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Postharvest quality of apples from 'Maxi Gala' trees grafted on different rootstocks

Qualidade pós-colheita de frutos de macieira 'Maxi Gala' sobre diferentes porta-enxertos

Mariuccia Schlichting De Martin[1*] (ORCID 0000-0002-6857-5594), Tiago Afonso de Macedo[2] (ORCID 0000-0003-3474-3681), Cristiano André Steffens[3] (ORCID 0000-0003-0936-8656), Cristina Soethe[3] (ORCID 0000-0002-1828-617X), Angélica Schmitz Heinzen[3] (ORCID 0000-0003-2558-9336), Leo Rufato [3] (ORCID 0000-0001-9545-7035)

[1]Empresa de Pesquisa Agropecuária e Extensão Rural de Santa Catarina, São Joaquim, SC, Brasil. * Author for correspondence: mariucciamartin@epagri.sc.gov.br
[2]Agromillora, Lages, SC, Brasil.
[3] Universidade do Estado de Santa Catarina, Lages, SC, Brasil.

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ABSTRACT

This study analyzed the effect of rootstocks G.213, M.9 and Marubakaido with M.9 interstem of 30 and 20 cm (MB/M.9-30cm and MB/M.9-20cm) on postharvest quality, mineral composition and functional properties of 'Maxi Gala' apples. The evaluations were performed using fruits from a commercial orchard in Vacaria, RS, Brazil. Fruits were stored for 135 and 147 days in the 2014/2015 and 2015/2016 seasons, respectively, and analyzed one day after harvest and after cold storage (1.0±0.2 °C) followed by seven days in ambient condition. The mineral composition of fruits showed small and inconsistent differences between rootstocks. The MB/M.9-20cm provided higher total antioxidant activity and levels of total phenolic compounds in fruit peel than MB/M.9-30cm. For 2014/2015 season, soluble solids content at harvest was higher in fruits from trees with G.213 rootstock, not differing only from MB/M.9-30cm. In the 2015/2016 season, G.213 and M.9 provided higher soluble solids content after storage than MB/M.9-30 cm and MB/M.9-20cm. G.213 rootstock anticipated fruit maturity compared to M.9 in 2014/2015 season. At harvest and after cold storage, other quality attributes of 'Maxi Gala' apples were similar between rootstocks G.213, M.9 and Maruba with M.9 interstem of 30 and 20cm.

KEYWORDS: *Malus domestica*, storage, maturity, functional properties, mineral composition.

RESUMO

Este estudo analisou o efeito dos porta-enxertos G.213, M.9 e Marubakaido com filtro de M.9 de 30 e 20cm (MB/M.9-30cm e MB/M.9-20cm) sobre a qualidade pós-colheita, composição mineral e propriedades funcionais de maçãs 'Maxi Gala'. Os experimentos foram conduzidos utilizando frutos provenientes de um pomar comercial localizado em Vacaria, RS, Brasil. Os frutos foram armazenados por 135 e 147 dias nas safras 2014/2015 e 2015/2016, respectivamente, e analisados um dia após a colheita e após armazenamento refrigerado (1,0±0,2°C) seguido por sete dias em condição ambiente. A composição mineral dos frutos apresentou diferenças pequenas e pouco consistentes entre porta-enxertos. O MB/M.9-20cm proporcionou atividade antioxidante total e teores de compostos fenólicos totais mais elevados na casca dos frutos comparativamente ao MB/M.9-30cm. Para a safra 2014/2015, o teor de sólidos solúveis na colheita foi mais elevado nos frutos provenientes de plantas com porta-enxerto G.213, não diferindo apenas do MB/M.9-30cm. Na safra 2015/2016, o G.213 e o M.9 proporcionaram maior teor de sólidos solúveis após a armazenagem em comparação ao MB/M.9-30cm e MB/M.9-20cm. O porta-enxerto G.213 antecipou a maturação dos frutos em comparação ao M.9 na safra 2014/2015. Os demais atributos de qualidade de maçãs 'Maxi Gala', na colheita e após o armazenamento, foram similares entre porta-enxertos G.213, M.9, MB/M.9-30cm e MB/M.9-20cm.

PALAVRAS-CHAVE: *Malus domestica*, armazenamento, maturação, propriedades funcionais, composição mineral.

