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CROP SCIENCE

Post-harvest quality and sensory analysis of 'Prata' bananas produced in different cultivation field locations

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Abstract: Banana 'Prata' has a significant demand in the Brazilian market, and Minas Gerais is one of the largest banana producers in the country. Scientific studies that evaluate the bananas quality produced in different cultivation regions are still incipient. Thus, this study evaluated the physical, biochemical and sensory attributes of banana 'Prata' from south and north of Minas Gerais and Vale do Ribeira (SP). Bananas from south were also cultivated in different production systems, organic and conventional. Data were submitted to multivariate analysis that provided the discrimination of the samples according to the cultivation regions. Bananas from southern presented higher levels of soluble solids and acidity, better taste, higher diameter and overall acceptance, where in the organic bananas were the most preferred by consumers. Fruit from northern stood out in appearance, texture, aroma and color, in addition to greater length. Fruit from Vale do Ribeira had higher levels of total phenolics and antioxidant activity. With these results we can assume that fruit quality is highly related to the specific climatic conditions from each producing region. Bananas from the south of Minas Gerais showed superiority for most of the evaluated traits, reflecting on consumer preference.

Key words: Musa spp., physical-chemical characterization, post-harvest, test with consumers.

INTRODUCTION

Brazil stands out in the international market as one of the largest banana producers, although 98% of the production is destined for the domestic market. The Northeast and Southeast regions of Brazil account for 67% of national production, especially São Paulo, Bahia and Minas Gerais States (Agrianual 2018).

'Prata', 'Prata-Anã' and 'Pacovan' varietal types constitute approximately 70% of the banana area cultivated in Brazil, wherein 'Prata' variety is widely produced in the northeast, southeast and south of the country (Hackmann & Barbieri 2019). Physical and biochemical traits of bananas such as size, color, acidity and soluble solids content are important quality parameters for commercialization (Ribeiro et al. 2012), and must be associated with the sensory attributes such as appearance, aroma and texture that are determinant during purchase of fresh fruit (Elizagoyen et al. 2017).

Banana quality is highly influenced by climatic conditions of the growing region as well as ripening development stage. The optimum temperature for banana cultivation ranges from 15 °C to 35 °C with annual rainfall of 1.900 mm well distributed over the year (Borges & Souza 2020, Turner et al. 2007). These climatic factors promote a series of biochemical and physiological modifications during the fruit development leading to organoleptic changes, such as color and texture, carbohydrates content, aromatic volatiles, phenolic compounds and organic acids (Maduwanthi & Marapana 2019).

The south and north of Minas Gerais represent an important banana producing region in Brazil, which has invested in the cultivation of banana ‘Prata’ for export (Emater-MG 2017). In addition, the southern region is also an important banana supplier to the domestic market due to its proximity to the main consumption and distribution centers, located in the states of Belo Horizonte, São Paulo and Rio de Janeiro. Thus, ensuring fruit quality is essential to meet the requirements of these markets.

The characterization of the quality of the banana fruit from traditionally producing regions, but with different climatic conditions, can provide important information for their marketing chain, contributing to the valorization of the product. With this information, it will be possible to adopt management practices to improve and/or maintain production conditions, according to the demands of the consumer market.

Thus, this study evaluated the physical, biochemical and sensory attributes of banana ‘Prata’ from south and north of Minas Gerais and Vale do Ribeira (SP). Bananas from south of Minas Gerais were also cultivated in different production systems, organic and conventional.

MATERIALS AND METHODS

Plant Material

Samples of banana ‘Prata’ were obtained from bunches that weighed 10 to 30 kg, with each “finger” weighing 100 to 130 grams. Four samples were arranged according to their origin: two from the southern Minas Gerais, produced in organic (SMG-O) and conventional (SMG-C) systems, provided by ABASSUL (Associação dos Bananicultores das Serras do Sul de Minas) in Brasópolis. The third from the north of Minas Gerais (NMG), provided by ABANORTE (Associação Central dos Fruticultores do Norte de Minas) in Janaúba; and the fourth from south of São Paulo, provided by ABAVAR (Associação de Bananicultores do Vale da Ribeira), Registro (SP).

