIA-21 and the Control have lower Hue values than the other varieties. This implies that they are more “redish” than pure yellow. When Chroma information (**Figure 15**) is considered, it can be seen that, though CRBP 39, FHIA-21 and the Control have similar Hue, the overall perceived color is different since the Control’s Chroma is somewhat higher than for the other two varieties. In other words, the Control has a more intense shade of redish-yellow (orange) compared to the other two varieties.

In contrast, varieties PV 42-320 and PV 42-81 have a Hue value on the 1.4 to 1.6 range; close to the center of the yellow span where the color is more pure. Chroma of the later varies greatly from a very fade shade of yellow to a more intense shade while intensity variations of PV 42-320 are less dramatic. In both varieties, however, color saturation tends to increase with maturation.

Peel Hue (**Figure 16**) clearly shows the change in color through maturation. Initial Hue values are negative while final values are positive. Since Hue is computed as the arctangent of the *b* to *a* ratio, interpretation of the negative sign requires knowing that *a* are negative. This means that *a* negative arctangent values implies that the point falls in the second quadrant of the Cartesian plane. In other words, the negative Hue values in **Figure 16** refer to points in the green spread of the Hue spectrum.

Peel Hue and Chroma (**Figure 17**) data clearly show a movement from green color to yellow. On the green end of the spectrum, colors are less intense (lower Chroma) and saturation increases with maturity. The final Hue and Chroma after maturation were not significantly different among varieties, although some variations were observed.

