

RESEARCH ARTICLE

Ideal harvest stage and quality descriptors of 5 banana cultivars based on 5 fruit diameters

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ABSTRACT

Quality attributes of fruits such as pH, titratable acidity, soluble solids, maturity indices, firmness, skin colour and sugar content should support choosing the choice of the most appropriate stage to harvest bananas. Therefore, this study aimed to identify the optimal harvest stage of different cultivars according to five fruit diameters. Through a randomized block design with 4 replicates, the following variables were evaluated such as pH, titratable acidity, soluble solids, maturity index, firmness, fruit peel colour and sugar content on the cultivars Prata-Anã, Maçã, FHIA 18, Grand Naine and Nanicão IAC 2001. Fruits from the second bunch of banana bundle were harvested when they reached the diameters of 32, 34, 36, 38 and 40 mm. Results showed that the harvest stages (*i.e.*, banana fruit diameters) affect the fruit quality attributes among cultivars; thus, it is recommended to harvest the fruits of 'FHIA 18' with 34, 36 or 38 mm in diameters; Grand Naine with 38 or 40 mm; 'Maçã' and 'Nanicão IAC 2001' with 38 mm; and 'Prata-anã' with 34 or 36 mm.

Keywords: *Musa spp.*; Physicochemical quality; Physiological maturity

INTRODUCTION

Bananas are one of the world's most popular fruits; also, they are the main profit of some countries. The popularity of bananas relies on their distinctive traits such as taste, ease of consumption, low cost and high nutritional value, *i.e.* high contents of carbohydrates, vitamins and minerals. Bananas are highly consumed by many segments of society, being the world's fourth-biggest traded fruit commodity (Mesquita *et al.*, 2016). In 2017, Brazil was the world's fourth largest producer of bananas at 6.7 million tons, just behind India at 30.5 million tons, China at 11.2 million tons and the Indonesia at 7.1 million tons (Faostat, 2019).

The cultivation of banana in Brazil is practiced to a certain extent throughout the entire country; however, determining their optimal harvest point can be quite subjective (Costa *et al.*, 2002; Lazia, 2013). There is a general agreement that bananas must be harvested while they are still green and unripe, and therefore to extend their postharvest life, since the ripening process of bananas is highly sensitive by the drop of fruits from

the trees and during transportation (Castricini *et al.*, 2012; Sauls, 2018).

The natural fruit ripening causes various changes in the metabolic processes before and after harvest, leading to an improvement in appearance and flavour, but also significant losses (Paniagua *et al.*, 2014). The changes in the skin colour and firmness of the fruits are within the most common physical changes. Moreover, the climacteric is a stage of fruit ripening associated with increased ethylene production and a rise in cellular respiration; consequently, promoting changes in organic acids and sugars (Kheng *et al.*, 2012). Banana is a typical climacteric fruit with rapid deterioration (Seymour, 1993), which reinforces the importance of being harvested at an appropriate maturity, which would otherwise be adversely affected by quality loss and short shelf life.

Nevertheless, some studies have been determining the optimal harvest point for bananas and other fruits. Keng *et al.* (2012) considered two harvest points for the Rastali banana, 11 and 12 weeks between the emission of the first

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bunch and harvest; also, these authors reported higher ethylene production and accelerated senescence in the fruits after harvest. Nassur et al. (2015), evaluated the quality of mangoes harvested in three ripening stages based on the fruit firmness, found that fruits of the cultivars Haden and Tommy Atkins expressed high quality when harvested with medium firmness, while those from 'Ataulfo' achieved great attributes with low firmness.

Regarding to the harvest of bananas in Brazil, some producers consider the disappearance of corners or angularities from the finger surface, as an indicator of complete physiological development; but this criterion cannot be adopted in all cultivars, because some genotypes may be ripe even with remained prominent angularities. Moreover, another criterion adopted by several producers is to measure fruit diameter (from 32 to 38 mm), especially in the second bunch of the bundle (Carvalho et al., 2011).

The criteria for harvesting bananas in Brazil can be quite subjective, since the particularities of each cultivar are not been taken into further consideration. Therefore, this study aimed to identify the optimal harvest stage of different cultivars according to the evaluation of the quality parameters of five cultivars harvested in five different stages (fruit diameters).

MATERIAL AND METHODS

Experimental area characterization

The experiment was carried out at experimental farm located at the School of Agriculture (FCA UNESP) located at 22°44'28" S, 48°34'37" W at an altitude of 740 m above sea level. According to Köppen climatic classification, the climate of the area is the Cfa type, that is, a hot temperate climate (mesothermic), the rainy season is concentrated from November to April (*i.e.* Summer) with an average annual rainfall of 1376,70 mm; the mean temperature of the hottest month exceeds 22 °C (CUNHA; MARTINS, 2009). In the experimental area, the soil was classified as Dystrophic Red Latosol (EMBRAPA, 2006).

