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SCIENTIFIC COMMUNICATION

PRODUCTIVE PERFORMANCE OF 'FUJI' APPLE TREES ON 'JM' SERIES ROOTSTOCKS, IN SÃO JOAQUIM/SC[1]

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ABSTRACT – Worldwide, research has developed new apple rootstocks that induce higher yields, pest resistance and adaptation to different climatic and soil conditions. Thus, the performance of these new rootstocks in the conditions of the main regions that grow apples should be investigated. The objective of this study was to evaluate the performance of 'Fuji' trees on different rootstocks of JM series and M.7 in the region of São Joaquim, SC. The experiment was performed from 2010 to 2015. Plant material consisted on the cultivar Fuji grafted on the rootstocks JM.2, JM.3, JM.5, JM.7, JM.8 and M.7, planted as single axis trees in the winter of 2002, and spaced at 5 x 1.5m. Trees were trained in a central-leader system and arranged in a randomized complete block design with four replicates. The number of fruits per tree, production per tree, yield, yield efficiency, fruit weigh, and trunk cross sectional area were evaluated. The results showed that the yield of 'Fuji' apple trees is greater with the rootstocks JM.3, JM.7, JM.8, and M.7. The rootstocks JM.2, JM.5, JM.7 and JM.8 induce similar vigor as M.7. The results also show that fruit weight is little affected by rootstock.
Index terms: *Malus domestica* Borkh, yield, yield efficiency, fruit size.

DESEMPENHO PRODUTIVO DE MACIEIRAS 'FUJI' EM PORTA-ENXERTOS DA SÉRIE 'JM', EM SÃO JOAQUIM/SC

RESUMO – Centros de pesquisa internacionais têm desenvolvido novos porta-enxertos de macieira com maior produtividade, resistência a pragas e doenças e adaptação a diferentes condições edafoclimáticas. Então, o desempenho desses novos porta-enxertos nas condições das principais regiões produtoras deve ser pesquisado. O objetivo do trabalho foi avaliar o desempenho de macieiras 'Fuji' em porta-enxertos da série JM e M.7, na região de São Joaquim, SC. O experimento foi desenvolvido no período de 2010 a 2015. O material vegetal consistiu de plantas da cultivar Fuji enxertadas nos porta-enxertos JM.2, JM.3, JM.5, JM.7, JM.8 e M.7. As mudas de haste simples foram plantadas no inverno de 2002 em espaçamento de 5 x 1,5m. As plantas foram conduzidas no sistema de líder central. O delineamento experimental foi de casualização por blocos com quatro repetições. As variáveis analisadas foram produção por planta, número de frutos por planta, produtividade, eficiência produtiva e área da seção transversal do tronco. Os resultados obtidos mostraram que a produção de 'Fuji' foi maior com os porta-enxertos JM.3, JM.7, JM.8, e M.7. Os porta-enxertos JM.2, JM.5, JM.7 e JM.8 induzem vigor semelhante a M.7. Os resultados também mostram que a massa de fruto é pouco influenciada pelo porta-enxerto.
Termos para indexação: *Malus domestica* Borkh, produtividade, eficiência produtiva, tamanho de fruto.

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Apple is a very important fruit crop produced in Brazil, ranking in the second position in the production of temperate climate fruits (1,377,747Mg), where the states of Rio Grande Sul (690,422 Mg) and Santa Catarina (633,079 Mg) are the main producers (IBGE, 2014). The region of São Joaquim responds for approximately 38 % of all apples produced in Santa Catarina (EPAGRI/CEPA, 2013), and is characterized by shallow and rocky soils, reason why the vigorous rootstock 'Marubakaido' became popular and is currently the most used in this region. However, due to its high vigor this rootstock is not well suited to plantings at higher densities. Increasing planting density is one of the most important factors affecting yield (PETRI et al., 2011) and profitability (KREUZ et al., 2006) of apple orchards, but its efficiency depends on suitable techniques to control tree size, like the right choice of rootstock (PASA; EINHORN, 2014).

Given the soil conditions of the region, research efforts have focused in semi-dwarf rootstocks. In the past, the semi-dwarfing rootstock M.7 was studied but its susceptibility to woolly aphid (*Eriosoma lanigerum*) (DENARDI et al., 2015), mainly due to its high level of suckering (FERREE; CARLSON, 1987), limited its adoption. Currently, the combination of 'Marubakaido' with an interstock of M.9 has given the tree size control necessary to increase planting density, but at medium densities (~1000 plantas ha^{-1}). Besides, it offers the disadvantages of woolly aphid attack in the susceptible interstock (M.9), higher cost of trees, and variability of tree size (PASA et al., 2016). Therefore, the development and evaluation of new apple rootstocks is still necessary in order to achieve better performance of apple orchards.

