DOI: http://dx.doi.org/10.1590/1678-4499.2016.350

CROP PRODUCTION AND MANAGEMENT - Article

Sunki mandarin and Swingle citrumelo as rootstocks for rain-fed cultivation of late-season sweet orange selections in northern São Paulo state, Brazil

Eduardo Augusto Girardi[1]*, Thales Sandoval Cerqueira[1], Tatiana Eugenia Cantuarias-Avilés[2], Simone Rodrigues da Silva[2], Eduardo Sanches Stuchi[1]

1.Empresa Brasileira de Pesquisa Agropecuária - Mandioca e Fruticultura - Cruz das Almas (BA), Brazil.
2.Universidade de São Paulo - Escola Superior de Agricultura "Luiz de Queiroz" - Produção Vegetal - Piracicaba (SP), Brazil.

ABSTRACT: In Brazilian regions affected by the citrus sudden death disease, sweet orange cultivation depends on the use of resistant rootstocks. Rangpur lime was mainly replaced by Swingle citrumelo and Sunki mandarin rootstocks, more drought-sensitive ones. The diversification of scion selections is also desirable aiming at the increasing demand for not from concentrate orange juice (NFC) that requires high-quality fruits. In this work, we evaluated the performance of 6 selections of Valencia (IAC, Dom João, Late Burjasot IVIA 35-2, Rhode Red SRA 360, Temprana IVIA 25 and Campbell) and Natal IAC sweet oranges grafted onto Swingle citrumelo and Sunki mandarin. The planting occurred in 2001 under rain-fed cultivation in Bebedouro, northern São Paulo state, Brazil. The outline was made through randomized blocks in a 7 × 2 factorial design (selections × rootstock), with 4 replications and 2 trees in unit. Both rootstocks performed well in the region. Sunki mandarin rootstock induced greater tree size and production per plant to the scion selections, 38 and 21%, respectively, plus higher precocity of production compared to Swingle citrumelo. The later determined a greater productive efficiency, as well as a greater percentage of juice in general, albeit with lower concentrations of soluble solids and acidity. Natal IAC, Valencia IAC and Rhode Red Valencia selections presented a higher accumulated production, on average, 218.6 kg·plant^{-1} (2004 – 2008), and a higher productive efficiency (kg fruit·m^{-3} of canopy) due to their smaller tree size. All assessed selections produced fruits with high soluble solids content that were suitable for juice processing.

Key words: *Citrus sinensis*, *C. sunki*, [*C. paradisi* × *Poncirus trifoliata*], drought tolerance, fruit quality, production.

*Corresponding author: eduardo.stuchi@embrapa.br

Received: Aug. 17, 2016 – Accepted: Dec. 2, 2016

INTRODUCTION

The cultivation of oranges exists in all Brazilian states, with the state of São Paulo being the largest producer, responsible for 74% of Brazilian production in 2014 (IBGE 2016). In this state, orange varieties [*Citrus sinensis* (L.) Osbeck] have the following distribution: 43.6% of late-season selections (Natal, Valencia and Folha Murcha), 18.5% of early-season selections (Hamlin, Westin, Rubi and Valencia Americana), and 33.6% with the Pera midseason selection, besides the less cultivated ones (Fundecitrus 2016).

The Valencia orange has major economic importance in the world due to its high-quality fruit for juice processing and usually high productivity, whereas the Natal selection is only cultivated in Brazil, with it being a high-quality later-maturing selection compared to the Valencia (Pio et al. 2005; Tazima et al. 2008). In recent years, the demand for high quality not from concentrate orange juice (NFC) has remarkably increased (Neves et al. 2010), thus requiring orange selections with better fruit quality. Historically, fruits with this profile have been harvested in the north and center of São Paulo under rain-fed cultivation (Nonino 1995).

Rangpur lime (*C. limonia* Osbeck) became the rootstock of choice for nurserymen and the citrus growers in past decades in Brazil as result of its tolerance to *citrus tristeza virus* (CTV) and drought, and for inducing high yield and early bearing to several scion varieties (Pompeu Junior 2005). However, citrus sudden death (CSD) disease has been affecting mandarin and orange trees grafted onto Rangpur lime and Volkamer lemon (*C. volkameriana* Pasq.) since 1999 in the "Triângulo Mineiro", region of Minas Gerais state, and in the north of São Paulo state (Müller et al. 2002). On the other hand, trees grafted onto Cleopatra (*C. reshni* hort ex Tanaka) and Sunki mandarins (*C. sunki* hort ex Tanaka), Swingle citrumelo [*C. paradisi* Macfad. cv Duncan × *Poncirus trifoliata* (L.) Raf.] and trifoliate orange (*P. trifoliata*) are not affected. This situation accelerated the diversification of the rootstocks, especially in these regions.

Swingle citrumelo is tolerant to CTV, exocortis, xiloporosis, and citrus blight and CSD, in addition to being resistant to the gummosis-of-*Phytophthora* and to citrus nematodes (Pompeu Junior 2005). The plants can grow well in sandy or clayey soils and are moderately tolerant to drought and frost, but they do not perform well in soils with a high pH or those that are poorly drained. This rootstock provides good productivity of high-quality Valencia oranges (Castle et al. 2010a; Pompeu Junior and Blumer 2011). The commercial production of the Sunki mandarin rootstock was initially reported in Brazil in 1985 due to its resistance to CTV and for producing fruit that is generally superior in quality to that provided by the Cleopatra mandarin (Pompeu Junior 2005). Due to their tolerance to CSD, the use of these 2 rootstocks increased despite their greater sensitivity to drought in relation to Rangpur lime (Pompeu Junior and Blumer 2008; Pompeu Junior 2005).

