https://doi.org/10.71252/2177-34912025720003
ISSN: 2177-3491

revista Ceres

Rootstocks for ‘Valência’ sweet-orange in Santa Catarina in the context of plant size and spacing reduction[1]

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[1] Funding: Financiadora de Estudos e Projetos and Fundação de Amparo à Pesquisa e Inovação do Estado de Santa Catarina.

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Editors:
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Submitted: September 19th, 2024.
Accepted: December 18th, 2024.

ABSTRACT

Citrus orchards have been planted in higher tree densities, which encourage the use of rootstocks that reduce scion tree size. The performance of low-vigor rootstocks with ‘Valência’ orange is not well known, especially in southern Brazil. The objective of this work is to compare the agronomic performance of ‘Valência’ sweet orange grafted on seventeen rootstocks in western Santa Catarina, Brazil, and analyze the results in light of the search for small trees for orchards with narrower spacing. An experiment was conducted over 10 years for evaluation of seventeen rootstocks, concerning tree size, yield and fruit quality. The rootstocks were classified in Standard (six genotypes, including ‘Swingle’, main rootstock in Santa Catarina), Super-standard (two genotypes), Semi-standard (seven genotypes) and Dwarf (two genotypes). An estimated hectare yield was calculated after a tree spacing adjustment based on tree diameter. In conclusion, the citrandarin ‘San Diego’ forms trees similar in size to the widespread citrumelo ‘Swingle’, but is more productive, and maintains the quality of the fruit. ‘Fepagro C37 Dornelles’ reduces ‘Valência’ tree size, facilitates fruit harvest and induces it to produce big, good quality fruits. Dwarf rootstocks lead to a low hectare yield even in reduced space orchards.

Keywords: *Citrus* spp.; *Poncirus trifoliata*; grafting; yield; vigor.

INTRODUCTION

The 'Valência' sweet orange [*Citrus sinensis* (L.) Osbeck] is the main citrus cultivar in the world. Its late harvest extends until the beginning of summer, both for the fresh fruit market and for industrial or fresh juice production. Besides its rusticity, 'Valência' growth and yield are affected negatively by drought, flooding, chilling/freezing, high temperature, pests and diseases, among other factors. Many of them are fully or partially overcome by using tolerant/resistant rootstock cultivars. Growers must take into account a list of attributes when selecting a rootstock. Bowman & Robert[1] classified them in 16 groups. Among them, it seems important to consider disease tolerance (gummosis and citrus tristeza virus, endemic in South Brazil), cold hardiness, tree size, yield, and fruit quality.

The innovation of citrus orchards through higher densities planting systems increases yield and net returns in the early years beyond making cultural practices easier. They better use the resources of a portion of land (photosynthetic active radiation, water and minerals).[2-5] The spread of huanglongbing throughout South America, including Santa Catarina state, encouraged researchers to study the progress of the disease in orchards diverging in tree size mediated by rootstocks. In small-tree orchards, huanglongbing is observed to spread more slowly, and they have been proposed as a tool in integrated huanglongbing management.[5,6] However, tree spacing must be adjusted for its size. The primary option to form high-density orchards is size-controlling rootstocks.[7]

In Santa Catarina state (Brazil), trifoliate orange [*Poncirus trifoliata* (L.) Raf.] and its hybrids (citranges, citrandarins and citrumelos) have been recommended by citrus experts and governmental agencies, since they tolerate *Phytophthora* sp. root rot and frosts, and induce good fruit quality. The fast-growing rootstocks 'Swingle' citrumelo and 'Cravo' Rangpur lime shorten nursery tree production time and are therefore preferred by nurserymen. Those rootstocks produce tall trees in the field.

The recommendation of a series of rootstocks for 'Valência' cultivation in the Rio Grande do Sul and Santa Catarina states are based on observations from other scions, from experiments in few sites or empirical tests. Long term scientific works were carried out in medium textured soils of southern Rio Grande do Sul state[8,9] and in northern Paraná state.[10,11] Therefore, the objective of this work is to compare the agronomic performance of 'Valência' sweet orange grafted on seventeen rootstocks in western Santa Catarina, Brazil, and analyze the results in light of the search for small tree orchards with narrower spacing.

