Inibap Technical Guidelines 4

Post-harvest characteristics of black Sigatoka resistant banana, cooking banana and plantain hybrids

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Contents

Introduction

As starchy foods, banana, cooking banana and plantain (*Musa* spp. AAA, AAB and ABB groups) are important sources of high-calorie energy (Johnson, 1958). They are major staple crops for millions of people in the tropical world. In West and central Africa, they supply approximately 70 million people more than a quarter of their food energy needs (IITA, 1992; Swennen, 1990). Banana, cooking banana and plantain exports are essential for the economies of central and South America, and the West Indies. However, in recent years, their production has been seriously threatened by decreasing soil fertility, yield-decline phenomena, pest problems and black Sigatoka (*Mycosphaerella fijiensis*), a serious leaf-spot disease (Stover and Simmonds, 1987). Products are available for chemical control of the disease. However, banana, cooking banana and plantain cultivation is currently in great jeopardy in many countries due to the development of pathogen resistance to systemic fungicides, coupled with the difficulty and high cost of controlling the disease. Chemical treatments are also health hazards and can threaten fragile ecosystems in producing countries. Durable host-resistance is thus considered to be the best available option for black Sigatoka control.

The *Fundación Hondureña de Investigación Agrícola* (FHIA) in Honduras, through years of breeding and selection, have identified some promising tetraploid banana (FHIA-01 and FHIA-02), cooking banana (FHIA-03) and plantain (FHIA-21 and FHIA-22) hybrids with superior agronomic and disease-resistance characteristics. However, few studies have focused on defining the post-harvest characteristics and consumer acceptability of these new hybrids. In 1993, a collaborative project was therefore set up, involving the International Network for the Improvement of Banana and Plantain (INIBAP), the Natural Resources Institute (NRI) and the FHIA, with funding from the British Department For International Development (DFID).

This manual is based on the results of 2.5 years (1993 - 1995) of research work conducted at FHIA (Honduras) as part of an international collaborative project on post-harvest banana and plantain characterisation (Dadzie, 1993a,b,c; 1994a,b,c). The manual describes post-harvest characteristics at harvest, maturation, green-life, ripening quality and organoleptic features of these black Sigatoka resistant hybrids. It is designed to serve as a reference manual and provide basic valuable information to assist researchers in post-harvest evaluation of FHIA hybrids under the International *Musa* Testing Programme (IMTP). The manual provides useful information for private individuals and companies contemplating growing FHIA hybrids as substitutes for black Sigatoka susceptible cultivars.

The manual is divided into three chapters. Chapter 1 is devoted to two banana hybrids, FHIA-01 and FHIA-02, with comparisons to two commercial cultivars, Grande Naine and Williams. Chapter 2 describes one cooking banana hybrid, FHIA-03. In chapter 3, two plantain hybrids, FHIA-21 and FHIA-22, are compared to Cuerno (Horn Plantain).

1. Banana hybrids

Through breeding and selection, FHIA has developed two promising tetraploid banana hybrids, FHIA-01 (Figure 1) and FHIA-02 (Figure 2), that are resistant to black Sigatoka. The post-harvest characteristics at harvest, maturation, green-life, ripening quality and organoleptic features of these hybrids are presented, as well as comparisons with two commercial black Sigatoka susceptible triploid cultivars, Grande Naine and Williams. The materials and methods used to obtain the results/data presented in the tables and figures below were previously described by Dadzie and Orchard, (1996); Dadzie, (1993a,b,c); (1994a,b,c).

Genomic group

Table 1 shows the type, genomic group and parentage of FHIA-01 and FHIA-02 banana hybrids.

Table 1. Type, genomic group and parentage of FHIA-01 and FHIA-02

Characteristics	FHIA-01	FHIA-02
Type	Banana	Banana
Genomic group	AAAB	AAAB
Parentage	SH-3142 x Prata Aña	Williams x SH-339

Disease resistance

FHIA-01 has the following disease resistance features (FHIA, 1993):

* Highly resistant to black Sigatoka (*Mycosphaerella fijiensis*)
* Resistant to race 1 of Fusarium wilt (Panama disease)
* Resistant to race 4 of Fusarium wilt
* Tolerance to burrowing nematodes
* Resistant to crown rot disease.

FHIA-02 has the following disease resistance features (FHIA, 1993):

* Highly resistant to black Sigatoka (*Mycosphaerella fijiensis*)
* Resistant to crown rot disease.

Uses

The following are some of the uses of FHIA-01 and FHIA-02 bananas:

* Eaten as dessert bananas when ripe
* Cooked or boiled green or unripe and eaten as a vegetable
* Fried when ripe or unripe to make chips
* Baked when ripe or green
* Mashed
* Peel can be used for feeding livestock, soup-making and as a tenderiser.

Drawbacks

The following are some of the drawbacks of FHIA-01 and FHIA-02 bananas:

* When ripe both FHIA-01 and FHIA-02 bananas are softer (or less firm) than triploid cultivars such as Grande Naine and Williams
* FHIA-01 is slightly susceptible to finger drop at colour stage 6 and beyond
* FHIA-02 is highly susceptible to finger drop at colour stage 6 and beyond.

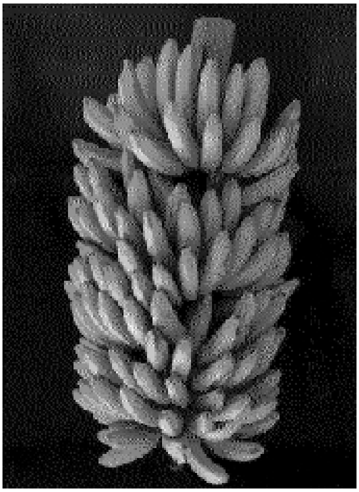
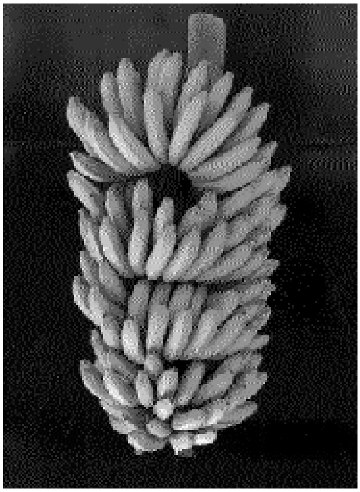


Figure 1. Typical bunch of FHIA-01 bananas (left).

Figure 2. Typical bunch of FHIA-02 bananas (right).



POST-HARVEST CHARACTERISTICS AT HARVEST

The post-harvest characteristics at harvest used to assess FHIA-01 and FHIA-02 include:

a. Bunch and fruit characteristics
b. Post-harvest quality.

Tables 2 and 3 show the post-harvest characteristics (at harvest) of FHIA-01 and FHIA-02 banana hybrids.

Table 2. Bunch and fruit characteristics (at harvest) of FHIA-01 and FHIA-02.

Characteristics	FHIA-01	FHIA-02
Bunch weight (kg)	30 - 40	12 - 18
Number of hands	10 - 12	10 - 12
Fruit weight (g)	150 - 240	90 - 150
Fruit length (cm)	18 - 23	17 - 21
Fruit circumference (cm)	12 - 16	10 - 14
Pedicel length (cm)	1.7 - 3.0	1.4 - 2.3
Pulp weight (g)	70 - 130	55 - 80
Peel weight (g)	65 - 110	60 - 75
Pulp to peel ratio	0.90 - 1.20	0.80 - 1.10
Pulp thickness (cm)	3.00 - 3.80	2.50 - 3.00
Peel thickness (cm)	0.35 - 0.45	0.30 - 0.40

Table 3. Post-harvest qualities (at harvest) of FHIA-01 and FHIA-02

Characteristics	FHIA-01	FHIA-02
Peel colour	Green	Green
Pulp colour	White/creamy	White/creamy
Pulp firmness (kgf)	0.86 - 1.30	0.90 - 1.35
Pulp pH	5.30 - 6.50	5.70 - 6.40
Titratable acidity (mEq/100 g)	2.50 - 3.00	2.00 - 2.50
Pulp dry matter content (%)	23 - 25	22 - 25
Pulp moisture content (%)	75 - 77	75 - 78

Comparison of the post-harvest characteristics (at harvest) of Grande Naine and Williams banana cultivars to those of FHIA-01 and FHIA-02

The acceptability of the new FHIA banana hybrids will generally be assessed in terms of the post-harvest characteristics (at harvest) of the best currently available commercial cultivars, which mainly belong to the Cavendish group. The post-harvest characteristics (at harvest) of Grande Naine and Williams are compared below to those of FHIA-01 and FHIA-02 (Figure 3).

a. Genomic group and bunch characteristics

Table 4 shows the genomic group, black Sigatoka resistance and bunch characteristics of Grande Naine and Williams relative to FHIA-01 and FHIA-02. FHIA-01 and FHIA-02 are tetraploid (AAAB) banana hybrids, while Grande Naine and Williams are triploid (AAA) dessert bananas that are grown commercially for export. Compared to FHIA-01, Grande Naine and Williams had smaller bunch sizes ($P < 0.01$), with fewer hands per bunch (Table 4) compared to both FHIA-01 and FHIA-02.

Table 4. Genomic group, black Sigatoka resistance and bunch characteristics of Grande Naine and Williams compared to FHIA-01 and FHIA-02.

	Cultivar/hybrid			
Characteristics	Grande Naine	Williams	FHIA-01	FHIA-02
Type	Banana	Banana	Banana	Banana
Genomic group	AAA	AAA	AAAB	AAAB
Black Sigatoka resistance	S	S	HR	HR
Bunch weight (kg)	34.65[b1]	24.90[c]	37.42[a]	14.38[d]
Number of hands	9.00[b]	7.70[c]	10.70[a]	12.31[a]

HR: Highly resistant - S: Susceptible
[1] Letters in common within rows were not significantly different at the 1% level by Duncan's multiple range test.

b. Fruit characteristics

Table 5 indicates the fruit characteristics (at harvest) of Grande Naine and Williams compared to FHIA-01 and FHIA-02. Mean fruit weight was higher in FHIA-01 than in Grande Naine, Williams and FHIA-02. FHIA-01, Grande Naine and Williams had statis-tically similar fruit lengths, but there was a significant difference compared to FHIA-02 ($P < 0.01$). FHIA-01 and Grande Naine had similar fruit girths, but they differed significantly in comparison to FHIA-02 and Williams. Pulp and peel weights were hybrid/cultivar-dependent ($P < 0.01$), and Grande Naine had a higher mean pulp weight than FHIA-01 and FHIA-02. In contrast, FHIA-01 had a higher mean peel weight compared to Grande Naine and Williams. The high peel content in FHIA-01 could be an advantage, i.e. offering protection against mechanical damage during handling and shipping. Furthermore, hybrids such as FHIA-01 would be very useful in some African and Asian countries where banana peel is used in making soap, for tenderizing meat and feeding livestock. Grande Naine and Williams had a higher mean pulp to peel ratio compared to the two tetraploid hybrids. This indicates that Grande Naine and Williams had a more edible portion per unit fresh weight of fruit in comparison to FHIA-01 and FHIA-02. Pulp thickness was similar in Grande Naine and Williams, but significantly different compared to FHIA-01 or FHIA-02 ($P < 0.01$; Table 5). FHIA-01 had a higher mean peel and pulp thickness compared to Grande Naine and Williams. The fruit of FHIA-01 is resistant to mechanical injury during handling because of its very thick peel.

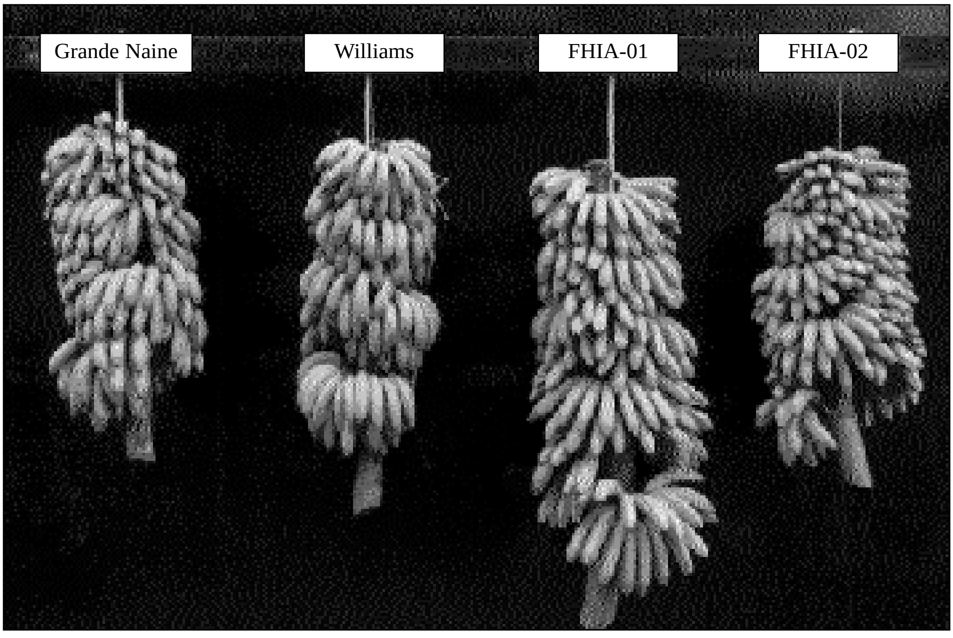


Figure 3. Bunches of Grande Naine, Williams, FHIA-01 and FHIA-02 bananas.

Table 5. Fruit characteristics of Grande Naine and Williams compared to FHIA-01 and FHIA-02.

	Cultivar/hybrid			
Characteristics	Grande Naine	Williams	FHIA-01	FHIA-02
Fruit weight (g)	219.59[b1]	198.41[c]	232.83[a]	146.68[d]
Fruit length (cm)	24.02[a]	23.34[ab]	23.05[ab]	21.01[c]
Fruit girth (cm)	13.78[a]	13.27[b]	14.67[a]	12.89[b]
Pulp weight (g)	135.17[a]	121.77[b]	124.41[b]	74.25[c]
Peel weight (g)	84.42[b]	76.63[c]	108.18[a]	72.43[c]
Pulp to peel ratio	1.60[a]	1.59[a]	1.15[b]	1.02[b]
Pulp thickness (cm)	3.27[b]	3.13[b]	3.50[a]	2.86[c]
Peel thickness (cm)	0.36[b]	0.36[b]	0.44[a]	0.38[b]

[1] Letters in common within rows were not significantly different at the 1% level. M
by Duncan's multiple range test.

c. Post-harvest qualities

Table 6 shows the post-harvest qualities of Grande Naine and Williams banana cultivars compared to FHIA-01 and FHIA-02. Consumers often decide whether bananas are ripe or unripe solely on the basis of peel colour. Peel colour is also assessed to predict shelf-life for retail distribution. The peel "L" values obtained for FHIA-01 and FHIA-02 were similar to those of Grande Naine and Williams. In contrast, the peel "a" value of FHIA-01 was significantly different ($P < 0.01$) from that of Grande Naine and Williams. At the mature unripe stage, the peel colour of FHIA-01 was thus greener than that of Grande Naine and Williams. Similarly, the peel "b" value of FHIA-02 was significantly different from Grande Naine and Williams, indicating that FHIA-02 had a slightly yellower peel colour than the triploid cultivars. Visually, the pulp colours of Grande Naine and Williams were similar to those of FHIA-01 and FHIA-02 (i.e. white/creamy). Pulp firmness (at harvest) was similar in Grande Naine and Williams, but significantly different ($P < 0.01$) from FHIA-01 or FHIA-02. Both triploid cultivars were firmer than the tetraploid hybrids. Total soluble solids were not recorded since the fruit was green and unripe. Pulp pH levels of FHIA-01 and FHIA-02 were similar to those of Grande Naine and Williams ($P < 0.01$; Table 6). In contrast, FHIA-01 had higher mean total titratable acidity compared to Grande Naine and Williams. The percentage peel and pulp dry matter content varied in the different cultivars, with Williams having the highest mean peel and pulp dry matter content and FHIA-02 the lowest ($P < 0.01$). The two triploid cultivars had higher mean pulp dry matter contents compared to the two tetraploid hybrids. Peel and pulp moisture contents were cultivar-dependent ($P < 0.01$). FHIA-02 had the highest peel moisture content and Williams the lowest. The pulp moisture content of FHIA-01 and FHIA-02 were similar, but significantly different in comparison to Grande Naine and Williams ($P < 0.01$).

Table 6. Post-harvest qualities of Grande Naine and Williams compared to FHIA-01 and FHIA-02 bananas.

	Cultivar/hybrid			
Characteristics	Grande Naine	Williams	FHIA-01	FHIA-02
Peel L value	59.90[a1]	57.31[b]	57.29[b]	58.00[ab]
Peel a value	-20.11[b]	-20.62[b]	-18.82[a]	-20.87[b]
Peel b value	35.54[b]	34.81[b]	35.14[b]	36.65[a]
Pulp colour	white/creamy	white/creamy	white/creamy	white/creamy
Pulp firmness (kgf)	1.65[a]	1.67[a]	0.86[c]	1.30[b]
Finger drop (%)	8.20[c]	10.40[c]	15.50[b]	35.60[a]
Total soluble solids (%)	-	-	-	-
pH	5.95[a]	6.02[a]	5.77[a]	5.98[a]
Total titratable acidity (mEq/100 g)	2.84[b]	2.23[b]	3.39[a]	2.47[b]
Peel dry matter content (%)	10.26[b]	11.34[a]	10.97[b]	9.06[c]
Pulp dry matter content (%)	25.95[a]	27.38[a]	23.90[b]	23.79[b]
Peel moisture content (%)	89.74[b]	88.66[c]	89.03[b]	90.94[a]
Pulp moisture content (%)	74.05[b]	72.62[b]	76.10[a]	76.21[a]

[1] Letters in common within rows were not significantly different at the 1% level. Mean separa
Duncan's multiple range test.

FRUIT MATURATION

Typical changes during maturation of FHIA-01 and FHIA-02 bananas

During maturation, morphological changes occur in the fruit, i.e. fruit characteristics such as fruit weight, girth relative to length and the pulp to peel ratio can increase. These changes occur concomitantly with other visual changes in the fruit, such as, size, shape, angularity, skin colour and nature of the stylar end. The extent of changes in fruit characteristics during maturation are generally hybrid/cultivar-dependent (Dadzie and Orchard, 1996).

Some typical changes during maturation of FHIA-01 and FHIA-02 bananas are as follows:

a. Visual changes during maturation

Figure 4 (page 12) shows typical visual changes in the morphological characteristics of FHIA-01 and FHIA-02 bananas during maturation. In both hybrids, changes occurred in the fruit size, shape, length and circumference during maturation. As bunches aged, fruit plumpness increased, fingers lost their angularity and the fruit became more rounded and fuller in shape. The stylar ends also become very dry, black and loosely attached to the tip of the fruit. Furthermore, in FHIA-01 and FHIA-02, vertical lines on the fruit surface seemed to be more pronounced in immature fruit, but became less marked as the fruit matured (Figure 4). These visual changes in fruit morphology during maturation are important maturity indices for overall assessment of the time to harvest in FHIA-01 and/or FHIA-02.

b. Changes in fruit characteristics during maturation

The following changes in fruit characteristics occurred during maturation:

i. Fruit weight

Figure 5 shows changes in fruit weight during maturation in FHIA-01 and FHIA-02. FHIA-01 had higher mean fruit weight compared to FHIA-02. There were significant differences in fruit weight at different stages of maturity (P < 0.01). Although there was a significant positive correlation between bunch age and fruit weight, the extent of relationship was cultivar-dependent (Tables 7 and 8). Similarly, there was a linear relationship between bunch age and fruit weight (Tables 7 and 8). This implies that fruit weight increased as bunch age increased. At 70 and 71 days after shooting, the respective mean fruit weights of the FHIA-02 and FHIA-01 banana hybrids were approximately 83 and 102 g, but at 102 and 113 days, respectively, the mean fruit weights had almost doubled (i.e. approx. 165 and 220 g, respectively).

Table 7. Regressions and correlations between bunch age and fruit characteristics during maturation in FHIA-01.

Characteristics	Equation	R^2	r	P<
Bunch age and fruit weight	Y=-68.75+2.5X	0.74	0.86	0.0001
Bunch age and fruit circumference	Y=-7.315+0.065X	0.74	0.86	0.0001
Bunch age and cross-sectional area	Y=-0.467+0.134X	0.77	0.88	0.000
Bunch age and pulp to peel ratio	Y=-0.473+0.014X	0.90	0.95	0.0001

Table 8. Regressions and correlation between bunch age and fruit characteristics during maturation in FHIA-02.

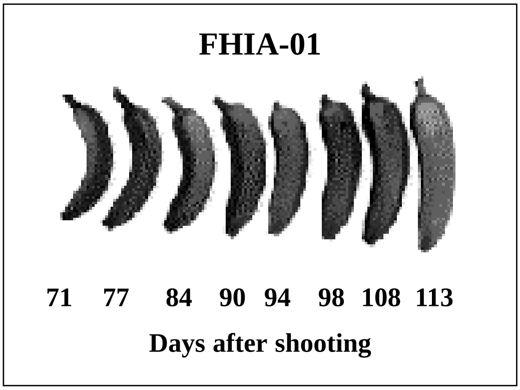
Characteristics	Equation	R^2	r	P<
Bunch age and fruit weight	Y=-70.33+2.3X	0.76	0.87	0.0001
Bunch age and fruit circumference	Y= 5.961+0.073X	0.70	0.84	0.0001
Bunch age and cross-sectional area	Y=-0.32+0.121X	0.71	0.83	0.0001
Bunch age and pulp to peel ratio	Y=-0.0009+0.011X	0.88	0.94	0.0001

ii. Fruit length

Figure 6 shows changes in fruit length during maturation in FHIA-01 and FHIA-02. Finger lengths were generally higher in FHIA-01 than in FHIA-02. In these hybrids, fruit length characteristically increased initially, then leveled off or decreased, followed by an increase as the fruit matured.

iii. Fruit girth or circumference

Figure 7 depicts variations in fruit girth or circumference during maturation in FHIA-01 and FHIA-02. FHIA-01 had consistently higher mean fruit circumferences as compared to FHIA 02. There was a highly significant correlation between bunch age and fruit girth in FHIA-01 and FHIA-02 (Tables 7 and 8). Fruit circumference was plotted as a function of bunch age and indicated a close linear



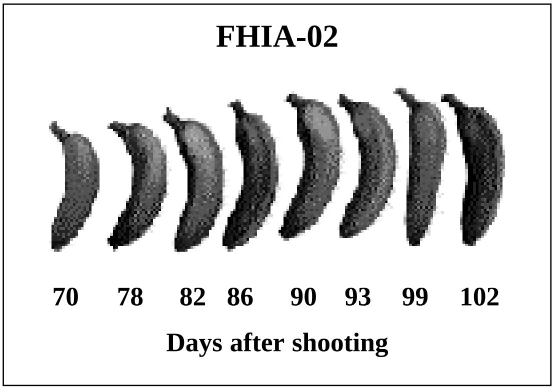


Figure 4. Typical changes in the morphological characteristics of FHIA-01 and FHIA-02 bananas during maturation.

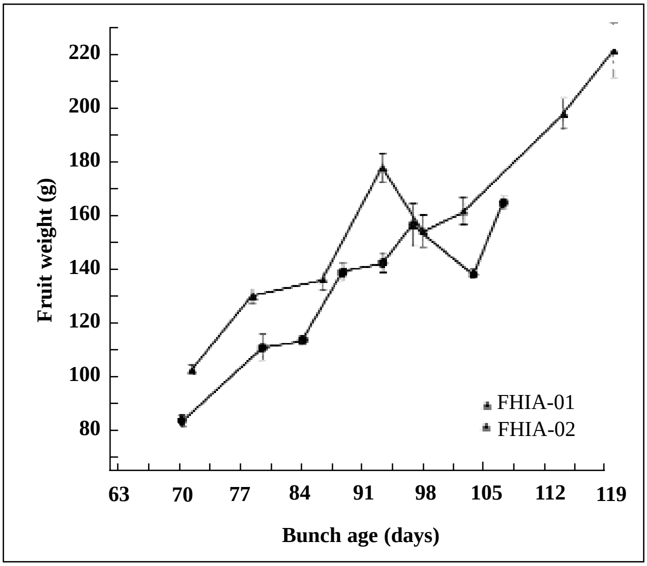


Figure 5. Changes in fruit weight in FHIA-01 and FHIA-02 during maturation.
Vertical bars indicate standard error of the means.

relationship between fruit girth and bunch age.

iv. Fruit cross-sectional area

The fruit cross-sectional dimension (A) was obtained by cutting the fruit transversely at the midpoint and tracing the cut surface on a piece of paper with a soft sharp pencil. The paper was allowed to dry and, due to latex stains, the traced sections were copied onto a clean sheet of paper. The sections were then cut out and weighed (B) on a Mettler balance (± 0.0001). Similarly, a 100 x 100 mm piece of paper was cut and weighed (C). The weight of the 100 x 100 mm paper gave the weight per square millimeters (mm). The weight of traced section per fruit divided by the weight per square mm gave the cross-sectional area for each separate fruit in square millimeters ((B/C)=A).

Figure 8 shows changes in cross-sectional areas of FHIA-01 and FHIA-02 bananas during maturation. The cross-sectional areas of FHIA-01 were consistently higher than those obtained for FHIA-02. Highly significant positive correlations were noted between bunch age and cross-sectional area for FHIA-01 and FHIA-02 (Tables 7 and 8), however the degree of relationship was hybrid-dependent. The fruit cross-sectional dimensions became more round and plump or larger in size with age, thus providing a basis for subjective assessment of fruit age. Moreover, the angles became less sharp or wide as the fruit matured. The photographs (Figure 9) clearly indicated that, in both hybrids, there were also typical changes in the locular architecture of the fruit as maturity progressed. The locular architecture as well as the degenerating seeds in the fruit became more pronounced with fruit maturity.

v. Pulp to peel ratio

Changes in the pulp to peel ratio during fruit maturation represented the most significant index of maturity (Figure 10, page 16). The pulp to peel ratio for FHIA-02 was consistently higher than that obtained for FHIA-01. Variations in pulp to peel ratios of FHIA-01 and FHIA-02 during maturation were hybrid-dependent and varied significantly between different ages of maturity ($P < 0.01$). There was a linear relationship between bunch age and pulp to peel ratio in FHIA-01 and FHIA-02. Highly significant positive correlations were also obtained between bunch age and pulp to peel ratio for FHIA-01 and FHIA-02. FHIA-01 and FHIA-02 were characterized by consistent increases in pulp to peel ratio during fruit maturation. An increase in the pulp to peel ratio during maturation indicated that a more edible portion per unit fresh weight was obtained as bunches aged. The pulp to peel ratio is thus a good fruit maturity indicator.