Based on previous soil analysis and crop recommendations, land was prepared through ploughing, sorting and liming (Teixeira et al., 2014). Also, the seedlings of the cultivars were micropropagated at 4 m spacing between rows and 2.5 m between plants in November 2012.

Experimental design

A randomized design in a 5x5 factorial scheme evaluated 5 banana cultivars (Prata-Anã, Maçã, FHIA 18, Grand Naine and Nanicão IAC 200) and 5 fruit diameters (32, 34, 36, 38 and 40 mm), with 4 replicates. The five central

fruits of the second bunch of the bundle were evaluated per experimental plot.

Cultivars description

'FHIA 18': this tetraploid cultivar (AAAB), developed at the Honduran Agricultural Research Foundation (FHIA), presents low to medium-size fruits with sweet flavour, like the 'Prata' type (Fig 1A) (Silva et al., 2003).

'Grand Naine': this Cavendish cultivars belong to the AAA genome group, the fruits are thin, long, curved with rounded apices and short pedicels; the pulp as fruit ripens is extremely sweet, like the 'Nanica' type (Fig 1B) (Cordeiro, 2013).

'Maçã': this cultivar is within the most cultivated in Brazil and belongs to the AAB genome group. The fruits have a thin skin with light yellow colour. The pulp is white, soft and juicy with a very pleasant taste. But the fruit skin is thin and offers little resistance to mechanical injuries through transportation and storage (Fig 1C) (Silva et al., 2003).

Nanicão-IAC-2001: this triploid cultivar (AAA) belongs to the Cavendish subgroup. The pulp of the fruit is not farinaceous, and the fruit has a prolonged shelf life. When compared to the other fruits from the same subgroup, this cultivar presents high levels of vitamin C and highly digestibility for human consumption (Fig 1D) (Moreira, 2013).

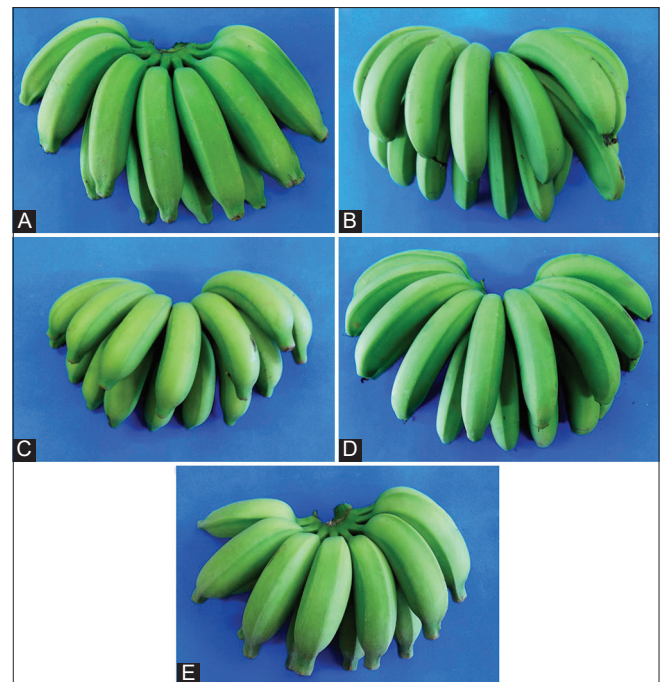


Fig 1 .Banana bunches of cultivars FHIA 18 (A), Grande Naine (B), Maçã (C), Nanicão IAC 2001 (D) and Prata Anã (E) with 36 mm in diameter at harvest.

Prata-Anã: this cultivar is also known as ‘Grafting’ or ‘Prata-de-Santa-Catarina’, belongs to the AAB genome group. The fruits shape and flavour are alike ‘Prata’, but smaller and round-shaped (Fig 1E) (Silva et al., 2003).

Experiment management and harvesting

The plants were conducted in a rainfed system, receiving all cultural treatments recommended for the crop (Teixeira et al., 2014). Evaluations were carried out in the first production cycle and fruits were harvested manually between 8:00am and 10:00am from March to May 2014. Evaluated fruits were picked from the second bunch of the bundle, when they reached the following diameters: 32, 34, 36, 38 and 40 mm, measured by a digital pachymeter. All fruits were harvested in grade 1 (E1) of the green skin colour in the respective diameters. Afterwards, they were taken to the fruit culture laboratory, where they remained under room temperature and relative humidity ($\pm 21\text{-}23^\circ\text{C}$ and $\pm 55\text{-}65\%$ RH), until reaching the grade 6 (E6) of yellow skin colour (*i.e.* ideal consumption point) (Loesecke, 1950).