MATERIAL AND METHODS

An experiment was performed in Santa Catarina state, Brazil, (Águas de Chapecó municipality, sited in Rio Uruguay valley region, at 330m of elevation). The local climate is a warm subtropical, with hot summer (Koppen - Cfa).[12] The soil is a Nitisol, with 30-40% clay. It was previously corrected for pH, P and K levels. The experiment was designed in four completely random blocks with three plants per plot. 'Valência' (IAC, Cordeirópolis, SP) sweet orange nursery trees were transplanted in May 2013, spaced 7 m x 3 m. They had the following rootstocks (treatments):

- 'Swingle' citrumelo [*Citrus paradisi* Macf. × *Poncirus trifoliata* (L.) Raf.];
- 'Fepagro C37 Dornelles' citrange [*Citrus sinensis* (L.) Osb. × *Poncirus trifoliata* (L.) Raf.];
- 'Carrizo' citrange [*Poncirus trifoliata* (L.) Raf. × *Citrus sinensis* (L.) Osb.];
- 'C 35' citrange [*C. sinensis* (L.) Osb. × *P. trifoliata* (L.) Raf.];
- 'Fepagro C 13' citrange [*C. sinensis* (L.) Osb. × *P. trifoliata* (L.) Raf.];
- 'Flying Dragon' trifoliate orange (*Poncirus trifoliata* var. *monstrosa*);
- 'SCS453 Nasato' trifoliate orange (*Poncirus trifoliata*);
- 'Rubidoux' trifoliate orange (*P. trifoliata*);
- 'BRS CNPMF Tropical' mandarin [*Citrus sunki* (Hayata) hort. ex Tan.)];
- 'Sun Chu Sha Kat' mandarin (*Citrus reticulata* Blanco);
- 'Cravo' rangpur lime (*Citrus limonia* Osb.);
- 'HFD 25 EEI', F1 from open-pollination of *P. trifoliata* 'Flying Dragon';
- 'HFD 11 EEI', F1 from open-pollination of *P. trifoliata* 'Flying Dragon';
- 'Sunki' × 'Benecke' citrandarin [*Citrus sunki* (Hayata) hort. ex Tan. × *Poncirus trifoliata* (L.) Raf.];
- 'San Diego' citrandarin (*C. sunki* × *P. trifoliata*).
- 'Changsha' × 'English Large Trifoliate' citrandarin [*C. reticulata* Blanco × *Poncirus trifoliata* (L.) Raf.];
- 'Cravo' × 'Sunki' EEI hibrid. (*Citrus limonia* Osb. × *Citrus sunki* (Hayata) hort. ex Tan.).

The rain fed orchard was managed according to standard procedures for orange growing in Santa Catarina state, equally in all plots. In August 2013 all trees were topped at 50cm for canopy formation. No further pruning was made. Fungicides were regularly sprayed during flower and fruitlet time. Chemical sprays were used against mites and fruit flies as well.

Tree height (H) and canopy diameter (transversal and longitudinal to the row) were measured yearly in May. With this basic data, tree volume (V) was calculated ($V = 2/3\ \pi \times H \times D$). Rootstock means for tree height and V measured at the experiment end were submitted to analysis of variance and compared by Scott-Knott grouping test (α=0.05). The groups formed were named based on the classification proposed by Castle & Phillips,[13] considering as Standard the trees on ‘Swingle’ citrumelo. Tree yield (TY) (fruit harvested per live tree - kg) for the third to the tenth year was determined, separating fruits harvested by pedestrians, without ladders (PH). Yearly, the yield efficiency (YE) was calculated by YE = TY / V. Average fruit mass was calculated by the ratio TY/(fruit number).