The SMG-O sample was composed of bananas produced in two organic certified properties, located in the Luminosa district in Brasópolis: one at latitude 22°36’22’’S and longitude 45°36’44”W, 1155 m altitude, and the other at 22°35’55”S and 45°37’23”W, 962 m altitude. Both areas have Köppen’s Cwb climate, characterized as subtropical in altitude, with dry winter and mild summer, and average annual temperature and precipitation of 19 °C and 1.593 mm, respectively. The SMG-C sample came from two properties: one at 22°34’46”S and 45°35’27”W, 1.306 m altitude, and the other at 22°30’20”S and 45°33’42”W, 1.190 m altitude.

The NMG sample came from Janaúbam-MG, characterized by a tropical climate with dry winter (Aw), according to the Köppen classification. The average annual temperature and precipitation in this region are 23.7 °C and 830 mm, respectively, and the altitude is 510 m. The Vale do Ribeira-SP is characterized as a humid subtropical climate with a hot summer, Cfa according to the Köppen classification. The average annual temperature and precipitation in this region are 20.9 °C and 1.429 mm, respectively, and 3 m of altitude. Bananas from Vale do Ribeira were produced using irrigation and in other locations it is produced in rainfed systems.

Bananas were harvested at commercial mature stage (green) in June 2019 and ripened artificially in ripening chambers, using 100 μg L^{-1} of ethylene for 12 hours at 25°C, until the banana peel color changed from green to yellow. Completely randomized design was applied with five replications, where each plot consisting of a "bunch" ranging from 10 to 12 bananas for SMG-O, SMG-C and SP samples, and from 15 to 20 for NMG.

Physical and biochemical characterization

The peel and pulp color were measured with a colorimeter (Minolta Co. Japan, model CR-13). The diameter and length of the fruit (with peel) were measured using a digital caliper (Starrett®, EC799). The pulp soluble solids content was determined in a portable digital refractometer (Atago®, with value corrected to 25°C), with values expressed in °Brix. The titratable acidity was quantified by titration with 0.1 N NaOH and the result expressed as a percentage of malic acid.

For the extraction of total phenolic and others compounds with antioxidant activity, a suspension was prepared from 1.0 g of fresh samples with 10 mL of 70% ethanol (v/v), shaking the suspension for two hours (Orbital-Nova Orgânica), at room temperature. Then, the extract was centrifuged at 1013xg (Excelsa 2 Fanem model 205N) for five minutes and the supernatant was reserved for analysis (Vázquez et al. 2008). The total phenolic compounds were quantified by spectrophotometry using the Folin-Ciocateau reagent (Swain & Hillis 1959), with reading of absorbance at 765 nm (Micronal, AJX1600). The gallic acid was used as a standard and the results expressed as mg equivalent of gallic acid per 100 g of sample (mg EAG 100 g^{-1}). The antioxidant activity was quantified by the sequestration test of the radical 2,2-Diphenyl-1-picryl- hydrazil (DPPH •) in a spectrophotometer (Micronal, AJX1600) at 517 nm. The analytical curve was prepared with Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid) as a standard and the results were expressed as percentage of free radical inhibition (Brand-Williams et al. 1995).

Sensory analysis

The acceptance and preference tests were applied in a single session to a group of 121 evaluators (untrained volunteers), members of the university community of the State University of Londrina. The project was approved by the Committee for Ethics in Research on Human Beings under registration CAAE 56498216.3.0000.0106.

In the acceptance test, the evaluators received one sample at a time, encoded with three random digits, served on a transparent disposable plate, containing a part of the fruit cut transversely with a thickness of approximately 4 cm, accompanied by a glass of water and a napkin of paper. The samples evaluation was done using a 10 cm hybrid hedonic scale anchored in the middle and extreme regions of the scale (0 = disliked extremely, 5 = neither liked nor disliked, 10 = liked extremely) (Villanueva et al. 2005) for the attributes: appearance, color, aroma, taste, texture, overall acceptance. To verify the purchase intention of the product, a 5-point structured scale was used (1 = certainly would not buy, to 5 = certainly would buy). For the ordering preference test, the samples were served simultaneously to the evaluators, who ordered them in an increasing way (sample that least preferred until the one that most preferred).