Regarding to huanglongbing (HLB), all commercial scion and rootstocks used in Brazil are sensitive, even though HLB incidence is relatively low in northern São Paulo state (Fundecitrus 2016).

Therefore, aiming at the diversification of late-season sweet orange selections grafted onto CSD-tolerant rootstocks in northern São Paulo, tree growth, production and fruit quality were evaluated for Natal and 6 selections of Valencia sweet orange grafted on Sunki mandarin and Swingle citrumelo, having been cultivated under rain-fed conditions.

MATERIAL AND METHODS

The experiment was carried out in the Bebedouro Citriculture Experimental Station (EECB) in the municipality of Bebedouro, northern region of São Paulo state (lat 20°53′16″S, long 48°28′11″W, 601 m above sea level), with a Cwa subtropical climate (Figure 1). The soil was a dark red oxisol, eutrophic endoalic, with a moderate A horizon, with intermediate texture (38% clay) [pH ($CaCl_2$) = 5.7; CEC = 55 mmolc·dm^{-3} in the 0 – 20 cm soil layer] (Embrapa 1999). This type of soil is commonly planted with commercial citrus orchards in this region, as well other oxisoils and argisoils (Corá et al. 2005).

Six selections of Valencia sweet orange were evaluated: Valencia IAC, Dom João, Valencia Late Burjasot IVIA 35-2, Rhode Red Valencia SRA 360, Valencia Temprana IVIA 25 and Campbell Valencia, in addition to Natal IAC sweet orange. Valencia IAC and Natal IAC are the main late-season orange varieties in current use in São Paulo

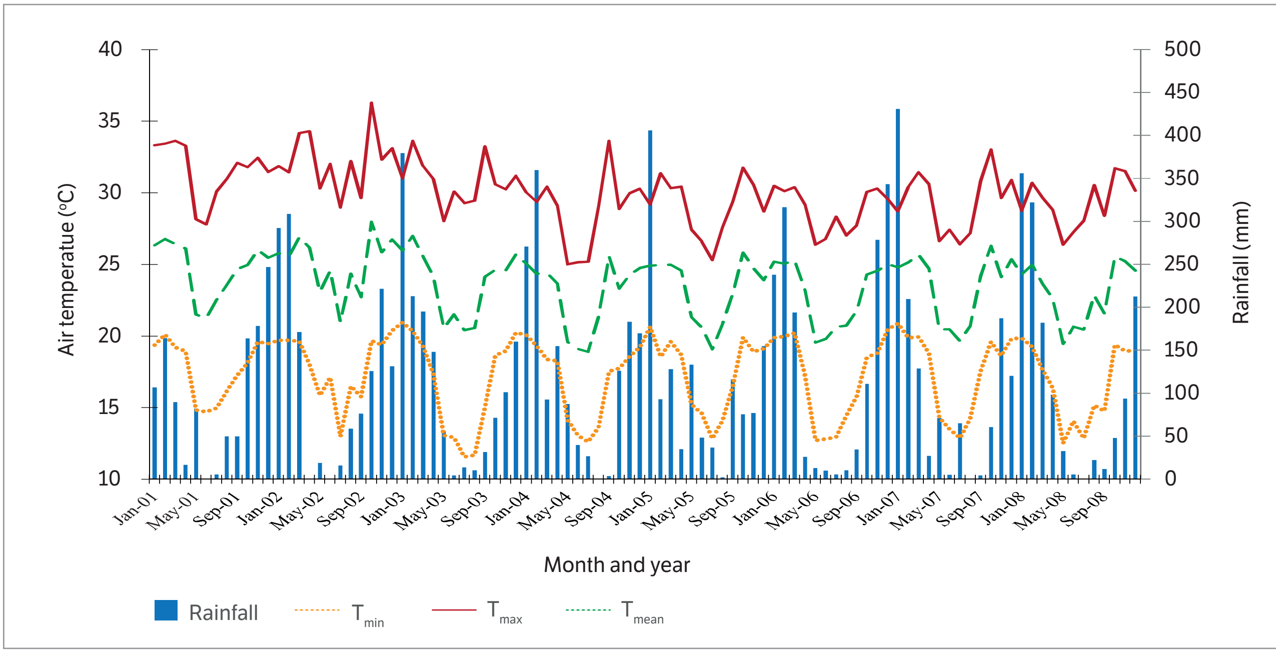

Figure 1. Monthly mean air temperatures (maximum, minimum, and average) and rainfall in the experimental area, obtained from automatic meteorological station in 2001 – 2008. Bebedouro, São Paulo, Brazil.

state. The other selections were previously introduced in EECB and, after presenting good fruit quality in preliminary evaluations in the germplasm collection, were selected for this study.

All the scion selections were virus- and viroid-free, and only Valencia IAC and Natal IAC were inoculated with the protective isolate PIAC of CTV. Budwood was originated form EECB's collection in screen house, and the selections were grafted onto nucellar seedlings of Swingle citrumelo and Sunki mandarin. The transplantation to the field took place in February 2001 at 7.0 × 5.0 m and 7.0 × 3.0 m tree spacing for Swingle citrumelo and Sunki mandarin, respectively. No irrigation was provided, and the trees grew using only water provided by rainfall. Cultural practices that are usually recommended for orange cultivation in São Paulo state were adopted, and N was applied at average rate of 185 g·tree^{-1} annually (2001 – 2008).