GREEN-LIFE

Green-life of FHIA-01 and FHIA-02 bananas during storage at 27 ± 1°C

In the banana industry, bananas are usually harvested at a physiologically mature green stage, packed and transported or exported to distant markets where they are ripened. During the period between harvesting and ripening, the fruit should remain firm and green without marked changes in skin colour, texture or composition for extended periods of time (depending on the temperature and humidity) before the onset of ripening. This well defined period after harvest, during which the fruit remains green and firm, is called the pre-climacteric life or green-life (Marriott *et al.*, 1979; Marriott and Montoya, 1981; Peacock, 1966). The process is irreversible once the green-life ends and ripening has been initiated, which means that any fruit in this condition will be overripe at the handling and marketing stage. The green-life of FHIA-01 and FHIA-02 bananas was assessed during storage at 27 ± 1°C.

Figures 11 and 12 (page 16) illustrate the relationship between bunch age and green-life of FHIA-01 and FHIA-02 during storage at 27 ± 1°C. A plot of bunch age as a function of green-life of FHIA-01 indicated an exponential relationship between bunch age and green-life (Figure 11). In contrast, in FHIA-02, there was a close linear relationship between green-life and bunch age (Figure 12). Fruit from bunches of FHIA-01 bananas harvested 71, 77, 84 and 90 days after flower emergence and stored at 27 ± 1°C had a green-life of 19 days, while those harvested at 108 and 113 days had a green-life of 8 and 5 days, respectively. FHIA-02, harvested 70 and 78 days after flower emergence and stored at 27±1°C had a green-life of 18 days, while those harvested at 99 and 102 days had a green-life of 7 and 6 days, respectively.

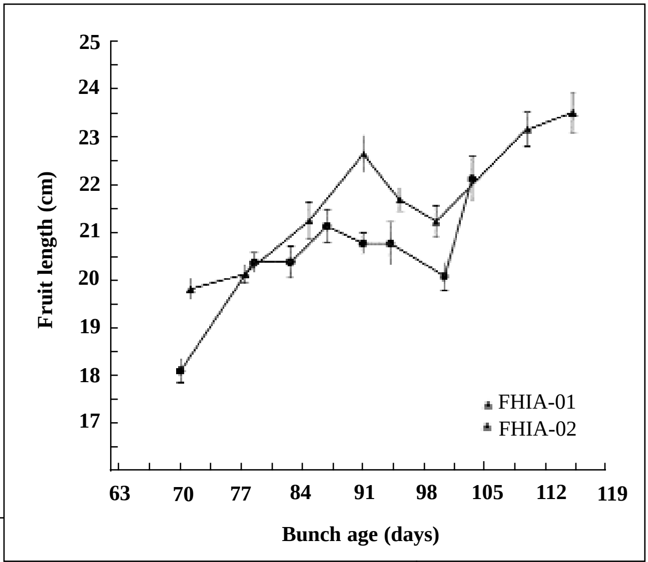


Figure 6. Changes in fruit length during maturation of FHIA-01 and FHIA-02.
Vertical bars indicate standard error of the means.

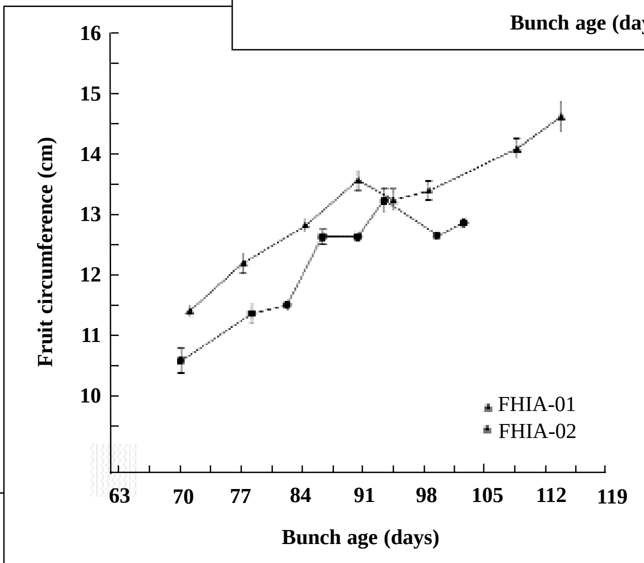


Figure 7. Changes in fruit circumference during maturation of FHIA-01 and FHIA-02.
Vertical bars indicate standard error of the means.

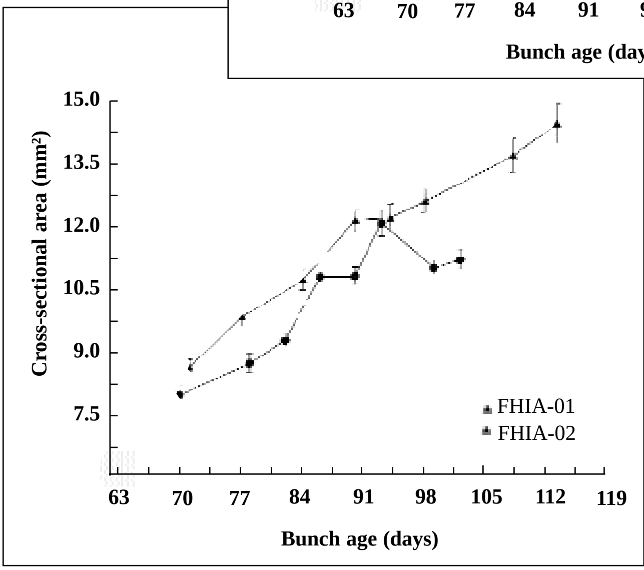


Figure 8. Changes in fruit cross-sectional area during maturation of FHIA-01 and FHIA-02.
Vertical bars indicate standard error of the means.

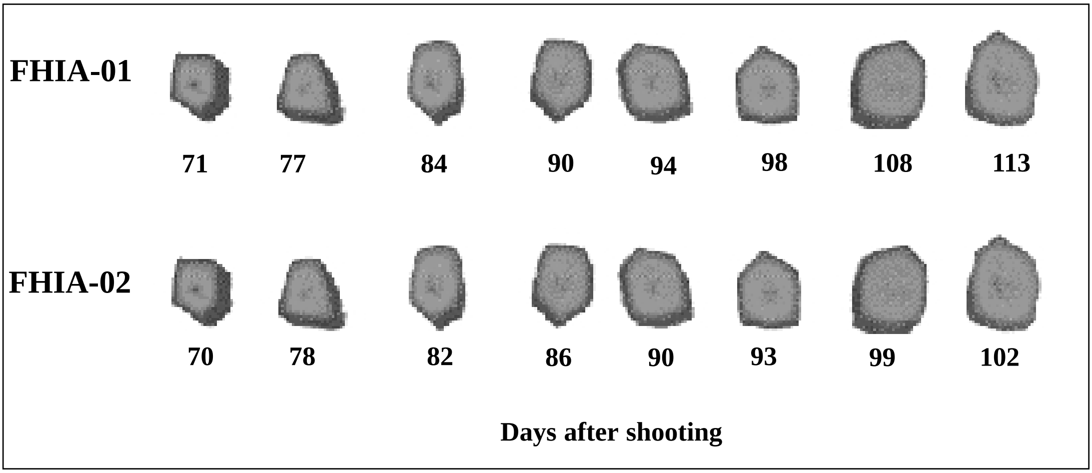


Figure 9. Typical changes in the angles, shape and size of the cross-sectional area during maturation of FHIA-01 and FHIA-02 bananas.

FRUIT RIPENING QUALITY

Assessment of stages of ripeness in FHIA-01 and FHIA-02 bananas

In the banana industry, fruit at advanced stages of maturity are harvested and sold in local or nearby markets, while those destined for distant markets are usually harvested at less advanced but physiologically mature stages (Marriott, 1980). The fruit should arrive firm and green at the final destination before being ripened with ethylene. Traditionally, the stage of banana ripening is closely linked with changes in peel colour (Loesecke, 1950; Palmer, 1971), and the peel colour is generally matched against a set of standard colour plates to assess ripeness. Under high temperature and low relative humidity conditions, the peel can remain green even though internal ripening has already commenced, and in such cases peel colour does not reflect the internal status.

In addition, fruit can ripen during transportation from producing countries to distant markets, even before the final destination is reached, i.e. ripening was already initiated but not recognised at the outset of the journey. This is a serious problem for the banana industry. Various methods can be used to assess the stage of banana ripeness, including the use of colour charts (Loesecke, 1950), carbohydrate and respiratory changes during ripening (Marriott *et al.*, 1981), and firmness or textural changes (Palmer, 1971). It is essential to use a combination of external and internal ripeness indicators to assess the stage of ripeness.

A combination of simple and reliable external and internal indicators of ripeness were used to assess ripeness stages in FHIA-01 and FHIA-02 bananas, including:

a. Peel colour changes

The disappearance or loss of green peel colour and a corresponding increase in peel yellowing are obvious signs of banana ripening. Peel colour charts have been developed to help standardize banana maturity ratings for industry and research purposes (Loesecke, 1950). Figure 13 shows a colour chart depicting typical changes in peel colour during ripening of FHIA-01 and FHIA-02 bananas, i.e. peel colour clearly changes from green to deep yellow with ripening. The peel colour change rate often depends on the stage of maturity at harvest, temperature and other environmental factors. Peel yellowing during ripening is due primarily to chlorophyll degradation. The chlorophyll content decreases slowly with ripening (Palmer, 1971).

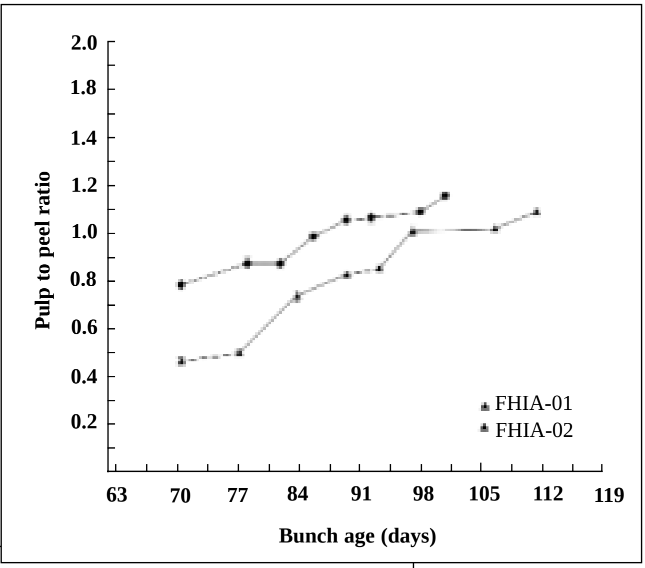


Figure 10. Changes in pulp to peel ratio of FHIA-01 and FHIA-02 during maturation. Vertical bars indicate standard error of the means.

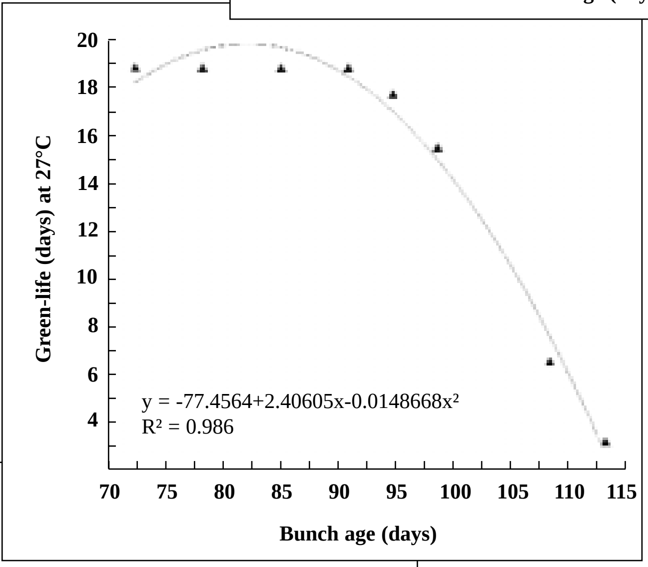


Figure 11. Relationship between bunch age and green-life of FHIA-01 during storage at 27°C.

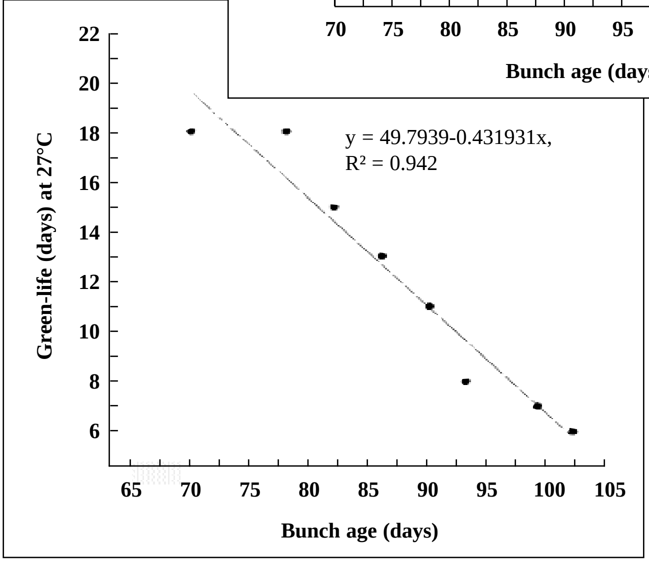


Figure 12. Relationship between bunch age and green-life of FHIA-02 during storage at 27°C.

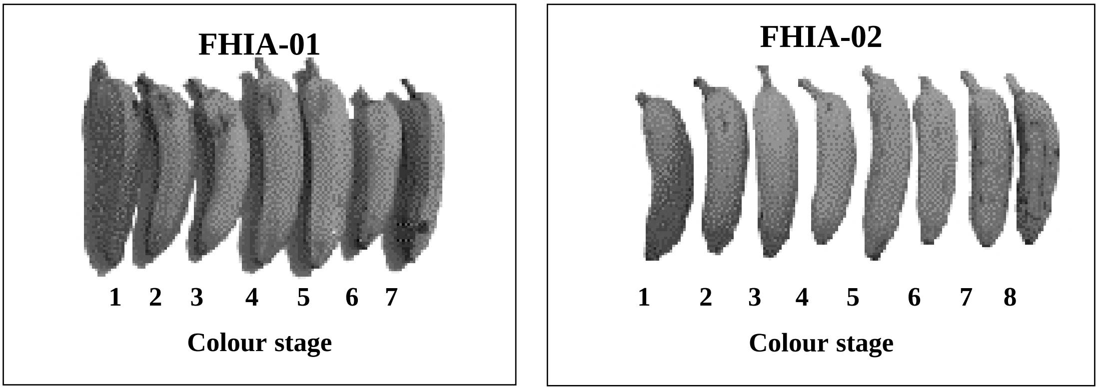


Figure 13. Colour chart depicting the typical changes in peel colour of FHIA-01 and FHIA 02 during ripening

b. Pulp colour changes

Internal indicators of ripeness, e.g. the use of pulp colour charts, can provide additional information on the progress of banana ripeness (Wainwright and Hughes, 1989, 1990). Figure 14 shows a colour chart depicting typical changes in pulp colour during ripening of FHIA-01 and FHIA-02 bananas. Visually, the pulp of FHIA-01 and FHIA-02 changed from white (at the mature green stage) to a deep creamy colour over the course of ripening.
Figure 14 also shows visible changes in the locular structure of FHIA-01 and FHIA-02 bananas as ripeness progressed. The colour of the center of the pulp in both hybrids became slightly yellower with ripening (i.e. from colour stages 1 to 7).

c. Starch index pattern

The use of starch index patterns to distinguish between different stages of banana ripeness provided a rapid and simple method for assessing pulp starch conversion during ripening. Iodine staining of starch has been used to assess maturity in apples and pears (Watkins, 1981; Reid *et al.*, 1982; Saltveit and Hale, 1982). The method is based on the hydrolysis of starch to sugar as fruit ripens. This technique was adopted with the aim of developing a starch iodine staining chart for FHIA-01 and FHIA-02. Figure 15 shows changes in the starch index for FHIA-01 and FHIA-02 bananas during ripening. The pulp was intensely and uniformly stained with an iodine/potassium iodide solution. At colour stage 1, the pulp showed complete deep blue staining. The first visible signs of starch staining failure during ripening were noted in locules next to degenerate seeds, where starch degradation usually begins and spreads during ripening. The first visual signs of staining failure in the locules were observed in FHIA-01 and FHIA-02 at colour stage 2. The unstained area expanded with ripening. This indicates an increase in the conversion of starch to sugar, or simply a loss of starch and an increase in the sugar concentration in the pulp over the course of ripening.

Comparison of ripening quality in Grande Naine and Williams bananas relative to FHIA-01 and FHIA-02

There has been increased interest in cultivating black Sigatoka resistant banana hybrids as yields of commercial banana cultivars (e.g. Grande Naine and Williams) have declined as a result of black Sigatoka infestations, combined with an increase in the cost of fungicides to control this disease. FHIA has developed black Sigatoka resistant banana hybrids. The acceptability of these FHIA banana hybrids depends on their disease resistance characteristics and ripening quality.

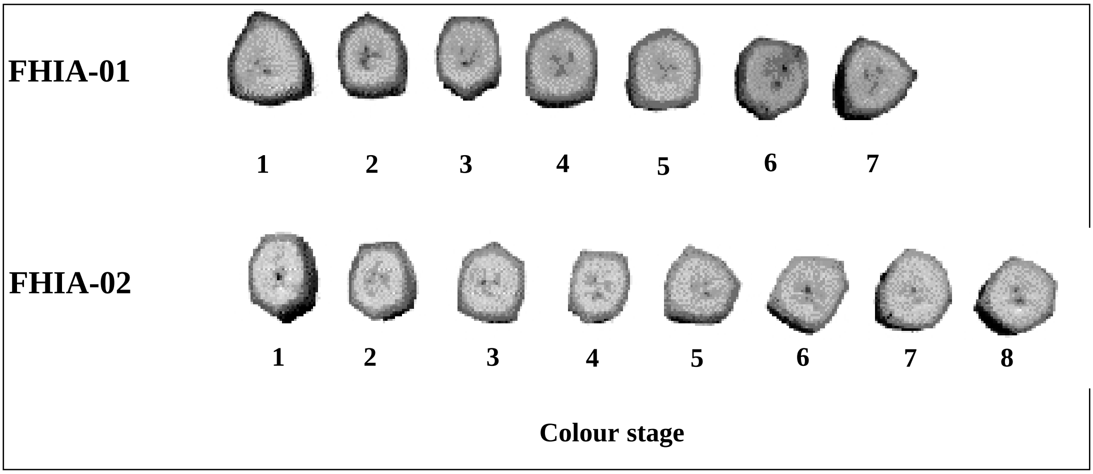


Figure 14. Colour chart depicting typical changes in pulp colour of FHIA-01 and FHIA-02 bananas during ripening.

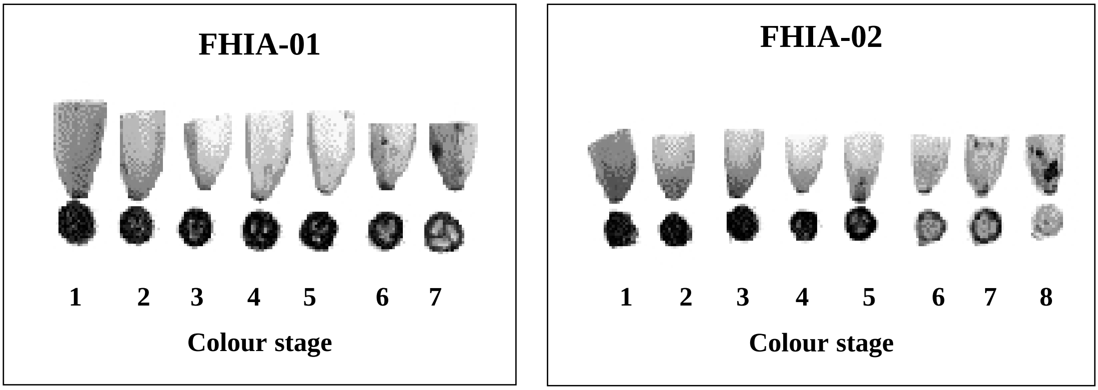


Figure 15. Colour chart depicting typical starch index pattern changes corresponding to peel colour changes of FHIA-01 and FHIA-02 bananas during ripening.

Post-harvest ripening qualities of two commercially-grown Cavendish varieties, i.e. Grande Naine and Williams, were compared to those of two FHIA banana hybrids, FHIA-01 and FHIA-02.

Typical changes during ripening include:

a. Pulp to peel ratio

Figure 16 shows changes in the pulp to peel ratio during ripening of Grande Naine and Williams bananas compared to FHIA-01 and FHIA-02. Grande Naine and Williams had consistently higher pulp to peel ratios than FHIA-01 and FHIA-02. In Grande Naine and Williams, the pulp to peel ratio increased from an initial value of around 1.42 at colour stage 1 to 2.30 at colour stage 8. In contrast, it increased from about 0.9 to 1.33 in FHIA-01 and to 1.57 in FHIA-02.

Changes in pulp to peel ratios reflect differential changes in peel and pulp moisture contents. Pulp to peel ratio increases during ripening are related to sugar concentrations in both tissues. During ripening, the sugar concentration rapidly increases in the pulp but not in the peel, thus prompting a differential change in osmotic pressure. The peel loses water by transpiration to the atmosphere and also by osmosis to the pulp (Stover and Simmonds, 1987), leading to an increase in the fresh weight of the pulp as the fruit ripens. This results in an increase in the pulp to peel ratio during ripening. The pulp to peel ratio is therefore a simple reliable index of ripening.

b. Pulp firmness

The pulp loses firmness during ripening. Figure 17 shows pulp firmness changes that occurred during ripening in Grande Naine and Williams bananas compared to FHIA-01 and FHIA-02. At colour stage 1, mean pulp firmness was higher for both Cavendish clones than for the FHIA banana hybrids. Pulp firmness declined rapidly after the onset of ripening, but the rate of decline was cultivar/hybrid-dependent. Between colour stages 6 and 8, pulp firmness was similar in FHIA-01, FHIA-02, Grande Naine and Williams. There was an inverse correlation ($r = 0.83$; $P < 0.0001$) between pulp firmness and ripening, implying that pulp firmness declined as ripening progressed. Softening or loss of pulp firmness during ripening has been associated with a reduction in middle lamella cohesion, characterized by the solubilization of pectin (Palmer, 1971).

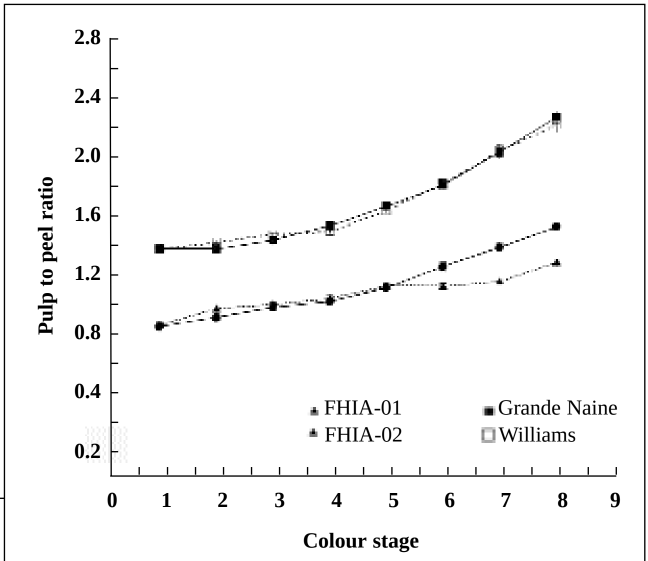


Figure 16. Changes in pulp to peel ratio during ripening of banana hybrids/cultivars.
Vertical bars indicate standard error of the means.

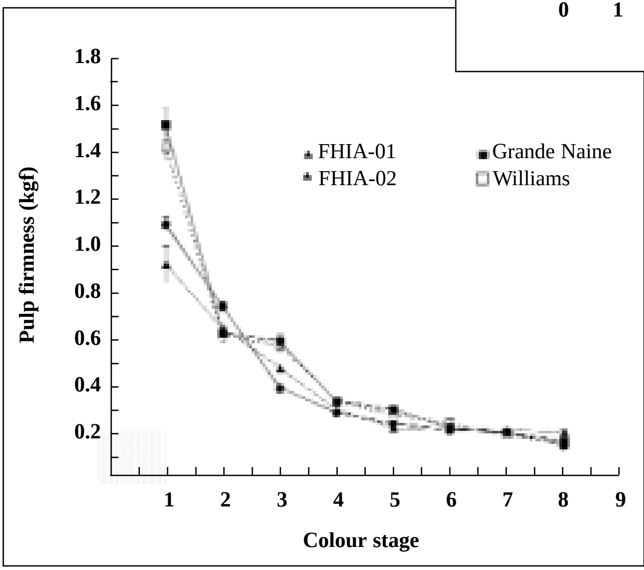


Figure 17. Changes in pulp firmness during ripening of banana hybrids/cultivars.
Vertical bars indicate standard error of the means.

c. Total soluble solids content

Fruit contains many water-soluble compounds, e.g. sugars, acids, vitamin C, amino acids and some pectins. The soluble solids content of fruit is based on these soluble compounds. Sugar is the main soluble solids component in most ripe fruit including bananas. Figure 18 shows changes in total soluble solids (TSS) content during ripening of Grande Naine and Williams bananas compared to FHIA-01 and FHIA-02. At colour stage 1, total soluble solids contents were similar in Grande Naine, Williams, FHIA-01 and FHIA-02. However, as ripening progressed from colour stage 2 to 8, the total soluble solids contents were consistently higher in Grande Naine and Williams than in FHIA-01 and FHIA-02. This means that Grande Naine and Williams were sweeter than FHIA-01 and FHIA-02 at eating stage 6. In Grande Naine, total soluble solids contents increased from 0% at peel colour stage 1 to approximately 13% at peel colour stage 6 and declined thereafter, while in Williams, total soluble solids contents increased from 0% to approximately 13.5% at colour stage 7. In contrast, in FHIA-01, soluble solids contents increased from 0% at peel colour stage 1 to 12% at colour stages 7 and 8, while in FHIA-02, it increased to 11% at stage 7 and declined thereafter.

d. Pulp pH

In both the FHIA banana hybrids and the two Cavendish clones, there was a decrease and then a rise in pulp pH during ripening (Figure 19). In FHIA-01 and FHIA-02, pulp pH dropped sharply from initial values of 6.00 and 5.70, respectively, at peel colour stage 1 to 4.50 and 4.40, respectively, at stage 5, followed by a slow increase to 4.90 and 5.2, respectively, at stage 8. In contrast, in Grande Naine and Williams, pulp pH dropped sharply from an initial value of 5.80 at peel colour stage 1 to 5.40 at stage 2, then leveled off and increased slowly to 5.50 and 5.60, respectively, at stage 8. Pulp pH is generally high when fruit is harvested at a mature green stage, but it drops at the onset of ripening.

e. Titratable acidity

Organic acids are essential for maintaining the sugar-to-acid balance, thus providing a pleasing fruit taste during ripening (Loesecke, 1950). Acidity (i.e. titratable acidity) in FHIA-01 and FHIA-02 pulp tissues increased as ripeness progressed to a peak at colour stages 6 and 5, respectively, and then declined (Figure 20). In contrast, in Grande Naine and Williams, titratable acidity increased to a peak at colour stages 3 and 2, respectively, and then declined.

