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Performance of 'Cadenera' orange trees grafted on five rootstocks

Allan Ricardo Domingues[1], Carmen Silvia Vieira Janeiro Neves[2], Inês Fumiko Ubukata Yada[3], Rui Pereira Leite Junior[4], Zuleide Hissano Tazima[5]

Abstract - Citriculture is an important alternative for the agribusiness development in the state of Paraná, Brazil. However, the use of a few cultivars of scion and rootstock restricts the harvest period and increases the vulnerability to pests and diseases. This study aimed to evaluate the vegetative growth, production and fruit quality of 'Cadenera' orange trees (*Citrus sinensis* (L.) Osbeck) grafted on five rootstocks, during nine harvests, under a subtropical environmental condition. The experimental design was randomized blocks with six replications, two plants per plot, and five rootstocks: 'Rangpur' lime (*C. limonia* Osb.), 'Cleopatra' (*C. reshni* hort. ex Tanaka) and 'Sunki' mandarins (*C. sunki* hort. ex Tanaka (L.) Raf.), 'Swingle' citrumelo [*C. paradisi* Macfad. x *Poncirus trifoliata* (L.) Raf.], and 'C-13' citrange [*C. sinensis* (L.) Osbeck cv. Pera x *P.s trifoliata* (L.) Raf.]. Biometric variables, and fruit yield and quality were analyzed. The smallest canopy size was induced by 'Rangpur' lime and 'C 13' citrange rootstocks. 'Swingle' citrumelo and 'C 13' citrange provided the highest yields for the 'Cadenera' sweet orange trees and were superior to 'Rangpur' lime. Trees grafted on 'C 13' citrange presented the highest yield and productive efficiency.
Index Terms: *Citrus* spp; vegetative growth; postharvest quality; fruit yield.

Comportamento da laranjeira 'Cadenera' sobre cinco porta-enxertos

Resumo- A atividade cítricola é uma importante alternativa para o agronegócio no Estado do Paraná. Entretanto, o uso de poucas cultivares, tanto de copa quanto de porta-enxerto, restringe o período de colheita e aumenta a vulnerabilidade da cultura à ocorrência de pragas e doenças. O objetivo deste estudo foi avaliar o crescimento vegetativo, a produção e a qualidade de frutos da laranjeira 'Cadenera' sobre cinco porta-enxertos, durante nove safras, nas condições edafoclimáticas de Londrina-PR, Brasil. Foi adotado o delineamento experimental em blocos casualizados, com seis repetições, duas plantas úteis por parcela e, como tratamentos, cinco porta-enxertos: limoeiro 'Cravo' (*C. limonia* Osbeck), tangerineiras 'Cleópatra' (*C. reshni* hort. ex Tanaka) e 'Sunki' (*C. sunki* hort. ex Tanaka), citrumeleiro 'Swingle' [*C. paradisi* Macfad. x *Poncirus trifoliata* (L.) Raf.] e citrangeiro 'C 13' [*C. sinensis* (L.) Osbeck cv. Pera x *P.trifoliata* (L.) Raf.]. Foram analisadas variáveis biométricas, de produção e de qualidade dos frutos. O menor porte de copa foi induzido pelos porta-enxertos limoeiro 'Cravo' e citrangeiro 'C 13'. O citrumeleiro 'Swingle' e o citrangeiro 'C 13' proporcionaram às plantas maiores valores de produção acumulada e foram superiores ao limoeiro 'Cravo'. Além disso, as plantas enxertadas sobre citrangeiro 'C 13' apresentaram melhor eficiência produtiva e maior produtividade por hectare.
Termos para indexação: *Citrus* spp; desenvolvimento vegetativo; qualidade pós-colheita; produtividade.

