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Tree Growth and Production of Rainfed Valencia Sweet Orange Grafted onto Trifoliate Orange Hybrid Rootstocks under Aw Climate

Eduardo Augusto Girardi [1,*], Antonio Juliano Ayres [2], Luiz Fernando Girotto [3] and Leandro Peña [2,4]

[1] Embrapa Cassava & Fruits, Rua Embrapa, s/n, Cruz das Almas 44380-000, Brazil
[2] Fund for Citrus Protection—Fundecitrus, Av. Dr. Adhemar Pereira de Barros, 201, Araraquara 14807-040, Brazil; juliano.ayres@fundecitrus.com.br (A.J.A.); lpenya@ibmcp.upv.es (L.P.)
[3] Agronomist, Av. Brasil, 740, Araraquara 14801-050, Brazil; lgirotto@farocapital.com.br
[4] Institute of Molecular and Cellular Plant Biology, Higher Council for Scientific Research, Polytechnic University of Valencia, Camino de Vera, s/n, 46022 Valencia, Spain
* Correspondence: eduardo.girardi@embrapa.br; Tel.: +55-016-3301-7025

Abstract: Brazil is the largest producer of sweet orange and its juice in the world. Extensive cultivated area is located under an Aw climate in the North–Northwest of the state of São Paulo and the Triângulo of Minas Gerais state, being subjected to severe drought events. Although 56% of the orchards are irrigated in these regions, there is a need for drought tolerant rootstocks as an alternative to traditional genotypes such as Rangpur lime and Volkamer lemon, which are susceptible to the endemic citrus sudden death disease (CSD). In this sense, the tree size and production of Valencia sweet orange grafted onto 23 rootstock genotypes were evaluated over a ten-year period in rainfed cultivation at 7.0 m × 3.0 m spacing. Most evaluated types resulted from the cross of *Poncirus trifoliata* with *Citrus*, but two interspecific hybrids of *Citrus* (Sunki mandarin × Rangpur lime hybrids), the Barnes trifoliate orange and a tetraploid selection of Swingle citrumelo were also tested. Tropical Sunki mandarin was used as the reference control. Those hybrids coming from the cross of Sunki × Flying Dragon induced large tree sizes to Valencia sweet orange as well as the other citrandarins, Tropical Sunki mandarin and the Sunki mandarin × Rangpur lime hybrids, whereas only the tetraploid Swingle citrumelo behaved as a dwarfing rootstock, decreasing the canopy volume by 77% compared to that induced by the most vigorous citrandarin 535. The citrandarins 543 and 602 and the citrange C38 induced the highest mean fruit production, 67.2 kg·tree^{-1}, but they also caused pronounced alternate bearing and only the hybrid 543 led to a high production efficiency consistently. Graft incompatibility symptoms were not observed over the evaluation period, and the canopy shape of Valencia sweet orange was also influenced by the rootstocks tested. Two citrandarins and one citrange were selected as the most promising alternative rootstocks for Valencia sweet orange grown under an Aw climate, even though productivity would likely benefit from supplementary irrigation.

Keywords: *Citrus* spp.; *Poncirus trifoliata*; drought tolerance; fruit yield; tree size control; genotype evaluation

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1. Introduction

Brazil is the largest producer of sweet orange [*Citrus* × *sinensis* (L.) Osbeck] and its derived products in the world, corresponding to 21.7% of the 78.7 million tons harvested worldwide in 2019 [1]. Sweet oranges are grown mainly for juice processing, and Brazil accounts for three-fourths of the international orange juice exports [2]. The citrus belt of São Paulo and Minas Gerais States comprises about 80% of the Brazilian sweet orange production in a cultivated area of 400 thousand hectares in 2021 [3]. About 30% of the orchards are located in the North–Northwest of the state of São Paulo and in the Triângulo Mineiro region, which are characterized by the typical Aw climate (tropical savannah

type) [4], deep alic red oxisols [5], and a limited use of irrigation (just in about 56% of the cultivated area in the region), despite its history of severe drought events [3].

In these same regions, although huanglongbing (HLB) incidence is relatively low [6], the citrus sudden death disease (CSD) has been endemic since 1999 [7], which has hindered the use of traditional rootstock genotypes such as Rangpur lime (*C.* × *limonia* Osbeck) and Volkamer [*C.* × *volkameriana* (Risso) V. Ten. & Pasq.] and Rough (*C.* × *jambhiri* Lush.) lemons [8]. Two to fifteen-year-old sweet orange and mandarin trees grafted onto CSD-susceptible rootstocks decline and die within a few months after infection, especially upon drought conditions. As a result, only CSD-tolerant or resistant rootstocks can be recommended as replacements, which include Swingle citrumelo [*C. paradisi* Macfad. cv. Duncan × *Poncirus trifoliata* (L.) Raf.], Sunki [*C. sunki* (Hayata) hort. ex Tanaka] and Cleopatra (*C. reshni* hort. ex Tanaka) mandarins, as well as trifoliate orange (*P. trifoliata*) [9]. From 2000 to 2020, the use of the Rangpur lime in nurseries in Sao Paulo dropped from 75% to 27% of grafted trees, whereas Swingle citrumelo and Sunki mandarin increased to 55% and 9%, respectively, and became the main commercial alternatives [10,11]. However, all of these rootstock genotypes are more sensitive to drought compared to the CSD-susceptible types [9,10], which has increased the exposure of the citrus industry in the region to severe drought events regardless of the use of irrigation. In 2020–2021, it was estimated that the eradication of orchards increased almost two-fold and fruit drop grew in relation to the previous season mainly due to severe drought conditions that resulted in significant tree decline and death [3].

Because citrus cultivation is irrigated in most subtropical and Mediterranean regions, drought tolerance has been of less concern as a desirable trait in rootstock breeding programs, even though a higher water use efficiency has been increasingly relevant in the search of new rootstocks due to the escalating water scarcity worldwide derived from climate warming [12–14]. Furthermore, rainfed cultivation is usual in tropical conditions in Latin America, Africa and Asia, which has encouraged the creation and evaluation of new rootstocks in Brazil, mostly trifoliate orange hybrids and Sunki mandarin selections, that cope with seasonal water deficit and, in the case of São Paulo, should also be CSD-tolerant or resistant [15–20]. However, the etiology of CSD and other diseases such as blight is unknown, and reliable diagnosis tests are not available to date, making selection dependent on the observation of typical symptoms over time in endemic regions as compared to susceptible genotypes [8,9,21]. Some citrandarins (mandarin × trifoliate orange hybrids) grafted with Valencia sweet orange presented good performance under such conditions in Brazil [22–25], so their use in nurseries increased to about 2.3% of the grafted trees in Sao Paulo in 2020 [11]. Another proposed strategy for the improvement of rootstocks is to select elite genotypes for obtaining tetraploid genotypes that usually present lower vegetative growth and higher abiotic stress tolerance in relation to their diploid counterparts [26–28]. However, the performance of tetraploid rootstocks has not been extensively reported in the field, notably under drought conditions.

Given this scenario, in this work the tree size and production of Valencia sweet orange grafted onto 23 rootstock genotypes, mainly new trifoliate orange hybrids in addition to a tetraploid selection of Swingle citrumelo, Barnes trifoliate orange and Tropical Sunki mandarin, were evaluated over 10 years in rainfed cultivation under an Aw climate in the Northwest of the State of São Paulo, Brazil.

2. Materials and Methods

2.1. Plant Material and Experimental Design

The IAC selection of Valencia sweet orange was used as the scion variety due to its importance for the Brazilian citrus belt [3]. Twenty-three different rootstocks were studied as described in Table 1. With the exception of Tropical Sunki mandarin and Barnes trifoliate orange, most rootstocks were hybrids between *Citrus* and *Poncirus*: 14 citrandarins, two citrumelos, two citranges and one citrumelandarin. These new hybrids are potentially tolerant to CSD because at least one parent or both are CSD-tolerant [8]. Addi-

tionally, two lemandarins and a tetraploid selection of Swingle citrumelo were included because the parents of mandarins and Swingle citrumelo are CSD-tolerant, while parents of lemons/limes are drought tolerant. The tetraploid nature of the latter was confirmed by flow cytometry analysis. All trees were grafted and grown in 5 L bags in a screenhouse nursery in the farm, using the inverted T-budding method, and were sent to the field at one year of age. Budwood of Valencia sweet orange was collected from a protected mother tree, and rootstocks were propagated from nucellar seedlings. No ungrafted tree was evaluated.

