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Pomology/ Original Article

Agronomic performance of 'Valência' orange combined with 13 rootstocks in the state of Rio Grande do Sul, Brazil

Abstract – The objective of this work was to evaluate the agronomic performance of 'Valência' sweet orange (*Citrus sinensis*) tree, in combination with 13 rootstocks cultivated in soil and climate conditions of the Brazilian state of Rio Grande do Sul. The following agronomic variables were evaluated: scion height and volume, plant production, production efficiency, productivity, fruit diameter, fruit mass, peel mass, juice yield, soluble solids content, titratable acidity, soluble solids:acidity ratio, ascorbic acid, peel color, antioxidant capacity, and phenolic compounds. A randomized complete block experimental design was used, with three replicates and nine plants per plot, in a two-factor arrangement (13 rootstocks and the 2015 and 2016 harvests). The following rootstocks stood out: TSKC × TRDP-023 for its juice yield (54.0 and 51.7%), soluble solids:acidity ratio (8.66 and 6.99), and ascorbic acid (49.3 and 51 mg 100 g^{-1}); and the citrandarin 'San Diego', for its higher phenolic-compound content (106.4 and 74.9 100 g^{-1} gallic acid), coloration (76.2 and 75.9 hº), and ascorbic acid (42.2 and 44.7 mg 100 g^{-1}). The TSKC × TRDP-026 and TSKC × CTQT1434-004 rootstocks induce canopy formation and productive precocity in 'Valência' orange trees grown in the southern region of the state of Rio Grande do Sul state, in the first few years of growth.

Index terms: *Citrus sinensis*, bioactive compounds, fruit quality.

Desempenho agronômico de laranja 'Valência' em combinação com 13 porta-enxertos no Rio Grande do Sul, Brasil

Resumo – O objetivo deste trabalho foi avaliar o desempenho agronômico de laranjeira 'Valência' (*Citrus sinensis*), em combinação com 13 porta-enxertos cultivados nas condições edafoclimáticas do Rio Grande do Sul. Avaliaram-se as seguintes variáveis agronômicas: altura e volume da copa, produção por planta, eficiência produtiva, produtividade, diâmetro dos frutos, massa dos frutos, massa das cascas, rendimento do suco, sólidos solúveis, acidez titulável, relação sólidos solúveis:acidez, ácido ascórbico, coloração da casca, capacidade antioxidante e compostos fenólicos. Utilizou-se um delineamento experimental de blocos ao acaso, com três repetições e nove plantas por parcela, em arranjo bifatorial (13 porta-enxertos e as safras 2015 e 2016). Destacaram-se os porta-enxertos: TSKC x TRDP-023, quanto ao rendimento de suco (54,0 e 51,7%), à relação açucar:acidez (8,66 e 6,99) e ao ácido ascórbico (49,3 e 51 mg 100 g^{-1}); e o citrandarin 'San Diego', quanto ao teor de compostos fenólicos (106,4 e 74,9 100 g^{-1} de ácido gálico), à coloração (76,2 e 75,9 hue) e ao ácido ascórbico (42,2 e 44,7 mg 100 g^{-1}). Os porta-enxertos TSKC x TRDP-026 e TSKC x CTQT1434-004 induzem a formação de copa e a precocidade produtiva de laranjeira 'Valência' nos primeiros anos, na região sul do Rio Grande do Sul.

Termos para indexação: *Citrus sinensis*, compostos bioativos, qualidade de frutos.

Introduction

Brazil occupies a notable position within global citriculture, with an annual production of 16 million tonnes. Sweet oranges [*Citrus sinensis* (L.) Osbeck] are particularly notable; and Brazil accounts for 30% of its global production whose primary focus is juice export (IBGE, 2014). 'Valência' is the main sweet orange cultivated on a global level (Fundecitrus, 2017), and it is highly adapted to the Brazilian state of Rio Grande do Sul (Cunha Sobrinho et al., 2013). Citrus production in the South of Brazil amounts to approximately 1.654 million tonnes, out of which 504 thousand tonnes (27%) come from Rio Grande do Sul (IBGE, 2014).

Various agronomic characteristics are influenced by the rootstock chosen, such as fruit productivity and quality, nutrient absorption, synthesis and use, plant size and longevity, and tolerance to drought and salinity (Schäfer et al., 2001). Rootstock choice also affects the content of bioactive compounds in citrus fruits (Legua et al., 2014). These compounds exhibit antioxidant properties that are beneficial to human health.