SENSORY EVALUATION

Comparative sensory evaluation studies on FHIA-01, FHIA-02, Grande Naine and Williams

Instruments can be used to objectively measure various aspects of post-harvest quality of banana hybrids, but these measurements are not very useful if they are not correlated with human evaluations. In addition, comparative assessment of the organoleptic qualities of these hybrids with existing commercial cultivars is essential to ensure consumer acceptance and potential marketing of these new hybrids. Consumer acceptability of FHIA-01 and FHIA-02 was compared with that of two commercial cultivars, i.e. Grande Naine and Williams, based on texture, taste, flavour, sweetness and overall acceptability.

Sensory evaluation

A total of 111 untrained male and female taste panelists were involved in the sensory studies. Coded single samples of FHIA-01, FHIA-02, Grande Naine and Williams fruit (Figure 21) were sealed in transparent polyethylene bags and presented to each untrained taste panelist under standard blind taste-test conditions. Panelists were asked to assess the samples on the basis of texture, taste, flavour, sweetness and overall acceptability, using a hedonic scoring scale of 1 to 5 (Table 9). In addition, panelists were asked to state which of the four samples they preferred most. All panelists were

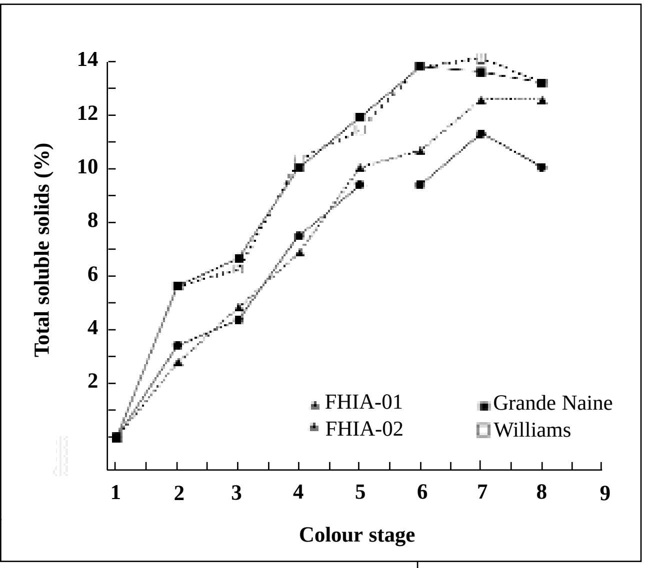


Figure 18. Changes in total soluble solids during ripening of banana hybrid/cultivars. Vertical bars indicate standard error of the means.

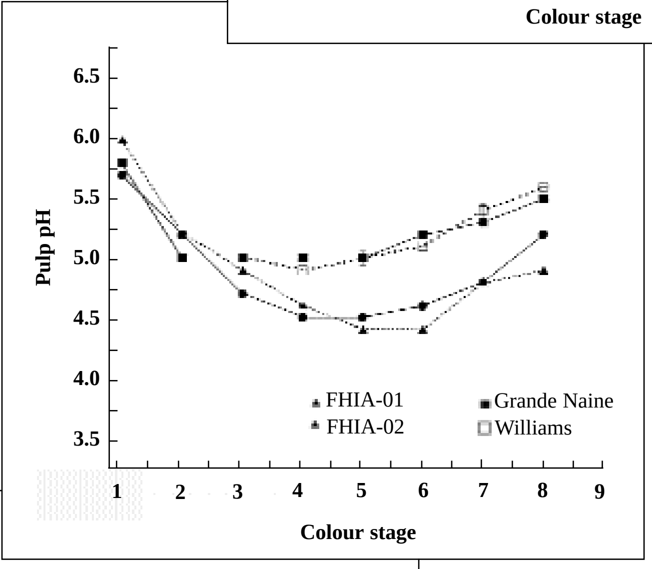


Figure 19. Changes in pulp pH during ripening of banana hybrids/cultivars. Vertical bars indicate standard error of the means.

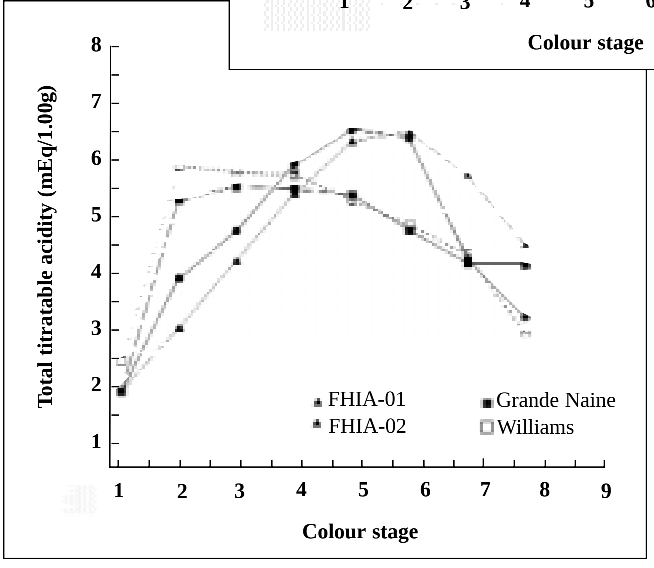


Figure 20. Changes in total titratable acidity during ripening of banana hybrids/cultivars. Vertical bars indicate standard error of the means.

instructed on basic taste-test procedures, i.e. to make their own assessments after a moderate amount of consideration. They were also asked to take a sip of water and pause briefly before tasting each sample and to retaste the samples if they were not sure of their assessments.

Pulp to peel ratio

On the day of the sensory evaluation studies, some key post-harvest quality indices were also assessed for comparison with the sensory data. The pulp to peel ratios of the two Cavendish clones differed significantly from those of the two FHIA banana hybrids (P < 0.01; Table 10). Grande Naine and Williams had significantly higher mean pulp to peel ratios than FHIA-01 and FHIA-02. This implies that the Grande Naine and Williams fruit assessed in the sensory studies had a more edible portion of pulp per unit weight of fruit compared to FHIA-01 and FHIA-02. FHIA-01, Grande Naine and Williams fruit pulp samples ranged from soft to firm (based on the hedonic scale), while FHIA-02 fruit pulp was soft (Table 9). The results of an objective assessment of pulp firmness (kgf) using a bench-top firmness tester confirmed that pulp firmness was similar in the FHIA-01, Grande Naine and Williams fruit used in the sensory studies, but significantly higher than in FHIA-02 (P < 0.01; Table 10). The objective test of pulp firmness thus confirmed the texture data obtained in the sensory studies.

Sensory quality features

The sensory quality features assessed included:

a. Texture

The textures of FHIA-01, Grande Naine and Williams were similar but differed significantly in comparison to FHIA-02 (P < 0.01; Table 11). In other words, the panelists indicated that the texture of FHIA-01, Grand Naine and Williams were between soft and firm (based on the Hedonic scale), while that of FHIA-02 was soft (Table 9). When the pulp firmness (kgf) was assessed objectively using a bench-top firmness tester, the results confirmed that the pulp firmness of FHIA-01, Grand Naine and Williams fruits used in the sensory studies were significantly similar and higher than those of FHIA-02 (P< 0.01; Table 10). Thus, the objective test of pulp firmness confirmed the texture data obtained from the sensory studies.

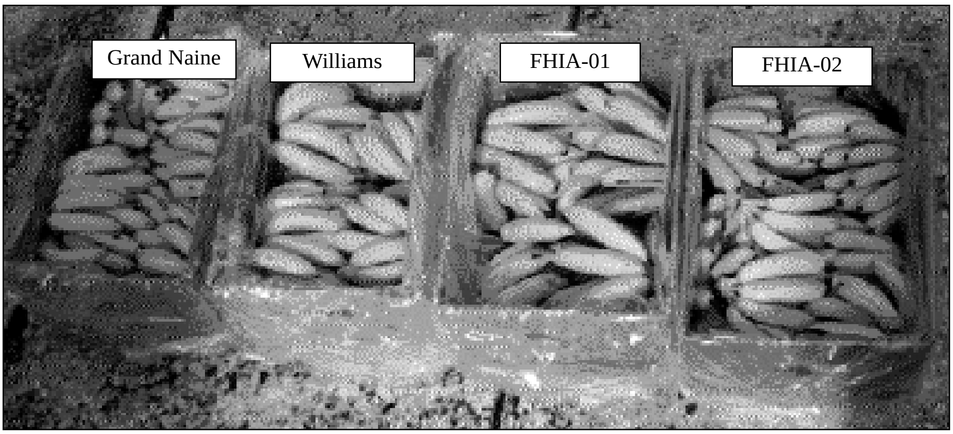


Figure 21. Grande Naine, Williams, FHIA-01 and FHIA-02 fruit used in the sensory evaluation studies.

Table 9. Hedonic scoring scale for the comparative sensory evaluation of FHIA-01, FHIA-02, Grande Naine and Williams fruit.

Scale	Texture	Taste	Flavour	Sweetness	Overall acceptability
5	Very firm	Excellent	Excellent	Too sweet	Excellent
4	Firm	Very acceptable	Like very much	Very sweet	Very good
3	Soft	Good	Good	Sweet	Good
2	Very soft	Fair	Fair	Slightly sweet	Fair
1	Too soft	Poor	Poor	Unsweet	Poor

Table 10. Important post-harvest quality indices for sensory evaluation of FHIA-01, FHIA-02, Grande Naine and Williams banana cultivars.

	Hybrid/cultivar			
Characteristics	FHIA-01	FHIA-02	Grande Naine	Williams
Pulp to peel ratio	1.33^{b}[1]	1.30^{b}	1.83^{a}	1.80^{a}
Pulp firmness (kgf)	0.27^{a}	0.20^{b}	0.27^{a}	0.29^{a}
Total soluble solids (%)	11.80^{b}	12.00^{ab}	14.00^{a}	13.20^{ab}
pH	4.30^{c}	4.50^{b}	4.93^{a}	4.90^{a}
Titratable acidity (mEq/100 g)	5.65^{a}	5.25^{b}	4.38^{c}	4.40^{c}

[1] Letters in common within rows were not significantly different at the 1% lev
Mean separation by Duncan's multiple range test.

Table 11. Mean scores obtained in the comparative sensory evaluation of FHIA-01, FHIA-02, Grande Naine and Williams banana cultivars.

	Sensory quality features				
Hybrid/cultivar	Texture	Taste	Flavour	Sweetness	Overall acceptability
FHIA-01	3.70^{a}[1]	2.28^{b}	2.25^{b}	1.71^{b}	2.08^{b}
FHIA-02	3.19^{b}	2.44^{b}	2.44^{b}	1.94^{b}	2.43^{b}
Grande Naine	3.74^{a}	3.54^{a}	3.50^{a}	2.83^{a}	3.51^{a}
Williams	3.84^{a}	3.64^{a}	3.56^{a}	2.87^{a}	3.57^{a}

[1] Letters in common within columns were not significantly different at th
Mean separation by Duncan's multiple range test.

b. Taste and flavour

In terms of taste, Grande Naine and Williams differed significantly from FHIA-01 and FHIA-02 ($P < 0.01$; Table 11). The tastes of Grande Naine and Williams were rated from good to very acceptable, while FHIA-01 and FHIA-02 were rated fair (based on a hedonic scoring scale of 1-5; Table 9). In other words, the panelists liked the taste of Grande Naine and Williams more than FHIA-01 and FHIA-02. This could have partly been due to the fact that the panelists were used to eating Grande Naine and Williams (since they are widely available on the market).

Similarly, the flavours of Grande Naine and Williams differed significantly in comparison to FHIA-01 and FHIA-02 ($P < 0.01$; Table 11). Grande Naine and Williams have a typical Cavendish banana flavour, while FHIA-01 and FHIA-02 have tart apple-like flavour.

c. Sweetness

Comparative assessment of the sweetness of FHIA-01, FHIA-02, Grande Naine and Williams bananas indicated that Grande Naine and Williams were sweeter than FHIA-01 and FHIA-02 ($P < 0.01$; Table 11). The panelists rated FHIA-01 and FHIA-02 bananas as slightly sweet, while Grande Naine and Williams bananas were rated as sweet (based on the hedonic scale, Table 9).

Total soluble solids, pH and titratable acidity

Pulp total soluble solids, pH and titratable acidity are important objective post-harvest indices for sensory evaluation of bananas because they indicate the sugar and acid content of the fruit. In most types of ripe fruit such as banana, sugar is the main soluble solids component which ultimately indicates sweetness. The sugar to acid balance is also important for providing the pleasant fruit taste. Fruit used in the sensory studies was ripened to colour stage 6. In the objective chemical analysis, the total soluble solids contents were cultivar-dependent ($P < 0.01$; Table 10). The mean total soluble solids contents of Grande Naine and Williams were higher than in FHIA-01 and FHIA-02. This indicates that Grande Naine and Williams were sweeter than FHIA-01 and FHIA-02. This objective test confirmed the sensory data on sweetness, i.e. the panelists preferred the sweetness of Grande Naine and Williams as compared to FHIA-01 and FHIA-02.

Pulp pH and titratable acidity were cultivar-dependent ($P < 0.01$; Table 10). FHIA-01 and FHIA-02 bananas had similar and lower mean pulp pH and higher mean titratable acidity in comparison to Grande Naine and Williams. FHIA-01 and FHIA-02 were therefore more acidic than Grande Naine and Williams. The high acid contents measured in FHIA-01 and FHIA-02 bananas partly explains the comparatively low sugar content (i.e. total soluble solids). It also confirms the sensory data, which indicated that Grande Naine and Williams bananas differed fundamentally from FHIA-01 and FHIA-02 bananas in terms of taste and sweetness. These sensory differences between cultivars, based on taste and sweetness, clearly highlight the importance of concomitantly conducting chemical analyses on the samples used in the studies.

d. Overall acceptability

Based on overall acceptability, analysis of the sensory data revealed two facts:

1) The panelists indicated that, in terms of overall acceptability, Grande Naine and Williams were similar but significantly different when compared to FHIA-01 and FHIA-02 ($P < 0.01$; Table 11). Panelists rated Grande Naine and Williams as good to very good, while FHIA-01 and FHIA-02 were rated as fair to good (Table 9).
2) There are fundamental differences between the two Cavendish clones, Grande Naine and Williams, and the two FHIA banana hybrids, FHIA-01 and FHIA-02.

Preference

When each of the 111 panelists was asked to state which of the samples they preferred most, 50 and 48 people, respectively, indicated that they preferred Williams and Grande Naine, while five and six people, respectively, opted for FHIA-01 and FHIA-02 (two people did not express an opinion; Figure 22).

The results conclusively showed that, on the basis of taste, flavour and sweetness, the two Cavendish clones (Grande Naine and Williams) differed markedly from the two FHIA banana hybrids (FHIA-01 and FHIA-02). The objective chemical analysis (i.e. total soluble solids, pH and titratable acidity) also confirmed these basic differences. Grande Naine and Williams were sweeter than FHIA-01 and FHIA-02. Conversely, FHIA-01 and FHIA-02 were more acidic than Grande Naine and Williams. Grande Naine and Williams have a typical Cavendish banana flavour, while FHIA-01 and FHIA-02 have a tart apple-like flavour.

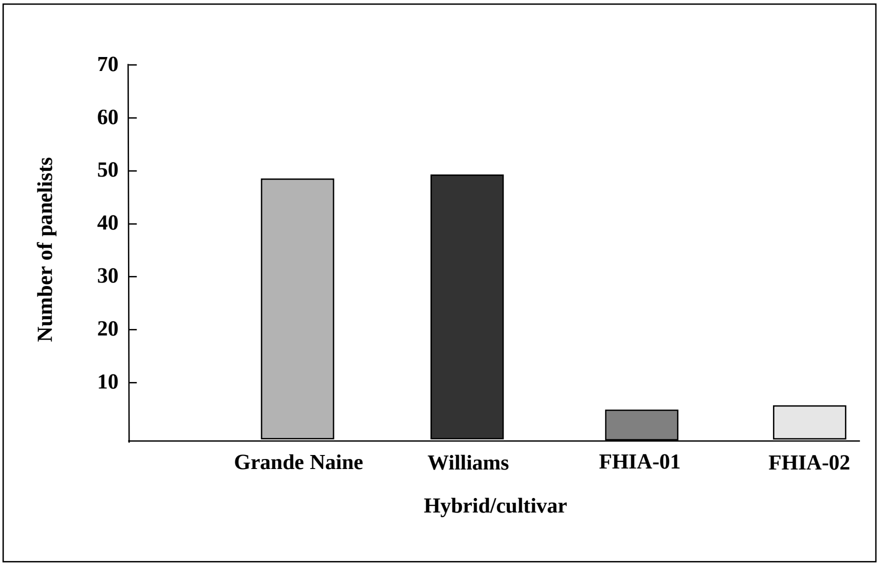


Figure 22. Comparative consumer preference of Grande Naine, Williams, FHIA-01 and FHIA-02 hybrids/cultivars (n=109).

2. Cooking banana hybrids

FHIA has developed a promising black Sigatoka-resistant tetraploid cooking banana hybrid, FHIA-03 (Figure 23). The post-harvest characteristics at harvest, maturation, green-life, ripening quality and organoleptic features of FHIA-03 are presented. The materials and methods used to obtain the results/data presented in the tables and figures below were previously described by Dadzie and Orchard, 1996; Dadzie, 1993, 1994; Dadzie *et al*., 1994.

Genomic group

Table 12 shows the type, genomic group, parentage and black Sigatoka resistance of the FHIA-03 cooking banana hybrid.

Table 12. Type, genomic group, parentage and black Sigatoka resistance of FHIA-03.

Characteristics	FHIA-03
Type	Cooking banana
Genomic group	AABB
Parentage	SH-3386 X SH-3320
Black Sigatoka	Resistant

POST-HARVEST CHARACTERISTICS AT HARVEST

The post-harvest characteristics at harvest used to assess FHIA-03 include:

a. Bunch and fruit characteristics
b. Post-harvest quality.

Tables 13 and 14 show the post-harvest characteristics (at harvest) of the FHIA-03 cooking banana hybrid.

Figure 23. Typical bunch of FHIA-03 cooking bananas

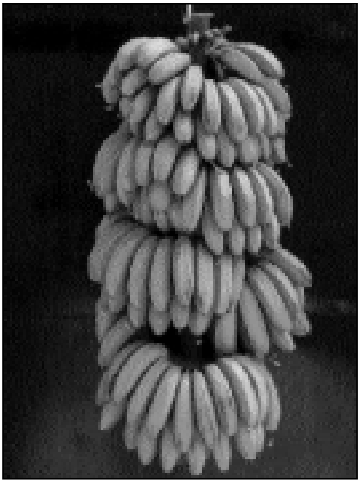


Table 13. Bunch and fruit characteristics (at harvest) of FHIA-03.

Characteristics	FHIA-03
Bunch weight (kg)	20 - 30
Number of hands	8 - 10
Fruit weight (g)	125 - 140
Fruit length (cm)	15 - 18
Fruit circumference (cm)	12 - 14
Pulp weight (g)	60 - 70
Peel weight (g)	60 - 65
Pulp to peel ratio	0.95 - 1.20
Pulp thickness (cm)	3.30 - 3.50
Peel thickness (cm)	0.40 - 0.45

Table 14. Post-harvest qualities (at harvest) of FHIA-03.

Characteristics	FHIA-03
Peel colour	Green
Pulp colour	White/creamy
Pulp firmness (kgf)	1.30 - 1.60
Pulp pH	6.00 - 6.50
Titratable acidity (mEq/100 g)	2.20 - 2.50
Pulp dry matter content (%)	24 - 26
Pulp moisture content (%)	74 - 76

FRUIT MATURATION

Typical changes during maturation of the FHIA-03 cooking banana hybrid

Fruit is harvested at the mature green stage on the basis of several harvest maturity indicators. On most banana, cooking banana and plantain plantations or farms, maturity is generally assessed on the basis of experience and visual signs or the appearance of hanging bunches, and particularly by the angularity of fingers (Marriott and Lancaster, 1983; Palmer, 1971; Sanchez-Nieva *et al*., 1968). Most scientific research staff calculate yield data by harvesting fruit a specific number of days after flower emergence or when the first hand on the bunch shows visual signs of ripening or yellowing. However, operators using standard duration periods (i.e. from flowering to maturation) are liable to harvest underfilled bunches, and the yield data thus tend to be underestimated. Harvest time should thus be calculated to maximize shelf-life, while not risking abnormal ripening.

Some typical physical/morphological changes during maturation of FHIA-03 cooking bananas are as follows:

a. Visual changes during maturation

The most significant changes in fruit morphological characteristics during maturation are fruit weight, length, girth, cross-sectional dimension, pulp to peel ratio and peel and pulp thickness. Figure 24 shows typical visual changes in various morphological characteristics of FHIA-03 cooking bananas at different stages of maturity. Visual changes were noted in the fruit size, shape, weight, length and volume (circumference) as bunches aged. During maturation, fingers lost their angularity and the fruit became fuller in shape. The stylar ends also became drier and, in some cases, attached to the fruit. Furthermore, in FHIA-03, vertical lines on the fruit surface were more pronounced in immature fruit but became less marked as the fruit matured. During the early stages of maturation, the fruit is arc or crescent shaped but straightens as it matures. These visible changes in the morphology of the fruit during maturation are important maturity indices for the overall assessment of the time to harvest.

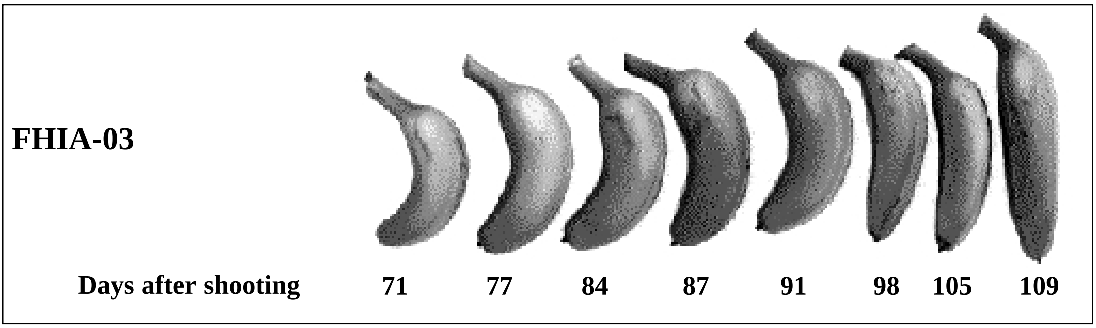


Figure 24. Typical changes in the morphological characteristics of FHIA-03 cooking bananas during maturation.

b. Changes in fruit characteristics during maturation

The following changes in fruit characteristics occurred during maturation:

i. Fruit weight, circumference and cross-sectional area

Figures 25, 26 and 27 show changes in fruit weight, circumference and cross-sectional area during maturation in FHIA-03. There was a close positive correlation between bunch age and fruit weight, circumference and cross-sectional area (Table 15). Figure 28 shows typical changes in the cross-sectional dimensions of FHIA-03 bananas during maturation. The cross-sectional dimensions of the fruit became more rounded and plump or larger in size with age, thus providing a basis for subjective assessment of fruit age. The angles became less sharp or wide as the fruit aged. The photographs (Figure 28) highlight that typical changes also occurred in the locular architecture of the fruit with maturity. The locular architecture and the degenerating seeds in the fruit became more marked with fruit maturity.

ii. Pulp to peel ratio

Changes in the pulp to peel ratio during fruit maturation was the most significant index of maturity. Variations in pulp to peel ratios during maturation varied significantly between different ages of maturity ($P < 0.01$; Figure 29). A plot of the pulp to peel ratio as a function of bunch age indicated that they were linearly related, and a highly significant positive correlation between the pulp to peel ratio and bunch age was also obtained (Table 15). FHIA-03 was characterized by a rapid increase in the pulp to peel ratio during fruit maturation (Figure 29). Increases in the pulp to peel ratio during maturation indicated that a more edible portion per unit fresh weight was obtained as bunches aged. These results clearly showed that there was more edible pulp in the most mature fruit. The pulp to peel ratio is thus a good factor for predicting fruit maturity.

Table 15. Regressions and correlation between bunch age and fruit characteristics during maturation in FHIA-03.

Characteristics	Equation	R^2	r	P<
Bunch age and fruit weight	Y=1.171+1.367X	0.78	0.85	0.0001
Bunch age and fruit circumference	Y=10.296+0.033X	0.45	0.54	0.0001
Bunch age and cross-sectional area	Y=4.914+0.0832X	0.66	0.73	0.0001
Bunch age and pulp to peel ratio	Y=0.062+0.009X	0.97	0.98	0.0001

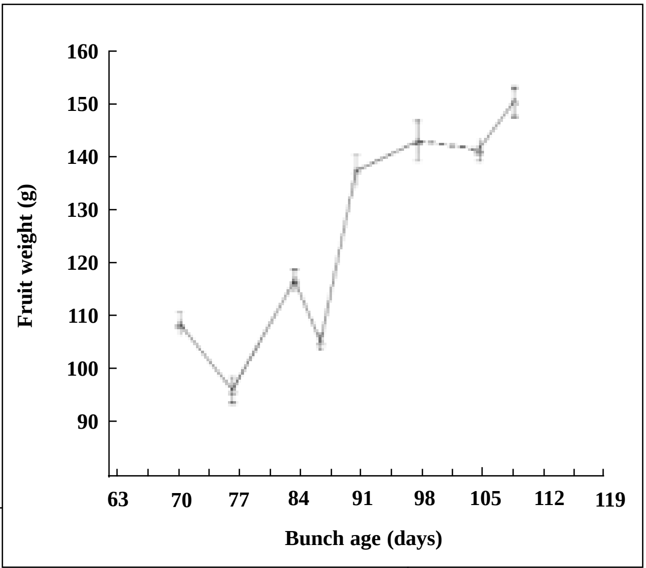


Figure 25. Changes in fruit weight during maturation of FHIA-03.
Vertical bars indicate standard error of the means.

