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Artigo/Article

Potential rootstocks for Valencia sweet orange in rain-fed cultivation in the North of São Paulo, Brazil

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SUMMARY

The North region of São Paulo has a high incidence of citrus sudden death (CSD), making Rangpur lime an inappropriate rootstock for use in this region. Identified CSD-tolerant rootstocks require supplementary irrigation. An ideal rootstock must be CSD-tolerant, provide high yields of fruits with high quality juice, be tolerant to drought, and induce some level of dwarfism in order to allow closer spacing. These characteristics were evaluated for Valencia orange trees on rootstocks of Dancy mandarin, Santa Cruz Rangpur lime (LCRSC) and 25 diverse hybrid rootstocks. The main parents of the hybrids were *Citrus sunki*, *C. reshni*, *C. volkameriana*, *C. limonia*, *C. sinensis* and *Poncirus trifoliata*. The experiment was performed in Colômbia, SP, Brazil, from 2009 to 2015 in rain-fed cultivation. At seven years of age, 54% of the rootstocks presented tree size similar to or higher than LCRSC, whereas in the others there was a reduction between 75 and 8% compared to LCRSC. Sacaton citrumelo rootstock resulted in substantial dwarfism and the hybrids of *C. volkameriana* x *C. limonia* were semi-dwarfing. All rootstocks presented juice with soluble solids varying from 9.89 to 11.06 °Brix and ratio from 13.52 to 18.31. A Selection Index (SI) was developed to compare rootstocks. Twelve rootstocks exhibited SI superior to LCRSC. Citrange 25 and *C. reshni* x *P. trifoliata* Swingle 224, 287 and 71158 produced smaller tree size with greater production efficiency, soluble solids and processing index superior to LCRSC. The latter citrandarin rootstock presented incompatibility with Valencia sweet orange at age eight.

Index terms: *Citrus* spp., *Poncirus trifoliata*, drought tolerance, fruit quality, dwarfism.

Porta-enxertos potenciais para laranjeira Valência em cultivo de sequeiro no Norte do Estado de São Paulo, Brasil

RESUMO

A região norte do Estado de São Paulo tem uma alta incidência de morte súbita dos citros (MSC), tornando o limoeiro Cravo um porta-enxerto inapropriado para uso nesta região. Os porta-enxertos tolerantes à MSC identificados requerem irrigação suplementar. Um porta-enxerto

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ideal deve ser tolerante à MSC, induzir elevada produtividade de frutos com alta qualidade, ser tolerante à seca e induzir algum nível de nanismo para permitir um espaçamento mais próximo. Essas características foram avaliadas para laranjeira Valência enxertada em tangerineira Dancy, limoeiro Cravo Santa Cruz (LCRSC) e 25 híbridos diversos. Os principais parentais dos híbridos foram *Citrus sunki, C. reshni, C. volkameriana, C. limonia, C. sinensis* e *Poncirus trifoliata*. O experimento foi realizado em Colômbia, São Paulo, Brasil, de 2009 a 2015, sob sequeiro. Aos sete anos de idade, 54% dos porta-enxertos apresentaram tamanho de árvore semelhante ou superior ao LCRSC, enquanto nos demais houve redução entre 75 e 8% em relação ao LCRSC. O porta-enxerto de citrumelo Sacaton mostrou potencial ananicante e os híbridos de *C. volkameriana* x *C. limonia* foram semiananicantes. Todos os porta-enxertos apresentaram suco com sólidos solúveis variando de 9,89 a 11,06 °Brix e ratio de 13,52 a 18,31. Um índice de seleção (SI) foi desenvolvido para comparar porta-enxertos. Doze porta-enxertos exibiram SI superior ao LCRSC. Citrange 25 e C. reshni x P. trifoliata Swingle 224, 287 e 71158 resultaram em tamanho de planta menor, com maior eficiência de produção, sólidos solúveis e índice de processamento superior ao LCRSC. O último citrandarin apresentou incompatibilidade com a laranjeira Valência aos oito anos de idade.

Termos de indexação: *Citrus* spp., *Poncirus trifoliata*, tolerância à seca, qualidade do fruto, ananicante.

INTRODUCTION

Brazil is the major producer of orange [*Citrus sinensis* (L.) Osbeck] in the world (FAO, 2016). Production is most prominent in the State of São Paulo (SSP), which produced 279 million orange boxes (40.8 kg/box) in 2014/2015, with the North region of the state responsible for 63.8 milion boxes amounting to 22.9% of SSP production (FUNDECITRUS, 2016).

Rangpur lime [*C. limonia* (L.) Osbeck] rootstock has several agronomic characteristics which made it the most used rootstock in the country: tolerance to tristeza and drought, high number of polyembryonic seeds per fruit, compatibility with most scion varieties, early bearing and high productivity for all scions grafted to it, and fair fruit quality. It also has important limitations, such as susceptibility to blight, citrus nematode, citrus sudden death (CSD), as well as moderate susceptibility to gummosis from *Phytophthora* spp. (Pompeu Junior, 2005; Castle, 2010).

Swingle citrumelo [*C. paradisi* Macfad. x *Poncirus trifoliata* (L.) Raf.], the trifoliate orange (*P. trifoliata*) and the mandarin rootstocks Sunki [*C. sunki* (Hayata) hort. ex Tanaka] and Cleopatra (*C. reshni* hort. ex Tanaka) have been most widely used as CSD-tolerant rootstocks (Bassanezi et al., 2003), however they are more sensitive to drought than Rangpur (Pompeu Junior, 2005).