The following parameters were measured in 2008: tree height (H), from the soil to the top of the tree; canopy diameter (D), by the mean of 2 diameters at right angles at half height of the tree; canopy volume (V), which was calculated from:

$$V = 2/3 \times [(\pi \times D^2 \times 4^{-1}) \times H],$$

adapted from Cantuarias-Avilés et al. (2011), and the mean annual growth rate (GR), which was calculated by the mean annual variation of V between 2006 and 2008.

The fruit production (kg·plant^{-1}) was measured annually, and the mean yield was calculated from 2004 to 2008. The alternate-bearing harvest index (HI) was calculated for the same period as follows:

$$HI = [1 / (n - 1)] \times \{[|a_2 - a_1| / (a_2 + a_1)] + [|a_3 - a_2| / (a_3 + a_2)] + \ldots + [|a_n - a_{n-1}| / (a_n + a_{n-1})]\},$$

where: n is the total number of years that were evaluated; a_1, a_2, …, a_{n-1}, a_n represent the production in the corresponding year (Pearce and Doberšek-Urbanc 1967).

Additionally, the precocity of production (PP) was estimated by the percentage of production per plant corresponding to the first 2 yields compared with the total accumulated production, and the productive efficiency (PEf) was calculated by the mean ratio between the annual production (kg·plant^{-1}) and the canopy volume in the respective year, in this case, between 2006 and 2008 (Cantuarias-Avilés et al. 2011).

The variables regarding to the fruit quality comprised the fruit weight (g), the diameter and the length of the fruit (cm), juice yield (JY, in %), from the relationship between the weight of the extracted juice using an industrial extractor (Otto 1800, OIC, Limeira, São Paulo, Brazil) and the fruit sample weight, the concentration of total soluble solids (SS, in °Brix), the titratable acidity (TA, in g citric acid $100 \cdot g^{-1}$), the SS/TA ratio, and the industrial technological index (TI), which expresses the amount of SS (kg) per box. It is calculated by:

$$TI = [JY \times SS \times 40.8],$$

where the value of 40.8 kg corresponds to the standard industrial citrus box capacity.

Fruit quality variables were calculated as the mean values in the 2004 to 2008 period, with 10 fruits collected per plot, which was always in October for each harvest, considering a minimum SS/TA ratio ≥ 12.0. This fruit sample size detects differences between means of ~0.55% SS and ~0.11% TA in oranges (Barry et al. 2003).

The experimental design was a randomized complete blocks in a 7 × 2 factorial setting (selections of oranges × rootstocks), with 14 treatments, 4 replications and 2 trees per plot. The results were submitted to analysis of variance, and the means were grouped by the Scott-Knott test ($p \leq 0.05$). An arcsine square root transformation was performed when necessary to meet the normality and homogeneity of variance.

RESULTS

Sunki mandarin induced largest tree size to the orange selections compared to Swingle citrumelo in 2008 (Table 1). In plants grafted onto Sunki mandarin, the tallest selections and those with greatest canopy diameters →

Table 1. Diameter, height and volume of tree canopy at 8 years old and mean tree growth rate in 2006 – 2008 of 6 selections of Valencia and Natal sweet oranges grafted onto Swingle citrumelo and Sunki mandarin. Bebedouro, São Paulo, Brazil.

Selection	Diameter (m)	Height (m)	Volume (m^3)	GR ($m^3 \cdot year^{-1}$)
Swingle citrumelo				
Natal IAC	2.7 b	2.4 b	10.0 b	1.4 a
Valencia IAC	2.7 b	2.6 b	10.4 b	2.3 a
Dom João	3.3 a	3.1 a	20.0 a	3.9 a
Valencia Late Burjasot	3.6 a	3.4 a	23.8 a	3.5 a
Rhode Red Valencia	2.8 b	2.5 b	10.0 b	1.7 a
Valencia Temprana	3.4 a	3.2 a	19.4 a	3.3 a
Campbell Valencia	3.3 a	3.0 a	17.0 a	2.9 a
Rootstock mean	3.1 B	2.9 B	15.8 B	2.7 B
Sunki mandarin				
Natal IAC	3.3 b	3.1 b	18.0 b	3.2 b
Valencia IAC	3.1 b	3.0 b	15.8 b	2.8 b
Dom João	3.1 b	2.9 b	16.1 b	2.8 b
Valencia Late Burjasot	3.1 b	2.7 b	33.6 a	7.3 a
Valencia Rohde Red	3.0 b	3.1 b	15.1 b	2.2 b
Valencia Temprana	3.8 a	3.5 a	27.7 a	7.0 a
Campbell Valencia	3.9 a	3.4 a	26.9 a	6.3 a
Rootstock mean	3.5 A	3.2 A	21.9 A	4.5 A
CV (%)	11.92	8.35	31.50	32.00
p-value				
Rootstock (R)	0.0345	0.0021	0.0034	0.0162
Scion selection (S)	0.0015	< 0.0001	0.0001	0.0442
R × S	0.0319	< 0.0001	0.0271	0.0389

Means followed by different capital and lowercase letters in the column, respectively for rootstocks means and within the scion selections means on the same rootstock, belong to distinct groups by the Scott-Knott test ($p \leq 0.05$). GR = Growth rate; CV = Coefficient of variation.

were Temprana and Campbell, which were larger than the mean for the others (3.10 m). Regarding the Swingle citrumelo, the scion selections with the largest tree sizes were also Temprana and Campbell, in addition to Late Burjasot and Dom João.

