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Fruit quality of Tahiti acid lime and Sicilian lemon trees grown on different rootstocks and spacings in the semi-arid region

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Abstract

The objective of this work was to evaluate the fruit quality of Tahiti acid lime and Sicilian lemon trees grown on different rootstocks and planting spacings in the semi-arid region of the state of Minas Gerais, Brazil. Two experiments were conducted, using Tahiti acid lime tree scions (*Citrus latifolia* Tanaka) (1) and Sicilian lemon trees scions [*Citrus limon* (L.) Burm] (2). A randomized block design was used, with a 6×2 factorial arrangement consisted of six rootstocks: Cravo Santa Cruz lemon (*Citrus limonia* Osbeck), Swingle citrumelo [*Citrus paradisi* Macfaden × *Poncirus trifoliata* (L.) Rafinesque], Indio citrandarin and Riverside citrandarin [*Citrus sunki* (Hayata) hort. ex Tanaka × *Poncirus trifoliata* (L.) Rafinesque], Hybrid TSKC × (LCR × TR) - 059 [*Citrus sunki* (Hayata) hort. ex Tanaka × (*Citrus limonia* Osbeck × *Poncirus trifoliata* (L.) Rafinesque)], and Sunki Tropical tangerine [*Citrus sunki* (Hayata) hort. ex Tanaka]; and two planting spacings: 6.0 × 4.0 m and 6.0 × 2.0 m, with three replications and four plants per plot. The physical and chemical characteristics of fruits were evaluated. Most quality characteristics of Tahiti acid lime and Sicilian lemon are not affected by the different rootstocks and spacings used, but the fruits present excellent quality for the national and international markets. Tahiti acid lime plants grown on less vigorous rootstocks under denser spacings have fruits with higher pH, whereas those grown on more vigorous rootstocks have fruits with thicker mesocarps and lower soluble solid contents. The use of Sunki Tropical tangerine rootstock results in bigger Sicilian lemons, however, with lower soluble solid contents, whereas an opposite result is found with the use of Swingle citrumelo rootstocks.

Keywords: *Citrus latifolia*, *Citrus limon*, post-harvest, attributes physical and chemical

Introduction

Lemon and lime crops present wide distributions and economic importance, mainly in tropical and subtropical regions, where edaphoclimatic conditions contribute for their growth. In Brazil, the most common lime is the Tahiti acid lime (*Citrus latifolia*), known as lemon, and the most common lemon is the Sicilian lemon (*Citrus limon*), known as true lemon (Mendonça et al., 2006).

Most orchards of citrus plants In Brazil are from grafted seedlings, combining favorable attributes of scions and rootstocks. However, a small number of scion varieties is used on an even smaller number of rootstocks in these orchards (Carvalho et al., 2016). Lemon and lime crops in Brazil are based almost exclusively (approximately 80%) n the use of grafting on Cravo lemon rootstocks due to their vigor induction, water stress tolerance, resistance to some diseases, and high yields (Bastos et al., 2014; Schäfer et al., 2001).

The rootstock is important for the scion development, affecting more than 20 characteristics, including size, longevity, yield, tolerance to pests and diseases, tolerance to salt, drought, and cold stresses, transpiration, maturation time, fruit quality, and post-harvest conservation (Bastos et al., 2014; Lima et al., 2014).

The use of denser spacings is a practice that has grown considerably in the Brazilian fruticulture (Azevedo et al., 2015). Several studies have been conducted over the last two decades using different fruit trees, including passion fruit, banana, orange, papaya, and mango, presenting promising results (Almeida et al., 2019; Azevedo et al., 2015; Araújo Neto et al., 2005; Rodrigues et al., 2015).

This practice is simple and can generate benefits; it can increase protection against wind and excess radiation, decrease weed emergence, increase water

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use efficiency, and favor an early orchard production without compromising the crop yield (Rodrigues et al., 2015).

