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Mineral composition of leaves and fruits of apple 'Fuji' on different rootstocks in the region of São Joaquim-SC

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Abstract – This work evaluated the mineral composition of leaves and fruits of apple (*Malus domestica* Borkh) 'Fuji' on different rootstocks. The experiment was conducted from 2008 to 2011 in the municipality of São Joaquim (SC). The treatments evaluated rootstocks: CG.008, CG.24, CG.56, CG.058, CG.210, CG.213, CG.757, CG.814 and CG.969 of the American series Cornell Geneva (CG); JM.2 and JM.7 of the Japanese series Japan, Morioka (JM); and M.7, M.9 and M.26 of the English series, EMLA (M). The experimental design was randomized blocks with four repetitions. Annually, the leaves were collected for the chemical analysis. Only in the years 2009 and 2010, the fruit samples were collected to determine nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg). The leaf Ca content differed between rootstocks, especially for CG.213 and CG.969, which presented a higher content of the nutrient. However, there were no differences between rootstocks in terms of Ca content in the fruit, which confirms the low ratio between the contents in leaves and fruits. Ratios between nutrients, mainly (K+Mg)/Ca, are more sensitive to the Ca content to discriminate groups of rootstocks about possible risk of physiological disorders in the fruits.

Indexation terms: *Malus domestica*, mineral nutrition, physiological disorders, fruit quality.

Composição mineral de folhas e frutos da macieira 'Fuji' em diferentes porta-enxertos na região de São Joaquim-SC

Resumo – O trabalho objetivou avaliar a composição mineral de folhas e frutos de macieira (*Malus domestica* Borkh) 'Fuji' sobre diferentes porta-enxertos. O experimento foi conduzido durante o período de 2008 a 2011, no município de São Joaquim (SC). Os tratamentos consistiram na avaliação de 14 porta-enxertos: CG.008, CG.24, CG.56, CG.058, CG.210, CG.213, CG.757, CG.814 e CG.969 da série americana Cornell Geneva (CG); JM.2 e JM.7 da série japonesa Japan, Morioka (JM); e M.7, M.9 e M.26 da série inglesa, EMLA (M). O delineamento experimental foi em blocos ao acaso, com quatro repetições. Anualmente, foram coletadas as folhas para a análise química. Apenas nos anos de 2009 e 2010, as amostras de frutos foram coletadas para determinação de nitrogênio (N), fósforo (P), potássio (K), cálcio (Ca) e magnésio (Mg). O teor foliar de Ca diferiu entre porta-enxertos, com destaque para CG.213 e CG.969, os quais apresentaram maior teor do nutriente. Entretanto, não houve diferenças entre porta-enxertos em relação ao teor de Ca no fruto, o que confirma a baixa relação entre os teores nas folhas e nos frutos. As relações entre os nutrientes, principalmente de (K+Mg)/Ca, são mais sensíveis que o teor individual de Ca para discriminar grupos de porta-enxertos quanto ao possível risco de apresentar distúrbios fisiológicos nos frutos.

Termos para indexação: *Malus domestica*, nutrição mineral, distúrbios fisiológicos, qualidade de frutos.

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Introduction

Apple orchards in Brazil are concentrated in the southern region, mainly in the states of Santa Catarina and Rio Grande do Sul, which in 2016, accounted for roughly 96% of 1,049,251 tons produced in the country (IBGE, 2017). The plantations are composed of a combination of rootstocks M.9/Maruba and Maruba (DENARDI et al., 2015), and the latter is used mainly in the region of São Joaquim, Santa Catarina State, where soils are shallow and stony (POTTER et. Al., 2004). However, rootstock Maruba is vigorous, resulting in large canopy, which hinder the work and intensify the use of work force to carry out the cultural management practices of the apple tree. Rootstock Maruba when combined with M.9 (filter) significantly reduces the size of the plant, however, results in excessive regrowth, requiring additional work for its removal. Rootstock M.7 has intermediate vigor and has already been used; however, it is little used today due to its high susceptibility to new aphid. The dwarf and semi-dwarf rootstocks (M.9 and M.26) are also traditionally used in Brazil, with emphasis on M.9, which appears in most dense planting and in deeper soils in the regions of Vacaria-RS and Fraiburgo-SC. The increase in the density of planting, besides favoring cultural practices and production precocity, is one of the most important factors for increased productivity of apple orchards (PETRI et al., 2011). Amiri et al. (2014) observed that cultivars 'Royal Gala' and 'Golden Delicious' showed reduced vegetative growth and, consequently, greater productive efficiency when grown on dwarfing rootstock M.9 than on rootstock MM.111 (more vigorous).

Regarding agronomic characteristics, in addition to yield, the selection of new rootstocks seeks other features like balanced vigor, ease of propagation, resistance to the main pest and disease, absence of regrowth, good compatibility of grafting and scion support and efficient absorption of nutrients from the soil. Based on these and other parameters, rootstocks of American series Geneva® present as the most complete among the rootstocks recently developed worldwide (FAZIO et al., 2013; DENARDI et al., 2015). In addition, the Japanese series JM, mainly JM.2, stands out for its high yield (PASA et al., 2016). Consequently, several studies on these rootstocks have been conducted recently, focusing mainly on aspects of adaptation (DENARDI et al., 2013; DENARDI et al., 2015) and performance (PASA et al., 2016) in different regions of cultivation of Brazil.