Variables evaluated

- pH - measured direct in homogenized fruit pulp with the aid of a digital potentiometer, DMPH-2 Digimed model.
- Titratable acidity (TA): expressed as a percentage of citric acid, titrated with 1.0 mol L^{-1} sodium hydroxide (NaOH), in 1 ml juice solution, 50 ml distilled water and 0.3 ml phenolphthalein (Instituto Adolfo Lutz, 2005).
- Soluble solids (SS): expressed in °Brix, measured using an aliquot of the homogenized pulp through Palette digital refractometer (ATAGO 3405 PR-32a).
- Maturity indices (SS/TA): obtained by means of the relationship between soluble solids and titratable acidity contents.
- Firmness: determined in fruits with a texturometer (TA. XT Plus Texture Analyzer). Texture was analysed by penetration test with a SMS P/2N probe and 2.0 mm s^{-1} velocity. The reading was carried out at two different centres of the fruit, expressed in Newtons (N).
- Skin colour descriptors: evaluated using a CR-400 Chroma Meter (Konica Minolta, Osaka, Japan). Skin colour was measured on opposite sides of the mid-equatorial region of each fruit surface. The evaluated parameters were L^* indicates lightness, the saturation or intensity of colour is represented by Chroma (C^*) and angle Hue ($^\circ\text{h}$) that indicates the chromatic hue, where 0° refers to red, 90° to yellow, 180° to green and 270° to blue.
- Sugar content: to quantify total sugars, reducing sugars (glucose + fructose) and non-reducing sugars (sucrose), used the methodology described by

Somogy and adapted by Nelson (1944). Readings were performed in a spectrophotometer and results were expressed as a percentage.

Statistical analysis

Results were submitted to analysis of variance; and when there was significant interaction between cultivars and fruit diameters, means were compared by Tukey test at 1 and 5% of significance. For the results of soluble solids, data were compared between cultivars. All analyses used the System for Analysis of Variance program (Sisvar, version 5.6) (Ferreira, 2011).

The mean data were also submitted for principal component analysis (PCA) with Minitab 17 statistical software, PCA was used as a tool to help choosing in different cultivars the optimal harvest point, since they were individually analysed; consequently, giving a global and integral view of all quality parameters according to the diameters at harvest.

RESULTS AND DISCUSSION

Results indicated variations in the soluble solids contents only as a function of the evaluated cultivars, in which fruits of ‘Prata-Anã’ presented the highest values (25.93° Brix), while the lowest was found in ‘FHIA 18’ fruits (21.63 Brix) (Tables 1). The results of the present study corroborate the finding of Jesus et al. (2004), who assessed 10 genotypes of bananas and observed that soluble solids contents varied from 19.8 in cv. Prata Graúda to 27.4 in cv. Pacovan.

A significant interaction occurred between cultivars and fruit diameters at harvest for all measured variables, that way each cultivar presented singularity with regards to the evaluated variables, according to fruit diameter at harvest.

For the firmness of the fruits, ‘Grand Naine’ and ‘Nanicão IAC 2001’ presented the highest means (Table 2). During ripening process, the solubilization and depolymerization of pectins and hemicelluloses result in extensive cell wall degradation and, as a consequence, the softening of the fruit (Asif and Nath, 2005; Lehniger, 2006); therefore,

Table 1: Mean values of soluble solids of banana cultivars (*Musa spp.*). Botucatu, state of São Paulo, 2017

Cultivar	Soluble solids (Brix)
FHIA 18	21.63 C
Grand Naine	22.94 B
Maçã	23.56 B
Nanicão IAC 2001	23.61 B
Prata-Anã	25.93 A
LSD	1.23

Means followed by the same uppercase letter indicates that the results do not differ significantly by Tukey's test at 5% probability

Table 2: Mean values of firmness, lightness (L), coordinates *a and *b, chroma (C*) and hue angle (°h) of the external surface of fruits (skin) of banana cultivars (*Musa* spp.) in different stages of physiological development. Botucatu, state of São Paulo, 2017