Figure 14: Hue data for pulp

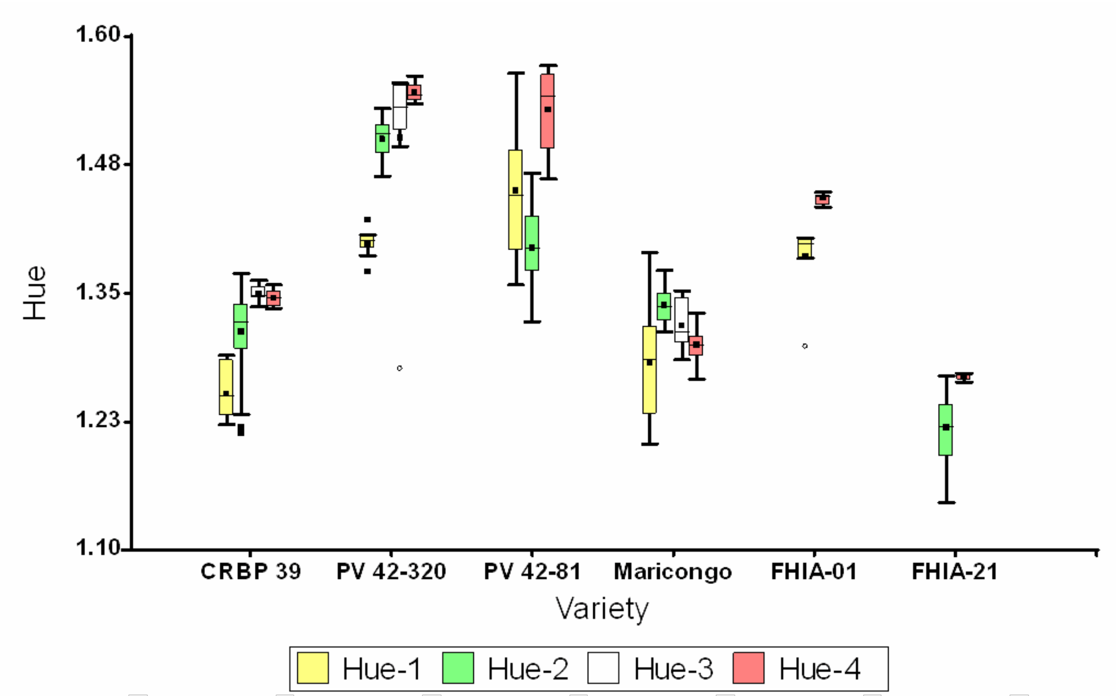


Figure 15: Chroma data for pulp

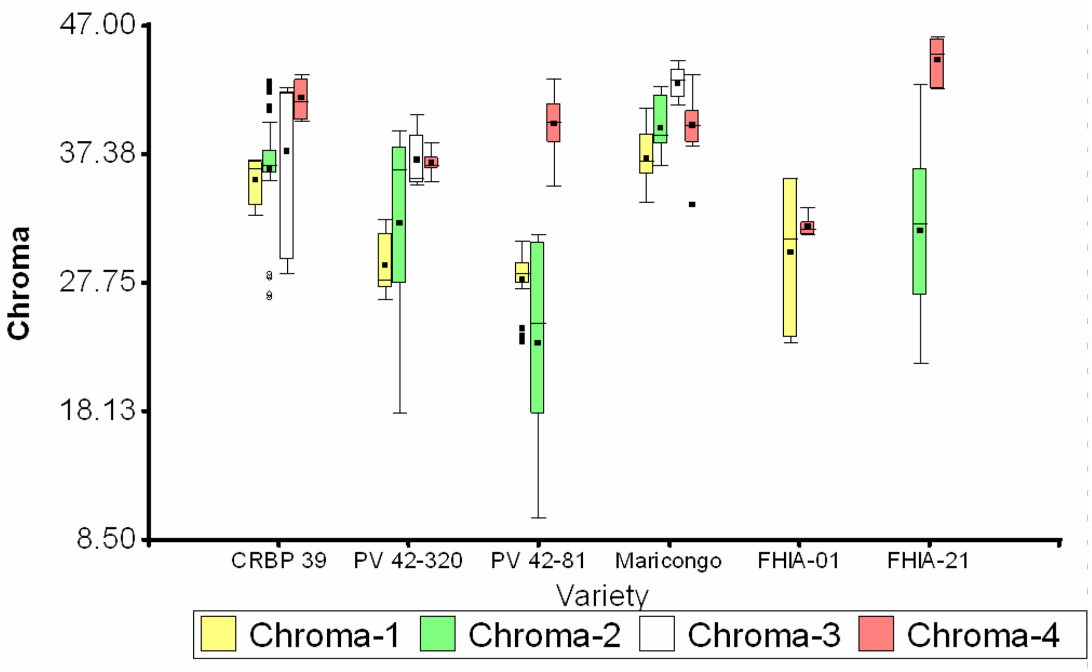


Figure 16: Hue data for peel

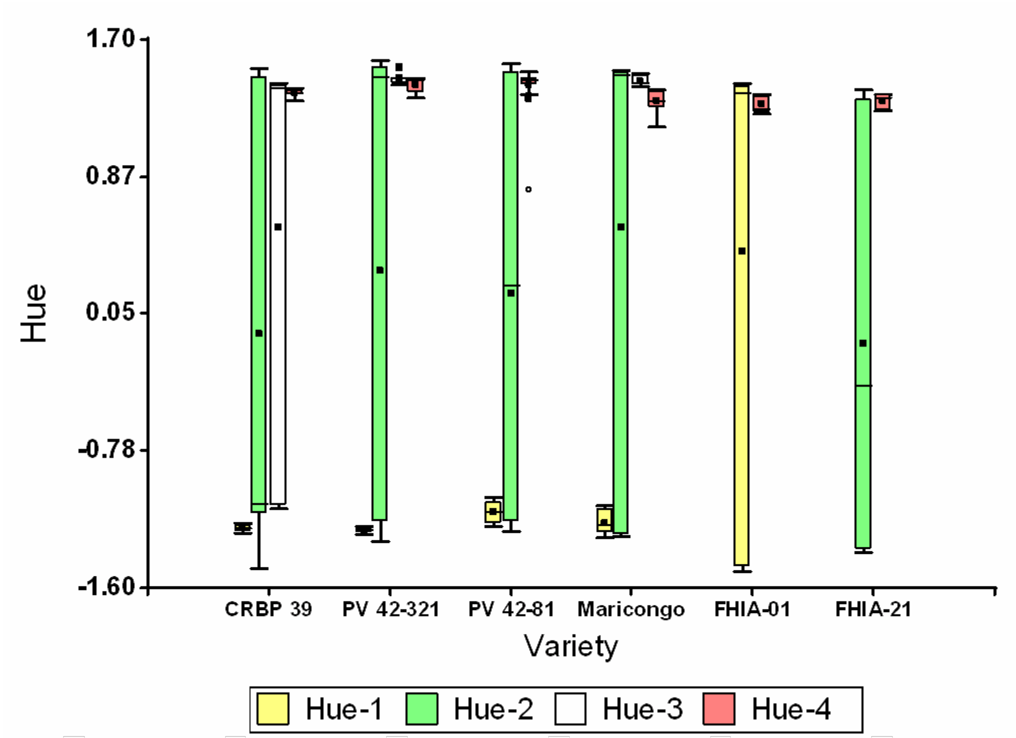
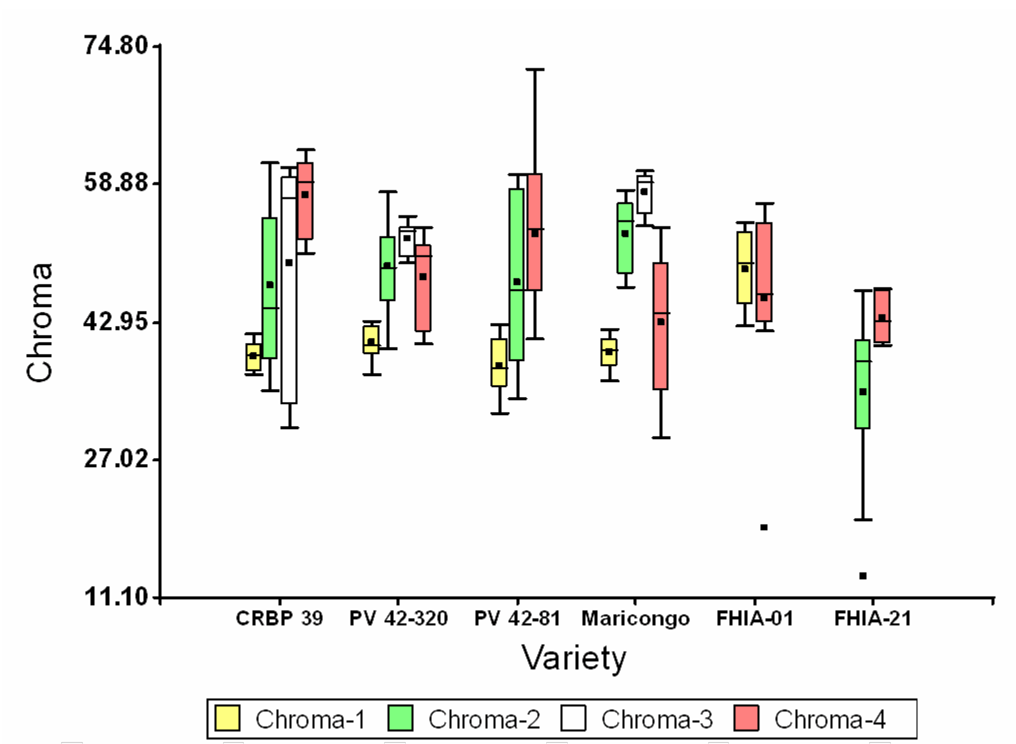


Figure 17: Chroma data for peel



4.10 Pulp fraction (yield)

In agricultural products, yield refers to the fraction of the total good that has greater commercial importance. In fruits, such as plantains, the component of importance is the pulp and, typically, does not include peel, seeds or stems, thus the name pulp fraction. In literature, another indicator of yield is the pulp/peel ratio. For example, Moreno-Velázquez et al., (2008) worked with white and pink ilama fruit and reported pulp/peel ratios of 0.3540 and 0.3028, respectively.

Dadzie (1998) studied pulp fractions for several *Musa* cultivars and reported that FHIA-02 has a higher pulp/peel ratio (0.80) than FHIA-01 (0.48). The author also reported that variations in pulp/peel ratio cultivars depend on maturity stages and established a linear relationship between pulp/peel ratios and maturation; thus, suggested the use of pulp/peel ratio as an indicator of fruit maturity. Zakpaa et al. (2010), working with ripe French horn plantain, obtained a yield of 25.86%. This value is lower than pulp fractions reported in this study.

Table 18 presents average yield data as a pulp fraction of the total fruit weight. Data entries “ND” mean the value is missing. This happened because fruits ripen so fast that the sampling schedule couldn’t capture the particular maturity stages for that variety. The general trend exhibited by varieties was for yield to increase between 10 (FHIA-21) and 17 (Control) percentage points as maturation progressed. Data shows, for example, that Control yield significantly increased from 0.61 at the green stage (1-2) to about 0.78 at the overripe stage (7). Data for FHIA-01 at this maturity stage is similar to the 0.48 reported by Dadzie (1998).

Table 3: Pulp fraction (yield) at the different maturity stages.

Variety	1-2	3-4	5-6	7
SH 3640	0.52^{ABC}_{a}	0.53^{AB}_{a}	0.62^{AB}_{b}	ND
PITA 16	0.56^{CD}_{a}	0.61^{CD}_{ab}	0.65^{AB}_{bc}	0.70^{AB}_{c}
CRBP 39	0.50^{AB}_{a}	0.56^{ABC}_{a}	ND	0.65^{A}_{b}
PV 42-320	ND	0.49^{A}_{a}	0.59^{AB}_{b}	ND
PV 42-81	0.49^{A}_{a}	0.55^{ABC}_{ab}	0.57^{A}_{bc}	0.65^{A}_{c}
Maricongo++	0.61^{D}_{a}	0.65^{D}_{a}	0.72^{B}_{ab}	0.78^{B}_{b}
FHIA-21	0.55^{BC}_{a}	0.60^{BCD}_{a}	ND	0.65^{A}_{b}
FHIA-01	0.47^{A}_{a}	ND	0.54^{A}_{b}	0.63^{A}_{c}

*** 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.
++ = Control plantain
ND = No Data

At the green stage (1-2), yield ranged between 0.47 and 0.61. Significant differences were found between the Control (0.61) and all hybrids, except PITA 16. The average yield for this variety was consistently lower than that of the Control at every maturity stage, but such difference was statistically insignificant. Hybrids, in general, had lower yield that the Control at this stage.