Corresponding author:
allandomingez@hotmail.com

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[1]Agronomist, M.S., Department of Agronomy, State University of Londrina (Universidade Estadual de Londrina–UEL), Londrina-PR, Brazil. Email: allandomingez@hotmail.com
[2]Agronomist, Professor, Ph.D., Department of Agronomy, UEL, Londrina-PR, Brazil. E-mail: csvjneve@uel.br
[3]Mathematician, M.S., Biometrics Sector, IAPAR, Londrina-PR, Brazil. E-mail: inesyada@iapar.br
[4]Researcher, Ph.D., IAPAR, Londrina-PR, Brazil. E-mail: ruileite@iapar.br
[5]Researcher, Ph.D., IAPAR, Londrina-PR, Brazil. E-mail: zuleideh@iapar.br

Introduction

In Brazil, citriculture is an agricultural activity of high economic and social importance. The country is the world leader in orange production, with approximately 16 million tons being harvested in 2016 (IBGE, 2017; FAO, 2016). In addition, citriculture serves as an important alternative for agricultural diversification in Paraná, which ranks fourth in orange production at the national level (after the states of São Paulo, Bahia, and Minas Gerais). Paraná produced more than 800,000 tons in 2016 (IBGE, 2017).

Orange (*Citrus sinensis* (L.) Osbeck) cultivars that grow best in Paraná are 'Pêra', 'IAPAR 73', 'Folha Murcha', 'Valência', 'Navelina', 'Shamouti', 'Salustiana', 'Cadenera' and 'Jaffa' (TAZIMA and LEITE JÚNIOR, 2002; LEITE JÚNIOR, 1992). The varieties most commonly grown in Paraná are 'Pêra', 'Folha Murcha', 'Valência' and 'IAPAR 73' that is cultivated in a smaller area. These varieties mature from the mid-season to the late-season (TAZIMA and LEITE JÚNIOR, 2002; AULER et al., 2014).

The orange 'Cadenera' is originated in Spain where it is commercially produced. The trees are medium to large in size and show high yield, adequate sugar/acidity ratio, and high juice content. The maturation period of this cultivar is intermediate from early- to mid-season, and the fruits are usually harvested in May and June in the northwest and northern regions of Paraná, respectively. This characteristic of fruit maturation allows for the extension of the orange harvest period in these regions (TAZIMA; LEITE JÚNIOR, 2002).

In Paraná, 'Rangpur' lime (*C. limonia* Osbeck) is the most commonly used rootstock for all orange cultivars (AULER et al., 2014). However, the use of a single rootstock may fail to meet the requirements of each variety or region and increases the risk of diseases to the orchards. The effects of rootstock on orange trees may be assessed by factors such as canopy vigor, yield, fruit size and quality, and plant tolerance to pests and diseases (POMPEU JUNIOR et al., 2002; POMPEU JUNIOR et al., 2005).

Studies on the cultivation of 'Cadenera' orange trees in Paraná have been performed by grafting the trees only on 'Rangpur' lime rootstocks (TAZIMA; LEITE JÚNIOR, 2002). Therefore, it is necessary to evaluate new orange scion-rootstock combinations to identify other rootstocks that may enhance the performance of 'Cadenera' cultivars under local conditions. The objective of this study was to evaluate plant development and yield as well as the quality of fruits from the 'Cadenera' orange trees grafted on five rootstocks in the northern region of Paraná.

Material and methods

Experimental location

The experimental orchard was planted at the Londrina Experimental Station of the Agronomic Institute of Paraná –IAPAR, Londrina, Paraná, Brazil (23º21'34" S; 51º09'53" W; 585 m a.s.l), in December 2005. According to the Köppen's classification, the climate is type Cfa, i.e., subtropical humid climate with maximum and minimum averages temperatures of 27 ºC and 16 ºC, respectively, and average annual rainfall is 1626 mm with mean relative humidity of 71% (IAPAR, 2015).

Plant material and cultural practices

Six replications of each treatment were arranged in a completely randomized block design, with two useful trees per plot. The following rootstocks were used as treatments: 'Rangpur' lime (*C. limonia* Osbeck), 'Cleopatra' mandarin (*C. reshni* hort. Tanaka), 'Sunki' mandarin (*C. sunki* hort. Ex Tanaka), 'Swingle' citrumelo (*C. paradisi* Macfad. cv. Duncan x *Poncirus trifoliata* (L.) Raf.), and 'C-13' citrange (*C. sinensis* (L.) Osbeck cv. Pear x *P. trifoliata* (L.) Raf.). The orange scion used was 'Cadenera' (*C. sinensis* (L.) Osbeck). The seeds used for producing rootstocks and the buds used in grafting were obtained from the Active Germplasm Bank of IAPAR. The planting spacing was 7.0 m × 4.0 m. The adopted cultural practices complied with the technical recommendations for orange cultivation in the region (IAPAR, 1992) with the spraying of copper-based products to prevent the occurrence of citrus canker and other diseases and pests. Fertilization for plant development and growth was performed on the basis of the results of soil analysis. Invasive plants were managed with herbicides in crop rows, a brush cutter in inter-rows, and non-irrigation.