Data analysis

Normality and homogeneity of the data were verified by the Shapiro-Wilk and Bartlett test, respectively. Variables that did not show normality and/or homogeneity of variances were transformed by the Box-Cox transformation family (1964). The data were analyzed using multivariate analysis of variance (MANOVA) at a level of 5% significance using the Pillai test. Principal component analysis (PCA) and Ward hierarchical grouping were also performed using Euclidean distance. The software *R* was used in all statistical analyzes using the 'pheatmap', 'mass' and 'factoextra'.

RESULTS

The MANOVA indicated that there is a difference between the banana samples (Pillai's trace = 2.69 and P-value <0.01) in response to the analyzed variables. Thus, the multivariate approach using PCA (Figure 1a) and Ward hierarchical grouping (Figure 1b) indicated the formation of three distinct clusters among the samples: Southern Minas Gerais (SMG), Northern Minas Gerais (NMG) and Vale do Ribeira (SP).

Based on the physical, biochemical and sensory attributes evaluated, the banana samples were clustered into groups associated with their respective producing region, except for soluble solids and the acceptance score for texture (Figure 1). It is possible to note that due to the direction and intensities of the vectors in the PCA and the predominance of the hottest colors in the heatmap, the bananas from the southern Minas Gerais were more appreciated by the evaluators. Ratio and taste presented vectors in the same direction and quadrant in the PCA,