The mature green stage (3-4) is a transition period where the fruit is not suitable for the green market or the mature market. No significant differences were found between the Control (0.65) and varieties PITA 16 (0.61) and FHIA-21 (0.60). As in the previous stage, other hybrids score lower than the Control.

At maturity stages 5-6, the only cultivars found to be significantly different to the Control (0.72) were FHIA-01 (0.54) and PV 42-81 (0.57). As fruits continue to ripen onto stage 7, the yield of the Control increased to 0.78. At this stage, the Control yield significantly surpassed that of other hybrids, except for PITA 16 (0.70).

Dadzie (1998) studied the relation of pulp/peel ratio. He found that FHIA-02 has a higher pulp/peel ratio (0.80) than FHIA-01 (0.48); a value similar to data in **Table 18** for the green stage.

Zakpaa et al., (2010) working with ripe French horn plantain and obtained a yield of 25.86%. This value is lower than pulp fractions presented on **Table 18**. On another study, with ilama fruit white and pink pulp, reported pulp/peel ratios of 0.3540 and 0.3028, respectively (Moreno-Velázquez et al., 2008).

4.11 Stack test

The stack test is designed to simulate the effect of piling up fruits or the compression exerted on fruits by a pile of overfilled boxes. Fruit resistance to mechanical damage by stacking is related to fruit firmness. Thus, firmness is a measure of the resistance to mechanical damage caused during recollection, handling and transportation (Velázquez et al., 2005). Somewhat mishandled green plantains aren't a loss to traders because, at this stage, plantains are hard and doesn't collapse when stacked, however, mechanical damage at the green stage will become evident as the fruit ripens. Stacking when the banana is mature increases the probability of loss, unless good handling practices are followed. Good keeping characteristics under mechanical damage has been attributed to peel has a thickness (Dadzie, 1998).

Table 19 presents data on maximum deformation (in mm) of fruits under three different forces (1.5, 3.0 and 4.5 kgf). Data, in general, shows that deformation increases as maturation progress regardless of the magnitude of the applied force. Also, deformation significantly increased when the applied force increased from 1.5 to 3.0 kgf, but further increasing to 4.5 kgf did not produce further damage than at 3.0 kgf.

At green stage (1-2), regardless of the applied force, no significant differences were found between hybrids and the Control. The only exception to this general observation was FHIA-21 that deformed 12.39 mm at 3.0 kgf in comparison to Control (2.25 mm) and 11.27 mm at 4.5 kgf (Control 3.48 mm).

At green mature stage (3-4), significant difference was only observed for FHIA-21 (9.54 mm) at 1.5 kg (Control 2.25 mm). Such difference was not evident at higher compression forces or for other varieties. As maturation progresses onto the mature (5-6) and overripe (7), differences among varieties and the Control disappear at all compression forces.

Table 19 includes an additional column labeled "stage at peel breakage". It indicates the stage of maturation at which the peel broke when the particular compression force was applied. At 1.5 kgf, the Control was the variety that better withstood the applied force, followed by PV 24-320 and PV 42-81. In contrast, variety CRBP 39 yielded under a stress of 1.5 kgf while still at the mature green stage (3-4). In general, as applied force increased, varieties broke at earlier stages of maturity. The best resistance to stress was exhibited by the Control and PV 24-320.

4.12 Impact test

This test is a modified version of the drop test reported in literature (Idah et al., 2007). It's designed to determine the damage inflicted by dropping the fruit from a given height. Previous versions of this test actually dropped the fruit from a predetermine height and assessed the damage. This test was modified to use a texture analyzer to inflict the desired damage by setting constant the applied force and adjusting the probe's velocity. The test allows measuring the localized deformation under the applied stress and its effect over time. The impact test differs from the previously reported stack test in two aspects. First, the probe's velocity is considerably lower for the stack test than for impact test. Second, the applied force in the impact test is instantaneous while for the stack test it is applied for a specific amount of time.

Table 19: Maximum deformations (mm) of fruits under (a) 1.5 kgf (b) 3.00 kgf and (c) 4.5 kgf at the different maturity stages.

(a) 1.5 kgf

Variety	1-2	3-4	5-6	7	Stage at peel breakage
SH 3640	1.72^{A}_{a}	4.45^{AB}_{ab}	7.19^{A}_{b}	ND	5-6
PITA 16	1.82^{A}_{a}	2.80^{A}_{ab}	5.46^{A}_{b}	9.23^{A}_{c}	5-6
CRBP 39	1.32^{A}_{a}	2.98^{AB}_{ab}	2.77^{A}_{ab}	7.22^{A}_{b}	3-4
PV 42-320	6.06^{A}_{a}	1.83^{A}_{a}	5.50^{A}_{a}	11.99^{A}_{b}	7
PV 42-81	1.08^{A}_{a}	4.27^{AB}_{a}	ND	13.25^{A}_{b}	7
Maricongo^{++}	1.31^{A}_{a}	2.21^{A}_{a}	4.24^{A}_{ab}	6.92^{A}_{b}	"no breakage"
FHIA-21	1.54^{A}_{a}	9.54^{B}_{a}	3.56^{A}_{a}	ND	5-6
FHIA-01	5.60^{A}_{a}	ND	7.68^{A}_{a}	ND	5-6

*** 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.
$^{++}$ = Control plantain
ND = No Data

(b) 3.0 kgf

Variety	1-2	3-4	5-6	7	Stage at peel breakages
SH 3640	2.78^{A}_{a}	10.79^{A}_{ab}	17.86^{AB}_{b}	ND	5-6
PITA 16	2.83^{A}_{a}	4.41^{A}_{ab}	7.90^{AB}_{bc}	12.01^{A}_{c}	5-6
CRBP 39	1.84^{A}_{a}	5.28^{A}_{ab}	4.24^{A}_{a}	10.18^{A}_{b}	3-4
PV 42-320	2.41^{A}_{a}	3.25^{A}_{a}	9.78^{AB}_{ab}	12.45^{A}_{b}	7
PV 42-81	2.24^{A}_{a}	9.57^{A}_{b}	ND	13.88^{A}_{b}	7
Maricongo^{++}	2.25^{A}_{a}	9.49^{A}_{a}	6.89^{AB}_{a}	10.85^{A}_{a}	7
FHIA-21	2.85^{A}_{a}	11.90^{A}_{a}	6.99^{AB}_{a}	ND	3-4
FHIA-01	12.39^{B}_{a}	ND	20.66^{B}_{a}	ND	5-6

*** 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.
$^{++}$ = Control plantain
ND = No Data

(c) 4.5 kgf

Variety	1-2	3-4	5-6	7	Stage at peel breakages
SH 3640	3.82^{AB}_{a}	17.15^{A}_{b}	12.37^{AB}_{ab}	ND	3-4
PITA 16	3.98^{AB}_{a}	6.60^{A}_{ab}	8.75^{A}_{bc}	12.80^{A}_{c}	5-6
CRBP 39	3.52^{A}_{a}	8.17^{A}_{a}	6.10^{A}_{a}	8.48^{A}_{a}	3-4
PV 42-320	1.82^{A}_{a}	4.70^{A}_{a}	9.13^{AB}_{ab}	14.47^{A}_{b}	5-6
PV 42-81	3.70^{A}_{a}	10.19^{A}_{b}	ND	13.60^{A}_{b}	3-4
Maricongo++	3.48^{A}_{a}	7.96^{A}_{a}	13.66^{AB}_{a}	14.75^{A}_{a}	5-6
FHIA-21	4.38^{AB}_{a}	18.61^{A}_{a}	8.81^{A}_{a}	ND	3-4
FHIA-01	11.27^{B}_{a}	ND	24.85^{B}_{b}	ND	5-6

*** 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.
++ = Control plantain
ND = No Data

The demand of high quality fruits by consumers increases the need for this type of test that provides information about the design, handling and transport requirements to minimize mechanical damage (Idah et al., 2007). The major cause of fruit losses is mechanical damage due to impact. The effect of the impact depends on the height that fruits are dropped from and the maturation stage of fruits (Idah et al., 2007).