CSD is the driving factor for replacing Rangpur lime as rootstock, particularly in the regions North of SSP and South of the Triângulo Mineiro (Müller et al., 2002; Roman et al., 2004; Fundecitrus, 2007). The North region of SSP is characterized by the occurrence of high temperatures and a prolongued period of drought. The use of supplementary irrigation is increasing in the region, with about 25% of the orchards irrigated (FUNDECITRUS, 2016); however, lack of water availability prevents adoption of irrigation in the whole cultivated area. Thus, it is important that new rootstocks provide satisfactory performance in rain-fed cultivation, as well as general tolerance to drought.

The programs for genetic improvement of citrus rootstocks in Brazil conduct introductions and hybridizations to identify/develop genotypes with superior characteristics to standard varieties, focusing on tolerance to biotic and abiotic stresses (Machado et al., 2005; Soares Filho et al., 2013). As a component of this process, Valencia orange was grafted on 25 hybrid rootstocks as well as Dancy mandarin (*C. reticulata* Blanco) and Santa Cruz Rangpur lime. Trees were rain-fed cultivated in the North of SSP for evaluation of resulting plant size, production and juice quality.

MATERIAL AND METHODS

The experiment was installed in a commercial area in Colômbia-SP (20º17'48" S, 48º41'41" W, 492 m). The climate of the region is subtropical with a hot and rainy summer and moderate and dry winter, with an average annual precipitation around 1,414 mm and average temperature of 26 ºC. The average precipitation in the dry season (257 mm, May to October) can be 4.5x lower than in the raining season (1,158 mm, November to April). The experiment was planted in 2009 with spacing of 7.0 m between rows and 3.0 m between plants in a dark red argisol, medium to clayey texture [pH ($CaCl_2$) = 4.5; CEC = 55; Ca = 16; Mg = 4; K = 2; H+Al = 33 $mmol_c\ dm^{-3}$, V% = 40; P = 73 mg dm^{-3}; OM = 2 g dm^{-3}, in the 0-20 cm soil layer]. Trees were not irrigated, relying solely on rain for trees needs. Production practices were typical for orange cultivation in SSP, without pruning. The annual mean fertilization per tree, from 2009 to 2015, was 218 g of N, 18 g of P_2O_5 and 190 g of K_2O.

The scion used was Valencia IAC sweet orange. The hybrids and citrus species evaluated as rootstocks are listed on Table 1, as well as, an identifying code, parental and origin of the genotypes. Seeds were provided by Embrapa Cassava & Fruits from accessions belonging to the Citrus Germplasm Bank in Cruz das Almas, Bahia State, Brazil. In 2014, at age seven, tree size was evaluated: height and mean diameter of plant canopy were measured with a graduated ruler; canopy volume (V) was calculated, with the formula $V=(2/3)\pi r^2 h$, where r is the radius of plants canopies and h, their height. Fruit production was obtained by weighting on a digital scale and the results were expressed in kg of fruits per plant in the crop years of 2011 to 2015. Productive efficiency was calculated by the division of fruit production per plant by canopy volume, expressed in kg m^{-3}, in the years 2011-2014. The alternate bearing index was calculated as $ABI = 1/n\text{-}1 \times \{|(a2\text{-}a1)|/(a2+a2) + |(a3\text{-}a2)|/(a3+a2)+...+|(a(n)\text{-}a(n\text{-}1))|/(a(n)+a(n\text{-}1))\}$, where n = number of crops evaluated and $a1, a2,..., a(n\text{-}1), a(n)$ = production in the corresponding years (Pearce & Dobersek-Urbanc, 1967).

Table 1. Identifying codes, parental and origin of the hybrids and citrus species studied in this research

Identifying codes	Parental common and scientific names	Origin of the accession[1,2]
Dancy mandarin	*Citrus reticulata* Blanco	University of California, Riverside, California, USA
Sacaton citrumelo	*C. paradisi* Macfaden x [*Poncirus trifoliata* (L.) Raf.]	University of California, Riverside, California, USA
citrangequat Thomasville 1439	*Fortunella* spp. x Citrange [*C. sinensis* (L.) Osbeck x *P. trifoliata*]	University of California, Riverside, USA.
CLEO x TRSW - 224	Cleopatra mandarin (*C. reshni* hort. ex Tanaka) x Swingle trifoliate orange (*P. trifoliata*)	U.S Date and Citrus Station, Indio, California, USA.
CLEO x TRSW - 287	Cleopatra mandarin (*C. reshni*) x Swingle trifoliate orange (*P.trifoliata*)	U.S Date and Citrus Station, Indio, California, USA.
CLEO x TRSW - 295	Cleopatra mandarin (*C. reshni*) x Swingle trifoliate orange (*P.trifoliata*)	U.S Date and Citrus Station, Indio, California, USA.
CLEO x TRSW - 30113	Cleopatra mandarin (*C. reshni*) x Swingle trifoliate orange (*P.trifoliata*)	U.S Date and Citrus Station, Indio, California, USA.
CLEO x TRSW - 71158	Cleopatra mandarin (*C. reshni*) x Swingle trifoliate orange (*P.trifoliata*)	U.S Date and Citrus Station, Indio, California, USA.
CTC - 25	citrange (*C. sinensis* x *P. trifoliata*)	Taquari Experimental Station, Taquari, Rio Grande do Sul, Brazil
LVK x LCR - 017	Volkamer lemon (*C. volkameriana* Ten. & Pasq.) x Rangpur lime (*C. limonia* Osbeck)	Embrapa Cassava & Fruits, Bahia, Brazil.
LVK x LCR - 030	Volkamer lemon (*C. volkameriana*) x Rangpur lime (*C. limonia*)	Embrapa Cassava & Fruits, Bahia, Brazil.
LVK x LCR - 048	Volkamer lemon (*C. volkameriana)* x Rangpur lime (*C. limonia*)	Embrapa Cassava & Fruits, Bahia, Brazil.