The canopy volume of the selections grafted onto Sunki mandarin was significantly larger (38% on average), with Temprana, Campbell and Late Burjasot being the largest (30 m^3 on average), while the others presented a canopy of only 16 m^3 on average (Table 1). On the other hand, trees grafted onto Swingle citrumelo had a mean canopy volume of 15.8 m^3, the smallest being Natal, Valencia IAC and Rhode Red (mean of 10.0 m^3). However, the mean growth rate of all the selections was not different regarding this last rootstock (mean of 2.7 $m^3 \cdot year^{-1}$). When the same selections were evaluated on Sunki mandarin, the greatest growth rate was verified for Temprana, Campbell and Late Burjasot (around 7.0 $m^3 \cdot year^{-1}$).

The effects of the rootstocks and of the interaction between the scion selections versus the rootstock were significant for many of the production variables in 2004 – 2008 (Table 2). The accumulated production of the selections on Sunki mandarin may be categorized as: Natal (high production, 300.5 $kg \cdot plant^{-1}$) > Valencia IAC, Dom João, Rhode Red Valencia and Campbell Valencia (intermediary production, 240.0 $kg \cdot plant^{-1}$) > Valencia Temprana (low production, 180.6 $kg \cdot plant^{-1}$) > Valencia Late Burjasot (low production, 165.9 $kg \cdot plant^{-1}$). The accumulated production on Swingle citrumelo resulted

Table 2. Mean production, alternate-bearing harvest index and precocity of production in 2004 – 2008, as well as productive efficiency in 2006 – 2008 of 6 selections of Valencia and Natal sweet oranges grafted onto Swingle citrumelo and Sunki mandarin at 8 years old. Bebedouro, São Paulo, Brazil.

Selection	Production ($kg \cdot tree^{-1}$)	HI	PP* (%)	PEf ($kg \cdot m^{-3}$)
Swingle citrumelo				
Natal IAC	47.9 a	0.28 b	23.7 a	7.2 a
Valencia IAC	30.4 b	0.30 b	21.1 b	4.8 b
Dom João	26.9 b	0.52 a	5.4 d	2.6 d
Valencia Late Burjasot	46.1 a	0.67 a	4.2 e	3.9 c
Rhode Red Valencia	33.0 b	0.22 b	22.1 b	5.1 b
Valencia Temprana	35.9 b	0.40 b	8.9 c	3.6 c
Campbell Valencia	45.2 a	0.26 b	21.8 b	4.0 c
Rootstock mean	37.9 B	0.38 A	15.3 B	4.5 A
Sunki mandarin				
Natal IAC	60.1 a	0.19 b	23.0 b	5.5 a
Valencia IAC	46.7 b	0.20 b	23.9 b	4.7 a
Dom João	48.1 b	0.21 b	29.3 a	4.6 a
Valencia Late Burjasot	33.2 d	0.53 a	0.3 d	2.3 c
Rhode Red Valencia	44.1 b	0.17 b	23.2 b	4.7 a
Valencia Temprana	36.1 c	0.41 a	23.0 b	2.2 c
Campbell Valencia	52.3 b	0.33 b	19.8 c	3.6 b
Rootstock mean	45.8 A	0.29 B	20.4 A	3.9 B
CV (%)	11.52	35.60	3.43	16.37
p-value				
Rootstock (R)	< 0.0001	0.0114	< 0.0001	0.0032
Scion selection (S)	< 0.0001	< 0.0001	< 0.0001	< 0.0001
R × S	< 0.0001	0.0960	< 0.0001	< 0.0001

Means followed by different capital and lowercase letters in the column, respectively for rootstocks means and within the scion selections means on the same rootstock, belong to distinct groups by the Scott-Knott test ($p \leq 0.05$). *Percentage of production in the first 2 harvests in relation to the total accumulated production. HI = Harvest index; PP = Precocity of production; PEf = Productive efficiency; CV = Coefficient of variation.

in only 2 groups: mean production (230.0 kg·plant^{-1}) for Natal, Late Burjasot and Campbell, with the others presenting a low productivity (150.0 kg·plant^{-1}).

Regarding the precocity of the production, the selections that stood out were Natal IAC, Valencia IAC, Rhode Red and Campbell when grafted on Swingle citrumelo, presenting around 22% of the fruits harvested in the 2004 and 2005 harvest (3rd and 4th year after planting, respectively). Accumulating below 10% of the fruits were Dom João, Late Burjasot and Temprana (Table 2). Considering the Sunki mandarin as rootstock, it must be highlighted that Late Burjasot was the latest selection, with only 0.3% of the production in the first 2 harvests. The other selections presented between 20 – 30% of production in the same period.

The HI value was also the highest for trees grafted onto Swingle citrumelo, with an average of 0.38 (Table 2). Late Burjasot was the selection with the greatest annual variation in production on both rootstocks (mean of 0.55), besides Dom João on Swingle citrumelo and Temprana on Sunki mandarin. The other selections presented an average HI of 0.25.