Biometric variables

Tree growth parameters, including tree height (H) and canopy diameter (D), were used to calculate canopy volume (V) with the equation $V = 2/3\pi R2H$ (MENDEL, 1956), where R is the canopy radius and H is tree height. Canopy diameter was calculated by making two orthogonal measurements in the middle portion of the canopy using a graduated scale. Tree height was determined by measuring the distance between the soil and the tree top. The ratio of scion trunk circumference to rootstock trunk circumference (at 10 cm above and below the graft union) was measured using a metric tape. Tree growth was evaluated after the fruit harvest in 2010 and 2016.

Production variables

For measuring yield, the fruits from each plot were harvested and weighed using a digital scale. The results were expressed as mass (kg) of fruits per tree in the period from 2008 to 2016. The cumulative yield (fruits per plant) was calculated by summing the annual yields from 2008 to 2016. Furthermore, the yields of the developing orchard (2008-2011 harvest) and adult orchard (2012-2016 harvest) were summed. Yield efficiency (YE) was calculated for the year 2016 using the equation YE (kg/m^3) = fruit yield (kg×tree^{-1}×canopy^{-1})/volume (m^3/tree^1).

For future plantings, the theoretical number of trees per hectare was calculated using the equation E = (D × 0.75) × (D + 2.5), where E is the suitable theoretical spacing and D is the canopy diameter of each scion-rootstock combination. The calculation assumes an overlap of 25% of canopies in each row and 2.5 m of free space between the rows, which comply with the cultural practices for orange orchards (DE NEGRI; BLASCO, 1991). The yield of new plantings was estimated by the theoretical number of trees per hectare and the experimental yield.

Fruit quality

The physicochemical analysis of the fruits was performed using 10 fruits per plot. Fruits were collected from the outside of the plants at 1 to 2 m high. The evaluations were carried out in the month of June of the years 2012, 2014, and 2016. Fruit height and diameter were determined using a digital caliper, with a precision of 0.1 cm (Mitutoyo® IP 67). The fruits were weighed on a digital scale (Filizola® C & F model P15) and the juice was extracted (Croydon® Extractor model ES4EA-B60000). Juice content (JC), expressed as percentage, was determined using the equation JC = (JM/FM) × 100, where JM is the juice mass (g) and FM is the fruit mass (g).

Soluble solids (SS) were determined by direct reading in a refractometer (Atago®), and the results were expressed in °Brix. Titratable acidity (TA) was determined by titrating 25 mL of orange juice with 0.1 N NaOH solution to pH 8.1 using a digital titration unit (Tritoline® easy 220). The results were expressed as percentage (%) of citric acid (AOAC, 1990). The ratio was determined as relationship between SS and TA.

Technological index (TI) or amount of soluble solids in the juice from a box of fruits (40,8 kg), was calculated using the equation TI = (juice content [%] × SS [°Brix] × 40.8 kg)/10000, and the results were expressed in kilogram of SS per box (DI GIORGI et al., 1990). The results of the fruit quality variables were presented as means for the years 2012, 2014, and 2016.

Statistical analysis

All data were subjected to analysis of variance using Sisvar software (FERREIRA, 2000). Mean values of treatments were compared by Scott-Knott test at < 0.05 level.

Results and discussion

Plant development

In the evaluation carried out in 2010, no significant differences were observed in the height of the 'Cadenera' orange trees grafted on the five analyzed rootstocks (Table 1). However, the trees grafted on Rangpur lime rootstocks presented smaller canopy diameter and volume than those grafted on other rootstocks (Table 1). For the evaluations conducted in 2016, the trees grafted on Rangpur lime and 'C-13' citrange rootstocks presented smaller canopy height, diameter, and volume than those grafted on 'Swingle' citrumelo, 'Cleopatra' mandarin, and 'Sunki' mandarin rootstocks (Table 1).

