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Full Length Article

Performance of Seven Peach Rootstocks in a Brazilian Subtropical Climate

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Abstract

The commercial orchards of peach trees are propagated by grafting, and the combination of rootstock and scion cultivars has significant importance to produce quality fruits. Many studies evaluating the influence of scion cultivars on fruit yield and quality have been executed, but studies on rootstocks under subtropical climate conditions in Brazil are still incipient, making it necessary to evaluate the performance of new rootstocks. This study aimed to evaluate the performance of seven rootstocks based on tree growth, fruit quality, and yield of the scion cultivars Aurora 1 and Tropic Beauty in Brazilian subtropical climate conditions. Seven rootstocks were evaluated from the UFV breeding program (UFV 1701-2, UFV 102-1, UFV 186, UFV 1701-1, UFV 102-2, UFV 286 and UFV 202-1) and one control representing the cultivar most used in the southeastern Brazil (Okinawa). A randomized block design was arranged, with sixteen treatments and five replications. The variables evaluated were trunk cross-sectional area, plant height, fresh weight of pruned material, production per plant, yield, fruit weight, fruit size, skin color, firmness, and soluble solids content. The cultivars Aurora 1 and Tropic Beauty presented a less vigorous growth when grafted onto the rootstocks UFV 186, UFV 286 and UFV 102-1, being suitable for high-density plantings, and a greater yield when grafted onto UFV 1701-1, UFV 1701-2 and UFV 202-1. The fruit weight was similar for all the rootstocks tested, and the quality of fruits from Aurora 1 and Tropic Beauty did not differentiate from the control Okinawa, which means that the performance of the rootstocks from the UFV breeding program meets the standards required by the market and their use can be successful in regions of subtropical climate.

Keywords: Aurora 1; Fruit quality; Productivity; *Prunus persica* (L.) Batsch; Vigor; Tropic beauty

Introduction

The peach tree (*Prunus persica* (L.) Batsch) is the most important species of the genus *Prunus* and has a great prospect of growth in world production in the coming years, currently, China, the European Union, and the United States are the largest producers in the world (Singerman *et al.* 2017; Penso *et al.* 2018; Mendes *et al.* 2019; Ding *et al.* 2020). In Brazil, it can be found in several states with commercial cultivation concentrated in the states of Rio Grande do Sul, São Paulo, Santa Catarina, Paraná, and Minas Gerais (Gonçalves *et al.* 2019).

The Brazilian production is about 216 thousand tons, with a yield of 11.59 tons ha^{-1} (Barreto *et al.* 2020), where this crop has great relevance in family farming, the generation of direct and indirect jobs, and in industry and commerce. In peach commercial crops the seedlings production is mainly through the grafting technique with the rootstocks obtained by seeds, which can provide a high genetic variability among them (Gonçalves *et al.* 2019; Oliveira *et al.* 2020).

Grafting is a technique used in asexual propagation that joins two different plants together, scion and rootstock, to form a new plant, the graft. In this technique, the features of interest from both materials are combined in one individual to obtain edaphoclimatic adaptation, productivity increase, and fruit quality improvement (Orazem *et al.* 2011; Forcada *et al.* 2012; Hussain *et al.* 2013). Research on rootstocks for peach production in Brazil started in the last few decades, while some European countries and the United States have already selected materials for different growth conditions (Picolotto *et al.* 2009).

The precise evaluations of the agronomic and productive responses of rootstocks and the determination of the best scion-rootstock combination are crucial to producing quality fruits (Picolotto *et al.* 2012; Almeida *et al.* 2016;

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Balbinot *et al.* 2020). The interactions between rootstocks and scions are responsible for productivity and fruit quality (Minas *et al.* 2018). The main rootstocks used in the propagation of peach trees in Brazil are from the cultivar Okinawa, which confers resistance to soil-borne pathogens. However, it generates an increase in plant vigor, hindering the use of high-density (Aguiar *et al.* 2005; Santana *et al.* 2020).

Rootstocks are responsible for nutrient and water uptake, resistance to soil pathogens, and tolerance to environmental stresses (Dubey and Sharma 2016); they can influence scion growth by changing the trunk cross-sectional area, height, shape, branch angle, plant nutrition, xylem water potential, phenology, fruit quality, precocity, production, diseases resistance, and plant survival (Picolotto *et al.* 2012; Galarça *et al.* 2013; Marra *et al.* 2013; Gullo *et al.* 2014).