Several apple rootstocks have been developed in the past few years. The CG (Cornel-Geneva) rootstocks are promising, showing important traits like vigor control and disease resistance (FAZIO et al., 2013). Another option is the JM series rootstocks, which also show disease resistance, vigor control and are easy to propagate (SOEJIMA et al., 1998). Recently, Pasa et al. (2016) tested some of these rootstocks with 'Imperial Gala' and 'Mishima Fuji' and reported promising results of some rootstocks of both JM and CG series.

The objective of this study was, therefore, to evaluate the performance of 'Fuji' apple trees on different rootstocks of JM series and M.7 in the region of São Joaquim, SC.

The study was performed at the Experimental Station of São Joaquim – Santa Catarina State Agricultural Research and Rural Extension Agency (EPAGRI), located in the municipality of São Joaquim, in the state of Santa Catarina (SC), Brazil (28º17'39''S, 49º55'56''W, at 1,415 m of altitude), between 2010 and 2015. The climate of the region is mesothermal humid (Cfb) according to Köppen-Geiger classificaton, i.e, temperate climate constantly humid, without dry season, and cool summer (BENEZ, 2005). Average accumulation of temperatures bellow 7,2ºC is 900 hours. The soil of the experimental field is a Cambissolo Húmico (Inceptisol), according to the Brazilian soil classification system (SANTOS et al., 2013).

Plant material consisted of 'Fuji Standard' trees grafted on different rootstocks. Single axis trees were planted in a single row in the winter of 2002. Two adjacent rows of 'Gala' were planted as pollinator. Soil fertility was previously corrected according to soil analysis: Clay - 30%; pH-water (1:1) - 5,4; SMP index – 5,1; Phosphorus – 7,3 mg L^{-1}; Potassium – 159 mg L^{-1}; Organic matter (m/v) – 6,1%; Aluminum – 0,0 cmol L^{-1}; Calcium – 7,2 cmol L^{-1}; Magnesium – 3,4 cmol L^{-1}. The analysis were performed in the soil analysis laboratory of the Experimental Station of São Joaquim, linked to the Official Network of Soil Analysis Laboratories of RS and SC – ROLAS. Trees were spaced at 5 m between rows and 1.5 m within the row, totalizing 1,333 trees per hectare and trained in a central-leader system. Orchard management was performed according to recommendations of the apple production system (EPAGRI, 2006).

Treatments consisted on the rootstocks of Japanese series JM (Japan, Morioka) JM.2, JM.3, JM.5, JM.7 and JM.8, and as control the rootstock M.7 (Malling series). JM rootstocks originated from a controlled cross of Marubakaido (Seishi) x M.9 made in 1972 at Morioka Branch, Fruit Tree Research Station (Japan), and show as main characteristics disease resistance, vigor control and easy propagation by hardwood cuttings (SOEJIMA et al., 1998). The Malling apple rootstock series was described and classified at the East Malling Research Station, Kent, England (1912-1918) (FERREE; CARLSON, 1987). This rootstock breeding program began when two of its former directors (Drs. Wellington and Hatton) sorted out the incorrect naming and mixtures then widespread in apple rootstocks distributed throughout Europe; from the original Malling selections only M.9 and M.7 were extensively used by commercial growers around the world (WEBSTER et al., 2000). M.7 produces a tree 55-65% the size of apple seedling, shows great disease tolerance and adaptation to a different range of soil types and climates, and is easy to propagate

(FERREE; CARLSON, 1987).

Trees were arranged in a randomized complete block design with four replicates of five trees each. Three out of the five trees were used for evaluations (leaving one at each end as border). Trunk diameter was measured at 5 cm above graft union at the end of each growing season and was expressed as trunk cross sectional area (TCSA). TCSA was calculated according the following formula: $TCSA = \pi.r^2$, where $\pi = 3.1416$ and r (radius) = d/2, where d = trunk diameter. Fruits were harvest at commercial maturity, according to starch-iodine index (4-5), flesh firmness (80-90 N), and soluble solids (11-12°Brix) (EPAGRI, 2006). Total number of fruit per tree was counted and weighed (kg), with a digital scale (UR 1000 Light, URANO, Canoas/RS). From these data, the following parameters were calculated: production per tree (kg); fruit weight (g); yield (Mg ha^{-1}); and yield efficiency (kg cm^{-2}), calculated as the reason between production per tree and TCSA. The biennial bearing tendency of each rootstock was assessed by calculating the alternate bearing index (ABI) using the formula: $ABI = [(a_{y2} - a_{y1})/(a_{y2} + a_{y1}) + (a_{y3} - a_{y2})/(a_{y3} + a_{y2})\ldots(a_{y} - a_{y-1})/(a_{y} + a_{y-1})]/n\text{-}1$, where a = yield (Mg ha^{-1}), y = year, and n = number of years. This index gives values ranging from 0 to 1 with 0 = no biennial bearing and 1 = complete biennial bearing.