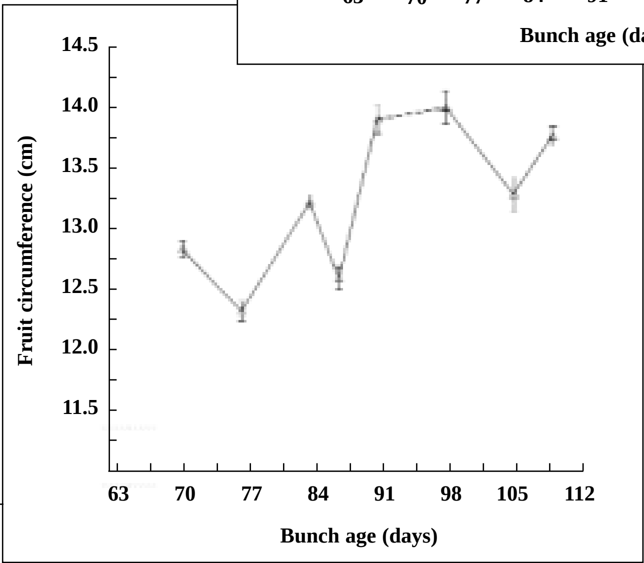


Figure 26. Changes in fruit circumference during maturation of FHIA-03.
Vertical bars indicate standard error of the means.

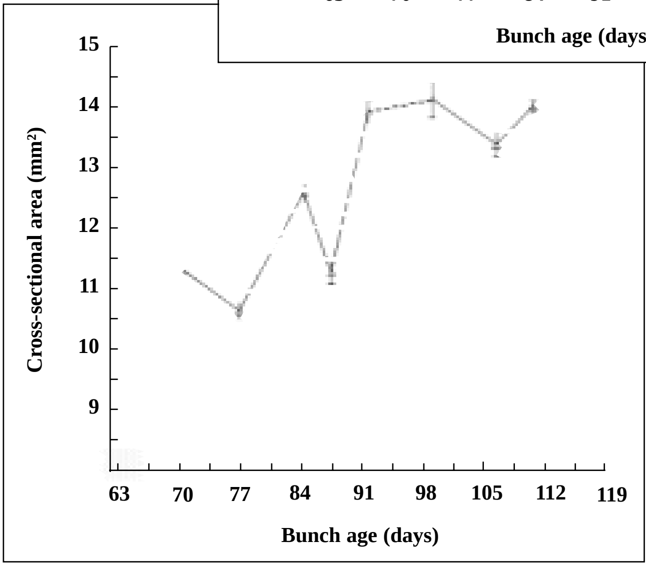


Figure 27. Changes in cross-sectional area during maturation of FHIA-03. Vertical bars indicate standard error of the means.

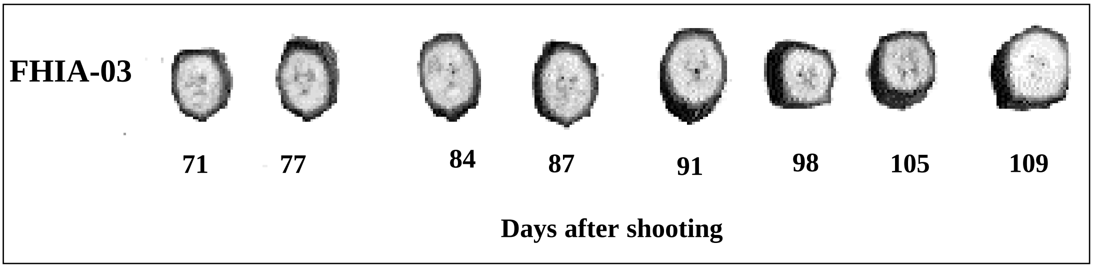


Figure 28. Typical changes in the angles, shape and size of the cross-sectional area during maturation of FHIA-03 cooking bananas.

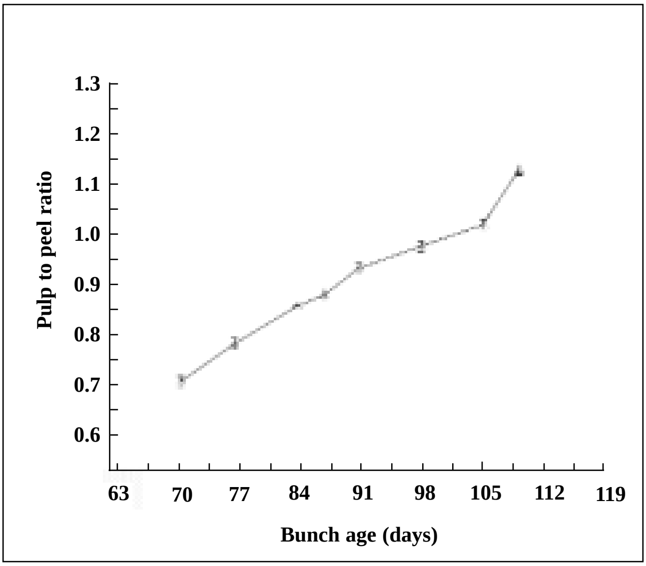


Figure 29. Changes in pulp to peel ratio during maturation of FHIA-03.
Vertical bars indicate standard error of the means.

GREEN-LIFE

Assessment of green-life of FHIA-03 during storage at 27 ± 1°C

The consumer acceptability of new FHIA cooking banana hybrids will not be solely based on their disease resistance durability and agronomic suitability, i.e. the green-life potential of these hybrids will also be critical. Selection of hybrids which have a long green-life or remain green for a long time after harvest, or ripen slowly, would facilitate marketing of the fruit and reduce post-harvest losses. Systematic assessment of the green-life of FHIA hybrids is thus essential.

The green-life of FHIA-03 was determined at different ages after the fruit had been stored at 27 ± 1°C. Figure 30 illustrates the relationship between bunch age and green-life of FHIA-03 during storage at 27 ± 1°C. Fruit harvested 71 and 77 days after flower emergence and stored at 27 ± 1°C had a green-life of 16 days, while those harvested at 105 and 109 days had a green-life of 5 days. A plot of bunch age as a function of green-life indicated a close linear relationship between bunch age and green-life, i.e. the green-life was shorter in more mature fruit. Similar findings have been reported by other investigators, including Blake and Peacock (1971), Marriott *et al.* (1979), Marriott and Montoya (1981) and Peacock (1966).

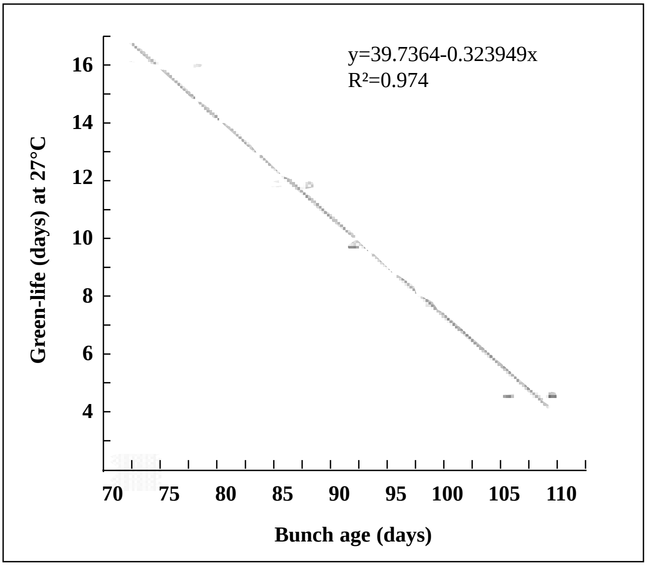


Figure 30. Relationship between bunch age and green-life of FHIA-03 during storage at 27°C.

Fruit Ripening Quality

Assessment of stages of ripeness in FHIA-03 cooking bananas

Banana, cooking banana and plantain are usually harvested at the green ripe stage of maturity and ripened or cooked prior to consumption. Selection of a suitable utilization or cooking method often depends on the stage of fruit ripeness. Similarly the type of processed products prepared from banana, cooking banana and plantain depends on the ripeness stage. The quality of the end product also depends on the physical and chemical properties of the fruit at the stage of ripeness when it is processed. In most plantain and cooking banana growing areas, the fruit is consumed right from the green mature and unripe stage until it is ripe and overripe.

Post-harvest characteristics such as ripening quality are essential for the overall assessment and consumer acceptability of new cooking banana hybrids. The post-harvest ripening quality of FHIA-03 cooking bananas was assessed. In addition, colour stage charts of peel and pulp colour as well as starch iodine patterns for determining ripeness stages in FHIA-03 bananas were developed.

Typical changes in FHIA-03 cooking bananas during ripening are as follows:

a. Peel colour changes

During ripening, the peel colour changes from green to yellow. Peel yellowing during ripening is due primarily to chlorophyll breakdown. Figure 31 shows a colour chart depicting typical changes in peel colour during ripening of FHIA-03 cooking bananas.

b. Pulp colour changes

In most hybrids/cultivars, the external or peel colour changes that occur during ripening reflect changes in pulp colour. Figure 32 shows a colour chart depicting typical changes in pulp colour during ripening of FHIA-03 cooking bananas. The locular structure generally changed as ripening progressed. Visually, in FHIA-03, the pulp changed from white (at mature green stage) to a deep creamy colour during ripening.

c. *Starch index pattern*

Figure 33 shows changes in the starch index for FHIA-03 during ripening. The pulp was stained uniformly and intensely with an iodine/potassium iodide solution. The first visible signs of starch staining failure during ripening were noted in the locules next to degenerate seeds, where starch degradation usually begins and spreads during ripening. Visual signs of starch staining failure (or a decrease in staining intensity in the locule) during ripening were observed at ripeness stage 3. Conversion of starch to sugars is generally less complete in plantain and cooking bananas as compared to dessert bananas (Marriot *et al*., 1981).

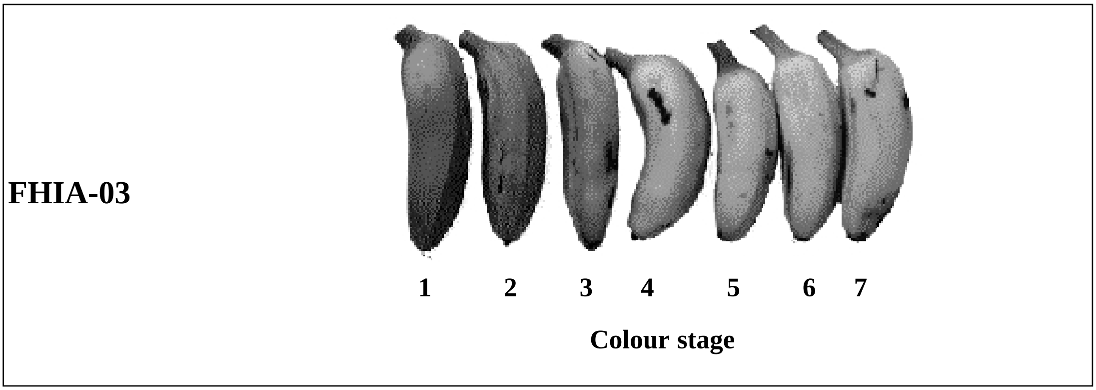


Figure 31. Colour chart depicting typical changes in peel colour of FHIA-03 during ripening.

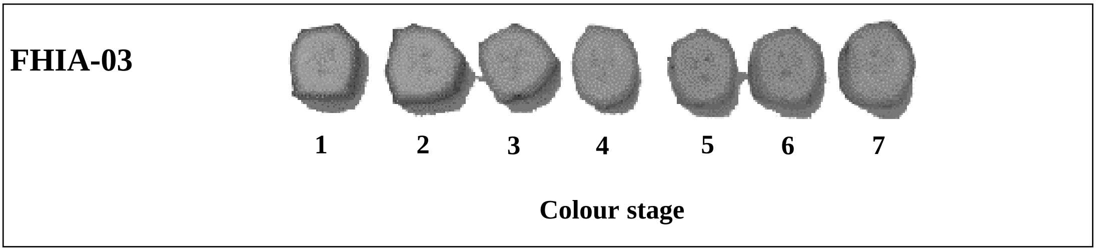


Figure 32. Colour chart depicting typical changes in pulp colour of FHIA-03 during ripening.

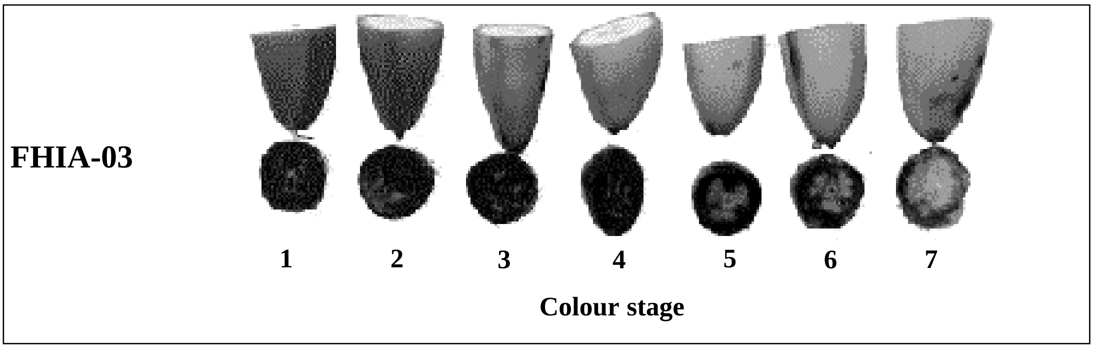


Figure 33. Chart showing typical starch index pattern changes of FHIA-03 during ripening.

d. Pulp to peel ratio

Figure 34 shows changes in the pulp to peel ratio during ripening of FHIA-03 cooking bananas. The pulp to peel ratio increased as ripening progressed and there were significant differences between the ripeness stages ($P < 0.001$; Figure 34). Changes in pulp to peel ratios reflect the differential nature of changes in the moisture contents of these tissues. Pulp to peel ratio increases during ripening are related to sugar concentrations in both tissues. During ripening, the sugar concentration increases more rapidly in the pulp than in the peel, prompting a differential change in osmotic pressure. The peel loses water both by transpiration to the atmosphere and by osmosis to the pulp (Stover and Simmonds, 1987), leading to an increase in the fresh weight of the pulp as the fruit ripens. This results in an increase in the pulp to peel ratio during ripening.

e. Pulp firmness

Under normal storage conditions, cooking bananas show a progressive loss of pulp firmness over the course of ripening. Figure 35 shows changes in pulp firmness or loss of firmness in FHIA-03 during ripening. Pulp firmness decreased from an initial value of about 1.2 kgf at colour stage 1 to nearly 0.3 kgf at colour stage 3, whereas it declined to about 0.12 kgf at colour stage 8. Softening or loss of pulp firmness during ripening has been attributed to the solubilisation of pectic substances in the cell wall and middle lamella (Palmer, 1971).

f. Total soluble solids content

Figure 36 shows changes in total soluble solids (TSS) content during ripening of FHIA-03 bananas. In FHIA-03, the TSS increased steadily during the ripening process. From an initial level of 0% at peel colour stage 1, TSS increased regularly after the onset of ripening, reaching about 12% at colour stage 8.

g. Pulp pH

In FHIA-03, there was a decline and then a rise in pulp pH during ripening (Figure 37). Pulp pH dropped sharply from an initial value of about 5.00 at peel colour stage 1 to nearly 4.50 at stage 5, followed by a slow increase to about 4.8 at stage 8.

h. Titratable acidity

Figure 38 shows changes in total titratable acidity in FHIA-03 during ripening. Organic acids are important for maintaining the sugar-to-acid balance, thus providing a pleasing fruit taste during ripening (Loesecke, 1950). Acidity (i.e. titratable acidity) in FHIA-03 pulp tissues increased as ripeness progressed to a peak at colour stage 8.

SENSORY EVALUATION

Sensory evaluation studies on FHIA-03

Sensory evaluation is important for assessing consumer acceptability of new hybrids. Moreover, the results could provide some key information on important post-harvest quality features for consumers, and help in guiding further breeding programmes. Consumer acceptability of fried unripe FHIA-03 banana chips was determined on the basis of texture, taste, colour, crispiness and overall acceptability.

A total of 30 male and female taste panelists were involved in the sensory study. Panelists were given unripe plantain chips made from FHIA-03 (Figure 39) and asked to appraise the sample on the basis of texture, taste, colour, crispiness and overall acceptability. They scored the samples for each quality feature using a hedonic scoring scale of 1 to 5 (Table 16, page 37). All panelists were instructed on basic taste-test procedures, i.e. to make their own assessments after a moderate amount of consideration.

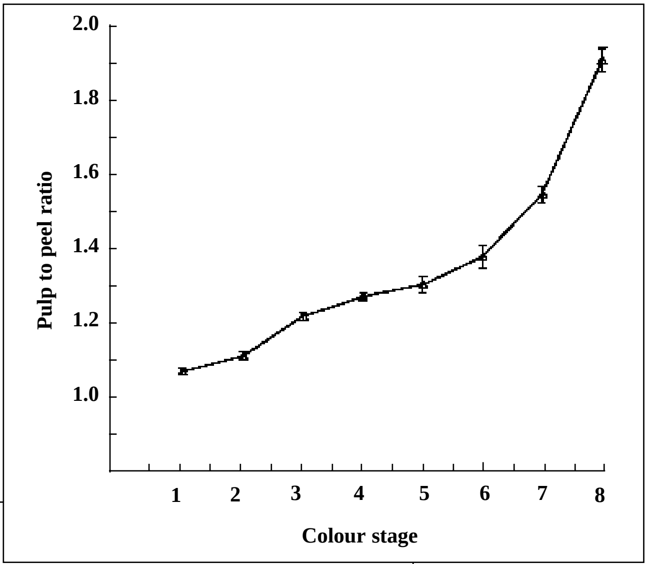


Figure 34. Changes in pulp to peel ratio of FHIA-03 during ripening.
Vertical bars indicate standard error of the means.

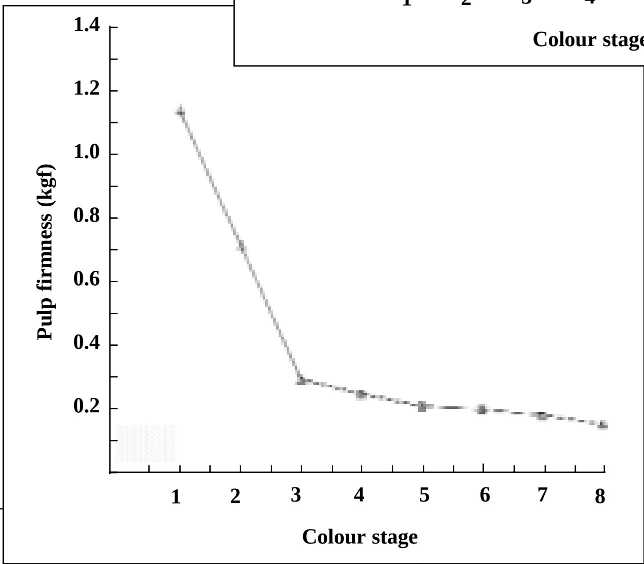


Figure 35. Changes in pulp firmness of FHIA-03 during ripening.
Vertical bars indicate standard error of the means.

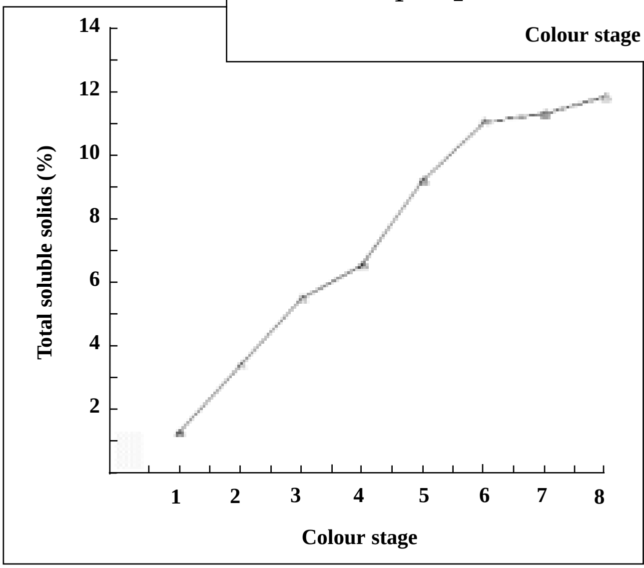


Figure 36. Changes in total soluble solids of FHIA-03 during ripening.
Vertical bars indicate standard error of the means.

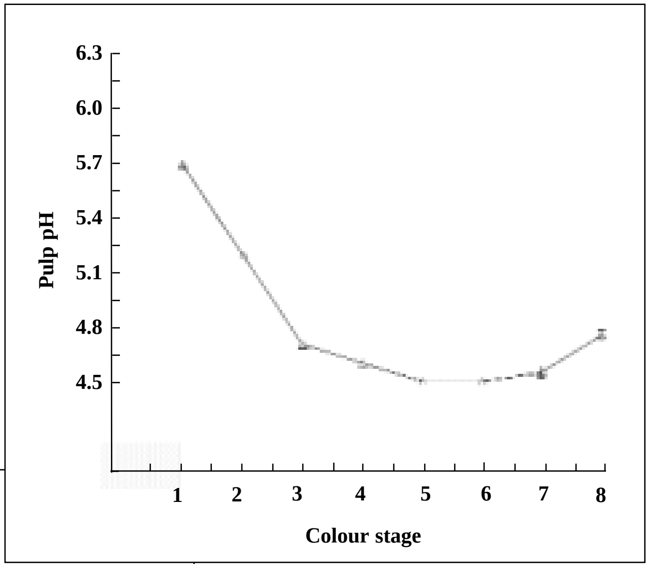


Figure 37. Changes in pulp pH of FHIA-03 during ripening.
Vertical bars indicate standard error of the means.

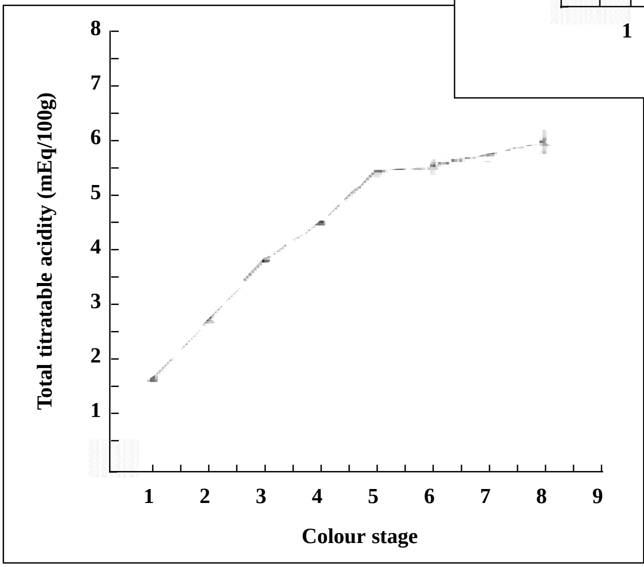


Figure 38. Changes in total titratable acidity of FHIA-03 during ripening. Vertical bars indicate standard error of the means.

Figure 39. Fried unripe chips of FHIA-03.

Table 17 shows the percentage scores given for fried unripe FHIA-03 banana chips. Of the 30 panelists involved in the sensory evaluation of FHIA-03 chips, 93% indicated that the texture was good and none rated it as poor (Table 16). On the basis of taste, 33% stated that the chips were excellent tasting, while 20% and 40% indicated that the taste was very acceptable and good, respectively. 52% of the panelists indicated that the colour of fried unripe FHIA-03 chips was fair, while 34% stated that it was good. 62% considered that the chips were very crispy. In terms of the overall acceptability of FHIA-03 chips, 18%, 61% and 14% indicated that it was excellent, very good and good, respectively.

Oil absorption was high in FHIA-03 chips (nearly 46%), with a recovery rate of 39%.

Table 16. Hedonic scoring scale for assessing consumer acceptability of fried unripe FHIA-03 banana chips.

Scale	Texture	Taste	Colour	Crispiness	Overall acceptability
1	Too hard	Excellent	Excellent	Too crispy	Excellent
2	Very hard	Very acceptable	Like very much	Very crispy	Very good
3	Good	Good	Good	Good	Good
4	Fair	Fair	Fair	Fair	Fair
5	Poor	Poor	Poor	Poor	Poor

Table 17. Percentage scores for fried unripe FHIA-03 banana chips.

Scale	Texture	Taste	Colour	Crispiness	Overall acceptability
1	7	33	7	17	18
2	0	20	7	62	61
3	93	40	34	14	14
4	0	7	52	7	7
5	0	0	0	0	0

n = 30

COOKING QUALITY

Cooking qualities of FHIA cooking banana hybrids

The texture and appearance of banana pulp after cooking are particularly important features for consumers. Consumers of boiled green plantain or cooking banana usually prefer the pulp to remain firm and crunchy after cooking, rather than too soft and waterlogged. The cooking suitability of three black Sigatoka-resistant cooking banana hybrids (FHIA-03, FHIA-06 and Bluggoe) were compared to that of a common susceptible plantain cultivar, i.e. Cuerno (Table 18).

Post-harvest quality indices

Post-harvest quality indices essential for the evaluation of banana cooking quality include:

Pulp to peel ratio and pulp thickness

The pulp to peel ratio and pulp thickness are essential post-harvest quality indices for the assessment of cooking quality of mature green plantains and cooking bananas. Indeed, consumers of boiled green plantains and cooking bananas often prefer thicker and bulkier pulp (i.e. more pulp than peel). The proportion of pulp to peel as well as the pulp thickness were thus determined by assessing the pulp to peel ratio and pulp thickness of the new hybrids and the standard cultivar. There were significant differences in the pulp to peel ratios of the hybrids/cultivar ($P < 0.01$; Table 18). FHIA-06 and Cuerno had similar pulp to peel ratios, but they differed significantly in comparison to FHIA-03 or Bluggoe ($P < 0.01$; Table 18). In contrast, Bluggoe had the highest mean pulp thickness compared to the FHIA cooking banana hybrids or Cuerno.