Similar results were observed for Satsuma 'Okitsu' mandarin (*C. unshiu* Marc.) trees grafted on nine different rootstocks under experimental conditions similar to those used in the present study (TAZIMA et al., 2013). Satsuma 'Okitsu' trees grafted on 'Cleopatra' and 'Sunki' mandarin rootstocks and 'Swingle' citrumelo rootstock presented larger canopy volume, diameter, and height than those grafted on 'Rangpur' lime. However, only 'Cleopatra' and 'Sunki' rootstocks were superior to 'C-13' citrange rootstock (TAZIMA et al., 2013).

Rootstocks that produce low-vigor trees identified by the lower sprouting rate and shoot growth may help decrease infections from insects and pests that transmit citrus pathogens, including the psyllid *Diaphorina citri* Kuwayama (Hemiptera: Psyllidae). *D. citri* is the main vector of *Candidatus liberibacter* spp., the causative agent of huanglongbing (HLB), which is known to severely damage the Brazilian citriculture (STUCHI et al., 2012). Smaller plants usually present high YE and are easier to harvest, thereby decreasing the production cost (STUCHI et al., 2012).

The 'Swingle' citrumelo rootstock induced a larger trunk girth below the graft union than that observed with other rootstocks and produced the highest ratio of scion trunk circumference to rootstock trunk circumference in the two evaluations (Table 2). In 2010, the trunk girth above the graft union was larger for the trees grafted on 'Cleopatra' and 'Sunki' mandarin and 'Rangpur' lime rootstocks (Table 2). Moreover, the trees grown on these three rootstocks presented the smallest ratio of scion trunk circumference to rootstock trunk circumference (Table 2).

The 'Okitsu' mandarin trees grafted on 'Swingle' citrumelo and 'C-13' citrange rootstocks presented the largest trunk diameter below the graft union and the highest trunk diameter ratio between below and above the graft union (TAZIMA et al., 2013). The trunk diameter ratio in some scion-rootstock combinations may indicate the incompatibility between the genotypes (CASTLE et al., 1989) and may also be related to the differences in plant vigor.

Table 1. Canopy height, diameter, and volume of "Cadenera" orange trees grafted on five rootstocks in Londrina, Paraná, Brazil, in 2010 and 2016.

Rootstock	Canopy dimensions					
	Height (m)		Diameter (m)		Volume (m^3)	
	2010	2016	2010	2016	2010	2016
'Rangpur' lime	2,5 a[1]	3,3 b	2,3 b	3,8 b	6,7 b	24,8 b
'Cleopatra' mandarin	2,7 a	3,8 a	2,4 a	4,4 a	8,0 a	37,8 a
'Sunki' mandarin	2,7 a	3,9 a	2,5 a	4,1 a	8,9 a	33,7 a
'Swingle' citrumelo	2,7 a	3,9 a	2,4 a	4,2 a	8,4 a	35,8 a
'C 13' citrange	2,6 a	3,5 b	2,6 a	3,9 b	9,1 a	27,5 b
CV (%)	5,53	4,41	5,62	5,08	12,70	10,77

[1]The means followed by the same letters in the column show no statistical difference from one another, as evaluated using the Scott-Knott's test at a level of significance of 5%. CV: coefficient of variation.

Table 2. Trunk circumference below and above the grafting line, and the ratio of the trunk circumference below and above the grafting line the 'Cadenera' orange trees grafted on five rootstocks in Londrina, Paraná, Brazil, in 2010 and 2016.