Table 1. Rootstocks grafted with Valencia sweet orange [*Citrus* × *sinensis* (L.) Osbeck] and evaluated in Northern São Paulo State, Brazil.

Rootstock Identification	Parents	Origin
SSW1	*Citrus sunki* (Hayata) hort. ex Tanaka × [*C.* × *paradisi* Macfad. × *Poncirus trifoliata* (L.) Raf.] cv. Swingle	Obtained by Citrolima Nursery, Casa Branca-SP, Brazil
SC4 and SC7	*C. sunki* × *C.* × *limonia* Osbeck	Obtained by Citrolima Nursery, Casa Branca-SP, Brazil
506, 530, 535, 539, 543, 568, 575, 582, 596 and 602	*C. sunki* × *P. trifoliata* var. *monstrosa* (T. Itô) Swingle cv. Flying Dragon	Obtained by Citrolima Nursery, Casa Branca-SP, Brazil
IAC 1710	*C. reticulata* Blanco cv. Changsha × *P. trifoliata* cv. English Small	Accession of the Citrus Germplasm Bank of the Centro de Citricultura Sylvio Moreira, Cordeirópolis-SP, Brazil
Cleo × English	*C. reshni* hort. ex Tanaka × *P. trifoliata* cv. English	Accession of the Citrus Germplasm Bank of the Centro de Citricultura Sylvio Moreira, Cordeirópolis-SP, Brazil
Cleo × Rubidoux	*C. reshni* × *P. trifoliata* cv. Rubidoux	Accession of the Citrus Germplasm Bank of the Centro de Citricultura Sylvio Moreira, Cordeirópolis-SP, Brazil
IAC 1697	*C. sunki* × *P. trifoliata* cv. Benecke	Accession of the Citrus Germplasm Bank of the Centro de Citricultura Sylvio Moreira, Cordeirópolis-SP, Brazil
C7 and C38	*C.* × *sinensis* (L.) Osbeck × *P. trifoliata*	Accession of the Citrus Germplasm Bank of the Centro de Citricultura Sylvio Moreira, Cordeirópolis-SP, Brazil
F.80-8	*C.* × *paradisi* × *P. trifoliata*	Accession of the Citrus Germplasm Bank of the Centro de Citricultura Sylvio Moreira, Cordeirópolis-SP, Brazil
Barnes	*P. trifoliata*	Accession of the Citrus Germplasm Bank of the Centro de Citricultura Sylvio Moreira, Cordeirópolis-SP, Brazil
4× SW	Tetraploid selection of Swingle citrumelo	Seedlings selected in the farm's nursery based on morphological traits according to [29]
Tropical Sunki (control treatment)	Putative nucellar embryo mutant of *C. sunki*	Obtained by Embrapa Cassava & Fruits, Cruz das Almas-BA, Brazil

The experimental design was completely randomized with 23 treatments (rootstocks), four replications and 15–40 trees per plot. Tropical Sunki mandarin was the control treatment. For tree size variables, 10–12 trees per treatment were sorted at random within the replications and used as experimental units. All trees were visually scouted for typical symptoms of rootstock-related diseases (CSD, tristeza and blight) as described by [8] at the end of the experiment in July 2021. A total of 3092 trees was evaluated.

2.2. Planting and Maintenance

The experiment was planted in November 2011 in a commercial farm in the municipality of Onda Verde (20°35′49″ S, 49°14′57″ W, 517 m), in the Northwestern region of the State of São Paulo, Brazil. Local climate is typical Aw (tropical with dry winter; normal average air temperature of the warmest and coldest month ≥ 22 °C and ≥ 18 °C, respectively; total rainfall of the year and of the driest month < 2500 mm and < 60 mm, respectively) or C2rA'a' depending on the classification [4]. Meteorological variables from July 2016 to July 2021 are presented in Figure A1.

The soil type at the experimental area is classified as *argissolo vermelho-amarelo* (Red-Yellow ultisol), with sandy to loamy texture and moderately wavy relief, presenting the following attributes at 0–20 cm at the end of the evaluation period: pH ($CaCl_2$) = 5.2; Cation Exchange Capacity (CEC) = 53 $cmol_c \cdot dm^{-3}$; Ca = 21 $cmol_c \cdot dm^{-3}$; Mg = 10 $cmol_c \cdot dm^{-3}$;

K = 3.2 $cmol_c \cdot dm^{-3}$; H + Al = 19 $cmol_c \cdot dm^{-3}$; V = 65%; P = 58 $mg \cdot dm^{-3}$; B = 0.93 $mg \cdot dm^{-3}$; Fe = 14 $mg \cdot dm^{-3}$; Mn = 21.5 $mg \cdot dm^{-3}$; Cu = 3.3 $mg \cdot dm^{-3}$; Zn = 3.6 $mg \cdot dm^{-3}$; Organic Matter (O.M.) = 13 $g \cdot kg^{-1}$. Trees were planted at 7.0 m × 3.0 m spacing (476 $trees \cdot ha^{-1}$), and the cultivation was rainfed. Trees were not pruned during the evaluation period, and the annual mean rates of fertilizers were 330 g of N, 95 g of P_2O_5, and 160 g of K_2O per tree in addition to 0.56 $t \cdot ha^{-1}$ of limestone. Area-wide management of HLB was performed as recommended by [30].

2.3. Tree Size

In 2016, 2017 and 2021 (five, six and ten years after planting), tree height (*H*) was measured from the ground level to the apex, and the canopy diameter was measured on the equatorial section of the scion canopy at parallel (*Da*) and perpendicular (*De*) positions to the planting line, using a ruler. The mean canopy diameter (*Dm*) was calculated, and the canopy volume (*V*) was estimated according to [31], Equation (1):

$$V = \frac{\pi}{6} \times Da \times De \times H. \quad (1)$$

In addition, the canopy shape was evaluated by an index (*CSI*), calculated by the mean ratio between *H* and *Dm* over the evaluation period (2016-2021), Equation (2):

$$CSI = \frac{H}{Dm}. \quad (2)$$

2.4. Fruit Production and Efficiency

Fruits were manually harvested from 2015 to 2017 according to the monitoring of the maturity index by the farm staff. All fruits from each replicate were placed in 500 kg bags, and weighed on a digital scale suspended by a tractor. The annual and average fruit yield per tree (*FY*) in the period are presented. From 2018 to 2021, the production was not evaluated because of low overall fruit yield and erratic fruit drop across the replications due to severe drought conditions. Nevertheless, in July 2021, the relative fruit production per cubic meter of canopy was estimated on the trees used for size measurement by counting the remaining fruits within a 0.5 m × 0.5 m × 1.0 m (width × length × depth) frame, placed at 1.5 m to 2.0 m height on the center of both sides of the canopy in relation to the planting line. This sampling volume corresponds to the medium portion of the tree and to the usual depth of the bearing volume into the canopy of adult sweet orange trees [32]. In addition, the production efficiency (*PE*, kg of fruit per cubic meter of canopy volume) was calculated in 2016 and 2017 by the Equation (3):

$$PE = \frac{FY}{V}. \quad (3)$$

2.5. Statistical Analysis

After the statistical assumptions were observed, data were submitted to the analysis of variance, and the means were grouped by the Scott-Knott test ($p < 0.05$) using the AgroEstat software [33]. The variable 'number of counted fruits per cubic meter of bearing volume' was transformed by $\sqrt{(x + 0.5)}$ to address the normality of data.

