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# Post-harvest physicochemical profile and bioactive compounds of 19 bananas and plantains genotypes

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**ABSTRACT:** Nineteen genotypes of bananas and plantains were analysed in order to differentiate the subgroups and/or groups of consumption or industrial use. Genotypes of banana and plantain from different genomic groups and in three ripening stages (2, 5 and 7) were studied in relation to physical and physicochemical characteristics, including bioactive compounds. Furthermore, with the obtained data analysed by multivariate statistical analyses (Principal Component Analysis) it was possible to relate all analysed characteristic profile of samples with the different genotype. The three ripening stages

were differentiated by total soluble solids, titratable acidity, chrome (C\*) and the carotenoids contents. ‘Ney Poovan’ contain high total soluble solid content and pulp-to-peel ratio, an interesting result for the promotion of this genotype for *in natura* consumption. ‘Ney Poovan’, ‘Ouro da Mata’, ‘Pelipita’ and ‘Tiparot’ are sources of antioxidant compounds. The genotypes ‘Pelipita’ and ‘Samurá B’ are promising for the industrial use, mainly for the processing of banana chips, for both green and ripe fruit.

**Key words:** *Musa* spp., carotenoids, vitamin C, cooking banana.

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## INTRODUCTION

Banana and plantains cultivation is an activity of great economic and social importance. Their worldwide production represents around 107 million tons and are the fourth most produced food in the world (FAO 2017). In comparison to other tropical fruits, the consumption of bananas and plantains is high, mainly due to its versatility in use (*in natura* consumption, processing, fried, cooked, among others), and flavor and aroma characteristics. The edible bananas (*Musa* spp.) are generally classified according to the consumption mode (dessert or cooking bananas) and the constitution of their genome (AA, AB, BB, AAA, AAB, ABB, AAAA, AAAB, and ABBB) (de Jesus et al. 2013). The botanic classification is based in morphologic characteristics that help in the differentiation of dessert bananas (AA, AAA and AAB), cooking bananas (AAA, AAB and ABB) and plantains (AAB). During the ripening, there are modifications in the physicochemical characteristics associated to the organoleptic and nutritional alterations. Dessert bananas are consumed *in natura* in advanced ripening stages (5, 6 and 7), depending on the consumer preference. However, cooking bananas are consumed in many ripening stages, going through a cooking process and are not generally appreciated in its *in natura* form (e.g., absence of sweetness and unpleasant firmness) (Gibert et al. 2009).

Physicochemical and biochemical characteristics are influenced by many factors, such as the genotype and ripening stage, which contribute to the differentiation and variation of these characteristics. Furthermore, these parameters help to identify the best application for each genotype (e.g., banana for *in natura* consumption, banana candy, banana chips, banana pulp, among others). Studies have indicated that banana and plantain fruit contain appreciable quantities of antioxidant compounds, such as carotenoids (Yan et al. 2016) and phenolic compounds (e.g. flavonoids). Analysis of physicochemical and biochemical parameters (fruit quality) such as peel color, pulp firmness, soluble solids (SS), pH, titratable acidity (TA), and bioactive compounds, will be useful for the characterization and selection of genotypes with superior characteristics for genetic improvement, as well as for the introduction of new varieties in existent agricultural systems. Thus, the aim of this study was to analyse physicochemical and biochemical characteristics

in different banana fruit genotyped of dessert, nonplantain cooking and plantain cooking in three different stages of ripening, in order to differentiate the subgroups and/or groups of consumption.

## MATERIAL AND METHODS

The plant material consisted of 19 banana genotypes from different genomic groups maintained in the Active Germplasm Bank of Embrapa Cassava & Fruits (lat 12°40'12" S; long 39°06'07" W; alt 225 m) (Table 1). This working collection was organized in six genotypes groups based on their consumption mode, genomic constitution and morphological characters. When the fruits reached the ripening stage 1, central bunches of each genotype were harvested (2 bunches = 40 fruit) and they were stored at room temperature ( $20 \pm 2$  °C) and relative humidity ( $80 \pm 2\%$ ), without ethylene treatment, until complete the desired ripening stage. The three ripening stages assessed, 2, 5 and 7, corresponded to the scale described by Soltani et al. (2011) and Yan et al. (2016) and were: stage 2 - all green; stage 5 - yellow with green ends; and stage 7 - yellow with brown areas.

The fruits were washed and separated into peel and pulp. The pulp was cut in the length and across the width, creating four quarters. With the quarters, two groups were created, one for biochemical analysis, and other for physicochemical analysis. For biochemical analysis, the pulps were ground to a fine powder (IKA, A.11, Germany) in liquid nitrogen, lyophilized and stored at - 80 °C. Three banana/plantain fruits constituted each analysis ( $n = 3$ ) and all analyses were performed in triplicate.

Fruit firmness (N) was determined using a TA-XT2i texture analyser (Stable Micro System Ltd., Gidalming, UK), with an 8 mm diameter probe at a speed of  $2 \text{ mm} \cdot \text{s}^{-1}$  and penetration of 10 mm (two measures in the central part of peel (Firmness WP) and unpeeled banana fruit (Firmness UP). The SS content was obtained using a manual refractometer (Atago, model N-1E, Atago Co. Ltd., Japan) and the results were expressed in °Brix (AOAC 2005). The pH was determined in aqueous solution, using approximately 10 g of banana pulp in 100 mL of distilled water (IAL 2008) and same aqueous extract it was measured the titratable acidity, with standardized solution (0.0996 N NaOH) (IAL 2008). Dry weight (%)

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**Table 1.** Accessions of bananas and plantains.

Accesses	Ploidy	Subgroup/Subspecies	Use form
Yangambi Km5 (Ykm5)	AAA	Ibota	<i>In natura</i>
Grande Naine (GN)	AAA	Cavendish	<i>In natura</i>
Khai (Kh)	AAA	Ibota	<i>In natura</i>
Prata-Anã (PA)	AAB	Prata	<i>In natura</i>
Pisang Kepok Bung (PKB)	AAB	Peyan	<i>In natura</i>
Ney Poovan (NP)	AB	Ney Poovan	<i>In natura</i>
Ouro da Mata (OM)	AAAB	-	<i>In natura</i>
Monthan 172 (M172)	ABB	Monthan	Cooked
Simili Radjah (SR)	ABB	Peyan	Cooked
Pelipita (PPT)	ABB	Bluggoe	Cooked
Pacha Nadan (PN)	ABB	Saba	Cooked
Namwa Khom (NK)	ABB	Pisang Awak	Cooked
Muisa Tia (MT)	ABB	Pisang Awak	Cooked
FC06-02 (F02)	AABB	Figo	Cooked
Tiparot (TPT)	ABBB	Klue Teparod	Cooked
D'Angola (DA)	AAB	Plantain	Cooked
Terra Sem Nome (TSN)	AAB	Plantain	Cooked
Terra Anã Branca (TAB)	AAB	Plantain	Cooked
Samurá B (SB)	AAB	Plantain	Cooked

was determined by oven drying for 24 h at 105 °C (AOAC 2005). CIE colour values of luminosity ( $L^*$ ), chromaticity ( $C^*$ ) and angle Hue ( $H^*$ ) for each fruit on both peel and pulp were determined using the spectrophotometer (CR 410 Chroma Meter, Konica Minolta, Osaka, Japan). Peel thickness was measured with a digital caliper (Jomarca®, São Paulo, Brazil) in a central portion of the peel. The pulp-to-peel ratio was determined by pulp fresh weight and peel fresh weight.

Total carotenoid contents were determined according to Lichtenthaler (1987), with minor modifications. Lyophilized samples (200 mg) were extracted twice with 80% acetone by sonication for 30 min. The extracts were combined and centrifuged at 3,800 rpm (10 min) and the absorbance (A663, A646 and A455) of the acetone extracts was measured at 663, 646, and 455 nm, respectively, using a UV-Vis spectrophotometer Ultrospec 3000 (Pharmacia Biotech, Uppsala, Sweden) and expressed in  $\mu\text{g}\cdot\text{g}^{-1}$  DW (dry weight).