Worldwide, the peach tree is grown mainly in temperate climatic conditions, being more resistant to cold than other species (Souza *et al.* 2017; Khatamova and Kimsanova 2020), but since there is an increasing need for food production, the breeding programs have been advancing in the development of new promising cultivars suitable for propagation in subtropical areas (Marwah *et al.* 2022).

To meet the market demand, peach production in subtropical climate areas, like in Southwestern Brazilian, depends on optimizing the scion and rootstock combinations to increase yield and fruit quality. Because of this, the peach Breeding Program of the Federal University of Viçosa in Brazil carried out outcrosses between genotypes adapted to subtropical and tropical altitude climates and genotypes used as rootstocks from other countries. The program selected the best genotypes based on their adaptation to test as rootstocks for peach and other *Prunus* species (Oliveira *et al.* 2018).

Studying alternative rootstocks for peach cultivation in subtropical climate conditions is substantial to determine compatible and more favorable combinations between the main scion cultivars used by producers in Southwestern Brazilian. Given what has been exposed, it has been formulated, as a hypothesis, that at least one of the rootstocks from the UFV breeding program will be compatible with the cultivars Aurora 1 and Tropic Beauty, presenting similar results to the control Okinawa. This study aimed to evaluate the performance of seven rootstocks based on tree growth, yield, and fruit quality of the scion cultivars Aurora 1 and Tropic Beauty in subtropical climate conditions.

Materials and Methods

The research took place in an experimental orchard located in Minas Gerais State, Brazil (20°45’26’’S, 42°52’08’’W, and 648 m in altitude) from January 2015 to December 2017. The region has a humid subtropical climate (Cwa) with cool dry winters and warm humid summers, according to the Köppen–Geiger climate classification system. The average temperature is about 20°C and the annual precipitation is 1251 mm.

The temperature, relative humidity, and precipitation were recorded during the experimental period (Fig. 1) in a weather station located 850 m away from the orchard. The orchard was implanted in November 2014 in an area with Yellow Red oxisol, using 666 plants ha^{-1} with 1.0 m tall, planted 3.0 m in the row, and 5.0 m between rows.

The cultivars Aurora 1 and Tropic Beauty were both grafted onto the cultivar Okinawa and seven rootstocks of the breeding program from the Federal University of Viçosa (UFV) (UFV 1701-2, UFV 102-1, UFV 186, UFV 1701-1, UFV 102-2, UFV 286 and UFV 202-1). The cultivar Okinawa represented a control and was propagated by cuttings aiming to maintain the genetic identity of the rootstock. Was adopted the recommended agricultural practices for cultivation in subtropical regions, including split fertilization, pruning in summer and early spring, implementation of dormancy-breaking chemicals (0.8% Dormex + 1% mineral oil), management of pests and diseases, and drip irrigation system.

The experimental design was a completely randomized block with five replications and one plant per experimental unity.

After the procedures of winter pruning (2015), green pruning (2016), and at the third crop year (2017), the characteristics related to the vegetative growth were evaluated via the trunk cross-sectional area (TCSA, cm²), obtained through the equation:

$$TCSA = \frac{\pi d^2}{4}$$

Where: d = trunk diameter measured 5 cm above the grafting point.

In the first crop year after the winter pruning (2015) and the second crop year after the green pruning (2016), were evaluated the plant height (m) and the fresh weight of the pruned branches (kg).

The harvest was performed based on the characteristic color change of the peel for each variety studied (Matias *et al.* 2016) during the first (2015) and third (2017) crop years. The fruit production was determined based on the yield per plant (kg pl^{-1}), given by the number and weight of fruits from each plot.

For the physicochemical analysis, ten fruits located at the medium third of each quadrant of the trees were harvested. The peel color was given by the CIELAB coordinates a* (redness), b* (yellowness), and Hue angle (h°) measured at the equatorial region on opposite faces of the fruits using a Minolta CR-10 colorimeter. The fruit weight was evaluated with a precision digital scale with an accuracy of 0.01 g, and the fruit size was obtained by measuring the maximum transversal distance perpendicular to the suture zone with a digital caliper.

After the peel removal, the flesh firmness was evaluated using a digital penetrometer with an 8 mm diameter plunger tip measuring the equatorial region in one face of each fruit, and these results were expressed in newton force (N). The pulp was evaluated for the soluble solids concentration (ºBrix) using a digital refractometer at 20°C.

