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Productivity and quality of 'Fuji Suprema' apple fruit in different rootstocks and growing conditions

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ABSTRACT

Planting density increasing with the use of dwarf rootstocks it is a fact that has changed the scenario of the pome culture in Brazil. The objective of this work was to evaluate the plant growth, productivity and fruit quality of the Fuji Suprema cultivar grafted on the rootstocks G.213 and M.9 in a new area (virgin soil) and in the replanting area of apple trees in Vacaria City in Rio Grande do Sul state, Brazil. The cultivar Fuji Suprema grafted on the rootstocks G.213 and M.9 was used, being the experiment 1 in new area and the experiment 2 in area of replanting of apple trees. In both experiments, the orchard was implanted in 2014. The spacing adopted was 4.0 m between rows and 0.9 m between plants, totaling a density of 2,777 plants per hectare. Vegetative/productive evaluations were carried out in the 2014, 2015, 2016, 2017, 2018 and 2019 harvests in commercial orchards of the company Rasip Agro Pastoril S/A. In the experiment 1, the G.213 rootstock was highlighted for the variables accumulated productivity, accumulated productive efficiency, ASTT, number of branches and scion volume. In this same experiment, the M.9 rootstock was overestimated in some crops for the variables fruit mass and pulp firmness. In the experiment 2, the G.213 rootstock was highlighted as to the accumulated productivity, accumulated productive efficiency, ASTT, number of branches and scion volume. In the 2016 crop, the rootstock M.9, stood out for the diameter and mass of fruits and soluble solids and in the 2017 harvest for pulp firmness. In order to cultivate Fuji Suprema, both in the new area and in the replanting area of apple trees, the G.213 rootstock is a new dwarf rootstock option for the southern region of Brazil.

1. Introduction

In southern Brazil, apple orchards have reached high yields, as producers invest in new technologies to improve fruit quality and financial returns (Chagas et al., 2012). The implantation of new orchards prioritizes the increase in the density of plants, that is, a greater number of plants per area. In the present study, it is possible to estimate the effect of plant densities on fruit production (Petri et al., 2011), precocity for entry into production, high fruit quality and lower labor costs (Hampson et al., 2002). However, for high-density planting to be profitable, it is important to select the correct scion for the efficient control of plant size (Pasa and Einhorn, 2014).

The M.9 dwarf rootstock is the most widely used in the world (Marini et al., 2009), because it allows the development of orchards with high productivity, productive efficiency and good physical and chemical quality of fruits (Borbála, 2001). However, 'M.9′ is not adapted to shallow and acidic soils, predominant in apple producing regions of southern Brazil, besides being susceptible to Wooly apple aphid (Boneti et al., 2001).

The genetic improvement program of the Cornell University in the USA has been developing new rootstocks of the Geneva® American series (CG series) with plant characteristics required for use in Brazil (Denardi et al., 2015). The rootstocks of this series are resistant to leafhopper, increase productivity, are tolerant to replanting disease (Fazio et al., 2013), better induce scion budding (Denardi et al., 2012) and insertion angulation from the branches to the stem (Fazio and Robinson, 2008). Among the rootstocks developed by the CG series, the rootstock G.213 is considered with vigor similar to 'M.9′, has resistance

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to the larval aphid and *Erwinia amylovora* and good tolerance to the disease of replanting and with productivity equal or higher than in 'M.9′ (Fazio et al., 2016).

Most of the Brazilian orchards are being planted in areas of apple replanting, due to the low availability of new areas, that is, virgin soil (Denardi et al., 2015). However, some replanting areas present diseases of the replanting complex characterized by abiotic factors such as toxins released by previously cultivated plants and biotic factors such as soil fungus, nematode complexes and bacteria (Zhu et al., 2014). In this way, the CG series rootstocks can be considered as new options for the cultivation of apple trees in Brazil. However, new studies on the behavior of the CG series rootstocks in southern Brazil's soil and climatic conditions are necessary. Thus, the objective of this work was to evaluate the plant growth, productivity and fruit quality of the Fuji Suprema cultivar grafted on the rootstocks G.213 and M.9 in a new area (virgin soil) and in the replanting area of apple trees in Vacaria countryside in the Rio Grande do Sul state, Brazil.