Rootstocks are commonly used in fruit farms for their favorable attributes to scions. However, there is a limited diversity available for citriculture rootstocks within Southern Brazil. The hybrid lemon 'Cravo' (*C. limonia* Osbeck) holds a notable position in domestic citriculture when used as a rootstock. In Rio Grande do Sul, the main rootstock use is the trifoliate orange [*Poncirus trifoliata* (L.) Raf.], as it shows and excellent adaptability to the local climate conditions, reduces the size of the scion, increases planting density, and is resistant to diseases, such as gummosis caused by Phytophthora. In addition, it improves fruit productivity and quality (Cunha Sobrinho et al., 2013; Carvalho et al., 2016). Nonetheless, this rootstock species is susceptible to drought. This problem is most evident both in years with drought stress and in very sandy soils, leading to production fluctuations. In some cases, the use of inappropriate rootstocks for a given scion can result in incompatibility issues or gum formation on the graft line, leading to minimally productive and short-lived orange trees (Pompeu Junior & Blumer, 2014).

The use of hybrid rootstocks is a method to increase the distribution of favorable characteristics within the available citric genetic diversity in Southern Brazil. For instance, hybrid citrandarin rootstocks are used due to their improved ability to tolerate citrus decline and sudden death, immunity to the tristeza virus, and resistance to gummosis (Pompeu Junior & Blumer, 2014).

Diversifying the variety of scions and rootstocks is significantly important for reducing risks. Fruit farms that restricts the use of the varieties that are available to them are subject to natural, biotic stress (in the form of plagues and diseases), as well as abiotic stress (mainly relating to climate).

The objective of this work was to evaluate the agronomic development of 'Valência' orange trees, combined with 13 rootstocks cultivated in climate and soil conditions of the Brazilian state of Rio Grande do Sul.

Materials and Methods

The experiment was performed in Monte Bonito (31º40'47"S, 52º26'24"W, at 60 m altitude), a district of Pelotas county, in the state of Rio Grande do Sul, Brazil. 'Valência' orange scions, combined with 13 rootstocks, were evaluated during the 2015 and 2016 harvests. Twelve-month-old seedlings of 40 cm height were planted in 5.0 m x 4.0 m spacing and analyzed at four and five years of age. The local soil is moderately deep, with a medium texture sand in the horizon A and clay in the horizon B, and it is classified as Argissolo Vermelho Amarelo (Santos et al., 2006), i.e., Oxisol. According to the Köppen-Geiger classification, the region exhibits a Cfa climate, indicating a humid subtropical climate with hot summers. Climactic data were obtained in an Embrapa experimental station near the fruit farm. The area has 1,590 mm mean annual precipitation, 18.4°C mean annual temperature, and 78.8% relative annual air humidity (INMET, 2016).

A randomized complete block experimental design was employed, with three replicates and nine plants per plot, and a bifactorial arrangement with 13 rootstocks over the 2015 and 2016 harvests. The three central plants of each block were evaluated. The rootstocks consisted of hybrids selected by the program for the improvement of Citrus genetics of Embrapa Mandioca e Fruticultura, in Bahia state, Brazil (Table 1).

The following vegetative characteristics were evaluated for: scion height (H), measured with a graduated ruler from the intersection point of stalk and root until the scion apex, expressed in meters; scion volume (V), obtained by the formula $V = \pi/6 \times H \times (d1 \times d2)$, provided by Fallahi & Rodney (1992), in which d represents the diameter of the scion measured both longitudinally (d1) and perpendicularly to the line of the plant (d2); plant productivity, obtained by counting and weighing the collected fruit (kg per plant); production efficiency, corresponding to the number of fruit per unit of scion volume, obtained with the formula EP = (number of fruit × fruit mass) / V (expressed in kg m^{-3}); and fruit farm productivity, obtained from fruit mass and production area (Mg ha^{-1}).

Fruit were collected at the maturation stage, at the ready-for-sale point 10 on the scale adapted from Barbasso et al. (2005), which randomly considers the four quadrants of the scion. The collected fruit were placed in cleaned and disinfected plastic boxes and then transported to the laboratory of the Universidade Federal de Pelotas. There, fruit undergone a pre-selection, and damaged or otherwise affected fruit were discarded. In this way, fruit were effectively standardized. From the selected fruit, 20 ones from each replicate were assigned to analysis, which totaled three replicates per combination of rootstocks and scions.