The data were subjected to analysis of variance and tested by the F test. The Dunnett test at 5% probability level ($P < 0.05$) compared the UFV series rootstocks with the control (Okinawa), and the Duncan test at a 5% probability level ($P < 0.05$) compared the averages of UFV rootstocks. The statistical analyses were performed using the software SAEG 9.1 and the graph of precipitation, temperature, and relative humidity was plotted in OriginPro 9.0.0.

Results

The rootstocks influenced the vegetative growth of Aurora 1 and Tropic beauty scions. In the first crop year (2015), the combination of Aurora 1 grafted onto the rootstock UFV 286, and Tropic Beauty grafted onto UFV 102-1 presented the lowest trunk cross-sectional area (TCSA) (15.47 cm² and 7.80 cm², respectively). In the second crop year (2016), the scion Aurora 1 grafted onto UFV 186, and Tropic Beauty grafted onto the rootstocks UFV 102-1, UFV 186, and UFV 286 presented the lowest TCSA values (34.72 cm², 17.90 cm², 17.95 cm², and 19.36 cm², respectively). In the third crop year (2017), the rootstocks UFV 186 and UFV 286 presented the lowest TCSA values, both for the combination with Aurora 1 (77.56 and 72.37 cm², respectively), as for Tropic Beauty (31.98 and 31.70 cm², respectively). There was no difference between the evaluated rootstocks and the control rootstock (Okinawa) regardless of the scion in the first and second crop years. However, in the third crop year, the cultivar Aurora 1 grafted onto UFV 202-1 differed from the control, presenting the highest TCSA, and the cultivar Tropic Beauty grafted onto UFV 102-2, UFV 186, and UFV 286 also differed from Okinawa, with the highest TCSA observed for the combination with the rootstock UFV 102-2 (Table 1).

For the plant height in Aurora 1, the was no difference between the rootstocks in the first (2015) and second (2016) crop years. However, for Tropic Beauty, there were observed differences between the rootstocks, being the lower plant height values observed in the combinations with rootstocks UFV 102-1 in 2015 and UFV 286 in 2016, where both differed from the control Okinawa (Table 1).

The rootstocks influenced the fresh weight of the pruned branches (FWPB) in both crop years. For the scion Aurora 1, the combinations with UFV 286 in 2015 and 2016 presented the lowest FWPB, not differing from Okinawa, and for Tropic Beauty, the combination with UFV 102-1 in 2015 and the rootstocks UFV 102-1, UFV 186 and UFV 286 in 2016 resulted in the lowest FWPB, in which UFV 286 in 2016 has differed from Okinawa (Table 1).

The rootstocks have influenced the yield per plant of both scion cultivars. When using the scion Aurora 1, the rootstock UFV 1707-2 in 2015 and UFV 1701-1 in 2017 promoted the highest yield per plant. For the scion Tropic Beauty, the combinations with UFV 202-1 in 2015, UFV 1701-1, and UFV 1701-2 in 2017 resulted in the highest yield per plant. The performance of Tropic Beauty and Aurora 1 grafted onto the rootstock UFV 1701-1 in 2017 was better than in Okinawa.

Regarding the fruit weight, the scion cultivar Aurora 1 presented the highest performance when grafted onto UFV 1701-2, UFV 102-1 and UFV 186 in 2015, not differing from the cultivar Okinawa. However, there was no difference between the evaluated rootstocks in the third crop year (2017). For Tropic Beauty, there was no difference between the rootstocks in 2015, but in 2017 the fruits of the combinations with the rootstocks UFV 1701-1, UFV 1701-2, UFV 102-2, UFV 286, and UFV 202-1 presented a higher performance (Table 2).

The fruit size has differed between the rootstocks for Aurora 1 and Tropic Beauty. However, there was no difference when comparing the rootstocks with Okinawa. The scion Aurora 1 grafted onto the rootstocks UFV 102-1, UFV 186, UFV 202-1 in 2015 and UFV 1701-1 in 2017, increased the fruit size. For Tropic Beauty, there was no difference between the rootstocks in 2015, and in 2017 the combination with the rootstocks UFV 1701-1, UFV 1701-2, UFV 102-2, UFV 286, and UFV 202-1 promoted a greater fruit size (Table 3).

The flesh firmness of fruits produced by the scion Aurora 1 grafted onto UFV 1701-1 in 2015 was higher than the results obtained from the other combinations. However, in 2017 the flesh firmness showed no difference between the rootstocks and Okinawa. The fruits of Tropic Beauty differed between the rootstocks, in which the highest performance was obtained in the combinations with UFV 286 in 2015 and UFV 186 in 2016, both presenting fruits with firmer flesh than Okinawa (Table 3).