[1]According to Passos et al. (2007) and Vasconcelos & Araújo (1975); [2]Numbers of the identifying codes regarding to introduced germplasm are given as the original registration number received in Brazil, while hybrids obtained by Embrapa follow the Citrus Breeding Program own nomenclature.

Table 1. Continued...

Identifying codes	Parental common and scientific names	Origin of the accession[1,2]
LVK x LPA - 016	Volkamer lemon (*C. volkameriana*) x Palmeiras sweet orange (*C. sinensis*)	Embrapa Cassava & Fruits, Bahia, Brazil.
Rangpur lime cv. Santa Cruz	Rangpur lime cv. Santa Cruz (*C. limonia)*	Embrapa Cassava & Fruits, Bahia, Brazil.
TCLN x CTSF - 092	Clementina De Nules mandarin (*C. clementina* hort ex. Tanaka) x citrange Sanford (*C. sinensis* x *P. trifoliata*)	Embrapa Cassava & Fruits, Bahia, Brazil.
trifoliate orange CRC 3551 CN	*P. trifoliata* selection CRC 3551 CN (nucellar budline)	University of California, Riverside, California, USA
TSK x TRSW - 294	Sunki mandarin [*C. sunki* (Hayata) hort. ex Tanaka] x Swingle trifoliate orange (*P. trifoliata*)	U.S Date and Citrus Station, Indio, California, USA.
TSK x TRSW - 308	Sunki mandarin (*C. sunki*) x Swingle trifoliate orange (*P. trifoliata*)	U.S Date and Citrus Station, Indio, California, USA.
TSK x TRSW - 311	Sunki mandarin (*C. sunki*) x Swingle trifoliate orange (*P. trifoliata*)	U.S Date and Citrus Station, Indio, California, USA.
TSKC x LHA - 004	Sunki mandarin (*C. sunki*) x Hamlin sweet orange (*C. sinensis*)	Embrapa Cassava & Fruits, Bahia, Brazil.
TSKC x LHA - 010	Sunki mandarin (*C. sunki*) x Hamlin sweet orange (*C. sinensis*)	Embrapa Cassava & Fruits, Bahia, Brazil.
TSKC x LVKCT2 - 001	Sunki mandarin tree (*C. sunki*) x Volkamer Catânia 2 lemon (*C. volkameriana*)	Embrapa Cassava & Fruits, Bahia, Brazil.
TSKC x TRBK - 010	Sunki mandarin (*C. sunki*) x Benecke trifoliate orange (*P. trifoliata*)	Embrapa Cassava & Fruits, Bahia, Brazil.
TSKFL x CTARG – 002	Sunki mandarin (*C. sunki)*Florida selection x Argentina citrange (*C. sinensis x P. trifoliata*)	Embrapa Cassava & Fruits, Bahia, Brazil.
TSKFL x CTARG – 028	Sunki mandarin (*C. sunki)*Florida selection x Argentina citrange (*C. sinensis x P. trifoliata*)	Embrapa Cassava & Fruits, Bahia, Brazil.
TSKFL x CWEB - 004	Sunki mandarin (*C. sunki*) Florida selection x *C. webberi* Wester	Embrapa Cassava & Fruits, Bahia, Brazil.
TSKFL x LRM -011	Sunki mandarin (*C. sunki)* Florida selection x Mazoe rough lemon (*C. jambhiri* Lush.)	Embrapa Cassava & Fruits, Bahia, Brazil.

[1]According to Passos et al. (2007) and Vasconcelos & Araújo (1975); [2]Numbers of the identifying codes regarding to introduced germplasm are given as the original registration number received in Brazil, while hybrids obtained by Embrapa follow the Citrus Breeding Program own nomenclature.

Fruit quality was evaluated in 2011 to 2013, and 2015. Ten fruits were randomly picked on the medium canopy height around the trees in each plot. Samples were collected in October/November, whenever fruits presented typical mature appearance, as this is the usual harvesting period for Valencia in the locality (Nonino, 1995), and the following factors were evaluated: weight, diameter and height of the fruits, total soluble solids (SS) measured in a refractometer (Palette PR-101, ATAGO, Tokyo, Japan), total acidity (TA) by titration with sodium hydroxide (0.3125 N), ratio calculated as SS/TA, juice yield (JY, %), using an extractor designed for point-of-sale small lot juicing (Otto 1800, OIC, Limeira, São Paulo, Brazil) and processing index (kg SS box^{-1}, with the mean of 2012, 2013 and 2015), according to the formula: $PI = [JY \times SS \times 40.8] \times 10.000^{-1}$, with 40.8 kg as the weight for a standard orange box.

A selection index (SI) was developed based on: production per plant (Prod, 2011-2015), productive efficiency (Efp, 2011-2014) and processing index (PI, 2012, 2013 and 2015). SI was calculated as *SI = (Prod*50)*(Efp*15)*(PI*35)/100000*, and was used to compare general performance among rootstocks.