The correct use of dense spacings (spaces between plants and interrows), considering the scion, rootstock, soil, and phytosanitary conditions (cultural practices), contributes to the improvement of the production level and fruit quality (Azevedo et al., 2015). Despite of advances in some crop areas in the semi-arid region of Brazil, few studies about citrus plants have been developed, requiring settings for each species, cultivar, and scion-rootstock relation.

In this context, the objective of this work was to evaluate the fruit quality of Tahiti acid lime and Sicilian lemon trees grown on different rootstocks and spacings in the semi-arid region of the state of Minas Gerais, Brazil.

Material and Methods

The fruits used in the experiments were from four-year old plants of an experimental crop in the Dosanko Farm of the Brasnica company, in Jaíba, Minas Gerais (MG), Brazil. The region has a hot and dry climate presenting a cold and dry winter and a hot and wet summer, and mean annual temperature from 23 °C to 25.5 °C (maximum between 32 °C and 35°C, and minimum of approximately 16 °C), high insolation, and mean rainfall depth of 800 mm (Reboita et al., 2015). The chemical and physical analysis of the soil 0-20 cm layer showed the following results: pH = 5.7; organic matter = 2.5 dag kg^{-1}; P = 13.9 mg dm^{-3}; K = 274 mg dm^{-3}; Ca = 4.9 $cmol_c$ dm^{-3}; Mg = 2.1 $cmol_c$ dm^{-3}; Al = 0 $cmol_c$ dm^{-3}; H + Al = 83.1 $cmol_c$ dm^{-3}; sum of bases = 7.74 $cmol_c$ dm^{-3}; effective cation exchange capacity (CEC) = 7.74 $cmol_c$ dm^{-3}; CEC = 10.84 $cmol_c$ dm^{-3}; base saturation = 71%; aluminum saturation = 0%; B =1 mg dm^{-3}; Cu =1.2 mg dm^{-3}; Fe = 17 mg dm^{-3}; Mn = 59.1 mg dm^{-3}; Zn = 3.8 mg dm^{-3}; sand = 17.5%, silt = 7.5%, and clay = 75%.

Two experiments were conducted: the first to evaluate Tahiti acid lime scions (clone CNPMF 01), and the second to evaluate Sicilian lemon tree scions. Each experiment was conducted in a randomized block design with three replications and four plants per plot, using a 6 × 2 factorial arrangement consisting of six rootstocks—Cravo Santa Cruz lemon (*Citrus limonia* Osbeck), Swingle citrumelo [*Citrus paradisi* Macfaden × *Poncirus trifoliata* (L.) Rafinesque], Indio citrandarin and Riverside citrandarin [*Citrus sunki* (Hayata) hort. ex Tanaka × *Poncirus trifoliata* (L.) Rafinesque], Hybrid TSKC × (LCR × TR) - 059 [*Citrus sunki* (Hayata) hort. ex Tanaka × (*Citrus limonia* Osbeck × *Poncirus trifoliata* (L.) Rafinesque)], and Sunki Tropical tangerine [*Citrus sunki* (Hayata) hort. ex Tanaka]—and two spacings (6.0 × 4.0 m and 6.0 × 2.0 m).

The fruits were manually harvested on September 26, 2017 and six fruits per plot were randomly chosen and packaged in transparent plastic bags, which were placed in plastic boxes and taken to the Post-Harvest Physiology Laboratory of the Agricultural Sciences Department of the State University of Montes Claros (UNIMONTES), Janaúba Campus, MG, Brazil.

The following physical and chemical characteristics of fruits were evaluated: diameter, length, peel thickness, mesocarp thickness, fresh weight, firmness, peel color and pulp color (luminosity, hue angle, and chromaticity), juice yield, pH, soluble solid contents, titratable acidity, soluble solid to titratable acidity ratio, and ascorbic acid contents.