Ascorbic acid (AA) and dehydroascorbic acid (DHAA) were measured according to the method of (Pertuzatti et al. 2015), with modifications. In 50 mg of banana pulp were added 5 mL of cold extraction solution, consisted of 10 g of metaphosphoric acid (4.5% w/v) and 40 mL of

glacial acetic acid. Afterwards, the tubes were homogenized in vortex (1 min) and incubated for 30 min in ultrasonic bath at 5 °C. The samples were centrifuged at 3,800 rpm for 15 min. The residue was twice subjected to similar procedures of extraction, and the supernatants were combined to reach a final volume of 15 mL. The sample was transferred to a 1.5 mL vial, and 20  $\mu\text{L}$  were injected into a UPLC system (Ultimate 3000, Dionex-Thermo Fisher Scientific Inc., San Jose, USA) equipped with a diode array detector and Ace 5 C18 (Advanced Chromatography Technologies, ACT, UK) column (5 $\mu\text{m}$ , 250  $\times$  4.6 mm). The mobile phase was 2% acetic acid in an isocratic flow of 0.5 mL $\cdot\text{min}^{-1}$ . The column temperature was set to 25 °C, and the detection wavelength was 248 nm for ascorbic acid and 240 nm for the dehydroascorbic acid. The results were expressed in mg AA or Vitamin C 100 $\cdot\text{g}^{-1}$  (DW). The total flavonoids was performed according to Popova et al. (2005) with adjustments. Fresh pulp or peel powdered in liquid nitrogen was homogenized with 10% acidified methanol. After 30 min in ultrasonic bath, 5%  $\text{AlCl}_3$  (w/v) was added and the samples were centrifuged for 20 min at 3,800 rpm (Mikro220R, Hettich Zentrifugen, Tuttlingen, Germany). Finally, the samples were filtered, and the absorbance was measured at

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425 nm. The results were expressed as mg of quercetin equivalents (QE) per 100 g dry weight (DW).

All analysis were conducted in entirely randomized design, with factorial scheme  $19 \times 3$  (genotypes  $\times$  ripening stages), with three repetitions (three fruit by parcel). The data were collected, summarized and submitted to the variance analysis (ANOVA), followed by Scott Knott ( $p < 0.01$ ) averages comparison test among the genotypes, and Tukey test ( $p < 0.01$ ) among the ripening stages, using the SISVAR program. Pearson's correlation (SAS 9.1.) and principal component analysis (PCA) were performed for the physicochemical and biochemical data using the statistical analysis software XLSTAT Version 2014.2.03 (STATCON, Wittenhausen, Germany).

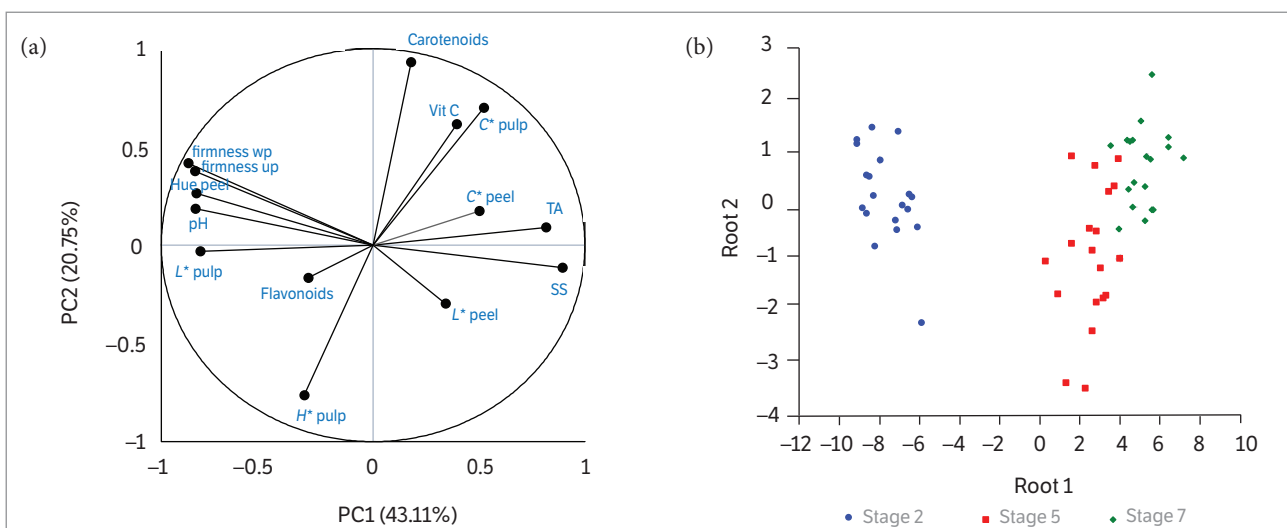
## RESULTS AND DISCUSSION

Significant differences were observed in the indexes of color  $L^*$  and  $C^*$  of the peel and pulp, firmness (with peel and unpeeled), soluble solids (SS), pH and dry weight pulp, total flavonoids, carotenoids and vitamin C content (ascorbic and dehydroascorbic acid), during the ripening process and in different genotypes. Aiming to establish a descriptive model of grouping the ripening stage in function of physicochemical characteristics, we compared the results by principal components analysis (PCA). The dispersion of the genotypes, according to the PC1 and PC2 axis (Figs. 1a and 1b), show the existence

of three groups, correspondent to each ripening stage analyzed. PC1 and PC2 explained 63.96% of the data variance.

The three groups are separated by the first principal component (PC1) in ascending order from left to right. The PC1 axis represents 43.11% of the total variance, separating the green fruit from the ripe ones. SS, TA,  $C^*$  pulp, carotenoids and vitamin C content are positively correlated with the ripening stage, suggesting that these parameters increase during the ripening process.  $L^*$  and  $C^*$  peel also have a positive correlation with the ripening stage, but in less extension. There was an increase in  $L^*$  peel values during the banana fruit ripening process (until stage 5) due to the change of color from the unripe (green) to ripe (coloration completely yellow) (Table 2). In stage 7, there was a decrease in  $L^*$  peel values, due to the increase of dark pigmentation, characteristic of ripening stage. Changes in the peel and in the pulp color (Tables 2 and 3) associated with the ripening can be described by the evolution of  $L^*$  and  $C^*$ . Luminosity ( $L^*$ ) decrease and chrome ( $C^*$ ) increase reflect the decrease of whiteness and the raise of the color intensity. An increase of  $L^*$  and  $C^*$  of the peel to a maximum level at stage 5 expresses the change from green to yellow, due to the degradation of chlorophyll and the accumulation of carotenoids.

The genotypes 'Simili Radjah' and 'Namwa Khom' showed lower values of  $C^*$  and higher Hue\* angle, which demonstrates to be the genotypes with the lightest pulp



**Figure 1.** Two-dimensional projection (a) and scores (b) of physicochemical and biochemical attributes in the first two main components among the 19 genotypes of banana fruit evaluated in three ripening stages (stage 2 - all green; stage 5 - yellow with green ends; and stage 7 - yellow with brown areas).

**Table 2.** Coordinate luminosity ( $L^*$ ), Chrome ( $C^*$ ) and angle Hue ( $H^*$ ) at ripening stages 2, 5 and 7 in the post-harvest ( $20 \pm 2^\circ\text{C}$  and  $\text{RH } 85 \pm 2\%$ ) of the peel of *Musa* spp. genotypes.