Because the rootstock tested were expected to vary in tree size induced to the scion, to better understand each rootstock value in a production system, an estimated tree spacing was calculated based on De Negri et al.[14] A factor of 1.2 [based on canopy growth reported by Koller at al.[15]] multiplied the mean canopy diameter to estimate further canopy growth upon ten years of the trees. For each plot, the estimated between-row space was the estimated canopy diameter added 2.5m for equipment traffic. The estimated inside-row tree space was 75% of the estimated diameter.[14] Then, an estimated yield by hectare (TYH) was calculated using the TY and tree density.

Fruit peel color of 15 fruits per plot was evaluated in 2019 by colorimetry, using a Konica-Minolta CR-400 colorimeter, expressing the measures in L.a.b scale. A peel color index (PCI) was calculated by PCI = 1000*a/(L*b). In 2023 a second color evaluation was performed using a scale with the scores 0 = dark green; 1= predominantly green; 2 = 50% green; 3 = predominantly light yellow; 4 = light yellow; 5 = yellow; 6 = yellow-orange; 7 = yellow. In 2019, 2020, 2022 and 2023 a sample of 15 fruits was submitted to juice extraction using kitchen equipment. The entire fruits and the residue of the extraction were weighed. The mass difference was assumed to be mass of juice which was divided by the mass of fruit to obtain the juice content (% m/m). Soluble solids (SS) content was determined using a digital refractometer (Quimis Aparelhos Científicos, São Paulo, BRA). The titratable acidity (% citric acid) (TA) was determined by titration with NaOH until pH 8.0-8.1. The ratio SS/TA was calculated.

TY, YE, PH, TYH, average fruit mass, color indexes, juice content, SS, TA and juice ratio were submitted to an analysis of variance with time repeated measures, and rootstock means were compared by a Tukey test (α=0.05).

RESULTS AND DISCUSSION

Results

The tree heights and canopy volume of ‘Valência’, measured 10 years after planting in the field, were significantly affected by the rootstocks (Anova, $p<0.01$) (Table 1). The Scott-Knott test formed the same three groups for tree height and canopy volume. The first containing the Super standard trees: ‘Sun Chu Sha Kat’ and ‘BRS CNPMF Tropical’; the second was formed by the Standard trees: ‘Changsha’ × ‘English Large Trifoliate’, ‘Swingle’, ‘San Diego’, ‘Carrizo’, ‘Sunki’ × ‘Benecke’ and ‘Cravo’; another group accommodated Semi-standard trees, as named ‘Cravo’ × ‘Sunki’, ‘C 35’, ‘Fepagro C 13’, ‘Rubidoux’, ‘HFD 11 EEI’, ‘SCS453 Nasato’ and ‘Fepagro C37 Dornelles’; and the Dwarf trees were formed with ‘HFD 25 EEI’ and ‘Flying Dragon’.

The average tree yield (Table 2) was affected significantly by the rootstocks (Anova, $p < 0.01$). The significantly biggest production was obtained with ‘San Diego’ (77.4 kg $tree^{-1}$ $year^{-1}$), which showed one of the best yield efficiency as well (4.51 kg m^{-3}). Among the Semi-standard tree group, ‘Fepagro C37 Dornelles’ stood out, with higher averages (46.63 kg $tree^{-1}$ $year^{-1}$ and 4.58 kg m^{-3}) than ‘Fepagro C 13’, ‘Rubidoux’ and ‘SCS453 Nasato’. The dwarf trees on ‘Flying Dragon’ and ‘HFD 25 EEI’ yielded similarly, with averages significantly smaller than the other rootstocks (15.27 and 11.97 kg $tree^{-1}$ $year^{-1}$, respectively), but the former showed to be more efficient, averaging 4.67 kg m^{-3}).

Only the dwarf trees could be fully harvested by pedestrian workers (Table 2). Meanwhile, super standard trees were 89% harvested by pedestrians. PH were positively correlated to tree height (r=0,8). No significant difference was observed between rootstocks inside the groups Super Standard, Semi-standard and Dwarf. However, among the Standard trees, ‘Sunki’ × ‘Benecke’ had a bigger PH compared to ‘Swingle’ and ‘San Diego’.