3. Results

3.1. Tree Size

The evaluated rootstocks induced different tree sizes to the Valencia sweet orange scions over the evaluation period. The canopy volume was directly related to the tree height and canopy diameter, and it increased 1.22- and 2.88-fold in average from 2016 to 2017 and 2021, respectively. Ten years after planting, the most vigorous rootstock was the citrandarin 535 (53.53 m^3), followed by the group comprised of the Tropical Sunki mandarin, IAC 1710, both Sunki × Rangpur hybrids and most of the Sunki × Flying Dragon hybrids, with an

averaged mean of 41.70 m^3. Only the tetraploid Swingle citrumelo was consistently a true dwarfing rootstock (12.29 m^3), decreasing in tree size by 77% in relation to the citrandarin 535. The remaining groups can be classified as semi-dwarfing (Cleopatra × Rubidoux, Barnes, F.80-8 and 506) and substandard (IAC 1697, Cleopatra × English, both citranges, SSW1 and citrandarins 582 and 568), leading to a mean canopy volume of 24.86 m^3 and 34.63 m^3, respectively. The canopy shape was also influenced by the rootstocks, and can be classified in three groups: vertical ellipsoid or prolate, with *CSI* > 1 (506, 568, 596, Barnes, 4× Swingle, C38, F.80-8, IAC 1710 and Tropical Sunki); horizontal ellipsoid or oblate, with *CSI* < 1 (582, both Cleopatra × trifoliate orange hybrids, IAC 1697, SC4 and SSW1); the remaining rootstocks induced spherical or round trees, with *CSI* ≅ 1 (Table 2).

Table 2. Tree height (*H*), mean canopy diameter (*Dm*), volume of the canopy (*V*), and canopy shape index (*CSI*) in 2016, 2017 and 2021, five to ten years after the planting of Valencia sweet orange [*Citrus* × *sinensis* (L.) Osbeck] grafted onto 23 rootstocks and cultivated without irrigation in Northwestern São Paulo State, Brazil.

Rootstock	*H* (m)			*Dm* (m)			*V* (m^3)			*CSI* [1]
	2016	2017	2021	2016	2017	2021	2016	2017	2021	
506	2.79 [b]	2.83 [d]	3.84 [c]	2.51 [e]	2.78 [c]	3.68 [d]	9.29 [c]	11.55 [d]	27.65 [d]	1.06 [a]
530	3.04 [a]	3.13 [b]	4.13 [b]	2.92 [b]	3.16 [a]	4.53 [b]	13.54 [a]	16.24 [b]	44.53 [b]	0.98 [b]
535	2.85 [b]	3.45 [a]	4.45 [a]	2.85 [c]	3.20 [a]	4.79 [a]	12.22 [b]	18.41 [a]	53.53 [a]	1.00 [b]
539	2.93 [b]	3.23 [b]	4.02 [b]	2.79 [d]	3.03 [b]	4.48 [b]	11.97 [b]	15.50 [c]	42.40 [b]	1.00 [b]
543	2.91 [b]	2.83 [d]	4.08 [b]	2.79 [d]	2.94 [b]	4.38 [b]	11.91 [b]	12.81 [d]	41.04 [b]	0.98 [b]
568	2.97 [a]	3.40 [a]	4.43 [a]	3.02 [a]	3.20 [a]	3.98 [c]	14.25 [a]	18.11 [a]	36.66 [c]	1.05 [a]
575	2.88 [b]	3.07 [c]	4.12 [b]	2.93 [b]	3.02 [b]	4.39 [b]	12.98 [b]	14.61 [c]	41.66 [b]	0.98 [b]
582	2.55 [c]	2.94 [d]	3.83 [c]	2.67 [d]	2.98 [b]	4.22 [c]	9.60 [c]	13.65 [d]	35.87 [c]	0.95 [c]
596	2.95 [a]	3.13 [b]	4.38 [a]	2.86 [c]	3.03 [b]	4.23 [c]	12.70 [b]	15.02 [c]	40.92 [b]	1.03 [a]
602	3.11 [a]	3.09 [c]	4.18 [b]	2.93 [b]	3.28 [a]	4.36 [b]	13.96 [a]	17.32 [a]	42.16 [b]	0.99 [b]
4× SW	2.32 [d]	2.48 [f]	3.09 [e]	2.13 [f]	2.50 [d]	2.73 [e]	5.58 [d]	8.22 [e]	12.29 [e]	1.08 [a]
Barnes	3.10 [a]	3.06 [c]	3.75 [c]	3.03 [a]	3.21 [a]	3.52 [d]	14.92 [a]	16.44 [b]	24.45 [d]	1.02 [a]
C38	2.86 [b]	3.49 [a]	4.12 [b]	2.84 [c]	3.23 [a]	4.09 [c]	12.12 [b]	18.93 [a]	36.42 [c]	1.03 [a]
C7	2.80 [b]	3.10 [c]	4.12 [b]	2.89 [c]	3.18 [a]	3.98 [c]	12.31 [b]	16.20 [b]	34.54 [c]	1.00 [b]
Cleo × English	2.83 [b]	2.87 [d]	3.88 [c]	2.92 [b]	3.13 [a]	3.94 [c]	12.64 [b]	14.55 [c]	31.70 [c]	0.96 [c]
Cleo × Rubidoux	2.93 [b]	2.62 [e]	3.38 [d]	2.88 [c]	2.98 [b]	3.51 [d]	12.83 [b]	12.11 [d]	22.64 [d]	0.95 [c]
F.80-8	2.88 [b]	3.23 [b]	3.89 [c]	2.96 [b]	3.15 [a]	3.47 [d]	13.23 [a]	16.66 [b]	24.72 [d]	1.04 [a]
IAC 1697	2.81 [b]	2.62 [e]	4.06 [b]	3.03 [a]	2.98 [b]	3.98 [c]	13.49 [a]	12.11 [d]	33.92 [c]	0.95 [c]
IAC 1710	2.99 [a]	3.20 [b]	4.38 [a]	2.92 [b]	3.13 [a]	4.15 [c]	13.36 [a]	16.28 [b]	39.74 [b]	1.04 [a]
SC4	2.85 [b]	3.08 [c]	4.05 [b]	2.92 [b]	3.19 [a]	4.46 [b]	12.78 [b]	16.33 [b]	42.22 [b]	0.95 [c]
SC7	2.99 [a]	3.07 [c]	4.12 [b]	2.77 [d]	3.09 [b]	4.40 [b]	12.06 [b]	15.37 [c]	42.59 [b]	1.00 [b]
SSW1	3.02 [a]	2.99 [c]	3.79 [c]	3.01 [a]	3.15 [a]	4.08 [c]	14.37 [a]	15.45 [c]	33.30 [c]	0.96 [c]
Tropical Sunki (control treatment)	2.92 [b]	3.45 [a]	4.58 [a]	3.05 [a]	3.20 [a]	4.06 [c]	14.20 [a]	18.41 [a]	39.75 [b]	1.06 [a]
p-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
CV%	5.78	5.40	7.04	5.20	3.83	6.77	12.69	8.84	17.15	2.52

Means followed by the same letters (a–f) belong to the same group by the Scott-Knott test ($p \leq 0.05$). Rootstock acronyms according to Table 1. [1] *CSI* is the mean ratio between tree height and canopy diameter in the 2016–2017–2021 period.

3.2. Fruit Production and Efficiency

The fruit yield per tree differed over the evaluation period, with an overall alternate behavior due to a low production in 2016. Nevertheless, the rootstocks induced variable fruit yields in all seasons. The Sunki × Flying Dragon hybrids 602 and 543, and the citrange C38 induced the highest mean fruit yield, 67.2 kg·tree^{-1}. Ranging from 45.7 to 54.7 kg·tree^{-1}, a second group ranked next comprising 596, 539, 575, F.80-8, IAC 1710, IAC 1697, Cleopatra × English, Barnes trifoliate orange and Tropical Sunki mandarin, while all other rootstocks produced less than an orange box per tree, which included dwarfing and some vigorous rootstocks. The tetraploid Swingle citrumelo and citrandarin

506 yielded consistently the least production over the evaluated seasons, whereas C38, IAC 1710, IAC 1697, Cleopatra × Rubidoux, 596 and 575 presented a more pronounced alternate bearing (Figure 1).