Table 20 presents the average maximum deformation (in mm) of fruits impacted at the three probe velocities (6, 8 and 10 m/s). Again, each probe velocity represents a given drop height (5, 10 and 15 ft, respectively). Differences in probe velocity or variety did not explain the observed variability. Data, in general, shows how deformation values (mm) increases as maturation progress. In fact, considering all data, significant difference were found according to maturity stage (i.e., green 1.72 mm; mature green 3.10; mature 4.93). Deformation for the overripe stage (5.84 mm), however, was not significantly different than at the mature stage. As with the stack test, the columns labeled "stage at peel breakage" indicates the stage of maturity where the peel broke under the applied stress. It can be seen that several varieties resisted the applied stresses, as well as the Control, without peel breakage.

Table 20: Maximum deformation (mm) of fruits dropped at equivalent heights of (a) 5 ft (b) 10 ft and (c) 15 ft at the different maturity stages.

(a) 5 ft (Probe velocity 6 m/s)

Variety	1-2	3-4	5-6	7	Stage at peel breakages
SH 3640	1.37^{A}_{a}	3.70^{A}_{ab}	8.47^{A}_{b}	ND	5-6
PITA 16	1.53^{A}_{a}	2.80^{A}_{ab}	4.64^{A}_{b}	4.52^{A}_{b}	"no breakage"
CRBP 39	1.20^{A}_{a}	2.58^{A}_{a}	2.65^{A}_{a}	5.79^{A}_{a}	"no breakage"
PV 42-320	6.06^{B}_{a}	1.91^{A}_{a}	4.51^{A}_{a}	6.16^{A}_{a}	7
PV 42-81	1.76^{A}_{a}	2.33^{A}_{a}	ND	6.08^{A}_{b}	7
Maricongo++	0.69^{A}_{a}	2.02^{A}_{a}	2.51^{A}_{a}	5.62^{A}_{b}	"no breakage"
FHIA-21	1.86^{A}_{a}	5.97^{A}_{a}	4.42^{A}_{a}	ND	"no breakage"
FHIA-01	2.27^{A}_{a}	ND	5.12^{A}_{b}	ND	5-6

*** 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.
++ = Control plantain
ND = No Data

(b) 10 ft (Probe velocity 8 m/s)

Variety	1-2	3-4	5-6	7	Stage at peel breakages
SH 3640	1.48^{A}_{a}	3.39^{A}_{ab}	8.48^{A}_{b}	ND	5-6
PITA 16	1.53^{A}_{a}	2.88^{A}_{ab}	4.17^{A}_{b}	4.43^{A}_{b}	"no breakage"
CRBP 39	1.00^{A}_{a}	2.75^{A}_{ab}	2.00^{A}_{ab}	6.16^{A}_{b}	"no breakage"
PV 42-320	2.41^{A}_{a}	1.96^{A}_{a}	4.42^{A}_{ab}	6.23^{A}_{b}	7
PV 42-81	1.16^{A}_{a}	2.94^{A}_{b}	ND	6.15^{A}_{c}	7
Maricongo++	0.90^{A}_{a}	2.06^{A}_{a}	2.88^{A}_{a}	6.35^{A}_{b}	"no breakage"
FHIA-21	1.97^{A}_{a}	4.56^{A}_{a}	4.07^{A}_{a}	ND	"no breakage"
FHIA-01	2.40^{A}_{a}	ND	8.11^{A}_{a}	ND	5-6

*** 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.
++ = Control plantain
ND = No Data

(c) 15 ft (Probe velocity 10 m/s)

Variety	1-2	3-4	5-6	7	Stage at peel breakages
SH 3640	1.61^{A}_{a}	3.25^{A}_{ab}	5.84^{A}_{b}	ND	5-6
PITA 16	1.77^{A}_{a}	3.67^{A}_{ab}	4.57^{A}_{b}	4.55^{A}_{b}	"no breakage"
CRBP 39	2.60^{A}_{a}	2.65^{A}_{a}	2.3^{A}_{a}	5.16^{A}_{a}	"no breakage"
PV 42-320	1.82^{A}_{a}	2.26^{A}_{ab}	5.12^{A}_{bc}	5.68^{A}_{c}	7
PV 42-81	1.25^{A}_{a}	3.42^{A}_{ab}	ND	7.42^{A}_{b}	7
Maricongo^{++}	0.87^{A}_{a}	2.15^{A}_{a}	2.77^{A}_{a}	6.09^{A}_{b}	"no breakage"
FHIA-21	2.52^{A}_{a}	4.51^{A}_{a}	3.22^{A}_{a}	ND	"no breakage"
FHIA-01	2.43^{A}_{a}	ND	4.48^{A}_{b}	ND	5-6

*** 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.
$^{++}$ = Control plantain
ND = No Data

4.13 Peeling force

Consumers prefer easy peeling fruits. Determination of peeling force provides information about which plantain is more or less easy to peel at different stages of maturation. On study to determine physico-mechanical properties of orange peel and pulp, results reflect how peeling force decreases according storage time in ambient and refrigerated conditions (Singh and Reddy, 2005). Dadzie and Orchard (1997) found that at green stage, ease of peeling depends on peel thickness and its adhesion to the pulp and, as fruits ripen, in general, they are easier to peel. Dadzie (1998) worked with hybrids FHIA-03, FHIA-06 and Bluggoe to determine the peeling force. Results showed that cooking banana hybrids had significantly higher values of peeling force than their Control (Cuerno). They results was analyze subjectively. High values of peeling force tell which plantains are more difficult to peel.

Table 21 shows average peeling force (g) as fruit mature. In general, data agrees with reported literature that indicates decreasing peeling force with fruit maturity. For the Control specifically, there is a decreasing tendency in average peeling force with maturity, but significance could not be established.

At green stage (1-2), no significant differences were found between the Control (776.66 g) and other varieties. It must be noted, however, that peeling force for the Control fell on the lower end of the range; suggesting it might be easier to peel than other varieties whose peel force ranged from 931.48 g (PITA 16) to 1220.93 g (PV 42-320).

At 3-4 stage, only PV 42-320 (1699.25 g) had significantly higher peeling force than the Control (513.36 g). Peel force for varieties similar to the Control ranged from 394.44 g (PV 42-81) to 982.64 g (FHIA-21).

Table 21: Peeling force (g) at the different maturity stages.