There were no differences in peel color parameters redness (a*), yellowness (b*), and Hue angle (h°) between the rootstocks and Okinawa in 2015 and 2015, regardless of the scion. The rootstocks had not influenced the redness of fruits from Aurora 1 in 2015, but in 2017 the combination with the rootstock UFV 202-1 resulted in fruits with an intense red peel. The rootstocks have not affected the redness of fruits from Tropic Beauty produced in 2015 and 2017. The grafting of Aurora 1 onto the rootstocks UFV 102-1 in 2015 and UFV 102-2 and UFV 186 in 2017 resulted in higher peel yellowness. For Tropic Beauty, there was no difference between the rootstocks in 2015, but in 2017 the combination with UFV 202-1 promoted a greater yellowness. For Aurora 1 fruits, the Hue angle had no difference between the rootstocks in 2015, but in 2017, the combination with UFV 1701-2 promoted the highest Hue angle values, and for Tropic Beauty, the combination with UFV 1701-2 promoted an increase in Hue angle values in 2015, while in 2017 there was no difference between the rootstocks evaluated (Table 4).

Table 1: Trunk cross-sectional area, plant height, and fresh weight of the pruned branches of Aurora 1 and Tropic Beauty scion cultivars grafted onto different rootstocks in a Brazilian subtropical climate

Cultivar	Rootstock	Trunk cross-sectional area (cm^2)			Plant height (m)		Fresh weight of the pruned branches (kg)	
		2015	2016	2017	2015	2016	2015	2016
Aurora 1	UFV 1701-1	21.33 ns a	48.25 ns ab	99.88 ns ab	2.67 ns a	3.62 ns a	0.80 ns ab	7.40 ns ab
	UFV 1701-2	21.81 ns a	46.88 ns ab	91.02 ns ab	2.78 ns a	3.68 ns a	0.89 ns ab	9.30 ns a
	UFV 102-1	17.00 ns ab	48.85 ns ab	95.72 ns ab	2.63 ns a	3.60 ns a	1.01** a	7.05 ns ab
	UFV 102-2	17.94 ns ab	44.59 ns ab	97.44 ns ab	2.62 ns a	3.69 ns a	0.67 ns ab	7.45 ns ab
	UFV 186	16.61 ns ab	34.72 ns b	77.56 ns b	2.59 ns a	3.44 ns a	0.85 ns ab	6.70 ns ab
	UFV 286	15.47 ns b	41.61 ns ab	72.37 ns b	2.58 ns a	3.59 ns a	0.56 ns b	5.40 ns b
	UFV 202-1	18.74 ns ab	55.54 ns a	115.31** a	2.64 ns a	3.58 ns a	0.88 ns ab	8.36 ns ab
	Okinawa (control)	19.71	43.58	76.84	2.59	3.72	0.56	7.29
CV (%)		19.15	25.66	26.14	8.72	7.09	31.16	31.18
Tropic Beauty	UFV 1701-1	12.74 ns ab	34.77 ns a	64.09 ns ab	2.40 ns a	3.34 ns a	0.41 ns a	3.94 ns ab
	UFV 1701-2	14.28 ns a	28.21 ns ab	55.05 ns abc	2.32 ns a	3.06 ns ab	0.29 ns ab	2.68 ns bc
	UFV 102-1	7.80 ns c	17.90 ns b	45.49 ns bc	1.90** b	2.98 ns ab	0.17 ns b	1.91 ns c
	UFV 102-2	15.50 ns a	36.57 ns a	71.53** a	2.41 ns a	3.25 ns a	0.31 ns ab	4.36 ns a
	UFV 186	9.23 ns bc	17.95 ns b	31.98** c	2.25 ns a	2.99 ns ab	0.30 ns ab	1.68 ns c
	UFV 286	9.44 ns bc	19.36 ns b	31.70** c	2.13 ns ab	2.62** b	0.23 ns ab	1.38 ** c
	UFV 202-1	14.20 ns a	28.60 ns ab	46.29 ns bc	2.39 ns a	2.96 ns ab	0.31 ns ab	2.48 ns bc
	Okinawa (control)	12.80	28.76	52.12	2.48	3.46	0.45	3.39
CV (%)		28.31	28.80	28.22	10.28	10.39	43.49	40.16

**Differed significantly from control (Okinawa) by Dunnett test ($P \leq 0.05$), ns: non-significant
Averages followed by the same letter in the columns show no statistical differences ($P \leq 0.05$) (comparing the UFV series rootstocks) according to the Duncan test