The following physical characteristics were evaluated: fruit diameter (mm), measured with a digital caliper; mean mass (g) of whole fruit and peel, measured with a semi-analytical balance; juice yield (%), determined by taking the ratio of the whole fruit mass and pulp mass; peel color, identified with a Minolta CR-300 colorimeter (Konica Minolta, Ramsey, NJ, USA) and described using the Cielab color space; and chromatic tonality (hº), calculated as the arctangent of b*/a* and expressed in degrees.

The following chemical characteristics were evaluated: soluble solids content (°Brix), which was quantified using a PAL-1 digital refractometer (Atago, Bellevue, WA, USA); titratable acid, determined by titrating 10 mL of fruit juice, added to 90 mL of distilled water at 8.1 pH, with a digital burette containing a 0.1 N solution of sodium hydroxide, and expressed as a percentage of citric acid, in line with AOAC (Horwitz & Latimer Jr., 2005); the ratio of soluble solids to titratable acids, obtained by following the analytic manual of Instituto Adolfo Lutz (Zenebon et al., 2008); and ascorbic acid content, quantified using the official AOAC method (Horwitz & Latimer Jr., 2005) by oxidative titration with 2,6-dichlorophenolindophenol to the point of the initial conversion of the solution to pink (mm ascorbic acid 100 g^{-1} sample (Jacobs, 1958; Leme Junior & Malavolta, 1950).

The following phytochemical characteristics were evaluated: antioxidant capacity (µg Trolox equivalent g^{-1} juice), determined by spectrophotometry using a method adapted from Brand-Williams et al. (1995); and total phenolic compounds (mL gallic acid equivalent 100 g^{-1} juice, quantified using the Folin-Ciocalteu reagent in line with the method described by Swain & Hillis (1959).

Table 1. Description of citrus rootstocks used with 'Valência' orange (*Citrus sinensis*) scions in the 2015 and 2016 harvests, in the municipality of Pelotas, in the state of Rio Grande do Sul, Brazil.

Rootstock	Scientific description
TSKC × CTQT 1439–035	['Sunki' mandarin, common, *C. sunki* (Hayata) hort. ex Tanaka] × [citrangequat 'Thomasville' [kumquat 'Oval' or 'Nagami' *Fortunella margarita* (Lour.) 'Swingle' selection 1439 × citrange (*C. sinensis* × *P. trifoliata*) 'Willits' selection 035]
TSKC × TRDP-026	['Sunki' mandarin, common, *C. sunki* (Hayata) hort. ex Tanaka] × [*P. trifoliata* selection diploid selection 026]
HTR-206	Trifoliate hybrid selection 206
HTR-208	Trifoliate hybrid selection 208
TSKFL × CTTR-006	['Sunki' mandarin, Florida selection, *C. sunki* (Hayata)] × [citrange 'Troyer' *C. sinensis* (L.) Osbeck selection 006]
TSKC × CTRK-001	['Sunki' mandarin, common, *C. sunki* (Hayata) hort. ex Tanaka] × [citrange 'Rusk' *C. sinensis* (L.) Osbeck × *C. trifoliata* selection 001]
TSKC × CTTR-028	['Sunki' mandarin, common, *C. sunki* (Hayata) hort. ex Tanaka] × [citrange 'Troyer' *C. sinensis* (L.) Osbeck selection 028]
LVK × LCR-010	['Volkameriano' lemon *C. volkameriana* V. Ten. & Pasq.] × ['Cravo' lemon *C. limonia* Osbeck selection 010]
TSKC × TRBK-007	['Sunki' mandarin, common, *C. sunki* (Hayata) hort. ex Tanaka] × [*P. trifoliata* 'Benecke' selection 007]
TSKC × CTQT 1434-004	['Sunki' mandarin, common, *Citrus sunki* (Hayata) hort. ex Tanaka] × [citrangequat 'Thomasville' [kumquat 'Oval' or 'Nagami' *Fortunella margarita* (Lour.) 'Swingle' selection 1434 × citrange (*C. sinensis* × *Poncirus trifoliata*) 'Willits' selection 004]
HTR-207	Trifoliate hybrid selection 207
TSKC × TRDP-023	['Sunki' mandarin, common, *C. sunki* (Hayata) hort. ex Tanaka] × [*P. trifoliata* selection diploid selection 023]
Citrandarin San Diego	[*C. sunki*] × [*P. trifoliata* 'Swingle' selection 314]

Data were analyzed for normality and homoscedasticity, using the Shapiro-Wilk and Hartley tests, respectively. Afterward, data were subjected to the analysis of variance at 5% probability. When significant, the Scott-Knott test was performed, at 5% probability, in order to compare the grouping of the means.

