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Physicochemical characterization of 'Pera' orange fruits selections grafted on two rootstocks in the São Francisco Valley, Brazil

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Abstract

'Pera' orange is a scion variety widely grown in commercial orchards of various citrus-producing regions in Brazil due to the good acceptance of its fruits by the consumer market, both for fresh consumption and industrial processing. The development of clones or selections occurs by genetic mutations within genetic improvement studies with the different varieties, consisting of the selection of plants with superior quality and production characteristics to the variety of origin. In this perspective, this study aimed to evaluate the physicochemical characteristics of four 'Pera' orange selections ('D9', 'D12', 'D25', and 'C21') grafted on two rootstocks (Rangpur lime (*Citrus limonia* Osbeck) and 'Volkamer' lemon (*Citrus volkameriana* Tan. and Pasq.), under the semi-arid conditions of the São Francisco Valley, Brazil. The experimental design was completely randomized, in a 4 x 2 factorial arrangement, with the first factor corresponding to the orange selections ('Pera D9', 'Pera D12', 'Pera D25', and 'Pera C21') and the second factor corresponding to the Rangpur lime and 'Volkamer' lemon rootstocks, using five replications of 10 fruits. The physical characteristics evaluated were: fruit mass (g), diameter, and length (mm); fruit firmness (Lb), peel thickness (mm), number of seeds, and juice yield (%). The chemical parameters were determined through the contents of vitamin C, soluble solids (°Brix), and titratable acidity (g of citric acid 100 mL-1), also calculating the maturation index (SS/TA ratio). The interaction between rootstock varieties and orange scions (selections) induced differences in the physical and chemical attributes of fruits, with the Rangpur lime rootstock inducing better fruits for the orange selection 'Pera D-9', which showed the highest values of fruit mass and diameter, associated with thicker peels, lower soluble solids content, lower acidity, and higher vitamin C content, while inducing higher values of fruit length and soluble solids content in the fruits of the orange selection 'Pera C-21', and lower number of seeds and higher juice yield for the orange selection 'Pera D-12'. Based on these results, under these conditions, the physical and chemical characteristics observed in the fruits of the 'Pera' orange selections meet the standards required by the market of fresh fruits.

Keywords:*citrus*, citrus production, sweet orange, postharvest, semi-arid

Introduction

Sweet orange (*Citrus sinensis* (L.) Osbeck) has been consolidated as the main representative of the family Rutaceae, standing out among other citrus species, such as tangerine (*Citrus reticulata* Blanco), lemon [*Citrus limon* (L.) Burm. f. (pro. sp.)] and key lime [*Citrus aurantifolia* (Christm.) Swingle] (Cunha Sobrinho et al., 2013), and relying on scion/rootstock combinations to unite productive potential and quality with tolerance or resistance to biotic and abiotic stresses (Cunha Sobrinho et al., 2013; Bowman et al., 2016).

'Pera' orange is a sweet orange variety whose origin is still unknown, initially cultivated in the Baixada Fluminense region (Rio de Janeiro, Brazil), from there spreading in the early 20th century when it was implanted in Limeira (São Paulo, Brazil) (Donadio et al., 1995). Since then, it has become the most cultivated scion in the country and has contributed significantly to the expansion and consolidation of the national citrus production, mainly due to its adaptability to different edaphoclimatic conditions and the high acceptability of its fruits, which usually present an attractive appearance, flavor, and nutritional value (Coelho et al., 2019) to both fresh consumption (*in natura*) and the frozen concentrated orange juice (FCOJ) processing industry (Cunha Sobrinho et al., 2013). In addition to the cultivar 'Pera,' the 'Pera' selections obtained by genetic improvement have generated "clones" with superior characteristics to the cultivars of origin, with fruits of superior size and quality. This fact has been the subject of research aimed at the physical and chemical characterization of the fruits of these clones, the object of study of this research.

The physicochemical characteristics of fruits may vary due to several factors, such as the cultivar or selection (genotype), the edaphoclimatic conditions, the management practices and fertilization, and the

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maturation stage. These factors give the fruits a complex composition, with values ranging from 86 to 92% of water, 5 to 8% of sugars, 1 to 2% of pectins, 0.2 to 0.5% of lipids, and 0.2 to 0.5% of essential oils, in addition to other components, such as enzymes, pigments, volatile compounds, flavonoids, and vitamins (Oliveira et al., 2012; França et al., 2016; Coelho et al., 2019).