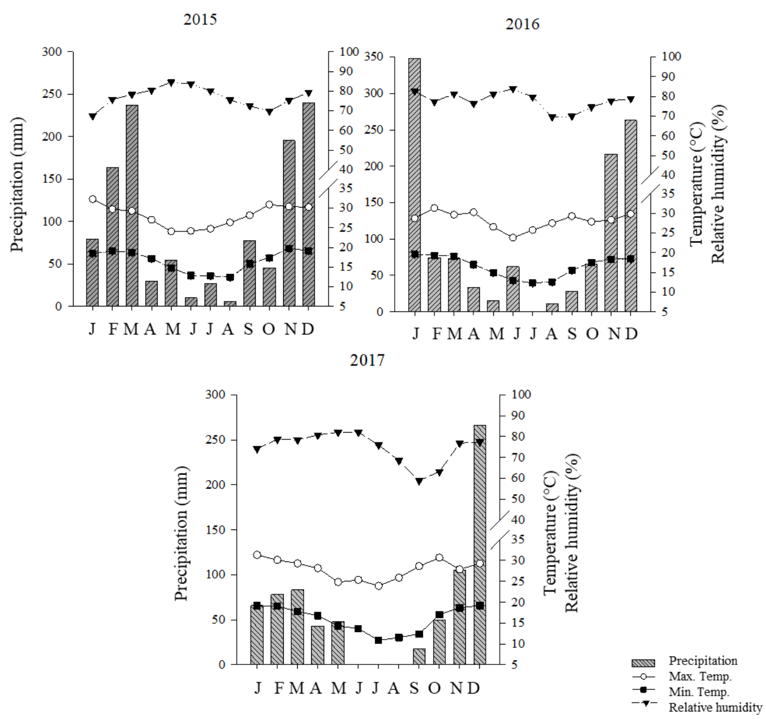

Fig. 1: Precipitation, relative humidity, and maximum and minimum temperatures recorded during the experimental period. Source: Weather station from the Federal University of Viçosa – MG – Brazil

The combination between the scion Aurora 1 and rootstock UFV 202-1 in 2015 resulted in a higher soluble solids concentration (SSC), although there was no difference between the rootstocks and Okinawa. In 2017 the SSC was not influenced by the rootstocks. The scion Tropic Beauty grafted onto UFV 1701-2, UFV 102-1, and UFV 186 in 2015 produced fruits with higher SSC, in which the combination between Tropic Beauty and UFV 186 resulted in an SSC higher than Okinawa. In 2017, the scion Tropic Beauty grafted onto UFV 202-1 provided fruits with a higher SSC (Table 4).

Discussion

The combinations with some rootstocks resulted in less vigorous plants, presenting a smaller trunk cross-sectional

Table 2: Yield per plant and fruit weight of Aurora 1 and Tropic Beauty scion cultivars grafted onto different rootstocks in a Brazilian subtropical climate

Cultivar	Rootstock	Yield per plant (kg)		Fruit weight (g)	
		2015	2017	2015	2017
Aurora 1	UFV 1701-1	2.06 ns abc	4.48** a	41.01 ns b	61.76 ns a
	UFV 1701-2	3.18 ns a	3.17 ns ab	46.63 ns a	59.18 ns a
	UFV 102-1	1.65 ns bc	2.92 ns ab	53.08 ns a	54.59 ns a
	UFV 102-2	1.25 ns c	2.84 ns ab	46.14 ns ab	57.76 ns a
	UFV 186	2.91 ns ab	2.39 ns b	53.37 ns a	58.28 ns a
	UFV 286	2.34 ns abc	3.72 ns ab	50.90 ns ab	60.34 ns a
	UFV 202-1	2.33 ns abc	3.39 ns ab	51.44 ns ab	61.55 ns a
	Okinawa (control)	2.25	2.06	42.70	55.16
CV (%)		37.18	36.17	14.37	9.36
Tropic Beauty	UFV 1701-1	1.81 ns bcd	4.88** a	52.87 ns a	82.43 ns a
	UFV 1701-2	2.35 ns ab	3.64 ns a	48.02 ns a	86.06 ns a
	UFV 102-1	0.88** d	1.76 ns b	52.74 ns a	73.64 ns ab
	UFV 102-2	2.04 ns abc	3.09 ns ab	51.36 ns a	81.94 ns a
	UFV 186	1.09** cd	1.61 ns b	47.14 ns a	65.08** b
	UFV 286	1.41 ns bcd	1.71 ns b	49.47 ns a	78.92 ns a
	UFV 202-1	2.77 ns a	3.10 ns ab	47.98 ns a	86.51 ns a
	Okinawa (control)	2.59	2.11	46.19	80.93
CV (%)		33.76	37.75	12.31	10.37