2. Material e methods

The experiments were conducted in the years 2014– 2019 in commercial orchards of Rasip AgroPastoril S/A, located in Vacaria city, Rio Grande do Sul state, Brazil. The geographical coordinates of the experimental units are 50° 54′12″W and 28° 24′ 93″ S, with an average elevation of 930 m. The climate of Vacaria, according to the classification of Köeppen is type Cfb: humid temperate climate with mild summers. The average monthly temperature varies from 11.4 °C to 20.6 °C, and the average monthly rainfall varies from 101 to 174 mm (Pereira et al., 2009).

The soil of the region is classified as typical dystrophic Bruno Latossolo with deep soils, well drained, with high clay content, marked acidity and low nutrient reserve for plants, with predominant mineralogy of kaolinite, iron and aluminum oxides and with high content of organic matter (Embrapa, 2006).

The experiments were carried out in two different soil conditions: experiment 1 in a new area (virgin soil), where no fruiting species had been cultivated previously and experiment 2 in the replanting area, where apple cultivation was done for approximately 20 years.

In 2012 an area of apple trees with 20 years of age was eradicated, followed by the cleaning of the area and corrections of soil, the following maize was grown in the area and in winter of 2014 planting experiment 2 with apple trees. The new area (virgin soil) was constituted of native grass at its origin, later it was cultivated with grains and in 2014, it was prepared and corrected to receive the implantation of experiment 2 of apple trees.

The cultivar Fuji Suprema was used in the rootstocks M.9 and G.213, the seedlings were made by the company's own nursery. Plants were conducted and pruned following the concepts of the Tall Spindle training system. The spacing adopted was 4.0 m between rows and 0.9 m between plants, totaling a density of 2,777 plants per hectare. Both areas with anti-hail screen from the second year of deployment. The orchard was planted with four rows of the cultivar Maxi Gala for one of the cultivar Fuji Suprema, which represents 80% of Maxi Gala and 20% of Fuji Suprema.

In both experiments, the following variables evaluated were:

Productivity (t ha^{-1}): was calculated by multiplying the average fruit mass per plant and the number of plants per hectare as a function of the spacing used in each experiment.

Cumulative productivity (t ha^{-1}): obtained by the sum of the productivity of all crops.

Productive efficiency (kg cm^{-2}): calculated by the ratio of the average mass per plant (kg plant^{-1}) to the cross-sectional area of the trunk (cm^2).

Cumulative productive efficiency (kg cm^{-2}): obtained by the sum of the efficiency of all the crops.

Cross-sectional area of the trunk (cm^2): obtained by means of the longitudinal and transverse measurements of the trunk diameter, 10 cm above grafting point. To convert the diameter values into ASTT, the formula A = (πd2) / 4 was used where, d = trunk diameter.

Height of plant (m): it was done with the aid of a topographic rule, from the point of grafting to the end of the plant. In order to carry out the measurements, the five plants of each plot were used.

Number of branches per plant: was obtained by counting all branches greater than thirty centimeters from the leader, from the grafting point to the lateral branch at the highest point of the plant, excluding the branch at the end of the central leader.

Scion volume (m^3): a graduated topographic ruler was used with the aid of the formula (L x E x H), where: L = scion width in the direction of the planting line; E = scion thickness in the direction of the line; H = scion height, from the point of insertion of the first branch to the apex.

Mean fruit diameter (mm): a sample of 30 fruits was collected per plot, at random, a graded wooden ruler, adapted in the form of 'L', was used. To obtain the mean diameter, the total value visualized in the ruler by the 30 fruits was divided.

Fruit Mass (g): a sample of 30 fruits per plot was collected at the time of harvest, at random. The average fruit mass was calculated by the total mass of the sample divided by the number of fruits in the sample.

Pulp Firmnes (lb): was measured with the aid of a digital texturometer, with 11 mm tip. The reading was made in the equatorial zone of the fruit, being made a superficial cut of two disks of epidermis of about 1 cm in diameter, in opposite sides for realization of the reading.

Soluble solids (°Brix): the soluble solids content (SS) was determined from the juice extracted from a slice of each sample fruit (30 fruits).