Denardi et al. (2015) suggest the use of rootstocks CG.213 and CG.202 for areas of good soil fertility, as potential options for the formation of new orchards with the cultivar 'Fuji' and rootstock CG.213 for 'Gala'. For low fertility soils, regardless of the cultivar, rootstock CG.210 is the most indicated. Pasa et al. (2016) observed that, among six rootstocks of the Geneva series evaluated, four showed performance similar to M.9/Marubakaido (interstem) for the soil and climate conditions of São Joaquim region, which can be an advantage, since the rootstocks do not present regrowth problems, not requiring additional labor force for theirs control.

Identical cultural practices carried out in apple plants do not guarantee the same nutrient concentration in the different organs of the aerial part of the plant variety, due to the significant variations offered by the type of rootstock used (ERDAL et al., 2008); KUCUKYUMUK; ERDAL, 2011; FAZIO et al., 2013; FAZIO et al., 2015). Studies indicate that the difference in absorption of nutrients from the soil by rootstocks is not attributed only to morphological differences in the root system, but especially to its physiological activity in a given growth season, expressed by the different absorption of water and nutrients (BEN; KOSZORZ, 2005).

In Brazil, the nutritional behavior of cultivars traditionally planted, such as 'Fuji', on rootstocks of the Geneva and JM series have not yet been evaluated. The selection of rootstocks with greater capacity for absorption of nutrients is important not only to increase productivity, but also to improve the nutritional value and organoleptic quality of the fruits, as well as assist in the reduction of physiological disorders caused by deficiency of some nutrients (FALLAHI, 2012; FAZIO et al., 2015). The influence of rootstocks on concentration is even more important for nutrients that are directly related to fruit quality, such as calcium (Ca). Due to Ca association with pectic substances of the middle lamella of the cell wall and selectivity of cell membranes, appropriate Ca contents (above 40 mg kg^{-1}) are associated to the preservation of fruit quality (ARGENTA; SUZUKI, 1994; NEILSEN; NEILSEN, 2009; AMARANTE et al., 2012). However, rather than consider the individual Ca content in fruits, several studies indicate that its ratios with other nutrients, notably N, K and Mg, are more sensitive to predict the occurrence of physiological disorders in apples (ARGENTA; SUZUKI, 1994). Although different works have reported variable critical levels of relations between nutrients, in southern Brazil, it has been considered 14 and 30 as critical values for the ratios N/Ca and (K+Mg)/Ca, respectively (AMARANTE et al., 2012), above which the postharvest quality of apples would be compromised.

Therefore, in order to assist in recommending materials with more suitable agronomic characteristics, this work aimed to evaluate the influence of different rootstocks on nutrient concentrations in leaves and fruits of 'Fuji' apple tree cultivated in the region of São Joaquim-SC.

Materials and Methods

The experiment was conducted in a commercial orchard from 2008 to 2011, in São Joaquim (SC) ((28° 17' 39'' S, 49º 56' 56'' W, altitude 1415 m). The climate of the region is classified as humid (Cfb), according to Köppen, with mild summers and harsh winters. The annual average temperature is 13°C, and the average precipitation is 1,600 mm per year. Table 1 shows precipitation and temperature data during the experiment.

The orchard was established in 1999 with the cultivar 'Fuji' with 4.0 m spacing between rows and 1.5 m between plants, totaling 1667 plants per hectare. The soil of the experimental area is classified as Humic Cambisol (EMBRAPA, 2013), which was submitted to the application of lime to raise the pH up to 6.5 (saturation of bases of approximately 85%) and P and K levels considered suitable for the apple culture (greater than 24 and 120 mg kg^{-1}, respectively) at the experiment deployment. After deployment of the orchard, limestone was reapplied on the soil surface whenever the pH was below 5.5 and in quantities corresponding to ¼ of the recommended dose to raise the pH to 6.5. In 2008, in the first evaluation, the soil showed the following chemical and physical characteristics: 340, 408 and 252 g kg^{-1} clay, silt and sand, respectively; 58 g dm^{-3} of organic matter; pH 5.8 in water; 8.4 mg dm^{-3} of P and 3.15 $mmol_c$ dm^{-3} of K (both extracted by Mehlich-1); 83 $mmol_c$ dm^{-3} of Ca, 32 $mmol_c$ dm^{-3} of Mg (both extracted by KCl 1 mol L^{-1}).

The experimental design was randomized blocks consisting of 14 treatments with the same compounds of different rootstocks and with four replicates. The rootstocks evaluated were: CG.008, CG.24, CG.56, CG.058, CG.210, CG.213, CG.757, CG.814 and CG.969 of American series Cornell Geneva (CG); JM.2 and JM.7 of Japanese series Japan, Morioka (JM); and M.7, M.9 and M.26 of English series, EMLA – East Malling Long Ashton (M). Each experimental unit consisted of four useful plants. The experimental unit received the same cultural practices recommended for commercial orchards of apple cultivar 'Fuji'.