Genotypes	$L^*$			$C^*$			$H^*$		
	Stage 2	Stage 5	Stage 7	Stage 2	Stage 5	Stage 7	Stage 2	Stage 5	Stage 7
<b>Dessert bananas</b>									
Yangambi Km5	$57.4 \pm 1.2^{\text{bC}\#}$	$65.4 \pm 2.4^{\text{aA}}$	$62.9 \pm 3.5^{\text{aA}}$	$22.3 \pm 2.3^{\text{aB}}$	$32.0 \pm 1.7^{\text{bA}}$	$32.9 \pm 3.0^{\text{aA}}$	$116.6 \pm 0.5^{\text{bA}}$	$80.4 \pm 1.8^{\text{bB}}$	$79.7 \pm 3.5^{\text{aC}}$
Grande Naine	$49.8 \pm 1.2^{\text{dB}}$	$56.6 \pm 0.3^{\text{cA}}$	$54.1 \pm 3.9^{\text{cA}}$	$28.24 \pm 4.3^{\text{aA}}$	$28.0 \pm 0.6^{\text{bA}}$	$27.9 \pm 2.5^{\text{bA}}$	$122.9 \pm 1.7^{\text{aA}}$	$82.8 \pm 3.6^{\text{aB}}$	$75.0 \pm 2.7^{\text{bC}}$
Khai	$63.8 \pm 0.6^{\text{aB}}$	$68.6 \pm 1.7^{\text{aA}}$	$58.1 \pm 1.2^{\text{bC}}$	$27.1 \pm 2.7^{\text{aB}}$	$36.0 \pm 2.3^{\text{aA}}$	$27.5 \pm 2.3^{\text{bB}}$	$111.2 \pm 1.5^{\text{cA}}$	$84.6 \pm 1.4^{\text{aB}}$	$79.9 \pm 0.8^{\text{aB}}$
Prata-Anã	$49.4 \pm 0.2^{\text{dC}}$	$62.5 \pm 1.4^{\text{bA}}$	$55.4 \pm 2.5^{\text{bB}}$	$18.8 \pm 1.1^{\text{bC}}$	$39.2 \pm 2.9^{\text{aA}}$	$30.4 \pm 3.3^{\text{aB}}$	$126.0 \pm 1.4^{\text{aA}}$	$86.2 \pm 1.2^{\text{aB}}$	$77.4 \pm 2.5^{\text{aC}}$
Pisang K. Bung	$49.8 \pm 1.3^{\text{dB}}$	$55.4 \pm 3.9^{\text{cA}}$	$51.5 \pm 1.2^{\text{cB}}$	$11.7 \pm 4.3^{\text{cB}}$	$25.0 \pm 5.3^{\text{cA}}$	$16.9 \pm 1.8^{\text{cB}}$	$121.1 \pm 1.0^{\text{bA}}$	$80.3 \pm 3.4^{\text{bB}}$	$70.3 \pm 2.9^{\text{cC}}$
Ney Poovan	$54.4 \pm 2.7^{\text{bA}}$	$56.6 \pm 1.8^{\text{cA}}$	$48.6 \pm 1.8^{\text{dB}}$	$32.2 \pm 6.8^{\text{aA}}$	$24.4 \pm 2.6^{\text{cB}}$	$14.7 \pm 1.3^{\text{cC}}$	$110.9 \pm 3.3^{\text{cA}}$	$77.8 \pm 1.2^{\text{bB}}$	$52.9 \pm 0.6^{\text{cC}}$
Ouro da Mata	$56.6 \pm 2.0^{\text{bC}}$	$67.2 \pm 0.2^{\text{aA}}$	$61.2 \pm 0.9^{\text{aB}}$	$24.1 \pm 3.3^{\text{aB}}$	$37.2 \pm 1.2^{\text{aA}}$	$31.5 \pm 0.2^{\text{aA}}$	$120.2 \pm 1.3^{\text{bA}}$	$88.3 \pm 1.4^{\text{aB}}$	$78.9 \pm 0.5^{\text{aC}}$
Mean	54.5	61.7	56.0	23.4	27.7	26.0	85.5	82.9	73.5
<b>Nonplantain cooking</b>									
Monthan 172	$53.8 \pm 1.0^{\text{bB}}$	$61.7 \pm 2.2^{\text{bA}}$	$52.4 \pm 0.8^{\text{cB}}$	$15.1 \pm 3.8^{\text{bB}}$	$27.8 \pm 2.5^{\text{bA}}$	$19.1 \pm 1.8^{\text{cB}}$	$117.4 \pm 0.6^{\text{bA}}$	$80.1 \pm 0.8^{\text{bB}}$	$72.9 \pm 2.5^{\text{bC}}$
Simili Radjah	$49.3 \pm 0.3^{\text{dA}}$	$50.1 \pm 3.4^{\text{cA}}$	$47.58 \pm 3.4^{\text{dA}}$	$10.0 \pm 2.7^{\text{cB}}$	$19.3 \pm 3.1^{\text{dA}}$	$18.5 \pm 1.7^{\text{cA}}$	$102.4 \pm 4.1^{\text{dA}}$	$64.7 \pm 4.5^{\text{dB}}$	$53.4 \pm 3.5^{\text{cC}}$
Pelipita	$51.3 \pm 1.2^{\text{cB}}$	$56.2 \pm 1.1^{\text{cA}}$	$52.8 \pm 1.2^{\text{cB}}$	$12.2 \pm 1.2^{\text{cB}}$	$31.7 \pm 3.7^{\text{bA}}$	$28.6 \pm 3.2^{\text{bA}}$	$125.9 \pm 0.1^{\text{aA}}$	$67.1 \pm 4.3^{\text{dB}}$	$65.4 \pm 2.0^{\text{dB}}$
Pacha Nadan	$56.4 \pm 1.5^{\text{bB}}$	$65.8 \pm 2.4^{\text{aA}}$	$57.6 \pm 5.0^{\text{bB}}$	$26.0 \pm 2.4^{\text{aA}}$	$32.5 \pm 3.8^{\text{bA}}$	$26.6 \pm 3.8^{\text{bA}}$	$114.7 \pm 0.3^{\text{cA}}$	$83.8 \pm 1.9^{\text{aB}}$	$77.5 \pm 3.7^{\text{aC}}$
Namwa Khom	$52.5 \pm 2.5^{\text{cB}}$	$54.7 \pm 3.2^{\text{cA}}$	$51.6 \pm 4.15^{\text{cB}}$	$16.4 \pm 3.0^{\text{bA}}$	$18.6 \pm 5.2^{\text{dA}}$	$17.66 \pm 3.2^{\text{cA}}$	$111.3 \pm 2.0^{\text{cA}}$	$80.2 \pm 5.4^{\text{bB}}$	$74.2 \pm 2.1^{\text{bC}}$
Muísa Tia	$51.6 \pm 1.9^{\text{cC}}$	$59.3 \pm 0.8^{\text{cA}}$	$55.6 \pm 2.0^{\text{bB}}$	$20.0 \pm 7.3^{\text{bA}}$	$26.0 \pm 3.8^{\text{cA}}$	$19.38 \pm 3.8^{\text{cA}}$	$117.7 \pm 3.2^{\text{bA}}$	$85.6 \pm 1.1^{\text{aB}}$	$68.8 \pm 3.1^{\text{cC}}$
FC06-02	$54.5 \pm 0.9^{\text{bA}}$	$53.2 \pm 0.4^{\text{cA}}$	$46.6 \pm 1.8^{\text{dB}}$	$17.7 \pm 3.3^{\text{bB}}$	$24.6 \pm 2.1^{\text{cA}}$	$15.26 \pm 2.6^{\text{cB}}$	$104.8 \pm 4.4^{\text{dA}}$	$68.2 \pm 1.9^{\text{dB}}$	$53.6 \pm 3.4^{\text{cC}}$
Tiparot	$51.2 \pm 1.7^{\text{cB}}$	$56.4 \pm 1.2^{\text{cAB}}$	$54.1 \pm 1.9^{\text{bA}}$	$15.1 \pm 2.7^{\text{bB}}$	$24.0 \pm 2.3^{\text{cA}}$	$17.34 \pm 1.7^{\text{cB}}$	$127.4 \pm 3.0^{\text{aA}}$	$77.3 \pm 4.3^{\text{bB}}$	$66.0 \pm 2.9^{\text{aC}}$
Mean	52.6	57.2	52.3	16.6	25.6	20.3	85.2	75.9	66.5
<b>Plantain</b>									
D'Angola	$47.7 \pm 1.8^{\text{dB}}$	$54.6 \pm 2.3^{\text{cA}}$	$51.1 \pm 1.0^{\text{cB}}$	$22.26 \pm 3.3^{\text{aA}}$	$29.0 \pm 3.6^{\text{bA}}$	$23.3 \pm 1.7^{\text{cA}}$	$118.6 \pm 2.2^{\text{bA}}$	$81.3 \pm 1.1^{\text{bB}}$	$72.3 \pm 1.8^{\text{bC}}$
Terra S. N.	$52.6 \pm 3.6^{\text{cA}}$	$56.5 \pm 2.6^{\text{cA}}$	$53.5 \pm 0.6^{\text{cA}}$	$27.44 \pm 2.1^{\text{aA}}$	$28.2 \pm 3.1^{\text{bA}}$	$25.3 \pm 1.7^{\text{bA}}$	$111.9 \pm 1.7^{\text{cA}}$	$81.2 \pm 2.3^{\text{bB}}$	$75.5 \pm 3.1^{\text{bC}}$
Terra A. B.	$48.5 \pm 1.8^{\text{dB}}$	$56.5 \pm 1.3^{\text{cA}}$	$54.16 \pm 1.7^{\text{cA}}$	$27.15 \pm 4.0^{\text{aA}}$	$28.2 \pm 5.0^{\text{bA}}$	$24.6 \pm 2.3^{\text{bA}}$	$119.6 \pm 1.0^{\text{bA}}$	$73.5 \pm 3.8^{\text{cB}}$	$76.5 \pm 0.3^{\text{aB}}$
Samurá B	$48.3 \pm 1.8^{\text{dB}}$	$57.7 \pm 0.4^{\text{cA}}$	$52.23 \pm 0.7^{\text{cB}}$	$25.83 \pm 4.2^{\text{aB}}$	$31.1 \pm 2.9^{\text{bA}}$	$33.9 \pm 1.6^{\text{aA}}$	$119.6 \pm 1.8^{\text{bA}}$	$80.3 \pm 0.4^{\text{bB}}$	$75.5 \pm 1.4^{\text{bB}}$
Mean	49.3	56.3	52.7	25.6	29.1	26.7	87.5	79.0	75.0