A digital refractometer for sugar was used. The experiments were implanted in randomized blocks with two treatments, ten replicates and ten plants per plot, and the five central plants were evaluated. Data were submitted to the 5% error probability F test using the statistical program SISVAR 5.6.

3. Results and discussion

Experiment 1: Fuji Suprema cultivar on rootstocks G.213 and M.9 in new planting area.

Productivity and productive efficiency differed according to the rootstocks in all evaluations, except for the first crop (2016) (Table 1). The cultivar Fuji Suprema grafted on the rootstock G.213 had high productivity and productive efficiency in most harvests evaluated in

Table 1
Productivity and productive efficiency in the Fuji Suprema cultivar in rootstocks M.9 and G.213 in new area of apple trees, Brazil, 2019.

Rootstock	Productivity (t ha^{-1})					Productive efficiency (kg cm^{-2})				
	2016	2017	2018	2019	Cumulative	2016	2017	2018	2019	Cumulative
M.9	13.9	8.1	39.8*	15.8	77.6	0.6	0.2	1.0*	0.34	2.14
G.213	13.1	26.7*	24.9	32.5*	97.2	0.5	0.7*	0.5	0.58*	2.28
CV.(%)	12.6	20.0	13.0	21.1	16.7	24.6	32.2	27.4	16.09	25.0

Note. * Significant at 5% probability of error.

Table 2
Trunk cross-sectional area (ASTT), scion volume, height and number of branches per plant of Fuji Suprema cultivar in rootstocks M.9 and G.213 in new condition of apple trees, Brazil 2019.

Porta-enxertos	ASTT (cm^{-2})					Plant Height(m)				
	2014	2015	2016	2017	2018	2014	2015	2016	2017	2018
M.9	1.4*	5.2	8.3	11.9	14.9	1.6	2.2	2.4	2.7	3.05
G.213	0.9	5.4	10.6*	13.9	18.5*	1.5	2.1	2.4	2.7	3.17
CV.(%)	4.4	13.9	18.7	14.4	16.8	11.9	8.3	5.9	5.2	4.91
Porta-enxertos		Number of branches per plant				Scion volume (m^3)				
	2014	2015	2016	2017	2018	2015		2016	2017	
M.9	10.1*	10.6	16.0	21.4	27.5	0.8		3.5	3.9	
G.213	0.4	13.1*	20.7*	28.8*	35.1*	1.5*		5.2*	4.9*	
CV.(%)	18.6	5.7	4.2	5.3	7.8	25.1		11.2	12.3	

Note. * Significant at 5% probability of error.

Table 3
Fruit diameter and mass, pulp firmnes and soluble solids of the Fuji Suprema cultivar in the rootstocks M.9 and G.213 in condition of new area of apple trees, Brazil, 2019.

Porta-enxertos	Fruit diameter (mm)				Fruit mass (g)			
	2016	2017	2018	2019	2016	2017	2018	2019
M.9	71.5*	78.9	69.0	71.0	136.9*	205.7	143.8	156.0*
G.213	67.5	76.6	70.3	69.0	122.9	202.9	149.9	144.0
CV.(%)	3.5	3.3	3.3	1.79	9.5	8.4	7.2	2.0
Porta-enxertos	Pulp firmnes (lb)					Soluble solids (°Brix)		
	2016	2017	2018	2019	2016	2017	2018	2019
M.9	18.3	17.0*	16.8	14.9	13.8	13.4	11.9	13.3
G.213	18.9	16.1	16.6	15.5	14.5	13.1	13.3	12.9
CV.(%)	4.7	3.2	4.5	5.2	5.8	4.2	7.5	6.1

Note. * Significant at 5% probability of error.

comparison to the M.9 rootstock. In relation to the accumulated productivity, the cultivar Fuji Suprema grafted on 'G.213′ was 20.10% higher in comparison to 'M.9′, representing 20 tons more of fruits in four harvests. After four productive crops, it was possible to observe a marked antenation of production of the Fuji Suprema cultivar with the rootstock M.9, and greater productive constancy of the rootstock G.213 with the same cultivar. These results corroborate with those obtained by Denardi et al. (2015), which concluded that the combination of the cultivar Fuji in the rootstock G.213 in new area, has high accumulated production and productive efficiency in contrast with the rootstock M.9, in the edaphoclimatic conditions of Fraiburgo city in Santa Catarina state.