**Differed significantly from control (Okinawa) by Dunnett test ($P \leq 0.05$), ns: non-significant
Averages followed by the same letter in the columns show no statistical differences ($P \leq 0.05$) (comparing the UFV series rootstocks) according to the Duncan test

Table 3: Fruit size and flesh firmness of Aurora 1 and Tropic Beauty scion cultivars grafted onto different rootstocks in a Brazilian subtropical climate

Cultivar	Rootstock	Fruit Size (mm)		Flesh Firmness (N)	
		2015	2017	2015	2017
Aurora 1	UFV 1701-1	40.04 ns b	44.79 ns a	59.27 ns a	31.02 ns a
	UFV 1701-2	42.15 ns ab	44.00 ns ab	37.07** c	32.78 ns a
	UFV 102-1	43.64 ns a	41.70 ns b	42.09 ns bc	29.75 ns a
	UFV 102-2	41.44 ns ab	42.79 ns ab	47.84 ns abc	34.12 ns a
	UFV 186	43.60 ns a	43.61 ns ab	38.75** bc	36.09 ns a
	UFV 286	43.02 ns ab	44.17 ns ab	51.52 ns ab	35.60 ns a
	UFV 202-1	43.75 ns a	44.38 ns ab	38.59** bc	30.91 ns a
	Okinawa (control)	40.57	43.31	57.65	35.79
CV (%)		4.99	3.55	19.98	14.52
Tropic Beauty	UFV 1701-1	43.53 ns a	49.74 ns a	53.04 ns ab	45.18 ns bc
	UFV 1701-2	42.02 ns a	50.87 ns a	52.35 ns ab	44.81 ns c
	UFV 102-1	42.23 ns a	46.91 ns b	56.81** ab	47.96 ns abc
	UFV 102-2	44.49 ns a	49.53 ns a	48.97 ns b	47.54 ns abc
	UFV 186	41.26 ns a	45.46 ns b	56.67** ab	54.31** a
	UFV 286	41.91 ns a	49.49 ns a	61.14** a	52.22 ns ab
	UFV 202-1	43.31 ns a	49.61 ns a	52.12 ns ab	46.57 ns bc
	Okinawa (control)	41.55	49.19	45.51	44.45
CV (%)		6.74	3.93	11.75	10.29

**Differed significantly from control (Okinawa) by Dunnett test ($P \leq 0.05$), ns: non-significant
Averages followed by the same letter in the columns show no statistical differences ($P \leq 0.05$) (comparing the UFV series rootstocks) according to the Duncan test

area (TCSA), plant height, and fresh weight of pruned branches. The vigor can represent an increase in the cost of pruning practices and affect the fruit quality (Gullo *et al.* 2014). Vigorous plants are responsible for inducing a low fruit quality due to the canopy shading; in contrast, less vigorous plants provide more nutrients to the fruits because of the lower competition with vegetative parts, producing fruits with higher size and sugar content (Yahmed *et al.* 2016).

The rootstocks UFV 186, UFV 286 and UFV 102-1 can originate less vigorous plants with desirable characteristics for commercial orchards, helping to define the spacing, the possibility of high-density, and facilitating cultural practices like pruning, thinning, phytosanitary treatments, and harvest (Gonçalves *et al.* 2019). Breeding programs have been seeking to produce rootstocks with moderated or reduced vigor, focusing on intensification and high-density plantings (Yahmed *et al.* 2020). Less vigorous rootstocks used for high-density have been widely studied for apple tree crops (Pasa *et al.* 2016) and could be useful in other crops such as peach trees.

In the present study, the yield per plant could not be considered significant for peach crop potential since the plants had not yet reached their full productive potential for being in the first (2015) and third (2017) year after planting, although the effect of the rootstocks could be observed. Comiotto *et al*. 2012, 2013 reported similar for results the cultivars Maciel and Chimarrita, indicating the earliness of the rootstocks evaluated, which becomes an advantage

Table 4: Color parameters a*, b* and hue angle of peel, and soluble solids content (SSC) of Aurora 1 and Tropic Beauty scion cultivars grafted onto different rootstocks in a Brazilian subtropical climate