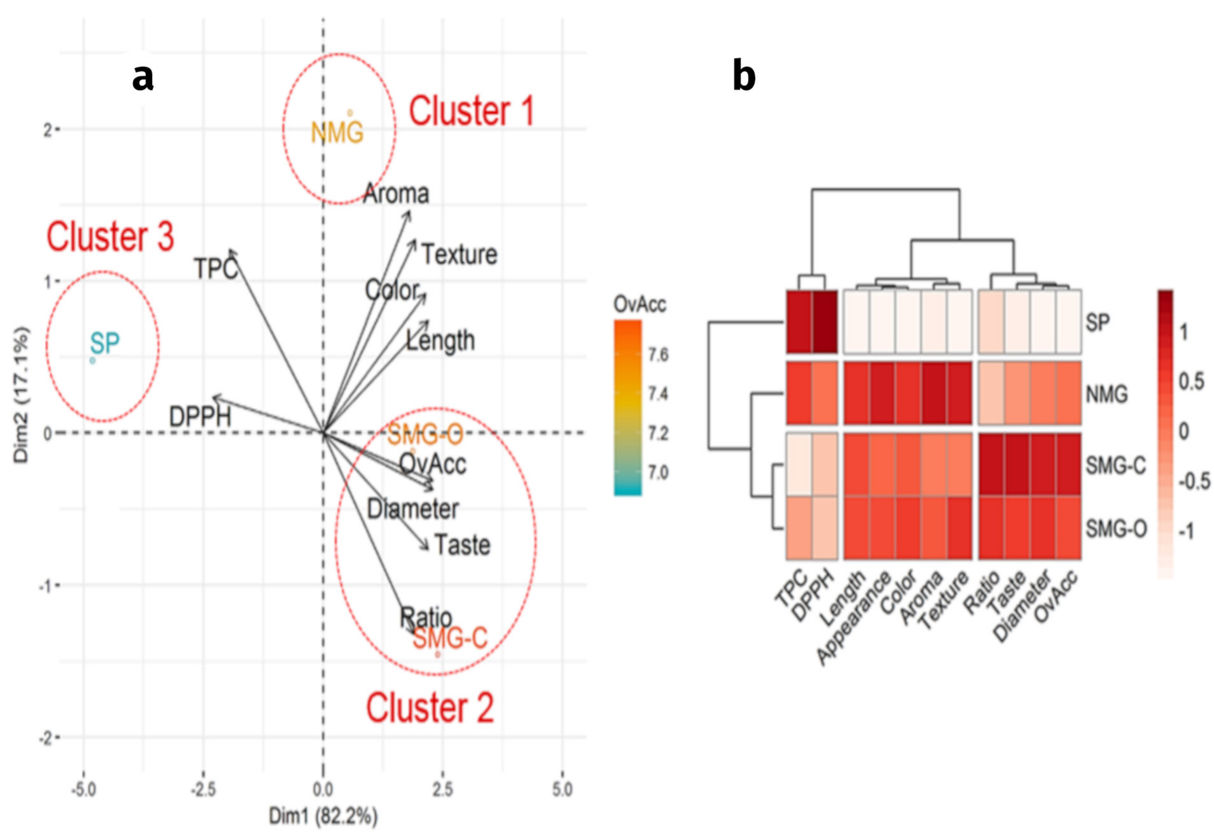

Figure 1. Multivariate analysis: (a) Principal components analysis and (b) heatmap for the attributes and samples of silver banana from Vale do Ribeira (SP), northern Minas Gerais (NMG) and southern Minas Gerais, under conventional (SMG-C) and organic (SMG-O) systems. Legend: Ratio (SS/TA), in which SS = soluble solids and TA = titratable acidity, DPPH = antioxidant activity by DPPH assay, TPC = total phenolic content, OvAcc =overall acceptance.

which corroborates with a positive correlation between them, evidence confirmed in Figure 2. It should also be noted that the samples from Minas Gerais (NMG, SMG-C and SMG-O) were separated graphically of the samples from Vale do Ribeira (SP), in the positive axis range of main component 1 (Figure 1a), and the greater distance between SP and SMG-O, which was later confirmed in the hierarchical clustering analysis of the heatmap (Figure 1b).

The flavor and Ratio (r=0.95) were positively correlated, corroborating with other studies that report consumer preference for fruit with higher values of ratio soluble solids/titratable acidity. Bananas with higher level of phenolic compounds and antioxidant activity (Vale do Ribeira, SP samples – Table I) were the least preferred (Figure 3), indicating that consumers perception of appearance, taste, aroma and texture are not associated with the higher content of bioactive compounds (Figure 2).

Banana 'Prata' from southern Minas Gerais cultivated in an organic system was the most preferred among the evaluators, as can be seen in Figure 3, while the banana from Vale do