The experimental planting design was randomized blocks with four replications and four plants per plot, with 27 rootstocks. Analysis of variance was performed by plots subdivided in time, and for grouping of the means of treatments, the Scott-Knott multiple comparison test was used at 5% probability. Scott-Knott uses a hierarchical cluster analysis to partition treatments into distinct groups with no overlapping as with Duncan's Multiple Range Test (Scott & Knott, 1974). Statistical analyses were performed using the program AgroEstat (Barbosa & Maldonado Junior, 2015).

RESULTS

At seven years of age, the rootstocks presented differences for height, diameter and canopy volume, forming six groups of mean (Table 2). Of the 27 rootstocks evaluated, 11.1, 33.3 and 41.7% induced plants that were higher, larger and bulky, respectively, than those of trees on Santa Cruz Rangpur lime. Dancy mandarin rootstock was noteworthy for the induction of the largest trees, whereas Sacaton citrumelo rootstock resulted in the smallest Valencia trees.

For productive efficiency of the plants, 48% of the rootstocks evaluated were superior to the standard, Santa Cruz Rangpur lime, and two groupings were observed. Thomasville 1439, Sacaton citrumelo, CLEO x TRSW - 71158, CLEO x TR - 30113, CLEO x TRSW - 224, CTC 25, CLEO x TRSW - 287, TSKFL x CTARG - 028, CLEO x TRSW - 295, TSK x TRSW - 294, TSK x TRSW – 308 and TSKFL x LRM - 011 were more efficient than Santa Cruz Rangpur lime. Rootstocks TSKFL x CTARG - 028 and TSKFL x LRM - 011 were more efficient than Santa Cruz Rangpur lime, in spite of presenting a superior tree size. Among the rootstocks with highest production efficiency (Table 2), rootstocks CLEO x TRSW - 71158, CLEO x TRSW 224, CTC 25, CLEO x TRSW – 287 and TSK x TRSW – 308 also had production per tree similar to Santa Cruz Rangpur lime (Table 3), making them especially desirable for high density plantings.

The production per tree of Valencia orange from 2011 to 2015 varied with the year of evaluation, with usually increasing yields and most of the rootstocks presenting the highest production per tree in 2015 (Table 3). The Valencia orange trees grafted on TSKFL x CTARG - 028, TSK x TRSW - 311, CLEO x TRSW - 295, CLEO x TRSW - 71158, CLEO x TRSW - 224, TSK x TRSW - 308, CTC 25, CLEO x TRSW - 287 and TSKC x LHA - 010 did not differ from those grafted on Santa Cruz Rangpur lime, being classified in the group of the highest average annual production per tree (Tables 3). Rootstocks LVK x LCR - 017, LVK x LCR - 048 and Sacaton citrumelo presented the lowest average annual production per tree of the 27 rootstocks evaluated.

For the quality attributes, the rootstocks TSK x TRSW-308 and Thomasville 1439 were superior to Santa Cruz Rangpur lime regarding all variables analyzed, including lower acid (Table 4). CRC 3551 CN trifoliate orange, TSKC x LHA - 004, TSKFL x CTARG - 028 and TSKC x LHA - 010 had similar results with the exception of lower ratio as titratable acidity was the same of Rangpur lime. Rootstocks TSKFL x CTARG - 028 and TSKC x LHA - 010 were also highlighted for being in the group of the most productive together with Santa Cruz Rangpur lime rootstock (Table 4).

Processing index, considered the most important variable among the quality characteristics studied, was superior to Rangpur lime (1.89 kg SS cx^{-1}) for the group of rootstocks comprised of CLEO x TR – 30113, CLEO x TRSW – 71158, -224, -287 and -295, TSKC X TRBK – 010, TSK x TRSW – 294, -308 and -311, TSKC x LVKCT2 – 001, trifoliate orange CRC 3551 CN, TCLN x CTSF – 092, LVK x LPA – 016, TSKC x LHA – 004 and -010, Thomasville 1439 and TSKFL x CTARG – 028 (1.94 to 2.19 kg SS cx^{-1}) (Table 4).

The mean values of soluble solids varied from 9.89 to 11.06 ºBrix, with the mean of the years (2011 to 2015, except 2014) of 10.62 ºBrix. Except for rootstocks TSKC x LHA - 004, LVK x LCR - 030, TSKFL x LRM - 011, LVK x LCR - 048 and Sacaton citrumelo, the other rootstocks were superior to Rangpur lime (10.3 ºBrix), varying from 10.4 to 11.1 ºBrix. Conversely, the highest values of soluble solids were obtained in the year 2015, reaching a mean of 11.4 ºBrix, without difference among the rootstocks in this year nor in 2011 and 2013 (Table 5).

In SI analysis (data not shown), 44.4% of the rootstocks were superior to Santa Cruz Rangpur lime tree, being described in ranking (decreasing): CLEO x TRSW - 71158, CLEO x TRSW - 224, Thomasville 1439, CLEO x TRSW - 287, CLEO x TR - 30113, CTC 25, CLEO x TRSW - 295, TSKFL

Table 2. Mean values of height, diameter and volume of the canopies in 2014 and mean production efficiency of Valencia orange tree on 27 rootstocks in the period 2011-2014. Colômbia-SP, 2016