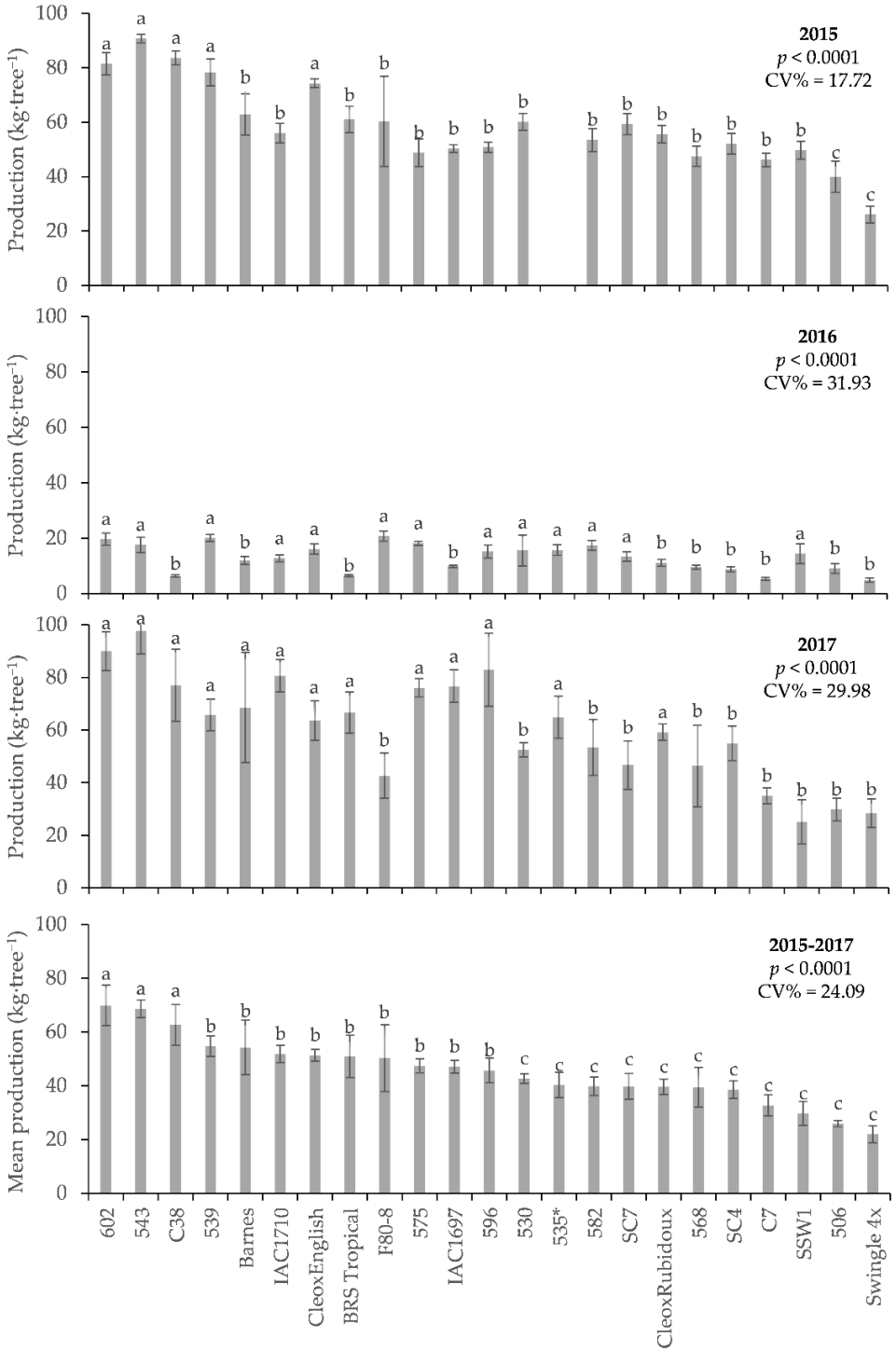


Figure 1. Fruit yield per tree in 2015, 2016 and 2017, and mean fruit yield in the 2015–2017 period, five to seven years after the planting of Valencia sweet orange [*Citrus* × *sinensis* (L.) Osbeck] grafted onto 23 rootstocks and cultivated without irrigation in Northwestern São Paulo State, Brazil. Means followed by the same letters belong to the same group by the Scott-Knott test ($p \leq 0.05$). The bar indicates the standard error of the mean. Rootstock acronyms according to Table 1. * Not evaluated in 2015. BRS Sunki Tropical is the control treatment.

The fruit yield potential of the evaluated rootstocks was estimated in 2021 by counting the number of fruits in the canopy bearing volume. Sunki Tropical mandarin, IAC 1697 and the citrandarins 543, 602 and 535 induced the highest number of fruits (28 to 39 fruits per cubic meter of bearing volume), followed by C38 and the citrandarins 596, 575, 568 and 539 (17 to 25 fruits). The least number of fruits, 0 to 5, was provided by Barnes trifoliate orange, Cleopatra × English, tetraploid Swingle citrumelo, C7, SSW1 and 506 (Figure 2). Considering the production efficiency (*PE*), that is, the total production divided by the whole tree canopy volume, citrandarin 543 corroborated its better performance because *PE* was the highest in 2016 and 2017, regardless of inducing large tree size (Table 2), while Tropical Sunki mandarin led to a lower *PE*, and other high-yielding rootstocks varied according to the year evaluated. Although tetraploid Swingle citrumelo, Barnes trifoliate orange, 506 and Cleopatra × Rubidoux decreased the tree size (Table 2), *PE* was still low due to their low fruit yield. Conversely, low to medium size-inducing rootstocks that presented a higher *PE* comprised citrumelo F.80-8, and citrandarins 582, Cleopatra × English and IAC 1697 (Figure 2).

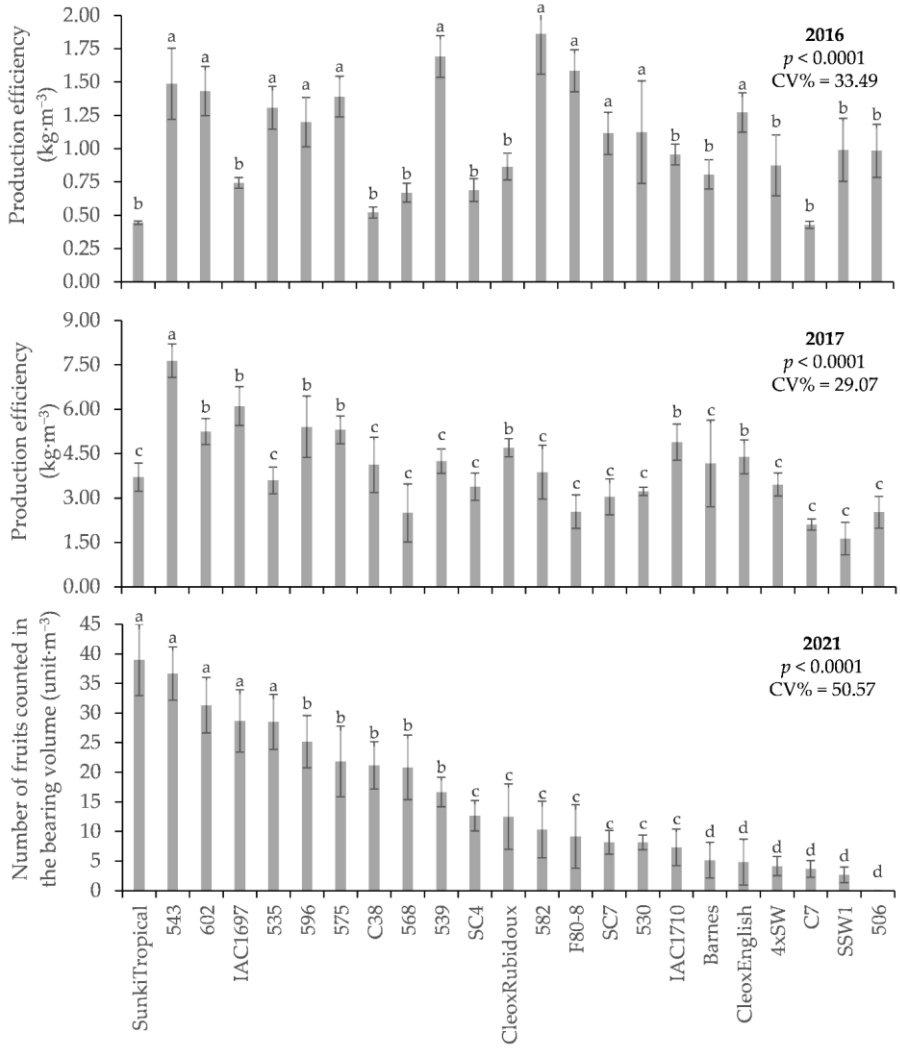


Figure 2. Production efficiency (*PE*) in 2016 and 2017, and mean number of fruits (*NF*) counted per cubic meter of bearing volume in 2021, ten years after the planting of Valencia sweet orange [(*Citrus* × *sinensis* (L.) Osbeck] grafted onto 23 rootstocks and cultivated without irrigation in Northwestern São Paulo State, Brazil. Means followed by the same letters belong to the same group by the Scott-Knott test ($p \leq 0.05$). Rootstock acronyms according to Table 1. Sunki Tropical is the control treatment.