#Values in the same column followed by different lower case (genotypes) and in the same row followed by different upper case letters (ripening stages), for each parameter, differ by the Scott Knott test ( $p < 0.01$ ) (genotypes) and by Tukey test ( $p < 0.01$ ) (ripening stages). Stage 2 - all green; stage 5 - yellow with green ends; and stage 7 - yellow with brown.

color (Table 3). With the ripening there is an increase of color intensity ( $C^*$ ), while the Hue\* angle decreases, which indicates that the pulp gets more yellow/orange with the ripening (Aquino et al. 2017). The genotype 'Namwa Khom' showed the highest intensity only when the fruit reached the stage 7. The highest  $C^*$  indicates that the pulp has a higher intensity of the yellow/orange color (Table 3). The genotypes 'Khai', 'Simili Radjah' and FC06-02 presented the highest color intensity by the Hue\* angle in the stages 5 and 7. In addition, SS, pH and TA acidity strongly influenced the fruit separation in the stages 5 and 7 (Fig. 1). Fruit softening, SS, pH and TA acidity content are factors that indicate the ripening and quality of fruit. The increase of SS and decrease of pH was observed during the ripening process and the content depends on genotype and on ripening stage. During the ripening,

the lower pH was found in fruit in stages 5 and 7, similar with the results found in other genotypes of *Musa* spp. In this process, pH decrease and acidity increase, inducing a raise in the acid flavor on the fruit (Youryon and Supapvanich 2017) (Fig. 2). Pulp pH decrease is associated with the accumulation of some acids, mainly malic acids in bananas, promoting acidity alteration and inducing acid flavor (Newilah et al. 2009).

According to previous studies, fruit with high SS levels are the ones that present the highest possibility of acceptance (Gibert et al. 2009). There were SS variations, as 4.51 to 23.38 ° Brix in dessert bananas (Fig. 2a), 7.18 to 25.37 in cooking bananas (Fig. 2b) and 7.19 to 26.87 in plantains (Fig. 2c). The fruit green (e.g. plantain) also present higher percentage dry weight (Fig. 2i) and firmness (Fig. 3). A clear differentiation was verified among the

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**Table 3.** Coordinate luminosity (L\*), Chrome (C\*) and angle Hue (H\*) at ripening stages 2, 5 and 7 in the post-harvest ( $20 \pm 2^\circ\text{C}$  and RH  $85 \pm 2\%$ ) of the pulp of *Musa* spp. genotypes.

Genotypes	L*			C*			H*		
	Stage 2	Stage 5	Stage 7	Stage 2	Stage 5	Stage 7	Stage 2	Stage 5	Stage 7
<b>Dessert bananas</b>									
Yangambi Km5	$81.2 \pm 0.4^{a\#}$	$74.1 \pm 0.4^{cB}$	$73.0 \pm 0.3^{cB}$	$24.7 \pm 0.3^{eB}$	$30.9 \pm 1.7^{bA}$	$30.9 \pm 0.7^{bA}$	$93 \pm 0.3^{aA}$	$89.4 \pm 0.6^{bB}$	$88.7 \pm 0.1^{aB}$
Grande Naine	$80.8 \pm 1.4^{aA}$	$73.0 \pm 0.6^{cB}$	$71.8 \pm 0.7^{dC}$	$29.6 \pm 1.1^{dC}$	$34.01 \pm 4.5^{bB}$	$36.2 \pm 7.0^{aA}$	$90.6 \pm 0.5^{aA}$	$84.0 \pm 1.0^{dB}$	$83.5 \pm 0.6^{dB}$
Khai	$78.8 \pm 0.4^{bA}$	$74.1 \pm 0.4^{cB}$	$71.9 \pm 4.5^{dB}$	$25.9 \pm 0.9^{eB}$	$29.02 \pm 0.5^{cA}$	$30.7 \pm 0.7^{bA}$	$92.7 \pm 0.2^{aA}$	$90.8 \pm 0.4^{aB}$	$90.3 \pm 1.7^{bB}$
Prata-Anã	$81.7 \pm 1.5^{aA}$	$76.8 \pm 0.4^{bB}$	$75.3 \pm 0.6^{bB}$	$26.9 \pm 3.9^{dB}$	$32.12 \pm 0.1^{bA}$	$32.8 \pm 2.9^{bA}$	$88.6 \pm 0.8^{cA}$	$86.4 \pm 0.3^{cB}$	$86.4 \pm 1.0^{bB}$
Pisang K. B.	$81.9 \pm 0.4^{aA}$	$76.4 \pm 2.1^{bB}$	$72.8 \pm 1.7^{cC}$	$23.4 \pm 2.2^{eB}$	$26.5 \pm 0.2^{cA}$	$27.7 \pm 0.6^{cA}$	$85.2 \pm 1.6^{dA}$	$85.2 \pm 1.2^{dA}$	$82.2 \pm 2.1^{dB}$
Ney Poovan	$77.2 \pm 1.3^{bA}$	$76.5 \pm 1.4^{bA}$	$75.8 \pm 1.6^{bA}$	$28.5 \pm 1.2^{dA}$	$29.1 \pm 2.2^{cA}$	$27.3 \pm 1.1^{cA}$	$87.6 \pm 1.4^{cA}$	$87.3 \pm 2.1^{cA}$	$87.2 \pm 1.3^{bA}$
Ouro da Mata	$82.7 \pm 1.3^{aA}$	$71.5 \pm 1.4^{dB}$	$71.9 \pm 1.3^{dB}$	$21.0 \pm 0.5^{cC}$	$24.9 \pm 0.65^{dB}$	$31.5 \pm 0.3^{bA}$	$89.2 \pm 0.8^{cA}$	$86.5 \pm 0.5^{dB}$	$85.7 \pm 0.5^{cB}$
Mean	80.6	74.7	73.2	25.7	29.5	31.0	89.6	87.1	86.3
<b>Nonplantain cooking</b>									
Monthan 172	$80.8 \pm 0.3^{aA}$	$76.5 \pm 0.3^{bB}$	$76.3 \pm 0.3^{bB}$	$27.1 \pm 0.2^{dA}$	$26.8 \pm 0.7^{cA}$	$29.9 \pm 0.8^{bA}$	$85.1 \pm 0.4^{dA}$	$84.7 \pm 0.5^{dA}$	$85.0 \pm 0.3^{cA}$
Simili Radjah	$84.5 \pm 1.2^{aA}$	$78.2 \pm 1.6^{aB}$	$75.1 \pm 0.7^{bC}$	$16.5 \pm 0.5^{gB}$	$24.4 \pm 0.9^{dA}$	$24.7 \pm 0.6^{dA}$	$91.9 \pm 0.9^{aA}$	$91.1 \pm 1.2^{aA}$	$89.5 \pm 0.0^{dB}$
Pelipita	$82.4 \pm 1.1^{aA}$	$76.0 \pm 0.2^{bB}$	$73.7 \pm 1.4^{cB}$	$28.7 \pm 0.2^{dB}$	$36.2 \pm 1.2^{aA}$	$36.1 \pm 1.8^{aA}$	$81.5 \pm 0.9^{eA}$	$77.5 \pm 0.2^{fB}$	$78.3 \pm 0.2^{eB}$
Pacha Nadan	$81.1 \pm 1.0^{aA}$	$74.6 \pm 0.1^{cB}$	$74.2 \pm 0.7^{cB}$	$24.6 \pm 1.6^{eB}$	$29.1 \pm 1.6^{cA}$	$32.1 \pm 0.2^{bA}$	$89.0 \pm 0.6^{cA}$	$85.4 \pm 0.5^{dB}$	$86.9 \pm 1.3^{bB}$
Namwa Khom	$79.5 \pm 0.3^{bA}$	$76.6 \pm 1.2^{bB}$	$77.3 \pm 1.4^{aAB}$	$22.2 \pm 0.6^{eA}$	$22.5 \pm 1.9^{eA}$	$22.9 \pm 1.6^{dA}$	$88.3 \pm 0.2^{cA}$	$89.2 \pm 0.3^{bA}$	$89.2 \pm 0.5^{aA}$
Muisa Tia	$81.7 \pm 0.8^{aA}$	$78.3 \pm 1.2^{aB}$	$77.8 \pm 1.4^{aB}$	$16.4 \pm 0.4^{gB}$	$19.8 \pm 0.6^{fA}$	$21.3 \pm 2.8^{dA}$	$87.7 \pm 0.9^{cA}$	$87.6 \pm 1.4^{cA}$	$88.8 \pm 0.3^{aA}$
FC06-02	$79.7 \pm 1.3^{bA}$	$78.8 \pm 0.8^{aA}$	$75.6 \pm 0.7^{bB}$	$25.5 \pm 1.3^{eA}$	$25.4 \pm 1.0^{dA}$	$27.3 \pm 1.2^{cA}$	$90.6 \pm 0.6^{bA}$	$91.1 \pm 0.8^{aA}$	$89.7 \pm 0.6^{aA}$
Tiparot	$82.3 \pm 0.4^{aA}$	$71.18 \pm 1.1^{dB}$	$73.4 \pm 0.8^{cB}$	$16.4 \pm 0.5^{gB}$	$22.9 \pm 0.6^{eA}$	$23.3 \pm 0.2^{dA}$	$80.8 \pm 0.6^{eA}$	$76.7 \pm 0.3^{fB}$	$76.6 \pm 0.5^{fB}$
Mean	81.5	76.3	75.4	22.2	25.91	27.2	86.9	85.4	85.5
<b>Plantain</b>									
D'Angola	$80.3 \pm 1.2^{aA}$	$78.6 \pm 2.4^{aA}$	$78.2 \pm 0.5^{aA}$	$38.4 \pm 2.2^{bA}$	$37.0 \pm 0.8^{aA}$	$35.7 \pm 1.0^{aA}$	$82.6 \pm 2.06^{eA}$	$80.7 \pm 0.4^{eB}$	$79.4 \pm 0.1^{bB}$
Terra S. N.	$74.6 \pm 1.9^{cA}$	$74 \pm 0.3^{cA}$	$72.6 \pm 0.5^{cA}$	$40.9 \pm 1.1^{aA}$	$38.2 \pm 0.9^{aA}$	$38.2 \pm 0.9^{aA}$	$77.5 \pm 1.9^{fA}$	$76.7 \pm 1.6^{gA}$	$76.6 \pm 0.9^{fA}$
Terra A. B.	$77.6 \pm 0.4^{bA}$	$74.6 \pm 1.9^{cB}$	$74.8 \pm 1.6^{bB}$	$37.4 \pm 1.5^{bA}$	$38.4 \pm 0.2^{aA}$	$37.1 \pm 2.2^{aA}$	$78.2 \pm 0.7^{fA}$	$78.0 \pm 0.3^{fA}$	$76.3 \pm 0.1^{fB}$
Samurá B	$78.6 \pm 2.6^{bA}$	$74.5 \pm 0.3^{cB}$	$71.5 \pm 0.4^{dC}$	$32.8 \pm 5.9^{cB}$	$33.8 \pm 0.5^{bB}$	$36.2 \pm 0.3^{aA}$	$78.3 \pm 1.2^{fA}$	$75.6 \pm 0.7^{gB}$	$72.2 \pm 0.2^{cC}$
Mean	77.8	75.4	74.3	37.4	36.9	36.85	79.2	77.7	76.1