Cultivar	Fruit diameter				
	32 mm	34 mm	36 mm	38 mm	40 mm
Firmness (N)					
FHIA 18	0.9 ^{Ed}	1.76 ^{Ca}	1.85 ^{Ca}	1.55 ^{Cb}	1.41 ^{Dc}
Grand Naine	2.08 ^{Bc}	2.59 ^{Aa}	2.31 ^{Bb}	1.85 ^{Ad}	2.04 ^{Ac}
Maçã	1.63 ^{Ca}	1.74 ^{Ca}	1.22 ^{Db}	0.99 ^{Dc}	1.68 ^{Ca}
Nanicão IAC 2001	2.61 ^{Aa}	2.40 ^{Bb}	2.51 ^{Aab}	1.73 ^{Bd}	1.87 ^{Bc}
Prata-Anã	1.17 ^{Db}	0.99 ^{Dc}	1.06 ^{Ebc}	1.52 ^{Ca}	0.76 ^{Ed}
Lightness					
FHIA 18	62.10 ^{Bab}	64.94 ^{ABab}	66.85 ^{Aa}	64.81 ^{Aab}	60.94 ^{BCb}
Grand Naine	58.63 ^{Bbc}	57.64 ^{Cc}	59.31 ^{Babc}	63.96 ^{ABa}	62.89 ^{Bab}
Maçã	68.59 ^{Aab}	68.58 ^{Aab}	63.82 ^{ABb}	66.69 ^{Aab}	70.37 ^{Aa}
Nanicão IAC 2001	61.94 ^{Bab}	63.45 ^{Ba}	61.21 ^{ABab}	59.14 ^{Bab}	56.89 ^{Cb}
Prata-Anã	57.66 ^{Bb}	61.13 ^{BCb}	61.77 ^{ABb}	68.94 ^{Aa}	58.81 ^{BCb}
C*					
FHIA 18	42.55 ^{ABCab}	46.94 ^{Aa}	40.16 ^{ABb}	44.11 ^{BCab}	41.06 ^{BCb}
Grand Naine	40.79 ^{BCbc}	38.79 ^{Bc}	41.18 ^{ABbc}	46.52 ^{Ba}	44.67 ^{Bab}
Maçã	46.46 ^{Aa}	49.25 ^{Aa}	37.71 ^{Bb}	46.01 ^{Ba}	50.14 ^{Aa}
Nanicão IAC 2001	43.91 ^{ABab}	44.42 ^{Aa}	42.78 ^{ABab}	40.45 ^{Cab}	38.97 ^{Cb}
Prata-Anã	38.08 ^{Cc}	45.65 ^{Ab}	44.97 ^{Ab}	52.61 ^{Aa}	44.77 ^{Bb}
°h					
FHIA 18	82.39 ^{BCa}	83.23 ^{Ba}	83.01 ^{Ba}	83.97 ^{Aa}	82.21 ^{Ba}
Grand Naine	82.86 ^{BCbc}	86.08 ^{Aa}	81.75 ^{Bc}	84.26 ^{Aab}	84.63 ^{Aab}
Maçã	84.05 ^{ABbc}	85.61 ^{Aab}	82.37 ^{Bc}	83.93 ^{Abc}	86.36 ^{Aa}
Nanicão IAC 2001	84.97 ^{Aa}	84.52 ^{ABa}	85.38 ^{Aa}	84.24 ^{Aa}	81.43 ^{Bb}
Prata-Anã	81.27 ^{Cc}	83.16 ^{Bb}	82.94 ^{Bbc}	85.12 ^{Aa}	81.38 ^{Bbc}

Means followed by the same uppercase letter indicates that the results do not differ significantly by Tukey's test at 5% probability

'Grand Naine' and 'Nanicão IAC-2001' have undergone minor changes in this regard.

A variation occurred in firmness of all cultivar fruits as a function of diameter. The fruits of 'Nanicão IAC 2001' had great firmness with 32 and 36 mm in diameters at harvest, while 'Grand Naine' presented great firmness with 34, 38 and 40 mm in diameters (Table 2). Therefore, each cultivar individually showed highest firmness values in different harvest stages (diameters), that is, 'FHIA 18' was obtained with 34- and 36- mm, while 'Grand Naine' with 34 mm, 'Maçã' with 32, 34 and 40 mm, and 'Nanicão IAC 2001' obtained great firmness with 32 mm in diameter, but did not differ statistically from those with 36 mm at harvest; and 'Prata Anã' with 38 mm (Table 2).

With regards to skin lightness of the fruits, 'Maçã' presented the highest means in all maturity indices, except for 36 mm, in which 'FHIA 18' presented the highest one. Nevertheless, 'Maçã', 'FHIA 18' and 'Prata-Anã' also had high means with 38 mm in diameter at harvest (Table 2).

Moreover, 'Prata-Anã' presented the highest means for chroma (C*). Also, none of them presented high values with 36 mm in diameter at harvest, indicating that these

fruits have less colour intensity when compared to the fruits harvested with other diameters (Table 2).

For hue angle, all cultivars had high values by target diameter harvesting, but there was no difference between them with 38 mm in diameter. For each diameter for each cultivar, 'Prata-Anã' had the lowest hue angle with 32 mm, while 'Maçã' and 'Grand Naine' with 36 mm; and 'Nanicão IAC 2001' with 40 mm at harvest. Despite that 'FHIA 18' did not show any changes in the hue angle, as a function of harvest and diameters (Table 2).

Externally, the yellowing of the skin is the most striking change during banana ripening process. The chlorophyll that gives green colour to banana skin is rapidly degraded by the enzyme chlorophyllase activity (Pakkavatmongkol, 1996), that is, rising the carotenoids (yellow pigments). This behaviour has already been reported by Ding et al. (2007) in Cavendish and Berangan bananas. Regardless of fruit diameters at harvest, all cultivars presented values between 81.27 and 86.36 °h (Table 2).