In the period from January 15 to February 15, from 2008 to 2011, samples of 40 complete leaves were collected from the median portion of the branch growth in the year and located at the average height of the plant. The leaves were oven dried at 65°C with forced air circulation for about 72 h until a constant weight of the samples was obtained. After drying, the samples were ground in a stainless steel type Wiley mill with 0.84 mm sieve. A sub-sample of 0.5 g of the crushed material was subjected to acidic digestion with nitroperchloric acid $HClO_4$ (1.0 ml) + HNO_3 (6.0 ml) at 190°C, in digester block as suggested by Tedesco et al. (1995). In the extract, it was determined the concentrations of phosphorus (P) by UV spectrophotometry (vanadate/molybdate method) and potassium (K), calcium (Ca), magnesium (Mg) by flame atomic absorption spectrometry. Nitrogen (N) was determined by the Micro-Kjeldahl method, after the digestion of 0.2 g with H_2O_2 (2 ml) + H_2SO_4 (5.0 ml).

The chemical analysis of fruits was performed only in 2009 and 2010. For that, 30 fruits per plot were collected randomly during the harvest. In the laboratory, the fruits were washed with distilled water. The subsamples comprised two longitudinal triangular slices (1 cm wide, externally) of each fruit, cut radially, including the epidermis, as proposed by Tedesco et al. (1995). These parts were ground with the aid of a processor and approximately 5 g of this material were digested with H_2O_2 (3.0 ml) + H_2SO_4 (1.5 ml) at 200°C in a digester block. In the extract, it was determined the concentrations of P by UV spectrophotometry (vanadate/molybdate method) and K, Ca and Mg by flame atomic absorption spectrometry. N was determined by the Micro-Kjeldahl method, after the digestion of 5 g with H_2O_2 (5.0 ml) + H_2SO_4 (5.0 ml) at 380°C.

The results were submitted to analysis of variance using the Statistical Program Analysis System (SAS, 2012) and, when the effects were significant, the means were grouped by the Scott-Knott test, at 5% probability.

Results and discussion

Nutrient contents in leaves

Leaf N contents in rootstocks CG.210, M.7 and M.26 were higher in the four years of assessment (Table 2). The higher N content obtained for these rootstocks may be beneficial, especially in shallow and stony soils, similar to soils in the apple-producing region of São Joaquim, SC. Proper N contents are positively associated with vigor balance of apple trees (NAVA, 2010), which may explain in part the higher yield of the apple tree grafted on M. 26 than on rootstock M.9 (PEREIRA; PASA, 2016). Denardi et al. (2015) observed among various rootstocks of the Geneva series evaluated that GC.210 demonstrated best adaptation in soils of low fertility, which could possibly be related to its greater capacity to absorb N from the soil in these conditions. Leaf N contents were always within or above the range of sufficiency considered normal (20 to 25 g kg^{-1}). When N contents were above this range, in any situation they were considered excessive (SBCS/CQFS-RS/SC, 2016). High N contents can promote imbalance of nutrients in the fruits, mainly N/Ca ratio, which is undesirable for conservation of apples (NEILSEN; NEILSEN, 2009).

Leaf P contents, regardless of the rootstock, remained in most years below the lower threshold range of sufficiency considered normal for apple trees (1.5 to 3.0 g kg^{-1}) (SBCS/CQFS-RS/SC, 2016), indicating the low efficiency of P absorption by most genotypes evaluated (Table 2). In 2008, P contents were considered insufficient (<1.10 g kg^{-1}) for rootstocks CG.56, CG.024, CG.969, CG.757, JM.2 and JM.7. Possibly, the low leaf P contents found in this cycle are associated with low nutrient content found in the soil of the experimental area (8.4 g dm^{-3}). Although the plants were fertilized with P annually during the evaluation period, the nutrient was applied onto the soil surface, which may have hindered nutrient absorption by the trees. In tropical and subtropical soils, there is a large number of adsorption sites that fix P (GUARDINI et al., 2012), preventing it from reaching soil layers where the roots are located. Nava et al. (2017) observed increase of P only in 10-20 cm layer of depth after two consecutive years of application of P doses on the soil surface cultivated with apple tree.

Rootstocks CG.56. CG.210 and JM.7 showed greater efficiency in terms of K accumulation in the leaves during the four years of assessment (Table 2). However, in all the years, rootstocks CG.969, CG.058, CG.213 and M.9 proved to be inferior to the others assessed. Fallahi et al. (2002) found higher K contents in the leaves of the cultivar 'Fuji' cultivated on rootstock M.7 in relation to the other rootstocks evaluated (M.9 and M.26), corroborating with the data obtained in this study, where rootstock M.7 also proved to be efficient in absorbing K in three of four years evaluated. Leaf K contents varied widely in different years, and in the year 2010, the lowest values were observed for most rootstocks, below the K threshold range (12 to 15 g kg^{-1}), except for rootstocks CG.814 and JM.7.