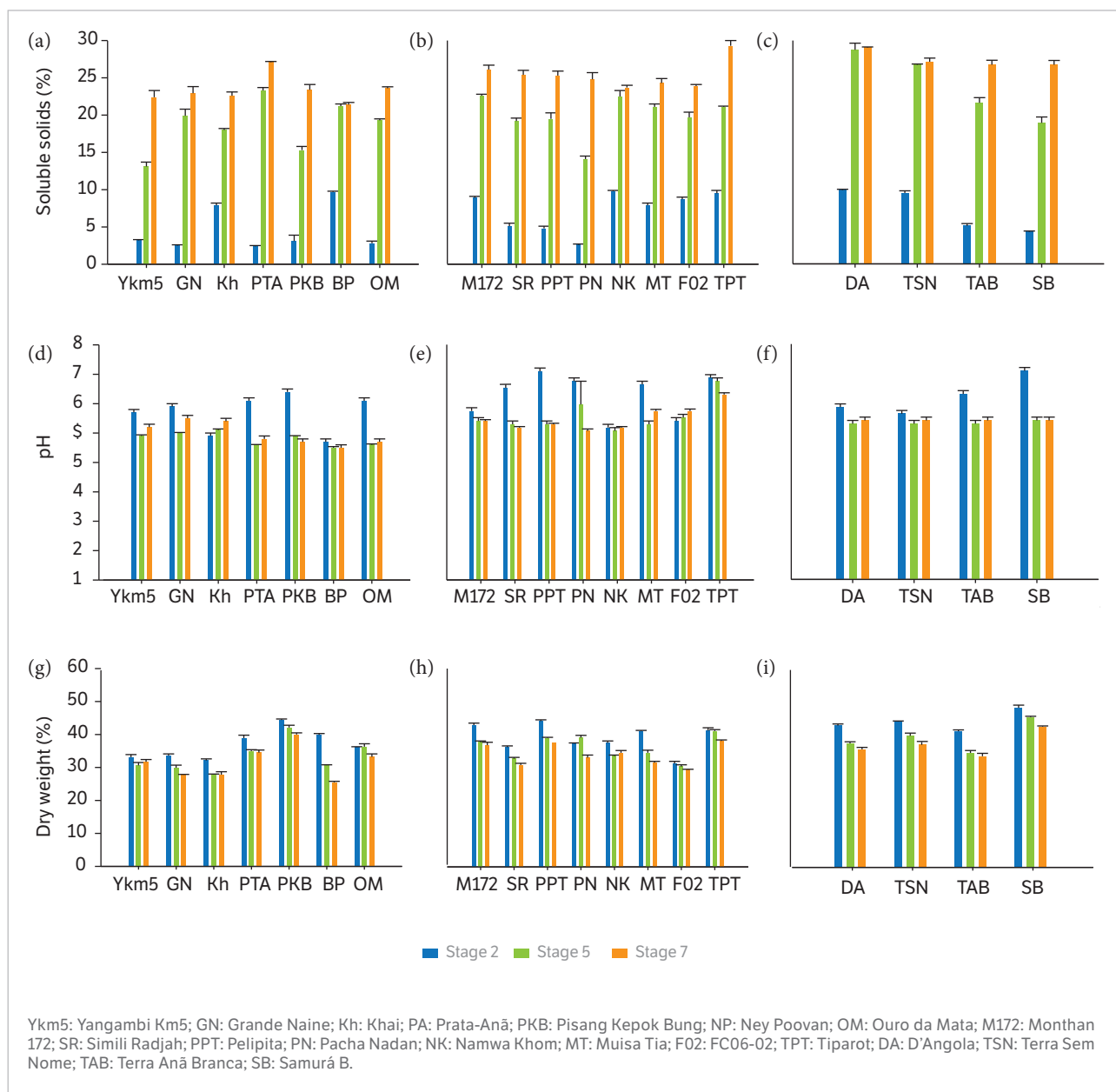
#Values in the same column followed by different lower case (genotypes) and in the same row followed by different upper case letters (ripening stages), for each parameter, differ by the Scott Knott test ( $p < 0.01$ ) (genotypes) and by Tukey test ( $p < 0.01$ ) (ripening stages). Stage 2 - all green; stage 5 - yellow with green ends; and stage 7 - yellow with brown.

subgroup and/or genotype of bananas in relation to SS, dry weight and firmness, based on its consumption. Plantains, generally present the highest SS contents (Fig. 2c), dry weight (Fig. 2i) and firmness (Figs. 3e and 3f) with values even superior when the fruit where green. Firmness change is one of the most perceptible attribute, resulting from the ripening process. There was a difference in the fruit among the genotypes and in the different ripening stages (Fig. 3). Genotypes with firmer pulps (e.g. plantain 'Samurá B') are for industrial use, mainly for the preparation of fried products e.g. banana chips. In addition, fruit with higher firmness are more resistant to transport and durable after the harvest (Pereira et al. 2004). During the ripening process, the pulp percentage dry weight decreases (Figs. 2g, 2h and 2i).

This characteristic is important to the selection of genotypes for industry (or even for the domestic consumption, for the preparation of cooked and/or fried dishes), mainly in cooking bananas, which are preferable in many countries.