In terms of PEf (kg of fruit·m^{-3} of canopy), Natal IAC, Valencia IAC and Rhode Red selections were the most efficient on Swingle citrumelo (> 4.5 kg·m^{-3}), with the Natal selection being the most efficient on average. →

Table 3. Weight, height, diameter, juice yield, soluble solids content, titratable acidity, ratio SS/TA, and technological index (kg SS 40.8 kg^{-1}) of fruits* of 6 selections of Valencia and Natal sweet oranges grafted onto Swingle citrumelo and Sunki mandarin. Bebedouro, São Paulo, Brazil

Selection	Weight (g)	Height (cm)	Diameter (cm)	JY (%)	SS (°Brix)	TA (g·100 g^{-1})	SS/TA	kg SS 40.8·kg^{-1}
Swingle citrumelo								
Natal IAC	167 a	6.9 b	6.6 b	52.0 a	13.1 a	1.07 a	13.1 c	2.78 a
Valencia IAC	198 a	7.3 b	7.1 b	52.1 a	12.1 b	0.90 b	14.1 b	2.56 b
Dom João	215 a	7.9 a	7.6 a	40.3 c	11.3 b	0.81 b	14.5 b	1.88 c
Valencia Late Burjasot	207 a	7.6 a	7.1 b	49.7 a	12.1 b	0.85 b	15.0 b	2.46 b
Rhode Red Valencia	187 a	7.0 b	6.9 b	52.6 a	11.6 b	0.82 b	15.6 b	2.50 b
Valencia Temprana	191 a	7.4 b	7.1 b	43.0 b	11.2 b	0.70 c	17.8 a	1.97 c
Campbell Valencia	197 a	7.3 b	7.0 b	52.4 a	11.9 b	1.00 a	12.9 c	2.54 b
Rootstock mean	195 A	7.3 A	7.1 A	48.87 A	11.9 B	0.88 B	14.7 A	2.38 A
Sunki mandarin								
Natal IAC	157 b	6.9 b	6.6 b	48.4 a	12.9 a	1.01 b	13.5 b	2.55 a
Valencia IAC	190 b	7.4 b	6.9 b	47.0 a	12.3 a	0.93 c	14.0 b	2.38 a
Dom João	177 b	7.1 b	6.9 b	45.9 a	12.7 a	1.20 a	11.5 c	2.38 a
Valencia Late Burjasot	232 a	8.0 a	7.4 a	46.7 a	12.1 a	1.00 b	12.7 c	2.34 a
Rhode Red Valencia	176 b	7.0 b	6.9 b	47.8 a	12.3 a	0.91 c	14.1 b	2.41 a
Valencia Temprana	179 b	7.3 b	7.0 b	40.9 b	12.3 a	0.83 c	16.2 a	2.05 b
Campbell Valencia	190 b	7.2 b	7.0 b	47.3 a	12.5 a	1.04 b	12.9 c	2.42 a
Rootstock mean	186 A	7.3 A	6.9 A	46.3 B	12.5 A	0.99 A	13.5 B	2.36 A
CV (%)	13.81	4.95	3.88	3.70	4.56	8.99	7.20	6.56
p-value								
Rootstock (R)	0.2272	0.3948	0.1587	< 0.0001	0.0004	< 0.0001	0.0001	0.6071
Scion selection (S)	0.0080	0.0003	0.0007	< 0.0001	0.0020	< 0.0001	< 0.0001	< 0.0001
R × S	0.0475	0.1009	0.0637	< 0.0001	0.0774	0.0002	0.0136	0.0005

Means followed by different capital and lowercase letters in the column, respectively for rootstocks means and within the scion selections means on the same rootstock, belong to distinct groups by the Scott-Knott test ($p \leq 0.05$). *Mean values in 2004 – 2008 of fruits harvested in October in each evaluated year. JY = Juice yield; SS = Soluble solids; TA = Titratable acidity; CV = Coefficient of variation.

Among the low efficient selections (< 4.5 kg·m^{-3}), Dom João produced only 2.6 kg·m^{-3}. On the other hand, this same selection matched that of the most efficient when grafted onto Sunki mandarin. The smallest means for PEf were presented by Temprana and Late Burjasot, because these 2 selections were the largest trees despite having achieved a good production.

Regarding the fruit quality attributes, no effect of the rootstocks was observed for the size of the fruits (Table 3). The fruit weight was equivalent among the selections grafted onto Swingle citrumelo. Dom João had larger fruits on Sunki mandarin, and Late Burjasot presented heavier, longer and wider fruits in relation to the other selections. Concerning JY, the selections grafted onto Swingle citrumelo were superior: Dom João (40%), Valencia Temprana (43%) and the other selections with 52% of juice on average (Table 3). On Sunki mandarin, only Valencia Temprana was inferior to the other selections (mean of 47%).

All the late-season selections presented similar and high concentration of total soluble solids (SS) on Sunki mandarin (mean of 12.5 °Brix) (Table 3). The mean concentration of SS on Swingle citrumelo was also high (11.9 °Brix), even though it was lower in relation to Sunki mandarin in the same period (the harvest took place in October in all years and for all treatments). However, Natal IAC presented higher SS (13.1 °Brix) than the other selections grafted on Swingle citrumelo. Regarding TA, Sunki mandarin led again to a greater mean value (0.99 g·100g^{-1}) than Swingle citrumelo (0.88 g·100g^{-1}), regardless of the scion. Temprana selection confirmed its greater precocity in fruit maturation, since it presented the smallest acidity values on both rootstocks (0.75 g·100g^{-1} on average).

This observation is corroborated by the classification of the selections regarding the SS/TA ratio, as Temprana presented a mean value of 17, which is higher than the mean value of the other selections, regardless of the rootstock (Table 3). Sunki mandarin resulted in a smaller SS/TA ratio compared to Swingle citrumelo, which reflects its greater juice acidity. The latest selections comprised Natal IAC and Campbell which made up the group of the smallest index on Swingle citrumelo, while Campbell, Late Burjasot and Dom João presented the smallest index on Sunki mandarin.

Valencia Temprana resulted in an inferior TI (kg SS·box^{-1}) compared to the other selections that were grafted onto Sunki mandarin, whereas, on the other hand, on Swingle citrumelo, it was observed that Natal IAC was the most efficient (2.78 kg·box^{-1}), followed by the group formed by Valencia IAC, Late Burjasot, Rhode Red and Campbell (2.52 in average) and, finally, Dom João and Temprana (< 2 kg·box^{-1}).