Varying K contents between years can be related to the load of fruits, since the greater the number of fruits per plant, the bigger the drain that they promote and, consequently, more K may be allocated to the fruits (ERNANI et al., 2002; NEILSEN et al., 2016). Ernani et al. (2002) observed K content in leaves of apple trees below the proper range in years of high production, despite the high nutrient content in the soil (above 500 mg kg^{-1}). In addition, the lower contents found in leaves collected in January 2010 may be related to lack of humidity, due to lower precipitation (91.6 mm) during the month of December of the previous year (Table 1). Proper K contents are directly associated with fruit size (NAVA; DECHEN, 2009).

Except for the year 2009, leaf Ca contents were influenced by the rootstock (Table 2). Ca is considered an important nutrient in the production system of apples, as it is directly related to quality and potential for storage of fruits (AMARANTE et al., 2010; MIQUELOTO et al., 2011). Among the rootstocks evaluated, CG.969 and CG.213 stood out with higher Ca contents in leaves in three of the four years of assessment. In the year 2008, Ca leaf concentration was 20.7 and 19.3 g kg^{-1} for rootstocks CG.969 and CG.213, respectively. These values are greater than levels considered suitable for apple trees (11 to 17 g kg^{-1}).

Table 1. Monthly and annual temperature averages (Temp. and AAT) and monthly and annual rainfall (Rainfall and TAR) over the years of the experiment (2008 to 2011).

Month	2008		2009		2010		2011	
	Temp. (ºC)	Rainfall (mm)	Temp. (ºC)	Rainfall (mm)	Temp. (ºC)	Rainfall (mm)	Temp. (ºC)	Rainfall (mm)
January	16.5	196.6	15.9	193	18.3	205.3	16.5	147.8
February	16.2	177.2	14.2	109.2	17.6	354.0	18.6	198.1
March	16.9	115.5	18.7	91.8	15.5	188.8	16.0	180.0
April	12.7	192.7	14.3	22.9	13.4	233.7	14.2	118.8
May	10.9	103.2	11.9	117.3	10.7	179.6	10.0	100.1
June	8.3	193.3	8.2	48.2	9.9	140.7	8.5	143.3
July	12.4	52.7	8	197.5	10.1	187.5	9.8	239.6
August	11.5	83.5	11.8	171.7	9.9	83.4	9.8	368.8
September	9.5	228.1	11.4	450.2	11.9	246.4	11.2	145.2
October	13.5	380.1	13.5	137.5	11.6	121.3	13.7	168.4
November	14	237.6	18.1	248.1	14.1	180.4	14.1	76.3
December	15.9	91.6	17.2	144.5	16.3	166.0	15.4	167.8
AAT or TAR	13.2	2052	13.6	1932	13.3	2287	13.2	2054

AAT = Average annual Temperature; TAR = Total annual rainfall

Table 2. Total leaf N, P, K, Ca and Mg content in "Fuji" apple tree in different rootstocks and years of evaluation (means of 4 replicates).