Rootstock	Trunk circumference (cm)[1]				circumference ratio[2]	
	Below		Above			
	2010	2016	2010	2016	2010	2016
'Rangpur' lime	36,2 b[3]	49,4 c	29,8 a	42,2 b	1,2 b	1,2 c
'Cleopatra' mandarin	35,5 b	57,4 b	30,8 a	47,0 a	1,2 b	1,2 c
'Sunki' mandarin	36,8 b	57,6 b	30,2 a	45,8 a	1,2 b	1,3 c
'Swingle' citrumelo	40,3 a	67,9 a	26,4 b	37,7 c	1,5 a	1,8 a
'C 13' citrange	37,9 b	56,7 b	25,8 b	36,0 c	1,5 a	1,6 b
CV (%)	6,27	4,09	5,55	6,88	4,71	6,29

[1]Trunk circumference measured at 10 cm above and below the graft union.
[2]Ratio of scion trunk circumference to rootstock trunk circumference
[3]The means followed by the same letters in the column show no statistical difference from one another, as evaluated using the Scott-Knott test at a level of significance of 5%. CV: coefficient of variation.

Table 3. Annual yield of the "Cadenera" orange trees grafted on five rootstocks in Londrina, Paraná, Brazil, from 2008 to 2016.

Rootstock	Annual yield (kg/planta)								
	2008	2009	2010	2011	2012	2013	2014	2015	2016
'Rangpur' lime	10,3 a[1]	35,3 a	59,4 a	59,6 b	101,9 a	70,2 b	66,3 b	83,2 b	83,3 b
'Cleopatra' mandarin	4,4 b	26,7 a	59,7 a	54,7 b	103,5 a	103,6 a	105,9 a	109,7 a	108,8 a
'Sunki' mandarin	8,1 a	35,2 a	57,2 a	60,3 b	114,4 a	99,7 a	103,4 a	109,4 a	94,1b
'Swingle' citrumelo	10,9 a	40,6 a	77,3 a	80,1 a	115,6 a	112,2 a	118,3 a	116,7 a	107,4 a
'C 13' citrange	4,5 b	29,7 a	69,1 a	73,3 a	119,8 a	102,8 a	117,3 a	108,3 a	109,5 a
CV (%)	33,39	25,03	25,33	16,75	20,03	16,72	15,49	13,87	14,67

[1]The means followed by the same letters in the column show no statistical difference from one another, as evaluated using the Scott-Knott's test at a level of significance of 5%. CV: coeffient of variantion.

Yield

Among the 2008 harvest, 'Swingle' citrumelo, 'Rangpur' lime, and 'Sunki' mandarin rootstocks provided the highest annual yields for the 'Cadenera' orange trees (Table 3). In the following three harvests, no significant differences were observed in the yield between the rootstocks (Table 3). Among the 2011 harvest, 'Swingle' citrumelo and 'C-13' citrange rootstocks induced higher yields for 'Cadenera' trees than 'Rangpur' lime, 'Sunki' mandarin, and 'Cleopatra' mandarin rootstocks (Table 3). It is known that 'Cleopatra' mandarin rootstock induces a delay in beginning of fruit production as compared to 'Rangpur' lime and 'Swingle' citrumelo rootstocks (POMPER JUNIOR et al., 2005).

From 2013 to 2015, the annual yield of trees grafted on 'Swingle' citrumelo, 'C13' citrange, 'Sunki' mandarin and 'Cleopatra' mandarin rootstocks was higher than that of trees grafted on the 'Rangpur' lime rootstock (Table 3). The yield of trees grafted on 'Swingle' citrumelo and 'C-13' citrange rootstocks was up to 50% higher than that of trees grafted on the 'Rangpur' lime rootstock (Table 3). In 2016, the yield was comparatively higher for orange trees grown on 'C-13' citrange, 'Cleopatra' mandarin and 'Swingle' citrumelo rootstocks (Table 3). A study conducted in Paraná indicated that the cumulative yield was comparatively higher for 'Tahiti' lime (*C. latifolia* ex Tanaka) trees grafted on 'C-13' citrange and 'Rangpur' lime rootstocks (STENZEL et al., 2004). However, 'Cleopatra' mandarin rootstock promoted the highest cumulative yield for 'Folha Murcha' orange trees (*C. sinensis* (L.) Osbeck), outperforming 'Rangpur' lime, 'C-13' citrange, and 'Sunki' mandarin rootstocks (STENZEL et al., 2005b).