In this perspective, this study aimed to evaluate the physicochemical characteristics of four 'Pera' orange selections ('D9', 'D12', 'D25', and 'C21') grafted on two rootstocks (Rangpur lime 'and 'Volkamer' lemon (*Citrus volkameriana* Tan. and Pasq.), under the semi-arid conditions of the São Francisco Valley.

Material and Methods

The experiment was conducted at the Bebedouro Experimental Field, belonging to Embrapa Semiárido, located in the municipality of Petrolina (PE), at the following coordinates: 9º09' S and 40º22' W, with an average elevation of 365 m. According to Köppen, the climate of the region can be classified as type Bsw'h' (Alvares et al., 2013), corresponding to a very hot semi-arid region with relative humidity around 70% and an average temperature of 26.5º C in March.

The fruits came from adult plants around 13 years old, belonging to four 'Pera' orange selections ('Pera D9', 'Pera D12', 'Pera D25', and 'Pera C21') grafted on Rangpur lime (*Citrus limonia* Osbeck) and 'Volkamer' lemon (*Citrus volkameriana* Tan. and Pasq.) rootstocks grown in a 6.0 x 4.0 m spacing with a drip irrigation system.

For the determination and evaluation of the physical and chemical characteristics, the fruits were harvested in May 2018, packed in transparent plastic bags, and sent to the Laboratory of Post-Harvest Physiology of Embrapa Semiárido (Petrolina, PE, Brazil).

The experimental design used was completely randomized (CRD), in a 4 x 2 factorial arrangement, with five replications of 10 fruits, with the first factor corresponding to the orange selections ('Pera D9', 'Pera D12', 'Pera D25', and 'Pera C21') and the second factor corresponding to the rootstocks (Rangpur lime and 'Volkamer' lemon), totaling 400 fruits.

The combinations of 'Pera' orange scions (selections) and rootstocks were evaluated using the following parameters: a) average fruit mass, measured with a digital scale (g); b) fruit length and diameter, measured with a digital caliper (mm); c) fruit firmness, determined using a laboratory penetrometer (Lb); d) peel thickness, obtained with the same caliper (mm); e) number of seeds, obtained by counting the seeds per fruit; f) vitamin C content, determined by Tillman's method, expressed in milligrams (mg) of ascorbic acid per 100 grams of juice (mg.100g of juice^{-1}); g) total soluble solids content (SS), measured with a portable digital refractometer (ºBrix); h) total titratable acidity (TA), determined by titration (Instituto Adolfo Lutz, 2008) and expressed in grams (g) of anhydrous citric acid per 100 g of juice; i) maturation index (SS/TA), calculated based on the relationship between the content of soluble solids (SS) and titratable acidity (TA); and j) juice yield, calculated as the difference between fruit mass and the juice mass, expressed as a percentage (%).

The data were subjected to analysis of variance (ANOVA), and the means were compared by Tukey's test at 5% probability ($p < 0.05$) using the statistical software SISVAR (Ferreira, 2014).

Results and Discussion

The mean values of fruit mass (g), length and diameter (mm), fruit firmness (Lb), peel thickness (mm), number of seeds, and juice yield (%) of the orange selections 'Pera D9', 'Pera D12', 'Pera D25', and 'Pera C21' grafted on the Rangpur lime and 'Volkamer' lemon rootstocks are seen in Table 1.

For the fruit mass (Table 1), a significant difference was observed between rootstocks only for the orange selection 'Pera D25', while the Rangpur lime rootstock induced higher fruit mass values than the 'Volkamer' lemon, with means of 188.60 g and 154.00 g, respectively. However, the highest fruit mass values were observed for the orange selection 'Pera D9' with the same Rangpur lime rootstock, with a mean of 202.40 g. Nevertheless, there were no significant differences between the rootstocks and the remaining 'Pera' orange selections (Table 1). These results were below those observed by Schinor et al. (2013) when evaluating 'Pera' orange fruits grafted on 42 rootstock hybrids, obtaining fruit mass values as high as 289 g. These variations observed may be associated with the characteristics of the 'Pera' orange selections studied, identified after the stages of selection and genetic improvement. In addition to external factors, especially the edaphoclimatic conditions of temperature, precipitation, and photoperiod, the management techniques used in cultivation, such as pruning, weeding, irrigation, and mulching, among other crop management practices, including nutritional management, the proper application of fertilizers, and phytosanitary control measures can support and allow the expression of the full genetic potential of orange selections, generating fruits with superior size and quality. However, they can also limit and impair expression and production (Cunha Sobrinho et al., 2013).

Table 1. Means of the physical characteristics of fruits of 'Pera' orange selections grafted on two rootstocks under semi-arid conditions. Petrolina, PE, Brazil. 2018.