Cooking quality criteria

The cooking quality criteria are as follows:

a. Ease of peeling

Consumers of green boiled plantain or cooking banana often prefer cultivars that are easy to peel, hence the ease of peeling was assessed subjectively in the present study. The cooking banana hybrids, FHIA-03, FHIA-06 and Bluggoe, were relatively difficult to peel in comparison to Cuerno. At the mature green stage, the ease of peeling cooking bananas and plantains generally depends on the peel thickness and the degree of peel to pulp adhesiveness. The results showed that the cooking banana hybrids had a significantly higher mean peel thickness than Cuerno ($P < 0.01$; Table 18). The high mean peel thickness of the cooking banana hybrids (FHIA-03, FHIA-06 and Bluggoe) may partly explain why they are difficult to peel.

b. Texture or pulp firmness

As cooking bananas and plantains are used and cooked in a variety of ways, the texture (especially softness) of the cooked pulp is often an important factor in determining a good cultivar. Users probably choose a cooking banana or plantain cultivar for a particular cooking or processing method on the basis of textural properties of the tissues after cooking. Consumers usually prefer cultivars that have good textural qualities after cooking, i.e. suitable for various uses. Figure 40 (page 40) illustrates changes in pulp firmness of FHIA-03, FHIA-06, Bluggoe and Cuerno fruit during cooking. The mean pulp firmness values (kgf) were high in both the cooking banana and plantain cultivars before cooking (i.e. Time 0). However, there was a sharp decline in firmness when the pulp of the different cultivars/hybrids was cooked or boiled for 5 minutes. However, the degree of loss of firmness or softening was cultivar-dependent ($P < 0.01$; Figure 40). For instance, when FHIA-03 and FHIA-06 bananas were boiled for 5 minutes, they lost nearly 80% and 75% (respectively) of their initial mean firmness, as compared to 35% in Bluggoe and 61% in Cuerno. Such remarkable differences in firmness loss may be due to inherent differences in cell size and structure, as well as differences in chemical composition before cooking. Studies by other researchers have revealed that a loss of firmness or softening in fruit as a result of cooking or heating, involves a loss of turgor, a series of chemical changes in the cell polysaccharide matrix, along with starch swelling and gelatinisation (van Buren and Pitifer, 1992; Fuchigami, 1987a, b; Palmer, 1971).

After 10, 15, 20, 25 and 30 minutes of cooking, pulp firmness changes were generally similar ($P < 0.01$) in each of the cultivars/hybrids. Note that the two triploid cultivars (Cuerno and Bluggoe) were significantly firmer than the two FHIA tetraploid cooking banana hybrids (FHIA-03 and FHIA-06) throughout the cooking period ($P < 0.01$). These differences could be related to the fact that the triploid cultivars had a higher percentage pulp dry matter content and lower pulp moisture content in comparison to the tetraploid cooking banana hybrids (Table 18). This may partially explain the fundamental differences in firmness when the triploid cultivars and tetraploid hybrids were compared (i.e. the former is firmer than the latter), as reported by other investigators including Marriott, 1980, and New and Marriott, 1983. Cooked pulp firmness was positively correlated with pulp dry matter content ($r = 0.77$; $P < 0.0001$) and negatively correlated with pulp moisture content ($r = -0.77$; $P < 0.0001$). In simple terms, the higher the percentage pulp dry matter content, the firmer the cooked pulp. Similarly, the lower the percentage pulp moisture content, the firmer the cooked pulp.

Table 18. Genomic group, black Sigatoka resistance and important post-harvest characteristics for evaluating the cooking qualities of cooking banana/plantain.

	Hybrids/cultivars			
Characteristics	FHIA-03	FHIA-06	Bluggoe	Cuerno
Type	Cooking banana	Cooking banana	Cooking banana	Plantain
Genomic group	AABB	AAAB	ABB	AAB
Black Sigatoka resistance	R	IR	R	S
Pulp to peel ratio	1.13^{c}[1]	1.68^{a}	1.46^{b}	1.63^{a}
Pulp thickness (cm)	3.35^{c}	4.12^{b}	4.60^{a}	3.63^{c}
Peel thickness (cm)	0.42^{a}	0.43^{a}	0.45^{a}	0.40^{b}
Pulp dry matter content (%)	25.20^{d}	29.07^{c}	31.97^{b}	39.68^{a}
Pulp moisture content (%)	74.80^{a}	70.93^{b}	68.03^{c}	60.32^{d}

R: Resistant - IR: Intermediate resistance - S: Susceptible

[1] Letters in common within rows were not significantly different at the 1% level. Duncan's multiple range test.

Samples that had been boiled for about 5 minutes did not taste well or fully cooked. Ten minutes of cooking seemed to be ideal for the cooking banana hybrids, since they tasted well cooked, firm and slightly crunchy. In contrast, Cuerno and Bluggoe (triploid cultivars), because of their initial high pulp firmness, high percentage pulp dry matter content and low moisture content, required about 10-15 minutes of cooking to taste well cooked.

c. Water absorption

During cooking, cooking bananas and plantains absorb some water, which ultimately results in softening the pulp. The amount of water absorbed depends to some extent on the duration of cooking and the cultivar. Figure 41 shows changes in the percentage (from the initial weight) of water absorption by FHIA-03, FHIA-06, Bluggoe and Cuerno fruit during cooking for 5, 10, 15, 20, 25 and 30 minutes. Generally, the percentage water absorption in all the cultivars/hybrids clearly increased to a peak and then decreased during the cooking period. However, the extent of the increase and

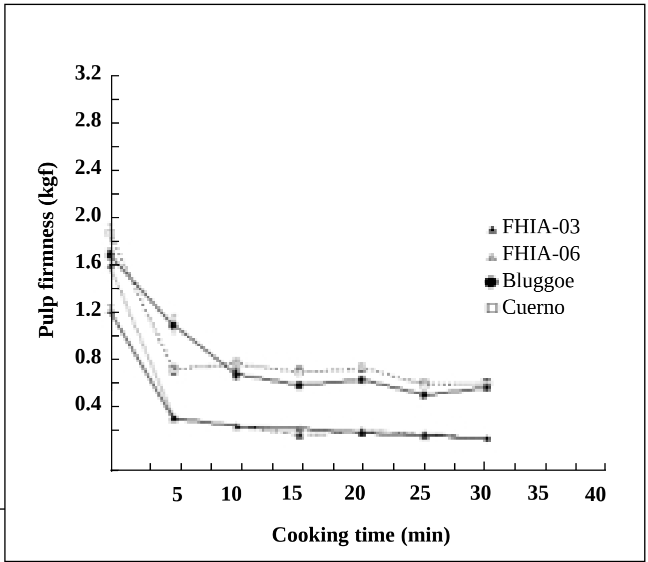


Figure 40. Changes in pulp firmness during cooking of three cooking banana hybrids compared to standard plantain cultivar. Vertical bars indicate standard error of the means (n=40).

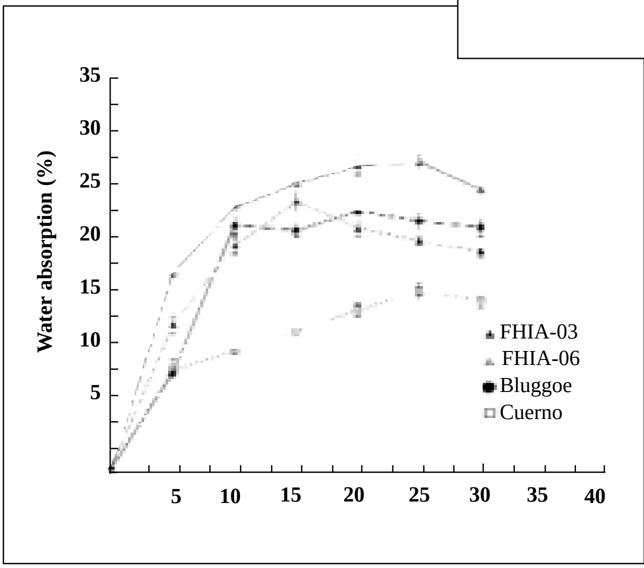


Figure 41. Percentage water absorption by banana/plantain during cooking. Vertical bars indicate standard error of the means (n=40).

decline were cultivar-dependent ($P < 0.01$). During the cooking period, the percentage water absorption was higher in FHIA-06 in comparison to the other cultivars/hybrids. In contrast, Cuerno absorbed comparatively less water during cooking. In the cooking banana hybrids/cultivar (FHIA-03, FHIA-06 and Bluggoe), there was an increase of nearly 17%, 23% and 7%, respectively, in the percentage water absorption after 5 minutes of cooking, compared to approximately 8% in Cuerno. This initial dramatic increase in the percentage water absorption in these hybrids/cultivars marks the onset of pulp softening during cooking. Studies conducted by other investigators indicated that water absorption by cellulose, starch and pectin in the pulp during boiling or cooking causes tissue softening. Starch granules in the pulp swell and gelatinize, resulting in a hard to soft-jelly textural change. The cellulose does not undergo further change. Pectin is hydrolysed by the hot water and converted into a softer more soluble form, making the tissues easier to bite and masticate (Birch *et al.*, 1978; Brinto and Bourne, 1972).

The cooking banana hybrids/cultivars absorbed more water during the cooking period compared to the plantain cultivar (Cuerno). This indicates that, relative to Cuerno, the cooking bananas (FHIA-03, FHIA-06 and Bluggoe) were less suitable for boiling, i.e. they absorbed more water during boiling, and the samples were thus softer and not as crunchy as the Cuerno plantain samples. The cooking bananas could therefore be more suitable for frying (as chips), roasting or baking. The good cooking qualities of Cuerno may be related to its comparatively higher pulp firmness, higher percentage pulp dry matter content and lower moisture content (Table 18).

Correlation analyses further indicated that the percentage water absorption was inversely related to cooked pulp firmness ($r = -0.67$; $P < 0.0001$). In other words, the higher the water absorption of the pulp of a particular cultivar during cooking, the less firm or softer the cooked pulp.

The conclusions were as follows:

1. Mature unripe FHIA-06 and Cuerno fruit had higher pulp to peel ratios compared to FHIA-03 and Bluggoe, indicating that a higher proportion of the pulp per unit weight (of FHIA-06 and Cuerno) is available for consumers.
2. At the mature green stage, the cooking banana hybrids/cultivars (FHIA-03, FHIA-06 and Bluggoe) were relatively difficult to peel compared to the plantain cultivar (Cuerno). This may partly be related to the high mean peel thickness of the cooking banana hybrids.
3. Throughout the cooking period, the triploid cultivars (Cuerno and Bluggoe) were comparatively firmer than the FHIA tetraploid cooking banana hybrids. These differences were related to the higher initial pulp firmness before cooking and the higher percentage pulp dry matter content and lower pulp moisture content of the triploid cultivars.
4. One advantage of the FHIA cooking banana hybrids over Cuerno and Bluggoe was that their cooking time was shorter.
5. The cooking banana hybrids/cultivar (FHIA-03, FHIA-06 and Bluggoe) absorbed more water during the cooking period and consequently were less firm or softer than Cuerno, indicating that the cooking banana hybrids/cultivar are less suitable for boiling, but perhaps better for frying (as chips), roasting or baking. The good cooking qualities of Cuerno may be explained by its comparatively lower water absorption potential, higher pulp firmness before cooking, higher percentage pulp dry matter content and lower moisture content.

3. Plantain hybrids

The post-harvest characteristics at harvest, maturation, green-life, ripening quality and organoleptic features of two black Sigatoka-resistant tetraploid plantain hybrids, FHIA-21 and FHIA-22, are compared to a traditional black Sigatoka susceptible triploid cultivar, Cuerno (Horn Plantain). Figure 42 shows typical bunches of FHIA-21, FHIA-22 and Cuerno plantains. The materials and methods used to obtain the results/data presented in the tables and figures in this chapter were previously described by Dadzie and Orchard (1996); Dadzie (1993a,b,c); Dadzie (1994a,b,c).

Genomic group

Table 19 shows the type, genomic group, parentage and black Sigatoka resistance of FHIA-21 and FHIA-22 plantain hybrids compared to Cuerno.

Table 19. Type, genomic group, parentage and black Sigatoka resistance of FHIA-21 and FHIA-22 compared to Cuerno.

Characteristics	FHIA-21	FHIA-22	Cuerno
Type	Plantain hybrid	Plantain hybrid	Horn Plantain
Genomic group	AAAB	AAAB	AAB
Parentage	AVP-67 X SH-3142	AVP-67 X SH-3142	Unknown
Black Sigatoka resistance	R	R	S

R = Resistant S = Susceptible

POST-HARVEST CHARACTERISTICS AT HARVEST

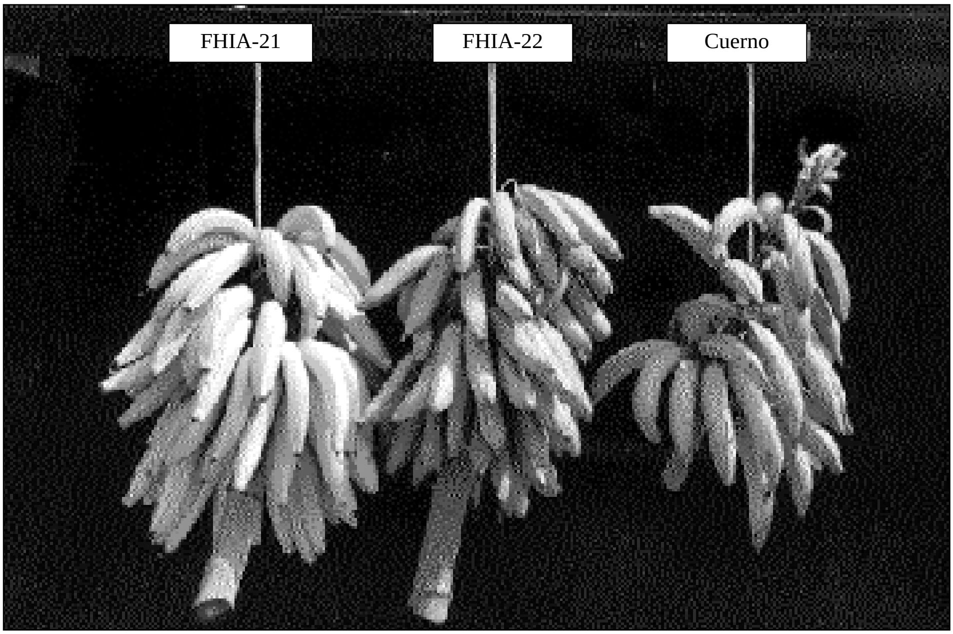


Figure 42. Typical bunches of FHIA-21, FHIA-22 and Cuerno plantains.

The two main FHIA plantain hybrids are FHIA-21 and FHIA-22. Tables 20 to 22 show the post-harvest characteristics (at harvest) of FHIA-21, FHIA-22 plantain hybrids and Cuerno (Horn Plantain).

FRUIT MATURATION

Table 20. Bunch characteristics (at harvest) of FHIA-21, FHIA-22 and Cuerno plantains.

	Hybrid/cultivar		
Characteristics	FHIA-21	FHIA-22	Cuerno
Bunch weight (kg)	20 - 25	18 - 25	5 - 10
Bunch weight (kg) (dehanded to 5)	18 - 25	18 - 24	-
Number of hands per bunch	8 - 10	8 - 10	4 - 6
Number of fingers per hand	12 - 16	12 - 16	4 - 7

Table 21. Fruit characteristics (at harvest) of FHIA-21, FHIA-22 and Cuerno plantains.

	Hybrid/cultivar		
Characteristics	FHIA-21	FHIA-22	Cuerno
Fruit weight (g)	180 - 250	150 - 250	180 - 295
Fruit length (cm)	20 - 25	20 - 25	20 - 28
Fruit circumference (cm)	12 - 16	12 - 15	13 - 17
Pulp weight (g)	80 - 130	85 - 150	87 - 140
Peel weight (g)	80 - 100	64 - 100	74 - 110
Pulp to peel ratio	1.30 - 1.60	1.40 - 1.70	1.50 - 1.70
Pulp thickness (cm)	3.00 - 4.00	3.00 - 4.00	3.50 - 4.50
Peel thickness (cm)	0.35 - 0.45	0.35 - 0.45	0.38 - 0.43

Table 22. Post-harvest qualities (at harvest) of FHIA-21, FHIA-22 and Cuerno plantains.

	Hybrid/cultivar		
Characteristics	FHIA-21	FHIA-22	Cuerno
Peel colour	Yellow/green	Green	Green
Pulp colour	Orange/yellow	Orange/yellow	Orange/yellow
Pulp firmness (kgf)	1.60 - 1.90	1.70 - 1.95	1.95 - 2.50
Pulp pH	6.00 - 6.30	6.00 - 6.40	6.00 - 6.50
Titratable acidity (mEq/100 g)	1.50 - 2.40	1.50 - 2.20	1.80 - 2.20
Pulp dry matter content (%)	29 - 32	30 - 34	33 - 39
Pulp moisture content (%)	68 - 71	66 - 70	61 - 67

Comparative assessment of maturation in FHIA-21 and Cuerno plantains

Plantains are widely grown for local consumption in most producing countries. However, some countries in Latin America, the West Indies and Africa export part of their plantain production to USA and Europe. Traditional methods are generally used to assess harvest maturity, i.e. monitoring visual signs of ripening or the appearance of hanging bunches, and particularly by the angularity of fingers (Marriott and Lancaster, 1983; Palmer, 1971; Sanchez-Nieva *et al*., 1968). Some farmers even wait until the fingers of the first hand of the bunch show visual signs of ripening or yellowing before the plantain bunches are harvested (Dadzie, 1994d). This system is unsuitable and unreliable for plantains that are to be shipped to Europe, as the fruit will either be ripe or could ripen abnormally because of the long shipping times. This is normally unsatisfactory for both exporters and importers.

Harvest times therefore have to be calculated to enable maximum green-life, without risk of abnormal ripening. The increase in consumer pressure to produce high-quality mature fruit has highlighted the need for objective criteria to assess fruit maturity at harvest, with the overall aim of optimizing fruit quality. A study was undertaken to develop simple reliable field and laboratory methods/procedures aimed at facilitating the determination or assessment of fruit maturity in FHIA-21 and Cuerno plantains. Figures 43 and 44 show typical mature bunches of FHIA-21 and Cuerno plantains.

Typical changes during maturation

a. Visual changes during maturation

The most significant visual changes in fruit morphological characteristics that occurred during maturation involved the size, shape, length and volume of the fruit as bunches aged. Figure 45 shows typical visual changes in various morphological characteristics of FHIA-21 and Cuerno plantains at different stages of maturity. During maturation, fruit plumpness increased, fingers lost their angularity and the fruit became more rounded and fuller in shape. In FHIA-21, the stylar ends also became drier and fell as the fruit matured. In contrast, in Cuerno, the stylar ends became drier and in some cases were loosely attached to the fruit, and the finger tips were initially yellow but turned black as the fruit aged. In both FHIA-21 and Cuerno, vertical lines on the fruit surface were more pronounced in immature fruit, but became less marked as the fruit matured (Figure 45). In FHIA-21, the peel colour during maturation was slightly green to yellow, becoming yellower at very advanced stages of maturity. In contrast, in Cuerno, the peel colour remained green throughout the maturation phase, except at very advanced stages of maturity when the peel became yellow. Most local farmers harvest

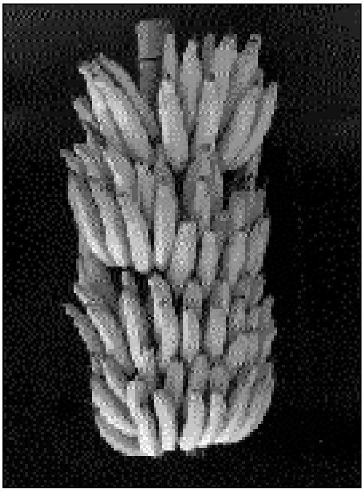


Figure 43. Typical mature bunch of FHIA-21 plantain (left).

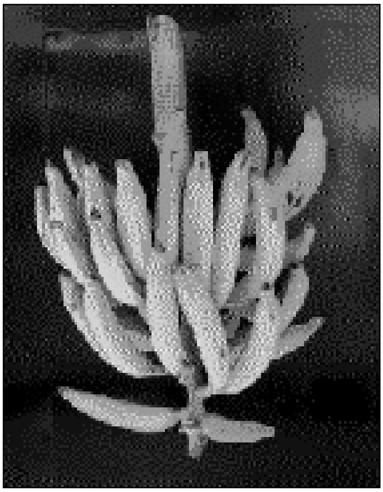


Figure 44. Typical mature bunch of Cuerno plantain (right).

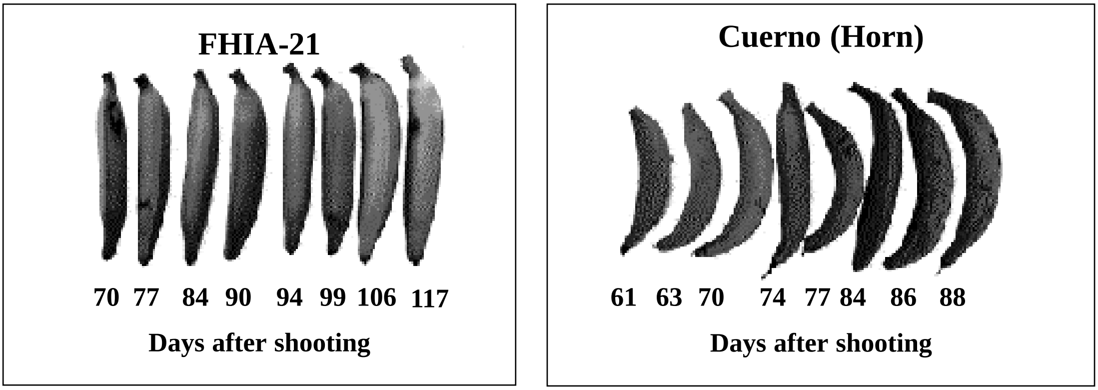


Figure 45. Typical changes in the morphological characteristics of FHIA-21 and Cuerno plantains during maturation.

Cuerno plantains at this stage. This harvest index used by farmers can be deceptive as black Sigatoka infections can result in premature ripening of immature fruit.)

The visible changes in fruit morphology during maturation are important maturity indices for the overall assessment of the time to harvest. Although some morphological changes that occurred in the fruit during maturation may be cultivar-dependent or specific to particular cultivars, most of these visual changes were noted in both FHIA-21 and Cuerno plantains.

b. Changes in fruit characteristics during maturation

i. Fruit weight, length and circumference

Although significant changes were noted in fruit weight (Figure 46), length (Figure 47) and circumference (Figure 48) during maturation of FHIA-21 and Cuerno plantains, the changes were not very consistent. In Cuerno, there were correlation between fruit weight and bunch age ($r = 0.76$; $P < 0.0001$; Figure 46), between fruit length and bunch age ($r = 0.54$; $P < 0.0001$; Figure 47) and between fruit circumference and bunch age ($r = 0.80$; $P < 0.0001$; Figure 48). In contrast, there were no clearly defined trends in FHIA-21, some weak correlations were obtained between fruit weight and bunch age ($r = -0.35$; $P < 0.001$), between fruit length and bunch age ($r = -0.75$; $P < 0.0001$) and between fruit circumference and bunch age ($r = -0.14$; $P < 0.01$). Changes in fruit weight, length and circumference during maturation therefore may not be good indicators of maturity.

ii. Fruit cross-sectional area

Figure 49 depicts typical changes in the cross-sectional dimensions of FHIA-21 and Cuerno plantains during maturation. In both FHIA-21 and Cuerno, the fruit cross-sectional dimensions became more round and plump or larger in size with age. Moreover, the angles became less sharp or wide as fruit aged. There were also clear typical changes in the locular architecture of the fruit as maturity progressed. The locular architecture and degenerating seeds in the fruit became more pronounced with fruit maturity. In FHIA-21, the pulp colour of immature fruit (e.g. 70 and 77 days) was creamy/light orange, then becoming yellow/orange as the fruit aged. In contrast, in Cuerno, the pulp colour remained yellow/orange throughout the maturation phase.

iii. Pulp to peel ratio

Of all the fruit characteristics measured, changes in pulp to peel ratios during fruit maturation in FHIA-21 and Cuerno represented the most significant and consistent index of maturity. Variations in pulp to

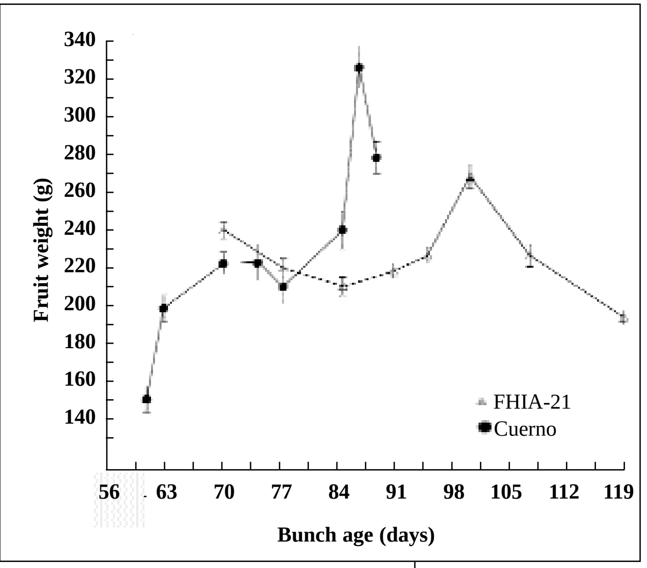


Figure 46. Changes in fruit weight of FHIA-21 and Cuerno during maturation.
Vertical bars indicate standard error of the means.

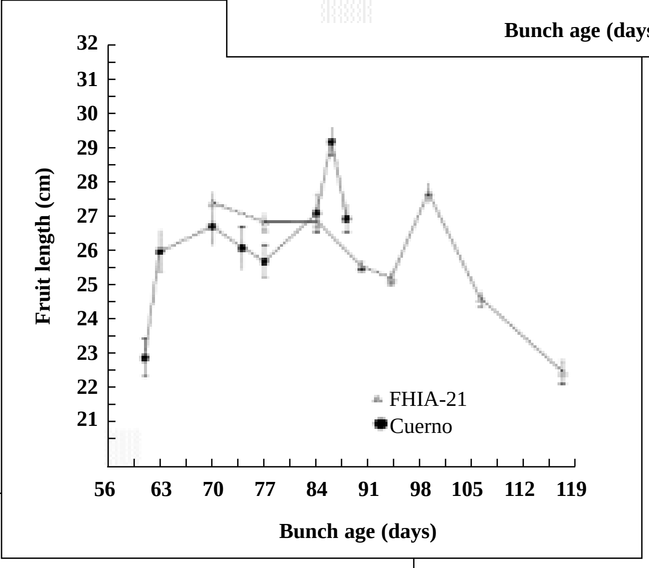


Figure 47. Changes in fruit length of FHIA-21 and Cuerno during maturation.
Vertical bars indicate standard error of the means.