Statistical analyses were performed using the R software (R CORE TEAM, 2014). Data were analyzed for statistical significance by means of F test. Duncan's test was performed to compare treatments when analysis of variance showed significant differences among means.

Production per tree and yield were significantly affected by rootstock in 2010, 2011, 2012, 2013, and cumulative yield (Table 1). The greatest production per tree was observed with JM.3, JM.7 and JM.8 in 2010; JM.3 and JM.8 in 2011; and JM.3, JM.7, JM.8, and M.7 in 2012. In 2013, all rootstocks behaved similarly, except JM.5, which showed the lowest production per tree. The rootstock JM.3 showed higher cumulative yield than JM.2 and JM.5, but did not differ of JM.7, JM.8 and M.7.

Number of fruit per tree differed among rootstocks in all years, except 2014 and 2015 (Table 2). The rootstock JM.3 showed greater number of fruits than JM.2 and JM.5 in all years, but did not differ of M.7. Cumulative number of fruit was greater with JM.3 and M.7, followed by JM.7, JM.8 which did not differ of JM.2. Yield efficiency was significantly affect only in 2010 and 2012 (Table 2). In 2010, JM.3, JM.7, and JM.8 were more efficient whereas in 2012 JM.7 showed the highest yield efficiency (Table 2).

The cumulative production per tree, number of fruit per tree and yield of all JM rootstocks, but JM.2 and JM.5, was similar do M.7. Soejima et al. (1998) studying the performance of some rootstocks found that JM.7 was more productive than M.26 (semi-dwarf as M.27). This author also reported the lowest cumulative yield of JM.5, followed by JM.2. Similarly, in the present study these rootstocks were also the less productive. These differences might be related with the vigor induced by the rootstock since until 2014 these rootstocks were among the ones with smaller TCSA as well as the greatest cumulative yield and number of fruits per tree was observed with the most vigorous JM.3. Studying the performance of 'Delicious' and 'Golden Delicious' apple on several rootstocks observed that the number of fruits per tree and yield tend to be greater on more vigorous rootstocks over the years. Besides, vigorous rootstocks are capable of filling the in-row space faster than less vigorous ones. It would explain why no differences on yield, production and number of fruits per tree were observed after 2013 (11th leaf), period where little differences in TCSA were observed among rootstocks (Table 4). In this case, the less vigorous rootstocks were capable of filling in the available in-row space while the more vigorous had its growth limited earlier due to neighboring trees canopy and root growth.

Yield efficiency usually, but not always, is negatively correlated with TCSA, such as found by Russo et al. (2007) studying the field performance of 64 apple rootstocks. In our study, however, the differences found in yield efficiency (2010 and 2012) were not correlated with lower TCSA. Indeed, in 2010, JM.5 showed the lowest yield efficiency and TCSA, showing that these two parameters are not always negatively correlated. In the other hand, cumulative yield efficiency did not differ among rootstocks, as well as final TCSA (2015), except for JM.3, which showed the highest TCSA. In this sense, the similar cumulative yield efficiency induced by the different rootstocks could be attribute to the similar TCSA among them.

Alternate bearing index (ABI) did not differ among rootstocks (Table 1). Biennial bearing is characterized by large yields of small sized fruit in "on" years, and low yields, sometimes even no fruit, in "off" years (GUITTON et al., 2012). Alternate bearing is affected by cultivar (MONSELISE; GOLDSCHMIDT, 1982) and rootstock (Jonkers 1979). A recent study describes 'Fuji' as susceptible to alternate bearing (ATAY et al., 2013). According to Jonkers (1979), weak or dwarfing rootstocks have been reported to reduce biennial bearing in apples. In the present study, except for JM.3, rootstocks showed similar vigor and no differences in the ABI were found among them. On the other hand, Robinson et al. (2011) observed different ABI among several rootstocks, but the differences were not closely related to tree vigor. Either way, the results we have found are very important, since the calculated ABI are considered low, since they are closer to 0, rather than 1, where 1 mean a high alternate bearing tendency.