Thus, all cultivars had a yellowish-coloured skin at evaluation time; however, tending somewhat red, since the 0° refers to red, 90° comprises yellow and 180° to green. Therefore, the lowest °h resulted in ripe fruits with a more

yellow coloration such as ‘Prata-Anã’ (32 mm), ‘Maçã’ and ‘Grand Naine’ (36 mm), and ‘Nanicão IAC 2001’ (40 mm). In an experiment with banana cv. Rastali, Kheng et al. (2012) found a more intense yellow skin colour in late harvest (*i.e.* 12 weeks) when compared to 11 weeks.

Regardless of fruit diameter at harvest, ‘Grand Naine’ and ‘Nanicão IAC 2001’ presented high pH values, whereas ‘FHIA 18’ showed the lowest. On the contrary, ‘Grand Naine’ and ‘Nanicão IAC 2001’ presented low titratable acidity means (Table 3). In addition to a genetic factor, the low acidity observed in these cultivar fruits is also the result of high respiratory rates, a process in which organic acids are subtracts (Ding; Ong, 2010).

Organic acids originate from the glycolytic pathway, thereby fruits with high acidity tend to have low sugar contents (Lehninger, 2006), explaining the low soluble solids and high titratable acidity in ‘FHIA 18’. Carvalho et al. (2011) observed an increase in acidity, soluble solids and sugars in the ripening process of bananas, in addition to a decrease in fruit firmness with a reduction in maturity indices and pH in all cultivars; according to the authors, pH values decrease after harvest, but may increase at the end of ripening or beginning of fruit senescence, which is a tendency observed in the present study.

‘Grand Naine’, ‘Nanicão IAC 2001’ and ‘Prata-Anã’ showed the highest maturity indices of all, practically in

Table 3 : Mean values of pH, titratable acidity, maturity indices, total sugars, reducing sugars and sucrose (g 100g⁻¹) of banana cultivars (*Musa* spp.) as a function of fruit diameter. Botucatu, state of São Paulo, 2017

