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Propagation

'Navelina' sweet orange trees on five rootstocks in Northern Parana state, Brazil

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Abstract- Studies on rootstocks and scions are of major importance for citrus crop production. The goal of this study was to evaluate vegetative growth, yield performance, and fruit quality of 'Navelina' sweet orange trees grafted on five different rootstocks in Northern Parana state, Brazil. The experimental design was completely randomized blocks, with six replications, two plants per plot, and five treatments: 'Rangpur' lime; 'Cleopatra' mandarin, 'Sunki' mandarin; 'Swingle' citrumelo; and 'Fepagro C-13' citrange. Tree vegetative growth, yield performance, and fruit physical-chemical characteristics were analyzed. 'Sunki' mandarin provided the largest canopy volume for 'Navelina' sweet orange trees, whereas 'Swingle' citrumelo, 'Fepagro C-13' citrange, and 'Rangpur' lime provided a smaller volume for tree canopy. Compared to Rangpur lime, 'Swingle' citrumelo provided higher accumulated yield and production efficiency for 'Navelina' sweet orange trees. All rootstocks induced good physical and chemical quality to 'Navelina' sweet orange fruits.

Index terms: *Citrus* spp., Vegetative growth, Production, Fruit quality

Plantas de laranja 'Navelina' sobre cinco porta-enxertos na região Norte do Paraná

Resumo- Estudos sobre porta-enxertos e copas têm grande importância para a produção de citros. O objetivo do estudo foi avaliar o crescimento vegetativo, a produção das plantas e a qualidade dos frutos de laranja 'Navelina' enxertada sobre cinco porta-enxertos, na região norte do Paraná, Brasil. O delineamento experimental foi de blocos ao acaso, com seis repetições, duas plantas por parcela e cinco tratamentos: limão 'Cravo'; tangerina 'Cleópatra'; tangerina 'Sunki', citrumelo 'Swingle' e citrange 'Fepagro C-13'. Foram avaliados crescimento vegetativo,desempenho produtivo das plantas e características físico-químicas dos frutos. A tangerina 'Sunki' proporcionou maior volume de copa às plantas de laranja 'Navelina', enquanto o citrumelo 'Swingle', o citrange 'Fepagro C-13' e o limão 'Cravo' proporcionaram menor volume. Comparado ao limão 'Cravo', o citrumelo 'Swingle' proporcionou maior produção acumulada e eficiência produtiva à laranja 'Navelina'. Todos os porta-enxertos avaliados induziram boa qualidade físico-química aos frutos de laranja 'Navelina'.

Termos para indexação: *Citrus* spp. Crescimento vegetativo. Produção. Qualidade do fruto.

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Introduction

Brazil is the major orange producer worldwide, with approximately 18.7 million tons of fresh fruits produced in 2017 (IBGE, 2017). Most of the Brazilian oranges are for processing to produce frozen concentrated orange juice (FCOJ) and not-from-concentrate (NFC) orange juice. Only 30% of the oranges go to the fresh fruit market (NEVES et al., 2010).

Paraná is the fourth largest Brazilian orange producer, with large potential for citrus production in the North and Northwest regions of the State. However, the citrus cultivars to be planted in Paraná need to have a certain level of resistance to citrus canker disease (*Xanthomonas citri* subsp. *citri*), which is one of the major concerns for citrus cultivation in the state (LEITE JUNIOR, 1992; VARGAS et al., 2013). Currently, the recommended sweet orange [*Citrus sinensis* (L.) Osbeck] cultivars for planting are 'Pêra', 'FolhaMurcha', 'Valencia', 'IAPAR-73', 'Natal', 'Navelina', 'Shamouti', 'Salustiana', 'Cadenera', and 'Jaffa' (PARANÁ, 2015; AULER et al., 2014). Among them, 'Navelina' is a seedless navel orange, with excellent fruit quality for the fresh fruit market (SANTOS et al., 2010; TAZIMA; LEITE JUNIOR, 2008). Navelina is also a very early maturing cultivar, making it possible for the fruit to arrive early in the Brazilian market and to obtain excellent marketing prices (TAZIMA; LEITE JUNIOR, 2008).