INTRODUCTION

Rootstocks are commonly used in apple (*Malus domestica* Borkh.) orchards for several purposes, including controlling plant vigor, providing resistance to pests and diseases, favoring adaptation to different soil conditions, improving fruit quality, inducing tree precocity (flowering and cropping in the early years) and increasing yield performance. The decision of which rootstock to use in an orchard varies according to the region of cultivation and with several factors inherent to the orchard and management conditions (PETRI & LEITE 2008, DENARDI et al. 2015b)

Worldwide, apple tree cultivation has a large number of rootstocks. However, few rootstocks are used commercially in Brazil, with Marubakaido (Maruba), M.9 and the combination Maruba with M.9 interstem prevailing. The most widely used rootstock in southern Brazil for high planting density is M.9 dwarfing rootstock due to its strong control over plant size, early production, high yield, and good fruit quality (DENARDI et al. 2015a). However, M.9 has poor anchorage and is susceptible to wooly apple aphid (WAA) (DENARDI et al. 2015b). On the other hand, Maruba rootstock is resistant to root rot (*Phythophtora cactorum*) and to WAA, with high adaptation to different soil conditions (PASA et al. 2016). However, this rootstock is classified as vigorous, making the management of the orchard more difficult (ROBINSON 2011).

The combination of Maruba rootstock with M.9 dwarfing interstem (commonly known as “filter”) has enabled to increase the density of orchards, being an alternative to reduce excessive vegetative growth (PETRI & LEITE 2008, DENARDI et al. 2015a). This approach has given intermediate vigor, but often, as the the tree ages, excessive vigor becomes a problem. Besides, this combination has some other disadvantages, such as the incidence of WAA in the susceptible interstem (M.9) and higher plant cost (ROBINSON 2011, PASA et al. 2016). In this sense, it is essential to identify alternative rootstocks to those traditionally used by apple growers in southern Brazil.

Among rootstocks recently developed worldwide, those of the American Geneva® series have several agronomic characteristics required for use in Brazil (DENARDI et al. 2015b). Among these, resistance to the main soil diseases and pests, absence of root suckers and burrknots, control of vegetative growth, induction of tree precocity, high sustained yields and excellent fruit quality (ROBINSON 2011, FAZIO et al. 2013, DENARDI et al. 2015b). ‘G.213' is a dwarfing rootstock from Geneva® series that provides a good number of lateral branches, with wide crotch angles, as well as good fruit size, being among those recommended by research for commercial use in Brazil (DENARDI et al. 2015a, DENARDI et al. 2016, MACEDO et al. 2018, MACEDO et al. 2019, RUFATO et al. 2019).

In apple culture, rootstocks can affect attributes associated with maturity and fruit quality, especially during postharvest, such as size, color, flesh firmness, titratable acidity (AT), soluble solids (SS) content, and incidence of physiological disorders (CORRÊA et al. 2012, DENARDI et al. 2016, PASA et al. 2016). Despite this, few studies compare rootstocks, especially those of the Geneva® series, regarding the quality and storage potential of fruits produced in Brazil.

Mineral concentrations in apples, a factor directly associated with quality, may also vary according to the rootstock since they directly interfere with the absorption of water and nutrients (MARTÍNEZ-BALLESTA et al. 2010, CORRÊA et al. 2012, NAVA et al. 2018). Furthermore, mineral composition of fruits is associated with the ability to store and maintain texture, and the incidence of physiological disorders that depreciate the quality of apples (MIQUELOTO et al. 2011, AMARANTE et al. 2012, CORRÊA et al. 2012). In addition, according to some authors, functional properties of fruits, such as antioxidant capacity and total phenolic compounds, can also be affected by the rootstock (REMORINI et al. 2008, KVIKLYS et al. 2014, MILOŠEVIĆ et al. 2019).

This work aimed to evaluate the effect of rootstocks G.213, M.9, and Marubakaido with M.9 interstem of 20 and 30 cm on postharvest quality, mineral composition, and functional properties of 'Maxi Gala' apples.

MATERIAL AND METHODS

In 2014/2015 and 2015/2016, an experiment was carried out with 'Maxi Gala' apples from a commercial orchard located in Vacaria, Rio Grande do Sul State, southern Brazil. (28° 24' 93 "S latitude, 50° 54' 12" W longitude and 930 m altitude). The experimental area was established in the winter of 2011 in a new area (virgin soil), previously corrected and fertilized according to the recommendation for apple tree culture. In this area, there was a grain production crop. However, fruit species had not previously been cultivated. Using the Tall Spindle planting system, the trees were spaced at 4.0 m between rows and 1.0 m between plants, with a density of 2,500 plants per hectare. The Fuji cultivar was used as a pollinator in a 4:1 ratio. The orchard used in the experiment was covered with a black hail protection net.

The climate of Vacaria is mesothermal humid (Cfb) according to the Köppen-Geiger classification, i.e, temperate climate constantly humid, without dry season, and cool summer. The average monthly temperature ranges from 11.4 ºC to 20.6 ºC, and the average monthly precipitation varies from 101 to 174 mm (PEREIRA et al. 2009). The average number of chilling hours (CH) below 7.2 ºC is 759 CH from May to

September, based on data from the 1983/2009 period (CARDOSO et al. 2012).

There is a predominance of typical dystrophic Latossolo Bruno (oxisol), in the region. They are deep, well-drained soils, with high clay contents, marked acidity and low reserve of nutrients for plants, predominant mineralogy of kaolinite, iron, and aluminum oxides, and a high content of organic matter (EMBRAPA 2006).