Rootstock[1]	Height (cm)	Diameter (cm)	Volume (m^3)	Mean efficiency (kg m^{-3})
Thomasville 1439	2.6 e[2]	2.8 d	11.2 f	3.4 a
Sacaton citrumelo	2.0 f	2.1 e	4.9 g	3.4 a
CLEO x TRSW - 71 158 (USDA)	2.5 e	2.8 d	10.4 f	3.2 a
CLEO x TR - 30 113 (USDA)	2.7 d	2.9 c	12.7 f	3.1 a
CLEO x TRSW 224	3.3 c	3.1 c	16.9 e	2.9 a
CTC 25	3.2 c	3.2 b	17.8 e	2.8 a
CLEO x TRSW – 287	2.9 d	3.3 b	16.6 e	2.6 a
TSKFL x LRM – 011	3.6 b	3.4 b	22.1 c	2.5 a
CLEO x TRSW – 295	3.3 c	3.4 b	20.8 d	2.4 a
TSK x TRSW – 294	3.2 c	3.4 b	19.3 d	2.4 a
TSKFL x CTARG – 028	3.8 a	3.8 a	28.8 a	2.2 a
TSK x TRSW – 308	3.4 c	3.5 a	22.4 c	2.1 a
TCLN x CTSF – 092	3.2 c	3.2 b	17.4 e	1.8 b
TSK x TRSW – 311	3.5 b	3.6 a	24.0 b	1.7 b
Santa Cruz Rangpur lime lime	3.5 b	3.2 b	19.3 d	1.6 b
TSKC x LVKCT2 - 001	3.2 c	3.1 c	15.9 e	1.6 b
TSKFL x CWEB – 004	3.6 b	3.5 a	23.2 c	1.6 b
TSKC x LHA – 010	3.6 b	3.6 a	24.7 b	1.5 b
TSKFL x CTARG – 002	3.7 a	3.7 a	27.7 a	1.5 b
LVK x LCR – 030	3.1 c	3.0 c	15.1 e	1.4 b
TSKC x LHA – 004	3.6 b	3.6 a	24.6 b	1.3 b
LVK x LCR – 017	2.9 d	2.7 d	11.6 f	1.2 b
Trifoliate orange CRC 3551 CN	3.6 b	3.6 a	24.5 b	1.1 b
Dancy mandarin	3.9 a	3.6 a	27.8 a	0.8 b
LVK x LPA – 016	3.4 c	3.3 b	19.8 d	0.8 b
LVK x LCR – 048	2.8 d	2.6 d	10.0 f	0.7 b
TSKC x TRBK – 010	3.6 b	3.6 a	25.6 b	0.7 b
F	37.1[3] **	23.0 **	39.6 **	5.5 **
CVexp (%)	8.7	10.2	27.3	73.3

[1]Rootstock identifying codes are explained on Table 1. [2]Means followed by the same lowercase and capital letters in the column and row, respectively, and by upper case letters for annual means, belong to the same group by the Scott-Knott test ($P \leq 0.05$). [3] **($P \leq 0.01$).

x CTARG - 028, TSK x TRSW - 294, TSK x TRSW - 308, TSKFL x LRM - 011 and TSK x TRSW - 311.

From these selected rootstocks, CLEO x TRSW - 71158, CLEO x TRSW - 224, CLEO x TRSW - 287 and CTC 25 had the following advantages in relation to the standard (Santa Cruz Rangpur lime): lower canopy volume (20% reduction), higher SS (5% increase), higher processing index (12% increase), and higher productive efficiency (74% increase) (Figure 1). The other rootstocks had similar fruit quality but large plant size, which prevents use in orchards with a higher planting density.

DISCUSSION

The search for superior citrus rootstocks which impart lower plant size, greater productivity and increased fruit quality is needed for citrus cultivation around the world (Schäfer et al., 2001). Based on these characteristics, rootstocks CLEO x TRSW - 71158, CLEO x TRSW - 224, CTC 25, CLEO x TRSW - 287 and TSK x TRSW - 308 were the most efficient in terms of production efficiency, as they exhibited a smaller tree size and similar production per tree in relation to the reference rootstock, Santa Cruz Rangpur lime.

Table 3. Mean production values of the Valencia orange tree on 27 rootstocks, evaluated from 2011 to 2014. Colômbia-SP, 2016