A digital caliper (Absolute AOS; Mitutoyo, São Paulo, Brazil) was used to measure: fruit diameter (mm), in the equatorial position; fruit length (mm), from the peduncle to the apex; and thicknesses of peel and mesocarp (mm), on fruits cut in half.

The fruit fresh weight (g) was determined using a semi-analytical balance (S2202H; Bel, Monza, Itália). The fruit firmness was determined using a digital texturometer (Brookfield CT3 10 KG; BrasEq, São Paulo, Brazil). The resistance to penetration (Newton) was measured in the median region of the fruits using a 4 mm diameter tip to penetrate the fruit pulp to a 10 mm depth.

The fruit color was analyzed using a digital colorimeter (Color Flex 45/0 - 2200; HunterLab, Reston, USA) with direct reading of reflectance of the coordinates *L** (luminosity), *a** (red or green hue), and *b** (yellow or blue hue). The *a** and *b** values were used to calculate the hue angle (°*h**) and chroma saturation index (*C**), according to the equations:

$^0h^* = actg\ (a^*/b^*)\ (-1) + 90$ for a* negative

$^0h^* = 90 - (actg\ (a^*/b^*))$ for a* positive

$C^* = \sqrt{}\ (a^*)2 + (b^*)2$

The juice of each fruit was extracted using an electric squeezer (E–10; Mondial, São Paulo, Brazil). The juice yield was obtained by the volume extracted from six fruits and the total weight of these fruits. The fruit pH was determined using a digital bench pH meter (mPA210; MS Tecnopon, São Paulo, Brazil), with reading on 10 mL of homogenized juice diluted into 90 mL of distilled water. Soluble solid contents were determined by refractometry, using a digital bench refractometer (HI96801; Hanna, São Paulo, Brazil), with readings in the range of 0 to 85 °Brix. Titratable acidity was determined by titration, using 10 mL of juice diluted into 90 mL of distilled water, which was titrated using a standardized solution of NaOH at 0.5M, and phenolphthalein as indicator; the result was expressed in grams of citric acid per 100 mL of juice. Soluble solid (SS) to titratable acidity (AT) ratio was obtained through the quotient between SS and AT.

Ascorbic acid (vitamin C) contents were determined through pipetting, using 2 mL of juice, which were transferred to a 250 mL Erlenmeyer containing 50 mL of 1% oxalic acid solution. The solution was titrated using the DCPIP solution (2,6-dichlorophenolindophenol) until the pink color persisted for 15 seconds; the result was expressed in milligrams per 100 g of juice, using the Tillmans solution.

The results of the variables were subjected to the Lilliefors and Bartlett tests to confirm the normality and homogeneity of the data. The data were then subjected to analysis of variance at 5% probability of error. The means with significant differences, due to the sources of variation involved in the experiments, were subjected to the Duncan's test (p<0.05) to evaluate the differences between the treatments. All statistical analyses were performed using the Genes software (Cruz, 2016).

Results and Discussion

The variables peel thickness, *L**, *C**, *h**, and pH of the Tahiti acid lime presented significant interaction between the evaluated factors: rootstocks and planting spacings (Table 1).

Table 1. Mean pH, peel thickness (PT), and color (*L**, *C** and *h**) of Tahiti acid lime grown on different rootstocks and spacings. Janaúba, MG, Brazil, 2018.