Table 1: Canopy size of 'Valência' sweet orange trees budded on different rootstocks. Águas de Chapecó, SC, Brazil, 2023

Rootstock	Tree height	Tree size groups[1]	Canopy volume
	m		m^3 $tree^{-1}$
Sun Chu Sha Kat	3.57a[2]	Super standard	23.07a[2]
BRS CNPMF Trop.	3.33a	Super standard	22.48a
Changsha × English	3.03b	Standard	18.14b
San Diego	2.91 b	Standard	19.22b
Swingle	2.87b	Standard	16.74b
Carrizo	2.86b	Standard	16.92b
Sunki × Benecke	2.85b	Standard	15.95b
Cravo	2.67b	Standard	14.51b
Cravo × Sunki	2.52c	Semi-standard	11.49c
Fepagro C 13	2.51c	Semi-standard	12.25c
C 35	2.49c	Semi-standard	13.15c
Rubidoux	2.45c	Semi-standard	11.25c
HFD 11 EEI	2.41c	Semi-standard	12.24c
SCS453 Nasato	2.40c	Semi-standard	10.43c
Fep. C37 Dornelles	2.39c	Semi-standard	11.54c
Flying Dragon	1,76d	Dwarf	4.72d
HFD 25 EEI	1.59d	Dwarf	3.59d

[1] Grouped by the Scott-Kott test. [2]Means followed by the same letter did not differ (Scott-Knott test, α =0.05).

Table 2: Yield of 'Valência' sweet orange trees budded on different rootstocks. Águas de Chapecó, SC, Brazil, 2012-2023

Rootstock	Annual tree yield	Yield Efficiency	Pedestrian harvest	Average fruit mass
	kg $tree^{-1}$	kg m^{-3}	%	g
Sun Chu Sha Kat	46.21bcde[1]	2.67f	88.62e	170.60cde
BRS CNPMF Trop.	55.78b	3.08ef	89.17e	180.15bcd
Changsha × English	49.24bc	3.23ef	93.81cd	174.97cde
San Diego	77.40a	4.51ab	92.56d	186.26abc
Swingle	49.82bc	3.55cdef	93.17d	173.77cde
Carrizo	46.27bcde	3.34def	94.29cd	171.61cde
Sunki × Benecke	45.33bcde	2.98ef	96.97abc	181.01bcd
Cravo	45.13bcde	4.00abcd	95.60bcd	184.18bc
Cravo × Sunki EEI	36.20def	4.37abc	98.77a	182.06bc
Fepagro C 13	35.61ef	3.29ef	96.80abc	179.54bcd
C 35	41.97cde	3.79bcde	98.71a	192.61ab
Rubidoux	29.70f	3.37def	99.37a	172.83cde
HFD 11 EEI	40.77cde	3.85bcde	98.05ab	173.03cde
SCS453 Nasato	27.30f	3.37def	99.43a	167.71cde
Fep. C37 Dornelles	46.63bcd	4.58ab	99.13a	200.74a
Flying Dragon	11.97g	3.48cdef	100.00a	165.70de
HFD 25 EEI	15.27g	4.67a	100.00a	159.90e

[1] Means followed by the same letter did not differ (Tukey test, α =0.05).

In Table 3 are presented the mean proposed tree spacing. For all rootstocks, row distance was reduced, while inter-tree space was increased for 'BRS CNPMF Tropical', 'Sun Chu Sha Kat', 'San Diego', 'Carrizo' and 'Changsha × English'. 'San Diego' was estimated to reach the highest TY – 35.21 t, which is 48% more than 'Swingle'. The dwarf average productivity (11.99 to 14.46 t ha^{-1}) was estimated to be smaller even with increased plant density.