Fruits for the fresh fruit market must meet some quality standards, including external appearance, such as size, shape, and color, and internal quality characteristics, such as soluble solids, acidity, and vitamin C content. These characteristics are related to several factors, such as the rootstock used, which can influence tree development, productivity, and fruit quality (CASTLE, 1995; CASTLE et al., 2010). Further, the rootstock may also influence several other characteristics of the citrus tree, such as canopy vigor and size, and resistance or tolerance to pests, diseases, and environmental stressors. Therefore, the selection of the most suitable rootstock may allow the cultivar to demonstrate its productive potential (MEDINA et al., 2005; BENJAMIN et al., 2013).

'Rangpur' lime (*Citrus limonia* Osb.) is the most important rootstock for the Brazilian citriculture, because of several reasons, such as tolerance to water stress, compatibility with most canopy cultivars, and good yield induction (OLIVEIRA et al., 2008). However, the susceptibility of this citrus rootstock to some diseases and the need to improve fruit quality has led to new investigations to identify more suitable rootstocks with the goal of diversifying and overcoming the problems encountered in 'Rangpur' lime as a citrus rootstock in Brazil (MOURÃO FILHO et al., 2007).

Studies were conducted to evaluate 'Navelina' sweet orange under the environmental conditions of Paraná State, Brazil, but 'Rangpur' lime was the sole rootstock tested (TAZIMA; LEITE JUNIOR, 2008). Thus, it is important to evaluate 'Navelina' sweet orange tree performance when grafted on other rootstocks to explore its total productive and quality potential under local conditions. The objective of this study was to evaluate the vegetative growth, yield performance, and fruit quality of 'Navelina' sweet orange trees on five different rootstocks in the Northern region of the state of Paraná, Brazil.

Material and methods

The experiment was conducted in Londrina, PR, Brazil, located at 23°21′34″S; 51° 09'53''W at 585 m altitude in a red-yellow Latosol. The climate of the region according to the classification of Koppen is Cfa, subtropical humid, with maximum and minimum mean temperatures of 27.3 °C and 16.1 °C, respectively. The annual rainfall average is 1,635 mm and the relative humidity average is 70.5% (IAPAR, 2016).

The 'Navelina' experimental orchard was planted in December 2005 at a tree spacing of 7.0 m × 4.0 m, with a total of 357 trees per hectare. The experimental design was a completely randomized block with six replications, two trees per plot, and five treatments comprised of the citrus rootstocks: 'Rangpur' lime (*C. limonia* Osb.), 'Cleopatra' mandarin (*C. reshni* hort ex Tanaka), 'Sunki' mandarin (*C. sunki* hort ex Tanaka), 'Swingle' citrumelo [*C. paradise* Macfad. 'Duncan' × *Poncirus trifoliata* (L.) Raf.], and 'Fepagro C-13' citrange [*C. sinensis* × *P. trifoliata* (L.) Raf]. Rootstock seeds and scion propagative material were obtained from the Citrus Active Germplasm Bank of the Agronomic Institute of Paraná – IAPAR, in Londrina, PR, Brazil. The orchard was not irrigated and weed control was performed with an ecological rotary mower. Cultural practices applied followed the recommendations for the Northern region of Paraná state (IAPAR, 1992).

Biometric variables were evaluated for the harvests of 2010 and 2017 and included tree height (m) and canopy diameter (m), both used to determine canopy volume (m^3) according to the equation proposed by Mendel (1956): V =2/3 × π × R^2 × H, in which V = canopy volume (m^3), R = canopy radius, and H= tree height (m). Trunk circumference was determined at 10 cm above and 10 cm below the graft union, and based on these values, the trunk diameter and the ratio between the trunk diameter above and below the graft union were calculated.

Physical and chemical analyses for all treatments were performed in April 2009, 2011, 2012, 2015, 2016, and 2017 and May 2010, 2013, and 2014. Samples of 10 fruits per plot, randomly picked at a tree height of 1.0 to 2.0 m were used to evaluated fruit characteristics based on the average of the period, except for peel color, which was only determined in 2017. Fruit height (H) and diameter

(D) (mm) were measured by direct readings using a digital caliper, with subsequent calculation of the relationship between them (H/D). The fruit mass was determined using a scale with 15 kg capacity and 5 g precision. For fruit peel color, three points in the equatorial region of each fruit was analyzed using a Minolta CR-400 colorimeter, which provided the values of L* (luminosity), a* (red-green), and b* (yellow-blue), and then the hue angle value (°h) was calculated according to McGuire (1992).