	PT (mm)		*L* Peel*		*C* Peel*		*h* Peel*		pH	
Rootstock	6×4	6×2	6×4	6×2	6×4	6×2	6×4	6×2	6×4	6×2
Cravo Santa Cruz Lemon	1.29 Aa	1.24 Aab	47.05 Aa	43.03 Ab	36.79 Aa	31.53 Bc	105.13 Aa	108.16 Aa	2.54 Aa	2.50 Ab
Indio citrandarin	1.25 Aab	1.28 Aab	45.41 Aa	49.46 Aa	34.96 Aa	39.49 Aa	106.02 Aa	104.18 Ab	2.57 Aa	2.48 Bb
Riverside citrandarin	1.24 Aab	1.31 Aa	46.35 Aa	47.09 Aab	36.00 Aa	36.06 Aabc	105.08 Aa	104.77 Aab	2.55 Aa	2.49 Ab
Swingle citrumelo	1.39 Aa	1.18 Babc	47.68 Aa	43.69 Ab	37.03 Aa	32.76 Abc	103.07 Aa	106.39 Aab	2.58 Ba	2.83 Aa
Sunki Tropical Tangerine	1.12 Ab	1.13 Abc	47.36 Aa	47.99 Aab	37.41 Aa	38.01 Aab	104.88 Aa	104.73 Aab	2.53 Ba	2.83 Aa
Hybrid 059	1.29 Aa	1.03 Bc	45.33 Ba	51.62 Aa	34.34 Ba	41.74 Aa	106.87 Aa	102.63 Bb	2.52 Ba	2.76 Aa
Coefficient of variation (%)	7.53		6.07		8.39		1.99		1.51	

Means followed by the same uppercase letters in the rows and lowercase letters in the columns are not statistically different by the Duncan's test at p<0.05.

Considering the rootstocks within the spacings, fruits grown on Swingle citrumelo and Hybrid 059 rootstocks in the 6.0 × 4.0 m spacing had thicker peels, whereas the others had similar peel thickness (Table 1). Sunki Tropical tangerine rootstocks resulted in thinner-peel fruits than the others rootstocks in the 6.0 × 4.0 spacing; the same was found in the 6.0 × 2.0 m spacing, including the Hybrid 059 rootstocks (Table 1). These rootstocks are less vigorous, which explains the lower peel thickness of the fruits. Despite the lower thickness, this characteristic is desired for Tahiti acid lime when focusing on higher juice yields. Studies have indicated that bigger fruits present thinner peels and better juice yields (Duarte et al., 2011). However, thicker-peel fruits are usually more favorable to fresh market because of their longer shelf-life. Application of high rates of nitrogen and potassium fertilizers can increase peel thickness (Castricini et al., 2017).

Considering the rootstocks within the spacings, the luminosity (*L**), chromaticity (*C**) and hue angle (*h**) of fruits from Hybrid 059 rootstocks, and *C** of fruits from Cravo Santa Cruz lemon rootstocks had differences (Table 1). Considering the spacings within rootstocks, the 6.0 × 2.0 m spacing had differences; the fruits from Indio citrandarin and Hybrid 059 presented higher luminosity than those from the Cravo Santa Cruz lemon and Swingle citrumelo rootstocks. Fruits from the Cravo Santa Cruz lemon presented higher hue angle than those of the Indio citrandarin and Hybrid 059 rootstocks.

The luminosity (*L**) represents the color brightness: values close to zero represent dark colors (black), and values close to 100 represent light colors (white) (Pathare et al., 2013); chromaticity (*C**) refers to saturation of pigments responsible for the color vividness; hue angle (*h**) represents the absorbance differences in different wave lengths, which allows the distinguishing of colors with the same luminosity: a *h** of 180° is pure green, and a *h** of 0° is pure red (Pathare et al., 2013). These three characteristics (*L**, *C**, and *h**) were significantly affected by the spacings evaluated, denoting that denser spacings have greater interference with the interception of solar radiation, affecting fruit color characteristics.

The maintenance of the green color of the Tahiti acid lime peel after harvest is desirable, since fruits with total or partial yellow color are less acceptable by consumers and, in the case of exportations, these fruits are not acceptable. The export and internal market standards require fruits with bright olive-green color (Castricini et al., 2017; Jomori et al., 2003). The peel color of fruits changes due to chlorophylls degradation and carotenoid syntheses. These processes can be affected by environmental factors such as temperature, moisture, solar radiation, soil, and rootstock used (Medina et al., 2005). Studies indicate that high temperature with low thermal amplitude characteristic of semi-arid regions can be the main factor for the maintenance of the peel green color (Farias et al., 1993).