Cultivar	Fruit diameter				
	32 mm	34 mm	36 mm	38 mm	40 mm
pH					
FHIA 18	4.06 ^{Dc}	4.24 ^{Bb}	5.22 ^{Cb}	4.40 ^{Ca}	4.14 ^{Cbc}
Grand Naine	4.98 ^{Aa}	5.02 ^{Aa}	5.03 ^{Aa}	5.03 ^{Aa}	5.12 ^{Aa}
Maçã	4.24 ^{Cc}	4.37 ^{Bbc}	4.52 ^{Ba}	4.41 ^{BCab}	4.36 ^{Bbc}
Nanicão IAC 2001	4.89 ^{Ac}	5.01 ^{Abc}	5.12 ^{Aab}	5.16 ^{Aa}	5.17 ^{Aa}
Prata-Anã	4.44 ^{Bab}	4.38 ^{Bb}	4.35 ^{Cb}	4.55 ^{Ba}	4.37 ^{Bb}
Titrable acidity (% acid malic)					
FHIA 18	0.64 ^{Aab}	0.60 ^{Ab}	0.60 ^{Ab}	0.50 ^{Ac}	0.69 ^{Aa}
Grand Naine	0.38 ^{Cab}	0.45 ^{Ba}	0.44 ^{Ba}	0.35 ^{Bb}	0.33 ^{Cb}
Maçã	0.52 ^{Ba}	0.47 ^{Ba}	0.51 ^{Ba}	0.49 ^{Aa}	0.49 ^{Ba}
Nanicão IAC 2001	0.40 ^{Ca}	0.37 ^{Cab}	0.35 ^{Cab}	0.31 ^{Bb}	0.34 ^{Cab}
Prata-Anã	0.62 ^{Aa}	0.41 ^{BCb}	0.44 ^{Bb}	0.37 ^{Bb}	0.54 ^{Ba}
Maturity indices (SS/TA)					
FHIA 18	32.31 ^{Cb}	37.18 ^{Cab}	36.65 ^{Dab}	45.33 ^{Ca}	30.65 ^{Cb}
Grand Naine	61.69 ^{Aab}	49.15 ^{Bc}	52.81 ^{BCbc}	64.99 ^{Ba}	70.96 ^{Aa}
Maçã	45.36 ^{Ba}	45.02 ^{BCa}	44.93 ^{CDa}	51.33 ^{Ca}	52.31 ^{Ba}
Nanicão IAC 2001	59.30 ^{Aa}	63.02 ^{Abc}	68.20 ^{Aabc}	76.63 ^{Aa}	71.52 ^{Aab}
Prata-Anã	42.23 ^{BCc}	62.81 ^{Aab}	60.44 ^{ABb}	70.85 ^{ABa}	47.01 ^{Bc}
Total sugars (g 100g⁻¹)					
FHIA 18	22.74 ^{Ca}	23.19 ^{Da}	21.69 ^{Cab}	20.86 ^{Cbc}	19.76 ^{Cc}
Grand Naine	28.05 ^{Bb}	30.46 ^{Ba}	29.35 ^{Aab}	24.61 ^{Bc}	27.67 ^{ABb}
Maçã	23.85 ^{Cc}	29.29 ^{BCa}	30.19 ^{Aa}	29.12 ^{Aa}	27.03 ^{ABb}
Nanicão IAC 2001	31.57 ^{Aa}	28.30 ^{Cb}	26.30 ^{Bc}	26.19 ^{Bc}	28.64 ^{Ab}
Prata-Anã	27.04 ^{Bc}	32.86 ^{Aa}	30.26 ^{Ab}	29.37 ^{Ab}	26.29 ^{Bc}
Reducing sugars (g 100g⁻¹)					
FHIA 18	20.35 ^{Cab}	21.80 ^{Da}	20.77 ^{Cab}	19.09 ^{Db}	15.71 ^{Cc}
Grand Naine	24.17 ^{Bb}	28.74 ^{Ba}	27.27 ^{Ba}	22.70 ^{Cb}	24.38 ^{Bb}
Maçã	23.26 ^{Bc}	29.03 ^{Ba}	29.35 ^{Aa}	28.62 ^{Aa}	25.66 ^{ABb}
Nanicão IAC 2001	27.94 ^{Aa}	25.26 ^{Cc}	25.54 ^{Bbc}	24.67 ^{Bc}	27.28 ^{Aab}
Prata-Anã	26.27 ^{Ac}	31.46 ^{Aa}	29.18 ^{Ab}	28.60 ^{Ab}	25.54 ^{ABc}
Sucrose (g 100g⁻¹)					
FHIA 18	2.27 ^{Bb}	1.32 ^{Bcd}	0.88 ^{Bd}	1.68 ^{Abc}	3.84 ^{Aa}
Grand Naine	3.69 ^{Aa}	1.63 ^{Bb}	1.98 ^{Ab}	1.81 ^{ab}	3.13 ^{Ba}
Maçã	0.56 ^{Cb}	0.25 ^{Cb}	0.80 ^{Bab}	0.47 ^{Bb}	1.30 ^{Ca}
Nanicão IAC 2001	3.45 ^{Aa}	2.89 ^{Aa}	0.72 ^{Bc}	1.45 ^{ab}	1.29 ^{Cbc}
Prata-Anã	0.73 ^{Ca}	1.33 ^{Ba}	1.03 ^{Ba}	0.73 ^{Ba}	0.71 ^{Ca}

Means followed by the same uppercase letter indicates that the results do not differ significantly by Tukey's test at 5% probability

any physiological harvest stages. According to the diameters changes at harvest, 'Prata-Anã', 'FHIA 18', 'Grand Naine' and 'Nanicão IAC 2001' had high maturity indices with a diameter of 38 mm at harvest, whereas 'Maçã' did not present any maturity parameter variation, as well as titratable acidity (Table 3).

The high maturity indices of 'Prata-Anã', 'FHIA 18', 'Grand Naine' and 'Nanicão IAC 2001' with a diameter of 38 mm at harvest revealed that soluble solids content superimposed the titratable acidity in ripe fruits; consequently, the expression of sweet taste becomes more evident; therefore, this characteristic must be considered in spite of the isolated factors of acidity and soluble solids.

In an experiment with Tommy Atkins mango harvested in three maturity stages, Nassur et al. found (2015) that fruits with medium-high firmness decreased the ripening rate in early harvesting stage than those of late harvest (*i.e.* soft texture). Similarly, this study found that fruits with 38 mm in diameter at harvest gave high maturity indices than those with 32 to 36 mm.

For total sugars and reducing sugars (glucose + fructose), the high means in cultivars varied according to fruit diameter at harvest. Except that 'FHIA 18' did not present high means at any harvest stages. None of the cultivars showed high total and reducing sugar contents with 40 mm in diameter, besides high values were found in 34 mm diameter for almost all cultivar fruits, unless 'Nanicão IAC 2001' that had the highest total and reducing sugars contents with 32 mm in diameter (Table 3). In addition to 34 mm, 'Maçã' had high values with 36 and 38 mm in diameters, and 'FHIA 18' presented high total sugar contents with 34 and 36 mm.

Regarding the non-reducing sugars contents (sucrose), the highest sucrose contents were obtained in 'Grand Naine', 'FHIA 18' and 'Nanicão IAC 2001'. The diameter of 40 mm provided the highest number of cultivars with higher individual sucrose contents (Table 3).