Variety	**1-2**	**3-4**	**5-6**	**7**
SH 3640	1451.42^{A}_{b}	571.77^{A}_{ab}	132.66^{A}_{a}	ND
PITA 16	931.48^{A}_{b}	623.71^{A}_{ab}	431.85^{A}_{ab}	353.46^{A}_{a}
CRBP 39	1014.00^{AB}_{b}	569.53^{A}_{ab}	ND	97.66^{A}_{a}
PV 42-320	ND	1699.25^{B}_{a}	277.31^{A}_{b}	ND
PV 42-81	1220.93^{A}_{b}	394.44^{A}_{a}	ND	218.85^{A}_{a}
Maricongo[++]	776.66^{A}_{a}	513.36^{A}_{a}	415.66^{A}_{a}	ND
FHIA-21	1121.84^{A}_{a}	982.64^{AB}_{a}	597.57^{A}_{a}	ND
FHIA-01	962.51^{A}_{a}	ND	839.17^{A}_{a}	71.47^{A}_{a}

*** 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.
[++] = Control plantain
ND = No Data

At the last stages of maturity (5-6 and 7), no significant differenced were found among cultivars. Data obtained in this study agrees with values reported by Dadzie (1998).

5. CONCLUSIONS

The main objective of this study was to determine the potential use of the Black Sigatoka resistant hybrids (SH 3640, CRBP 39, PITA 16, PV-42-320, PV 42-81, FHIA-21 and FHIA -01) by evaluating their fresh market and processing characteristics. In order to accomplish the objective, samples of each variety were gathered and subjected to a battery of test to evaluate the chemical properties, color changes, processing properties and resistance to mechanical damages. **Table 22** to **24** present comparative summaries of data at the different maturity stages. Symbol such as "+", "=" and "– refer to the relationship between Control data and data of varieties ("+" = higher values; "-" = lower values; "=" no significant difference). Data entries "ND" mean the value is missing.

At green stage (1-2), (**Table 22**) the best performances were exhibited by PITA 16, CRBP 39 and PV 42-81. PITA 16 lasted more days at storage time and have quality characteristics more similar to the Control, but moisture content is higher and pulp yield lower. CRBP 39 lasted less days in storage time and has higher moisture content than the Control, but other characteristics, including yield, are similar. PV 42-81 has similar characteristics to the Control, but its processing properties fall short. In other words, moisture absorption and moisture content are significantly higher than the Control and its yield is lower.

At mature stage (5-6), (**Table 23**) the best performances were observed in SH 3640, PITA 16 and PV 42-320. SH 3640 lasted more days of storage time. Other characteristics that are equal to the Control are degrees Brix, pH, weight loss, and fat and moisture absorption. A difference behavior was observed on moisture content (higher values); which considered a bad quality characteristic. PITA 16 exhibits better quality characteristics than the Control. Some of these characteristic include lower weight loss and lasted more days in storage time. The same behavior was observed in PV 42-320, which lasted more days at storage time and had lower weight loss.

At overripe stage (7), (**Table 24**) varieties that outperform the Control are CRBP 39, PV 42-81 and FHIA-21. CRBP 39 has lower degrees Brix and yield values than the Control (Maricongo). PV 42-81 lasted more days at storage time, but has lower yield values. FHIA-21 lasted less under storage and had lower yield values than the Control.

In conclusion, for fresh and processing market, data obtained shows that PITA 16 and CRBP 39 present quality characteristics that would make them suitable replacement for Maricongo (Control).

It must be noted, however, that PITA 16 has different physical appearance to the Control as it is smaller compared with the expected size for plantain. In addition, PITA 16 has visible seeds inside that may negatively influence the consumer and traders' acceptance. CRBP 39, on the other hand, has smaller diameter than the Control; resulting in lower pulp yields and given the impression of thin plantains.

Table 22: Comparative summary of data at green stage (1-2)

Variety	Green (1-2)											
Test	Storage time (days)	Brix	pH	Weight Loss	Cut Strength	Fat absorption	Moisture Absorption	Moisture content	Yield	Impact	Stack	Peeling Force
**Maricongo	7 to 10	6.67	5.83	2.87	736.45	3.12	11.4	0.59	0.61	NB	NB	776.66
SH 3640	-	=	=	=	-	=	=	+	-	-	-	=
PITA 16	+	=	=	+	=	=	=	+	-	=	-	=
CRBP 39	-	=	=	=	=	=	=	+	=	=	-	=
PV 42-320	=	=	=	=	=	ND	ND	ND	ND	-	-	ND
PV 42-81	=	=	=	=	-	=	+	+	-	-	-	=
FHIA-21	-	=	=	=	=	=	=	+	-	=	-	=
FHIA-01	-	=	=	=	-	=	+	+	-	-	-	=

"+" = higher values; "-" = lower values; "=" no significant difference ; ND = No data and NB = No breakage

Table 23: Comparative summary of data at mature stage (5-6)

Variety	Mature (5-6)											
Test	Storage time (days)	Brix	pH	Weight Loss	Cut Strength	Fat absorption	Moisture Absorption	Moisture content	Yield	Impact	Stack	Peeling Force
**Maricongo	less 4	24.32	4.40	11.29	126.85	12.02	30.85	0.61	0.72	NB	NB	415.66
SH 3640	+	=	=	=	=	=	=	+	=	-	-	=
PITA 16	+	=	=	-	=	=	=	+	=	=	-	=
CRBP 39	=	=	=	ND	ND	ND	ND	ND	ND	=	-	ND
PV 42-320	+	=	=	-	=	=	=	+	=	-	-	=
PV 42-81	=	=	=	ND	=	=	+	+	-	-	-	ND
FHIA-21	=	-	=	=	+	=	=	+	ND	=	-	=
FHIA-01	=	=	=	=	=	=	=	+	-	-	-	=
"+" = higher values; "-" = lower values; "=" no significant difference ;ND = No data and NB = No breakage												

Table 24: Comparative summary of data at overripe stage (7)

Variety	Overripe (7)											
Test	**Storage time (days)**	**Brix**	**pH**	**Weight Loss**	**Cut Strength**	**Fat absorption**	**Moisture Absorption**	**Moisture content**	**Yield**	**Impact**	**Stack**	**Peeling Force**
**Maricongo	4 to 7	31.21	4.27	17.08	113.16	21.84	48.61	0.63	0.78	NB	NB	ND
SH 3640	=	-	+	=	=	=	=	ND	ND	-	-	
PITA 16	=	-	+	+	=	=	=	+	=	=	-	
CRBP 39	=	-	+	=	=	=	=	=	-	=	-	
PV 42-320	=	-	+	=	=	ND	ND	ND	ND	-	-	
PV 42-81	+	-	=	=	-	=	=	+	-	-	-	
FHIA-21	-	=	=	=	-	=	=	=	-	=	-	
FHIA-01	-	-	=	=	-	=	=	+	-	-	-	

"+" = higher values; "-" = lower values; "=" no significant difference ;ND = No data and NB = No breakage