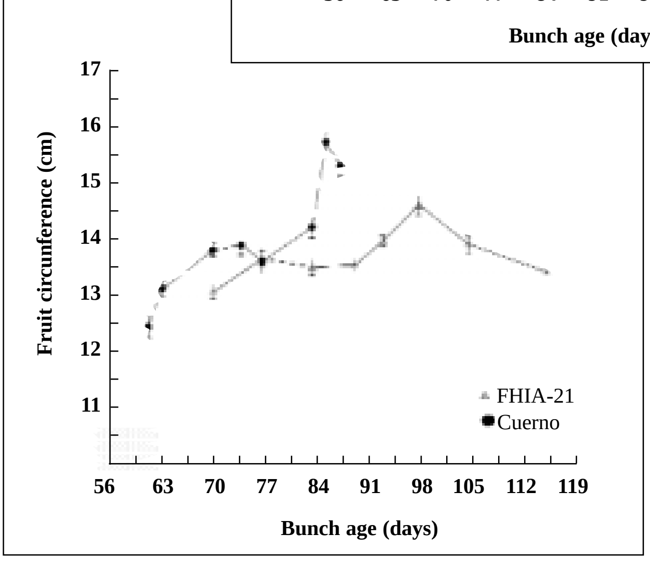


Figure 48. Changes in fruit circumference of FHIA-21 and Cuerno during maturation.
Vertical bars indicate standard error of the means.

peel ratios during maturation were cultivar-dependent ($P < 0.01$; Figure 50, see page 50). A plot of pulp to peel ratios as a function of bunch age indicated a linear relationship. Highly significant positive correlations were also obtained between pulp to peel ratio and bunch age for FHIA-21 ($r = 0.94$; $P < 0.0001$) and Cuerno ($r = 0.87$; $P < 0.0001$). The pulp to peel ratios of FHIA-21 and Cuerno thus increased with bunch age.

An increase in the pulp to peel ratio during maturation indicated that the edible portion per unit fresh weight increased as bunches aged. These results clearly show that there is more edible pulp in the most mature fruit. The pulp to peel ratio is thus a good consistent index of fruit maturity in FHIA-21 and Cuerno.

GREEN-LIFE

Assessment of green-life of FHIA-21 and FHIA-22 plantains

Plantains are usually harvested at the mature green stage and sold. In areas where large quantities of plantains are harvested at once, they are usually stored in bulk at ambient temperature and sometimes at 14°C. During storage, they remain firm and green without marked changes in skin colour, texture or composition for extended periods of time (depending on the temperature and humidity), before the onset of ripening. This well defined period after harvest, during which the fruit remains green and firm, is called the pre-climacteric life or green-life (Peacock, 1966). The process is irreversible once the green-life of the fruit ends and ripening has been initiated, which means that any fruit in this condition will be overripe when it is marketed.

Resistance of the new FHIA plantain hybrids to black Sigatoka and their agronomic suitability are not the only determining factors for their successful introduction. Their green-life potential also has a key role in the overall acceptability of these hybrids. Selection of hybrids which have a long green-life or remain green long after harvest, or ripen slowly, would facilitate marketing of the fruit and reduce post-harvest losses. A study was undertaken to determine the relationship between green-life and bunch age in FHIA-21 and FHIA-22 plantains stored at 14°C and 27°C.

Green-life at 27 ± 1°C

Figures 51 and 52 (next page) illustrate the relationship between bunch age and green-life of FHIA-21 and FHIA-22 during storage at 27 ± 1°C. A plot of bunch age as a function of green-life of FHIA-21 and FHIA-22 indicated a close linear relationship between bunch age and green-life. In simple terms,

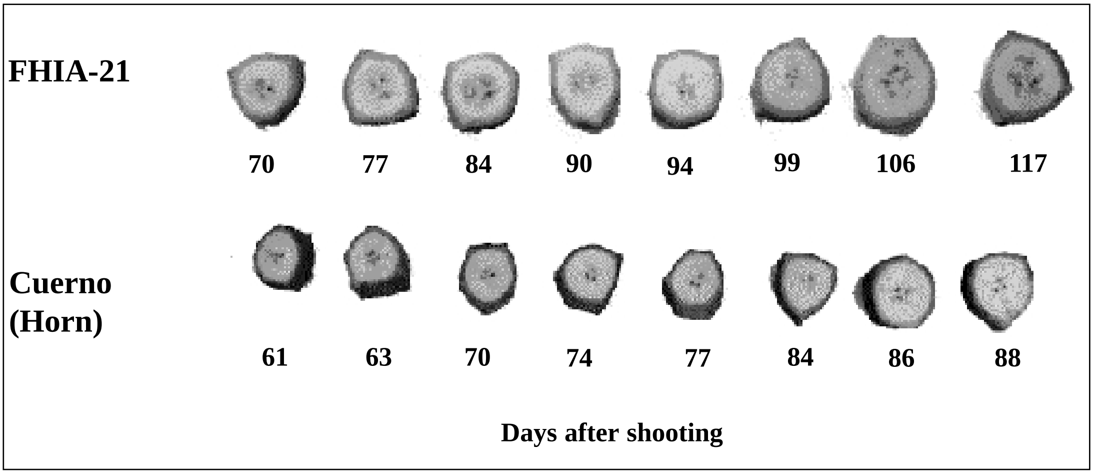


Figure 49. Typical changes in the angles, shape and size of the cross-sectional area of FHIA-21 and Cuerno plantains during maturation.

the green-life of both FHIA-21 and FHIA-22 plantains declined as bunch age increased, i.e. bunch age determines the length of the green-life, and the green-life is shorter in more mature or older fruit. Similar findings have been reported by other investigators, including Blake and Peacock (1971), Marriott *et al.* (1979), Marriott and Montoya (1981) and Peacock (1966).

At 27 ± 1°C, FHIA-22 plantains generally had a longer green-life compared to FHIA-21. For instance, FHIA-22 fruit harvested 70 days after floral emergence and stored at 27 ± 1°C had a green-life of 25 days, compared to 12 days for FHIA-21 fruit harvested 70 days from shooting. FHIA-21 or FHIA-22 should be harvested for local consumption any time beyond 100 days post-floral emergence. FHIA-21 harvested at 100 days thus have an estimated green-life (at 27 ± 1°C) of about 7 days, compared to about 11 days for FHIA-22 (i.e. deduced from the regression equations in Figures 51 and 52).

Green-life at 14 ± 1°C

At a storage temperature of 14 ± 1°C, bunch age in FHIA-21 or FHIA-22 was linearly related to green-life (Figures 53 and 54, page 51). This implies that the more mature the bunch is at harvest, the shorter the green-life and vice-versa. FHIA-21 plantains harvested 117 days after shooting and stored at 14°C had a green-life of 17 days, while those harvested at 70 days had a green-life of 31 days. Similarly, FHIA-22 plantains harvested 114 days after shooting and stored at 14°C had a green-life of 25 days, while those harvested at 70 days had a green-life of 41 days.

The estimated green-life (at 14 ± 1°C) of FHIA-21 plantains harvested 100 days after shooting would be approximately 22 days, compared to nearly 30 days for FHIA-22 (i.e. deduced from the regression equations in Figures 53 and 54). Indeed, storage at 14 ± 1°C increased the green-life (22 days) of FHIA-21 plantains by nearly threefold as compared to those stored at 27 ± 1°C (7 days). Similarly, in FHIA-22, storage at 14 ± 1°C increased the green-life (30 days) by approximately threefold in comparison to plantain stored at 27 ± 1°C (11 days).

The results of this study clearly demonstrate that, at storage temperatures of 14°C and 27°C, the bunch age of FHIA-21 and FHIA-22 plantains was linearly related to green-life. This implies that bunch age determined the length of the green-life in FHIA-21 and FHIA-22. The closeness and consistency of the relationship between bunch age and green-life indicates that bunch age is a good predictor of green-life in FHIA-21 and FHIA-22. FHIA-22 plantains generally had a longer green-life than FHIA-21 plantains.

Sensory Evaluation

Consumers' plantain selection criteria

Consumers' selection criteria when purchasing plantain are based largely on the visual impression or appearance, colour, shape and size (Dadzie, 1993d). Assessment of consumers' plantain selection criteria is important for the overall acceptability of the new plantain hybrids. Consumers have learnt from past experience to associate desired qualities with certain external features. They have a distinct preference for specific types of plantain. Hence, prior to purchasing plantains, the consumer makes a rapid visual assessment (according to past experience), based on the size, shape, colour and appearance or visual impression.

In addition to these criteria, in some West African countries and in Latin America, some consumers prefer plantains with attractive orange/yellow pulp colour. To ensure wide consumer acceptability of these plantain hybrids, it was therefore essential to evaluate these new FHIA hybrids on the basis of important consumers' plantain selection criteria.

An assessment of consumers' pre-purchase plantain selection criteria, based on visual impression or appearance, shape, size and colour of fingers, was undertaken using hands of FHIA-04, FHIA-16, FHIA-21, FHIA-22 and Cuerno plantain hybrids/cultivar (Figure 55). In a parallel study, consumer preferences based on pulp colour and size were also assessed.

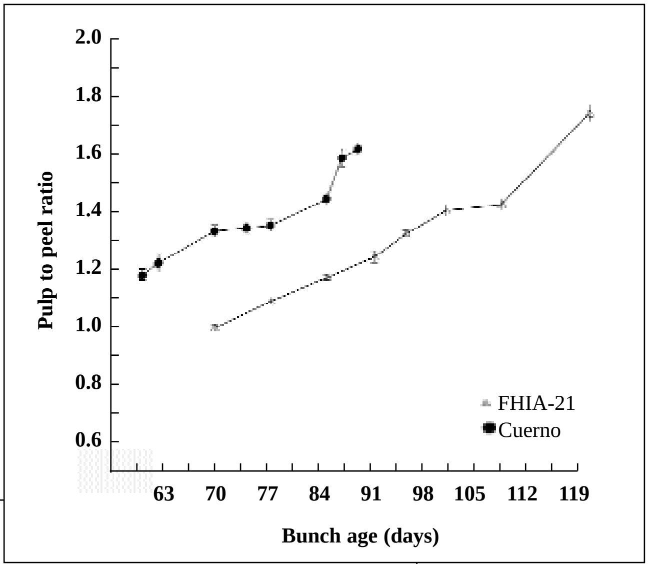


Figure 50. Changes in fruit pulp to peel ratio of FHIA-21 and Cuerno during maturation .
Vertical bars indicate standard error of the means.

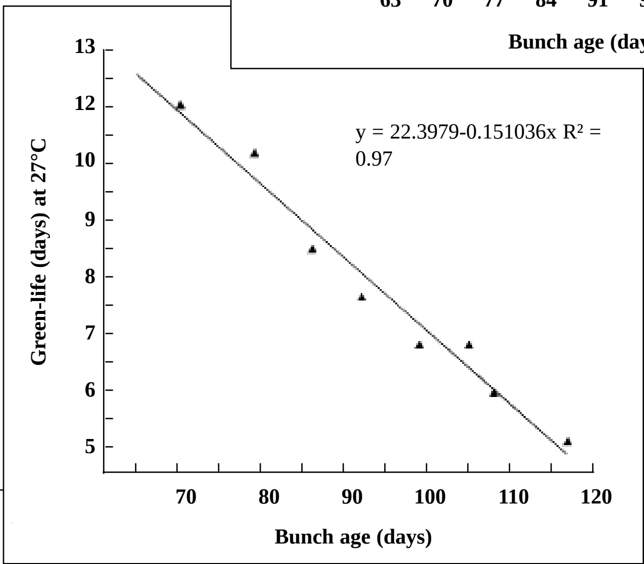


Figure 51. Relationship between bunch age and green-life of FHIA-21 during storage at 27°C.

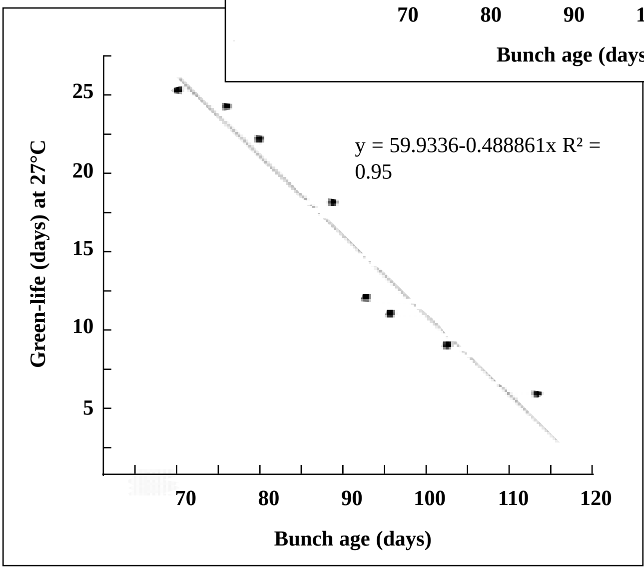


Figure 52. Relationship between bunch age and green-life of FHIA-22 during storage at 27°C.

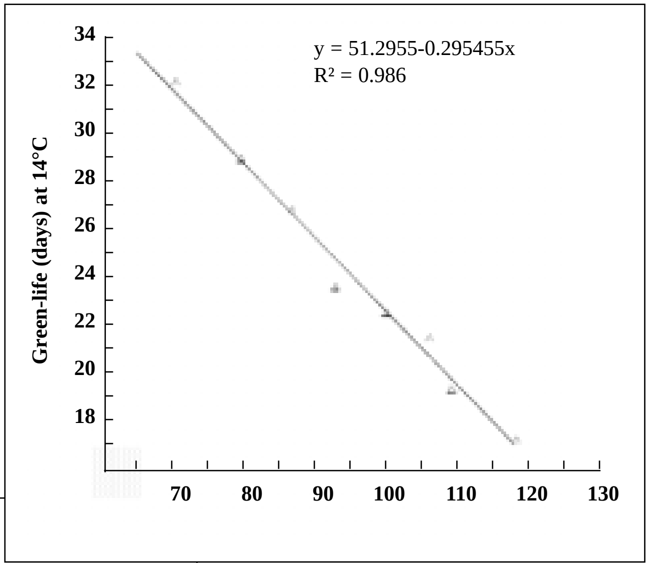


Figure 53.Relationship between bunch age and green-life of FHIA-21 during storage at 14°C.

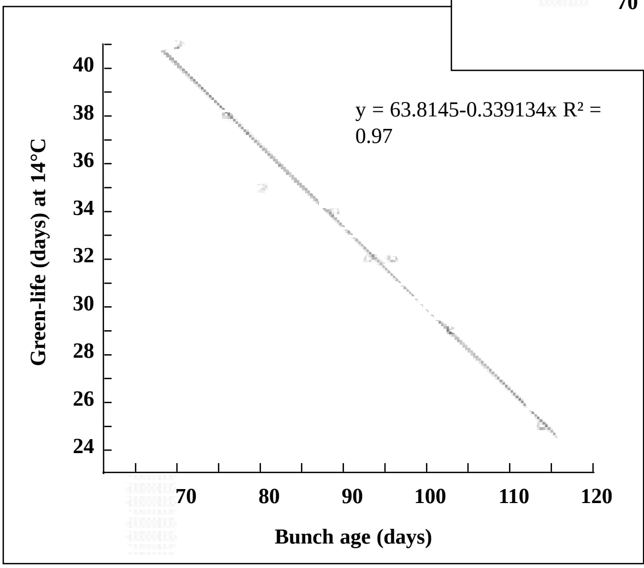


Figure 54. Relationship between bunch age and green-life of FHIA-22 during storage at 14°C.

Sensory evaluation

The second hand of the bunch of each cultivar/hybrid was coded (A, B, C, D and E) and displayed on a table. Twenty-eight untrained male and female panelists participated in the study. Panelists were asked to imagine that they are at the market buying plantains, where they find out that there are five different plantain varieties on display. Panelists had to rank the coded samples for each quality feature (i.e. colour, shape, size and appearance of the plantain fingers) in order of preference, using a hedonic scoring scale of 1 (most preferred) to 5 (least preferred).

Three fingers from the second hand of bunches of each cultivar/hybrid were hand-peeled and the pulp was put in transparent plastic bags, coded (A, B, C, D and E) and displayed on a table. Twenty-four untrained male and female panelists were asked to rank the coded samples for each quality feature (i.e. pulp colour and size) in order of preference using a hedonic scale of 1 (most preferred) to 5 (least preferred).

Consumers' selection criteria

Consumers' pre-purchase plantain selection criteria are as follows:

a. Peel colour

Plantain peel colour probably contributes more to consumer assessment of quality at the retail point than any other single factor. Consumers make distinct correlations between peel colour and the overall quality of specific products. In the sensory evaluations, panelists were asked to rank five different coded plantain cultivars in order of preference on the basis of colour, shape, size and appearance. In terms of peel colour, panelists ranked FHIA-04 as the most preferred, followed consecutively by FHIA-16, FHIA-22 and FHIA-21, while Cuerno was the least preferred (Table 23). The fact that Cuerno was ranked as the least preferred cultivar is interesting. The panelists were quiet familiar with Cuerno as it is widely grown in Honduras, but they ranked FHIA-04 as the most preferred cultivar on the basis of finger colour. Cuerno has a slightly yellow to green peel colour at maturity, while peel of FHIA-04, FHIA-16 and FHIA-22 is deep green at this stage. This indicates that consumers prefer plantains with a deep green peel colour. Ironically, the panelists preferred FHIA-21 over Cuerno, even though it has a slightly more yellow to green peel colour than Cuerno. These results indicate that plantain peel colour is an important quality parameter or selection criterion of consumers when purchasing plantains. Breeders should thus aim at breeding plantain hybrids that have a deep green peel at maturity, as this is the colour most preferred by consumers.

b. Shape of fingers

The shape of plantain fingers is an important factor in consumers' overall assessment of quality. Shape is a key consumer selection criterion for distinguishing between plantain cultivars. Indeed, consumers usually prefer characteristic shapes, as there is initial consumer resistance to plantains with uncharacteristic shapes. Plantain fingers that do not have a familiar shape are least preferred by consumers, and lower prices are generally paid for plantains with unusual-shaped fingers. The results presented in Table 23 clearly indicate that, on the basis of finger shape, the 28 panelists preferred FHIA-16, followed consecutively by FHIA-04, FHIA-22 and FHIA-21, and Cuerno was the least preferred. These data indicate that the shape of plantain fingers can alter consumer acceptability and hence the market potential. A new agronomically superior hybrid could thus be developed through breeding, but there could be some initial consumer resistance if it does not have a familiar shape.

Table 23. Sensory evaluation scores for consumers' pre-purchase plantain selection criteria based on peel colour, shape, size and appearance.

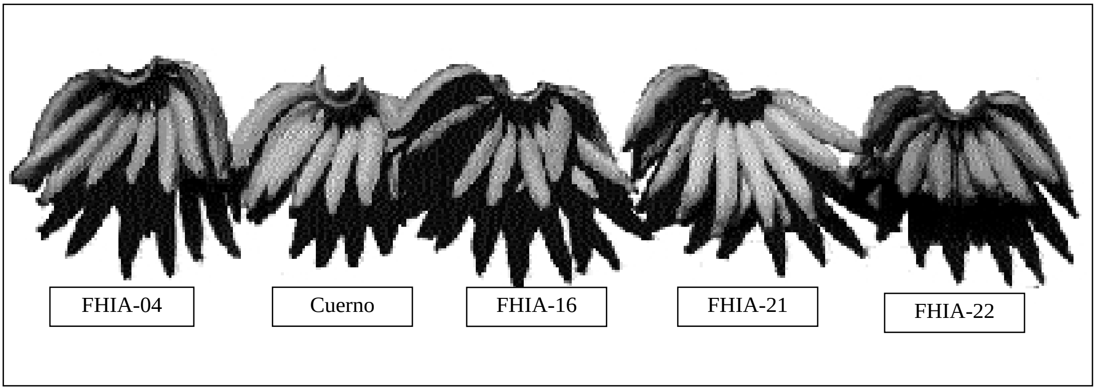


Figure 55. Typical hands of FHIA-04, FHIA-16, FHIA-21, FHIA-22 and Cuerno plantains.

Order of presentation	Cultivar/hybrid	Consumers' plantain selection criteria			
		Colour	Shape	Size	Appearance
A	FHIA-04	1	2	3	1
B	Cuerno	5	5	5	5
C	FHIA-16	2	1	2	4
D	FHIA-21	4	4	1	2
E	FHIA-22	3	3	4	3

Scale: 1 (most preferred) to 5 (least preferred)

c. *Size of fingers*

The size of plantain fingers can significantly affect consumer appeal, market selection and final use. Consumers can select plantains to buy on the basis of size. Very small plantain fingers are considered less acceptable and usually bring low prices, while large fruit (i.e. the highest quality) brings high prices. The results of this study (Table 23) clearly showed that FHIA-21 was the most preferred cultivar on the basis of size, followed consecutively by FHIA-16, FHIA-04 and FHIA-22, while Cuerno was the least preferred. Interestingly, the fact that FHIA-21 was the most preferred cultivar suggests that consumers pay less attention to peel colour when the plantain fingers are large. It is therefore important to dehand (i.e. remove some of the lower hands) FHIA-21 bunches during their development to enhance finger size.

d. *Appearance of plantain fingers*

Plantain appearance is an important post-harvest quality criterion determining the market value of the fruit, since consumers often buy solely on the basis of their visual impression. Consumers tend to associate desired plantain features with certain external appearances. The data presented in Table 23 clearly indicate that, on the basis of appearance, the panelists preferred FHIA-04, followed consecutively by FHIA-21, FHIA-22, FHIA-16, while Cuerno was the least preferred. Note that most consumers preferred green, large and long plantain fingers (this trend was also noted during a visit to Ghana and Nigeria; Dadzie, 1993d). Hence, breeders should take consumer preference into serious consideration in future breeding work.

Pulp colour and size

Interestingly, when the pulp of FHIA-04, FHIA-16, FHIA-21, FHIA-22 and Cuerno plantains were displayed, none of the 24 panelists were able to differentiate cultivars on the basis of pulp colour. In all five cultivars, the pulp was orange/yellow and most consumers prefer this colour. Consumers should thus accept the FHIA hybrids on the basis of pulp colour.

When the panelists were asked to rank the five cultivars in order of preference based on pulp size, FHIA-21 was the most preferred cultivar, followed consecutively by FHIA-22, FHIA-16 and FHIA-04, while Cuerno was the least preferred (Table 24).

In conclusion, on the basis of peel colour, shape, size and appearance (total score for each cultivar), FHIA-04 turned out to be the most preferred hybrid, closely followed by FHIA-16, FHIA-21 and FHIA-22 (in this order), while Cuerno (i.e. the standard cultivar grown in Honduras, and highly susceptible to black Sigatoka) was the least preferred. On the basis of pulp size, FHIA-21 was ranked as the most preferred cultivar, followed consecutively by FHIA-22, FHIA-16 and FHIA-04, while Cuerno was the least preferred. The five plantain cultivars had an orange/yellow pulp colour, which consumers generally prefer, but they could not be distinguished on the basis of this trait.

Table 24. Consumer preference scores based on pulp size.

Order of presentation	Hybrid/cultivar	Pulp size
A	FHIA-04	4
B	Cuerno	5
C	FHIA-16	3
D	FHIA-21	1
E	FHIA-22	2

Scale: 1 (most preferred) to 5 (least preferred)

Consumer acceptability of "tostones" prepared from FHIA-21, FHIA-22 and Cuerno plantains

In most areas where plantains are consumed, various kinds of dishes are prepared with mature green unripe plantain. In some Latin American countries, e.g. Honduras and Puerto Rico, "tostones" is a favourite dish prepared by slicing green unripe plantain pulp crosswise. The pulp is fried in vegetable oil for a few minutes and then removed. It is then placed on a flat surface (e.g. kitchen chopping board) and pressed. The pressed slices are refried in the same oil.

A study was undertaken to compare the post-harvest quality features and consumer acceptance/preference of "tostones" prepared with FHIA-21 and FHIA-22 plantains (FHIA hybrids) and standard Cuerno plantain, based on texture, taste, colour and overall acceptability. Figure 56 shows typical unripe fingers of FHIA-21, FHIA-22 and Cuerno plantains.

Sensory evaluation

Twenty-six male and female panelists were involved in the comparative assessment of consumer acceptance/preference concerning "tostones" prepared with FHIA-21 and FHIA-22 plantains (FHIA hybrids) and standard Cuerno plantains (Figure 57). The overall aim was to assemble a panel that would reliably reflect the range of preferences of Honduran consumers. Each panelist was used to eating "tostones", since it is one of the most favourite dishes in Honduras. They were presented with coded samples of "tostones" made with Cuerno, FHIA-21 and FHIA-22 plantains and asked to compare the samples based on texture, taste, colour and overall acceptability, using a hedonic scoring scale of 1 to 5 (Table 25). In addition, panelists were asked to state which of the samples they preferred most. All panelists were instructed on basic taste-test procedures, i.e. to make their own assessments after a moderate amount of consideration. They were also asked to take a sip of water and pause briefly before tasting each sample and to retaste if they were not sure of their assessments.

On the day the "tostones" were prepared for the sensory studies, some key post-harvest quality indices (e.g. peel and pulp colour, pulp to peel ratio, pulp firmness, total soluble solids, pulp pH and titratable acidity, pulp dry matter and moisture content) for the sensory evaluation of "tostones" were assessed. This complemented the sensory studies and also helped explain differences in consumer acceptance/preference with respect to the plantain hybrids/cultivar.

Table 25. Hedonic scoring scale for the comparative sensory evaluation of "tostones" prepared from FHIA-21, FHIA-22 and Cuerno plantains.