The tannin polymerization occurs as fruit ripens, but also a decrease in starch content and an increase in soluble sugars, especially sucrose, glucose and fructose (Adão and Glória, 2005); and a decrease in soluble solids contents. 'FHIA 18' showed the lowest levels of total sugars when compared to the other cultivars. Nevertheless, the synthesis of phenolic compounds is due to the partial oxidation of sugars and organic acids in the glycolysis and tricarboxylic acids cycle (Soethe et al., 2016); consequently, high sugars contents may allow the synthesis of more phenolic compounds during conservation period of the fruits.

Tables 1, 2 and 3 clearly shows the differences in banana cultivars. However, through principal component analysis (PCA) is possible to verify the effect of diameter size at harvest on each cultivar.

For 'FHIA 18', the first two components (PC1 + PC2) accounts for 80% of the total variability. Moreover, we found that the fruits with 32 and 40 mm in diameters at harvest were separated from those with 34, 36 and 38 mm in PC1 scores. Fruits with 34, 36 and 38 mm in diameters at harvest were correlated with a great number of descriptors. While fruits with 34 mm in diameter at harvest were associated with high content of reducing and total sugars, and with 36 and 38 mm in diameters with high maturity indices, firmness and soluble solids content. However, fruits with 32 mm in diameter at harvest were strongly associated with great titratable acidity (Fig 1A). Furthermore, PC2 separated fruits with 32 and 34 mm in diameters at harvest from those with 36, 38 and 40 mm (Fig 2A). Nevertheless, 'FHIA 18' can be considered the best choice due to its diameter size at harvest, regarding the high sugar contents in fruits with 34 mm and high maturity indices with 36- and 38 mm, as they do not lead to high titratable acidity.

For 'Grand Naine', the first two components (PC1 + PC2) also accounts for 80% of the total variability. In PC1, we found that fruits with 34- and 36-mm in diameters were separated from those with 32-, 38- and 40-mm. This separation was mainly due to the following descriptors: firmness, reducing and total sugars, titratable acidity, maturity indices and colour descriptors (L^* , C^* , b^* and Chroma C^*). But PC2 separated the fruits with 32 and 36 mm in diameters at harvest from those with 34, 38 and 40 mm according to the hue angle, soluble solids and sucrose. Noteworthy, the diameter of 32 mm is associated with high levels of sucrose and soluble solids, while the diameters of 38 and 40 mm are positively associated with a high maturity indices, and on the contrary to titratable acidity (Fig 2B).

For cultivar 'Maçã', PC1 and PC2 accounts for 73% of the total variability. PC1 scores showed that all parameters contributed to the separation of the diameters size at harvest. PC2 considered the separation of the 32 mm diameter from the others. Also, the diameter of 38 mm is strongly related to the high contents of pH, reducing and total sugars. While the diameters of 34 and 40 mm correlated with high maturity indices and firmness, as well as the colour descriptors. The diameter of 34 mm is an intermediate zone, resulting in high maturity indices; however, not contrary to the high sugars contents and firmness. In this cultivar, the maturity stages of 32 and 36 mm had no strong association with any of the evaluated characteristics (Fig 2C).