Table 3: Proposition of tree spacing for ‘Valência’ orange in different rootstocks (classified by tree size) based on canopy diameter; yield estimated for orchards with the spacing proposed along 10 years; and yield observed at 7 x 3m in Águas de Chapecó, SC, Brazil

		Spacing (m)		Annual Yield (t ha^{-1})	
Tree size group	**Rootstock**	**Inter-Row**	**Inter-Tree**	**Estimated[1]**	**Observed**
Super standard	BRS CNPMF Trop.	6.81	3.23	24.69b	25.86
Super standard	Sun Chu Sha Kat	6.76	3.20	20.59bc	21.04
Standard	San Diego	6.76	3.19	35.21a	36.14
Standard	Swingle	6.49	2.99	23.69bc	21.93
Standard	Carrizo	6.52	3.02	23.33bc	21.79
Standard	Sunki × Benecke	6.42	2.94	23.00bc	20.79
Standard	Changsha × English	6.55	3.04	22.82bc	21.77
Standard	Cravo	6.23	2.80	20.39bc	17.89
Semi-standard	Fep. C37 Dornelles	6.12	2.72	26.16b	20.93
Semi-standard	C 35	6.31	2.85	22.80bc	19.63
Semi-standard	HFD 11 EEI	6.22	2.87	22.13bc	18.89
Semi-standard	Cravo × Sunki	6.01	2.63	21.49bc	16.23
Semi-standard	Fepagro C 13	6.16	2.74	20.72bc	16.78
Semi-standard	Rubidoux	6.05	2.66	18.24cde	13.79
Semi-standard	SCS453 Nasato	5.95	2.59	17.21de	12.63
Dwarf	Flying Dragon	5.19	2.01	14.46e	7.20
Dwarf	HFD 25 EEI	4.97	1.90	11.99e	5.60

[1] Means followed by the same letter did not differ (Tukey test, α =0.05).

Significant differences were observed in average fruit mass (Table 4). ‘Fepagro C37 Dornelles’ stood out, with higher mean than fourteen others: ‘Flying Dragon’, ‘HFD 25 EEI’, ‘Rubidoux’, ‘HFD 11 EEI’, ‘SCS453 Nasato’, ‘Sun Chu Sha Kat’, ‘BRS CNPMF Tropical’, ‘Changsha × English’, ‘Swingle’, ‘Carrizo’, ‘Sunki × Benecke’, ‘Cravo’, ‘Fepagro C13’ and ‘Cravo × Sunki EEI’. On the negative side ‘HFD 25 EEI’ was surpassed by eight genotypes: ‘Fepagro C37 Dornelles’, ‘Sunki × Benecke’, ‘Cravo’, ‘Cravo × Sunki EEI’, ‘Fepagro C 13’, ‘C 35’, ‘BRS CNPMF Tropical’ and ‘San Diego’. Significant, positive correlations were found between residuals of average fruit mass and TY (r=0.49), or YE (r=0.27). Peel color was significantly affected by the treatments only in 2019 (Table 5), when the PCI on ‘Cravo’ × ‘Sunki’ EEI was lower than in ‘SCS453 Nasato’, ‘Changsha’ × ‘English’, ‘HFD 11 EEI’ and ‘Sunki’ × ‘Benecke’. Juice content in the fruits was less variable: only fruits on ‘San Diego’, ‘C 35’ and ‘Sunki × Benecke’ surpassed the ones on ‘Flying Dragon’ and ‘SCS453 Nasato’. ‘Fepagro C37 Dornelles’ produced juice with significantly lower acidity compared to eleven of sixteen opponents. ‘SCS 453 Nasato’ fruits had the highest soluble solids content, significantly higher than ‘BRS CNPMF Tropical’, ‘San Diego’, ‘Swingle’, ‘Cravo’, ‘Cravo’ × ‘Sunki’ EEI and ‘Fepagro C37 Dornelles’. ‘Sunki’ × ‘Benecke’ and ‘Cravo’ produced fruits with lower ratio compared to ‘San Diego’, ‘Fepagro C37 Dornelles’, ‘HFD 25 EEI’ and ‘C 35’.