The treatments consisted of four rootstocks: G.213, M.9 and Marubakaido with M.9 interstem of 30 and 20 cm in length (MB/M.9-30 cm and MB/M.9-20 cm). Trees were arranged in a randomized complete block design with five replicates of ten trees each. The sample unit consisted of 60 fruits.

Fruits were analyzed one day after harvest, and after cold storage (1.0 ± 0.2 °C and RH of 92 ± 2%), followed by another seven days in ambient conditions (23 ± 0.3 °C and RH 68 ± 0.6%), simulating the marketing period. Fruits were stored for 135 and 147 days in the 2014/2015 and 2015/2016 seasons, respectively. Before being stored, fruits with defects or low caliber were eliminated.

The attributes evaluated at harvest were fruit weight, diameter, red color index (RCI), skin color, starch index, flesh firmness, SS, TA, incidence and severity of physiological disorders, mineral composition, total phenolic compounds (TPC), total antioxidant activity (TAA; by the DPPH and ABTS methods) and total anthocyanins (TAN) in the fruit peel. In addition, after storage, flesh firmness, SS, TA, skin color and incidence of physiological disorders and decay were evaluated. All evaluations were carried out in both years of the experiment, with the exception of TPC, TAA and TAN, which were evaluated only in the 2015/2016 season.

The fruit weight of fruits was measured in grams, with the aid of an electronic scale and the diameter with a digital caliper. The starch index was determined by comparing the browning of the peduncular half of the fruits treated with iodine solution, with a scale of 1 to 5, where the index 1 indicates the maximum starch content (immature fruit) and the index 5 represents fully hydrolyzed starch (ripe fruit).

The red color index (RCI) was determined through subjective analysis of the surface of the fruits covered with red coloring, with grades from 1 to 4 being attributed to the percentages of the red-pigmented fruit surface from 0–25, 26–50, 51–75 and 76–100%, respectively.

The color of the peel was determined with an electronic colorimeter model CR 400 (Konica Minolta®, Tokyo, Japan) in terms of hue angle values (*h*º), lightness (L*) and chroma (C*). The readings were performed in the regions of red color (more red side) and background color of the fruit (less red side).

Flesh firmness (N) was determined in the equatorial region of the fruits, at opposite points, after removing a small portion of the peel, with the aid of an electronic penetrometer (GÜSS Manufacturing Ltd, Cape Town, South Africa) equipped with a 11.0 mm diameter tip.

The TA values (% malic acid) were obtained by diluting a 10 mL sample of juice (obtained by processing the fruits in a centrifuge) in 90 mL of distilled water, followed by titration with 0.1 N NaOH to pH 8.1. An automatic titrator TitroLine® Easy from SCHOTT Instruments (Mainz, Germany) was used to titrate the samples. The levels of SS (ºBrix) were determined in a digital refractometer model PR201α (Atago®, Tokyo, Japan), using an aliquot of the juice obtained for the quantification of TA.

For the quantification of TPC and TAA, fruit flesh extracts were obtained using a 5 g sample of processed flesh using a mixer. The sample was homogenized with 10 mL of 50% methanol (Synth, Diadema, Brazil), and placed for 60 min at room temperature and then centrifuged in an Eppendorf centrifuge model 5810R (Hamburg, Germany) at 10,000 rpm for 20 min at 4 °C. The supernatant was filtered in a 25 mL volumetric flask. From the residue of the first extraction, 10 mL of 70% acetone (Synth, Diadema, Brazil) was added, homogenized and placed at rest for 60 min at room temperature. After this period, it was again centrifuged at 10,000 rpm for 20 min at 4 °C. The supernatant was transferred to the volumetric flask (containing the first supernatant) and the volume was made up to 25 mL with distilled water. Extracts were reserved for TPC and TAA analysis.

The determination of TPC was performed using the reagent Folin-Ciocalteau. The standard curve was obtained with gallic acid (BIOTEC, Pinhais, Brazil), in concentrations of 0, 10, 30, 50, 70, 90 and 100 ppm. For analysis, 2.5 mL of Folin-Ciocalteau (SIGMA ALDRICH, St. Louis, USA) (1: 3), 0.5 mL of diluted sample (1:20) and 2.0 mL of the carbonate solution were added sodium 10% (Vetec, Duque de Caxias, Brazil). The tubes were vortexed and incubated for one hour in the dark. The reading was performed at a wavelength (λ) of 765 nm in a microplate reader, model EnSpire (PerkinElmer, USA). Results were expressed in mg of gallic acid equivalents (GAE) per 100 g of fresh weight.