Rootstock[1]	Production (kg tree^{-1})					
	2011	2012	2013	2014	2015	Mean
TSKFL x CTARG – 028	23.6 aB[1]	39.4 aA	16.4 aB	29.4 bB	39.5 bA	29.7 a
TSK x TRSW – 311	10.8 aB	27.6 aB	16.2 aB	47.9 aA	43.6 bA	29.2 a
CLEO x TRSW – 295	13.7 aB	40.7 aA	7.8 bB	42.5 aA	34.2 bA	27.8 a
CLEO x TRSW - 71 158	11.2 aB	23.7 aB	22.1 aB	40.1 aA	40.9 bA	27.6 a
Santa Cruz Rangpur lime lime	6.4 aC	24.3 aB	25.3 aB	27.6 bB	51.9 aA	27.1 a
CLEO x TRSW – 224	18.2 aB	25.9 aB	9.9 bB	42.6 aA	39.0 bA	27.1 a
TSK x TRSW – 308	16.3 aB	30.7 aA	11.9 bB	39.9 aA	35.9 bA	26.9 a
CTC 25	17.2 aB	34.9 aA	5.2 bB	36.9 aA	39.5 bA	26.8 a
CLEO x TRSW – 287	14.3 aB	30.1 aA	17.2 aB	40.0 aA	30.7 cA	26.5 a
TSKC x LHA – 010	10.1 aB	18.1 bB	26.8 aB	26.3 bB	45.2 bA	25.3 a
TSK x TRSW – 294	15.6 aB	32.6 aA	6.2 bB	40.9 aA	28.9 cA	24.8 b
TSKFL x LRM – 011	22.4 aA	30.5 aA	23.9 aA	24.7 bA	20.4 cA	24.4 b
TSKC x TRBK – 010	4.4 aC	5.2 bC	14.6 aC	27.8 bB	64.6 aA	23.3 b
TSKFL x CWEB – 004	7.6 aB	18.6 bB	10.7 bB	43.2 aA	36.0 bA	23.2 b
TSKC x LHA – 004	7.6 aB	21.4 aB	11.6 bB	25.8 bB	44.7 bA	22.2 b
Thomasville 1439	12.7 aA	23.3 aA	19.9 aA	24.5 bA	30.5 cA	22.2 b
CLEO x TR - 30 113	16.4 aB	23.6 aA	8.2 bB	34.5 aA	25.8 cA	21.7 b
LVK x LCR – 030	3.6 aC	8.0 bC	22.2 aB	28.3 bB	45.6 bA	21.5 b
Trifoliate orange CRC 3551 CN	11.2 aB	9.4 bB	17.2 aB	22.6 bB	40.3 bA	20.1 c
TSKFL x CTARG – 002	14.3 aB	15.4 bB	8.2 bB	29.9 bA	28.1 cA	19.2 c
Dancy mandarin	4.9 aB	10.7 bB	9.1 bB	31.0 bA	39.4 bA	19.0 c
TSKC x LVKCT2 – 001	9.4 aA	15.9 bA	12.2 bA	27.0 bA	25.8 cA	18.1 c
TCLN x CTSF – 092	9.2 aB	30.9 aA	7.7 bB	24.7 bA	15.9 cB	17.7 c
LVK x LPA – 016	0.8 aB	4.6 bB	17.2 aA	27.9 bA	28.4 cA	15.8 c
LVK x LCR – 017	6.5 aA	7.7 bA	8.7 bA	14.0 bA	18.4 cA	11.1 d
LVK x LCR – 048	0.01 aB	0.01 bB	7.0 bB	18.5 bA	26.6 cA	10.4 d
Sacaton citrumelo	3.9 aA	11.6 bA	3.2 bA	22.1 bA	8.5 cA	9.9 d
Annual means	10.8 D	20.9 C	13.6 D	31.1 B	34.4 A	22.3
F	1.2[3] NS	3.7 **	1.4 NS	2.3 **	4.3 **	7.2 **
CVexp (%)			52.2			-

[1]Rootstock identifying codes are explained on Table 1. [2]Means followed by the same lowercase and capital letters in the column and row, respectively, and by upper case letters for annual means, belong to the same group by the Scott-Knott test (P≤0.05). [3] NS (not significative), **(P≤0.01), *(P≤0.05).

In this work, rootstocks which were hybrids of Volkamer lemon x Rangpur lime induced semi-dwarfing and dwarfing canopy volume, which was not expected. Only Sacaton citrumelo was truly dwarfing (reduction to 25% of full size as represented by Santa Cruz Rangpur lime), according to the classification of Castle & Phillips (1977), even though it was previously described as normal size inducer, being equal or superior to 2.80 m of height (Arana et al., 2006).

Ramos et al. (2015) evaluated the preliminary behavior of Valencia orange on 44 rootstocks and found that, among the non-trifoliate types, Rangpur lime induced the best production, similar to the results in this study. This is consistent with the general consensus that Rangpur is highly productive in rain-fed conditions (Pompeu Junior, 2005).

Nine hybrid rootstocks of *P. trifoliata* induced fruit production per plant equivalent to Rangpur lime, and thus have great potential for use in the North region of SSP in rain-fed cultivation, while reducing risk of CSD. It must

Table 4. Mean values of quality attributes of Valencia orange fruits on 27 rootstocks in the period 2011-2015, except 2014. Colômbia-SP, 2016