Discussion

In this work, the agronomic performance of ‘Valência’ orange trees was evaluated under effect of seventeen rootstocks contrasting in size induced to the scion from dwarfing to super-standard genotypes (Table 1). It is the longest-term experiment performed with orange trees in Santa Catarina state. ‘Cravo’ Rangpur lime was widely used as rootstocks for all citrus scions in Santa Catarina, despite its susceptibility to gummosis and frost, and relatively low fruit quality induced to the scion. It has been replaced by ‘Swingle’ citrumelo, with advantages in gummosis tolerance, cold hardening and fruit quality. Other rootstocks like the trifoliate orange, some citranges and the tangerines ‘Sunki’ and ‘Cleópatra’ are almost insignificant, although they have been recommended by scientists and technicians.

The ‘San Diego’ citrandarin is the biggest highlight in the present work. It beat all the other rootstocks tested in yield by tree and by hectare, even though after a tree density adjustment by canopy size (Table 2). Although it was more productive, no disadvantage was observed in tree height (Table 1), or in difficulty in harvest the top of the canopy (Table 2), or in the quality of the fruit, (Table 3) when compared to 'Swingle', the main rootstock in Santa Catarina nurseries nowadays. A flaw is the bigger canopy area (Table 1), which means that canopies upon them are wider than on 'Swingle'. The consequence is a more difficult orchard management. But it diminishes the number of trees by hectare needed for a good occupation of the land. In Pelotas (Rio Grande do Sul state), young 'Valência' trees upon 'San Diego' produced better colored fruits, higher in polyphenol content than other rootstocks, with good early yield.[(15)] In São Paulo State, 'San Diego' induced drought tolerance similar to 'Cravo', but with higher survival rate (100%), showing similar symptoms of incompatibility with 'Valência' following a visual inspection under the trunk bark.[(16)] Its performance in nurseries is controversial, possibly because of differences in environment. Lower seedling emergence percentage (43.8%) compared to 'Swingle' and 'Cravo' was reported by Marques et al.[(17)] in subtropical southern Brazil, but 83.5% was observed by Sombra *et al*[(18)] in a tropical place, as well as a fast stem diameter growth, reaching 2.37 mm in 90 days.

'Fepagro C37 Dornelles' produced small 'Valência' trees compared to 'Swingle', with similar yield efficiency and yield by hectare, independently of spacing adjustment (Table 1 and 2), but with higher PH, which means it is easier to harvest. It is being observed to perform well as rootstock for young 'Murcott' tangor in a nearby place in western Santa Catarina[(19)]. Besides its seedling emergence rate in southern Brazil was observed to be lower than in 'Swingle', it reached about 80% (120 days after sowing).[(20)] Its stem diameter reached 2.99 mm 150 days after sowing, higher than trifoliate orange and 'Sunki' mandarin.[(21)] Furthermore, compared to the other, 'Valência' oranges on 'Fepagro C37 Dornelles' shown to be heavy (220g), significantly more than 'Swingle', good colored and few acidic, and, besides the moderate SS content, they had a high SS/TA ratio (11.9) (Table 3), which suggest it is a good option both for table oranges or juice extraction. However, most citranges are just moderately tolerant to gummosis, which discourage its use in fine-textured soils.[(22)]

Beyond 'Fepagro C37 Dornelles', is the Semi-standard group there are other options for replace 'Swingle' with the objective of form an easy-harvest orchard without losing in hectare production: 'C 35' citrange, 'HFD 11 EEI',

Table 4: Characteristics of 'Valência' sweet oranges produced on different rootstocks. Águas de Chapecó, SC, Brazil