Fruit mass (g)					
Rootstock	'Pera' orange selections				Mean
	D9	D12	D25	C21	
Rangpur Lime	202.40Aa	157.20Ab	188.60Aab	169.60Aab	179.45A
'Volkamer' Lemon	173.40Aa	177.00Aa	154.00Ba	169.40Aa	168.45A
Mean	187.90a	167.10a	171.30a	169.50a	
Fruit diameter (mm)					
Rootstock	'Pera' orange selections				Mean
	D9	D12	D25	C21	
Rangpur Lime	74.21Aa	66.38Ab	64.84Ab	67.90Ab	68.33A
'Volkamer' Lemon	68.91Ba	69.39Aa	66.45Aa	67.85Aa	68.15A
Mean	71.56a	67.88b	65.64b	67.87b	
Fruit length (mm)					
Rootstock	'Pera' orange selections				Mean
	D9	D12	D25	C21	
Rangpur Lime	67.62Aa	66.02Aa	65.73Aa	67.75Aa	66.8A
'Volkamer' Lemon	67.63Aa	68.64Aa	65.60Aa	66.90Aa	67.2A
Mean	67.6a	67.3a	65.7a	67.3a	
Fruit firmness (Lb)					
Rootstock	'Pera' orange selections				Mean
	D9	D12	D25	C21	
Rangpur Lime	1.25Bb	1.93Aa	1.69Ba	1.61Aa	1.62B
'Volkamer' Lemon	1.80Ab	2.10Aa	2.25Aa	1.84Ab	2.00A
Mean	1.53b	2.01a	1.97a	1.73b	
Peel thickness (mm)					
Rootstock	'Pera' orange selections				Mean
	D9	D12	D25	C21	
Rangpur Lime	3.25Aa	2.63Bc	2.68Abc	2.99Aab	2.89A
'Volkamer' Lemon	2.82Bab	3.08Aa	2.69Ab	2.75Aab	2.84A
Mean	3.04a	2.85ab	2.69b	2.87ab	
Number of seeds fruit^{-1}					
Rootstock	'Pera' orange selections				Mean
	D9	D12	D25	C21	
Rangpur Lime	9.40Aa	5.00Bb	7.80Aa	7.60Aa	7.45A
'Volkamer' Lemon	6.60Ba	8.60Aa	8.00Aa	8.00Aa	7.80A
Mean	8.00a	6.80a	7.90a	7.80a	
Juice yield (%)					
Rootstock	'Pera' orange selections				Mean
	D9	D12	D25	C21	
Rangpur Lime	49.13Aab	49.41Aa	42.11Bb	46.87Aab	46.88A
'Volkamer' Lemon	49.09Aa	47.77Aa	47.69Aa	47.05Aa	47.90A
Mean	49.11a	48.59a	44.90a	46.96a	

Consecutive uppercase means in the columns and consecutive lowercase means in the rows do not differ by Tukey's test (P≤0.05).

The fruit diameters of the 'Pera' orange selections grafted on the two rootstocks showed a similar behavior to that observed for fruit mass, with a significant effect of the Rangpur lime rootstock on the 'Pera D-9' selection (Table 1), resulting in the largest diameters (74.21 mm) compared to the remaining orange selections ('Pera D12', 'Pera D25', and 'Pera C21'). In contrast, the same 'Pera' orange selections, when grafted on the 'Volkamer' lemon rootstock, did not differ from each other even though the 'Pera D12' orange selection showed the highest values of fruit diameter (68.91 mm). There was a significant effect of the rootstock on the 'Pera D9' selection, with the Rangpur lime rootstock showing the best results (74.21 mm).

As for fruit length (Table 1), there was no significant effect between the rootstocks and the 'Pera' orange selections, as seen in the combination between the orange selection 'Pera C21' and the Rangpur lime rootstock, which resulted in the longest fruits (67.75 mm),

followed in descending order by the selections 'Pera D9', 'Pera D12', and 'Pera D25' (Table 1). Meanwhile, in the combinations with the 'Volkamer' lemon rootstock, the highest fruit length values were observed with the orange selections 'Pera D12' (68.64 mm) and 'Pera D9' (67.63 mm), which, however, did not differ from the orange selections 'Pera C21' and 'Pera D25'. Similar results were obtained by Rodrigues et al. (2019), who observed no significant effect of the rootstocks on fruit diameter and length of 'Pera' oranges. On the other hand, Schinor et al. (2013), evaluating 'Pera' orange scions grafted on rootstock hybrids, verified a significant effect of the rootstocks on fruit mass, diameter, and length.