4. Discussion

The extensive cultivation of citrus without irrigation in Brazil and other tropical regions has been possible due to the use of drought tolerant rootstocks. Among the traditional rootstock genotypes in current use, sour orange, Sunki mandarin, Rangpur lime, and Rough and Volkamer lemons address this trait properly [34]. However, citrus tristeza and sudden death diseases impair the use of sour orange and lemon-like rootstocks in affected areas, respectively, while Sunki mandarin is highly susceptible to Phytophthora gummosis [35]. Furthermore, the ramping climate warming is likely to alter the water regime and increase events of heat waves without rain in most citrus regions [36], which will in turn decrease the availability of water for irrigation and expose citrus trees to soaring stresses. Hence, citrus breeding programs around the world have expended efforts to create and select new citrus rootstocks that can cope with severe drought conditions or are more efficient in the use of water. In this work, we evaluated 23 rootstock genotypes grafted with Valencia sweet orange in an Aw climate, and we observed that some hybrids demonstrate potential for rainfed cultivation based on tree growth and production after ten years of planting under severe seasonal drought conditions. To the best of our knowledge, the long-term field performance of some of the evaluated rootstocks, such as the tetraploid Swingle citrumelo, is reported for the first time.

Hybrids of Sunki mandarin × Flying Dragon trifoliate orange. Ten hybrids of this cross were evaluated, and they induced different attributes to the Valencia sweet orange. Surprisingly, despite the use of a dwarfing parent (Flying Dragon), most hybrids induced high tree size, except 506, 568 and 582 that led to intermediate vigor. Other hybrids from the same cross that were previously evaluated in Brazil were dwarfing to semi-dwarfing rootstocks, even though there was a clear genetic segregation for this trait [16]. In this work, the fruit production and productive efficiency were higher for about half of the hybrids, with 602 and 543 being highlighted because of a consistently good performance throughout the evaluation period. On the other hand, the lowest mean production of 506 could be explained by a putative susceptibility to drought or blight disease, because visual symptoms suspicious of blight were observed for all trees at the end of the experiment, whereas all the other hybrids from this group presented no typical visual symptoms of rootstock-related diseases (Figure A2). Thus, the cross of Sunki mandarin × Flying Dragon trifoliate orange should be considered valuable in further rootstock breeding programs, and similar hybrids also performed well in rainfed cultivation in Brazil [16]. In Florida, the citrandarin US-942 is a cross of Sunki × Flying Dragon, and it is the most planted citrus rootstock in that State since 2018, likely because it is inducing good fruit production and quality to most scion varieties, intermediate tree size and putative field tolerance to HLB [34].

Hybrids of Sunki mandarin × Rangpur lime or Swingle citrumelo. Both Sunki × Rangpur hybrids evaluated induced high tree size but low fruit yield, which would preclude their use as commercial rootstocks. A similar result was observed for the Sunki × Swingle SSW1 hybrid, though it induced an intermediate tree size, and symptoms suspicious of blight were observed. However, in other studies under similar environmental and management conditions, other hybrids of Sunki × Swingle induced high fruit yield and tree survival, good drought tolerance and semi-dwarfing to vigorous tree size [15,16], indicating some potential for obtaining competitive hybrids from this cross.

Hybrids of Cleopatra mandarin × trifoliate orange. The decreased tree size, lower fruit production and a very typical oblate shape of the canopy were traits associated with Cleopatra × Rubidoux and Cleopatra × English hybrids tested. However, fruit yield was slightly higher for the latter rootstock, while the former was an alternate bearer. At the end of the experiment, symptoms suspicious of blight were observed for trees on both hybrids. These results corroborate previous works in Brazil, which also showed that these same hybrids induced high fruit quality to the Valencia sweet orange scions albeit overall performance was poor [15,22,37]. The X639 citrandarin is another hybrid obtained from the same cross in South Africa, and it has been commercially planted in the USA [34], after

exhibiting similar characteristics to these two hybrids evaluated here except by inducing larger tree size.

Citranges. C7 and C8 resulted in medium to large trees, but only C38 can be selected as a highly productive rootstock. Although its average production efficiency was lower compared to most citrandarins, C38 did not show visual blight symptoms ten years after planting, while blight susceptibility is a common trait for most citranges in general [34]. Therefore, C38 could be considered for further investigation similar to other citranges that performed well in Southern Brazil [38].

Commercial citrandarins. IAC 1710 and IAC 1697 were introduced from Florida [22], where they are denominated as US-801 and US-812, respectively, but only the latter was released for commercial exploration [34]. Conversely, in São Paulo only IAC 1710 has been significantly planted to date [10]. In this work, IAC 1710 induced larger trees than IAC 1697, but both citrandarins led to high fruit production with some alternate bearing. Moreover, the incidence of visual symptoms suspicious of blight was low at the end of the experiment, which corroborate previous observations in Brazil [22,23] even though US-812 is considered a blight-tolerant rootstock in Florida [34]. Both citrandarins induced good performance to Valencia sweet orange in São Paulo and Paraná States [22–24,39], with IAC 1697 being consistently less vigorous and inducing higher fruit quality, but only IAC 1710 was selected as a suitable rootstock for the Pera sweet orange scion, the most important sweet orange cultivar group in Brazil [40]. Other field observations in São Paulo indicate high drought tolerance and tree size for sweet orange scions grafted on this citrandarin. In Florida, it was also a vigorous rootstock for Valencia sweet orange, but it presented a higher HLB incidence compared with several other rootstock genotypes [41].

F.80-8 and tetraploid Swingle citrumelos. F.80-8 induced good production and intermediate tree size to Valencia sweet orange in regions with a milder climate in Brazil [39,42], which was also observed herein in Northwestern São Paulo State. In Florida, Valencia sweet orange grafted onto F.80-8 performed well and did not present blight symptoms in the long term, but Jaffa orange was severely affected on the same rootstock, and other siblings from this cross were also susceptible depending on the scion variety used [43,44]. Swingle citrumelo is considered highly tolerant to blight in Brazil [35,39], but this trait varies substantially in some soil and tropical climate conditions in Central America [45], suggesting that F.80-8 and other citrumelos should be carefully evaluated for blight incidence in specific circumstances, namely in soils likely affected by periodic severe droughts. Regarding the tetraploid selection of the Swingle citrumelo evaluated in this work, it was the only truly dwarfing rootstock among the genotypes assessed, decreasing the tree size by 77% in relation to the largest size-inducing rootstock. Nevertheless, its production efficiency was low due to its poor fruit production. The diploid Swingle citrumelo parent is intolerant to drought [9,10,35], and this may be related to the performance of the tetraploid selection, even though an enhanced adaptation to water deficiency was expected initially [25–27]. Interestingly, in the same farm, this selection was also cultivated in a commercial block of the same age, plant care and tree spacing, but in a more clayey soil and alongside a creek, and the tree height and fruit number in 2021 were of 2.65 $\pm$ 0.07 m and 28 $\pm$ 6 fruits·m^{-3}, respectively. In other experimental areas under evaluation, a similar behavior has been observed, indicating that drought tolerance of tetraploid citrus rootstocks still remains to be clearly elucidated in field conditions. Tetraploid citranges controlled the tree size of Valencia sweet orange and Ponkan mandarin to some extent but production was not satisfactory [22,46,47]. Nevertheless, several new tetraploid genotypes are promising as dwarfing rootstocks for sweet orange as well [48]. Tetraploidization rather than the diploid hybridization with the dwarfing Flying Dragon trifoliate orange parent is likely to be a more worthwhile method for producing rootstocks better adapted to high-density orchards.