The determination of TAA was based on the extinction of the absorption of the radicals DPPH (2,2-diphenyl-1-picryl hydrazyl) and ABTS (2,2-azinobis-3-ethylbenzothiazolin-6-sulfonic acid). The DPPH method was analyzed according to RUFINO et al. (2007b). In a dark environment, 100 µL of sample was pipetted and mixed with 3,900 µL of DPPH radical (SIGMA ALDRICH, St. Louis, USA) in 15 mL tubes with a lid. Tubes were shaken and left to react for 30 minutes. The readings were performed at a wavelength (λ) of 515 nm, and the results were expressed in µg of Trolox equivalent per 100 g^{-1} of fresh weight. The ABTS method was analyzed as described by RUFINO et al. (2007a) with adaptations. In a dark environment, 30 µL of the sample was pipetted and mixed with 3,000 µL of ABTS radical (SIGMA ALDRICH, St. Louis, USA). A new reading was performed after a six-minute reaction at a wavelength (λ) of 734 nm, and the results were expressed in µg of Trolox equivalent per 100 g^{-1} of fresh weight.

The determination of total anthocyanins was performed according to a methodology adapted by FULEKI & FRANCIS (1968). First, 5.0 g of peel sample was used, added to 15 mL of ethanol/distilled water (95: 5, v/v) acidified in the proportion 85:15 (v/v), ethanol/acid, with hydrochloric acid (HCl, 1.5 N). Samples were homogenized in ultraturrax model D-91126 (Schwabach, Germany), maintained for 24 h at 4 °C, and sent for centrifugation at a temperature of 4 °C, for 20 minutes at 12,000 rpm. After, 2.0 mL of the supernatant was transferred to a volumetric flask and made up to 50 mL with the extracting solvent. The readings were performed on a spectrophotometer at a wavelength of 535 nm. TAN was expressed in mg cyanidin 3-glucoside per 100 g^{-1} of fresh weight.

For the mineral analysis, samples of peel and flesh were obtained in the distal portion of the fruits (blossom end). Only the distal region of the fruits was used since it has the lowest Ca concentrations in apples, where the symptoms of bitter pit usually occur and, therefore, is the most recommended for the evaluation of mineral elements associated to the risk of occurrence of this disorder (MIQUELOTO et al. 2011). Sample processing was performed with the aid of a Braun Multiquick MR40 mixer. First, the levels of the minerals Ca, K, P, Mg and N (mg kg^{-1} of fresh weight) were determined. Then, samples were solubilized with concentrated sulfuric acid and 30% hydrogen peroxide and subjected to heating at 150 °C for 2 hours. After digestion, dilutions were made to determine the K, Ca and Mg elements using the atomic absorption spectrophotometer (SCHVEITZER & SUZUKI 2013), model Analyst 200, from the PerkinElmer® brand (Waltham, USA). Next, the phosphorus content was determined by the molybdate/vanadate method in an acid medium, and the concentration was determined by reading on a UV-VIS spectrophotometer (Varian®, Palo Alto, USA), at 420 nm (SCHVEITZER & SUZUKI 2013). N concentrations were determined using the Kjeldahl semi-micro method, as described by TEDESCO et al. (1995). After the determinations, the following relationships between nutrients were also calculated: N/Ca, K/Ca and K + Mg/Ca.

The physiological disorders assessed at harvest were sunburn incidence (%) and russeting severity (cm^2 $fruit^{-1}$). After storage, the incidence (%) of cracking, flesh browning and bitter pit were also evaluated. Finally, the incidence of decay was evaluated by counting the affected fruits, internally and externally, with lesions larger than 5 mm in diameter caused by pathogens.

All measurements were subjected to analysis of variance (ANOVA), and percentage data were transformed by the formula arcsin $[(x + 0.5) / 100]^{1/2}$ before being submitted to analysis of variance. The Tukey test ($p < 0.05$) was used to compare averages. The SAS statistical program (SAS Institute, Cary, NC, USA) was used for these procedures.

RESULTS AND DISCUSSION

No differences between the rootstocks evaluated were found for both years studied for fruit weight and diameter attributes. This data corroborates those found by MACEDO et al. (2019), who also found no differences between rootstocks G.213 and M.9 for fruit weight and diameter in four harvests evaluated with the Fuji Suprema cultivar. Furthermore, the color attributes of the fruits (RCI, L*, C* and *h*º) were not affected by the rootstock, in both years evaluated (data not shown). The similarity observed between treatments may be related to the apple clone 'Gala' used in the present work, since the 'Maxi Gala' presents an intense red color in the peel, with a large percentage of the skin covered by red (WEBER et al. 2013).

For the 2014/2015 season, the starch index at harvest was higher in fruits from trees with rootstocks MB/M.9-30 cm and G.213 compared to those from trees with 'M.9', not differing, however, from fruits of trees on MB/M.9-20 cm (Figure 1). In the 2015/2016 season, there was no difference between rootstocks for the starch index.