Juice yield was calculated based on the relationship between the sampled juice and fruit mass and expressed as a percentage. Soluble solid content (SS) was measured using an Atago® digital refractometer with results expressed in °Brix. Titratable acidity (TA) was obtained by titration of 25 ml of juice with a standard solution of 0.1N NaOH (AOAC, 1990), using phenolphthalein as the indicator. The acidity concentration was expressed as a percentage of citric acid. The ratio of soluble solids content and titratable acidity (SS/TA) indicates the citrus fruit ripening stage.

Fruit yield per tree was determined for the harvests of 2009 through 2017, by using a digital scale, and the results were expressed in fruit mass (kg) per tree. The cumulative fruit yield per tree was determined by the sum of the yields from 2009 to 2017. The cumulative yield of ‘Navelina’ orange trees grafted on ‘Rangpur’ lime was considered the base to determine the relative cumulative yield of the ‘Navelina’ trees on other rootstocks, as ‘Rangpur’ lime is the most used rootstock in Paraná state. Yield efficiency (YE) was calculated for the harvests of 2010 and 2017, by dividing the fruit yield (kg/tree) by the canopy volume (m^3/tree) and the result was expressed in kg m^{-3} of the tree canopy.

The theoretical number of plants per hectare was determined using the equations, E1 = (D + 2.5) and E2 = (D × 0.75), where E1 = theoretical spacing between rows (m), D = canopy diameter for each scion/rootstock combination, and E2 = theoretical spacing between trees (m). The equation assumes 25% of overlaid branches and 2.5 m of the freeway between rows, for the accomplishment of cultural practices and harvest (DE NEGRI; BLASCO, 1991). Yield estimation was calculated based on the theoretical number of trees per hectare and the mean cumulative yield of trees from 6 harvests (2012–2017).

The statistical analyses were performed using the R software, 3.4.3 version (http://www.r-project.org). Data were submitted to variance analysis, and the averages were compared by Tukey’s test at 5% probability.

Results and discussion

‘Navelina’ orange trees grafted on five different rootstocks did not show significant differences in height during the first five years, although the trees on ‘Sunki’ mandarin showed higher growth than those on ‘Fepagro C-13’ citrange, regarding tree diameter and canopy volume (Table 1). At 12 years of age, the citrus trees grafted on the five rootstocks presented significant differences in tree height, diameter, and canopy volume (Table 1). Trees grafted on ‘Sunki’ mandarin presented the highest values for these growth characteristics, followed by those on ‘Cleopatra’ mandarin; however, the ‘Navelina’ orange trees on ‘Cleopatra’ mandarin did not differ from the others (Table 1).

The highest vegetative growth for the citrus trees grafted on ‘Sunki’ and ‘Cleopatra’ mandarins as compared to trees on the other rootstocks has been reported in other studies for different scions, such as ‘Folha Murcha’ (STENZEL et al., 2003, 2005), ‘Jaffa’ (BACAR et al., 2017), and ‘Valencia’ sweet oranges (AULER et al., 2008), as well as ‘Okitsu’ mandarin (TAZIMA et al., 2013, 2014).

The large volume of the citrus trees will certainly require greater spacing between trees and some degree of pruning. This has a disadvantage for modern citriculture, which is moving toward high-tree density by area and smaller trees (AULER et al., 2008). The use of rootstocks, which induce small trees with high yield efficiency allowing for higher planting densities, increases yield per area, thus, facilitating harvest and crop management (POMPEU JUNIOR; BLUMER, 2009). In addition, the lower frequency of shoot growth and high efficiency of fruit yield may also contribute to a decrease in the attack of the Asiatic citrus psyllid *Diaphorina citri*, vector of the bacteria that cause the huanglongbing (HLB) disease, and other citrus pests (STUCHI et al., 2012).