Rootstock	PCI 2019[1]	Color score 2023[1]	Juice content[2]	Titratable acidity[2 3]	Soluble solids[2]	Ratio[2]
			%	%	°Brix	
BRS CNPMF Trop.	3.34b	3.43ns	54.00ab	1.16a	10.85cdef	10.71ab
Sun Chu Sha Kat	3.88b	3.29	53.85ab	1.19a	11.24abcdef	9.63b
San Diego	3.38b	3.39	55.28a	0.93bc	10.45def	11.34a
Cravo	3.56b	3.73	52.29ab	1.18a	11.14bcdef	9.64b
Sunki × Benecke	4.07a	3.61	55.83a	1.14a	11.55abcd	9.63b
Changsha × English	4.22a	3.58	54.35ab	1.10ab	11.57abcd	10.90ab
Swingle	3.86ab	3.48	54.51ab	1.05bc	10.79cdef	10.55ab
Carrizo	3.41b	3.73	54.11ab	1.14a	11.63abcd	10.48b
Fep. C37 Dornelles	2.67ab	3.29	52.48ab	0.92c	10.16ef	11.19a
C 35	3.68b	3.79	55.29a	1.01bc	11.4abcde	11.74a
Cravo × Sunki	1.95b	3.35	52.69ab	1.01bc	10.10f	10.12ab
Fepagro C 13	3.72b	3.80	53.36ab	1.10ab	11.54abcd	10.74ab
HFD 11 EEI	4.12a	3.51	53.82ab	1.17a	11.85abc	10.39ab
Rubidoux	3.92b	3.38	52.94ab	1.17a	11.89abc	10.41ab
SCS453 Nasato	4.23a	3.56	51.92b	1.19a	12.44a	10.71ab
Flying Dragon	3.58b	3.61	51.75b	1.11a	11.63abcd	10.52ab
HFD 25 EEI	3.32b	3.46	53.84ab	1.09abc	12.28ab	11.34a

[1] Harvest season. [2] Average of four seasons. [3] % of citric acid. Means followed by the same letter did not differ (Tukey test, α =0.05). ns = not significant (Anova, p=0.11)

‘Cravo × Sunki EEI’, ‘Fepagro C 13’ and ‘Rubidoux’ trifoliate orange, which performed satisfactorily in TYH (Table 2). Although the last two had more acidic juice, it resulted in a similar SS/TA ratio thanks to the SS content (Table 3). However, no information is available on the behavior of ‘HFD11 EEI’ and ‘Cravo × Sunki EEI’ facing the main citrus diseases, like gummosis, sudden death or citrus decline. ‘Fepagro C 13’ is moderately resistant to gummosis, but susceptible to citrus decline.[22] ‘C 35’ was considered more tolerant do *Phytophthora nicotianae* than ‘Carrizo’, but less than ‘Swingle’.[23] ‘Rubidoux’, as a *P. trifoliata* cultivar, is considered resistant to *Phytophtora parasitica*,[24] and so should be preferred for humid or fine-textured soils.

Considering the necessity of broadening the genetic diversity of citrus orchards, various rootstocks discussed above can be considered for use under ‘Valência’ orange in western Santa Catarina and nearby. Other ones showed some flaws. The super standard ‘Sun Chu Sha Kat’ and ‘BRS CNPMF Tropical’ rootstocks yielded satisfactorily (Table 1). However, they grew too much, which made the orchard hard to manage and, especially, to harvest, with PH around 89%. The manual harvesting is the main cost in citrus fruit production, which makes, in addition to productivity, orchards with better tree functionality are sought for current dense citrus production systems.[25- 31] In this context, Girardi *et al*[5] found that harvest time is directly related to canopy size, fruit production, and the need to use ladders. The authors observed that the ‘Valencia’ orange tree grafted onto rootstocks that provide larger canopy size required approximately three times more time to be harvested compared to the dwarf rootstocks. The latter dismissed the use of ladders, which contributed to speeding up the operation. Furthermore, harvesting efficiency was 17% higher on dwarf rootstocks, due to the easiness of harvesting, resulting in less time needed per fruit tone harvested. Furthermore, fruits on super standard rootstocks were more acidic than on ‘Swingle’ and ‘San Diego’ (Table 3). ‘Carrizo’ citrange, ‘Sunki’ × ‘Benecke’ citrandarin and ‘Cravo’ rangpur lime performed similarly to ‘Swingle’ in terms of size, yield and harvest easiness (Table 1-2), but produced more acidic juice (Table 3). ‘Cravo’, furthermore, had one third of the trees dead by gummosis.