Scale	Texture	Taste	Colour	Overall acceptability
5	Too soft	Excellent	Excellent	Excellent
4	Soft	Very acceptable	Like very much	Very good
3	Firm	Good	Good	Good
2	Hard	Fair	Fair	Fair
1	Too hard	Poor	Poor	Poor

Post-harvest features

The peel and pulp colour of FHIA-21, FHIA-22 and Cuerno plantains was one of the key post-harvest

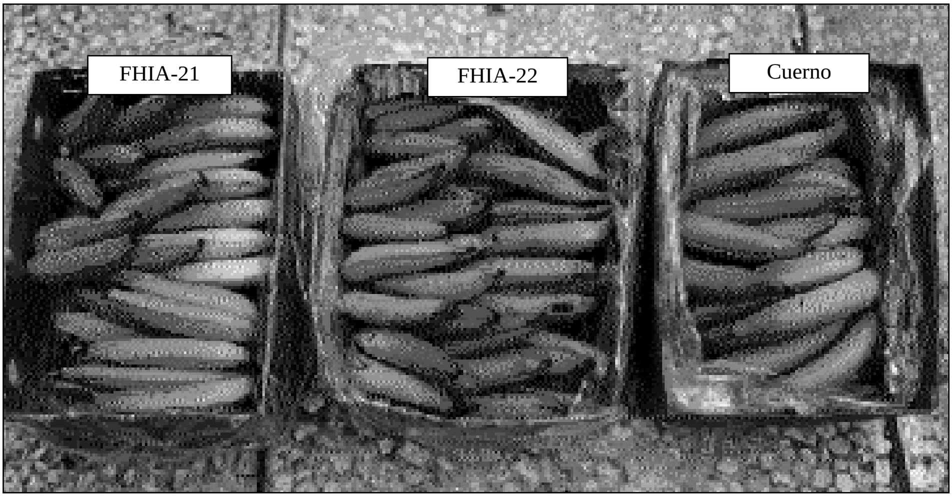


Figure 56. Typical unripe fingers of FHIA-21, FHIA-22 and Cuerno plantains.

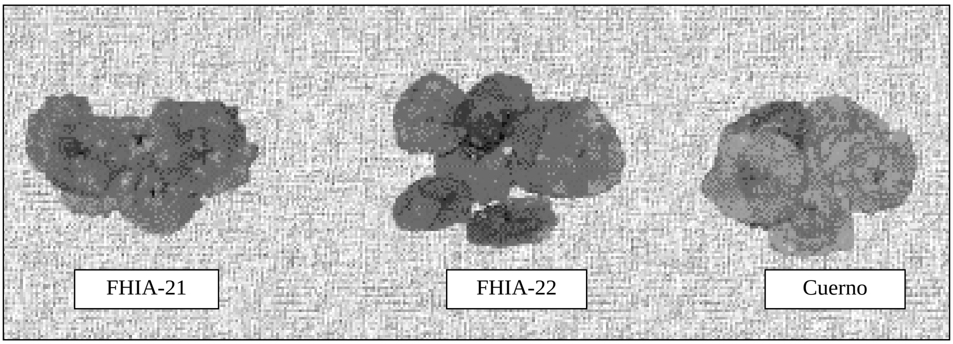


Figure 57. Photograph of “tostones” prepared from unripe fingers of FHIA-21, FHIA-22 and Cuerno plantains.

quality indices assessed on the day of the sensory studies. The overall aim was to objectively quantify and compare peel and pulp colours of plantain samples used to prepare “tostones”. The results highlighted significant differences in peel and pulp colour between the plantain hybrids/cultivars, as indicated by the “L”, “a” and “b” values ($P < 0.01$; Table 26). These differences in peel and pulp colour reflected fundamental differences between the plantain hybrids/cultivars. Peel colour was almost identical (i.e. green) in FHIA-22 and Cuerno plantains, whereas FHIA-21 had a slightly yellow to green peel at the mature green stage. In the visual assessment, the FHIA hybrids were found to have the same pulp colour as Cuerno plantains (i.e. orange/yellow). Although there are fundamental genetic differences in the peel and pulp colours of FHIA-21, FHIA-22 and Cuerno plantains, the fruit used in the preparation of “tostones” for the sensory evaluation studies was clearly green and unripe.

There were significant differences in the pulp to peel ratios of FHIA-21, FHIA-22 and Cuerno ($P < 0.01$; Table 26). FHIA-22 had a significantly higher mean pulp to peel ratio compared to FHIA-21. However, the pulp to peel ratios of FHIA-22 and Cuerno were statistically similar. In simple terms, FHIA-22 and Cuerno fruit used in the sensory studies had a more edible portion of pulp per unit weight of fruit in comparison to FHIA-21.

Analysis of the pulp total soluble solid content (TSS), pH and titratable acidity of the samples indicated that FHIA-21, FHIA-22 and Cuerno plantains used in these studies were green and unripe. Indeed, there were no measurable total soluble solids in any of the samples (Table 26), indicating that the fruit used in the sensory studies was unripe. Note that pulp pH is often high while the titratable acidity is low at the mature green stage. TSS increases, pH decreases and acidity increases after the onset of ripening.

Sensory quality features

The sensory quality features assessed included:

i. Texture

Analysis of the sensory data indicated significant differences in consumer acceptability of “tostones” on the basis of texture ($P < 0.01$; Table 27), i.e. the panelists preferred the soft texture of “tostones” prepared from FHIA-21 more than those prepared from FHIA-22 or Cuerno plantains. Similarly, the panelists preferred the texture of FHIA-22-based “tostones” more than that of Cuerno. The panelists generally considered that “tostones” prepared from Cuerno plantains were harder in comparison to those prepared from FHIA-21 or FHIA-22 plantains. In Honduras, consumers usually prefer soft to hard “tostones”.

Table 26. Key post-harvest quality indices for sensory evaluation of “tostones” prepared from FHIA-21, FHIA-22 and Cuerno plantains.

Features		Hybrid/cultivar FHIA-21	FHIA-22	Cuerno
Peel colour	L	66.85[a1]	55.58[c]	60.87[b]
	a	-15.12[a]	-20.68[b]	-21.29[b]
	b	29.17[c]	34.30[b]	37.48[a]
Pulp colour	L	82.01[b]	83.83[b]	86.55[a]
	a	-0.96[b]	-0.96[b]	1.44[a]
	b	31.73[b]	28.76[c]	34.76[a]
Pulp colour		Orange/yellow	Orange/yellow	Orange/yellow
Pulp to peel ratio		1.52[b]	1.74[a]	1.63[ab]
Pulp firmness (kgf)		1.47[b]	1.67[ab]	1.91[a]
Total soluble solids (%)		0.00[a]	0.00[a]	0.00[a]
pH		6.25[c]	6.45[b]	6.65[a]
Titratable acidity (mEq/100 g)		2.00[a]	1.80[b]	1.65[c]
Pulp dry matter content (%)		31.20[b]	33.06[b]	36.33[a]
Pulp moisture content (%)		68.80[a]	66.94[a]	63.67[b]

1 Letters in common within rows were not significantly different at the level. Mean separation by Duncan's multiple range test.

Table 27. Mean scores for the comparative sensory evaluation of "tostones" prepared from FHIA-21, FHIA-22 and Cuerno plantains.

Hybrid/cultivar	Sensory quality features Texture	Taste	Colour	Overall acceptability
FHIA-21	4.46[a1]	3.77[a]	3.92[a]	3.68[a]
FHIA-22	3.85[b]	3.12[ab]	2.04[b]	2.92[b]
Cuerno	1.92[c]	2.85[b]	3.77[a]	2.68[b]

[1] Letters in common within columns were not significantly dif the 1% level. Mean separation by Duncan's multiple range

When the sensory data was compared with the physical assessment of pulp before frying the "tostones", Cuerno clearly had higher mean pulp firmness than FHIA-21 or FHIA-22 (P < 0.01; Table 26), which may explain the hard texture of "tostones" prepared from Cuerno plantains. As the pulp dry matter and moisture contents were also important in determining fruit firmness, these parameters were assessed to help explain fruit firmness and for comparison with the sensory data. The results indicated that the percentage pulp dry matter and moisture content of Cuerno plantains differed significantly from those of FHIA-21 and FHIA-22 ($P < 0.01$; Table 26). Cuerno, a triploid plantain cultivar, had a higher mean pulp dry matter content and lower pulp moisture content compared to the two FHIA tetraploid hybrids (FHIA-21 and FHIA-22). This further explains the hard texture of Cuerno fruit compared to FHIA-21 and FHIA-22.

ii. Taste

The taste of "tostones" is equally important for Honduran consumers. Hence, in the sensory evaluation studies, panelists were asked to assess the taste of "tostones" prepared from FHIA-21, FHIA-22 and Cuerno plantains using a hedonic scoring scale of 1-5 (Table 25). The taste of FHIA-21 was significantly more acceptable in comparison to Cuerno ($P < 0.01$; Table 27), while the taste of FHIA-22 was ranked between that of FHIA-21 and Cuerno plantains.

iii. Colour

The colour of the "tostones" is important in the assessment of consumer acceptability. In the sensory studies, the panelists indicated that the colours of "tostones" prepared from FHIA-21 and Cuerno plantains were similar and more acceptable than those prepared from FHIA-22 ($P < 0.01$; Table 27).

iv. Overall acceptability

On the basis of overall acceptability, "tostones" prepared from FHIA-21 plantains were significantly more acceptable than those prepared from FHIA-22 and Cuerno plantains ($P < 0.01$; Table 27). In contrast, the overall acceptability of FHIA-22 and Cuerno was similar. Correlation analysis further indicated that the overall acceptability of "tostones" was closely related to taste ($r = 0.73$; $P < 0.0001$), but only partially related to texture ($r = 0.40$; $P < 0.001$) and colour ($r = 0.39$; $P < 0.001$). In other words, although texture and colour of "tostones" contributed to the overall acceptability of FHIA-21, FHIA-22 and Cuerno plantains, taste was the most important factor for overall consumer acceptability.

Preference

When the 26 panelists were asked which of the samples they preferred most, approximately 54% stated that they preferred "tostones" prepared from FHIA-21 plantains, while 31% opted for FHIA-22 and 15% chose Cuerno (Figure 58).

The conclusions of this study were as follows:

1. The key post-harvest indices (e.g. peel and pulp colour, pulp to peel ratio, total soluble solids, pH and acidity) indicated that FHIA-21, FHIA-22 and Cuerno plantains used in the sensory studies of "tostones" were green and unripe.
2. In the sensory studies, the panelists preferred the soft texture of "tostones" prepared from FHIA-21 more than those prepared from FHIA-22 and Cuerno plantains. Panelists indicated that "tostones" prepared from Cuerno plantains were hard. This may partly be related to the higher pulp firmness, higher pulp dry matter content and lower pulp moisture content of Cuerno (triploid cultivar) compared to FHIA-21 and FHIA-22 (tetraploid hybrids).
3. Based on taste, panelists indicated that the taste of "tostones" prepared from FHIA-21 plantains was more acceptable than that of "tostones" prepared from standard Cuerno plantains. In contrast, the colours of "tostones" prepared from FHIA-21 and Cuerno plantains were similar. On the basis of overall acceptability, "tostones" prepared from FHIA-21 were more acceptable than those prepared from FHIA-22 and Cuerno plantains. Panelists generally preferred "tostones" prepared from FHIA-21 plantains.

Consumer acceptability of plantain chips prepared from FHIA-21, FHIA-22 and Cuerno plantains

To assess consumer acceptability of the new plantain hybrids, a study was conducted to compare

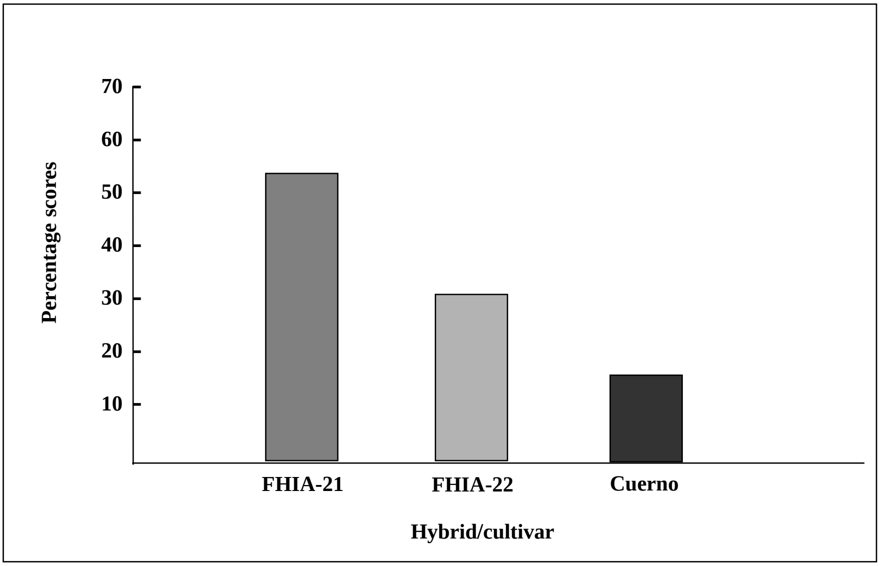


Figure 58. Comparative consumer preference of tostones prepared from FHIA-21, FHIA-22 and Cuerno hybrids/cultivars (n=26).

consumer acceptability of plantain chips prepared from FHIA plantain hybrids (FHIA-21 and FHIA-22) and the standard cultivar (Cuerno), based on texture, taste, colour, crispiness and overall acceptability. The plantain chips were prepared by *Alimentos Dixie*, a company based in San Pedro Sula (Honduras) that specializes in making plantain chips for export to USA.

Sensory evaluation

A total of 53 untrained male and female taste panelists were involved in this study. The overall aim was to assemble a panel that would reliably reflect the range of preferences of Honduran consumers. Panelists were presented coded samples of unripe plantain chips made from FHIA-21, FHIA-22 and Cuerno (Figure 59). Panelists were asked to assess the samples on the basis of texture, taste, colour, crispiness and overall acceptability, using a hedonic scoring scale of 1 to 5 (Table 28). In addition, panelists were asked to state which of the samples they preferred most. All panelists were instructed on basic taste-test procedures, to make their own assessments after a moderate amount of consideration. They were asked to take a sip of water and pause briefly before tasting each sample and to retaste the samples if they were not sure of their assessments.

Sensory quality features

The following sensory quality features were assessed:

i. Texture and taste

Compared to Cuerno plantains, there were no significant differences in the texture and taste of chips prepared from FHIA-21 and FHIA-22 plantains (Table 29).

ii. Colour and crispiness

The colour of chips made with FHIA-22 plantains differed significantly from that of FHIA-21 and Cuerno plantain chips (Table 29). The colour of chips prepared from FHIA-22 plantains was better than that of FHIA-21 and Cuerno plantain chips. On the basis of chip crispiness, there were no differences between the FHIA plantain hybrids and the standard plantain cultivar.

Table 28. Hedonic scoring scale for the assessment of consumer acceptability of fried unripe plantain chips.

Scale	Texture	Taste	Colour	Crispiness	Overall acceptability
5	Too hard	Excellent	Excellent	Too crispy	Excellent
4	Very hard	Very acceptable	Like very much	Very crispy	Very good
3	Good	Good	Good	Good	Good
2	Fair	Fair	Fair	Fair	Fair
1	Poor	Poor	Poor	Poor	Poor

Table 29. Mean scores for the sensory evaluation of fried unripe chips prepared from FHIA-21, FHIA-22 and Cuerno plantains.

	Sensory quality features				
Hybrid/cultivar	Texture	Taste	Colour	Crispin-ess	Overall acceptability
FHIA-21	3.29^{a1}	3.87^{ab}	3.39^{b}	3.71^{a}	4.81^{a}
FHIA-22	3.03^{a}	4.20^{a}	4.00^{a}	3.83^{a}	3.91^{b}
Cuerno	3.25^{a}	3.58^{b}	3.34^{b}	3.65^{a}	3.55^{b}

[1] Letters in common within columns were not significantly different at the 1% l
Mean separation by Duncan's multiple range test.

iii. Overall acceptability

FHIA-21 chips were more acceptable than those made from Cuerno and FHIA-22 plantains (Table 29). When panelists were asked to state which of the three samples they preferred most, nearly 56% of the 53 panelists indicated that they preferred FHIA-21 chips, compared to approximately 34% for FHIA-22 and 11% for Cuerno (Figure 60). All industrially-processed plantain chips on the market are made using the standard Cuerno plantain cultivar. Most of the panelist had already tasted Cuerno plantain chips in one form or another. The results of the sensory studies clearly indicated that most of the panelists preferred FHIA-21 plantain chips.

Oil absorption and recovery rate

Table 30 shows the percentage oil absorption and recovery rates of fried FHIA-21, FHIA-22 and Cuerno plantain chips. The percentage oil absorption and recovery rates were determined by the chip manufacturer, but the measuring procedure was not described.
In terms of percentage oil absorption, FHIA-22 had a lower level in comparison to Cuerno, whereas it was higher in FHIA-21. Both FHIA plantain hybrids had higher percentage recovery rates than Cuerno. The percentage recovery rate reflects the quantity or percentage of salable chips obtained after frying.

Table 30. Percentage oil absorption and recovery rates of chips prepared from FHIA-21, FHIA-22 and Cuerno plantains.

Figure 59. Chips prepared from FHIA-21, FHIA-22 and Cuerno plantains.

Hybrid/cultivar	Oil absorption (%)	Recovery rate (%)
FHIA-21	32.80	34.40
FHIA-22	17.36	37.00
Cuerno	25.00	33.30

Consumer acceptability of fried ripe plantain slices prepared from FHIA-21, FHIA-22 and Cuerno plantains

In most plantain growing regions, plantains are frequently ripened artificially or naturally before utilization. One favourite dish prepared with ripe plantain is made by slicing and frying ripe fruit in cooking oil. To assess potential consumer response to the FHIA plantain hybrids, a comparative study was carried out on consumer acceptability of fried ripe plantain slices made from FHIA plantain hybrids (FHIA-21 and FHIA-22) and the standard plantain cultivar (Cuerno). Fruit was exposed to ethylene (1 ml.l-1) for 24 hours and allowed to ripen to colour stage 6 (Figure 61) at ambient temperature (27°C). The plantains were then peeled, the pulp cut into small slices, soaked in a salt solution (1 g salt/600 ml water) for 5 seconds and deep fried in vegetable oil (Figure 62).

Sensory evaluation

Twenty-two male and female taste panelists were used in the comparative sensory evaluation of fried ripe plantain slices made from FHIA-21, FHIA-22 and Cuerno fruit. The overall aim was to assemble a panel that would reliably reflect the range of preferences of Honduran consumers. Panelists were presented coded samples of fried ripe plan0tain samples made from Cuerno and the two FHIA plantain hybrids (FHIA-21 and FHIA-22). They were asked to evaluate the samples on the basis of texture, taste, colour, sweetness and overall acceptability, using a hedonic scoring scale of 1 to 5 (Table 31). In addition, panelists were asked to state which of the three samples they preferred most. All panelists were instructed in basic taste-test procedures, to make their own assessments after a moderate amount of consideration. They were asked to take a sip of water and pause briefly before tasting each sample and to retaste the samples if they were not sure of their assessments.

Post-harvest quality indices

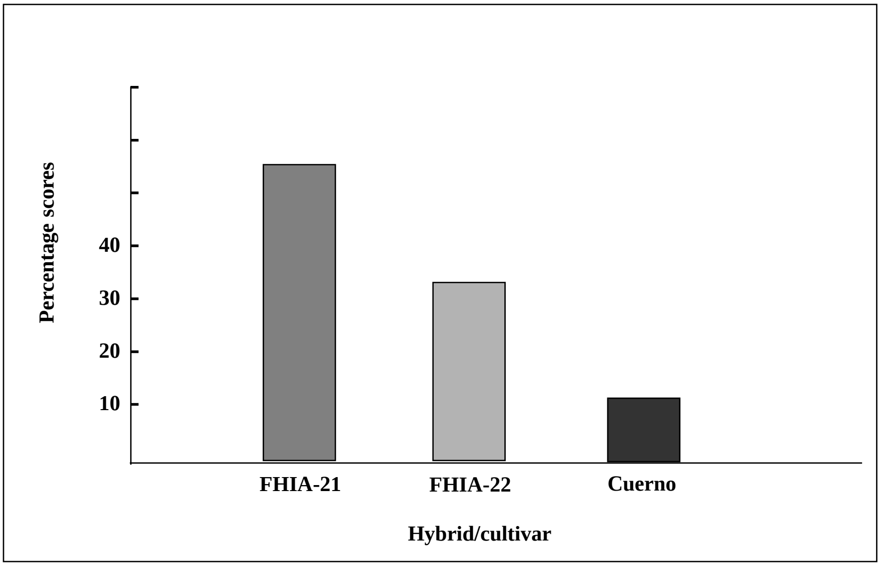


Figure 60. Comparative consumer preference of fried unripe chips prepared from FHIA-21, FHIA-22 and Cuerno hybrids/cultivars (n=53).

Key post-harvest indices (e.g. pulp firmness, total soluble solids, pulp pH and titratable acidity, pulp dry matter and moisture content) for the sensory evaluation of fried ripe plantain were assessed (using ripe fruit) on the day of the sensory studies. This assessment complemented the sensory studies and also helped explain differences in consumer acceptance/preference of the plantain hybrids/cultivar (Dadzie and Orchard, 1996).

Table 31. Hedonic scoring scale for the sensory evaluation of fried ripe slices of FHIA-21, FHIA-22 and Cuerno plantains.

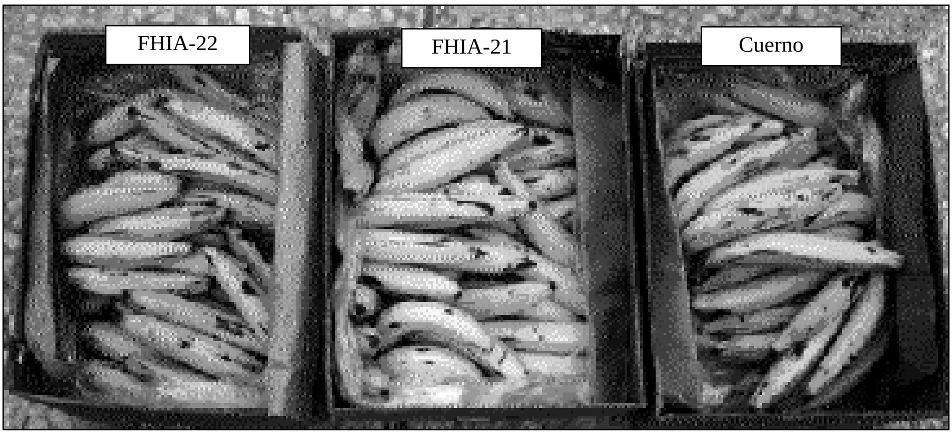


Figure 61. Ripe fingers of FHIA-21, FHIA-22 and Cuerno plantains used in the sensory evaluation studies.

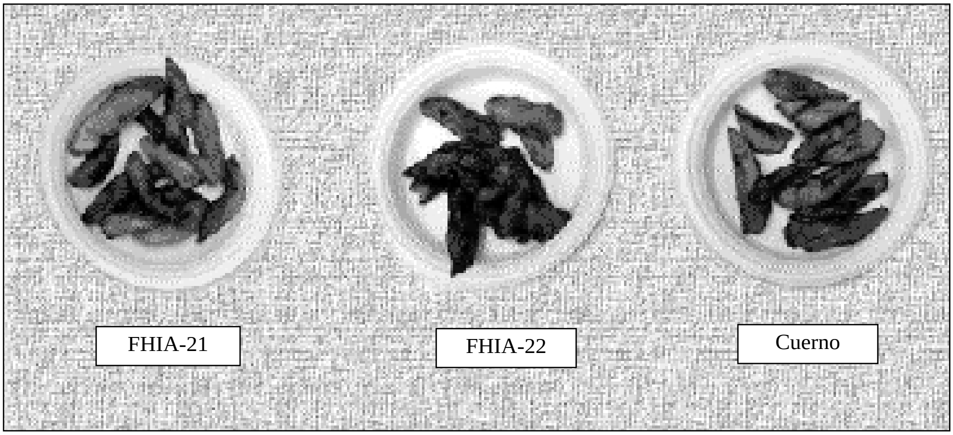


Figure 62. Sample of fried ripe slices of FHIA-21, FHIA-22 and Cuerno plantains used in the sensory studies.

Scale	Texture	Taste	Colour	Sweetness	Overall acceptability
5	Too soft	Excellent	Excellent	Too sweet	Excellent
4	Soft	Very acceptable	Like very much	Very sweet	Very good
3	Firm	Good	Good	Sweet	Good
2	Hard	Fair	Fair	Slightly sweet	Fair
1	Too hard	Poor	Poor	Unsweet	Poor

Sensory quality features

The sensory quality features assessed included:

i. Texture

The textural quality of fried ripe plantains is an important factor for consumers. Figure 63 shows the percentage scores for the sensory evaluation of fried ripe FHIA-21, FHIA-22 and Cuerno plantains based on texture. Of the 22 panelists who participated in the sensory studies, nearly 73% indicated that fried ripe FHIA-21 plantain samples were too soft, compared to 32% for FHIA-22 and 0% for Cuerno. In contrast, about 28% stated that FHIA-21 was soft, compared to 59% for FHIA-22 and 37% for Cuerno. Analysis of the sensory data indicated significant differences in texture ($P < 0.01$; Table 32). On the basis of texture, the panelists preferred the soft texture of the fried slices prepared from FHIA-21 plantains more than the textures of those prepared from FHIA-22 and Cuerno plantains.

Comparison of the sensory data with the physical assessment of pulp firmness before frying indicated that the pulp of Cuerno (a triploid plantain cultivar) was significantly firmer than that of the FHIA tetraploid plantain hybrids, FHIA-21 and FHIA-22 ($P < 0.01$; Table 33). FHIA-21 and FHIA-22 had lower mean pulp firmness compared to Cuerno. This may partly explain the high percentage scores (too soft and soft, respectively) for FHIA-21 (72.73%) and FHIA-22 (59.09%) and the low score for Cuerno (0%). Pulp dry matter and moisture content are critical factors for fruit firmness. The results indicated that the percentage pulp dry matter and moisture content of Cuerno plantains differed significantly from levels obtained for FHIA-21 and FHIA-22 (P < 0.01; Table 33). Cuerno, a triploid plantain cultivar, had a higher mean pulp dry matter content and lower pulp moisture content compared to the two FHIA tetraploid hybrids (FHIA-21 and FHIA-22).

ii. Taste

The taste of fried ripe plantains is an important feature for consumers. Hence, in the sensory evaluation studies, panelists were asked to evaluate the taste of the samples using a hedonic scoring scale of 1-5 (Table 31). Of 22 panelists, nearly 27% indicated that the taste of fried ripe FHIA-21 plantain samples was excellent, compared to 73% for FHIA-22 and 23% for Cuerno (Figure 64). In contrast, 50% stated that the tastes of FHIA-21 and Cuerno samples were similar and very acceptable, compared to 27% for FHIA-22. The mean scores indicated that the taste of fried ripe plantains prepared from FHIA-22 was significantly more acceptable than the tastes of those prepared from FHIA-21 and Cuerno (P < 0.01; Table 32). The results also showed that FHIA-21 and Cuerno were similar in taste (P < 0.01; Table 32).