Rootstock	N	P	K (g kg^{-1})	Ca	Mg
			2008		
CG.008	24.0 b	1.23 a	11.4 b	19.3 a	5.08 a
CG.56	27.4 a	0.60 b	13.5 a	22.0 a	4.10 a
CG.969	27.6 a	0.70 b	11.5 b	20.7 a	4.30 a
CG.24	23.1 b	0.98 a	11.4 b	19.3 a	4.00 a
CG.814	23.6 b	1.53 a	13.6 a	18.1 b	4.25 a
CG.058	24.2 b	1.35 a	10.9 b	16.9 b	4.23 a
CG.213	24.0 b	1.37 a	10.4 b	19.3 a	4.33 a
CG.757	22.4 b	0.40 b	12.6 a	18.7 b	4.30 a
CG.210	25.6 a	1.60 a	15.4 a	18.1 b	4.15 a
JM.2	20.5 b	1.05 a	13.5 a	18.2 b	4.00 a
JM.7	23.5 b	0.53 b	12.6 a	17.3 b	3.63 a
M.26	28.0 a	1.38 a	11.5 b	19.8 a	5.10 a
M.7	26.9 a	1.16 a	13.3 a	17.9 b	4.26 a
M.9	25.5 a	1.53 a	11.9 b	18.5 b	4.43 a
CV	12.4	8.1	13.1	28.2	28.5
			2009		
CG.008	28.0 a	1.60 b	12.4 b	13.0 a	3.18 a
CG.56	25.4 b	1.58 b	14.7 a	11.9 a	1.97 b
CG.969	24.9 b	1.51 b	12.2 b	10.5 a	2.31 b
CG.24	26.9 a	1.60 b	12.7 b	11.1 a	2.10 b
CG.814	27.1 a	1.64 b	11.4 b	11.8 a	2.69 a
CG.058	26.5 a	1.66 b	10.8 b	10.6 a	2.81 a
CG.213	24.9 b	1.42 b	11.0 b	11.8 a	2.58 b
CG.757	25.6 b	1.67 b	10.6 b	15.6 a	3.25 a
CG.210	28.5 a	1.86 a	15.1 a	12.2 a	2.55 b
JM.2	26.3 a	2.03 a	13.7 a	13.4 a	2.58 b
JM.7	24.0 b	2.03 a	16.4 a	11.2 a	2.09 b
M.26	27.5 a	1.58 b	13.3 a	12.0 a	2.91 a
M.7	27.4 a	1.63 b	14.0 a	10.8 a	2.41 b
M.9	27.3 a	1.66 b	13.0 b	12.9 a	2.99 a
CV	4.6	7.5	16.4	15.6	20.1
			2010		
CG.008	23.4 b	1.20 c	10.6 a	10.0 b	3.38 a
CG.56	23.2 b	1.31 c	10.9 a	10.5 b	2.11 b
CG.969	25.1 a	1.29 c	7.8 b	12.9 a	2.95 a
CG.24	25.1 a	1.35 c	9.1 b	11.7 a	2.93 a
CG.814	23.2 b	1.29 c	12.2 a	9.5 b	3.04 a
CG.058	24.3 a	1.28 c	9.3 b	12.4 a	3.36 a
CG.213	23.9 a	1.22 c	9.8 b	12.9 a	2.95 a
CG.757	23.1 b	1.25 c	9.7 b	12.6 a	3.52 a
CG.210	25.2 a	1.36 c	11.5 a	10.9 b	2.74 b
JM.2	21.6 b	1.26 c	11.0 a	10.9 b	2.34 b
JM.7	22.0 b	1.44 b	13.3 a	11.9 a	2.41 b
M.26	23.8 a	1.19 c	9.9 b	11.4 b	2.95 a
M.7	23.8 a	1.62 a	11.3 a	11.0 b	2.29 b
M.9	22.5 b	1.26 c	10.0 b	12.7 a	2.61 b
CV	15.1	11.9	15.4	19.9	12.7
			2011		
CG.008	25.9 a	1.38 b	13.3 b	12.4 b	3.51 a
CG.56	27.4 a	1.48 a	15.5 a	14.3 a	2.69 b
CG.969	27.4 a	1.50 a	12.3 b	12.7 a	2.84 b
CG.24	27.5 a	1.52 a	12.6 b	12.4 b	2.81 b
CG.814	25.8 a	1.53 a	14.4 a	11.4 b	2.62 b
CG.058	24.1 b	1.40 b	11.7 b	12.8 a	3.30 a
CG.213	26.0 a	1.40 b	12.5 b	13.2 a	3.05 a
CG.757	24.7 b	1.53 a	15.5 a	13.7 a	3.21 a
CG.210	26.4 a	1.58 a	14.4 a	13.0 a	3.15 a
JM.2	24.6 b	1.45 b	11.4 b	12.0 b	3.10 a
JM.7	25.5 b	1.48 a	15.2 a	12.4 b	3.06 a
M.26	26.7 a	1.44 b	13.0 b	11.6 b	3.26 a
M.7	26.0 a	1.42 b	13.4 b	11.2 b	2.96 b
M.9	26.8 a	1.39 b	12.6 b	11.7 b	3.18 a
CV	4.2	3.8	13.4	8.6	10.4

(1) Means followed by equal letters in the columns do not differ by the Scott-Knott test, at 5% probability; VC = variation coefficient.

However, rootstocks d M.26, M.7 and M.9, as well as JM.2 and JM.7, most often did not show higher leaf Ca contents, and did not corroborate the fact that the rootstock M.9 and its descendants would easily absorb Ca from the soil, according to Denardi (2002). In addition to the differences in Ca contents between rootstocks, which is associated mainly to the size of the root system (AMIRI et al., 2014), there was greater range of variation between the years of evaluation, especially in the year 2008 when leaf Ca contents were on average 36.2% higher than levels observed in other years. Ca accumulation depends on transpiration intensity from leaves (SAURE, 2005), which is influenced by soil and climate conditions such as temperature, relative humidity and soil moisture.

In relation to Mg contents, in the year 2008 there was no significant difference between rootstocks (Table 2). In other years, rootstocks CG.008, CG.058, CG.757 and M.26 stood out for showing higher leaf Mg contents. Rootstocks CG.56 and M.7 showed lower Mg contents. These results are in agreement with Fallahi et al. (2002), who had already observed greater efficiency of Mg absorption by M.26 when compared to M.7 in three of the five years evaluated. In the years 2009 and 2010, some rootstocks showed the Mg contents below 2.5 g kg^{-1}; however, for the remaining years and rootstocks, Mg concentration was established within or above the sufficiency range considered normal (2.5 to 5.0 g kg^{-1}) , indicating the good capacity to absorb Mg of most rootstocks evaluated.