Significant differences in fruit weight among rootstocks were observed in 2012 and 2015 (Table 3). In 2012, JM.5 showed the greatest fruit weight and M.7 the lowest. In 2015, fruits of M.7 were smaller than the other rootstocks. Reduction in fruit weight is often correlated with higher crop load (ROBINSON, 2011) and it partially explains the differences among rootstocks in 2012, where the greatest fruit weight was observed with JM.5 that had the lowest number of fruits. However, in 2015, no differences in the number of fruit per tree were observed among rootstocks (Table 2) whereas M.7 showed the smallest fruit weight (Table 3). The differences in fruit weigh are not consistent along the years and are probably not due to rootstock influence. Similar results were reported for 'Golden Delicious', 'Honeycrisp' (RUSSO et al., 2007), and 'Gala' (AL-HINAI; ROPER; 2004) which observed little influence of rootstock on fruit weight.

Trunk cross sectional area (TCSA) was significantly affect by rootstock in all years of evaluation (Table 4). The rootstocks JM.3 and JM.8 showed greater TCSA than JM.2 and JM.5 in 2010. In 2011 and 2014, TCSA of JM.3 was higher than all rootstocks but JM.8, whereas in 2012, 2013, 2015 this rootstock showed greater TCSA than the other rootstocks. Differences in TCSA were more evident at the beginning of evaluations (2010) but at the end of the trial (2015), when the orchard was 13 years old, the rootstocks JM.2, JM.5, JM.7, and JM.8 had similar TCSA as M.7, while JM.3 showed the greatest TCSA (Table 4). According to Ferree and Carlson (1987), vegetative growth of apple trees on rootstocks of M.26 size or smaller does not change after the trees are seven years old, but for rootstocks producing larger trees, the age is around 15 years before they no longer change their relative positions. As the rootstocks tested in this study are of greater vigor than M.26 (dwarf), the tested rootstocks fit in the second group. Thus, the differences among rootstocks along the first years of evaluation were not enough to accurately determine the vigor induced by each rootstock. However, the data from 2015 are more solid and from this point on, TCSA differences among rootstocks will probably not change over the next years.

The results found with JM.7 and JM.8 rootstocks are promising since they show a suitable yield and semi-dwarf effect similar to M.7. Therefore, they are potential alternatives to 'Marubakaido' and 'Marubakaido/M.9' for plantings at higher densities. Increasing planting density is one of the most important factors to achieve greater yield of apple orchards (PETRI et al., 2011), but depends on efficient techniques to control tree size (PASA; EINHORN; 2014). In light of this, the rootstocks JM.7 and JM.8 show great potential for increasing the planting density of apple orchards in the region of São Joaquim.

In conclusion, the results show that the rootstocks tested, except for JM.5, show similar productive behavior as M.7; fruit weight of 'Fuji' is little affected by the rootstock; and the rootstocks JM.2, JM.5, JM.7 and JM.8 induce similar vigor, expressed as trunk cross sectional area, as M.7.

TABLE 1- Production per tree, yield, and alternate bearing index (ABI) of ‘Fuji’ apple trees grafted on ‘JM’ apple rootstocks and M.7, from 2010 to 2015, in São Joaquim, SC.

Rootstock	Production per tree (kg)							
	2010	2011	2012	2013	2014	2015	Cumulative	
JM2	14.9 cd	27.0 c	20.5 bc	50.3 a	33.60	33.56	179.8 b	-
JM3	35.2 a	54.4 a	32.9 a	66.7 a	27.19	46.33	262.8 a	-
JM5	8.9 d	17.9 c	14.0 c	32.7 b	24.98	27.24	116.9 c	-
JM7	26.4 ab	41.5 b	34.5 a	48.6 a	28.00	48.29	227.3 ab	-
JM8	31.1 ab	52.8 ab	26.0 ab	55.9 a	21.07	42.51	229.4 ab	-
M.7	23.3 bc	41.5 b	25.2 ab	61.4 a	29.53	40.37	221.4 ab	-
P > F	<0.001	<0.001	0.005	0.001	0.809	0.058	<0.001	-
	Yield (Mg ha^{-1})							
JM2	19.9 cd	35.9 c	27.4 bc	67.0 a	44.78	44.73	239.7 b	0.297
JM3	47.0 a	72.6 a	43.9 a	88.9 a	36.25	61.75	350.3 a	0.297
JM5	11.9 d	23.8 c	18.7 c	43.6 b	33.30	36.31	167.6 c	0.287
JM7	35.7 ab	55.3 b	46.0 a	64.8 a	37.32	64.37	303.0 ab	0.255
JM8	41.5 ab	70.4 ab	34.7 ab	74.5 a	28.08	56.66	305.8 ab	0.355
M.7	31.1 bc	55.4 b	33.6 ab	81.9 a	39.36	53.81	295.1 ab	0.302
P > F	<0.001	<0.001	0.005	0.001	0.809	0.058	<0.001	0.530