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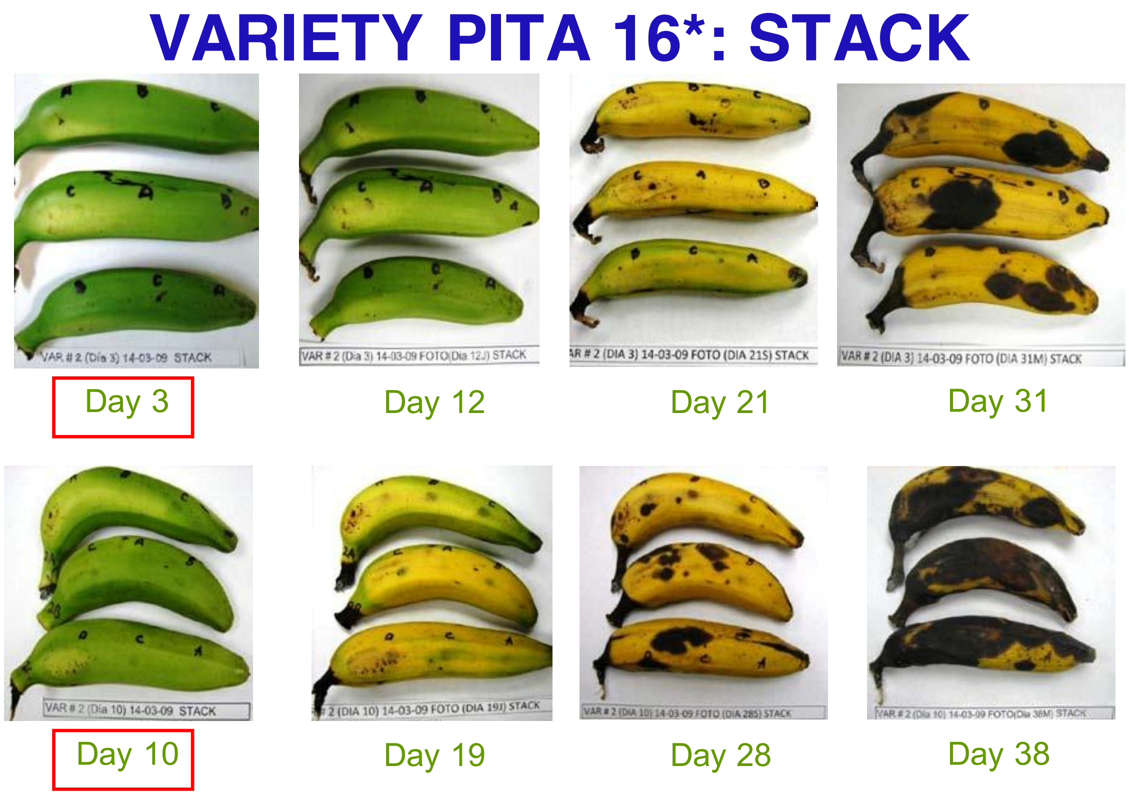
7. APPENDIX

Appendix 1: Photos of variety PITA 16 at stack test



Appendix 2: Photos of variety PITA 16 at stack test

VARIETY PITA 16*: STACK (cont.)