Nutrient contents in fruits

Nutrient contents in fruits and their ratios varied between years and between rootstocks (Table 3). The N and P content in fruits varied significantly between rootstocks, in the two years of assessment. In 2009, rootstocks CG.56 and CG.213 showed the highest N contents in fruits (average 422.5 mg kg^{-1}). In 2010, rootstocks CG.058, CG.757, CG.210, JM.2, JM.7, M.26 and M.7 (average 394.4 mg kg^{-1}) were superior to others (average 332.4 mg kg^{-1}) in terms of N concentration. Apples with N contents greater than 500 mg kg^{-1} and with N/Ca ratio greater than 14 (AMARANTE et al., 2010) have a higher risk for occurrence of "bitter pit", one of the major physiological disorders. However, none of the rootstocks evaluated reached this critical level, indicating the absence of risk of fruits in accumulating excess N.

The P content in fruits in the year 2009 was higher than that found in the following year (Table 3). As this nutrient is supplied mostly via diffusion, water restrictions caused by precipitation below average in December 2009, as well as in March and April 2010 (Table 1) may have influenced the nutrient content in fruits. Between rootstocks, JM.7 in 2009 stood out with 204 mg kg^{-1} of P in the fruit and CG.757, JM.2, JM.7 and M.7 in 2010, which showed an average of 93.5 mg kg^{-1} of P in the fruit, 24% higher than the other rootstocks that obtained on average only 75.2 g kg^{-1} of P in the fruit.

Table 3. Total fruit N, P, K, Ca and Mg content (mg kg^{-1} – wet weight) and N/Ca, K/Ca and (K+Mg)/Ca ratios in "Fuji" apple trees in different rootstocks and years of evaluation (means of 4 replicates).

Rootstock	N	P	K	Ca	Mg	N/Ca	K/Ca	K+Mg/Ca
				2009				
CG.008	355 b[1]	164 c	710 a	46.5 a	32.0 c	8.3 a	16.9 a	17.6 a
CG.56	424 a	159 c	638 a	55.8 a	31.8 c	7.7 a	11.7 a	12.3 a
CG.969	360 b	170 c	547 a	53.5 a	31.3 c	6.9 a	10.8 a	11.4 a
CG.24	370 b	187 b	667 a	47.3 a	31.3 c	7.9 a	14.4 a	15.0 a
CG.814	309 c	181 b	719 a	40.3 a	30.8 c	7.7 a	17.7 a	18.5 a
CG.058	354 b	178 b	733 a	48.8 a	34.3 c	7.5 a	15.4 a	16.1 a
CG.213	421 a	156 c	729 a	45.0 a	32.0 c	9.4 a	16.2 a	16.9 a
CG.757	361 b	159 c	839 a	43.0 a	40.3 b	8.5 a	19.8 a	20.8 a
CG.210	284 c	169 c	676 a	41.0 a	31.5 c	7.0 a	16.9 a	17.7 a
JM.2	283 c	183 b	765 a	46.5 a	35.5 c	6.3 a	17.1 a	17.9 a
JM.7	293 c	204 a	786 a	41.8 a	32.8 c	7.2 a	19.1 a	19.9 a
M.26	309 c	152 c	754 a	46.8 a	36.0 c	7.1 a	17.3 a	18.1 a
M.7	283 c	170 c	891 a	38.8 a	47.6 a	7.5 a	23.8 a	25.1 a
M.9	314 c	169 c	647 a	47.3 a	37.3 c	6.6 a	13.7 a	14.5 a
CV	12.4	6.0	18.9	17.6	12.7	19.8	28.6	28.1
				2010				
CG.008	314 b	74 b	1060 b	50.6 a	46.0 a	6.4 b	21.2 b	22.1 b
CG.56	335 b	80 b	1203 a	45.1 a	42.6 a	7.5 b	27.0 a	28.0 a
CG.969	339 b	71 b	1072 b	46.7 a	40.3 a	7.3 b	23.5 b	24.3 b
CG.24	317 b	78 b	1087 b	45.7 a	43.0 a	7.0 b	24.2 b	25.1 b
CG.814	344 b	78 b	1168 b	45.7 a	42.2 a	7.5 b	25.7 a	26.6 a
CG.058	368 a	72 b	1066 b	43.4 a	38.7 a	8.5 a	24.7 b	25.6 b
CG.213	343 b	82 b	1110 b	49.8 a	40.1 a	6.9 b	22.4 b	23.2 b
CG.757	417 a	86 a	1163 b	43.3 a	43.0 a	9.7 a	27.0 a	28.0 a
CG.210	411 a	80 b	1268 a	45.4 a	41.8 a	9.4 a	29.1 a	30.0 a
JM.2	382 a	103 a	1083 b	52.4 a	48.6 a	7.3 b	20.8 b	21.8 b
JM.7	409 a	95 a	1277 a	46.4 a	45.8 a	8.9 a	27.5 a	28.5 a
M.26	382 a	65 b	1369 a	43.3 a	43.4 a	9.0 a	32.5 a	33.5 a
M.7	392 a	90 a	1080 b	53.9 a	43.8 a	7.3 b	20.2 b	21.1 b
M.9	335 b	72 b	1315 a	48.0 a	44.2 a	7.0 b	27.5 a	28.4 a
VC	11.8	16.9	9.3	11.6	7.1	18.4	16.8	16.5

[1] Means followed by equal letters in the columns do not differ by the Scott-Knott test, at 5% probability; VC = variation coefficient.