Regarding trunk diameter below the graft union, there was no difference among the rootstocks in the evaluation performed in 2010 (Table 1). However, the trees grafted on ‘Swingle’ citrumelo rootstock differed from the trees grafted on the other rootstocks, having larger trunk diameters below the graft union in the 2017 evaluation (Table 1). Above the graft union, trees on ‘Swingle’ citrumelo and ‘Fepagro C-13’ citrange showed smaller trunk diameters than did the trees on the other rootstocks in both evaluations (Table 1). Regarding the relationship between diameters above and below the graft union, trees on ‘Fepagro C-13’ citrange and ‘Swingle’ citrumelo rootstocks presented the highest values in the 2010 evaluation (Table 1). In 2017, trees on ‘Swingle’ citrumelo presented the highest ratio, followed by those on ‘Fepagro C-13’ citrange, both differing from the other rootstocks (Table 1).

Relationships between diameters above and below the graft union differed from 1 because of differences in the vigor of the scion and the rootstock. The large trunk diameter below the graft union is characteristic of 'Swingle' citrumelo rootstock, which shows high vigor (CASTLE et al., 1988). Similar results were reported by Bacar et al. (2017) and Tazima et al. (2013, 2014) who studied different rootstocks for 'Jaffa' sweet orange and 'Okitsu' mandarin, respectively. They observed larger diameters below the graft union and diameter ratios for the trees grafted on 'Swingle' citrumelo.

The relationship of trunk diameter above and below the graft union may also reflect the degree of compatibility between the scion and the rootstock. Ratios closer to 1 indicate high similarity between the diameters below and above the graft union, and consequently, the compatibility between the scion and the rootstock, as observed for 'Navelina' sweet orange trees grafted on 'Cleopatra' and 'Sunki' mandarins and 'Rangpur' lime rootstocks (TAZIMA et al., 2013).

On the other hand, differences in scion and rootstock diameters may not be an indication of incompatibility, but rather differences in vigor. To clarify this issue, additional examinations of the tree tissues may be required to determine the presence of gum accumulation or necrosis that are characteristic of incompatibility (BARBASSO et al., 2005). The largest difference between scion and rootstock trunk diameters was observed for the trees grafted on 'Swingle' citrumelo. However, these trees did not show any symptoms of incompatibility.

Concerning fruit quality, the fruit mass of 'Navelina' sweet orange fruits ranged from 282.5 to 339.3 g (Table 2). Furthermore, the fruits produced by trees on 'Swingle' citrumelo and 'Fepagro C-13' citrange rootstocks had the largest fruit mass (Table 2). Similar results were reported by Tazima et al. (2013) for 'Okitsu' mandarin, where fruits produced by trees on 'Swingle' citrumelo, 'Fepagro C-13' citrange, and 'Sunki' mandarins showed the highest fruit mass.

Santos et al. (2010) also observed a mass of 308 g for fruits of 'Navelina' sweet orange trees grafted on 'Swingle' citrumelo. On the other hand, Oliveira et al. (2005) noted a mass of 248.6 g for fruits of 'Navelina' sweet orange trees on *P. trifoliata*, whereas Forner-Giner et al. (2003), who evaluated different rootstocks for 'Navelina' orange trees, found fruit masses ranging between 199.5 and 273.0 g. However, Bacar et al. (2017) did not observe differences in fruit mass of 'Jaffa' sweet oranges from trees on the same rootstocks evaluated in the present study.

'Navelina' sweet orange fruit height and diameter ranged from 86.3 up to 94.1 mm and 78.6 up to 85.1 mm, respectively (Table 2). These characteristics had the same trend as that observed for fruit mass, with higher values for the fruits produced by the trees on 'Swingle' citrumelo and 'Fepagro C-13' citrange rootstocks (Table 2). According to Forner-Giner et al. (2003), the best commercial fruit diameters for 'Navelina' sweet orange at the European market ranged from 73 to 96 mm. The fruits produced by 'Navelina' trees grafted on the five different rootstocks are within this range (Table 2).

The height and diameter values of the fruits produced by the 'Navelina' trees on 'Swingle' citrumelo were similar to those observed by Santos et al. (2010) for 'Navelina' fruits on the same rootstock, which were 96 mm in height and 84 mm in diameter. According to the classification for navel oranges by CEAGESP (2011), fruits less than 80 mm in diameter are considered small, from 80 to 90 mm are considered medium, and larger than 90 mm are considered large. Based on our results, fruits from trees grafted on 'Rangpur' lime and 'Cleopatra' mandarin could be classified as small and fruits from the trees on the other rootstocks could be considered medium by the Brazilian classification (Table 2). The international standards for citrus fruits established commercial fruit diameters for 'Navelina' sweet orange ranging from 67 to 76 mm and are smaller than the diameter observed in this experiment for all treatments (OECD, 2010).