Dwarfing rootstocks have been pointed out as the best way to obtain small-tree orchards which are easier to harvest and have shown advantages in pest and disease manage, including huanglongbing.[5,32] In the present experiment we evaluated two genotypes capable of producing dwarfed ‘Valência’ trees: ‘Flying Dragon’ trifoliate orange and a new hybrid ‘HFD25 EEI’. They reduced canopy volume to 28 and 21% of ‘Swingle’ average, fitting the Dwarf category.[13] Four years after planting, the trees on ‘HFD25 EEI’ averaged 1,7m tall (data not shown), while ‘Flying Dragon’ trees were 1.48m. Five years later the former had a decrease in height (Table 1), unlike the latter. ‘HFD25 EEI’ trees in all plots showed yellow-green leaves, poor fluxes and flowering and fruiting. One tree was inspected for incompatibility and no abnormality was found, nor any symptom of gummosis. On the other hand ‘Flying Dragon’ grew in height and volume. However, its performance in terms of hectare yield was poor. The TYH estimates on Table 2 showed that even if it had been planted in 5.9 x 2.1m, and keeping the same by-tree yield, the yearly average production by hectare would have been 14.46 tons of oranges, which is 39% less than the TYH with ‘Swingle’. In a nearby place, ‘Flying Dragon’ have demonstrated to perform better with ‘Ponkan’ mandarin (*Citrus reticulata* Blanco), having reached 4.88m³ of canopy and produced 22 t ha^{-1} yearly until the seventh year or the five first harvests, in 5 x 2m.[4] As the yield efficiency of ‘Valência’ on ‘Flying Dragon’ and ‘Swingle’ was similar, the small canopy volume by hectare seems to be a good explanation for the former’s poor performance. A significantly positive correlation (r=0.66) was observed between TYH and V, and a negative correlation (r=-0.35) between YE and V. So, bigger trees tended to be less efficient. However, a Standard ‘Swingle’ orchard at 6.49 x 2.99m would have 8,600 m³ of canopies per hectare, while with the Dwarf ‘Flying Dragon’ only 4,500 m³. So, YE of the Dwarf trees must be increased through management or the orchard design must be modified in a way to increase per-hectare volume.

CONCLUSIONS

The citrandarin ‘San Diego’ as rootstock for ‘Valência’ sweet orange in western Santa Catarina state form trees similar in size to the widespread citrumelo ‘Swingle’, but is more productive without losing fruit quality.

‘Fepagro C37 Dornelles’ reduce ‘Valência’ tree size, facilitate fruit harvest and induce it to produce heavy, good quality fruits.

Dwarf rootstocks lead to a low hectare yield even in reduced space orchards. Semi-standard rootstocks like ‘Fepagro C37 Dornelles’, ‘Fepagro C13’ and ‘C 35’ citranges, ‘HFD 11 EEI’, ‘Cravo × Sunki EEI’ and ‘Rubidoux’ trifoliate orange should be preferred for ‘Valência’ tree size reduction.

ACKNOWLEDGEMENTS, FINANCIAL SUPPORT AND FULL DISCLOSURE

We thank so much Mr. Sadi Comel and his family by the partnership; our retired colleague Dr. Osvino L. Koller by helping planning and executing the project; Dr. Evandro Spagnolo and Dr. Fernando Perobelli Ferreira by helping in soil identification; Dr. Cristiano Nunes Nesi by helping in repeated measures analysis; the Financiadora de Estudos e Projetos (FINEP) and Fundação de Amparo à Pesquisa e Inovação do Estado de Santa Catarina (FAPESC) by the financial resources granted.

The authors declare that they have no conflict of interest.

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