In the 2014/2015 season, fruits from plants with M.9 showed higher flesh firmness at harvest compared to fruits from G.213, not differing from the other treatments (Figure 1). However, there were no differences between rootstocks for fruit flesh firmness after cold storage. In the 2015/2016 season, the fruit flesh firmness did not differ between the rootstocks evaluated at harvest and after storage.

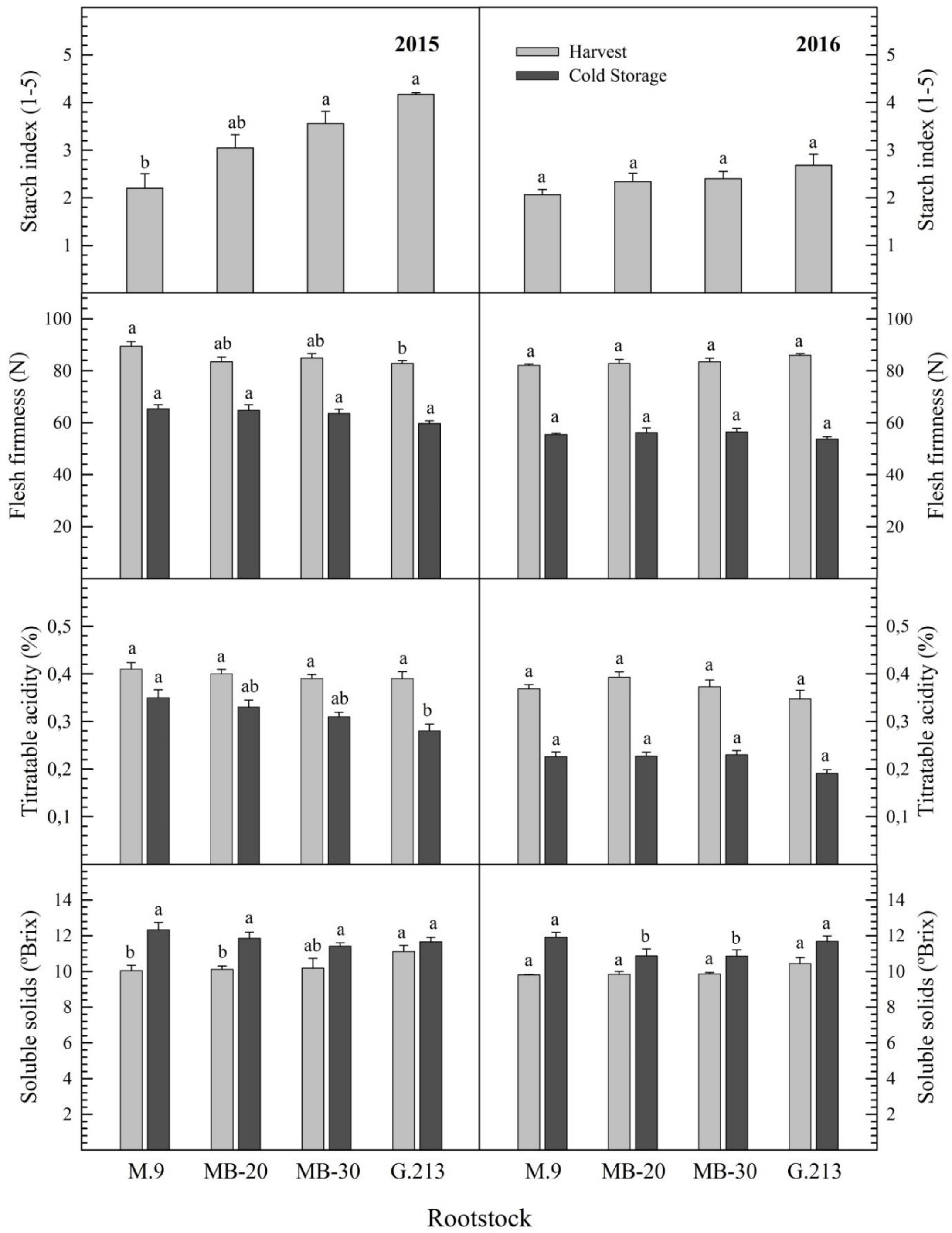

Figure 1. Starch index, flesh firmness, titratable acidity and soluble solids of 'Maxi Gala' apples grafted on different rootstocks in Vacaria, Rio Grande do Sul State, Brazil and evaluated in two consecutive seasons. Fruits were evaluated one day after harvest and after 135 days of cold storage (1.0 ºC) followed by another seven days in ambient condition (23 ºC). Means followed by distinct letters, between columns of the same color, differ by the Tukey test (p <0.05).

In the 2014/2015 season, G.213 rootstock provided a more advanced maturity stage at harvest than M.9, giving the fruits lower flesh firmness and a higher starch index. However, this same result was not observed for the 2015/2016 season. Working with 'Imperial Gala' and 'Fuji Mishima' apple cultivars during four seasons in the São Joaquim region, SC, Brazil, PASA et al. (2016) observed that the rootstock did not consistently influence the attributes of starch index and flesh firmness of fruits at harvest over the years.