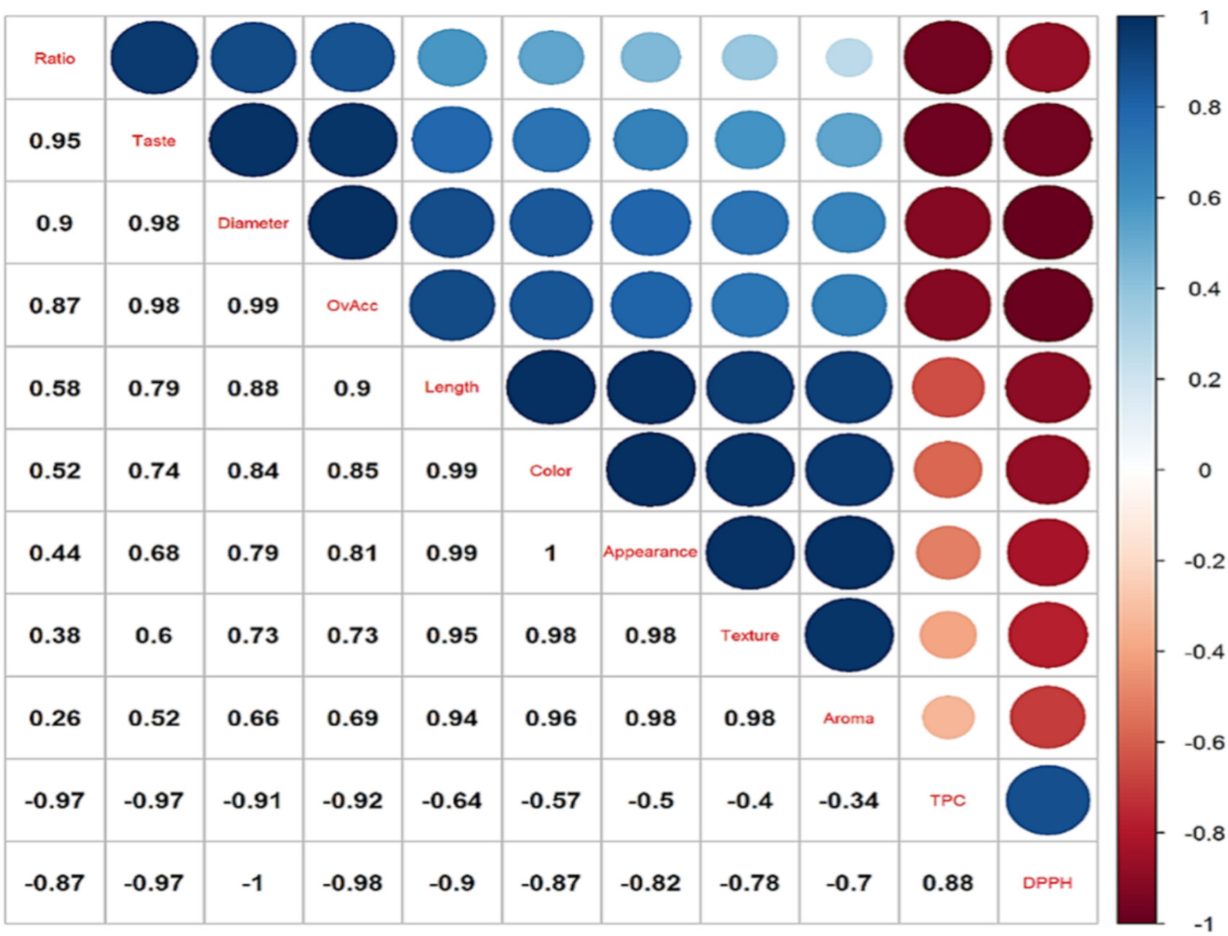

Figure 2. Pearson correlation matrix among the physical, biochemical and sensory attributes. The color intensity indicates higher correlation, in which blue refers to direct correlations and red to inverse. Legend: Ratio (SS/TA), in which SS = soluble solids and TA = titratable acidity, DPPH = antioxidant activity by DPPH assay, TPC = total phenolic content, OvAcc =overall acceptance.

Ribeira (SP) was the least preferred. Among the 121 evaluators who participated of the sensory analysis, 56% consume banana weekly, of which 61% are men, 90% are under the age of 35, and 94% declared that they buy the banana due to the appearance and quality of the fruit. The buying intention of bananas from Minas Gerais (SMG-C: 29.72%, SMG-O: 31.53%, and NMG: 29.72%) was higher than in Vale do Ribeira (SP: 17.12%).

Regarding physical attributes (Table I), it is possible to observe that the length of the fruit evaluated in this study are grouped commercially in class 12, with a variation of 12 to 15 cm while the caliber or diameter of bananas are grouped in classes 32 to 36 cm. The results demonstrate a lower concentration of solids in samples from the northern Minas Gerais and Vale do Ribeira (Table I). In these locations, temperature is a major factor in the accumulation of starch during fruit development.

Bananas from south of Minas Gerais cultivated in different production systems, organic and conventional, did not differ and both samples (SMG-C and SMG-O) showed the highest levels of soluble solids (Table I). Although the values of luminosity and Hue angle of the samples peeled and not peeled were similar, it is possible to observe that the fruit cultivated in Vale do Ribeira had relatively higher values, indicating that these bananas have a lighter yellow color (Table II). Even though the evaluators accepted all the samples (Table III) since the scores are higher than 5, it can be said that bananas from Vale do Ribeira (SP) were less preferred when compared to those from Minas Gerais (SMG-C, SMG-O, and NMG).

DISCUSSION

The formation of three clusters can be justified by edaphoclimatic heterogeneity of the regions where the bananas were produced. The differences among the regions, such as average temperature and precipitation reflects in physiological aspects of the banana production. The climate in the southern Minas Gerais provides favorable conditions for the highest content of soluble solids in the SMG-O and SMG-C samples, since there are better conditions for photosynthesis and, consequently, greater accumulation of sugars (Pisimisi et al. 2012).