DISCUSSION

The evaluated rootstocks had a substantial and differentiated influence on several traits of the late-season selections (Tables 1 to 3). For Castle (2010), production, precocity, PEf and the fruit quality are among the most important attributes for choosing a rootstock. The results of this work indicate that Sunki mandarin and Swingle citrumelo, the current main alternative rootstocks to Rangpur lime, demonstrated a good performance in rain-fed conditions in Bebedouro, São Paulo, Brazil, when combined with late-season orange varieties. Plants grafted onto Sunki mandarin presented a greater production, precocity and fruits with higher SS and acidity, whereas those on Swingle citrumelo presented a greater PEf, higher juice content and a smaller tree size. These differences between the evaluated rootstocks are of practical and commercial value, because they impact on the planning and management of the orchard, as well as on the economical return for NFC processing.

Castle et al. (2010a), while evaluating Valencia orange on 12 rootstocks in 2 locations in Florida, USA, observed the smallest trees at 5 years old on Swingle citrumelo, ≈ 2.5 m tall, and that Swingle citrumelo outperformed Sunki mandarin in terms of PEf and fruit quality.

Bordignon et al. (2003), while assessing the Valencia orange grafted on different clones and hybrids of CTV-tolerant rootstocks, verified that the Sunki mandarin induced later productions, as opposed to the production observed in this work, in which Sunki mandarin in general induced earlier productions when compared to Swingle citrumelo (Table 2).

In the presence of HLB, bearing precocity is an important trait for rootstock selection as the economical lifespan of the orchard is decreased (Stuchi and Girardi 2010). In this study, some varieties such Natal IAC presented earlier productions and highest yield in the whole evaluation period, thus highlighting their superior performance.

The difference between the HI induced by Swingle citrumelo and Sunki mandarin (Table 2) is possibly a consequence of the distinct degrees to which theses rootstocks are drought tolerant, as the more drought-sensitive Swingle citrumelo led to higher HI. Yildiz et al. (2013) found a greater HI in the Valencia Late (0.28) than in the Rhode Red Valencia (0.18) when grafted onto Troyer and Carrizo citranges (*C. sinensis* × *P. trifoliata*) and sour orange (*C. aurantium* L.), which are similar results to this study.

Castle et al. (2010b) observed a direct relationship between the total production and the height of the sweet orange trees, as observed in this article when considering the greater tree size of the plants grafted onto Sunki mandarin (plus 38% in average). Auler et al. (2008) suggested that Sunki mandarin is a superior alternative to Rangpur lime as rootstock for Valencia orange in the northeast of Paraná state, both for processing and for the fresh fruit market. Indeed, in the current work, the mean scion production on Sunki mandarin was 21% greater.

Although Swingle citrumelo led to smaller canopies and lower accumulated production, in general this rootstock resulted in greater PEf of the scion selections. These results concur with those reported by Pompeu Junior and Blumer (2011), who observed a greater PEf (6.2 kg·m^{-3}) for Valencia orange grafted onto Swingle citrumelo at 7 years old in Cordeirópolis, São Paulo, Brazil.

Although the root system was not evaluated in this work, the canopy growth is in general directly related to the root growth, and thus smaller trees on dwarfing rootstocks are usually more sensitive to drought conditions (Cantuarias-Avilés et al. 2011). Therefore, irrigation must be a plus for smaller trees on less vigorous rootstocks, such as Swingle citrumelo, and higher planting density could be more appropriate for these genotypes. Smaller trees that present high PEf (kg fruit·m^{-3} canopy) are desirable for reducing costs of pruning and harvest labor, especially for high-density orchards (Cantuarias-Avilés et al. 2011), and facilitate diseases and pests control by the application of lower volume of agrochemicals solutions and faster scouting (Stuchi and Girardi 2010).

Regarding to the evaluated sweet orange selections, Dom João, Valencia Late, and Campbell Valencia are typical late ripening Valencia selections described by Hodgson (1967). In Spain, Valencia Temprana has earlier fruit maturation of smaller fruits (Kimball 1991). Dom João, which is of Portuguese origin, is considered the same variety as Valencia. Valencia Late and Campbell Valencia, firstly reported in California, are indistinguishable from Valencia. Valencia Late has fruits ranging from 140 to 180 g, with high juice content, late-season ripening and trees with remarkable production, even though it has a tendency toward alternate bearing (Hodgson 1967), matching perfectly to the performance of this selection in this study (Table 2). Despite the reported similarity, some significant differences were observed among the selections (Tables 1 to 3) and are discussed herein.

Natal IAC, Valencia IAC and Rhode Red selections had greater production and smaller tree size (Tables 1 and 2), thus being more efficient and of greater interest for planting. The Valencia IAC and Rhode Red selections were outstanding on both rootstocks regarding their PEf. Yildiz et al. (2013) verified, for a period of 4 years, that Rhode Red and Valencia Late oranges grafted onto Carrizo citrange presented a similar performance to the one observed in this work for these 2 selections. The results obtained by these authors also point to the importance of the scion-rootstock interaction, given that Rhode Red and Valencia Late grafted onto Carrizo citrange were, respectively, 9 and 19% more productive than when grafted onto Troyer citrange.

Natal, Valencia IAC and Rhode Red Valencia selections, when compared to Temprana and Campbell, formed smaller plants on both rootstocks (Table 1), which suggests a greater inherent vigor for the last ones. Different selections of the same scion variety may present a horticultural performance that varies depending on the rootstock and location, as has already been reported about the Valencia sweet orange (Tazima et al. 2008). The differences among selections of the same variety may also result from spontaneous mutations, from distinct ontogenetic phases or even from the presence of different strains of viruses and viroids (Machado et al. 2005).