The highest carotenoids levels occur in plantains, except for the nonplantain cooking banana 'Pelipita', mainly in the green fruit (stage 2). The carotenoids content showed variations among the genotypes ( $2.90 \mu\text{g}\cdot\text{g}^{-1}$  in 'Muisa Tia' at stage 5 to  $53.82 \mu\text{g}/\text{g}$  in 'Samurá B' at stage 5), influenced by ripening and we verified that it is a genotype-depending characteristic (Figs. 4a, 4b and 4c). In bananas, studies describe a wide variability among the genotypes inside active germplasm banks of *Musa* spp. (Borges et al. 2014). Previous studies indicate that





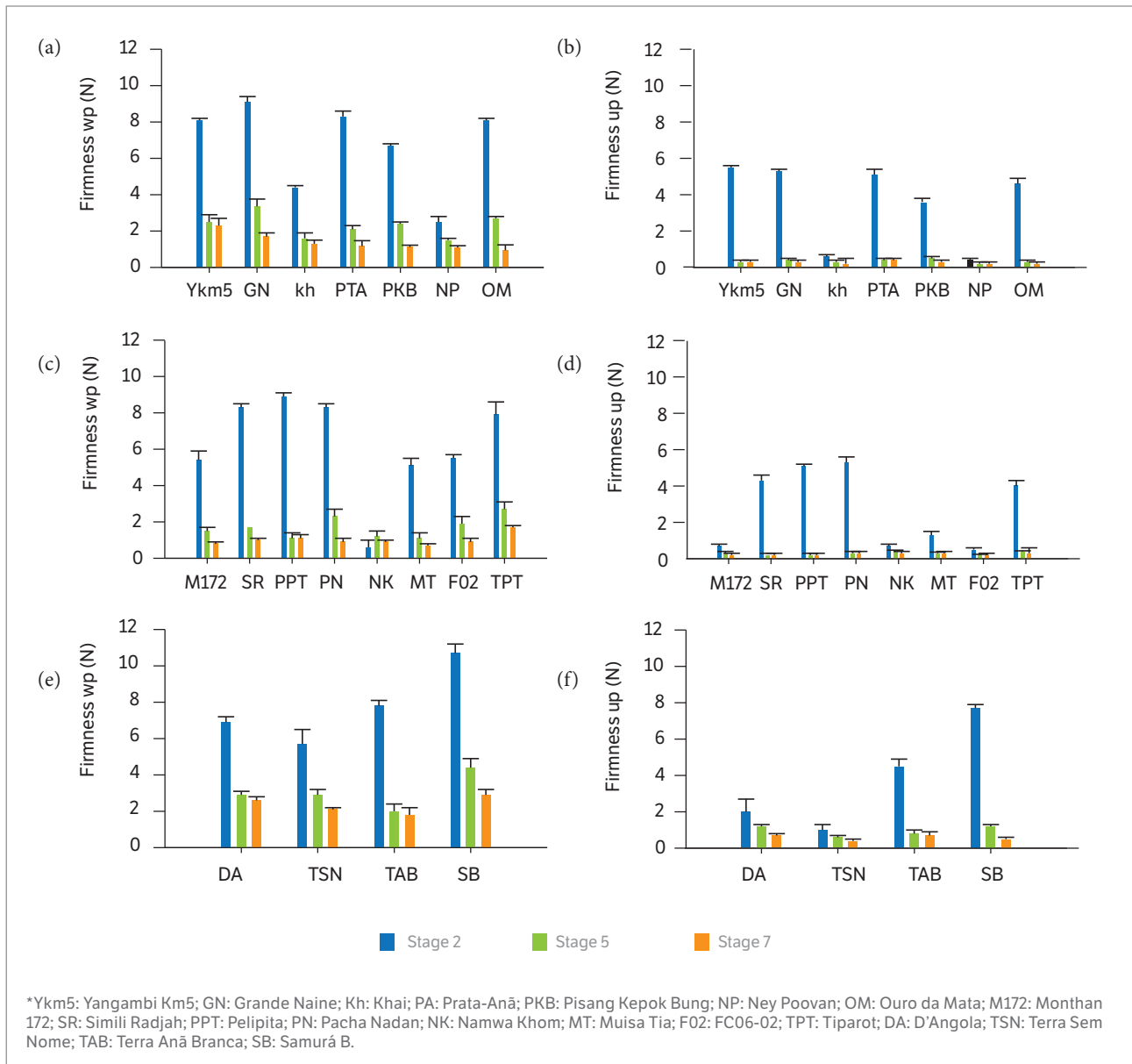
**Figure 2.** Soluble solids (°Brix), pH and dry weight (%) in banana fruit at ripening stages 2, 5 and 7 of *Musa* spp. genotypes, separated by subgroup and/or consumption mode (a, d and g) dessert bananas, (b, e and h) nonplantain cooking and (c, f and i) plantain. Stage 2 - all green; stage 5 - yellow with green ends; and stage 7 - yellow with brown areas.

carotenoids content in banana fruit is mainly constituted of pro-vitamin A compounds and the pulp coloration is a phenotypic characteristic that can indicate the quantity of pro-vitamin A carotenoids (pVACs) (Borges et al. 2014). Using the correlation analysis, we observed that C\* presented a positive linear correlation with the total carotenoids content ( $r = 0.78$ ,  $p < 0.05$ ), showing a strong negative correlation with the hue angle ( $H^*$ ). These results show that bananas with high C\* and pulp

yellow/orange, present higher contents of pro-vitamin A compounds. Genotypes with lighter coloration tend to have lower quantities of carotenoids, mainly the pVACs. However, these genotypes generally present higher proportions of antioxidant compounds such as the lutein and zeaxanthin (Englberger et al. 2010).

The vitamin C and ascorbic acid (AA) data showed a variation among the genotypes and the influence by the fruit ripening stage (Fig. 5), i.e., a genotype-dependent