Rootstock[1]	FH[3] (cm)	FD (cm)	FW (g)	JY (%)	TA (%)	*ratio*	PI[#] (kg SS cx^{-1})
CLEO x TR - 30 113	6.9 a[2]	6.8 b	178 b	46.2 a	0.62 b	18.3 a	2.19 a
CLEO x TRSW - 287	7.2 a	7.0 a	199 b	49.2 a	0.66 b	16.8 a	2.16 a
TSKC x TRBK - 010	7.3 a	6.9 b	192 b	49.3 a	0.65 b	16.7 a	2.14 a
CLEO x TRSW - 71158	7.1 a	6.9 b	194 b	48.6 a	0.61 b	18.0 a	2.12 a
TSK x TRSW - 311	7.3 a	7.0 a	200 b	48.1 a	0.63 b	16.9 a	2.08 a
TSKC x LVKCT2 - 001	7.2 a	7.0 b	194 b	46.4 a	0.67 b	16.7 a	2.04 a
TSK x TRSW - 308	7.4 a	7.2 a	213 a	45.9 a	0.62 b	17.9 a	2.03 a
CLEO x TRSW 224	7.1 a	7.0 b	196 b	45.6 a	0.68 b	16.5 a	2.03 a
Trifoliate orange CRC 3551 CN	7.2 a	7.1 a	202 a	45.8 a	0.72 a	15.4 b	2.02 a
TCLN x CTSF - 092	7.1 a	7.0 b	194 b	46.9 a	0.65 b	16.7 a	2.02 a
LVK x LPA - 016	6.9 a	6.7 b	174 b	46.6 a	0.75 a	14.6 b	2.01 a
TSKC x LHA - 004	7.3 a	7.1 a	211 a	47.1 a	0.72 a	14.9 b	2.00 a
Thomasville 1439	7.3 a	7.2 a	211 a	45.8 a	0.67 b	16.9 a	1.99 a
TSKFL x CTARG - 028	7.3 a	7.2 a	210 a	45.7 a	0.71 a	15.3 b	1.98 a
CLEO x TRSW - 295	7.2 a	7.0 b	199 b	45.7 a	0.67 b	16.5 a	1.97 a
TSK x TRSW - 294	6.9 a	7.0 a	196 b	44.1 b	0.60 b	18.2 a	1.95 a
TSKC x LHA - 010	7.3 a	7.1 a	207 a	45.3 a	0.72 a	15.1 b	1.94 a
CTC 25	7.2 a	7.0 a	194 b	43.7 b	0.70 a	16.1 a	1.92 b
TSKFL x CWEB - 004	7.4 a	7.1 a	209 a	44.6 b	0.67 b	16.4 a	1.91 b
LVK x LCR - 017	7.0 a	6.8 b	179 b	43.1 b	0.69 a	16.1 a	1.90 b
Santa Cruz Rangpur lime	7.2 a	6.9 b	197 b	44.8 b	0.74 a	14.7 b	1.89 b
TSKFL x CTARG - 002	7.4 a	7.1 a	211 a	43.5 b	0.68 b	15.7 b	1.88 b
LVK x LCR - 030	7.2 a	6.9 b	194 b	42.3 b	0.71 a	15.2 b	1.80 b
TSKFL x LRM - 011	7.3 a	7.1 a	205 a	43.5 b	0.67 b	15.4 b	1.78 b
LVK x LCR - 048	7.2 a	6.8 b	187 b	42.8 b	0.75 a	13.8 b	1.75 b
Dancy mandarin	7.1 a	7.0 a	197 b	40.7 b	0.79 a	13.5 b	1.73 b
Sacaton citrumelo	7.6 a	7.2 a	215 a	41.3 b	0.63 b	16.7 a	1.68 b
Annual means	7.2	7.0	198	45.4	0.69	16.1	1.98
F	2.1[4] **	2.6 **	2.8 **	1.8 *	2.1 **	3.0 **	2.2 **
CVexp (%)	5.6	4.0	11.4	12.3	16.2	15.9	15.1

[1]Rootstock identifying codes are explained on Table 1. [2]Means followed by the same letter in the column belong to the same group by the Scott-Knott test ($P \leq 0.05$). [3]Titratable acidity (TA), fruit height (FH), diameter (FD), processing index (PI), fruit weight (FW), ratio (SS/TA) and juice yield (JY). # cx = Box of 40.8 kg. [4]**($P \leq 0.01$), *($P \leq 0.05$).

be highlighted that among the four rootstocks selected as best in the present work (Figure 1), three are citrandarins, which emphasizes their potential for rain-fed cultivation (Blumer & Pompeu Junior, 2005). The poor fruit production of trees with Dancy mandarin rootstock was also previously reported (Pompeu Junior et al., 2003). Trifoliate orange and its hybrids generally induced the scion to produce fruits with traits superior to those obtained for other rootstocks, as found by Bordignon et al. (2003). According to Koller (1994), the ideal ratio is between 10 and 16. The fruits of Valencia on all rootstocks analyzed conformed with this range in most of the years evaluated.

Variation among rootstocks for soluble solids was only observed in 2012 (Table 4), a year in which drought conditions were present before and during harvest. Moderate water stress during maturation may sometimes enhance fruit quality (Aguado et al., 2012). The processing index values (2011-2015 means) recorded for rootstocks in this work were substantially lower than those reported by Di Giorgi et al. (1990) and by Nonino (1995), for the

Table 5. Mean values of the concentration of total soluble solids in Valencia orange fruits on 27 rootstocks evaluated in 2011, 2012, 2013 and 2015. Colômbia-SP, 2016