Natal IAC was the most productive scion variety on both rootstocks, with higher yield and slightly later fruit maturity than Valencia IAC, confirming its outstanding performance (Pio et al. 2005; Blumer et al. 2003). Although the other evaluated selections presented fair performance, Rhode Red Valencia is highlighted for its higher production efficiency, which was similar to the IAC selections, and fruit quality very close to that of Valencia IAC. This behavior was irrespective of the rootstock, thus presenting practical advantage for recommendation as the remaining selections were more variable and rootstock-dependent especially regarding to the production efficiency and bearing precocity.

Although flesh color was not evaluated in this work, Rhode Red Valencia had visually more deep color, which →

is typical of this variety (Yildiz et al. 2013), and other traits were almost equivalent to those on Valencia IAC (Tables 1 to 3). Rhode Red is described as an indistinguishable bud sport mutant of Valencia with the darker pulp and flesh being the only real advantage over Valencia (UCR 2016).

In this study, the effect of the rootstocks was not expressive on the weight of the Valencias fruits, which was also observed by Bordignon et al. (2003). Yildiz et al. (2013) verified the largest diameters in fruits from the Rhode Red Valencia orange on Carrizo citrange and the smallest diameters for the Valencia Late on the same rootstock. The authors also verified that Valencia Late grafted onto Carrizo citrange produced heavier fruits than onto other combinations, while Rhode Red did not present any differences as a result of the rootstocks. These results were similar to those observed in this article (Table 3). These authors did not report any differences among rootstocks for Rhode Red and Valencia Late regarding the juice content (50% in average) and the TA (1.3 g·100 g^{-1} on average), as well as for Valencia Late for SS (≈ 9 °Brix), which, in turn, differed from the results obtained in this work.

The early fruit maturation was confirmed for Valencia Temprana (Blumer et al. 2003), which presented the lowest juice content and acidity resulting, respectively, in low SS per box and high SS/TA ratio, of 16 – 18, whereas the other selections presented a ratio in the 12 – 15 range in October (Table 3). Other SS/TA differences among true late-season varieties were inherent to the respective selections, as observed by Blumer et al. (2003), with Campbell Valencia being the latest, and were significantly influenced by the rootstock. In this sense, Sunki mandarin induced expressively later fruit maturation to most of the selections.

The juice processing industry is demanding increasingly higher orange fruit quality to attend to the NFC requirements (Neves et al. 2010). Therefore, it is necessary to highlight the high SS of the juice overall (Table 3), as the evaluation period corresponded to the first 5 harvests, thus, to a young orange orchard which is generally recognized for bearing lower quality fruits. In the northeastern region of Paraná state, Tazima et al. (2008) observed fruits belonging to 3 selections of Valencia orange on Rangpur lime with a quality that was inferior to those reported in this analysis.

The rootstocks did not differ as far as the TI of the fruits is concerned (Table 3) and its mean value was of 2.37 kg of SS per box in the evaluation period. This can be explained by the inverse relation between the JY and the concentration of SS that was observed between Swingle citrumelo and Sunki mandarin, respectively. However, Sunki mandarin was more efficient in elevating and equaling the TI of the scion selections in the experimental edafoclimatic conditions.

CONCLUSION

Sunki mandarin and Swingle citrumelo performed well under rain-fed conditions in northern São Paulo state. The first rootstock induced higher tree size, accumulated production, SS content and acidity to most of the late-season selections evaluated.

Natal IAC, Valencia IAC, and Rhode Red Valencia sweet orange selections outstood for their higher production and PEf of high-quality fruits and are the preferable varieties for commercial use.

ACKNOWLEDGEMENTS

With thanks to the São Paulo Research Foundation (FAPESP), for the research funding number 2004/16077-3; to the Center APTA Citros "Sylvio Moreira" of the Agronomic Institute of Campinas, for some of the plant materials; to the EECB, for the experimental area, nursery trees, databases, technical and administrative support; and to Prof. Luiz Carlos Donadio, from School of Agricultural and Veterinarian Sciences/São Paulo State University, for introducing some of the late-season sweet orange selections that were evaluated at the EECB.

REFERENCES

Auler, P. A. M., Fiori-Tutida, A. C. G. and Tazima, Z. H. (2008). Comportamento da laranjeira Valencia sobre seis porta-enxertos no noroeste do Paraná. Revista Brasileira de Fruticultura, 30, 229-234. http://dx.doi.org/10.1590/S0100-29452008000100042.

Barry, G. H., Castle, W. S., Davies, F. S. and Littell, R. C. (2003). Variability in juice quality of 'Valencia' sweet orange and sample size estimation for juice quality experiments. Journal of the American Society for Horticultural Science, 128, 803-808.

Blumer, S., Pompeu Junior, J. and Garcia, V. X. P. (2003). Características de qualidade dos frutos de laranjas de maturação tardia. Laranja, 24, 423-431.

Bordignon, R., Medina Filho, H. P., Siqueira, W. J. and Pio, R. M. (2003). Características da laranjeira Valencia sobre clones e híbridos de porta-enxertos tolerantes à tristeza. Bragantia, 62, 381-395. http://dx.doi.org/10.1590/S0006-87052003000300005.

Cantuarias-Avilés, T. E., Mourão Filho, F. A. A., Stuchi, E. S., Silva, S. R. and Espinoza-Núñez, E. (2011). Horticultural performance of 'Folha Murcha' sweet orange onto twelve rootstocks. Scientia Horticulturae, 129, 259-265. http://dx.doi.org/10.1016/j.scientia.2011.03.039.