The highest cumulative yield during the growth period of citrus trees (first 4 years of harvest) was achieved using 'Swingle' citrumelo and 'C-13' citrange rootstocks (325.3 and 299.4 kg/plant, respectively) (Table 4). In the last 5 years of the study, the cumulative yield was high using all rootstocks except for the 'Rangpur' lime rootstock (Table 4). However, the cumulative yield considering the whole study period was higher for 'Swingle' citrumelo and 'C-13' citrange (779.8 and 737.3 kg/plant, respectively) than for the other rootstocks (Table 4). The cumulative yield was the lowest for the trees grafted on the 'Rangpur' lime rootstock, with differences of up to 30% as compared to the other rootstocks (Table 4). The cumulative yield of 'Okitsu' mandarin trees cultivated in the same site and grafted on the 'Swingle' citrumelo and 'C-13' citrange rootstocks was higher than that of trees grafted on the 'Rangpur' lime rootstock (TAZIMA et al., 2013). Furthermore, the cumulative yield of 'Valência' orange trees grown in the state of São Paulo and grafted on the 'Swingle' citrumelo rootstock was higher than that of trees on the 'Rangpur' lime rootstock (POMPEU JÚNIOR; BLUMER, 2011). Moreover, the mean annual yield of 'Murcott' tangor trees grafted on the Rangpur lime rootstock was lower than that of plants grown on other rootstocks (FIGUEIREDO et al., 2006).

The trees grown on the 'C-13' citrange rootstock showed the highest YE (Table 4). In addition, these trees presented a lower canopy volume (Table 1). But other researchers found the value of YE comparatively higher for 'Monte Parnasso' orange trees grown on 'Rangpur' lime and 'Volkamer' lemon (*C. volkameriana* Pasq.) rootstocks (PETRY et al., 2015).

Rootstocks that promote higher YE and lower canopy volume may serve as good alternatives for dense orchards (STUCHI et al., 2012). This factor is essential for optimizing resources related to the cost of the land and cultural practices and for phytosanitary aspects because highly productive orchards are desirable in the first harvests before the occurrence of diseases.

The analysis of the calculated theoretical spacing revealed that the trees grown on 'Swingle' citrumelo, 'Cleopatra' and 'Sunki' mandarin rootstocks required more spacing between rows and between trees than those grafted on 'Rangpur' lime and 'C-13' citrange rootstocks (Table 5). The highest values were > 550 plants/ha for 'Rangpur' lime and 'C-13' citrange rootstocks (Table 5). In addition, the yield per hectare was higher for trees grafted on the 'C-13' citrange rootstock than those grown on other rootstocks (Table 5).

Fruit quality

The fruit mass (FM) ranged from 147.5 to 170.3 g and was higher for the trees grafted on the 'C-13' citrange rootstock (Table 6). In contrast, the FM value was lower for the trees grafted on 'Rangpur' lime and 'Cleopatra' mandarin rootstocks (Table 6). Similar results were observed for the 'Okitsu' mandarin trees in the same cultivation site, wherein the FM value was lower for the trees grown on 'Rangpur' lime and 'Cleopatra' rootstocks (TAZIMA et al., 2013).

Fruit height ranged from 63.1 to 66.4 mm, while fruit diameter ranged from 65.2 to 68.6 mm (Table 6). Fruit diameter was comparatively high for the orange trees grafted on the 'C-13' citrange, 'Sunki' mandarin, and 'Swingle' citrumelo rootstocks (Table 6). The fruit height-diameter ratio for the trees grown using all rootstocks was close to 1, indicating that the fruit shape was round (Table 6). According to the norms of the classification of fresh citrus, oranges with diameters from 65 to 70 mm are considered as medium-sized fruits (CEAGESP, 2011). Therefore, all the analyzed rootstocks produced fruits with diameters considered adequate for the commercialization of medium-sized fruits *in natura*.