In the 2014/2015 season, immediately after harvest, the TA of the fruits did not differ between rootstocks (Figure 1). However, fruits from trees with M.9 showed higher TA after storage than fruits from trees with G.213, not differing from Maruba with interstem of 30 and 20 cm. This result may be related to fruit maturity at harvest, as the starch index and flesh firmness indicated that G.213 was at a more advanced maturity stage compared to M.9 in this season. Organic acids content tends to decrease with the maturity of fruits due to its use as a substrate in the respiratory process or its conversion into sugars. In the 2015/2016 season, the TA of the fruits was not influenced by the rootstock, both at harvest and after storage.

For the 2014/2015 season, the SS content in the harvest was higher in fruits from trees grafted on G.213, not differing only from MB/M.9-30 cm (Figure 1). After storage, there were no differences between treatments. In the 2015/2016 season, the SS content was not influenced by the rootstock immediately after harvest. However, G.213 and M.9 provided fruits with a higher SS content after storage compared to Maruba with interstem of 30 and 20 cm.

For 'Imperial Gala' and 'Fuji Mishima' apple cultivars evaluated during four seasons, in the São Joaquim region, the SS content, in general, was higher in fruits from trees with less vigorous rootstocks (PASA et al. 2016). For Fuji cultivar, CORRÊA et al. (2012) found that the Maruba rootstock with M.9 interstem provided fruits with a higher SS content after storage under controlled atmosphere compared to Maruba without interstem. This may explain, at least in part, the differences observed in the present study, since Maruba with M.9 interstem of 30 or 20 cm is about twice as vigorous as G.213 and M.9 rootstocks (MACEDO 2018). Less vigorous rootstocks provide better light interception due to a better canopy architecture, which can optimize the photosynthetic rate and increase the accumulation of carbohydrates in the fruits due to the lower demand for photoassimilates for the growth of branches and leaves.

For the 2014/2015 season, no differences were observed for the concentrations of minerals N, P, K and Mg, both in the peel and in fruit flesh (Table 1). The Ca concentrations in peel did not differ between the rootstocks evaluated. In the flesh, M.9 provided higher Ca contents compared to MB/M.9-30 cm. However, it did not differ from other treatments. The N/Ca and K/Ca ratios in the skin and flesh did not differ between the rootstocks evaluated. G.213 provided higher K + Mg/Ca ratios in the fruit peel than M.9, not differing from Maruba with M.9 interstem (20 or 30 cm). The K + Mg/Ca ratio in the flesh was not influenced by the rootstock.

Table 1. Concentrations of minerals N, P, K, Ca and Mg (mg kg^{-1} of fresh weight) and values of N/Ca, K/Ca and K + Mg/Ca ratios in the peel and flesh of fruits from 'Maxi Gala' apple grafted on different rootstocks in Vacaria, Rio Grande do Sul State, Brazil, evaluated in two consecutive seasons.

Porta-enxerto	N	P	K	Ca	Mg	N/Ca	K/Ca	K+Mg/Ca
				2014/2015 Season				
				Peel				
M.9	1073.5	247.8	1764.1	126.5	162.7	8.7	14.0	15.3 b
MB/M.9-20	1109.5	272.8	1892.0	121.5	191.4	9.3	15.8	17.4 ab
MB/M.9-30	1085.4	273.9	1957.6	107.4	171.9	10.2	18.5	20.1 ab
G.213	1111.0	280.4	2062.4	106.5	191.4	10.6	19.9	21.6 a
CV (%)	10.3	7.5	13.0	16.2	27.5	12.2	16.7	16.2
				Flesh				
M.9	415.0	144.3	896.7	38.5 a	32.0	10.9	23.9	24.8
MB/M.9-20	363.1	141.9	1123.6	34.9 ab	41.9	10.6	32.3	33.5
MB/M.9-30	465.5	142.5	1054.4	32.2 b	39.0	14.5	32.7	33.9
G.213	455.9	141.8	1159.4	36.9 ab	42.8	12.4	31.6	32.8
CV (%)	17.5	6.7	20.6	8.9	18.1	21.7	22.4	22.2
				2015/2016 Season				
				Peel				
M.9	1279.1 ab	413.5 a	1674.3	148.6	327.2	8.6 ab	11.3	13.5
MB/M.9-20	1177.1 b	363.6 b	1595.8	145.7	311.4	8.1 b	11.0	13.1
MB/M.9-30	1246.9 ab	350.5 b	1628.2	142.2	346.2	8.8 ab	11.5	13.9
G.213	1365.2 a	331.4 b	1539.8	138.5	314.6	9.9 a	11.3	13.6
CV (%)	5.0	5.3	6.6	7.7	6.4	9.8	12.2	11.3
				Flesh				
M.9	420.9 ab	120.4	932.3	46.7	41.7 b	9.1	20.3	21.2
MB/M.9-20	383.4 b	136.5	881.6	46.2	42.3 b	8.4	19.3	20.2
MB/M.9-30	449.5 a	142.2	930.8	51.1	46.7 b	8.9	18.7	19.6
G.213	467.9 a	131.1	1011.6	49.1	61.6 a	9.5	21.1	22.4
CV (%)	5.9	19.1	10.0	11.0	11.9	12.9	18.2	17.9