Castle, W. S. (2010). A career perspective on citrus rootstocks, their development, and commercialization. HortScience, 45, 11-15.

Castle, W. S., Baldwin, J. C. and Muraro, R. P. (2010a). Performance of Valencia sweet orange trees on 12 rootstocks at two locations and an economic interpretation as a basis for rootstock selection. HortScience, 45, 523-533.

Castle, W. S., Baldwin, J. C. and Muraro, R. P. (2010b). Rootstocks and the performance and economic returns of Hamlin sweet orange trees. HortScience, 45, 875-881.

Corá, J. E., Silva, G. O. and Martins Filho, M. V. (2005). Manejo do solo sob citros. In D. Mattos Junior, J. D. Negri, R. M. Pio and J. Pompeu Junior (Eds.), Citros (p. 347-368). Campinas: Instituto Agronômico; Fundag.

Empresa Brasileira de Pesquisa Agropecuária (1999). Sistema brasileiro de classificação de solos. Brasília: Embrapa.

Fundo de Defesa da Citricultura (2016). Inventário de árvores e estimativa da safra de laranja no cinturão citrícola de São Paulo e Triângulo/Sudoeste mineiro — retrato dos pomares em março/2016. Araraquara: Fundecitrus.

Hodgson, R. W. (1967). Horticultural varieties of citrus. In W. Reuther, L. D. Batchelor, H. J. Webber (Eds.), The citrus industry (v. 1, p. 431-591). Riverside: University of California.

Instituto Brasileiro de Geografia e Estatística (2016). Banco de dados — Estados. Estatística da Produção Agrícola; [accessed 2016 May 15]. http://www.ibge.gov.br/home/estatistica/indicadores/agropecuaria/lspa/estProdAgr_2013.pdf

Kimball, D. A. (1991). Citrus processing: quality control and technology. New York: van Nostrand Reinhold.

Machado, M. A., Cristofani, M., Amaral, A. M. and Oliveira, A. C. (2005). Genética, melhoramento e biotecnologia de citros. In D. Mattos Junior, J. D. Negri, R. M. Pio and J. Pompeu Junior (Eds.), Citros (p. 222-277). Campinas: Instituto Agronômico; Fundag.

Müller, G. W., Negri, J. D., Aguilar-Vildoso, C. I., Mattos Júnior, D., Pompeu Júnior, J., Teófilo Sobrinho, J., Carvalho, S. A., Girotto, L. F. and Machado, M. A. (2002). Morte súbita dos citros: uma nova doença na citricultura brasileira. Laranja, 23, 371-386.

Neves, M. F., Trombin, V. G., Milan, P., Lopes, F. F., Cressoni, F. and Kalaki, R. (2010). O retrato da citricultura brasileira. Ribeirão Preto: Markestrat Centro de Pesquisa e Projetos em Marketing e Estratégias; Universidade de São Paulo.

Nonino, E. (1995). Variedades de laranjas para fabricação de sucos. Laranja, 16, 119-132.

Pearce, S. C. and Doberšek-Urbanc, S. (1967). The measurement of irregularity in growth and cropping. Journal of Horticultural Sciences, 42, 295-305. http://dx.doi.org/10.1080/00221589.1967.11514216.

Pio, R. M., Figueiredo, J. O., Stuchi, E. S. and Cardoso, S. A. B. (2005). Seleções copas. In D. Mattos Junior, J. D. Negri, R. M. Pio and J. Pompeu Junior (Eds.), Citros (p. 39-60). Campinas: Instituto Agronômico; Fundag.

Pompeu Junior, J. (2005). Porta-enxertos. In D. Mattos Junior, J. D. Negri, R. M. Pio and J. Pompeu Junior (Eds.), Citros (p. 63-104). Campinas: Instituto Agronômico; Fundag.

Pompeu Junior, J. and Blumer, S. (2008). Laranjeiras e seus porta-enxertos nos viveiros de mudas cítricas do Estado de São Paulo em 2004-2007. Laranja, 29, 35-50.

Pompeu Junior, J. and Blumer, S. (2011). Citrumelos como porta-enxertos para a laranjeira 'Valencia'. Pesquisa Agropecuária Brasileira, 46, 105-107. http://dx.doi.org/10.1590/S0100-204X2011000100014.

Stuchi, E. S. and Girardi, E. A. (2010). Use of horticultural practices in citriculture to survive Huanglongbing. Cruz das Almas: Embrapa Mandioca e Fruticultura (Documentos, 189).

Tazima, Z. H., Auler, P. A. M., Neves, C. S. V. J., Yada, I. F. U. and Leite, R. P. J. R. (2008). Comportamento de clones de laranja 'Valencia' na região norte do Paraná. Revista

Brasileira de Fruticultura, 30, 970-974. http://dx.doi.org/10.1590/S0100-29452008000400022.

University of California, Riverside (2016). College of Natural and Agricultural, Citrus Variety Collection. Campbell nucellar Valencia orange; [accessed 2016 Oct. 5]. http://www.citrusvariety.ucr.edu/citrus/campbell.html

Yildiz, E., Demirkeser, T. H. and Kaplankiran, M. (2013). Growth, yield, and fruit quality of 'Rhode Red Valencia' and 'Valencia Late' sweet oranges grown on three rootstocks in eastern Mediterranean. Chilean Journal of Agricultural Research, 73, 142-146. http://dx.doi.org/10.4067/S0718-58392013000200009.