The interaction between rootstock and cultivar was also significant for fruit firmness (Table 1), highlighting the orange selections 'Pera D25' (2.25 Lb) and 'Pera D12' (2.10 Lb), which, grafted on the 'Volkamer' lemon rootstock, showed greater firmness, differing statistically from the orange selections 'Pera D9' and 'Pera C21'. These results indicate that the 'Volkamer' lemon rootstock induces the production of firmer fruits by 'Pera' orange selections compared to the Rangpur lime rootstock.

The Rangpur lime rootstock induced the highest peel thickness in the orange selection 'Pera D9' (3.25 mm) followed by the selection 'Pera C21', while the 'Volkamer' lemon rootstock induced the highest peel thickness in the orange selection 'Pera D12' (3.08 mm) followed by the selections 'Pera D9' and 'Pera C21'. These results were similar to those observed for fruit mass and diameter.

Regarding the number of seeds fruit^{-1} (Table 1), no significant difference was verified for the rootstocks and 'Pera' orange selections individually, despite the significance observed in the interaction between the two factors. The orange selection 'Pera D12' showed the lowest number of seeds when grafted on the Rangpur lime rootstock (5.0 seeds fruit^{-1}), while the 'Volkamer' lemon rootstock induced the lowest number of seeds in the orange selection 'Pera D9' (6.6), not differing statistically from the remaining selections. The number of seeds fruit $^{-1}$ is an important attribute used as a marketing parameter for fresh citrus fruits (*in natura*), given the growing interest by consumers in fruits with fewer or no seeds (CEAGESP, 2011).

The Rangpur lime rootstock also influenced the orange juice yield, with the orange selection 'Pera D12' showing the highest yield (49.41%), followed by the orange selections 'Pera D9' and 'Pera C21', which were statistically superior to the selection 'Pera D25'. The 'Volkamer' lemon rootstock, on the other hand, did not induce significant differences between scions, although the orange selection 'Pera D9' resulted in higher values (49.09%). These results are above the standards required by the fresh fruits market, which demands yields above 35%, and also above the industry standards, which demands values above 45% (CEAGESP, 2011). Similar results were observed by Rodrigues et al. (2019) when evaluating 'Pera' orange scions grafted on different rootstocks, obtaining juice yields above 51% with the Rangpur lime 'Santa Cruz', citrandarin 'Índio', and mandarin 'Cleopatra' rootstocks, as well as with the hybrid 'LVK x LCR- 038 '. Schinor et al. (2013), when evaluating 'Pera' orange scions grafted on different rootstocks, also obtained juice yield values above the required standards, both for fresh consumption and for industrial processing, ranging from 42 to 56% according to the rootstock used.

Among the main chemical attributes of orange fruits, the importance of the levels of total soluble solids (SS) and total titratable acidity (TA) is highlighted. Together, these data allow calculating the maturation index, directly inferring post-harvest fruit quality as well as the total vitamin C content. (Table 2).

The interaction between rootstocks and 'Pera' orange selections was significant for the content of total soluble solids (SS), resulting in higher values for this variable in the fruits of the orange selection 'Pera C21' when grafted on the Rangpur lime rootstock (12.78 °Brix), being statistically higher to the values obtained with the orange selection 'Pera D9' grafted on the same rootstock. For the 'Volkamer' lemon rootstock, the best results were observed with the orange selections 'Pera D12' (12.62 °Brix) and 'Pera C21' (12.56°Brix). These results were above the required for fresh consumption and for the juice industry, which is 10.0°Brix (CEAGESP, 2011), above the results obtained by Rodrigues et al. (2013) when evaluating the 'Pera' orange grafted on the citrandarin 'Índio' (9.55 °Brix), hybrid 'LVK x LCR - 038' (9.40 °Brix), and Rangpur lime 'Santa Cruz' (9.35 °Brix) rootstocks, and similar to the results obtained by Sampaio et al. (2016) with 'Pera' orange fruits, as well as by Sombra et al. (2018) with 'De Russas' orange fruits (*C. sinensis*).

The effect of the interaction between rootstocks and cultivars was also significant regarding total titratable acidity (TA). The orange selection 'Pera D25' showed higher acidity when grafted either on the Rangpur lime (0.90 g of citric acid.100 mg^{-1}) or on the 'Volkamer' lemon rootstocks (0.83 g of citric acid.100 mg^{-1}). On the other hand, the orange selection 'Pera D9' orange showed lower acidity with both rootstocks, resulting in 0.41 and 0.61 g of citric acid 100 mg^{-1} of juice.

Table 2. Means of the chemical characteristics of fruits of 'Pera' orange selections grafted on two rootstocks under semi-arid conditions. Petrolina, PE, Brazil. 2018.