The value of SS was higher (10.6 ºBrix) for fruits from the trees grown on the 'C-13' citrange rootstock than those grafted on 'Cleopatra' and 'Sunki' rootstocks (Table 6). Studies with 'Folha Murcha' orange trees grafted on

six rootstocks in the northern region of Paraná revealed that SS was lower for the fruits from the trees grafted on 'Cleopatra' and 'Sunki' rootstocks (STENZEL et al., 2005a), consistent with the result of our study using 'Cadenera' orange trees. SS content of fruits from the 'Cadenera' orange trees grown on 'Rangpur' lime and 'Swingle' citrumelo rootstocks was intermediate (Table 6). Acidity was lower in the fruits of the plants grafted on 'Rangpur' lime and 'Cleopatra' mandarin rootstocks (0.95% and 0.90%, respectively) than those from the trees grafted on 'Swingle', 'Sunki' and 'C-13' rootstocks (1.0%) (Table 6).

The ratio of SS/TA ranged from 10.2 to 11.2, and the values observed for the trees grafted on 'Rangpur' lime and 'Cleopatra' mandarin rootstocks were significantly higher than those obtained for the trees cultivated on the other rootstocks (Table 6). Furthermore, SS/TA ratios of the fruits from the 'Folha Murcha' orange plant grown on 'Rangpur' lime, 'Cleopatra' mandarin and 'C13' citrange rootstocks were higher than those of the fruits from the trees grafted on the 'Sunki' mandarin rootstock in the northwest region of Paraná (STENZEL et al., 2005b). In contrast, SS/TA ratios for the fruits from the 'Okitsu' mandarin trees grafted on the 'Swingle' or 'Sunki' citrus rootstock were higher than those observed for the fruits from the trees grafted on 'Rangpur' lime, 'Cleopatra' mandarin, and 'C-13' citrange rootstocks (TAZIMA et al., 2013). This discrepancy in these results may be related to differences in the soil and climatic conditions of each region and to scion-rootstock interactions.

No significant differences were observed in the juice content for the fruits of 'Cadenera' orange trees grafted on the five rootstocks (JC ranged from 50, 7% to 53, 2%) (Table 6). In contrast, the juice content was higher for the fruits from 'Folha Murcha' orange plants grown on 'Rangpur' lime and 'Cleopatra' mandarin rootstocks (STENZEL et al., 2005a).

The value of TI was comparatively higher for the fruits from the 'Cadenera' orange trees grafted on 'Rangpur' lime and 'C13' citrus rootstocks, with 2.2 kg of SS per box of 40.8 kg. This value was significantly higher than those for plants grown on 'Swingle' citrumelo and 'Cleopatra' and 'Sunki' mandarin rootstocks (Table 6). Stuchi et al. (2002) and Silva et al. (2013) found no significant differences in the technical indices of the fruits from 'Valência' orange and 'Span Americana' (*C. reticulata* Blanco) mandarin trees grown on different rootstocks, whereas Stenzel et al. (2005b) found that the technical index was higher for the fruits from 'Folha Murcha' orange plants grafted on the 'Sunki' mandarin rootstock. These results highlight the importance of the evaluation of the scion-rootstock combinations for local conditions because of the combined effect of genotype interactions and adaptation to edaphoclimatic conditions.

The results of the quality of 'Cadenera' orange fruits were similar to those reported in another study with this cultivar. Cavalcante et al. (2006) evaluated the characteristics of fruits from 'Cadenera' orange trees grown on the 'Swingle' citrumelo rootstock and obtained the following values: height of 67 mm, diameter of 69 mm, mean mass of 182.9 g, juice content of 46.6%, TI of 2.3 kg SS per box, acidity of 0.94%, and SS/TA ratio of 12.8.

Values considered acceptable for fresh oranges include a juice content of 35-45%, SS of 9-10 °Brix, and SS/TA ratio of 9.5 (CEAGESP, 2011). Considering these parameters, the quality of the fruits from the 'Cadenera' orange trees grafted on the five rootstocks complied with the classification standards for *in natura* fruits.

Table 4. Cumulative yield and yield efficiency (YE) of the 'Cadenera' orange trees grafted on five rootstocks in Londrina, Paraná, Brazil, from 2008 to 2016.