Results and Discussion

Rootstocks TSKC × TRDP-023, TSKC × TRDP-026, HTR-206, TSKC × CTTR-028, and citrandarin 'San Diego' provided a significant difference for plant height. These rootstocks favored a greater development of 'Valência' scion in comparison to other rootstocks (Table 2).

The trifoliate hybrid HTR-207 showed the lowest height (1.37 m). This indicates the potential of this species to be used as a dwarfing rootstock, thereby allowing of fruit farms with a greater plant density than usual ones. These kind of rootstocks are of significant interest due to the practicality they offer for fruit farm management (Pompeu Junior & Blumer, 2009).

In a study performed in the Bahia state, França et al. (2016) analyzed 'Tuxpan Valência' orange trees at four and eight years of age which had been combined with 14 rootstocks. They measured 2.20 m mean height, ranging from 1.40 m for TSKFL × CTSW-049 hybrid rootstock to 2.80 m for 'Indio' citrandarin rootstock.

The most rootstocks studied herein increased the scion volume over the evaluation period, with the most notable performance in the 2016 harvest attributed to HTR-206 and TSKC × CTTR-028.

Rootstocks TSKC × TRDP-026, HTR-206, TSKC × CTTR-028, and TSKC × CTQT1434-004 provided the most favorable fruit productivity values per plant in their fifth year of age, with values of 14.6, 17.4, 14.0, and 16.8 kg per plant (Table 3), respectively. This may be the result of the climactic conditions in the South region of Brazil during the evaluated period, as the mean temperature and rainfall were 18.4ºC and 1,590 mm, respectively. However, in their study of 'Tuxpan

Table 2. Scion height and longitudinal (d1) and perpendicular (d2) diameters to the line of the plant for 'Valência' orange (*Citrus sinensis*) combined with 13 rootstocks in the 2015 and 2016 harvests, in the municipality of Pelotas, in the state of Rio Grande do Sul, Brazil(1).

Rootstock	Height (m)		d1 (m)		d2 (m)	
	2015 B	2016 A	2015 B	2016 A	2015 B	2016 A
TSKC × CTQT1439-035	1.68c	1.96c	1.62b	2.05b	1.63c	1.86c
TSKC × TRDP-026	2.09a	2.43a	1.76b	2.23b	1.86a	2.26a
HTR-206	2.21a	2.66a	2.02a	2.60a	1.88a	2.46a
HTR-208	1.95b	2.30b	1.79b	2.33b	1.71a	2.48a
TSKFL × CTTR-006	1.81c	1.92c	1.67b	2.29b	1.64b	2.16b
TSKC × CTRK-001	2.01b	2.22b	1.80b	2.32b	1.79a	2.31a
TSKC × CTTR-028	2.11a	2.75a	2.04a	2.63a	1.94a	2.52a
LVK × LCR-010	2.02b	2.21b	1.82b	2.16b	1.78b	2.07b
TSKC × TRBK-007	2.02b	2.32b	1.86a	2.56a	2.03a	2.44a
TSKC × CTQT1434-004	1.84c	2.11c	1.84b	2.18b	1.88b	1.99b
HTR-207	1.35d	1.39d	2.21c	1.56c	1.27d	1.59d
TSKC × TRDP-023	2.14a	2.58a	2.07a	2.44a	1.84a	2.33a
Citrandarin San Diego	2.08a	2.48a	1.97a	2.52a	1.95a	2.41a
Mean	1.94	2.25	1.81	2.29	1.78	2.22
General mean	2.09		2.05		2.00	
Coefficient of variation (%)	9.5		11.3		12.0	
F(2) harvest	96.62**		133.27**		173.99**	
F(2) rootstock × harvest	23.96**		9.39**		12.70**	
F(2) rootstock	1.70^{ns}		1.39^{ns}		0.93^{ns}	

(1)Values followed by equal letters, lowercase in the columns and uppercase in the rows, do not differ by the Scott-Knott's test, at 5% probability. (2)F, analysis of variance. ^{ns}Nonsignificant. *, **Significant at 5 and 1% probability, respectively.