Considering the rootstocks within the spacings, the pH of the fruits differed significantly for the Swingle citrumelo, Tangerine Sunki Tropical, and 059 rootstocks (Table 1), which were less vigorous than the others rootstocks. Overall, the denser spacings increased the pH of fruits from these rootstocks (Table 1). Organic acids are the most metabolized cell elements during fruit ripening, decreasing acidity. Therefore, the greater shading between plants in the denser spacings using less vigorous rootstocks probably caused a higher decrease in accumulation of organic acids, as confirmed by the significant increase in pH. In addition to denser spacings and rootstock types, variations in organic acids and pH can be affected by the climate, soil type, and cultural practices (Mendonça et al., 2006). Moreover, pH is a quality attribute not established by legislation, thus, it presents no limit values.

The diameter, length, fresh weight, firmness, pulp luminosity, pulp hue angle, pulp chromaticity, juice yield, and ascorbic acid contents found in the Tahiti acid lime showed no significant differences between treatments, presenting overall means of 56 mm, 59.51 mm, 99.85 g, 46.06 N, 54.68, 99.05, 24.25, 46.67%, and 52.06 mg per 100 g of juice, respectively.

The fruits presented dimensions (length and diameter) within the requirements for fresh fruit market. Fruit sizes of 55 to 70 mm length and 47 to 65 mm diameter are preferred by the fresh fruit market. Regarding the fruit quality, the minimum values for juice percentage and ascorbic acid content are, respectively, 40% and 38.2 mg per 100 g of juice, according to the Brazilian Fruit Classification System (Ceagesp, 2011) and Brazilian Table of Foods Composition (Taco, 2011). In the present study, the Tahiti acid lime presented values above those established in official fruit and food composition and classification tables for both characteristics.

Tahiti acid lime presented thicker mesocarps when grafted on Cravo Santa Cruz lemon rootstocks, compared to Swingle citrumelo, Sunki Tropical tangerine, and Hybrid 059 rootstocks (Table 2). This can be explained by the higher vigor of Cravo Santa Cruz lemon when compared to the others, which probably provided a corresponding vigor to the fruit mesocarp (Carvalho et al., 2016).

The pulp chromaticity differed significantly between rootstocks (Table 2) and was higher for Tahiti acid lime grown on Swingle citrumelo rootstocks. Chromaticity defines the color vividness (when it is close to 60) and the color opacity (when it is close to zero). The lower vigor of Swingle citrumelo rootstocks probably resulted in more compact fruits, which presented higher vividness. However, the data indicated, in general, chromaticity means between 23.03 and 25.91, characterized by less vivid colors.

Table 2. Means for mesocarp thickness (MT), pulp chromaticity (C*), and solid soluble contents (SS) in Tahiti acid lime grown on different rootstocks. Janaúba, MG, Brazil, 2018.

Rootstock	MT (mm)	C* pulp	SS (°Brix)
Cravo Santa Cruz lemon	1.88 a	23.03 b	8.5 c
Indio citrandarin	1.62 ab	24.15 ab	9.58 b
Riverside citrandarin	1.59 ab	23.68 ab	9.25 bc
Swingle citrumelo	1.53 b	25.91 a	10.55 a
Sunki Tropical tangerine	1.51 b	24.09 ab	9.2 bc
Hybrid 059	1.44 b	24.78 ab	9.77 ab
Coefficient of variation (%)	11.13	5.8	4.94

Means followed by same letters in the columns are not different by the Duncan's test at $p<0.05$.

Solid soluble contents of Tahiti acid lime grown on Swingle citrumelo rootstocks were higher than those grown on Cravo Santa Cruz lemon, Indio citrandarin, Riverside citrandarin, and Sunki Tropical tangerine rootstocks, regardless of the spacing (Table 2). Solid soluble content is among the factors that affect the flavor and palatability of citrus fruits and, therefore, should not be ignored as a quality index (González-Molina et al., 2008). The use of Swingle citrumelo rootstocks promotes less vigor in scions, whereas the use Cravo Santa Cruz lemon rootstocks promotes more vigor; this may have affected the solid soluble contents in fruits from less vigorous rootstocks. In addition, the production period (late fruits) and other fruit quality attributes are also affected by the rootstocks.