Cultivar	Rootstock	a*		b*		Hue angle (hº)		SSC (ºBrix)	
		2015	2017	2015	2017	2015	2017	2015	2017
Aurora 1	UFV 1701-1	8.93 ns a	13.89 ns ab	24.94 ns b	36.67 ns ab	70.88 ns a	65.96 ns abc	12.74 ns b	12.72 ns a
	UFV 1701-2	8.99 ns a	12.26 ns b	25.92 ns ab	36.61 ns ab	67.79 ns a	72.02 ns a	12.98 ns ab	13.41 ns a
	UFV 102-1	9.48 ns a	14.93 ns ab	28.12 ns a	34.79 ns ab	71.33 ns a	64.84 ns abc	12.94 ns ab	12.90 ns a
	UFV 102-2	8.73 ns a	13.71 ns ab	24.85 ns b	47.07 ns a	71.27 ns a	70.09 ns ab	12.91 ns ab	12.69 ns a
	UFV 186	9.48 ns a	13.37 ns b	24.88 ns b	48.00 ns a	66.59 ns a	70.49 ns ab	13.07 ns ab	12.97 ns a
	UFV 286	9.10 ns a	15.23 ns ab	24.96 ns b	30.48 ns b	71.05 ns a	60.05 ns c	12.67 ns b	13.21 ns a
	UFV 202-1	11.33 ns a	16.92 ns a	25.46 ns ab	36.31 ns ab	63.52 ns a	62.98 ns bc	13.42 ns a	13.00 ns a
	Okinawa (control)	8.22	12.53	27.71	37.99	76.77	69.48	13.44	13.16
CV (%)		27.23	14.43	7.53	24	10.49	7.55	3.14	13.16
Tropic Beauty	UFV 1701-1	5.95 ns a	10.55 ns a	27.74 ns a	44.86 ns ab	79.96 ns ab	76.02 ns a	12.78 ns b	13.45 ns ab
	UFV 1701-2	5.17 ns a	9.85 ns a	28.45 ns a	46.21 ns ab	83.41 ns a	78.20 ns a	13.02 ns a	13.31 ns ab
	UFV 102-1	6.68 ns a	11.72 ns a	28.66 ns a	37.59 ns c	77.38 ns ab	71.33 ns a	13.13 ns a	13.23 ns ab
	UFV 102-2	6.66 ns a	12.08 ns a	27.55 ns a	44.32 ns abc	78.79 ns ab	74.32 ns a	12.86 ns b	13.47 ns ab
	UFV 186	5.89 ns a	10.16 ns a	25.85 ns a	39.19 ns bc	75.10 ns ab	75.67 ns a	14.02** a	12.46 ns b
	UFV 286	7.34 ns a	11.96 ns a	25.02 ns a	43.33 ns abc	71.98 ns b	74.08 ns a	13.66 ns ab	13.22 ns ab
	UFV 202-1	5.62 ns a	9.26 ns a	27.33 ns a	46.90 ns a	77.56 ns ab	79.10 ns a	13.37 ns ab	13.98 ns a
	Okinawa (control)	4.77	9.62	28.86	41.99	78.85	76.38	12.29	13.53
CV (%)		41.9	23.31	8.12	11.76	7.16	7.85	6.11	4.85

**Differed significantly from control (Okinawa) by Dunnett test ($P \leq 0.05$), ns: non-significant
Averages followed by the same letter in the columns show no statistical differences ($P \leq 0.05$) (comparing the UFV series rootstocks) according to the Duncan test

for peach producers, reducing the production costs in the first year after planting. Stern and Doron (2009) reported the influence of the rootstocks on the pear cultivar Coscia only after the 4th year of production, growing year by year, with considerable and significant differences in the 9th year of evaluation.

The low yield per plant observed for Tropic Beauty grafted onto UFV 186, UFV 286 and UFV 102-1, and for Aurora 1 grafted onto UFV 186 and UFV 286, compared with the other rootstocks can be explained by the smaller trunk cross-sectional area (TCSA) and fresh weight of pruned branches, since the yield per plant is generally greater on vigorous rootstocks than on those less vigorous (Guerriero *et al.* 1988). The less vigorous rootstocks can be evaluated in high-density plantings, and eventually, compensate for the low yield per plant. Although Okinawa is the most common rootstock and presents compatibility with several peach varieties (Shahkoomahally *et al.* 2021), it is worth noting that UFV 1701-1 was consistently more productive than Okinawa, regardless of the cultivar tested in 2017 (117.5% up for Aurora 1 and 131.3% up for Tropic Beauty).

