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.

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
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. reshi, 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. reshi 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 Macf. x Poncirus trifoliata (L.) Raf.], the trifoliata orange (P. trifoliata) and the mandarin rootstocks Sunki [C. sunki (Hayata) hort. ex Tanaka] and Cleopatra (C. reshi 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 prolonged 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 (20°17'48" S, 48°41'41" 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 °C. 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 (CaCl₂) = 4.5; CEC = 55; Ca = 16; Mg = 4; K = 2; H⁺Al = 33 mmol_c dm⁻³,
Volume ($V$) was calculated, with the formula $V = \frac{2}{3} \pi r^2 h$, 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 $\text{ABI} = \frac{1}{n-1} \left\{ \left| (a_2-a_1) / (a_2+a_2) \right| + \left| (a_3-a_2) / (a_3+a_2) \right| + \ldots + \left| (a(n)-a(n-1)) / (a(n)+a(n-1)) \right| \right\}$, where $n$ = number of crops evaluated and $a_1$, $a_2$, ..., $a(n-1)$, $a(n)$ = production in the corresponding years (Pearce & Dobersek-Urbanc, 1967).

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 $V = \frac{2}{3} \pi r^2 h$, where $r$ is the radius of plants canopies and $h$, their height.

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 |
|-------------------|--------------------------------------|-------------------------|
| 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. |

1According to Passos et al. (2007) and Vasconcelos & Araújo (1975); 2Numbers 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: $PI = [JY \times SS \times 40.8] \times 10.000^2$, 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 $SI = (Prod \times 50) \times (Efp \times 15) \times (PI \times 35) / 1000000$, 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 - 287 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 LHA – 010, Thomasville 1439 and TSKFL x LHA – 010 had similar results with the exception of lower acid (Table 4).

The mean values of soluble solids varied from 9.89 to 11.06 °Brix, with the mean of the years (2011 to 2015, except 2014) of 10.62 °Brix. 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 °Brix), varying from 10.4 to 11.1 °Brix. Conversely, the highest values of soluble solids were obtained in the year 2015, reaching a mean of 11.4 °Brix, without difference among the rootstocks in this year nor in 2011 (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                        | Height (cm) | Diameter (cm) | Volume (m³) | Mean efficiency (kg m⁻³) |
|----------------------------------|-------------|---------------|-------------|-------------------------|
| Thomasville 1439                 | 2.6 e²      | 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          | 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                                | 37.13 **    | 23.0 **       | 39.6 **     | 5.5 **                  |
| CVexp (%)                        | 8.7         | 10.2          | 27.3        | 73.3                    |

¹Rootstock identifying codes are explained on Table 1. ²Means 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**(P≤0.01).

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, CLEO x TRSW - 287 and CTC 25 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

| Rootstock1 | Production (kg tree⁻¹) | 2011 | 2012 | 2013 | 2014 | 2015 | Mean |
|------------|------------------------|------|------|------|------|------|------|
| TSKFL x CTARG – 028 | 23.6 aB | 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 | 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 aB | 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 aA | 25.3 a |
| TSK x TRSW – 294 | 15.6 aB | 32.6 aA | 6.2 bB | 40.9 aA | 28.9 aA | 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 bA | 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 aA | 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 aA | 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 aA | 28.1 cA | 19.2 c |
| Dancy mandarin | 4.9 aB | 10.7 bB | 9.1 bB | 31.0 aB | 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 aB | 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 bB | 3.2 aA | 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 | 1.21 NS | 3.7 ** | 1.4 NS | 2.3 ** | 4.3 ** | 7.2 ** |
| CVexp (%) | ** | 52.2 | - | - | - | - |

1Rootstock identifying codes are explained on Table 1. 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). 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
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

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

| Rootstock1 | FH1 (cm) | FD (cm) | FW (g) | JY (%) | TA (%) | ratio | PI1 (kg SS cx⁻¹) |
|------------|----------|---------|--------|--------|--------|-------|-----------------|
| CLEO x TR - 30 113 | 6.9 a | 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 a | 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 |

1Rootstock identifying codes are explained on Table 1. 2Means followed by the same letter in the column belong to the same group by the Scott-Knott test (P≤0.05). 3Titratable 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≤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 Rangpur lime rootstock presenting visual symptoms that resemble CSD. Trees on LVK x LCR hybrids presented poor plant growth and general nutritional deficiency 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

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                                  | Soluble Solids (°Brix) |
|--------------------------------------------|------------------------|
|                                            | 2011  | 2012  | 2013  | 2015  | Mean |
| CLEO x TR – 30113                           | 10.6 aB1 | 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 aB | 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 aB | 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 aB | 9.8 aB  | 11.4 aA | 10.4 a |
| TSKC x LHA – 004                            | 9.9 aA  | 10.1 aB | 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 aB | 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†  NS | 3.8 **  | 1.1 NS  | 0.7 NS | 2.4 ** |

CVexp (%) | 6.3

1Rootstock identifying codes are explained on Table 1. 2Means 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).
3NS (not significative), **(P≤0.01), *(P≤0.05).
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, m³), SS = soluble solids (mean 2012, 2013, 2015, °Brix), PI = processing index (mean 2012, 2013, 2015, SS box 40.8 kg⁻¹). *, ns significant or not (F test, p ≤ 0.05).

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limit its use as rootstock of Valencia sweet orange. It was also observed general nutritional deficiency on TSK x TRSW – 308 and the prominent 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 performance than Rangpur lime.
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