Fruits from 'Navelina' sweet orange trees on 'Swingle' citrumelo presented a higher height/diameter ratio, differing significantly from fruits of the trees on 'Rangpur' lime (Table 2). Despite the statistically significant difference, the height/diameter ratio of 'Navelina' sweet orange fruits on the trees on the different rootstocks had little variation, ranging from 1.09 to 1.11 (Table 2). These relationships above 1 indicated that fruit heights were always larger than their diameters, characterizing these fruits as oblong. These results are consistent with the results of Santos et al. (2010), who evaluated seedless citrus fruits and observed oblong fruits with a height/diameter ratio of approximately 1.14 for 'Navelina' sweet oranges from trees grafted on 'Swingle' citrumelo.

There was no significant difference in fruit peel color among the fruits produced by trees on different rootstocks. In all cases, the hue angle values were near 90°, indicating yellow (Table 2). This characteristic is appropriate, especially for fruits exported for the fresh fruit market. Oliveira et al. (2005) at the Rio Grande do Sul state observed a hue angle of 78° for 'Navelina' sweet orange fruits, which indicated an orange coloration. This peel color variation in distinct regions may be caused by climatic conditions because cold climates favor the synthesis of carotenoids, which are responsible for the yellow or orange coloration of the citrus fruits (SANTOS et al., 2010).

The rootstocks did not influence the 'Navelina' fruit TA, and the values ranged from 0.59% to 0.64% (Table 2). However, all rootstocks provided fruits with TA below 1% in agreement with Pereira et al. (2006), who stated that the citric acid values in mature sweet oranges and mandarin fruits should be between 0.5% and 1.0%. Similar results have been shown in other studies of the same citrus cultivar, with citric acid values ranging from 0.53% (SANTOS et al., 2010) to 0.70% (OLIVEIRA et al., 2005).

The SS values ranged from 9.3 to 10 °Brix, and fruits from trees on 'Rangpur' lime, followed by fruits from trees of 'Cleopatra' and 'Sunki' mandarins, had the highest sugar content (Table 2). Santos et al. (2010), evaluating 'Navelina' sweet orange grafted on 'Swingle' citrumelo reported SS of 7.1 °Brix, lower than the 9.4 °Brix found in the present study for the same rootstock (Table 2). In contrast, Oliveira et al. (2005) reported SS up to 11.3 °Brix for 'Navelina' sweet orange on *P. trifoliata*, similar to the value observed in Valencia, Spain (FORNER-GINER et al., 2003), where the SS for 'Navelina' on 14 different rootstocks ranged from 10.4 to 13.2 °Brix.

The highest SS accumulation in fruits of trees grafted on 'Rangpur' lime may have been caused by the earlier fruit maturation influenced by this rootstock. Stenzel et al. (2006) analyzed the maturation curve of 'Folha Murcha' sweet orange fruits on different rootstocks in the same region and observed earlier harvest points of 8 and 15 days for fruits of trees on 'Rangpur' lime compared to those for fruits of trees on 'Cleopatra' and 'Sunki' mandarins, respectively. In this study, only fruits produced by trees on 'Rangpur' lime attained the minimum quality requirements for the fresh market (CEAGESP, 2011), with SS of 10 °Brix (Table 2). Similar results were observed by Stenzel et al. (2005) where only 'Folha Murcha' sweet orange trees grafted on 'Rangpur' lime produced fruits with SS above 10 °Brix.