The fruit weight had not depended on plant vigor, being observed high weight in more and less vigorous rootstocks. It is worth noting that vigorous peach trees influence productivity without affecting fruit weight (Nava *et al.* 2011), and the results in the present study can be indicative of the good adaptation of the cultivars to subtropical climate conditions, being an alternative to increase the period of fruit supply (Gonçalves *et al.* 2019). For fruits that are consumed fresh, the weight is a significant attribute of quality since it is required by the consumers (Abdel-Sattar *et al.* 2021).

The processing industries require high-quality fruit with greater size to provide a good product to the final consumer (Domingo *et al.* 2011). The rootstocks influence the peach fruit size (Marra *et al.* 2013; Barreto *et al.* 2017) and other species like apple (Pasa *et al.* 2016), plum (Butac *et al.* 2015), cherry (López-Ortega *et al.* 2016), grape (Nelson *et al.* 2016), and lemon (Dubey and Sharma 2016). Vigorous rootstocks can negatively affect the size of the fruits and other characteristics related to their quality, reducing the commercial value of these fruits (Minas *et al.* 2018). The combination of some rootstocks with Aurora 1 and Tropic Beauty has reduced the fruit size, affecting the fruit quality.

Tropic Beauty grafted onto rootstocks UFV 102-1, UFV 186, and UFV 286 in 2015 and UFV 186 in 2017 has produced fruits with flesh firmness higher than Okinawa (24.8; 24.5; 34.3 and 22.2% up, respectively). The rootstocks have an important role in the flesh-firmness, varying significantly according to the type of rootstock (Tavarini *et al.* 2011). Less vigorous rootstocks tend to induce a higher flesh firmness (Legua *et al.* 2012), which is important because fruits with those characteristics can reach more distant markets with extended shelf-life and can stay longer on supermarket shelves (Silva *et al.* 2016; Shahkoomahally *et al.* 2021). The results obtained in the present study indicate the potential of the combination of Tropic Beauty and the rootstocks above mentioned to produce fruits for export.

The peel color varied among the rootstocks in the present study. For peach fruits, an accentuated color is desirable because the appearance of the fruits corresponds to 83% of the criteria considered by the consumers when choosing the fruits. The peel color evolves along the ripening and is strongly influenced by higher or lower sunlight exposure. Fruits from less vigorous rootstocks are favored by good exposure to the sunlight and present an increase in the accumulation of pigments, providing an intense peel color (Mathias *et al.* 2008; Kyriacou and Rouphael 2018).

In the present study, the combination with a less vigorous rootstock resulted in fruits with higher soluble solids content. These results agree with Comiotto *et al*. (2012), who have reported higher soluble solids content in Chimarrita peach fruits grafted onto a less vigorous rootstock, probably because less vigorous plants allow a higher light interception through the canopy. Some factors affect the soluble solids concentration, such as the fruit size and its position on the plant, penetration of light into the canopy, branch positions, and pruning type (Picolotto *et al.* 2009; Shahkoomahally *et al.* 2021). The peach quality is affected by the soluble solids content and it influences the acceptance by the consumers, who prefer fruits with approximately 13% of soluble solids contents and has a low acceptance of fruits with less than 11% of soluble solids content (Nascimento *et al.* 2016).

Conclusion

The rootstocks affected the vigor of the scion cultivars, which was less vigorous when grafted onto the rootstocks UFV 186, UFV 286 and UFV 102-1, being an alternative for high-density plantings. The cultivars Aurora 1 and Tropic Beauty presented greater yield when grafted onto UFV 1701-1, UFV 1701-2 and UFV 202-1. The fruit weight was similar for all the rootstocks tested, and the quality of fruits from Aurora 1 and Tropic Beauty did not differentiate from the control Okinawa, which means that the performance of the rootstocks from the UFV breeding program meets the standards required by the market and their use can be successful in regions of subtropical climate.

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Author Contributions

Oliveira, J.A.A.: Conceived and performed the experiment, carried out laboratory analyses, prepared the draft of the manuscript. Bruckner, C.H.: Conceived the experiment, supervised the experiments, carried out statistical analyses. Gomes, F.R.: Prepared the draft of the manuscript. Assunção, H.F.: Prepared the illustration. Cruz, S.C.S.: Data review. Silva, D.F.P.: Conceived the experiment, supervised the draft of the manuscript. All authors approved the final version of the manuscript.

Conflicts of Interest

Authors declare no conflicts of interests.

Data Availability

The data will be available uppon request to the corresponding author.

Ethics Approval

Not applicable.

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