Table 32. Comparative sensory evaluation of fried ripe slices of FHIA-21, FHIA-22 and Cuerno plantains.

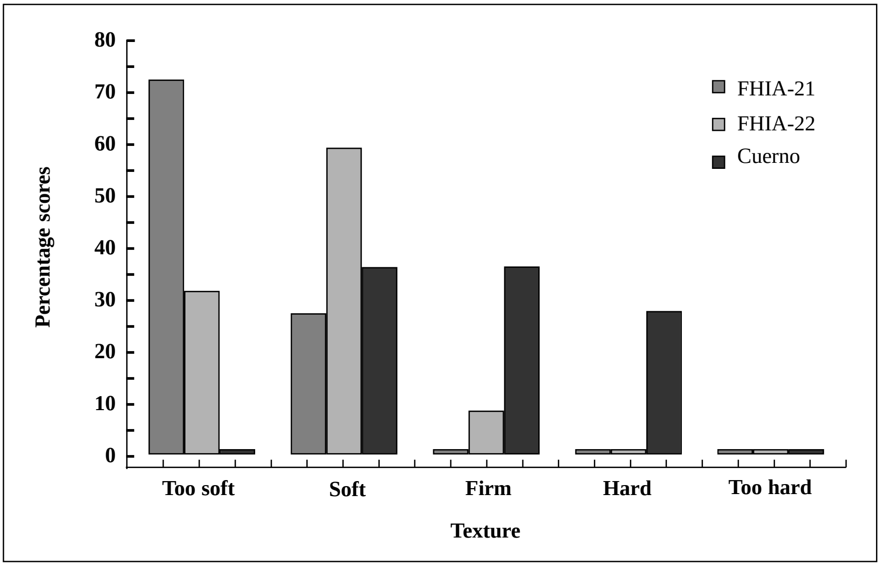


Figure 63. Comparative sensory evaluation of fried ripe plantain hybrids/cultivars based on texture (n=22).

	Sensory quality features				
Hybrid/cultivar	Texture	Taste	Colour	Sweetness	Overall acceptability
FHIA-21	4.73^{a1}	3.96^{b}	3.32^{a}	3.05^{a}	3.43^{b}
FHIA-22	4.14^{b}	4.73^{a}	4.18^{a}	3.64^{a}	4.33^{a}
Cuerno	3.09^{c}	3.91^{b}	3.91^{a}	3.05^{a}	3.48^{b}

[1] Letters in common within columns were not significantly different at the 1% level. Mean separation by Duncan's multiple range test.

Table 33. Key post-harvest quality indices for sensory evaluation of fried ripe FHIA-21, FHIA-22 and Cuerno plantains.

	Hybrid/cultivar		
Features	FHIA-21	FHIA-22	Cuerno
Pulp firmness (kgf)	0.32^{b1}	0.32^{b}	0.84^{a}
Total soluble solids (%)	15.00^{b}	13.20^{c}	16.80^{a}
pH	4.80^{b}	4.90^{a}	4.80^{b}
Titratable acidity (mEq/100 g)	6.80^{b}	6.70^{a}	6.85^{b}
Pulp dry matter content (%)	25.19^{b}	25.51^{b}	34.37^{a}
Pulp moisture content (%)	74.81^{a}	74.49^{a}	65.63^{b}

[1] Letters in common within rows were not significantly different at th
Mean separation by Duncan's multiple range test.

iii. Colour

The colour of fried ripe plantain is just as important for consumers as texture and taste. In the comparative sensory studies, about 14% of the 22 panelists indicated that the colour of fried ripe FHIA-21 plantain slices was excellent, compared to 59% for FHIA-22 and 27% for Cuerno (Figure 65, see page 67). In contrast, nearly 32% of the panelist stated that they liked the colour of fried ripe FHIA-21 plantains very much, compared to about 18% for FHIA-22 and 55% for Cuerno. Approximately 32% 23% and 18% of the panelists, respectively, mentioned that the colours of fried ripe FHIA-21, FHIA-22 and Cuerno samples were good. Statistical analysis of the sensory data indicated no significant differences in the taste panel assessments of the colour of fried ripe plantain samples ($P < 0.01$; Table 32).

iv. Sweetness

The sweetness of fried ripe plantain is important for consumers. The panelists were thus asked to compare the samples based on sweetness using a hedonic scoring scale of 1-5 (Table 31). Approximately 73% of the 22 panelists indicated that the fried ripe Cuerno plantain samples were sweet, compared to about 32% for FHIA-21 and 41% for FHIA-22 (Figure 66, see page 67). Analysis of the data showed no significant differences in sweetness between the samples ($P < 0.01$; Table 32). However, objective chemical analysis revealed significant differences in total soluble solid contents ($P < 0.01$; Table 33), indicating that the sugar content was significantly higher in Cuerno

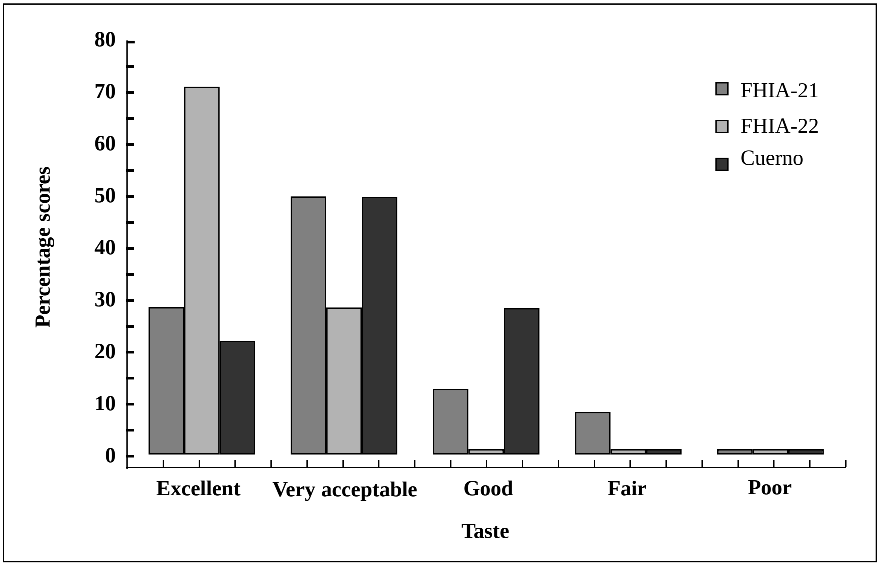


Figure 64.Comparative sensory evaluation of fried ripe plantain hybrids/cultivars based on taste (n=22).

than in FHIA-21 and FHIA-22. This explains the high percentage score obtained on the sweetness of the fried ripe Cuerno plantain samples.

The sugar to acid balance is important for plantain sweetness. Hence, pH and titratable acidity were also measured to facilitate sweetness comparisons between the fried ripe plantain samples. The results indicated significant differences in pH and acidity ($P < 0.01$; Table 33). Although the comparative sensory assessment of consumer acceptability of

FHIA-21, FHIA-22 and Cuerno based on sweetness detected no differences between the FHIA plantain hybrids and Cuerno, the objective chemical analysis revealed fundamental differences between the samples. This clearly highlights the importance of chemical analyses in this type of study.

v. Overall acceptability

Figure 67 presents the percentage scores for the comparative overall consumer acceptability of fried ripe FHIA-21, FHIA-22 and Cuerno plantains. Nearly 14% of the 22 panelists stated that, based on overall acceptability, fried ripe FHIA-21 plantain samples were excellent, compared to about 57% for FHIA-22 and 14% for Cuerno. Similarly, approximately 33% of the panelists mentioned that fried ripe FHIA-21 samples were very good, compared to about 24% for FHIA-22 and nearly 52% for Cuerno. Results of the data analysis indicated that fried ripe FHIA-22 plantain slices were significantly more acceptable than those made from FHIA-21 and Cuerno (Table 32). The overall acceptability of fried ripe FHIA-21 and Cuerno samples was similar ($P < 0.01$; Table 32). Correlation analysis of the sensory data also showed that the overall acceptability was directly related to taste ($r = 0.56$; $P < 0.0001$) and colour ($r = 0.65$; $P < 0.0001$), but weakly related to texture ($r = 0.06$; $P < 0.01$) and sweetness ($r = 0.35$; $P < 0.01$). This suggests that even though texture and sweetness of the fried ripe samples contributed to the overall acceptability of FHIA-21, FHIA-22 and Cuerno, taste and colour were the most important factors for overall consumer acceptability.

Preference

When 22 panelists were asked which of the samples they preferred most, approximately 67% of

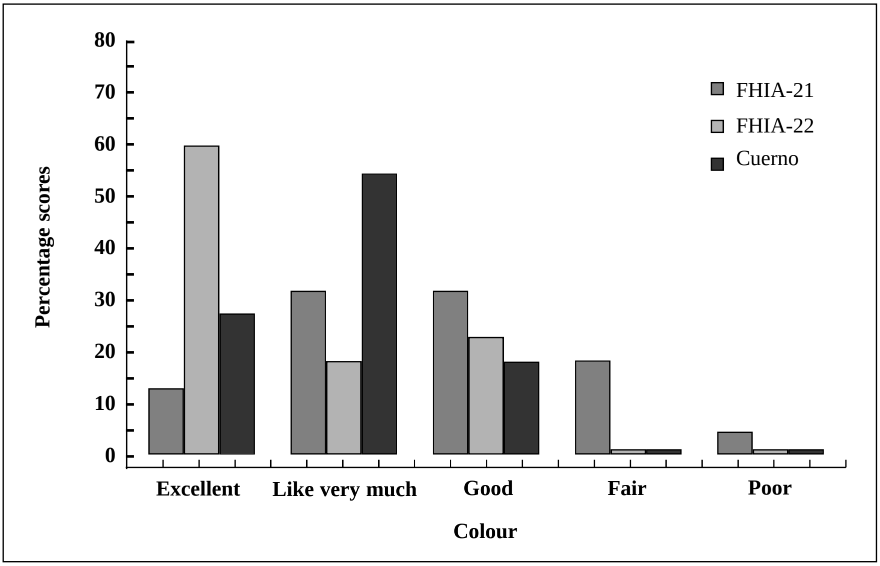


Figure 65. Comparative sensory evaluation of fried ripe plantain hybrids/cultivars based on colour (n=22).

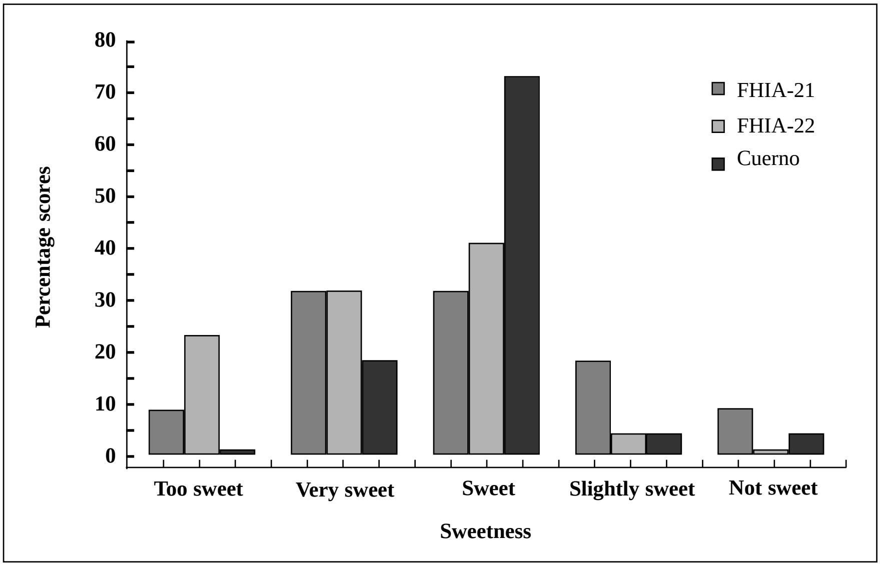


Figure 66. Comparative sensory evaluation of fried ripe plantain hybrids/cultivars based on sweetness (n=22).

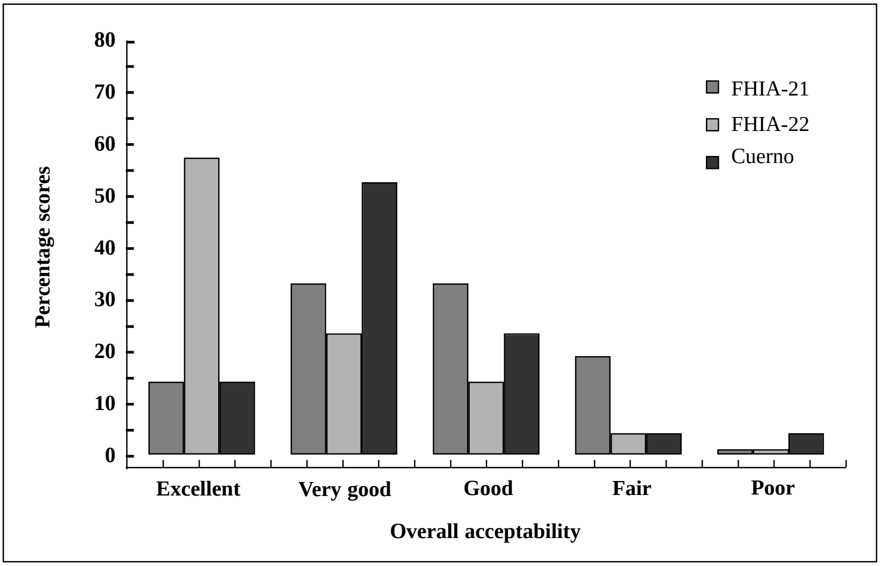


Figure 67. Comparative sensory evaluation of fried ripe plantain hybrids/cultivars based on overall acceptability (n=22).

them stated that they preferred FHIA-22 most, while about 33% opted for Cuerno and none of them selected FHIA-21 (Figure 68).

The conclusions of this study are as follows:

1. The objective assessments of the peel and pulp colour as well as pulp to peel ratios of FHIA-21, FHIA-22 and Cuerno plantains used in the sensory studies were generally similar, indicating that the samples used in the studies were quite similar.
2. Comparative sensory evaluation of fried ripe FHIA-21, FHIA-22 and Cuerno plantain samples based on texture revealed that the panelists preferred the soft texture of FHIA-21 more than that of FHIA-22 and Cuerno plantains.
3. The taste of fried ripe plantain FHIA-22 samples was more acceptable than that of FHIA-21 and Cuerno. In contrast, the colours of the fried ripe FHIA-21, FHIA-22 and Cuerno plantain samples were similar and suitable.
4. Although the sweetness levels of FHIA-21, FHIA-22 and Cuerno plantains were considered to be similar, the objective chemical analysis highlighted significant differences between the FHIA hybrids and Cuerno.
5. On the basis of overall acceptability, FHIA-22 samples were more acceptable than FHIA-21 and Cuerno. Although texture and sweetness played an important role in the overall acceptability of FHIA-21, FHIA-22 and Cuerno, taste and colour were the most important factors.
6. Fried ripe FHIA-22 plantain samples were most preferred by panelists, while those of FHIA-21 were least preferred.

COOKING QUALITY

Cooking qualities of black Sigatoka resistant plantain hybrids

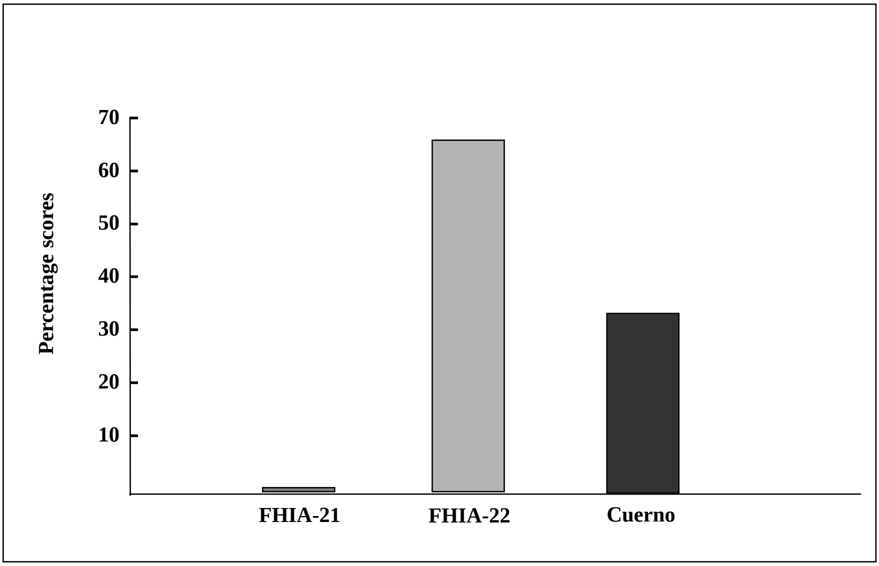


Figure 68. Consumer preference of fried ripe plantain of FHIA-21, FHIA-22 and Cuerno (n=22).

In most developing countries where green unripe plantain is a major staple food, the main methods of cooking this product include boiling or steaming and serving it as a cooked vegetable with other dishes/stews or sauces. Green plantain can be pounded after it is cooked, or otherwise it can be roasted, oven-baked or cooked in the ashes of a fire. The range of culinary processes that can be used depends largely on the texture and composition of the fruit. The texture and appearance of plantain pulp after cooking are especially important factors for consumers. Consumers of boiled green plantain or cooking banana usually prefer pulp that remains firm and crunchy after cooking, rather than soft and waterlogged (Dadzie and Wainwright, 1995).

A study was conducted to compare the cooking qualities of four black Sigatoka-resistant plantain hybrids with those of a common susceptible cultivar (Dadzie, 1995).

Cooking quality criteria

The cooking quality criteria considered are as follows:

a. Ease of peeling

Consumers often prefer plantain cultivars that are easy to peel. In the subjective assessment of ease of peeling, freshly harvested mature green FHIA-04 and Cuerno plantains were the easiest to peel, followed by FHIA-21. In contrast, FHIA-22 and FHIA-16 were difficult to peel since it took considerable time and effort to peel them. The peel thickness ranking (Table 34) indicated that FHIA-22 and FHIA-16 plantains had the highest mean peel thickness in comparison to FHIA-04, Cuerno and FHIA-21. These results suggest that peel thickness may affect the ease of peeling. At the mature green stage, the ease of peeling plantain generally depends on the thickness of the peel and the degree of adhesiveness of the peel to the pulp.

b. Texture

Because of the wide variety of plantain cooking methods and and uses of this fruit, the texture (particularly softness) of cooked plantain is very important in determining a good cooking plantain cultivar. Selecting a plantain cultivar for a specific cooking or processing method is therefore based largely on the textural properties of the tissues after cooking. Consumers usually prefer plantain cultivars that have good textural qualities after cooking, suitable for a variety of uses. Cuerno, a triploid cultivar, had the highest initial mean pulp firmness relative to any of the tetraploid hybrids (Figure 69). However, when the pulp of the different cultivars/hybrids was cooked or boiled for various periods of time, there was a decrease in firmness (or increase in softening), which varied according to the cultivar ($P < 0.001$; Figure 69). Compared to FHIA-21, FHIA-22 and Cuerno, FHIA-04 plantain was less firm throughout the cooking period, followed by FHIA-16. There was a sharp decline in firmness when pulp of the different cultivars/hybrids was cooked for 5 minutes. For instance, FHIA-04 lost nearly 74% of its initial mean firmness, compared to 28% in FHIA-22, 49% in FHIA-21 and 50% in Cuerno. Generally, after the initial drop in firmness, there were no significant changes ($P < 0.001$) in the pulp firmness in FHIA-04, FHIA-16, FHIA-21 and FHIA-22 when cooked for 10, 15, 20, 25 and 30 minutes (Figure 70). Studies conducted by other researchers indicated that a loss of firmness or softening in fruit as a result of cooking or heating involves a loss of turgor, a series of chemical changes in the cell polysaccharide matrix, and starch swelling and gelatinisation (van Buren, 1979; van Buren and Pitifer, 1992; Fuchigami, 1987a,b; Palmer, 1971).

Table 34. Peel thickness and pulp dry matter content of plantain hybrids.

Cultivar/hybrid	Peel thickness (cm)	Rank	Dry matter content (%)	Rank
FHIA-04	0.40^{b1}	2	34.29^{c}	5
FHIA-16	0.41^{a}	1	34.62^{c}	4
FHIA-21	0.37^{c}	4	35.02^{b}	3
FHIA-22	0.41^{a}	1	36.43^{a}	2
Cuerno	0.39^{b}	3	37.56^{a}	1

[1] Letters in common within columns were not significantly different
level. Mean separation by the least significant difference (LSD) pr

Samples that had been boiled for 5 minutes were tasted, but they did not seem well or fully cooked. Ten minutes cooking time seemed ideal for cooking the FHIA plantain hybrids, since they tasted well cooked, firm and slightly crunchy. When cooked longer, the hybrids (especially FHIA-04 and FHIA-16) lost their firmness and crunchiness. In contrast, Cuerno, a triploid cultivar, required 15 minutes of cooking.

c. Water absorption

Plantains absorb some water during cooking, which ultimately results in softening the pulp. The amount of water absorbed depends to a large extent on the duration of cooking, the starch content and cultivar. Figure 70 illustrates the percentage changes in water absorption by FHIA-04, FHIA-16, FHIA-21, FHIA-22 and Cuerno plantains during cooking. In most of the cultivar/hybrids, the percentage water absorption seemed to increase with the cooking time, but the extent of increase was cultivar/hybrid-dependent ($P < 0.001$). In FHIA-04, there was nearly 20% increase in water absorption after 5 minutes of cooking, compared to approximately 7% in Cuerno and FHIA-22, and 9% in FHIA-21. This initial dramatic increase in the percentage water absorption in these hybrids/cultivars marked the onset of pulp softening during cooking. Studies by other investigators have shown that absorption of water by cellulose, starch and pectin in the plantain pulp during boiling or cooking induces tissue softening. Starch granules in the pulp swell and gelatinize, resulting in a hard to soft-jelly textural change. The cellulose does not undergo further change. The pectin is hydrolysed by the hot water and converted into a softer, more soluble form, thus making tissues easier to bite and masticate (Birch *et*

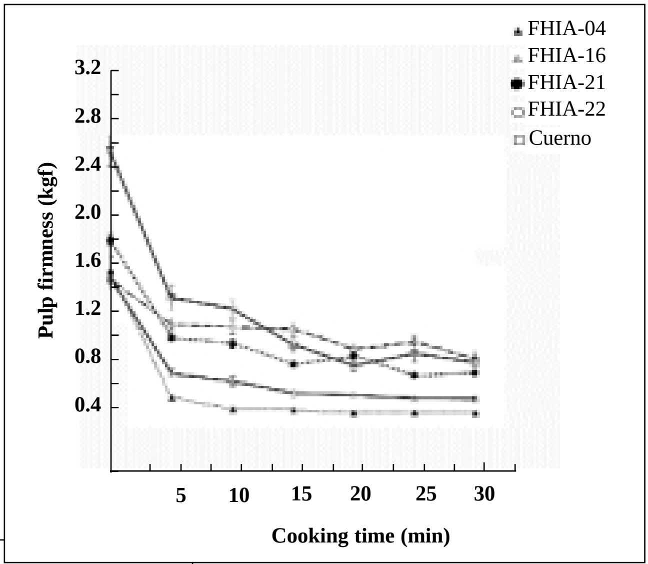


Figure 69. Changes in pulp firmness of five plantain hybrids/cultivars during cooking.
Vertical bars indicate standard error of the means (n=40)

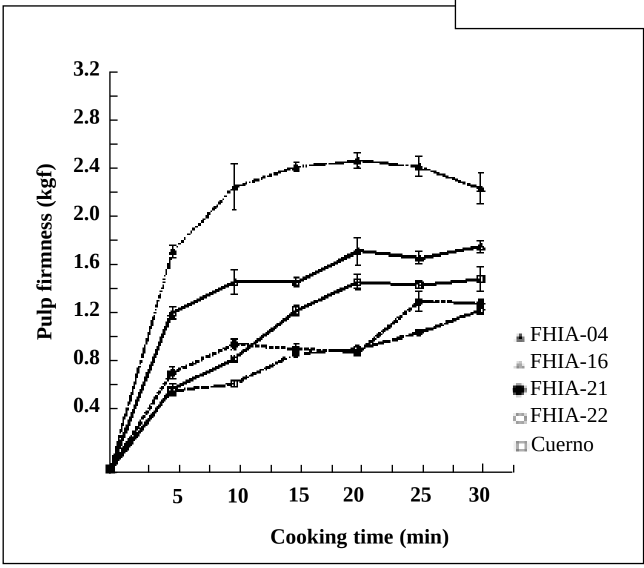


Figure 70. Water absorption by plantain hybrids/cultivars during cooking.
Vertical bars indicate standard error of the means (n=403).

al., 1978; Brinto and Bourne, 1972).

FHIA-04 and FHIA-16 plantains absorbed more water throughout the cooking period (Figure 70) and consequently lost more firmness in comparison to FHIA-22, FHIA-21 and Cuerno plantains (Figure 69). This suggests that FHIA-04 and FHIA-16 are less suitable for cooking or have poor cooking qualities. As FHIA-04 and FHIA-16 samples absorbed more water during boiling, they were softer, sticky and less crunchy, and therefore could be suitable for roasting, baking and frying. In contrast, as Cuerno, FHIA-21 and FHIA-22 have a comparatively low water absorption potential during boiling, they are more suitable for cooking (i.e. good cooking quality). Cuerno, FHIA-21 and FHIA-22 plantains had higher mean percentage dry matter contents compared to FHIA-04 and FHIA-16 (Table 34). The good cooking qualities of Cuerno, FHIA-21 and FHIA-22 may be related to their high dry matter contents.

In conclusion, when freshly harvested at the mature green stage, FHIA-04 and Cuerno had the advantage of being easier to peel than FHIA-22 and FHIA-16. FHIA-04 and FHIA-16 absorbed more water during the cooking period, thus losing more firmness, which suggests that FHIA-04 and FHIA-16 are less suitable for cooking or boiling. In contrast, FHIA-21, FHIA-22 and Cuerno are more suitable for cooking due to their relatively low water absorption potential (during cooking). The dry matter content may be an important parameter for cooking quality. All of the FHIA plantain hybrids required a shorter cooking time than Cuerno.

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List of Abbreviations

DFID	Department For International Development
FHIA	*Fundación Hondureña de Investigación Agrícola*
IITA	International Institute of Tropical Agriculture
IMTP	International *Musa* Testing Programme
INIBAP	International Network for the Improvement of Banana and Plantain
NRI	Natural Resources Institute