The SS/AT ratio ranged from 14.8 to 16.8, with the highest values for fruits produced by trees on 'Rangpur' lime and 'Cleopatra' mandarin (Table 2). Trees on all rootstocks produced fruits with SS/AT ratio above 9.5, the minimum required for internal fresh market sweet oranges (CEAGESP, 2011). Brazilian consumers prefer fruits with SS/AT ratio above 14 (COUTO; CANNIATTI-BRAZACA, 2010). Oliveira et al. (2005), who studied seedless citrus fruits, reported results similar to those in our study that 'Navelina' sweet orange fruits had SS/AT ratio of 16.4. On the other hand, Forner-Giner et al. (2003), evaluating 14 rootstocks for 'Navelina' sweet orange, observed lower ratio values, between 7.3 and 12.1. Stenzel et al. (2003) also found higher ratio values induced in 'Ponkan' mandarin by 'Rangpur' lime, which differed from the value induced by 'Fepagro C-13' citrange and was equivalent to the values provided by 'Cleopatra' and 'Sunki' mandarin rootstocks.

For juice yield, 'Swingle' citrumelo rootstock provided superior performance of 46.2% for 'Navelina' (Table 2). However, all rootstocks provided juice yield of 33% and 35%, above the minimum required for navel oranges in the internal and international market, respectively (CEAGESP, 2011; OECD, 2010). Santos et al. (2010) obtained juice yield of 49%, similar to that observed in this study for 'Navelina' orange on 'Swingle' citrumelo. On the other hand, Oliveira et al. (2005) reported higher juice yield of 62.7% for the same cultivar. Forner-Giner et al. (2003) observed a juice yield between 51.1% and 56.4% for 'Navelina' oranges.

'Swingle' citrumelo were among the rootstocks that induced the highest yield per tree during the entire experimental period (Table 3). Despite this, in 2011, 2014, 2016, and 2017, fruit yield among trees on the different rootstocks did not differ statistically (Table 3). Pompeu Junior and Blumer (2011) observed higher yields for 'Valencia' sweet orange trees on 'Swingle' citrumelo and 'Fepagro C-13' citrange compared to 'EEL Rangpur' lime. Tazima et al. (2013) also noticed superior performance for trees on 'Swingle' citrumelo for 'Satsuma Okitsu' mandarin in the same region as in the present study. However, a different performance was observed for the same canopy and rootstocks in the Northwest region of Parana state, Brazil, for 'Satsuma Okitsu' mandarin: trees on 'Rangpur' lime and 'Fepagro C-13' citrange presented higher yields than those on 'Swingle' citrumelo (TAZIMA et al., 2014).

In 2015, there was a decrease in the yield in all treatments because of drought during flowering (IAPAR, 2015). The yield increased in the next 2 years in all treatments, probably because of favorable climatic conditions throughout the rainy seasons, mainly because of regular precipitation among the years.

The trees of 'Navelina' sweet orange on 'Swingle' citrumelo rootstock had the highest cumulative yield, differing from the ones on 'Cleopatra' mandarin and 'Rangpur' lime (Table 3). Similar results were reported by Espinoza-Núñez et al. (2008), who showed that 'Swingle' citrumelo rootstock conferred higher cumulative yield to 'Fairchild' mandarin trees. Pompeu Junior and Blumer (2011) also found that 'Valencia' sweet orange trees on 'Swingle' citrumelo and 'Fepagro C-13' citrange had higher cumulative yields than those on 'EEL Rangpur' lime. On the other hand, 'Rangpur' lime yielded better performance than that of other rootstocks in other studies of sweet oranges and mandarins (STENZEL et al., 2005; TAZIMA et al., 2014).

The highest yield efficiency values were provided by 'Swingle' citrumelo, followed by 'Fepagro C-13' citrange (Table 3). On the contrary, 'Rangpur' lime induced low yield efficiency in both evaluation periods, along with 'Cleopatra' mandarin in the first evaluation (Table 3). The rootstocks with higher yield efficiency also induced a lower canopy volume for Navelina' sweet orange trees (Table 1). This is an extremely important characteristic for modern citrus production, because the reduction in yield per tree may be compensated by the increase in planting density per area (AULER et al., 2008).

The good performance of ‘Swingle’ citrumelo as ‘Navelina’ sweet orange rootstock may also have been influenced by the climatic conditions of the region, where precipitation was well distributed throughout the year and favorable conditions of soil and moisture under which ‘Swingle’ citrumelo show its full potential (BARRY et al., 2004; POMPEU JUNIOR; BLUMER, 2014).