Total soluble solids (°Brix)					
Rootstock	'Pera' orange selections				Mean
	D9	D12	D25	C21	
Rangpur Lime	11.60Ab	12.44Aab	12.48Aab	12.78Aa	12.33A
'Volkamer' Lemon	11.58Ab	12.62Aa	11.56Bb	12.56Aa	12.08A
Mean	11.59b	12.53a	12.02ab	12.67a	

Total titratable acidity (g of citric acid.100 g of juice^{-1})					
Rootstock	'Pera' orange selections				Mean
	D9	D12	D25	C21	
Rangpur Lime	0.41Bc	0.70Ab	0.90Aa	0.62Ab	0.66A
'Volkamer' Lemon	0.61Ab	0.68Ab	0.83Aa	0.61Ab	0.68A
Mean	0.51c	0.69b	0.86a	0.61b	

Maturation index (SS/TA)					
Rootstock	'Pera' orange selections				Mean
	D9	D12	D25	C21	
Rangpur Lime	28.31Aa	17.92Ab	13.95Ac	20.58Ab	20.19A
'Volkamer' Lemon	19.58Ba	18.77Aa	14.05Ab	20.85Aa	18.31B
Mean	23.95a	18.35b	14.00c	20.71b	

Vitamin C (mg.100 g of juice^{-1})					
Rootstock	'Pera' orange selections				Mean
	D9	D12	D25	C21	
Rangpur Lime	77.31Aa	75.47Aab	60.74Bb	69.94Aab	70.87A
'Volkamer' Lemon	66.26Aab	58.90Bb	80.99Aa	58.90Ab	66.27A
Mean	71.79a	67.19a	70.87a	64.42a	

Consecutive uppercase means in the columns and consecutive lowercase means in the rows do not differ by Tukey's test (P≤0.05).

The significance of the interaction was also verified in the maturation index, with higher ratio values (SS/TA) in the fruits of the orange selection 'Pera D9' grafted on the Rangpur lime rootstock, with a mean of 28.3. As for the 'Volkamer' lemon rootstock, the best results were observed with the orange selection 'Pera C21' (20.85), followed by selections 'Pera D9' and 'Pera D12'. According to Chitarra and Chitarra (2005), the maturation index determines the flavor of the fruit pulp, being more representative than the individual determination of soluble solids or titratable acidity as this index expresses the sweet-acid nature of the pulp. The values obtained were higher than those observed by Rodrigues et al. (2013) for 'Pera' orange grafted on the citrandarin 'Indio' (8.60), Rangpur lime 'Santa Cruz' (8.53), and on the hybrid 'LVK x LCR-038' (8.35) rootstocks, and similar to the values obtained by Sombra et al. (2018) with 'De Russas' orange fruits, in addition to meeting the requirements for fresh consumption, demonstrating that the fruits of the 'Pera' orange selections produced in the São Francisco Valley are above the standards required by the market (CEAGESP, 2011).

Following the trend observed for most of the chemical characteristics of fruits, the interaction between rootstocks and the scions of the different 'Pera' orange selections was also significant for the vitamin C content, highlighting the orange selection 'Pera D-25' grafted on the 'Volkamer' lemon rootstock, with 80.99 mg of ascorbic acid in 100 mg of juice-1. In turn, for the Rangpur lime rootstock, the best result was observed with the orange selection 'Pera D9' (77.31 mg in 100 mg of juice^{-1}). These results were similar to those obtained by Sombra et al. (2018) for 'BRS Russas 02' orange fruits, with a mean value of 77.95 mg of ascorbic acid in 100g of juice^{-1}, and above the values observed by Martins et al. (2020) in 'Pineapple' orange fruits, varying from 62 to 68 mg in 100g of juice^{-1}, according to the rootstock.

Conclusions

The interaction between rootstocks and 'Pera' orange selections induced differences in the physical and chemical attributes of fruits, in which the Rangpur lime rootstock influenced and provided better fruits with the orange selection 'Pera D9', resulting in higher values of fruit mass and diameter, higher peel thickness, lower soluble solids content, lower acidity, and higher vitamin C content. The fruits of the orange selection 'Pera C21' grafted on the same rootstock showed higher values of fruit length and soluble solids, while the fruits of the orange selection 'Pera D12' resulted in fewer seeds and higher juice yield.

The physicochemical attributes of fruits in the 'Pera'

orange selections studied met the standards required by the market of *in natura* fruits, showing satisfactory quality across the different combinations evaluated under the semi-arid conditions of the São Francisco Valley, Brazil.

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