Valência' orange trees in the state of Bahia, França et al. (2016) found fruit productivity values of 10.2, 8.4, 11.2, and 15.1 kg for five-year-old plants with rootstocks TSKFL × CTTR, LVK × LVA, TSKC × (LCR × TR), and 'Indio' citrandarin, respectively.

Rootstocks TSKC × CTQT1434-004 and HTR-207 yielded significant increases in production efficiency, both in 2015 and 2016 harvests, with final values of, respectively, 2.1 and 3.4 kg m^{-3}, and 3.1 and 2.4 kg m^{-3} (Table 3). These results suggest that these rootstocks induce precocity in fruit production. In addition, the hybrids TSKC × TRDP-026, HTR-206, HTR-208, and TSKC × TRDP-023 showed higher-production efficiency values specifically in the 2016 harvest. This is most likely the result of greater vegetative growth during the 2015 season, which led to greater production in the following year.

However, the first harvest showed no difference for productivity between the rootstocks due to plant precocity, and had an average value of 2.0 Mg ha^{-1}. The rootstock TSKC × CTQT1434-004 provided 3.0 Mg ha^{-1}, which is the highest-productivity value (Table 3). Meanwhile, in the 2016 harvest, the rootstocks that showed the highest-productivity values were HTR-206 (8.7 Mg ha^{-1}), TSKC × CTQT1434-004 (8.4 Mg ha^{-1}), TSKC × TRDP-026 (7.3 Mg ha^{-1}), TSKC × CTTR-028 (7.0 Mg ha^{-1}), and HTR-208 (6.7 Mg ha^{-1}).

As to fruit diameter, the rootstocks that provided the largest values were TSKC × CTTR-028 (74.9 to 75.0 mm), LVR × LCR-010 (77.9 to 77.5 mm), TSKC × TRBK-007 (75.9 to 76.9 mm), TSKC × CTQT1434-004 (75.9 to 78.3 mm), and HTR-207 (77.4 to 79.5 mm) (Table 4).

The hybrids HTR-07, TSKC × CTQT1434-004, and TSKFL × CTTR-006 provided an increased fruit mass across harvests, providing the highest values in 2016 (Table 4). In a comparison, Carvalho et al. (2016) found that rootstocks HTR-207, LVK × LCR-030, and LVK × LCR-038, when grafted with four-year-old 'Pera CNPMF-D6', showed fruit mass values of 193, 170, and 220 g, respectively, in their study in the Tabuleiros Costeiros region of Sergipe state, Brazil.

In the first season, juice yield varied between the different rootstock combinations (Table 4), with TSKC

Table 3. Vegetative characteristics of 'Valência' orange (*Citrus sinensis*) combined with 13 rootstocks, in the 2015 and 2016 harvests, in the municipality of Pelotas, in the state of Rio Grande do Sul, Brazil[(1)].

Rootstock	Scion volume (m^3)		Plant production (kg $plant^{-1}$)		Production efficiency (kg m^{-3})		Productivity (Mg ha^{-1})	
	2015	2016	2015	2016	2015	2016	2015	2016
TSKC × CTQT1439-035	2.4bB	4.0aC	4.8aA	6.9aC	1.6cA	1.7cA	2.4aA	3.5aC
TSKC × TRDP-026	3.6bA	6.5aB	4.9bA	14.6aA	1.3cB	2.4bA	2.5bA	7.3aA
HTR-206	4.4bA	9.0aA	3.3bA	17.4aA	0.8cB	2.0cA	1.7bA	8.7aA
HTR-208	3.2bA	6.9aB	3.9bA	13.5aA	1.2cB	1.9cA	1.9bA	6.7aA
TSKFL × CTTR-006	2.6bB	5.1aC	4.6aA	8.2aB	1.5cA	1.7cA	2.3aA	4.1aB
TSKC × CTRK-001	3.4bA	6.3aB	4.9bA	10.2aB	1.4cA	1.6cA	2.5bA	5.1aB
TSKC × CTTR-028	4.3bA	9.6aA	3.9bA	14.0aA	0.9cA	1.5cA	2.0bA	7.0aA
LVK × LCR-010	3.4bA	5.2aC	5.1aA	6.6aC	1.5cA	1.3cA	2.6aA	3.3aC
TSKC × TRBK-007	4.0bA	7.6aB	5.9aA	8.6aB	1.6cA	1.1cA	3.0aA	4.3aB
TSKC × CTQT1434-004	3.3bA	4.8aC	6.2bA	16.8aA	2.1bA	3.4aA	3.1bA	8.4aA
HTR-207	1.0aC	1.8aD	3.8aA	5.1aC	3.1aA	2.4bA	1.9aA	2.1aC
TSKC × TRDP-023	4.2bA	7.6aB	4.0bA	11.0aB	0.9cB	1.4cA	2.0bA	5.5aB
Citrandarin San Diego	4.2bA	7.9aB	4.4bA	8.5aB	1.1cA	1.6cA	2.2bA	4.2aB
Mean	3.43	6.30	4.50	11.10	1.46	1.85	2.31	5.52
Coefficient of variation (%)	24		41		47		41	
F[(2)] harvest	247.15**		162.6**		8.06**		162.87**	
F[(2)] rootstock × harvest	19.01**		4.76**		1.87*		4.76**	
F[(2)] rootstock	3.48**		4.91**		5.61**		4.90**	