When compared to other nutrients such as Ca and K, P has less importance on the potential for conservation of fruits. However, apples with less than 100 mg kg^{-1} of P have a higher occurrence of "water core", a disorder that often occurs in pre-harvest in 'Fuji' apples, due to the flooding of intercellular spaces with sorbitol-rich juice, which reduces the potential for post-harvest storage (NEILSEN et al., 2008). Regardless of the rootstock, P contents in fruits were below this threshold in 2010, which reflects the remarkable influence of climatic components on the levels of this nutrient in apples.

In relation to K contents in fruits, significant differences between rootstocks were observed in the year 2010. The contents obtained on average were about 60% greater than those recorded in the year 2009 (Table 3). Possibly, this variation may be related to water deficit in April 2009. As K is supplied mostly via diffusion, any restriction on the soil moisture content significantly reduces K uptake by the tree roots (ERNANI et al., 2002). Studies indicate the need for K contents in the fresh pulp below 950 mg kg^{-1} in order to minimize the incidence of "bitter pit" in apples (AMARANTE et al., 2011). In the year of 2009, none of the rootstocks obtained K content higher than 950 mg kg^{-1} and, on average, the K content of the fruit was 721 mg kg^{-1}. However, all the evaluated genotypes obtained levels above the critical level in 2010, and rootstocks CG.56, CG.210, JM.7, M.26 and M.9 showed K contents above 1,200 mg kg^{-1}. Thus, these genotypes are likely to show susceptibility to damage caused by physiological disorders in post-harvest, especially in years of greater K accumulation in fruits.

In the two years of assessment, the Ca contents in fruits were not influenced by the rootstocks (Table 3). All genotypes evaluated showed levels exceeding 40 mg kg^{-1} of Ca, considered appropriate for apple fruits. Below this value, the risk of quality loss and occurrence of physiological disorders increases in post-harvest apples (ARGENTA; SUZUKI, 1994). However, it is essential to carry out new studies with the same rootstocks analyzed in this work in the regions of Vacaria and Fraiburgo, since Ca contents are generally lower in these places when compared to São Joaquim (AMARANTE et al., 2012).

All rootstocks showed N/Ca ratio less than 14, which conforms to the suitable N contents obtained from leaves (Table 2) and fruits (Table 3). However, rootstock M.26 in 2010 surpassed the ratio value of 30 (K+Mg)/Ca, which may involve greater susceptibility of rootstock M.26 to the occurrence of physiological disorders such as "bitter pit" (NEILSEN; NEILSEN, 2009; AMARANTE et al., 2012). Although rootstocks CG.56, CG.757, CG.210, JM.7 and M.9 did not show values above 30 for ratio (K+Mg)/Ca, all these genotypes reached value equal to or near that in 2010. In addition, all these genotypes presented higher K/Ca and N/Ca ratios in fruits and higher N content, which may represent greater risk of these rootstocks to physiological disorders during storage. Since Ca and Mg contents in fruits were not influenced by the rootstock in the year 2010, the high values of K/Ca and (K + Mg)/Ca ratios were attributed to the increase of K content in fruits. Therefore, in assessing the nutritional efficiency of rootstocks, the chemical analysis of K contents can be even more important than Ca content of 'Fuji' apples.

In this study, rootstock CG.210 presented high K contents in fruits and (K + Mg)/Ca ratio values equal to the critical level (30), which increased the risk of inducing physiological disorders, such as the "bitter pit" (AMARANTE et. al., 2012). Although Denardi et al. (2015) indicate that rootstock CG.210 presents good adaptation to low fertility soils, the risk of this rootstock to accumulate K in excess in fruits should be considered, for recommendation purposes. Therefore, subsequent studies involving kinetic parameters of absorption and storage potential of the fruit are needed for a better assessment of this rootstock.

The relationship between the nutrient levels in leaves and fruits, depending on the nutrient, was not significant (Figure 1). When correlated Ca contents in leaves with those in fruits in the 2009 and 2010 growth seasons, there was a low relationship between these variables. As it is a nutrient with very low mobility in the phloem, Ca accumulation in fruits occurs exclusively through the xylem, unlike N, P, K and Mg, which have high mobility and can be transported to fruits via both the xylem and the phloem (SAURE, 2005). Due to this low mobility, most Ca that reaches the leaves tend to remain in them. Therefore, in studies that evaluate efficiency of Ca absorption by rootstocks, the analysis of Ca content in fruits should certainly have a weight greater than Ca content in leaves (VANG-PETERSEN, 1980), because what defines whether or not the occurrence of physiological disorder is the amount of Ca allocated to the fruit and not to the leaves. For mobile nutrients, except for Mg, levels in leaves are related, positively (P) and negatively (N and K) with levels in fruits, which reflects the ease of these nutrients in moving from one organ to another in the plant.