Barnes trifoliate orange. This small-flowered selection of trifoliate orange has been shown to induce higher tree vigor from the nursery [49], and higher fruit production to Valencia sweet orange under a Cwa climate in Brazil [50]. This motivated its inclusion in the present work. Although the fruit production was initially high, suggesting a fair

performance even under rainfed cultivation in an Aw climate, ten years after planting most trees presented visual decline that was putatively associated with blight symptoms, as this is usual for other trifoliate orange selections [21,35]. Nevertheless, its overall good performance encourages further evaluation with other scion varieties and regions. Moreover, the small flower phenotype of some *Poncirus trifoliata* accessions was co-related to a higher tolerance to water deficit [51].

Tropical Sunki mandarin. This is a putative nucellar embryo mutation of common Sunki mandarin that induced large tree size, high production and tree survival to sweet orange scions without irrigation under Aw and As climates in Brazil [15,19,20]. In this work, although the mean fruit production of Valencia sweet orange was relatively high, there was alternate bearing and low production efficiency, yet trees grafted on the Tropical Sunki induced the highest fruit number per cubic meter of bearing volume and excellent plant stand at the end of the experiment (Figure A2). As a comparison, neighboring Valencia trees grafted on the common Sunki mandarin with the same age at the same block presented an average of 4.37 ± 0.05 m and 36 ± 5 fruits·m^{-3} in 2021.

Taken together, the results herein indicate that some trifoliate orange hybrids can be grafted with Valencia sweet orange for rainfed cultivation due to a high mean fruit production after ten years of planting. Nonetheless, the productivity would likely benefit from the use of supplementary irrigation since none of the evaluated rootstocks were able to sustain high yields throughout the evaluation period, presenting a pronounced alternate bearing. Considering the tree spacing used and the mean fruit production of the most productive rootstocks, the average productivity would be of 31.9 t·ha^{-1}, which was significantly higher than the average productivity of commercial orchards in the same region in 2015–2017 (23.2 t·ha^{-1}), but still lower than that of orchards located in southern regions with a milder climate and higher water availability (42.9 t·ha^{-1}) [3]. Long-term studies showed yield increments of 15 to 64% with irrigation compared to rainfed sweet orange in São Paulo State [52]. Ten years after planting, none of the evaluated combinations presented visual symptoms suspicious of CSD or tristeza, but blight-like symptoms (tree slow decline, stem dieback, vigorous sprouting close to the trunk and scaffold) were observed for about half of the rootstock genotypes evaluated, thus, further investigation on disease resistance is necessary. Graft incompatibility was also not observed, with overall good plant stand (Figure A2), and the rootstock trunk caliper was wider than the scion's one for all trifoliate hybrids, as it is typical for this species, while it was similar for Sunki × Rangpur hybrids, and smaller for the Tropical Sunki mandarin. Finally, it is worth noting that not only the volume but also the canopy shape varied among the rootstocks tested, even within the same cross, suggesting that the branching habit may be incorporated into the citrus genetic improvement programs as it would be of interest to assist harvesting. In other perennial fruit crops, tree architecture is a major attribute for breeding or training trees that are more suitable for high tree density or mechanical harvesting, and can also be manipulated by the rootstock [53–56].

5. Conclusions

The citrandarins 543 and 602 and the citrange C38 have potential as alternative rootstocks for Valencia sweet orange in rainfed cultivation under an Aw climate. The commercial citrandarin genotypes of IAC 1710 and IAC 1697, and BRS Tropical Sunki mandarin corroborated their good performance in Northern São Paulo State, Brazil.

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Appendix A

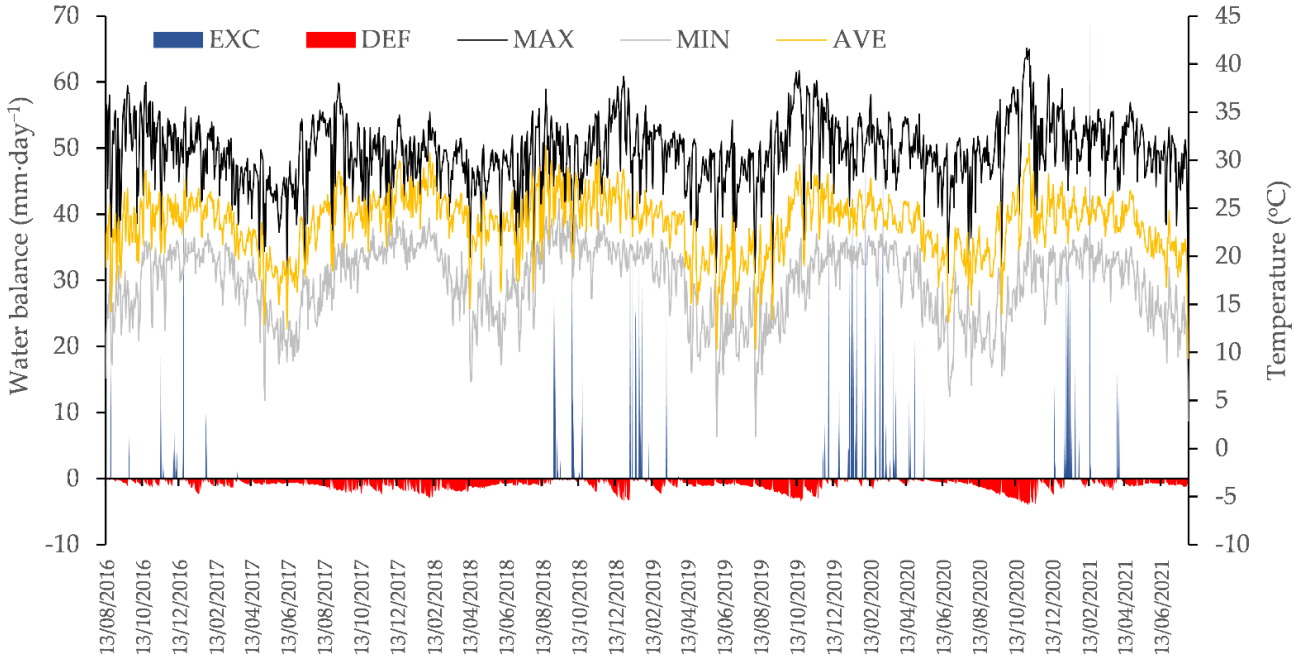


Figure A1. Daily air temperature [maximum (MAX), minimum (MIN) and average (AVE)] and daily water balance (EXC, excess; DEF, deficit) for the 2016–2021 period at the experimental area in Onda Verde, SP, Brazil. The sequential water balance and actual evapotranspiration were calculated between assessment dates as proposed by [57] using an available water capacity of 100 mm. The potential evapotranspiration was estimated using the FAO-56 Penman–Monteith (FAO PM) method [58].



Figure A2. *Cont.*



Figure A2. *Cont.*



Figure A2. Overall plant stands of Valencia sweet orange (*Citrus* × *sinensis* (L.) Osbeck) grafted onto 23 rootstocks in 2021, 10 years after rainfed cultivation in northwestern São Paulo, Brazil. Rootstock acronyms according to Table 1. SM is Sunki mandarin commercially cultivated at the same block, age and plant care conditions. Tropical Sunki is the control.