Rootstock	Cumulative yield (kg/tree)			YE (kg m^{-3})[1]
	Partial		Total	
	2008 a 2011	2012 a 2016	(2008 a 2016)	
'Rangpur' lime	266,4 b[2]	302,9 b	569,3 c	3,4 b
'Cleopatra' mandarin	249,1 b	427,9 a	677,0 b	2,9 b
'Sunki' mandarin	275,1 b	406,6 a	681,8 b	2,8 b
'Swingle' citrumelo	325,3 a	454,5 a	779,8 a	2,9 b
'C 13' citrange	299,4 a	437,9 a	737,3 a	4,0 a
CV (%)	11,08	12,5	9,07	8,25

[1]Yield efficiency determined on the basis of the 2016 harvest yield.
[2]The means followed by the same letters in the column show no statistical difference from one another, as evaluated using the Scott-Knott's test at a level of significance of 5%. CV: coefficient of variation.

Table 5. Theoretical spacing between rows and trees, number of trees per hectare, and expected yield of the 'Cadenera' orange trees grafted on five rootstocks in Londrina, Paraná, Brazil, in 2016.

Rootstock	Spacing		Number of trees	Yield
	Between rows (m)	Between trees (m)	(ha^{-1})	($t\ ha^{-1}$)
'Rangpur' lime	6,3 b[1]	2,8 b	582,4 a	47,7 b
'Cleopatra' mandarin	6,9 a	3,3 a	448,2 b	48,9 b
'Sunki' mandarin	6,6 a	3,1 a	497,8 b	47,0 b
'Swingle' citrumelo	6,7 a	3,1 a	486,5 b	51,5 b
'C 13' citrange	6,4 b	2,9 b	551,4 a	60,2 a
CV (%)	4,90	3,01	9,37	14,76

[1]The means followed by the same letters in the column show no statistical difference from one another, as evaluated using the Scott-Knott's test at a level of significance of 5%. CV: coefficient of variation.

Table 6. Mean values of mass, height, diameter, height-diameter ratio, soluble solids (SS), titratable acidity (TA), juice content (JC), and technological index (TI) of the fruits of the 'Cadenera' orange trees grafted on five rootstocks in Londrina, Paraná, Brazil, in 2012, 2014, and 2016.

Rootstock	Physical characteristics of fruits				Chemical characteristics of fruits				
	Mass (g)	Height (mm)	Diameter (mm)	Height-diameter ratio	SS (°Brix)	TA (%)	Ratio (SS/TA)	JC (%)	IT (SS/cx)
'Rangpur' lime	147,5 c[1]	63,1 b	65,2 b	0,97 a	10,3 b	0,95 b	11,0 a	53,2 a	2,2 a
'Cleopatra' mandarin	152,5 c	63,3 b	65,8 b	0,96 a	9,8 c	0,90 b	11,2 a	52,4 a	2,1 b
'Sunki' mandarin	158,5 b	63,9 b	67,3 a	0,98 a	9,8 c	1,0 a	10,2 b	51,5 a	2,1 b
'Swingle' citrumelo	161,5 b	64,8 b	67,5 a	0,96 a	10,2 b	1,0 a	10,2 b	51,2 a	2,1 b
'C 13' citrange	170,3 a	66,4 a	68,6 a	0,97 a	10,6 a	1,0 a	10,5 b	50,7 a	2,2 a
CV (%)	4,82	2,25	1,80	1,49	2,41	3,86	3,41	3,31	4,46

[1]The means followed by the same letters in the column show no statistical difference from one another, as evaluated using the Scott-Knott's test at a level of significance of 5%. CV: coeffient of variantion.

Conclusions

1. The canopy size of the 'Cadenera' orange trees grafted on 'Rangpur' lime and 'C-13' citrange rootstocks was smaller than that of the trees grown on the other analyzed rootstocks. The differences in the canopy diameter had no negative effect on the cumulative yield.

2. The cumulative yield of the trees grafted on 'Swingle' citrumelo and 'C-13' citrange rootstocks was higher than that of the trees grown on the other rootstocks.

3. The values of YE and yield per hectare were comparatively high for the orange plants grafted on the 'C-13' citrange rootstock.

4. On the basis of the experimental conditions and evaluated variables, the 'C-13' citrange rootstock was the most effective rootstock in promoting agronomic performance of the 'Cadenera' orange trees.

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