[(1)]Values followed by equal letters, lowercase in the columns and uppercase in the rows, do not differ, by the Scott-Knott's test, at 5% probability. [(2)]F, analysis of variance. [ns]Non significant. *, **Significant at 5 and 1% probability, respectively.

× CTQT1439-035 (56.3%), LVK × LVR-010 (58.7%), and TSKC × TRDP-023 (54.0%) providing the highest values. In the second season, HTR-207 and TSKC × TRBK-007 provided the greatest-yield increase, with mean values of 59.1 and 54.8%, respectively. Comparatively, in Bahia state, França et al. (2016) found 51% juice yield for TSKC × CTSW-028 and TSKFL × CTTR-017, as well as 42% for TSKFL × CTSW-049, from the 2010 to 2014 seasons.

Total soluble solids varied significantly across the evaluation years (Table 4). In the first year, the highest values were provided by TSKC × TRDP-023 (11.8ºBx) and the citrandarin 'San Diego' (11.4ºBx), whereas in the second year, the highest values were observed for HTR-207 (10.4ºBx), which meet the minimum requirements for total soluble solids. In a study performed in Paraná state, Brazil, Auler et al. (2008) found 10.4 and 11.9ºBx when using 'Cravo' lemon and 'Troyer' citrange, respectively, as rootstocks for 'Valência' oranges. However, França et al. (2016) found 10.8 and 11.3ºBx which were the highest values for TSKC × CTSW-028 and TSKFL × CTTR-017, respectively, over the course of four harvests in their aforementioned study.

The rootstock TSKC × CTQT1439-035 yielded plants with the most acidic oranges; citric acidity was measured at about 1.6% over both seasons (Table 4). However, HTR-206, TSKC × CTTR-028, TSKC × TRBK-007, TSKC × CTQT1434-004, TSKC × TRDP-023, citrandarin 'San Diego', and LVK × LCR-010 had the lowest values for acidity, and the latter one showed a minimum of 1.17%.

Alternatively, França et al. (2016) found acidity values below 1% in their aforementioned study. Likewise, Auler et al. (2009) found values lower than 1.2% in 'Valência' oranges produced in the northeastern Paraná state, in the first three harvest years of their experiment.

The soluble solid/acidity ratio was high, particularly for HTR-206, TSKC × CTTR-028, LVK × LCR-010, TSKC × CTQT1434-004, TSKC × TRDP-023, and citrandarin 'San Diego' rootstocks (Table 5). Meanwhile, the TSKC × CTQT1439-035 hybrid showed the lowest value for this ratio.

Table 4. Physicochemical characteristics of 'Valência' orange (*Citrus sinensis*) combined with 13 rootstocks for 2015 and 2016 harvests, in the municipality of Pelotas, in the state of Rio Grande do Sul, Brazil[1].