*Different letters within columns indicate significant differences according to Duncan’s test ($p < 0.05$). [1]ABI = Alternate Bearing Index

TABLE 2 - Number of fruit per tree and yield efficiency of ‘Fuji’ apple trees grafted on ‘JM’ apple rootstocks and M.7, from 2010 to 2015, in São Joaquim, SC.

Rootstock	Number of fruit per tree						
	2010	2011	2012	2013	2014	2015	Cumulative
JM.2	69.2 bc	120.8 c	94.2 b	289.3 bc	157.50	168.23	899.2 b
JM.3	157.8 a	252.7 a	146.6 a	433.3 a	137.58	227.65	1355.6 a
JM.5	40.2 c	74.8 c	44.0 c	190.1 c	136.78	136.24	622.1 c
JM.7	118.6 ab	186.9 b	131.1 ab	286.2 bc	133.25	233.02	1089.0 ab
JM.8	150.6 a	230.1 ab	99.8 b	354.7 ab	104.33	201.89	1141.4 ab
M.7	108.4 ab	202.9 ab	132.1 ab	371.2 ab	152.30	222.44	1189.4 a
P > F	<0.001	<0.001	<0.001	<0.001	0.860	0.070	<0.001
	Yield efficiency (kg cm^{-2})						
JM.2	0.36 ab	0.50	0.31 b	0.70	0.44	0.38	2.69
JM.3	0.52 a	0.61	0.32 b	0.60	0.25	0.35	2.66
JM.5	0.25 b	0.44	0.23 b	0.53	0.34	0.31	2.09
JM.7	0.49 a	0.63	0.46 a	0.64	0.34	0.54	3.10
JM.8	0.49 a	0.70	0.30 b	0.63	0.23	0.41	2.76
M.7	0.40 ab	0.62	0.30 b	0.73	0.32	0.40	2.77
P > F	0.024	0.141	0.007	0.540	0.615	0.082	0.084

*Different letters within columns indicate significant differences according to Duncan’s test ($p < 0.05$).

TABLE 3- Fruit weight of 'Fuji' apple trees grafted on 'JM' apple rootstocks and M.7, from 2010 to 2015, in São Joaquim, SC.

Rootstock	Fruit weight (g)						
	2010	2011	2012	2013	2014	2015	Average
JM.2	216.50	220.00	218.0 bc	174.50	214.73	199.9 a	207.27
JM.3	223.94	215.50	225.0 bc	152.50	197.60	203.5 a	203.01
JM.5	249.18	264.95	306.7 a	170.02	183.40	200.0 a	229.04
JM.7	223.50	222.00	278.5 ab	171.00	206.46	207.5 a	218.16
JM.8	208.00	228.50	257.2 abc	160.00	200.07	209.5 a	210.54
M.7	214.50	206.00	192.9 c	165.50	192.61	182.0 b	192.25
P > F	0.696	0.251	0.018	0.106	0.192	0.010	0.093

*Different letters within columns indicate significant differences according to Duncan's test ($p < 0.05$).

TABLE 4- Trunk cross sectional area of 'Fuji' apple trees grafted on 'JM' apple rootstocks and M.7, from 2010 to 2015, in São Joaquim, SC.

Rootstock	Trunk cross sectional area (cm^{-2})					
	2010	2011	2012	2013	2014	2015
JM.2	42.4 bc	53.4 cd	66.8 bc	72.3 bc	77.9 b	89.9 b
JM.3	71.1 a	90.8 a	101.2 a	111.6 a	112.6 a	132.9 a
JM.5	36.4 c	42.6 d	58.9 c	61.6 c	73.5 b	90.6 b
JM.7	54.1 ab	65.8 bc	74.4 bc	76.6 bc	84.0 b	90.0 b
JM.8	62.9 a	76.4 ab	83.3 b	89.7 b	93.8 ab	103.1 b
M.7	58.2 ab	68.0 bc	82.5 b	84.9 b	90.7 b	100.1 b
P > F	0.005	<0.001	0.001	<0.001	0.007	0.001

*Different letters within columns indicate significant differences according to Duncan's test ($p < 0.05$).

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