Regarding the theoretical tree space based on the vegetative growth, ‘Navelina’ sweet orange trees on ‘Sunki’ mandarin required larger distance between trees and rows than did trees on ‘Swingle’ citrumelo and ‘Fepagro C-13’ citrange. ‘Swingle’ citrumelo also induced higher yields for the sweet orange trees, differing from the mandarins and ‘Rangpur’ lime (Table 3). Lower yield estimation for trees of sweet oranges and mandarins on ‘Rangpur’ lime rootstock has also been documented previously (BACAR et al., 2017; TAZIMA et al., 2013).

Furthermore, the estimated number of ‘Navelina’ orange trees for 1 ha based on the theoretical spacing was estimated at 409.7 trees for the ‘Swingle’ citrumelo treatment compared to the 350.8 trees per hectare for ‘Sunki’ mandarin (Table 7). Similar results were observed by Tazima et al. (2014) for ‘Okitsu’ mandarin, in which ‘Swingle’ citrumelo presented the highest number of trees per hectare. This result may be related to the genetic origin of this rootstock, because ‘Swingle’ citrumelo present *P. trifoliata* as one parent and this rootstock induces less vigor to citrus tree canopies (POMPEU JUNIOR, 2005).

Overall, ‘Navelina’ sweet orange fruits presented good physical and chemical quality on all evaluated rootstocks. Compared to Rangpur lime, ‘Swingle’ citrumelo rootstock provided higher cumulative yield and yield efficiency to ‘Navelina’ sweet orange trees. Furthermore, ‘Swingle’ citrumelo rootstock required less spacing between rows, allowing 59 more plants per hectare compared to that when using ‘Sunki’ mandarin rootstock, which provided the highest vegetative growth to ‘Navelina’ sweet orange trees.

Table 1. Tree height, canopy diameter and volume, trunk diameter below (TDB) and above (TDA) the graft union, and trunk diameter ratio below/above graft union (TDB/TDA) for ‘Navelina’ sweet orange trees grafted on five different rootstocks in Londrina, Paraná, Brazil, for the 2010 and 2017 seasons.

Vegetative growth	Season	Rootstock[1] ‘Rangpur’ lime	‘Cleopatra’ mandarin	‘Sunki’ mandarin	‘Swingle’ citrumelo	‘Fepagro C-13’citrange	CV (%)
Tree height (m)	2010	2.6 a[1]	2.5 a	2.7 a	2.6 a	2.5 a	6.83
	2017	3.5 b	3.6 ab	3.8 a	3.5 b	3.5 b	4.55
Canopy diameter (m)	2010	2.8 ab	2.7 ab	2.9 a	2.7 ab	2.6 b	5.37
	2017	4.7 b	4.8 ab	5.1 a	4.6 b	4.7 b	4.12
Canopy volume (m)	2010	10.5 ab	9.6 ab	11.9 a	10.2 ab	8.4 b	14.08
	2017	40.6 b	44.8 ab	51.0 a	38.5 b	43.0 b	10.23
TDB* (cm)	2010	11.1 a	10.1 a	11.0 a	11.9 a	11.0 a	9.98
	2017	21.2 c	20.8 c	24.1 b	27.0 a	23.4 b	5.23
TDA* (cm)	2010	9.1 a	8.0 ab	9.1 a	7.8 b	7.2 b	9.08
	2017	16.1 b	16.0 b	17.9 a	13.0 c	12.7 c	4.02
TDB/TDA ratio	2010	1.2 b	1.3 b	1.2 b	1.5 a	1.6 a	10.64
	2017	1.3 c	1.3 c	1.3 c	2.1 a	1.8 b	4.47

[1]Means followed by the same letter in a row do not differ statistically according to Tukey’s test ($p \leq 0.05$). *Diameters determined based on the trunk circumference, 10 cm above and 10 cm below the graft union.

Table 2. Mass, Height (H), diameter (D), H/D ratio , peel color (PC), soluble solids content (SS), titratable acidity (TA), ratio (SS/TA), and juice yield (JY) of ‘Navelina’ sweet orange fruits from trees grafted on five different rootstocks, in Londrina, Paraná, Brazil. Each value is a mean of 9 years (2009 to 2017), except for peel color (2017).