References

1. Food and Agriculture Organization of the United Nations. Available online: https://www.fao.org/faostat/en/#data/QCL (accessed on 16 September 2021).
2. United States Department of Agriculture Foreign Agricultural Service. Citrus: World Markets and Trade. 2021; pp. 1–13. Available online: https://apps.fas.usda.gov/psdonline/circulars/citrus.pdf (accessed on 16 September 2021).
3. Fundo de Defesa da Citricultura. *Tree Inventory of the São Paulo and West-Southwest Minas Gerais Citrus Belt: Snapshot of Groves in March 2021*; Fundo de Defesa da Citricultura: Araraquara, Brazil, 2021; 143p, Available online: https://www.fundecitrus.com.br/pdf/pes_relatorios/2021_07_30_Tree_Inventory_and_Orange_Crop_Forecast_2021-2022_Plantio_2020_Revisado.pdf (accessed on 4 March 2021).
4. Rolim, G.S.; Camargo, M.B.P.; Lania, D.G.; Moraes, J.F.L. Classificação climática de Köppen e de Thornthwaite e sua aplicabilidade na determinação de zonas agroclimáticas para o estado de São Paulo. *Bragantia* **2007**, *66*, 711–720. [CrossRef]
5. Rossi, M. *Mapa pedológico do Estado de São Paulo: Revisado e Ampliado*; Instituto Florestal: São Paulo, Brazil, 2017; 118p.
6. Fundo de Defesa da Citricultura. *Levantamento da Incidência das Doenças dos Citros: Greening, CVC e Cancro Cítrico no Cinturão Citrícola de São Paulo e Triângulo/Sudoeste Mineiro 2020*; Fundo de Defesa da Citricultura: Araraquara, Brazil, 2020; 67p, Available online: https://www.fundecitrus.com.br/pdf/levantamentos/levantamento-doencas-2020.pdf (accessed on 4 March 2021).
7. Bové, J.M.; Ayres, A.J. Etiology of three recent diseases of citrus in Sao Paulo State: Sudden death, variegated chlorosis and huanglongbing. *IUBMB Life* **2007**, *59*, 346–354. [CrossRef]
8. Bassanezi, R.B.; Silva Junior, G.J.; Feichtenberger, E.; Belasque Júnior, J.; Behlau, F.; Wulff, N.A. Doenças dos Citros. In *Manual de Fitopatologia: Doenças das Plantas Cultivadas*, 5th ed.; Amorim, L., Rezende, J.A.M., Bergamin Filho, A., Camargo, L.E.A., Eds.; Editora Agronômica Ceres: Ouro Fino, Brazil, 2016; Volume 2, pp. 271–306.
9. Pompeu Junior, J.; Blumer, S. Comportamento de porta-enxertos em área afetada pela morte súbita dos citros. *Citrus Res. Technol.* **2019**, *40*, e1048. [CrossRef]
10. Girardi, E.A.; Cerqueira, T.S.; Cantuarias-Avilés, T.E.; Silva, S.R.; Stuchi, E.S. Sunki mandarin and Swingle citrumelo as rootstocks for rain-fed cultivation of late-season sweet orange selections in northern São Paulo state, Brazil. *Bragantia* **2017**, *76*, 501–511. [CrossRef]
11. Girardi, E.A.; Pompeu Junior, J.; Teofilo Sobrinho, J.; Soares Filho, W.S.; Passos, O.S.; Cristofani-Yaly, M.; Sempionato, O.R.; Stuchi, E.S.; Donadio, L.C.; Mattos Junior, D.; et al. *Guia de Reconhecimento dos Citros em Campo: Um Guia Prático Para o Reconhecimento em Campo de Variedades de Laranjeira-Doce e Outras Espécies de Citros Cultivadas No Estado de São Paulo e Triângulo Mineiro*; Fundecitrus: Araraquara, Brazil, 2021; 158p.
12. Castle, W.S. A career perspective on Citrus rootstocks, their development, and commercialization. *HortScience* **2010**, *45*, 11–15. [CrossRef]
13. Forner-Giner, M.A.; Continella, A.; Grosser, J.W. Citrus Rootstock Breeding and Selection. In *The Citrus Genome: Compendium of Plant Genomes*; Gentile, A., La Malfa, S., Deng, Z., Eds.; Springer: Berlin, Germany, 2020; pp. 49–74.
14. Rodríguez-Gamir, J.; Primo-Millo, E.; Forner-Giner, M.A. An Integrated View of Whole-Tree Hydraulic Architecture: Does Stomatal or Hydraulic Conductance Determine Whole Tree Transpiration? *PLoS ONE* **2016**, *11*, e0155246. [CrossRef]
15. Costa, D.P.; Stuchi, E.S.; Girardi, E.A.; Gesteira, A.S.; Coelho Filho, M.A.; Ledo, C.A.S.; Fadel, A.L.; Silva, A.L.V.; Leão, H.C.; Ramos, Y.C.; et al. Hybrid Rootstocks for Valencia Sweet Orange in Rainfed Cultivation Under Tropical Savannah Climate. *J. Agric. Sci.* **2020**, *12*. [CrossRef]
16. Costa, D.P.; Stuchi, E.S.; Girardi, E.A.; Moreira, A.S.; Gesteira, A.S.; Coelho Filho, M.A.; Ledo, C.A.S.; Silva, A.L.V.; Leão, H.C.; Passos, O.S.; et al. Less Is More: A Hard Way to Get Potential Dwarfing Hybrid Rootstocks for Valencia Sweet Orange. *Agriculture* **2021**, *11*, 354. [CrossRef]
17. Schinor, E.H.; Cristofani-Yaly, M.; Bastianel, M.; Machado, M.A. Sunki Mandarin vs. Poncirus trifoliata hybrids as rootstocks for Pera sweet orange. *J. Agric. Sci.* **2013**, *5*, 190–200. [CrossRef]
18. Fadel, A.L.; Stuchi, E.S.; Couto, H.T.Z.; Ramos, Y.C.; Mourão Filho, F.A.A. Trifoliate hybrids as alternative rootstocks for Valencia sweet orange under rainfed conditions. *Sci. Hortic.* **2018**, *235*, 397–406. [CrossRef]
19. Carvalho, L.M.; Carvalho, H.W.L.; Barros, I.; Martins, C.R.; Soares Filho, W.S.; Girardi, E.A.; Passos, O.S. New scion-rootstock combinations for diversification of sweet orange orchards in tropical hardsetting soils. *Sci. Hortic.* **2019**, *243*, 169–176. [CrossRef]
20. Ribeiro, L.O.; Costa, D.P.; Ledo, C.A.S.; Carvalho, L.M.; Carvalho, H.W.L.; Soares Filho, W.S.; Girardi, E.A. 'Tropical Sunki' mandarin and hybrid citrus rootstocks under 'Pera' sweet orange in cohesive soil and as climate without irrigation. *Bragantia* **2021**, *80*, e1321. [CrossRef]
21. Castle, W.S.; Baldwin, J.C.; Muraro, R.P. Rootstocks and the performance and economic returns of 'Hamlin' sweet orange trees. *HortScience* **2010**, *45*, 875–881. [CrossRef]
22. Pompeu Junior, J.; Laranjeira, F.F.; Blumer, S. Laranjeiras Valência enxertadas em híbridos de trifoliata. *Sci. Agric.* **2002**, *59*, 93–97. [CrossRef]
23. Pompeu Junior, J.; Blumer, S. Híbridos de trifoliata como porta-enxertos para a laranjeira Valência. *Pesqui. Agropecu. Bras.* **2009**, *44*, 701–705. [CrossRef]
24. Pompeu Junior, J.; Blumer, S. Citrandarins e outros híbridos de trifoliata como porta-enxertos para laranjeira Valência. *Citrus Res. Technol.* **2011**, *32*, 133–138. [CrossRef]