Means followed by different lowercase letters in the columns differ by the Tukey test ($p < 0.05$). ns: not significant. CV: Coefficient of variation.

In the 2015/2016 season, the N levels were higher in the peel of the fruit of tress grafted on G.213 compared to MB/M.9-20 cm, not differing from the other treatments (Table 1). In the flesh, MB/M.9-20 cm showed lower concentrations of N than MB/M.9-30 cm and G.213. The P concentrations in the peel were higher for M.9 rootstock compared to the others. However, no differences were observed for the P content in the fruit flesh. The levels of Ca and K in the peel and flesh were similar among the rootstocks evaluated. The Mg content did not differ in the fruit peel. However, it was higher in the fruit flesh of trees grafted on G.213 compared to the others. The N/Ca ratios were higher in peel of fruit of trees grafted on G.213 compared to MB/M.9-20 cm, not differing from other treatments. The other mineral relationships were not affected by the rootstock, both in the peel and in the flesh.

There is no consensus in the literature about how mineral content of apples is influenced by the rootstock. Some authors suggest that less vigor rootstocks are able to direct more nutrients to the fruits due to the less competition provided by the vegetative growth (REMORINI et al. 2008, CORRÊA et al. 2012). However, NAVA et al. (2018), working with 14 apple rootstocks in two consecutive years, observed that the Ca content in the fruits was not influenced by the rootstock, and the levels of nutrients such as N, P, K and Mg showed different behavior for rootstocks depending on the season. Few consistent differences were observed for mineral contents in the two years evaluated for the present study.

For the TAN content in the peel, there was no difference between the rootstocks evaluated (Figure 2). The levels of TPC in the peel were higher for rootstocks M.9 and MB/M.9-20 cm compared to MB/M.9-30 cm, not differing, however, from G.213. For the fruit flesh, rootstocks did not influence the levels of TPC. The TAA, measured by the DPPH method, was lower in the peel of the fruits of trees with rootstock MB/M.9-30 cm compared to MB/M.9-20 cm, not differing from the other rootstocks. For the ABTS method, the TAA in the peel was also higher in the fruits of trees grafted on MB/M.9-20 cm compared to MB/M.9-30 cm and G.213, not differing, however, from M.9. The TAA in the flesh did not differ between rootstocks, for both evaluation methods. The higher TAA in the peel of fruits from the MB/M.9-20 cm rootstock is possibly related to the higher TPC content, which was observed for fruits from trees with this same rootstock (Figure 2). According to STANGER et al. (2017), there is a positive correlation between the content of TPC and the TAA obtained by the ABTS and DPPH methods in apples.