In addition, it is important to emphasize the ability of 'G.213′ to emit branches, because when observing Table 2 it is possible to verify that the rootstock M.9 had 10 branches anticipated at the moment of planting against only 0.4 branches of the 'G.213′ and yet the two rootstocks provided equal productivity for 'Fuji Suprema' in the first crop (2016) (Table 1), exalting the precocity at the G.213 production input. This G.213 branch issuance capacity is observed over the years (Table 2), always higher than 'M.9′, which can be correlated with the higher accumulated productivity and lower G.213′combined with ‘Fuji Suprema’.

Considering vegetative variables as ASTT, number of branches and scion volume in the last year of evaluation (Table 2) it is possible to infer that the 'Fuji suprema' grafted on the rootstock G.213 is more vigorous than when grafted on 'M .9′. In the literature it is reported that plant vigor is directly related to ASTT (Czynczyk and Bielicki, 2012). In this way, it was proposed by some authors the classification of the rootstock G.213 as dwarf (Denardi et al., 2015) being in the same class of the rootstock M.9. This is true when observed only eplants height, however when observing the ASTT and the scion volume, it can be verified that the combination of the Fuji Suprema cultivar with the 'G.213′ gives a stronger force to the plants. However, these results corroborate the fact that 'G.213′ and 'M.9′ are classified as dwarf, since neither of them exceeded 90% of the line spacing, as indicated by Palmer (1999) in relation to plants height.

Fruit diameter and mass values were significantly higher in 'Fuji Suprema' apple trees in the M.9 rootstock in the 2016 harvest (Table 3). In the 2019 harvest, the M.9 rootstock provided higher fruit mass for the Fuji Suprema cultivar, which may be related to its lower productivity for the same year (Table 1). The pulp firmness was higher in the Fuji Suprema cultivar at the rootstock M.9 in the 2017 crop (Table 3). Soluble solids were not influenced by rootstocks throughout the study (Table 3). Dwarf rootstocks such as 'M.9′ and 'G.213′ may have a more efficient light trap interfering positively in soluble solids content (Pasa et al., 2016). Despite some differences in the attributes of evaluation of fruits at the time of harvest in certain years (Table 2), it is not possible to affirm that there are important differences between these two rootstocks when planted in an area of virgin soil.

Experiment 2: Fuji Suprema apple cultivar on G.213 and M.9 rootstocks in replanting area

Regarding productivity and productive efficiency, the highest accumulated values of the four harvests were obtained in 'Fuji Suprema' in the rootstock G.213 (Table 4). The G.213 rootstock showed regularity of production and good productive efficiency, standing out with 50% more of accumulated productivity in comparison to the M.9 rootstock. The high productivity is a characteristic of the CG series grafts, when compared to the worldwide used dwarf and semi-dwarf grafts, such as 'M.9′, 'M.26′ and 'M.27′ (Fazio et al., 2013).

Cross-sectional area of the trunk (ASTT) was higher in the 'Fuji Suprema' apple trees in the G.213 rootstock in the 2015– 2018 harvests in the replanting area (Table 5). However, plant height differences in the analysis of variance were not observed in all crops, except for the

Table 4
Productivity and productive efficiency in the cultivar Fuji Suprema on rootstocks M.9 and G.213 in condition of replanting of apple trees, Brazil, 2019.

Porta-enxertos	Produtividade ($t\ ha^{-1}$)					Eficiência produtiva ($kg\ cm^{-2}$)				
	2016	2017	2018	2019	Acumulada	2016	2017	2018	2019	Acumulada
M.9	5.2	4.9	43.2	6.1	59.4	0.3	0.2	1.0	0.1	1.6
G.213	6.3	27.4*	49.8	37.5*	121.0	0.3	0.8*	1.0	0.7*	2.8
CV.(%)	28.6	16.1	18.4	23.4	21.6	29.2	15.1	15.3	25.5	21,2

Note: * Significant at 5% probability of error.