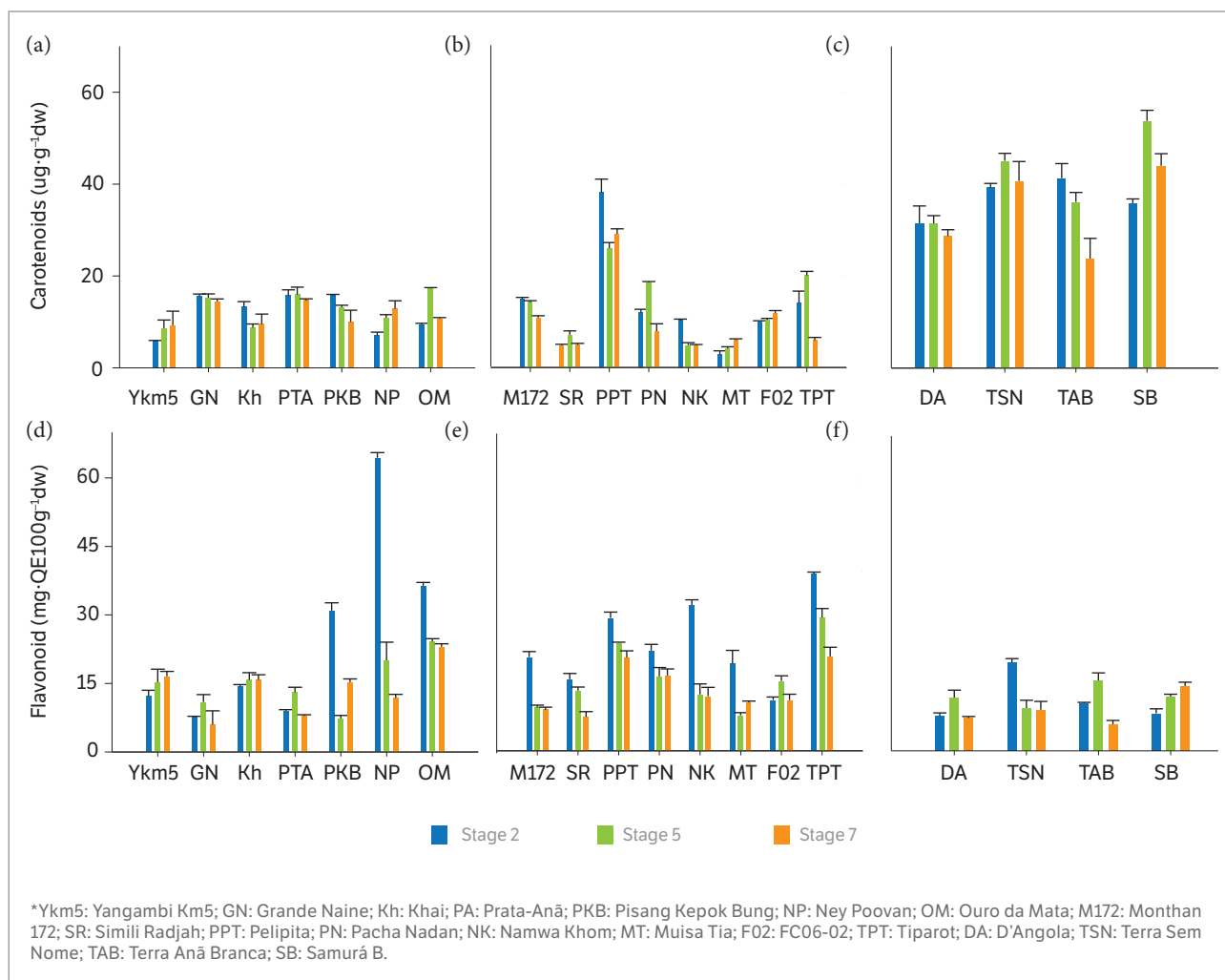




**Figure 3.** Firmness (N) of fruit with peel (Firmness WP) and unpeeled banana fruit (Firmness UP) at ripening stages 2, 5 and 7 of *Musa* spp. genotypes, separated by subgroup and/or consumption mode (a and b) dessert bananas, (c and d) nonplantain cooking and (e and f) plantain. Stage 2 - all green; stage 5 - yellow with green ends; and stage 7 - yellow with brown areas.

characteristic. Plantain generally also present higher carotenoids contents (i.e., pVACs). There are no variations in plantains during the ripening and in most of the genotypes (Figs. 5e and 5f). In the dessert (Figs. 5a and 5b) and cooking bananas (Figs. 5c and 5d), the variation of vitamin C and AA are higher than other ones. Dessert bananas presented a decrease of vitamin C content during the ripening (Fig. 5b). The dessert banana 'Prata-Anã' (Fig. 5b) presented the highest vitamin C contents in the ripe fruit (stage 5), higher than Cavendish banana

('Grande Naine'). Most of the edible bananas are genetic triploids, results of the genomic combination of the wild species *Musa acuminata* (A) and *M. balbisiana* (B), or a combination of both. The 'Prata-Anã' have a genomic constitution AAB (same of the plantains), while the 'Grande Naine' is AAA, demonstrating a possible importance of the B genome in the content of these compounds. Wall (2006) also verified that ripe fruit (yellow coloration) of bananas with genomic constitution AAB ('Dwarf Brazilian') had superior values (up to 3 times) of vitamin



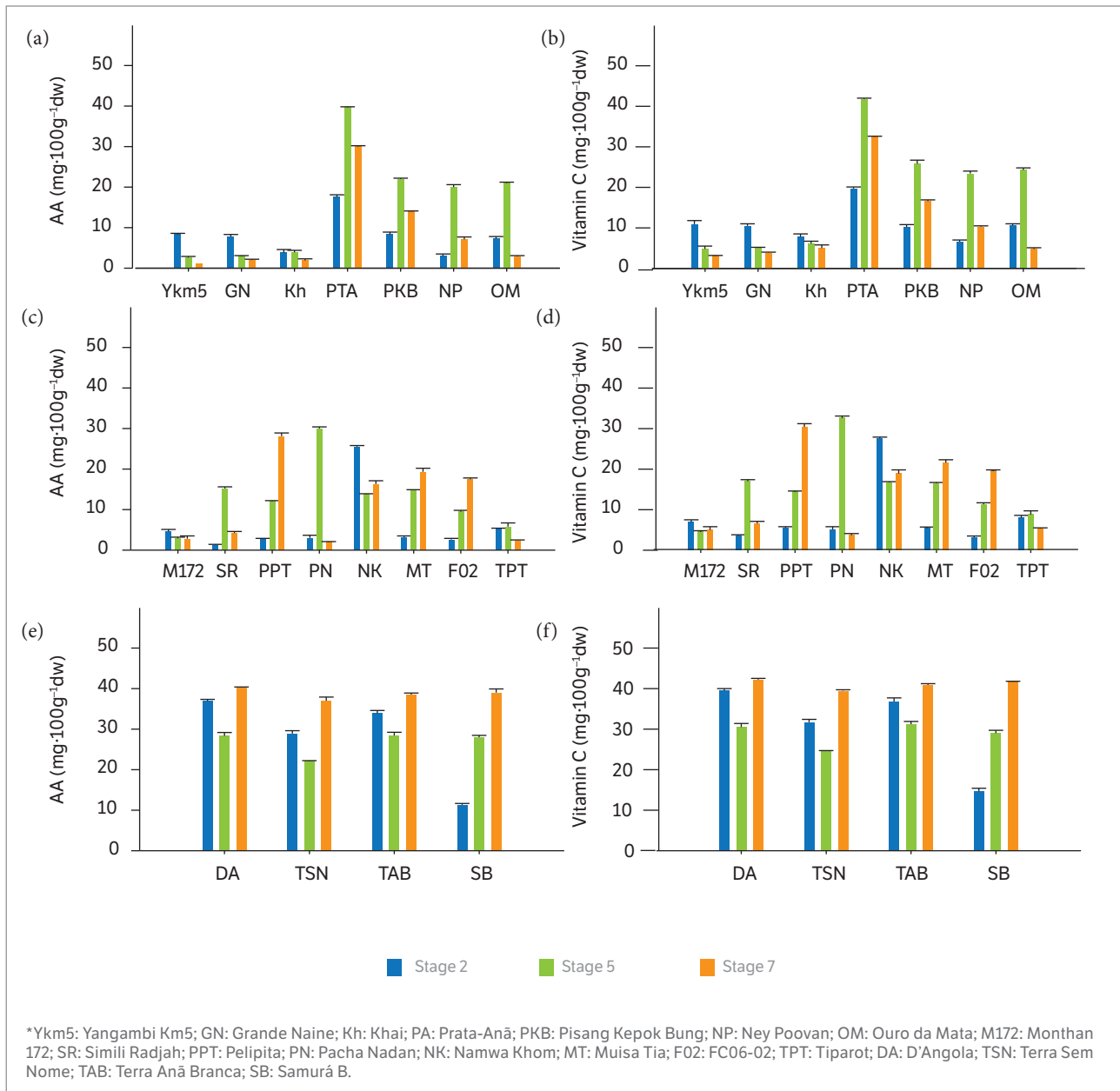
**Figure 4.** Total carotenoids and total flavonoids content in pulp of *Musa* spp. genotypes, at ripening stages 2, 5 and 7, separated by subgroup and/or consumption mode (a and d) dessert bananas, (b and e) nonplantain cooking and (c and f) plantain. Stage 2 - all green; stage 5 - yellow with green ends; and stage 7 - yellow with brown areas.

C than genotypes of the Cavendish subgroup AAA. Thus, it is evident the importance of the genomic group in the ascorbic acid content in *Musa* spp., proving that genotypes with genomic constitution AAB have higher contents (until 13 times more than the most commercialized ones) of these antioxidant compound. Among the cooking bananas (nonplantain cooking), we can observe that the highest AA and vitamin C values occur at stages 5 and 7 (Figs. 5c and 5d). However, in 'Namwa Khom', the profile was different with high contents of vitamin C in the three stages. 'Pacha Nadan' and the 'Pelipita' showed the highest contents in the stages 5 and 7, respectively.

Higher total flavonoid content was found in dessert bananas and some nonplantain cooking in their initial ripening stages (Figs. 4d and 4e), presenting a positive

correlation with the Hue angle ( $H^*$ ) of the peel ( $r = 0.354$ ,  $p < 0.05$ ) and a negative correlation with the SS content ( $r = -0.326$ ,  $p < 0.05$ ), differently from the other antioxidants analyzed (data not shown). This effect is attributed to the ripening process, with apparent gradual decrease of the contents of these compounds in fruit, which can be associated to the oxidative process (Parr and Bolwell 2000). Tsamo et al. (2014) verified increase in the total phenolic compounds in plantains until the stage 5 of ripening and a decrease at stage 7, similar to obtained in this study with plantains ('D'Angola' and 'Terra Anã Branca') and in some dessert bananas ('Grande Naine' and 'Prata-Anã').