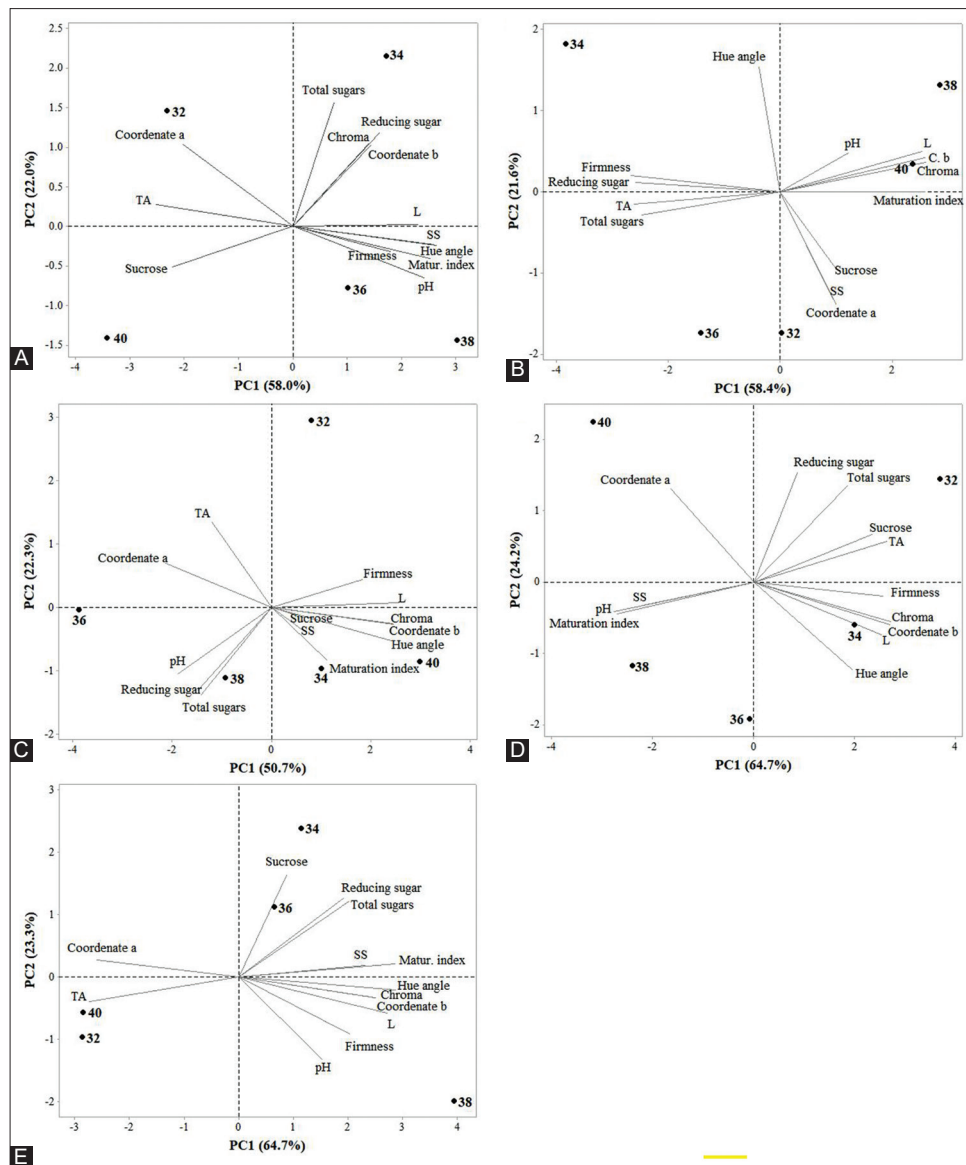


Fig 2. Principal component analysis of quality descriptors of ‘FHIA 18’ (A), ‘Grande Naine’ (B), ‘Maçã’ (C), ‘Nanicão IAC 2001’ (D) and ‘Prata-anã’ (E) banana at 5 harvest diameters.

For ‘Nanicão IAC 2001’, the first two components (PC1 + PC2) accounts for 88.9% of the total variability. Regarding to the PC1 scores, we observed that the quality parameters that most contributed to differentiate the diameters were pH, maturity indices, soluble solids, firmness, titratable acidity and chroma. Although, the separation was more affected by reducing sugars in PC2. High firmness and sugar content are found in ripe fruits with a diameter of 32 mm at harvest, besides those fruits are also associated with high titratable acidity values. Nevertheless, high maturity indices, soluble solids and pH are strongly associated with fruits with 38 mm in diameter at harvest. Furthermore, fruits with 34 mm in diameter at harvest presented great firmness and high colour descriptors values (Fig 2D).

For ‘Prata-Anã’, the first two components (PC1 + PC2) accounts for 88% of the total variability. The PC1 scores showed that most quality descriptors contributed to the separation of harvest diameters. However, sucrose and pH contributed to the separation according to PC2. Also, most quality descriptors are associated with fruits with 34, 36 and 38 mm in diameters at harvest. Moreover, the fruits that stood out were those with 34 and 36 mm in diameters at harvest, because there was a trend of high sugars, soluble solids and maturity indices. Still, the fruits with 38 mm in diameter at harvest had high values of pH, firmness and colour descriptors, except for ‘a’ coordinate (Fig 2E).

The harvest stage should not be defined based on sugar content alone. This fact was observed when the cultivars

were evaluated through the PCA. For 'Nanicão' and 'Grand Naine', the diameters that provided high sugars content also promoted high titratable acidity, which directly affected the maturity indices of them, justifying the choice of diameters that allow a great balance between sugars and acidity to obtain high maturity indices, as this characteristic can improve the consumer acceptance, in which was obtained with the diameters of 38- and 40-mm.

CONCLUSION

In banana crops, the harvest stages (fruit diameters) affect differently the fruit qualitative attributes among cultivars. By considering the quality parameters, the fruits of 'FHIA 18' should be with 34, 36 or 38 mm in diameters at harvest. 'Grand Naine' should be with 38 or 40 mm in diameters at harvest, because of the high maturity indices observed. 'Maçã' and 'Nanicão IAC 2001' should be with 38 mm in diameter at harvest, due to the high sugar content and adequate maturity indices in 'Maçã' and high soluble solids contents and maturity indices in 'Nanicão IAC 2001'. The fruits of 'Prata-anã' should be harvested with 34 or 36 mm in diameters at harvest to obtain high contents of sugar, soluble solids and maturity indices in ripe fruits.

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Authors' Contributions

All authors contributed equally to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript.

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