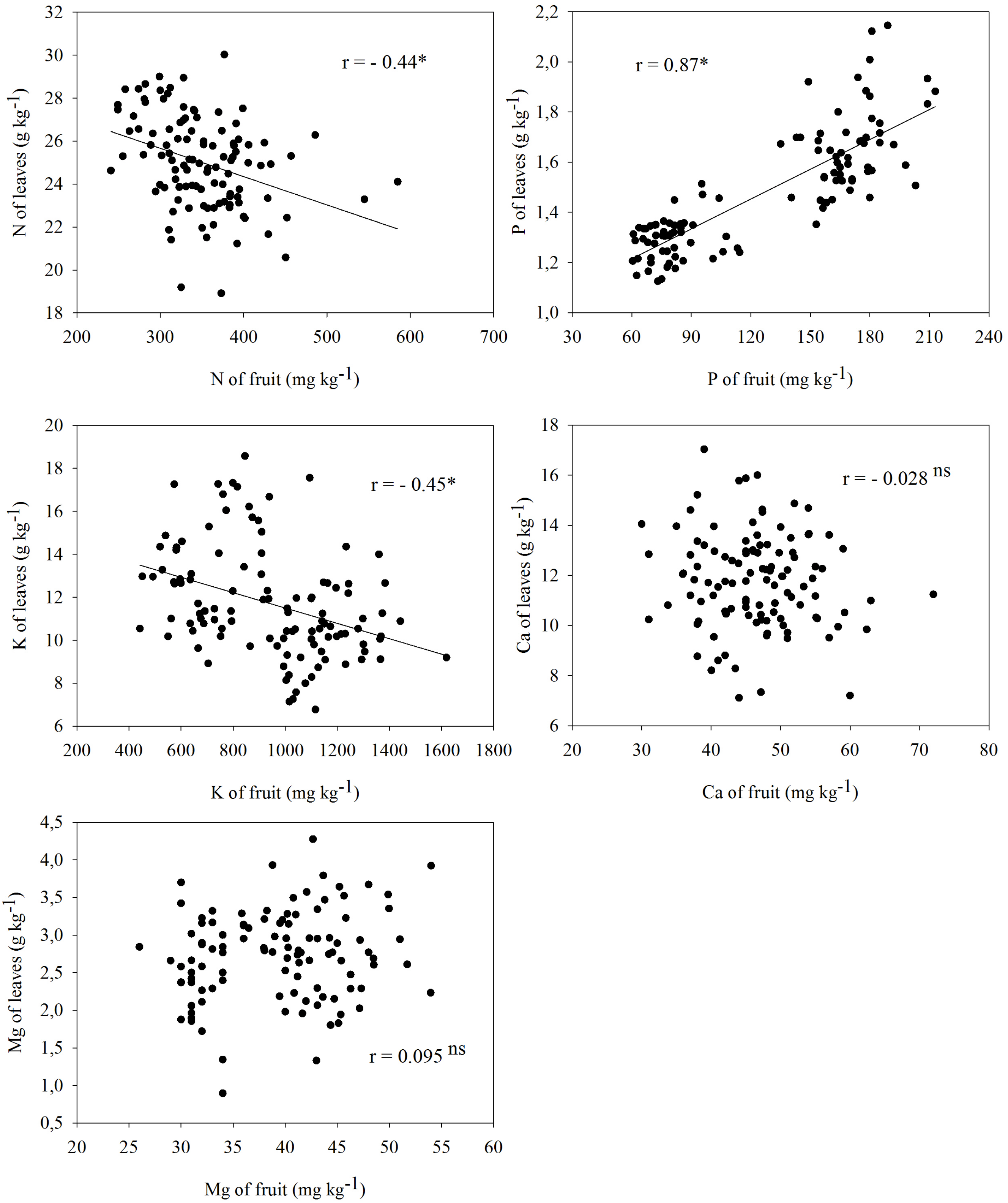

Figure 1. Correlation between the contents of N, P, K, Ca and Mg in fruits and their respective concentrations in the leaves of the apple tree 'Fuji' during the years 2009 and 2010; ns (non-significant) and * (significant at 5% probability).

Conclusions

The leaf Ca content differs between rootstocks, highlighting the rootstocks CG.213 and CG.969. However, there were no differences between them regarding the Ca content in the fruit. Except for M.7, all other rootstocks present Ca contents in the fruits above the critical level of 40 mg kg^{-1};

Rations between nutrients, primarily K/Ca and (K+Mg)/Ca, are more sensitive to the individual Ca content in the fruit to discriminate groups of rootstocks about the possible risk of physiological disorders;

Rootstocks M.26 and CG.210 showed (K + Mg)/ Ca ratio equal to or greater than 30 in one of the crops evaluated, which is conducive to increased risk of occurrence of physiological disorders in fruits. In addition, these rootstocks have higher concentrations of N, K and values of N/Ca and K/Ca ratio, which can decrease the storage potential of apple.

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