25. França, N.O.; Amorim, M.S.; Girardi, E.A.; Passos, O.S.; Soares Filho, W.S. Performance of Tuxpan Valencia sweet orange grafted onto 14 rootstocks in northern Bahia, Brazil. *Rev. Bras. Frutic.* **2016**, *38*, 1–9. [CrossRef]
26. Allario, T.; Brumos, J.; Comenero-Flores, J.M.; Iglesis, D.J.; Pina, J.A.; Navarro, L.; Talon, M.; Ollitrault, P.; Morillon, R. Tetraploid Rangpur lime rootstock increases drought tolerance via enhanced constitutive root abscisic acid production. *Plant Cell Environ.* **2013**, *36*, 856–868. [CrossRef] [PubMed]
27. Khalid, M.F.; Hussain, S.; Anjum, M.A.; Morillon, R.; Ahmad, S.; Ejaz, S.; Ejaz, S.; Hussain, M.; Jaafar, H.Z.E.; Alrashood, S.T.; et al. Physiological and biochemical responses of Kinnow mandarin grafted on diploid and tetraploid Volkamer lemon rootstocks under different water-deficit regimes. *PLoS ONE* **2021**. [CrossRef]
28. Tan, F.Q.; Tu, H.; Liang, W.J.; Long, J.M.; Wu, X.M.; Zhang, H.Y.; Guo, W.W. Comparative metabolic and transcriptional analysis of a doubled diploid and its diploid citrus rootstock (*C. junos* cv. Ziyang xiangcheng) suggests its potential value for stress resistance improvement. *BMC Plant Biol.* **2015**, *15*, 89. [CrossRef]
29. Guerra, D.; Wittmann, M.T.S.; Schwarz, S.F.; De Souza, P.V.D.; Gonzatto, M.P.; Weiler, R.L. Comparison between diploid and tetraploid citrus rootstocks: Morphological characterization and growth evaluation. *Bragantia* **2014**, *73*, 1–7. [CrossRef]
30. Bassanezi, R.B.; Lopes, S.A.; Miranda, M.P.; Wulff, N.A.; Volpe, H.X.L.; Ayres, A.J. Overview of citrus huanglongbing spread and management strategies in Brazil. *Trop. Plant Pathol.* **2020**, *45*, 251–264. [CrossRef]
31. Turrell, F.M. *Tables of Surfaces and Volumes of Spheres and of Prolate and Oblate Spheroids and Spheroidal Coefficients*; University of California: Berkeley, USA, 1946; 153p.
32. Tucker, D.P.H.; Wheaton, T.A.; Muraro, R.P. *Citrus Tree Pruning Principles and Practices*; University of Florida, Florida Cooperative Extension Service: Gainesville, FL, USA, 1994; 9p, Available online: https://ufdcimages.uflib.ufl.edu/IR/00/00/46/22/00001/CH02700.PDF (accessed on 4 March 2021).
33. Barbosa, J.C.; Maldonado Junior, W. *Experimentação Agronômica e AgroEstat: Sistema para Análises Estatísticas de Ensaios Agronômicos*; Gráfica Multipress Ltda: Jaboticabal, Brazil, 2015; 396p.
34. Bowman, K.D.; Joubert, J. Citrus rootstocks. In *The Genus Citrus*; Talon, M., Caruso, M., Gmitter, F.G., Jr., Eds.; Woodhead Publishing: Cambridge, UK, 2020; pp. 105–127. [CrossRef]
35. Pompeu Junior, J. Porta-enxertos. In *Citros*; Mattos Junior, D., De Negri, J.D., Pio, R.M., Pompeu Junior, J., Eds.; Instituto Agronômico Fundag: Campinas, Brazil, 2005; pp. 61–104.
36. Fares, A.; Bayabil, H.K.; Zekri, M.; Mattos Junior, D.; Awal, R. Potential climate change impacts on citrus water requirement across major producing areas in the world. *J. Water Clim. Chang.* **2017**, *8*, 576–591. [CrossRef]
37. Blumer, S.; Pompeu Junior, J. Avaliação de citrandarins e outros híbridos de trifoliata como porta-enxertos para citros em São Paulo. *Rev. Bras. Frutic.* **2005**, *27*, 264–267. [CrossRef]
38. Souza, E.L.S.; Schwarz, S.F.; Oliveira, R.P. Porta-enxertos para citros no Rio Grande do Sul. In *Indicações Técnicas Para a Citricultura do Rio Grande do Sul*; Souza, E.L.S., Schwarz, S.F., Oliveira, R.P., Eds.; Porto Alegre: Fepagro, Brazil, 2010; pp. 19–29.
39. Domingues, A.R.; Marcolini, C.D.M.; Gonçalves, C.H.d.S.; Resende, J.T.V.d.; Roberto, S.R.; Carlos, E.F. Rootstocks Genotypes Impact on Tree Development and Industrial Properties of 'Valencia' Sweet Orange Juice. *Horticulturae* **2021**, *7*, 141. [CrossRef]
40. Pompeu Junior, J.; Blumer, S. Híbridos de trifoliata como porta-enxertos para laranjeira Pêra. *Pesqui. Agropecu. Trop.* **2014**, *44*, 9–14. [CrossRef]
41. Bowman, K.D.; McCollum, G.; Albrecht, U. Performance of "Valencia" orange (*Citrus sinensis* [L.] Osbeck) on 17 rootstocks in a trial severely affected by huanglongbing. *Sci. Hortic.* **2016**, *201*, 355–361. [CrossRef]
42. Pompeu Junior, J.; Blumer, S. Citrumelos como porta-enxertos para a laranjeira 'Valência'. *Pesqui. Agropecu. Bras.* **2011**, *46*, 105–107. [CrossRef]
43. Youtsey, C.O.; Rosenthal, F.J. Incidence of citrus blight in Florida's citrus budwood foundation grove. *Proc. Fla. State Hort. Soc.* **1986**, *99*, 71–73.
44. Castle, W.S.; Baldwin, J.C. Tree Survival in Long-Term Rootstock Field Trials. *Proc. Fla. State Hort. Soc.* **1995**, *108*, 73–77.
45. Gutierrez, F. Swingle citrumelo decline in Belize. *Citrus News* **2002**, *5*, 4–12.
46. Rodrigues, J.D.B.; Moreira, A.S.; Stuchi, E.S.; Bassenezi, R.B.; Laranjeira, F.F.; Girardi, E.A. Huanglongbing incidence, canopy volume, and sprouting dynamics of 'Valencia' sweet orange grafted onto 16 rootstocks. *Trop. Plant Pathol.* **2020**, *45*, 611–619. [CrossRef]
47. Silva, S.R.; Stuchi, E.S.; Girardi, E.A.; Cantuarias-Avilé, T.; Bassan, M.M. Desempenho da tangerina 'Span Americana' em diferente porta-enxertos. *Rev. Bras. Frutic.* **2013**, *35*, 1052–1058. [CrossRef]
48. Kunwar, S.; Grosser, J.; Gmitter Junior, F.G.; Castle, W.S.; Albrech, U. Field Performance of 'Hamlin' Orange Trees Grown on Various Rootstocks in Huanglongbing-endemic Conditions. *HortScience* **2021**, *56*, 244–253. [CrossRef]
49. Girardi, E.A.; Mourão Filho, F.A.A.; Piedade, S.M.S. Desenvolvimento vegetativo e custo de produção de porta-enxertos de citros em recipientes para fins de subenxertia. *Pesqui. Agropecu. Bras.* **2007**, *42*, 679–687. [CrossRef]
50. Pompeu Junior, J.; Blumer, S. Comportamento de dezessete seleções de trifoliata como porta-enxertos para laranjeira Valência. *Rev. Laranja* **2006**, *27*, 287–295.
51. Ben Yahmed, J.; Constantino, G.; Amiel, P.; Talon, M.; Ollitrault, P.; Morillon, R.; Luro, F. Diversity in the trifoliate orange taxon reveals two main genetic groups marked by specific morphological traits and water deficit tolerance properties. *J. Agric. Sci.* **2016**, *154*, 495–514. [CrossRef]

52. Silveira, L.K.; Pavão, G.C.; Dias, C.T.S.; Quaggio, J.A.; Pires, R.C.M. Deficit irrigation effect on fruit yield, quality and water use efficiency: A long-term study on Pêra-IAC sweet orange. *Agric. Water Manag.* **2020**, *231*, 106019. [CrossRef]
53. Costes, E.; Lauri, P.E.; Regnard, J.L. Analyzing fruit tree architecture: Implications for tree management and fruit production. *Hortic. Rev.* **2006**, *32*, 1–61.
54. Cummins, J.N. Rootstock influence on fruit tree architecture. *HortScience* **1990**, *25*, 1177. [CrossRef]
55. Warschefsky, E.J.; Klein, L.L.; Frank, M.H.; Chitwood, D.H.; Londo, J.P.; Wettberg, E.J.B.; Miller, A.J. Rootstocks: Diversity, Domestication, and Impacts on Shoot Phenotypes. *Trends Plant Sci.* **2016**, *21*, 418–437. [CrossRef] [PubMed]
56. Rosati, A.; Paoletti, A.; Caporalli, S.; Perri, E. The role of tree architecture in super high density olive orchards. *Sci. Hortic.* **2013**, *161*, 24–29. [CrossRef]
57. Thornthwaite, C.W.; Mather, R.J. *The Water Balance*; Drexel Institute of Technology: Philadelphia, PA, USA, 1955; 104p.
58. Allen, R.G.; Pereira, L.S.; Raes, D.; Smith, M. *Crop Evapotranspiration-Guidelines for Computing Crop Water Requirements*; FAO Irrigation and Drainage Paper 56; FAO: Rome, Italy, 1998; 300p.