However, in some genotypes (e.g., 'Ney Poovan' and 'D'Angola') there was an increase in the total flavonoids



**Figure 5.** Ascorbic acid (AA) and vitamin C in pulp of *Musa* spp. genotypes, at ripening stages 2, 5 and 7, separated by subgroup and/or consumption mode (a and b) dessert bananas, (c and d) nonplantain cooking and (e and f) plantain. Stage 2 - all green; stage 5 - yellow with green ends; and stage 7 - yellow with brown areas.

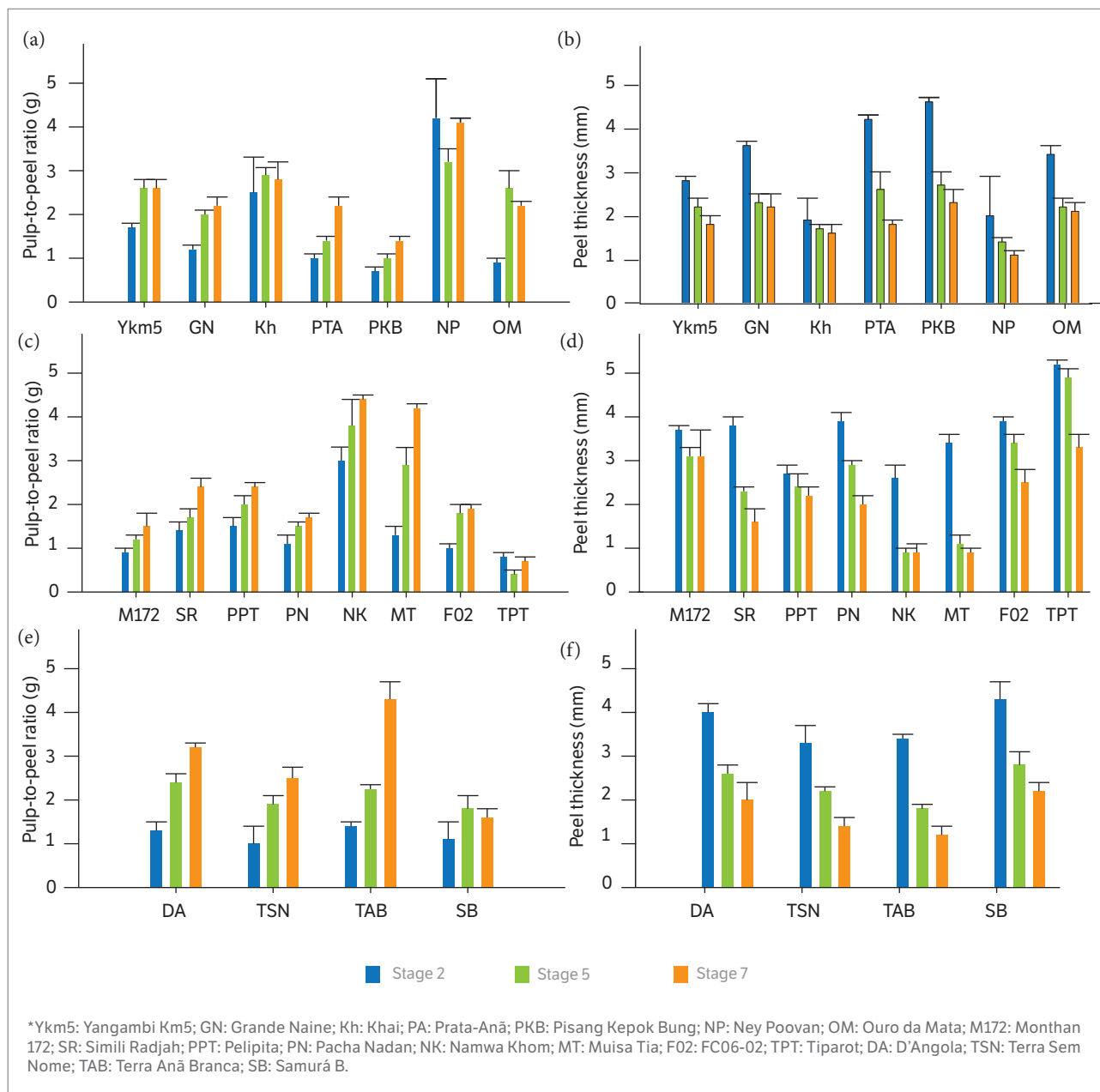
content at stages 5 and 7 (Figs. 4d and 4f). The total flavonoids contents varied widely among the analyzed genotypes (Figs. 4d, 4e and 4f). In all the genotypes of bananas, there was a wide variation of the flavonoids content. Plantains presented the lowest contents of these compounds (Fig. 4f) and high values of total flavonoids were found in dessert bananas (e.g., 'Ney Poovan') (Fig. 4d) and nonplantains bananas ('Pelipita' and 'Tiperot') (Fig. 4e). Among the plantains, 'Terra Sem Nome' showed the

highest total flavonoids values in stage 2 (green fruit) (Fig. 4f). In addition, there are genotypes with superior quantities of flavonoids, when compared to the most commercialized genotypes (e.g., dessert bananas 'Grande Naine' and 'Prata-Anã' and the plantain 'D'Angola'). This result is interesting for the promotion and incorporation of genotypes (e.g., 'Ney Poovan', 'Pelipita' and 'Tiparot') with superior contents of these bioactives or even for the use in programs of genetic improvement of the culture. In

addition, the dessert genotype 'Ney Poovan' also showed the highest pulp-to-peel ratio, interesting result for the promotion of this genotype for *in natura* consumption (Fig. 6a). The pulp-to-peel ratio varied among the genotypes and among the ripening stages (Figs. 6a, 6c and 6e). During the ripening, this relation showed variations, which resulted in a higher pulp yield (Aquino et al. 2017). In general, there was a decrease of the peel thickness during the fruit ripening (Figs. 6b, 6d and

6f). In addition, the increase of the pulp-to-peel ratio can be attributed to the migration of water from peel to the pulp because of the osmotic gradient, due to the increase of the sugar contents in the pulp, in relation to the peel (Aquino et al. 2017). In dessert banana genotype, the lower values of the pulp-to-peel ratio (highest peel thickness values) were verified in 'Pisang Kepok Bung', 'Khai', 'Grande Naine' and 'Yangambi Km5' (Figs. 6a and 6b). The genotype 'Ney Poovan' showed the highest

→



**Figure 6.** Pulp-to-peel ratio and peel thickness at ripening stages 2, 5 and 7 in the post-harvest ( $20 \pm 2^\circ\text{C}$  and  $\text{RH } 85 \pm 2\%$ ) of the *Musa* spp. genotypes, separated by subgroup and or consumption mode (a and b) dessert bananas, (c and d) nonplantain cooking and (e and f) plantain. Stage 2 - all green; stage 5 - yellow with green ends; and stage 7 - yellow with brown areas.

pulp-to-peel ratio and, consequently, highest pulp yield. In nonplantain cooking bananas, 'Namwa Khom' and 'Muisa Tia' presented the highest values (Figs. 6c and 6d). The pulp yield is an important quality parameter for the industry and *in natura* consumption.

## CONCLUSION

Higher contents of the SS, dry weight, firmness, carotenoids and vitamin C were found in plantain subgroup. Among all the genotypes, 'Samurá B' (plantain) and 'Pelipita' (nonplantain cooking) showed the highest firmness and both genotypes (green or ripe) are promising for the industrial use, mainly for the processing of banana chips. Plantains and/or nonplantain cooking bananas contain high carotenoids values, while dessert genotype (the most consumed worldwide) contain lowest amounts of these bioactives and present a strong correlation with the pulp color intensity (\*C). High vitamin C contents are verified in plantains (AAB) and dessert banana 'Prata-Anã' (AAB), mainly in the ripe fruit. The dessert banana 'Ney Poovan' contain high SS content, pulp-to-peel ratio and flavonoid content, an interesting result for the promotion of this genotype for *in natura* consumption. Our result leads us to suggest the promotion and incorporation of these genotypes in programs of genetic improvement of the culture and/or incorporation inside the existent agricultural systems.

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## AUTHORS' CONTRIBUTION

Conceptualization, Borges C.V. and Lima G. P. P.; Methodology, Borges C. V., Lima G. P. P., Minatel I. O. and Leonel M.; Sending samples (Accessions), Amorim E. P.; Laboratory tests, Borges C. V., Belin M. A. F., Gomez H. A. G. and Santos T. P. R.; Statistical analyses, Borges C. V., Ledo C. A. S., Almeida S. L., Writing – Review and Editing, Borges C. V. and Lima G. P. P.; Supervision, Lima G. P. P.

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