Table I. **Means (±standard deviation, n=5) of physical and biochemical attributes for samples of silver banana from Vale do Ribeira (SP), northern Minas Gerais (NMG) and southern Minas Gerais, under conventional (SMG-C) and organic (SMG-O) systems.**

Attribute	***Cluster 1***	***Cluster 2***		***Cluster 3***
	NMG	**SMG-C**	**SMG-O**	**SP**
Length (mm)	150.1±5.3	147.5±8.8	147.30±4.30	122.20±1.10
Diameter (mm)	36.5±2.0	39.9±1.7	39.20±1.20	31.50±2.10
Soluble solids - SS (°Brix)	17.3±0.1	20.4±0.4	20.83±0.12	18.13±2.15
Titrable acidity - TA (%)	0.2±0.0	0.23±0.02	0.24±0.01	0.30±0.02
Ratio (SS/TA)	64.2±3.6	88.83±7.53	86.79±3.52	60.43±6.92
Antioxidant activity (%)	50.8±0.7	46.14±1.65	50.04±1.61	59.38±1.28
Total phenolic content (mg 100 g^{-1})	23.71±0.27	17.29±0.92	22.52±0.97	25.71±1.21

Banana has C3 photosynthetic metabolism, which associated with the climatic conditions of the Cwb type of southern Minas Gerais, allows greater efficiency in the use of water and nitrogen. In the other regions of this study (Aw – NMG and Cfa – SP) it is more likely to occur photorespiration during the day and intense night breathing, both responsible for the consumption of sugars that compose soluble solids (Taiz et al. 2017).

The preference for the organic sample compared to the conventional one, can be explained by the higher concentration of macromolecules in the cytoplasm and vacuole of the cell due to trophobiosis (Alins et al. 2012), which results in higher levels of photoassimilates and a better balance among sugars and organic acids, determinant for taste (Guilherme et al. 2014). Similar results are reported by Ribeiro et al. (2012), wheretwo banana cultivars (Maravilha and Pacovan Ken) produced in the organic system, showed superior physical and chemical attributes (diameter and length of the fruit peeled and not peeled, soluble solids and titratable acidity), when compared to bananas from the conventional production system. The lower preference for fruit with high levels of phenolic compounds may be associated with the presence of higher levels of tannins, substance that promotes an astringent sensation during consumption, as they precipitate salivary proteins (Degáspari et al. 2005).

Thus, besides the crop evaluation of agronomic attributes, the importance of studies involving consumer perception in the fruit post-harvest characterization is emphasized (Rouphael & Kyriacou 2018), especially when the international market is targeted.

The levels of soluble solids found in the samples are within the expected for banana 'Prata'. This variation may be associated to the edaphoclimatic characteristics of each location during the formation of the fruit, in which the photosynthetic process supplies the storage tissues with high concentrations of starch, between 15 and 35% of their fresh weight (Maduwanthi & Marapana 2019, Tabtiang & Prachayawarakon 2017). Posteriorly, the softening and sweetening of the banana pulp during ripening are attributed to the changes in the activities of cell wall hydrolases and the conversion of starch to sugars. Therefore, the breaking down of starch granules into simple sugars are the main event that lead bananas to