The spacings significantly affected the mesocarp thickness and titratable acidity of the Tahiti acid lime, with higher values for the 6.0 × 4.0 m spacing (Table 3). Increases in mesocarp thickness and titratable acidity may be related to a higher solar radiation used for the photosynthesis and, consequently, higher accumulation of organic acids and photoassimilates, increasing the fruit mesocarps. Some studies report that bigger fruits present thinner peels, but high juice yield (Duarte et al., 2011).

Table 3. Means for mesocarp thickness (MT), titratable acidity (TA), and solid soluble to titratable acidity ratio (SS/TA) in Tahiti acid lime grown on different spacings. Janaúba, MG, Brazil, 2018.

Spacings	MT	TA*	SS/TA
6 × 4	1.78 a	6.30 a	1.42 b
6 × 2	1.41 b	5.42 b	1.76 a
Coefficient of variation (%)	11.13	10.76	18.43

*g of citric acid per 100 mL of juice; Means followed by same letter in the columns are not different by the Duncan's test at $p<0.05$.

The spacing 6.0 × 2.0 m resulted in fruits with higher solid soluble to titratable acidity ratio (SS/AT) (Table 3). The SS/TA indicates the balance between sugar and organic acid contents and is directly related to the fruit flavor (Almeida & Durigan, 2006). Environmental and physiological factors that affect the metabolism of sugars and acids may affect the SS/TA (Almeida, 2014). Grizotto et al. (2012) found Valencia orange fruits with better quality and higher solid soluble contents and juice yield when using denser spacings.

The interaction between the factors rootstock and spacing was significant for peel thickness, titratable acidity, and SS/TA of Sicilian lemons (Table 4).

Sicilian lemons grown on Riverside citrandarin or Swingle citrumelo rootstocks under spacing of 6.0 × 2.0 m had significantly thicker peels. Considering the effect of spacings within rootstocks, the fruits from Sunki Tropical tangerine rootstocks under spacing of 6.0 × 4.0 m had thicker peels than those from Cravo Santa Cruz lemon, Indio citrandarin, and Swingle citrumelo rootstocks. In the spacing 6.0 × 2.0 m, the Riverside citrandarin rootstocks resulted in thicker-peel fruits than Indio citrandarin rootstocks. It was not possible to find a specific interaction between dense spacings and rootstocks. Some rootstocks resulted in thicker-peel fruits while others resulted in thinner-peel fruits in response to the dense spacing. This is probably due to specific interactions related to compatibility between rootstock and scion genotypes.

Table 4. Means for peel thickness (PT), titratable acidity (TA), and solid soluble to titratable acidity ratio (SS/AT) of Sicilian lemons grown on different rootstocks and spacings. Janaúba, MG, Brazil, 2018.

Rootstock	PT (mm)		TA*		SS/TA	
	6×4	6×2	6×4	6×2	6×4	6×2
Cravo Santa Cruz lemon	1.65 Ab	1.91 Aabc	5.09 Bb	7.99 Aa	1.50 Aa	1.06 Ba
Indio citrandarin	1.68 Ab	1.65 Ac	5.57 Ab	6.47 Aa	1.59 Aa	1.37 Aa
Riverside citrandarin	1.84 Bab	2.22 Aa	5.18 Ab	6.64 Aa	1.61 Aa	1.18 Ba
Swingle citrumelo	1.68 Bb	2.18 Aab	5.61 Ab	6.44 Aa	1.81 Aa	1.41 Aa
Sunki Tropical tangerine	2.08 Aa	1.85 Abc	8.41 Aa	6.70 Ba	0.98 Ab	1.17 Aa
Hybrid 059	1.98 Aab	1.90 Aabc	9.75 Aa	6.95Ba	0.83 Ab	1.27 Aa
Coefficient of variation (%)	9.57		14.81		19.05	

*g of citric acid per 100 mL of juice; Means followed by the same uppercase letters in the rows, and lowercase letters in the columns, are not statistically different by the Duncan's test at $p<0.05$.