Rootstock	Fruit diameter (mm)		Fruit mass (g)		Peel mass (g)		Juice yield (%)		Soluble solids (ºBx)		Titratable acid (% citric acid)	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
TSKC × CTQT1439-035	70.0aB	70.5aB	165aB	172aC	92aB	91aD	56.3aA	52.8aA	9.9aC	8.6bC	1.61aA	1.60aA
TSKC × TRDP-026	66.1aC	67.3aB	151aB	145aC	70aC	69aE	46.7aB	47.6aA	10.5aB	9.6bB	1.48aA	1.18bB
HTR-206	66.8aC	69.1aB	152aB	157aC	64aC	76aE	42.2aB	48.2aA	9.7aC	9.5aB	1.28aB	1.30aB
HTR-208	67.0aC	69.6aB	141aB	160aC	57bC	73aE	40.9aB	45.6aA	10.3aB	9.6aB	1.47aA	1.26bB
TSKFL × CTTR-006	69.1bB	78.2aA	158bB	217aA	72bC	106aC	45.4aB	49.9aA	10.3aB	9.2bB	1.49aA	1.17bB
TSKC × CTRK-001	71.6aB	72.3aB	202aA	179aC	93aB	85aD	46.3aB	47.6aA	9.7aC	9.3aB	1.44aA	1.32aB
TSKC × CTTR-028	74.9aA	75.0aA	184aA	191aB	90aB	98aC	49.1aB	51.2aA	10.3aB	8.8bC	1.36aB	1.17bB
LVK × LCR-010	77.9aA	77.5aA	201aA	203aB	118aA	107aC	58.7aA	53.7aA	9.0aC	8.4aC	1.19aB	1.17aB
TSKC × TRBK-007	75.9aA	76.9aA	218aA	198aB	115aA	108aC	52.9aA	54.8aA	9.7aC	8.5bC	1.27aB	1.32aB
TSKC × CTQT1434-004	75.9aA	78.3aA	192bA	218aA	76bC	118aB	39.6bB	54.3aA	10.0ab	9.4aB	1.28aB	1.28aB
HTR-207	77.4aA	79.5aA	201bA	230aA	109bA	136aA	55.1aA	59.1aA	10.5aB	10.4aA	1.39bB	1.57aA
TSKC × TRDP-023	65.5bC	74.8aA	188aA	190aB	101aB	98aC	54.0aA	51.7aA	11.8aA	9.4bB	1.36aB	1.31aB
San Diego citrandarin	69.1bB	74.7aA	192aA	194aB	92aB	104aC	48.0aB	53.9aA	11.4aA	8.9bC	1.35aB	1.30aB
General mean	73.0		185.91		94.24		50.51		9.73		1.34	
Coefficient of variation (%)	3.0		7.8		8.6		10.0		4.9		7.2	
F[2] harvest	28.07**		10.24**		21.37**		2.34^{ns}		90.72**		11.48**	
F[2] rootstock × harvest	17.85**		13.33**		25.83**		4.30**		7.10**		6.49**	
F[2] rootstock	2.83**		3.38**		6.49**		2.14*		3.64**		3.15**	

[1]Values followed by equal letters, lowercase in the columns and uppercase in the rows, do not differ by the Scott-Knott test within 5% probability. [2]F, analysis of variance. ^{ns}Nonsignificant. *, **Significant at 5 and 1% probability, respectively.

The rootstock TSKC × TRBK-007 had the most pronounced peel color, with the largest hue angle in both harvests (Table 5). The first year showed a greater variation of hue angle between the different rootstocks. When comparing the 2016 season to the 2015 one, TSKFL × CTTR-006, LVK × LCR-010, TSKC × CTQT1434-004, TSKC × TRDP-023, and the citrandarin 'San Diego' were observed for maintaining their color. Nonetheless, in the state of Ceará, Pereira et al. (2014) found high-hue angle values of 100 hº for 'Valência Delta' oranges using the 'Swingle' citrumelo.

Variations were found across the different samples for the ascorbic acid content, whose highest values were observed for TSKC × CTRK-001 and TSKC × TRDP-023, with 50 mg 100 g^{-1} juice (Table 5).

The relative values of antioxidant capacity and phenolic compound content decreased from the first to the second harvest (Table 5). The number of fruit per plant affected the orange quality, as a consequence of the source/drain relationship that characterizes the distribution of photoassimilates to all fruit. The rootstocks HTR-207, TSKC × TRDP-023, and citrandarin 'San Diego' showed higher-antioxidant capacity than the other combinations across both harvests, with total productions of 5.1, 11.0, and 8.5 kg per plant, respectively, in 2016. The overall mean value of antioxidant activity across all tested combinations was 151.36 Trolox g^{-1} juice.