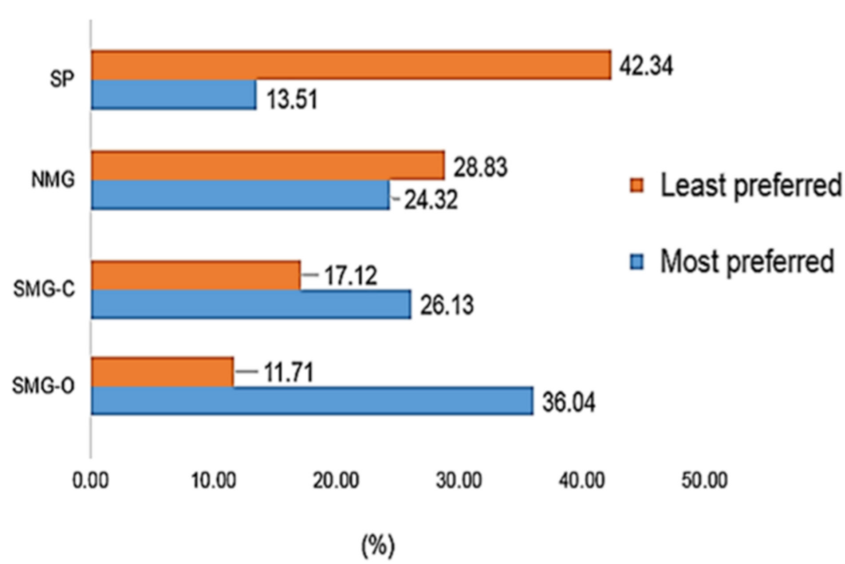

Figure 3. Sensory preference for samples of silver banana from Vale do Ribeira (SP), northern Minas Gerais (NMG) and southern Minas Gerais, under conventional (SMG-C) and organic (SMG-O) systems.

achieve the best post-harvest quality, which are related to sensory characteristics (Cordenunsi-Lysenko et al. 2019).

The knowledge of the mechanisms that regulate the sugar primary metabolism during the banana ripening is essential to reduce post-harvest losses and improve the quality of the final product. Recent studies have shown that the regulation of enzymes, mediated by ethylene, degrade starch at the transcriptional and translational levels, which is crucial for the sugar accumulation during banana ripening. In addition, the interference between ethylene and other hormones, including indole-3-acetic acid and abscisic acid, can influence the primary metabolism of sugar. During banana development, a large amount of starch accumulates in the amyloplasts of the fruit pulp cells. During maturation, a complex regulatory mechanism changes the metabolism of the synthesis, leading to the accumulation of soluble sugars, mainly sucrose, which has a significant impact on fruit taste. Sucrose is responsible for the sweetness of the pulp and the supply of energy to the metabolic processes that result in the development of molecules that affect the quality of the ripe fruit, such as color change, cellulosesynthesis and secondary metabolism compounds, responsible for taste and aroma (Shigaet al. 2011).

The high temperatures observed in Vale do Ribeira during the day and night, promote a higher rate of respiration and photorespiration, promoting losses of CO_2, through the glyoxylate cycle (photorespiration) and consumption of simple sugars (hexoses) through the glycolytic pathway and Krebs cycle (breathing) (Lehninger et al. 2014, Taiz et al. 2017). This additional expense, prominently contributes to the reduction of starch in vegetables, resulting in less conversion to sugars during ripening, decreasing soluble solids, which explains the results obtained in the present study.

The lower temperature in the production of SMG-C and SMG-O samples conditioning lower rates of respiration and photorespiration, which allows a higher concentration of starch and, consequently, a higher content of solids during ripening (Tabtiang & Prachayawarakon 2017).

The levels of soluble solids (17.3 to 20.83 °Brix) and titratable acidity (0.2 to 0.30%) in the present study are similar to that found by Viviani & Leal (2007) in studies involving postharvest of ‘Prata-Anã’ banana fruit ranging from 15 to 23 °Brix and 0.28 to 0.65% of titratable acidity. The content of soluble solids is important in determining the fruit quality, as an indirect indicator of the concentration of sugars, in addition to organic acids, vitamins, amino acids and some pectin (Lobo et al. 2005). In studies of

Table II. **Means (±standard deviation, n=5) of color parameters of the exocarp and endocarp for samples of silver banana from Vale do Ribeira (SP), northern Minas Gerais (NMG) and southern Minas Gerais, under conventional (SMG-C) and organic (SMG-O) systems.**

Sample	Luminosity	Hue	Chroma	Luminosity	Hue	Chroma
	Exocarp			Endocarp		
SP	61.3±0.4	83.4±1.7	25.5±1.0	66.3±1.9	83.4±1.7	25.5±1.0
NMG	58.9±1.3	81.9±1.0	34.4±1.2	64.8±2.4	81.9±1.0	34.4±1.2
SMG-C	60.6±0.4	82.5±1.1	33.1±2.1	64.2±2.6	82.5±1.1	33.1±2.1
SMG-O	59.7±1.3	79.9±1.2	34.7±0.9	63.7±2.3	79.9±1.2	34.7±0.9

Ribeiro et al. (2012), the value of soluble solids found for 'Prata-Anã' banana was 20.8 °Brix for fruit of conventional system and 25.2 °Brix for organic, while for total titratable acidity it was 0.21% for fruit of both systems. The authors attributed those differences to the different production systems and environmental factors from production sites.