Rootstock[1]	Soluble Solids (ºBrix)				
	2011	2012	2013	2015	Mean
CLEO x TR – 30113	10.6 aB[1]	11.5 aA	10.5 aB	11.5 aA	11.0 a
CLEO x TRSW – 224	10.8 aA	11.4 aA	10.0 aB	11.1 aA	10.8 a
TSK x TRSW – 308	10.0 aB	11.2 aA	9.9 aB	12.0 aA	10.8 a
TSK x TRSW – 294	10.2 aB	11.5 aA	10.0 aB	11.2 aA	10.7 a
LVK x LCR – 017	9.8 aB	10.9 aA	10.6 aA	11.6 aA	10.7 a
TSKC x LVKCT2 – 001	10.7 aA	10.6 aA	10.4 aA	11.2 aA	10.7 a
Trifoliate orange CRC 3551 CN	9.8 aB	10.4 bB	10.9 aA	11.7 aA	10.7 a
CLEO x TRSW – 287	10.4 aA	10.8 aA	10.4 aA	11.0 aA	10.7 a
CTC 25	10.0 aB	11.3 aA	10.0 aB	11.4 aA	10.7 a
CLEO x TRSW – 71158	9.5 aC	10.5 aB	10.7 aB	11.7 aA	10.6 a
CLEO x TRSW – 295	10.6 aA	11.1 aA	9.8 aB	10.9 aA	10.6 a
Thomasville 1439	9.4 aB	10.8 aA	10.5 aA	11.4 aA	10.5 a
LVK x LPA – 016	9.9 aB	10.6 aB	10.1 aB	11.6 aA	10.5 a
TSKFL x CTARG – 028	10.0 aB	11.0 aA	10.1 aB	11.0 aA	10.5 a
TSKC x TRBK – 010	9.7 aA	10.1 bA	10.9 aA	11.4 aA	10.5 a
TSK x TRSW – 311	9.8 aB	10.9 aA	10.0 aB	11.4 aA	10.5 a
Dancy mandarin	9.4 aB	10.7 aB	10.0 aB	11.9 aA	10.5 a
TSKFL x CTARG – 002	9.2 aB	10.7 aA	10.5 aA	11.3 aA	10.4 a
TCLN x CTSF – 092	9.6 aB	10.3 bB	10.5 aB	11.3 aA	10.4 a
TSKC x LHA – 010	8.9 aB	11.3 aA	9.9 aB	11.6 aA	10.4 a
TSKFL x CWEB – 004	10.2 aB	10.1 bB	9.8 aB	11.4 aA	10.4 a
TSKC x LHA – 004	9.9 aA	10.1 bA	10.1 aA	11.2 aA	10.3 b
LVK x LCR – 030	10.2 aB	9.7 cB	10.1 aB	11.2 aA	10.3 b
Santa Cruz Rangpur lime lime	10.1 aA	9.3 cA	10.4 aA	11.2 aA	10.2 b
TSKFL x LRM – 011	9.5 aB	9.5 cB	9.4 aB	11.4 aA	9.9 b
LVK x LCR – 048	8.1 aB	10.3 bA	10.3 aA	10.9 aA	9.9 b
Sacaton citrumelo	9.5 aB	9.1 cB	9.8 aB	11.0 aA	9.8 b
Annual means	9.8 D	10.6 B	10.2 C	11.3 A	10.6
F	1.7[3] NS	3.8 **	1.1 NS	0.7 NS	2.4 **
CVexp (%)			6.3		-

[1]Rootstock identifying codes are explained on Table 1. [2]Means followed by the same lowercase and capital letters in the column and row, respectively, and by upper case letters for annual means, belong to the same group by the Scott-Knott test (P≤0.05). [3]NS (not significative), **(P≤0.01), *(P≤0.05).

variety Valencia (2.49 to 2.86 kg and 2.42 to 2.73 soluble solids/box 40.8 kg, respectively). Those authors reports average data from processing plants, thus, juice extraction procedures could be one of the factors that explain the differences found.

Rootstocks that result in trees of smaller size, with high overall productivity and production efficiency are desirable for higher density orchards. Several rootstocks in this trial displayed significant dwarfing potential as they are plants of small size, efficient and productive that can be employed in high density orchards. In January 2017, trees were scouted and it was possible to observe some Valencia orange trees grafted on Santa Cruz Ranpur lime rootstock presenting visual symptoms that resemble CSD. Trees on LVK x LCR hybrids presented poor plant growth and general nutritional defficiency with more than 50% of tree death. Although trees on CLEO x TRSW – 71158 performed well, they presented general chlorosis, shoot dieback and incompatibility symptoms in the graft union, such as crease and rootstock phloem yellowing, which may

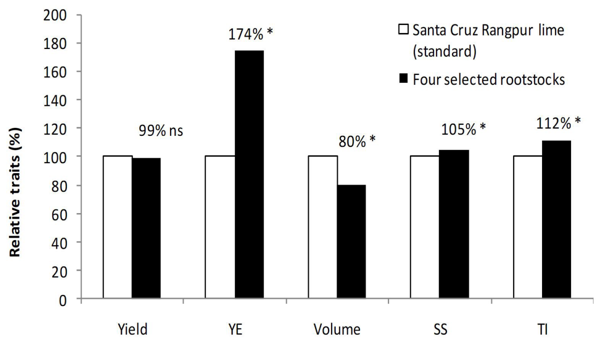

Figure 1. Relative traits (%) of Valencia sweet orange grafted onto Santa Cruz Rangpur lime and four selected rootstocks (CTC 25 and CLEO x TRSW - 224, - 287 and - 71158) under rain-fed cultivation from 2009 to 2015. Colômbia-SP, Brazil, 2016. Accumulated yield (2011-2015, kg tree^{-1}), YE = mean yield efficiency (2011-2014, kg m^{-3}), canopy volume (2014, m^3), SS = soluble solids (mean 2012, 2013, 2015, ºBrix), PI = processing index (mean 2012, 2013, 2015, SS box 40.8 kg^{-1}). *, ns significant or not (F test, $p \leq 0.05$).

limit its use as rootstock of Valencia sweet orange. It was also observed general nutritional defficiency on TSK x TRSW – 308 and the proeminent overgrowth of the scion trunk on TSKFL x CTARG – 002 rootstocks. Trees grafted on Dancy mandarin were the most vigorous without any symptoms of biotic either abiotic stresses and no tree loss. Considering the overall tree appearance, stand and fruit load in comparison to a commercial block of Valencia orange grafted on Swingle citrumelo with the same age and similar management just next to the experimental plot, the main rootstocks are ranked in the following descending order: Swingle citrumelo > CTC 25 > TSKFL x CTARG – 028 > CLEO x TRSW – 287 > CLEO x TRSW – 295 > Santa Cruz Rangpur lime with the other rootstocks with similar or inferior perfomance than Rangpur lime.

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