There was a significant variation for phenolic content between the different combinations (Table 5). TSKC × CTRK-001 and citrandarin 'San Diego' were associated with an elevated amount of bioactive compounds in the first harvest year. In a study of 'Clemenules' tangerines, Legua et al. (2014) found that the rootstock plays an important role in the determination of the concentration of phenolic compounds. In particular, they obtained 60 mg gallic acid equivalent 100 g^{-1} when using the 'Volkameriano' lemon as a rootstock. However, in the 2015 harvest, TSKC × CTRK-001 and citrandarin 'San Diego' had 102.7 and 106.4 mg gallic acid equivalent 100 g^{-1}. This shows that these rootstocks provide to 'Valência' orange the capacity to produce greater quantities of phenolic compounds, increasing the health potential that fruit can offer due to their antioxidant activity.

Table 5. Physicochemical and phytochemical characteristics of the 'Valência' orange (*Citrus sinensis*) combined with 13 rootstocks in the 2015 and 2016 harvests, in the municipality of Pelotas, in the state of Rio Grande do Sul, Brazil(1).

Rootstock	Soluble solid/acidity ratio		Peel color Hue angle		Ascorbic acid mg 100 g^{-1}		Antioxidant capacity Trolox g^{-1}		Phenolic compounds gallic acid 100 g^{-1}	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
TSKC × CTQT1439-035	6.17aB	5.41aC	72.6bC	75.8aA	47.5aA	46.7aB	160aB	121bB	82.6aC	70.8bA
TSKC × TRDP-026	7.09aB	8.18aA	73.3aC	74.0aB	45.0aB	45.7aB	174aB	119bB	87.4aC	70.2bA
HTR-206	7.61aA	7.36aA	71.5bC	73.9aB	41.6bB	46.7aB	173aB	117bB	87.9aC	70.6bA
HTR-208	7.06aB	7.67aA	72.0bC	75.0aB	48.1aA	44.7aB	196aA	111bB	98.1aB	70.2bA
TSKFL × CTTR-006	6.95aB	7.92aA	76.1aB	75.3aB	44.7bB	48.7aA	177aB	108bB	93.7aB	64.2bA
TSKC × CTRK-001	6.76aB	7.04aA	72.1bC	75.9aA	47.5bA	51.0aA	198aA	115bB	102.7aA	70.7bA
TSKC × CTTR-028	7.52aA	7.56aA	71.5bC	76.5aA	48.4aA	41.7bB	176aB	108bB	95.5aB	59.4bA
LVK × LCR-010	7.56aA	7.29aA	75.8aB	76.9aA	44.1aB	46.7aB	166aB	119bB	89.5aC	72.2bA
TSKC × TRBK-007	7.71aA	6.39bB	81.9aA	77.2bA	43.8aB	44.7aB	178aB	143bA	95.0aB	67.5bA
TSKC × CTQT1434-004	7.84aA	7.34aA	75.2aB	75.9aA	45.0aB	43.7aB	186aA	124bB	96.0aB	67.0bA
HTR-207	7.59aA	6.68aB	81.6aA	75.0bB	41.9aB	44.7aB	190aA	130bA	94.8aB	69.0bA
TSKC × TRDP-023	8.66aA	6.99bA	75.2aB	74.8aB	49.3aA	51.0aA	185aA	118bA	97.5aB	67.7bA
Citrandarin San Diego	8.53aA	6.85bA	76.2aB	75.9aA	42.2aB	44.7aB	210aA	146bA	106.4aA	74.9bA
General mean	7.30		75.33		45.79		151.36		81.18	
Coefficient of variation (%)	9.2		1.3		4.4		7.5		6.2	
F(2) harvest	4.29*		10.93**		1.47**		589.8**		497.49**	
F(2) rootstock × harvest	3.35**		14.48**		5.80**		5.28**		3.90**	
F(2) rootstock	2.66*		19.45**		3.99**		2.30*		3.70**	

(1)Values followed by equal letters, lowercase in the columns and uppercase in the rows, do not differ by the Scott-Knott test within 5% probability. (2)F, analysis of bariance. nsNonsignificant. *, **Significant at 5 and 1% probability, respectively.

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Conclusions

1. The rootstocks TSKC × TRDP-026 and TSKC × CTQT1434-004 encourage the development of 'Valência' orange scion, and increase its productive precocity in initial harvest years in the soil and climactic conditions of Rio Grande do Sul state.

2. The rootstock TSKC × TRDP-023 provides fruit with high levels of soluble solids, titratable acid, color, and ascorbic acid; and the rootstock citrandarin 'San Diego' offers fruit with improved color and phenolic compound content for 'Valência' oranges in early stages of production, under the soil and climactic conditions of Rio Grande do Sul.

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