Day 17

Day 26

Day 35

Day 24

Day 33

Day 31

Day 40

Appendix 3: Photos of variety CRBP 39 at stack test

VARIETY CRBP 39*:STACK

Day 1

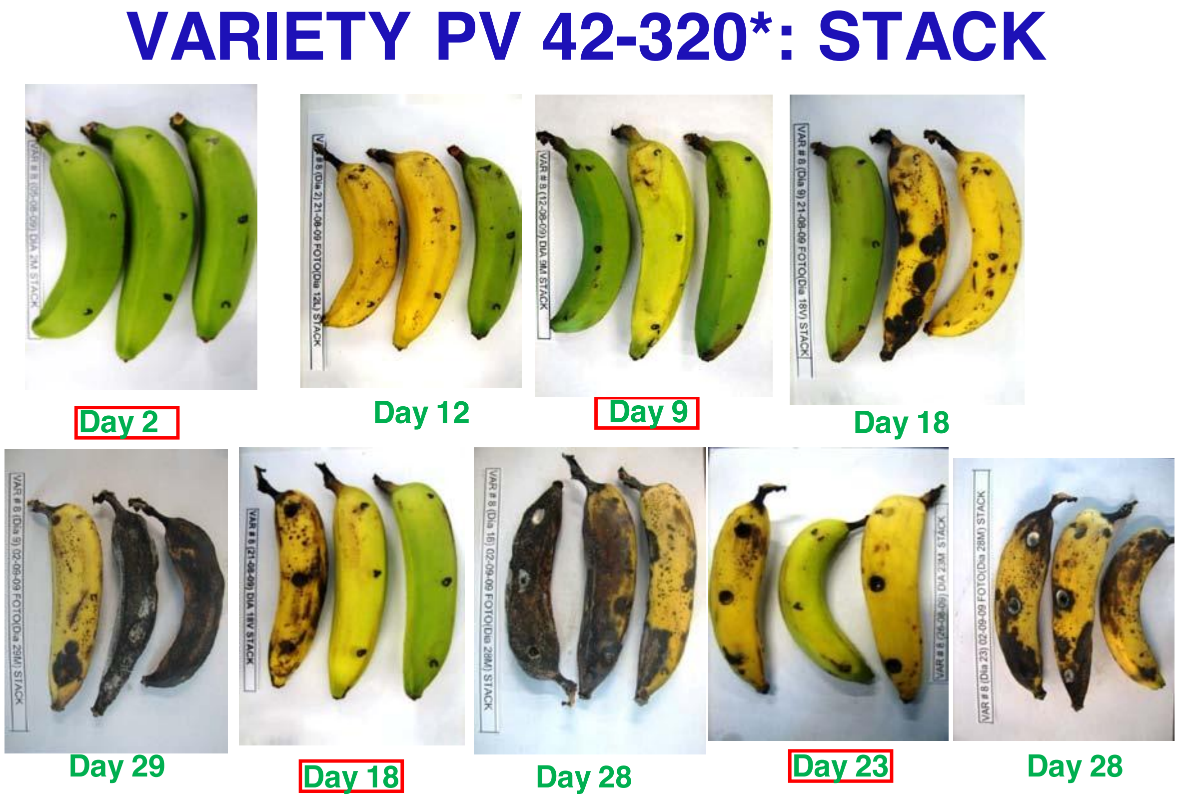
Day 9

Day 16

Day 23

Day 30

Appendix 4: Photos of variety PV 42-320 at stack test



Appendix 5: Photos of variety Maricongo at stack test

VARIETY MARICONGO*: STACK

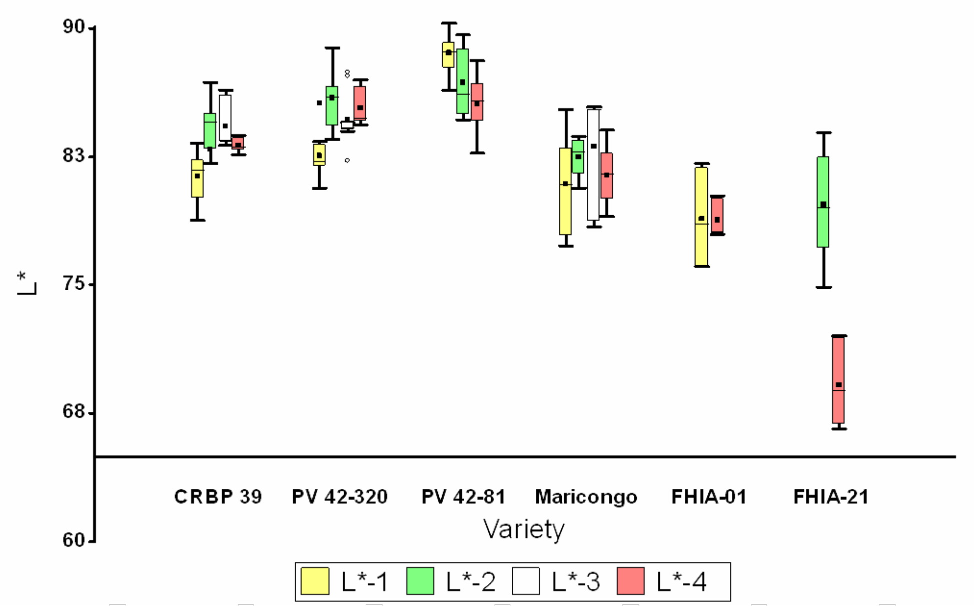
Day 1

Day 9

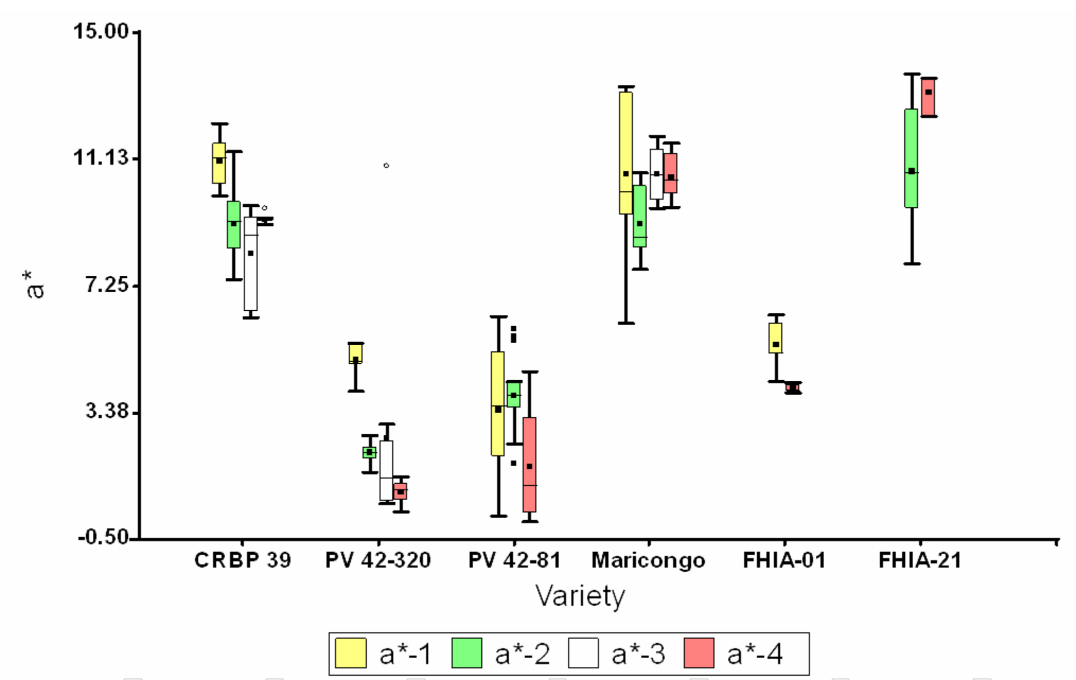
Day 16

Day 23

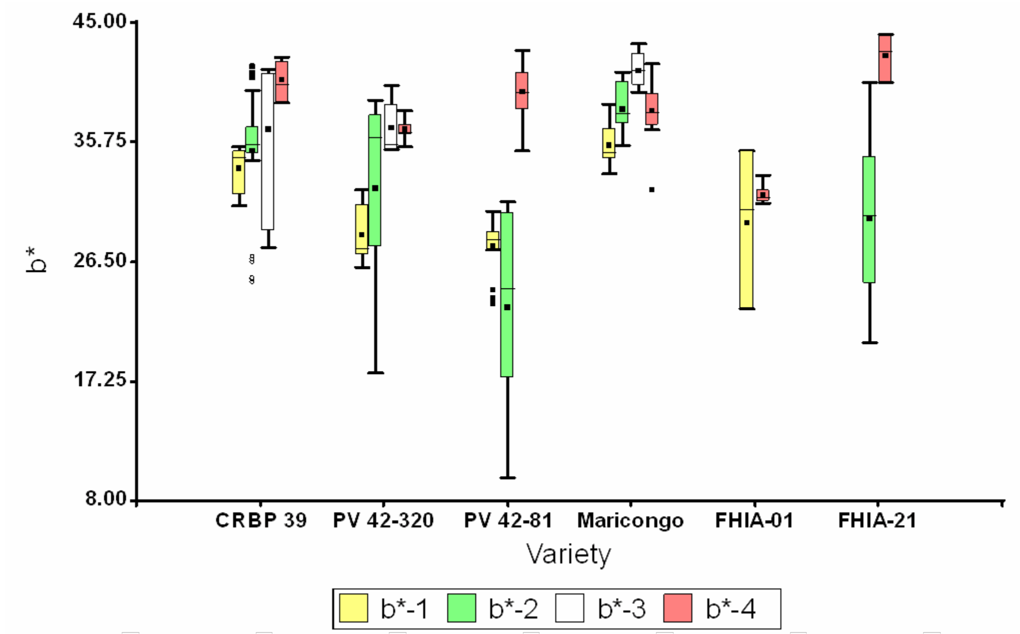
Appendix 6: L data for pulp



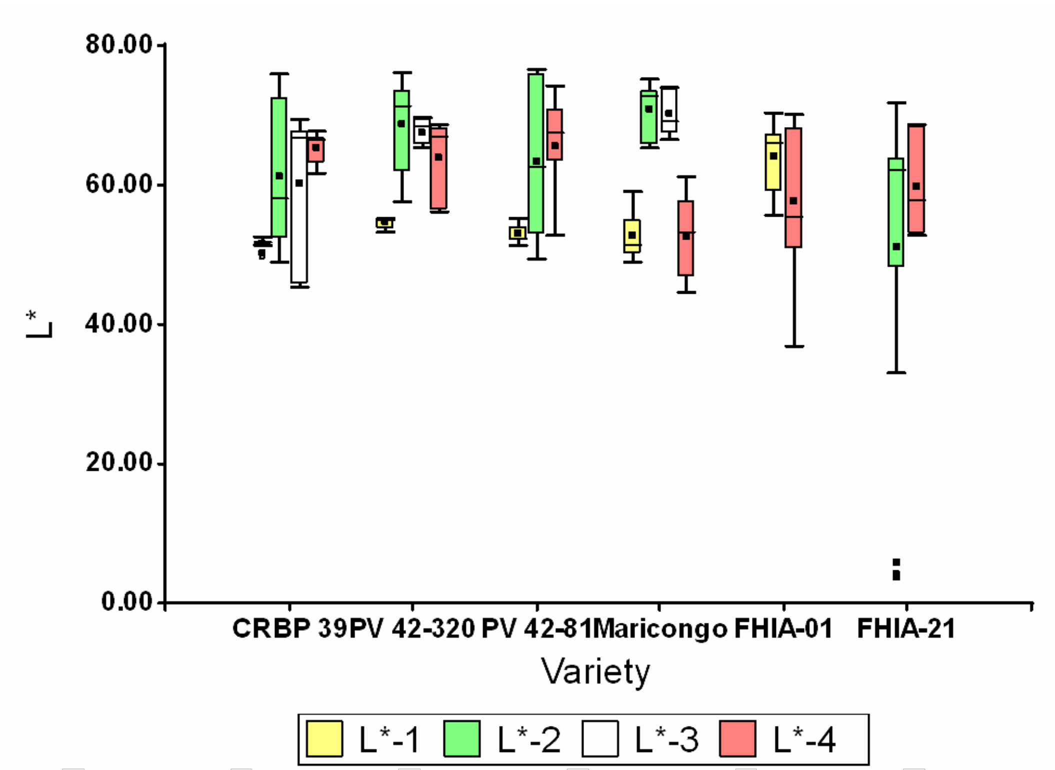
Appendix 7: a data for pulp



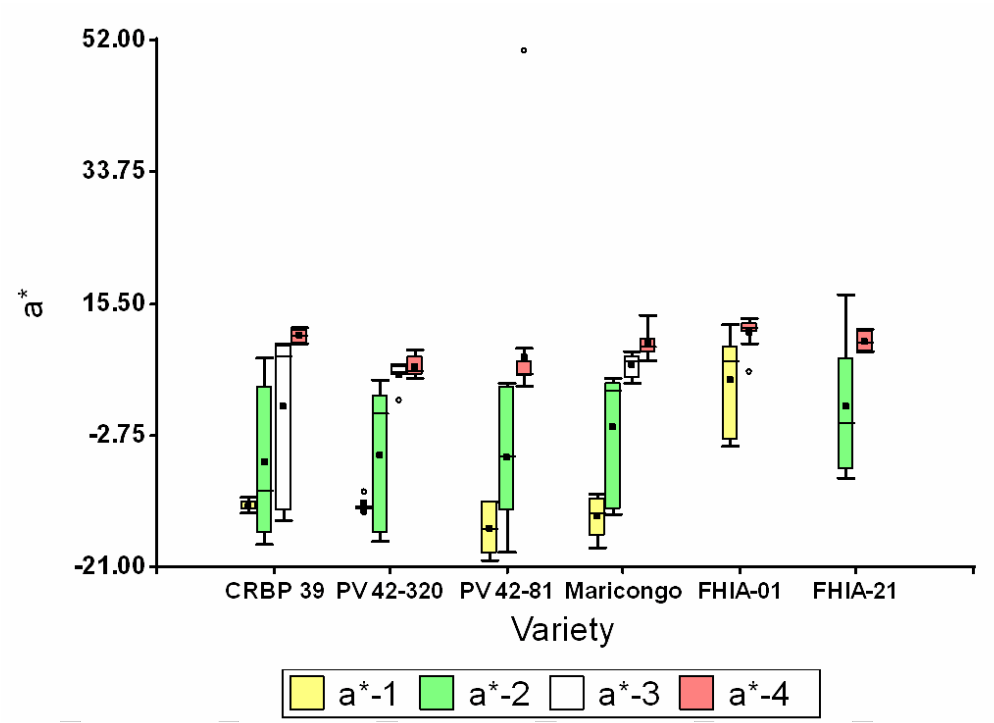
Appendix 8: b data for pulp



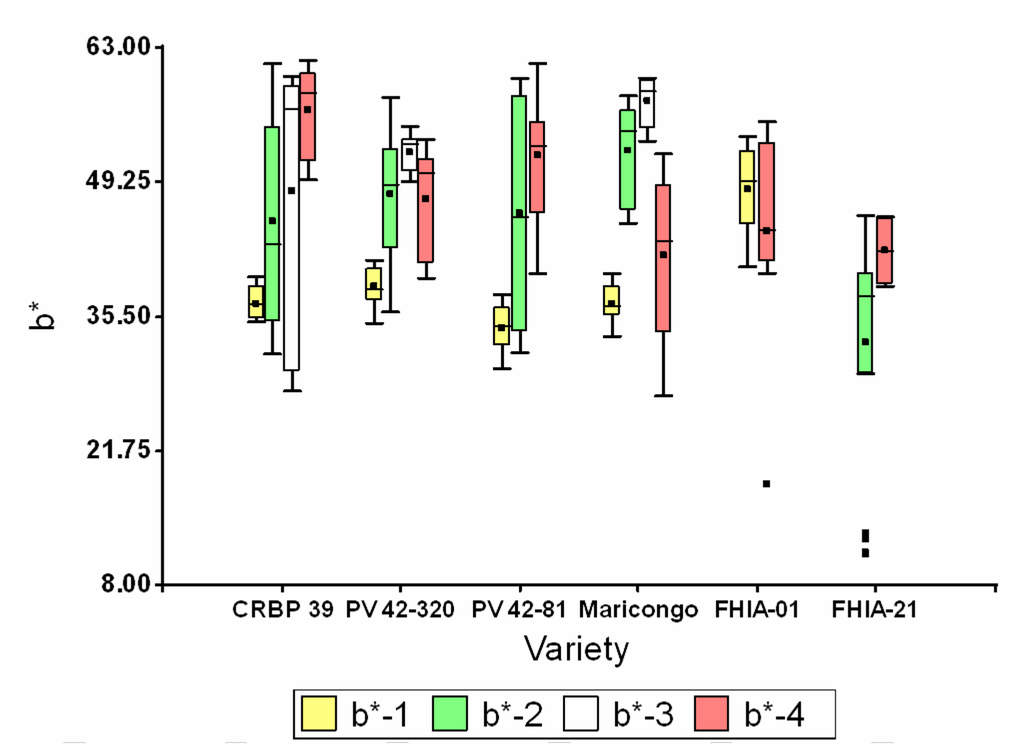
Appendix 9: L data for peel



Appendix 10: a data for peel



Appendix 11: b data for peel



Appendix 1: Information of Black Sigatoka field experiment established on 2008 at the USDA-TARS Isabela, PR.

Accession[1]	Country of Origin	Institute	Genome	Other identifier
SH 3640	Honduras	Fundación Hondureña de Investigación Agrícola (FHIA)	AAAB	ITC 1307
PITA 16	Nigeria	International Institutue for Tropical Agriculture (IITA)	AAB	ITC 1417
CRBP 39	Cameroon	Cameroon, African Research Centre on Banana and Plantain (CARBAP)	AAAB	ITC 1344
PV 42-320	Brazil	Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA)	AAAB	ITC 1313
PV 42-81	Brazil	Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA)	AAAB	ITC 1312
Maricongo	Puerto Rico	Local selection	AAB	TARS 16509
FHIA-21[3]	Honduras	Fundación Hondureña de Investigación Agrícola (FHIA)	AAAB	ITC 1331
FHIA-01[3]	Honduras	Fundación Hondureña de Investigación Agrícola (FHIA)	AAAB	ITC 0504

[1] All improved hybrids that came through ITC are protected with Stadard Material Transfer Agreement (SMTA)

[3] FHIA-25 and FHIA-20 came from Fundación Hondurña de Investigación Agrícola. A second accesion of FHIA-25 came from ITC (Bioversity).