For titratable acidity, total phenolic content and antioxidant activity, the results were the opposite to that observed for soluble solids and Ratio, which can be explained based on the metabolic processes of fruit development and ripening. With the respiration process, the production of glyceraldehyde-3-P and pyruvic acid occurs in the cell's cytoplasm, from sugars hydrolyzed in glycolysis. Pyruvate is converted by the action of pyruvate dehydrogenase to acetyl Coe-A, which is a precursor in the synthesis of organic acids (Taiz et al. 2017). These organic acids originate from mevalonic and shikimic acid, which are precursors to various phenolic compounds. Glucose-6-P and glyceraldehyde-3-P also act as precursors in the synthesis of phenolic compounds, in which their concentration depends on climatic conditions. High temperatures promote the synthesis of organic acids and important intermediate compounds in the synthesis of phenolics (Maduwanthi & Marapana 2019).

For most fruit, the loss of chlorophyll is necessary to give an attractive appearance. The golden yellow color of the ripe fruit is due to the degradation of chlorophyll, which unmasks the carotenoid pigments in plastids. According to Yang et al. (2009), high temperatures promote a marked reduction in the levels of gene expression responsible for the synthesis of enzymes that participate in the fruit ripening, indicating that chlorophyll degradation has been downregulated. The ripening of bananas at temperatures above 24°C lead to the peels light yellow (Maduwanthi & Marapana 2019), as observed in the present study.

The perception of consumers has been increasingly relevant in studies involving fruit and vegetables, since it supports the development of new cultivars and price discrimination based on the superior quality (Kyriacou & Rouphael 2018). In this context, the present study observed a greater appreciation by consumers for banana samples from the southern Minas Gerais, with emphasis on the greater preference for cultivated fruit in an organic system. Besides, banana production in this region is strategically favorable due to its

Table III. **Means (±standard deviation, n=121) of sensory attributes scores for samples of silver banana from Vale do Ribeira (SP), northern Minas Gerais (NMG) and southern Minas Gerais, under conventional (SMG-C) and organic (SMG-O) systems.**

Attribute	*Cluster 1*	*Cluster 2*		*Cluster 3*
	NMG	**SMG-C**	**SMG-O**	**SSP**
Appearance	8.0±1.6	7.7±1.7	7.8±1.8	6.8±2.2
Color	8.0±1.6	7.7±1.6	7.8±1.7	6.6±2.3
Aroma	7.4±2.1	7.8±1.6	7.5±1.8	6.9±2.0
Taste	7.2±2.3	7.7±2.0	7.5±1.9	6.8±2.1
Texture	7.8±1.8	7.6±2.0	7.7±1.9	7.3±1.9
Overall acceptance	7.4±2.07	7.8±1.7	7.6±1.8	6.9±1.9

proximity to large consumer and distribution centers such as Companhia de Entrepostos e Armazéns Gerais de São Paulo (CEAGESP) and seaports of Santos-SP and Paranaguá-PR. This fact, combined with the superior physical-chemical and sensorial quality of bananas from this region, are importantincentive for the expansion of banana productive chain and its introduction in international markets.

CONCLUSIONS

The physical, biochemical and sensory attributes did not differ among bananas from the southern Minas Gerais under conventional and organic system but allowed the discrimination of fruit produced in regions with different climatic conditions.

Although all samples have been accepted by consumers, bananas from the southern Minas Gerais in organic production system were the most preferred, followed by fruit under conventional system, from the northern Minas Gerais and Vale do Ribeira(SP).

Banana 'Prata' from the north and south of Minas Gerais have high physical, biochemical and sensory quality, attending the requirements of the national, whichcontribute to promote the expansion of banana culture in Brazil.

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RMC and JTVR conceived the idea and designed the study. LVC and LEDC performed the experiment; DMZ analyzed the data and built the figures. VYB and RMG wrote and translated the manuscript, while LSAG carried out text final revision. All authors discussed the results, conceived, and approved the final manuscript.