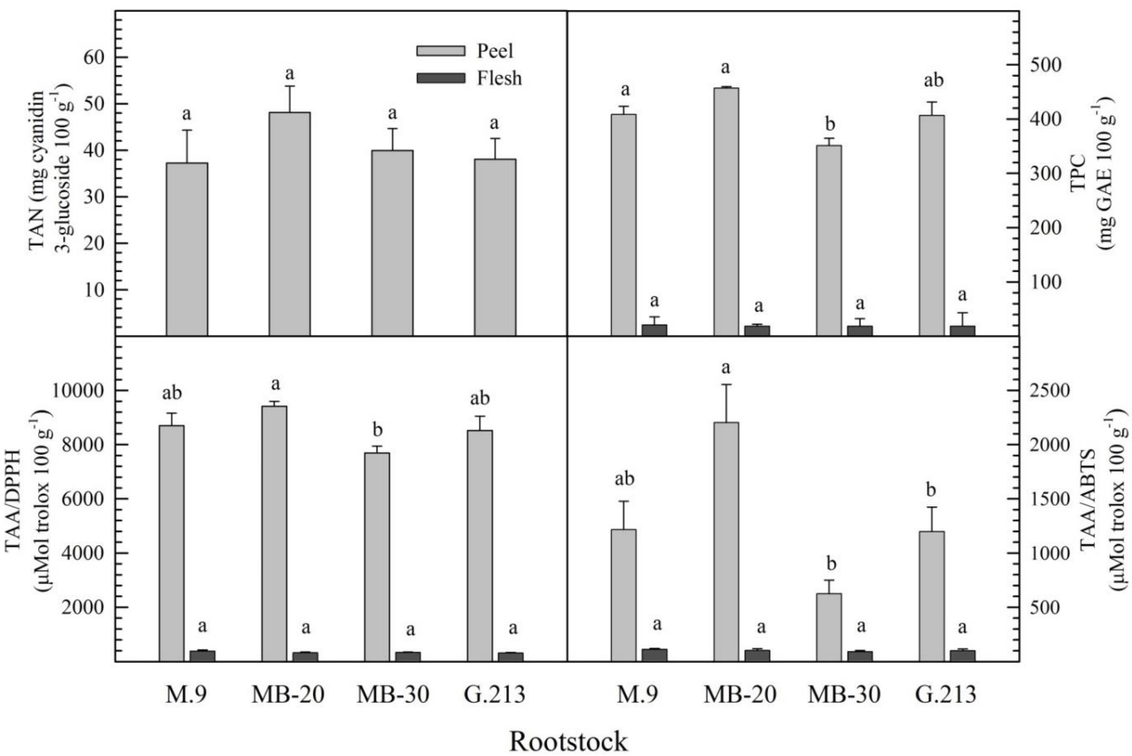

Figure 2. Total anthocyanins (TAN) in the peel of fruits and total phenolic compounds (TPC) and total antioxidant activity (TAA; by ABTS and DPPH methods) in the peel and flesh of 'Maxi Gala' apples grafted on different rootstocks in Vacaria, Rio Grande do Sul State, Brazil, evaluated after harvest in the 2015/2016 season. Means followed by distinct letters, between columns of the same color, differ from each other by the Tukey test (p <0.05).

In a study with eleven different apple rootstocks and separated according to vigor in three categories, KVIKLYS et al. (2014) observed that, although there are differences both in the profile of phenolic compounds and in the TPC of fruits, there were no clear differences between the groups of super-dwarfing, dwarfing and semi-dwarfing rootstocks. Working with the peach culture, REMORINI et al. (2008) observed that ascorbic acid, b-carotene and TAA and TPC levels were influenced by the rootstock used. However, according to the authors, it was impossible to establish a relationship between the observed behavior and the rootstock vigor, and rootstocks of similar vigor provided fruits with very different nutritional characteristics. These results indicate that the rootstock's effect on the fruits' functional compounds is associated with other factors besides the rootstock vigor.

The incidence of decay after storage was low (<1.5%), with no difference between treatments. In addition, there were no differences between rootstocks for russeting severity and incidence of bitter pit, cracking, flesh browning and sunburn in fruits, with a low incidence of these disorders (<5%) in both seasons and evaluation dates (data not shown).

Since the experiment was performed in a commercial orchard area, all the trees were managed to optimize the light entry into the canopy and improve the quality of the fruits, which may have contributed to quality attributes. Even the mineral composition and functional properties showed little difference between rootstocks. However, it is important to consider that dwarf rootstocks, such as M.9 and G.213, represent a considerable reduction in hand labor, especially in activities that are carried out to control the plant vigor, such as pruning and branch manipulation. Hand labor is currently one of the main concerns for apple growers in Brazil, since it often presents low efficiency and represents one of the highest production costs in the orchard (KVITSCHAL et al. 2019). For ROBINSON et al. (2011), the use of semi-vigorous rootstocks as in the case of MB/M.9 in southern Brazil, is still an alternative, however, these rootstocks give excessive vigor to the scion cultivar, making the management of the orchard much more difficult when compared to other available rootstocks.

MACEDO (2018) observed that 'Maxi Gala' apple cultivar on rootstocks M.9 and G.213 showed similar vigor six years after planting. However, G.213, provided higher yield and yield efficiency compared to M.9. Likewise, in a new area and in a replanting soil, MACEDO et al. (2019) comparing the dwarfs G.213 and M.9 with ‘Fuji Suprema’, verified higher cumulative yield during the first four seasons with the G.213 rootstock. According to DENARDI et al. (2016), G.213 is one of the most promising dwarf rootstocks for Gala cultivar, with high productivity and average fruit weight over the years. This rootstock can also be considered advantageous because of its precocity (MACEDO 2018), causing considerable yields in the early years after planting and allowing a faster return on invested capital.

CONCLUSIONS

Compared with M.9, G.213 rootstock can anticipate maturity of ‘Maxi Gala’ apples. G.213 rootstock favors the accumulation of SS in ‘Maxi Gala’ apples. The other quality attributes of apples at harvest and after cold storage are similar between rootstocks G.213, M.9 and Maruba with M.9 interstem of 30 and 20 cm.

Mineral composition of ‘Maxi Gala’ apples shows little variation between rootstocks G.213, M.9 and Maruba with M.9 interstem of 30 and 20 cm. The use of Maruba with M.9 interstem of 20 cm causes higher levels of TPC and TAA in fruit peel compared to the M.9 interstem of 30 cm.

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