Table 5
Trunk cross-sectional area (ASTT), scion volume, plant height and number of branches per plant of Fuji Suprema cultivar in rootstocks M.9 and G.213 in condition of replanting area of apple trees, Brazil 2019.

Porta-enxertos	ASTT (cm^{-2})					Altura de planta (m)				
	2014	2015	2016	2017	2018	2014	2015	2016	2017	2018
M.9	1.3*	3.9	6.2	10.9	14.3	1.7	1.8	2.3	2.6	3.2
G.213	1,0	4,4*	8,5*	122*	178*	1,6	1,8	2,4	2.6	3.4*
CV.(%)	11,0	12,1	9,6	9,6	8,9	8,8	6,1	7,0	7,8	3.6
Porta-enxertos	Número de ramos por planta					Volume de copa (m^3)				
	2014	2015	2016	2017	2018	2015	2016	2017		
M.9	7.4*	9.8	13.0	16.4	23.8	0.6	1.2	4.2		
G.213	0.6	12.3*	18.2*	25.3*	32.2*	1.1*	2.5*	4.8		
CV.(%)	19.4	6.6	6.6	9.4	9.9	36.1	32.7	16.0		

Note. * Significant at 5% probability of error.

Table 6
Fruit diameter and mass, pulp firmness and soluble solids of fruits of the cultivar Fuji Suprema in rootstocks M.9 and G.213 in condition of replanting area of apple trees, Brazil, 2019.

Porta-enxertos	Diâmetro de frutos (mm)				Massa de frutos(g)			
	2016	2017	2018	2019	2016	2017	2018	2019
M.9	71.5*	78.9	69.0	69.0	136.9*	205.7	143.8	142.0
G.213	67.5	76.6	70.3	71.0	122.9	202.9	149.9	146.0
CV.(%)	3.5	3.3	3.66	3.66	9.5	8.4	7.2	3.3
Porta-enxertos	Firmeza de polpa (lb)				Sólidos Solúveis (°Brix)			
	2016	2017	2018	2019	2016	2017	2018	2019
M.9	16.9	16.1*	16.3	16.5	12.7	13.6	12.4	14.2
G.213	17.3	14.3	16.6	16.0	13.7*	13.5	12.3	13.1
CV.(%)	4.7	9.9	5.3	4.1	5.4	5.7	5.3	8.9

Note: * Significant at 5% probability of error.

2018 harvest (Table 5). In relation to the number of branches per plant, the highest values were observed in the cultivar Fuji Suprema in the rootstock G.213, in the 2015– 2018 crops (Table 5). Scion volume was significant in the 2015 and 2016 crops for the G.213 rootstock, observing an increase in the values with the plant development (Table 5).

Pulp firmness results were significant in 'Fuji Suprema' apple trees in the M.9 rootstock in the 2017 crop (Table 6). Sugar content expressed as soluble solids was significant in the G.213 rootstock in the 2016 crop (Table 6). However, the fruit diameter and mass were not influenced by the rootstocks in this study (Table 6). The effect of rootstocks on fruit mass has not been constant over the years and is possibly not related to the number of fruits in different crops, according to Russo et al. (2007) rootstocks may have little influence on fruit mass.

Considering vegetative data, which quantifies plants growth, and the production data, it is possible to infer that G.213 is more adapted to soils of replanting of apple trees, because it was noticed a greater development of the plants and greater productivity accumulated with the Fuji Suprema grafted on G.213 when compared to M.9. The high performance of the Geneva® series materials under replanting conditions, as well as the susceptibility of the Malling series materials, in which the M.9 rootstock fits, has also been demonstrated in other studies (Kviklys et al., 2014; Robinson, 2003).

4. Conclusion

The G.213 rootstock provides greater trunk cross-sectional area, larger scion volume, and greater number of branches for the Fuji Suprema cultivar in virgin soil area and maizef replanting area.

The Fuji Suprema cultivar is more productive when grafted on G.213 in virgin soil and replanting area in apple trees.

The fruit quality parameters at the harves ttime do not suffer interference from the rootstock, regardless of the planting condition.

The G.213 rootstock is a new option for orchards with the cultivar Fuji Suprema in virgin soil and reforestation areas of apple trees in the southern region of Brazil.

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