Rootstock	Mass (g)	Height (mm)	Diameter (mm)	H/D ratio	PC** (°*h*)	SS (°Brix)	TA (%)	*Ratio* (SS/AT)	JY (%)
‘Rangpur’ lime	282.5 b[1]	86.3 c	79.4 bc	1.09 b	87.4 a	10.0 a	0.62 a	16.5 a	45.0 ab
‘Cleopatra’ mandarin	284.7 b	86.4 c	78.6 c	1.10 ab	88.0 a	9.6 ab	0.59 a	16.8 a	45.6 ab
‘Sunki’ mandarin	292.4 b	88.7 b	80.6 b	1.10 ab	87.6 a	9.8 ab	0.63 a	15.9 ab	44.7 b
‘Swingle’ citrumelo	330.2 a	94.1 a	84.4 a	1.11 a	87.3 a	9.4 b	0.61 a	15.6 ab	46.2 a
‘Fepagro C-13’ citrange	339.3 a	93.3 a	85.1 a	1.10 ab	88.1 a	9.3 b	0.64 a	14.8 b	45.2 ab
CV (%)	2.28	0.88	1.19	0.95	2.08	2.95	5.54	4.90	1.77

[1]Means followed by the same letter in a column do not differ statistically according to Tukey’s test ($p \leq 0.05$). **Peel color measured only in 2017.

Table 3. Mean annual yields, cumulative and relative yield, yield efficiency, estimated row and tree spacing, number of trees, and yield estimation of ‘Navelina’ sweet orange trees grafted on five different rootstocks from 2009 through 2017, in Londrina, Paraná, Brazil.

Yield and crop planning	Rootstock[1]					
	‘Rangpur’ lime	‘Cleopatra’ mandarin	‘Sunki’ mandarin	‘Swingle’ citrumelo	‘Fepagro C-13’ citrange	CV (%)
Yield in 2009 (kg per tree)	20.5 a[1]	15.9 ab	13.6 ab	22.5 a	10.5 b	33.75
Yield in 2010 (kg per tree)	41.9 ab	35.4 b	49.3 ab	55.8 a	45.7 ab	21.81
Yield in 2011 (kg per tree)	33.0 a	20.4 a	29.8 a	36.4 a	31.5 a	32.09
Yield in 2012 (kg per tree)	51.2 b	43.6 b	56.1 b	76.4 a	61.4 ab	19.39
Yield in 2013 (kg per tree)	47.0 ab	41.2 b	51.9 ab	60.6 a	57.7 a	17.89
Yield in 2014 (kg per tree)	78.2 a	77.5 a	93.4 a	99.6 a	89.3 a	22.31
Yield in 2015 (kg per tree)	34.7 ab	23.0 b	26.5 b	52.9 a	32.6 ab	43.43
Yield in 2016 (kg per tree)	63.9 a	53.8 a	80.5 a	67.8 a	65.9 a	29.39
Yield in 2017 (kg per tree)	121.8 a	153.0 a	167.1 a	175.3 a	187.3 a	23.51
Cumulative yield (kg per tree)	492.2 b[1]	463.8 b	568.1 ab	647.9 a	581.8 ab	15.51
Relative yield (%)	100	94	115	132	118	---
Yield efficiency in 2010 ($kg.m^{-3}$)	4.0 c	3.7 c	4.2 bc	5.5 a	5.4 ab	16.76
Yield efficiency in 2017 ($kg.m^{-3}$)	3.0 c	3.4 bc	3.5 bc	4.9 a	4.4 ab	19.06
Estimated rows spacing (m)	7.3 ab[1]	7.4 ab	7.6 a	7.1 b	7.2 b	2.71
Estimated trees spacing (m)	3.6 ab	3.6 ab	3.8 a	3.5 b	3.5 b	4.12
Number of trees (trees ha^{-1})	391.8 ab	374.5 ab	350.8 b	409.7 a	396.6 ab	7.18

[1]Means followed by the same letter in a row do not differ statistically according to Tukey’s test ($p \leq 0.05$).

Conclusions

All evaluated rootstocks induced adequate physical and chemical quality to ‘Navelina’ sweet orange fruits.

‘Swingle’ citrumelo rootstock was found to be the best alternative for improving ‘Navelina’ sweet orange production in Northern Parana State.

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