Considering the rootstocks within spacings, the less vigorous rootstocks (Sunki Tropical tangerine and Hybrid 059) presented Sicilian lemons with higher titratable acidity when combined with the spacing of 6.0 × 4.0 m. Moreover, the Cravo Santa Cruz lemon rootstocks (more vigorous) resulted in fruits with higher titratable acidity when combined with the denser spacing (6.0 × 2.0 m). Both spacings and some rootstocks resulted in fruits with standard titratable acidity, approximately 7% (Ceagesp, 2011). In addition to increase in fruit size by water absorption with the dilution of acids, decreases in acid concentrations during maturation is also due to increases in respiratory rate caused by increases in air temperature (Almeida, 2014). This denotes the importance of the adequate choice of rootstocks for each dense spacing system and each scion.

Considering the rootstocks within the spacings, fruits from Cravo Santa Cruz lemon and Riverside citrandarin rootstocks using spacing of 6.0 × 2.0 m had lower SS/TA. This was mainly due to increases in titratable acidity and maintenance of solid soluble contents. In the spacing of 6.0 × 4.0 m, Sunki Tropical tangerine and Hybrid 059 rootstocks resulted in fruits with the the lowest SS/TA, which was also affected by the high titratable acidity (Table 5). SS/TA is used to evaluate flavor; it is more representative that isolated measurements of sugars and acidity and indicates the balance between sugar and organic acid contents (Aroucha et al., 2012). Almeida (2014) found SS/TA mean of 1.57 for Sicilian lemons in the Northeast region, which was a similar mean to those found in the present work.

The fresh weight, diameter, mesocarp thickness, firmness, solid soluble contents, and ascorbic acid contents of the Sicilian lemons were significantly affected only by the rootstocks (Table 5). Sicilian lemons from Sunki Tropical tangerine rootstocks presented higher fresh weight, largest diameter, and thicker mesocarp than those from Swingle citrumelo rootstocks (Table 5). This denotes the good interaction between the Sunki Tropical tangerine rootstocks and Sicilian lemon scions for these fruit quality characteristics.

According to the Postharvest Handling Technical

Bulletin (2004), lemons with diameters smaller than 50.0 mm are usually not sufficiently developed and have a lower juice content, which is not suitable to exports. The results of the present study indicated that the lemons reached adequate diameters for exports.

Thick-peel fruits result in lower juice yield. Sandri et al. (2007) showed the importance of peel thickness for the increase of the fruit shelf-life by decreasing water loss and creating a barrier to the entry of pathogens and insects, although it represents losses of eatable parts.

Table 5. Means for diameter (D), fresh weight (FW), mesocarp thickness (MT), firmness, solid soluble contents (SS), and ascorbic acid contents (AA) contents of Sicilian lemons grown on different rootstocks and spacings. Janaúba, MG, Brazil, 2018.

Rootstock	D (mm)	FW (g)	MT (mm)	Firmness (N)	SS (°Brix)	AA
Cravo Santa Cruz lemon	68.96ab	186.97ab	2.20 b	35.46a	7.75b	50.57ab
Indio citrandarin	66.64ab	187.97ab	2.02 b	32.17ab	8.82ab	54.24ab
Riverside citrandarin	70.58ab	218.95ab	2.12 b	30.84 b	7.83b	45.48b
Swingle citrumelo	66.43 b	181.12 b	2.11 b	33.31ab	9.52a	56.92a
Sunki Tropical tangerine	74.32a	245.52a	2.76a	34.46ab	7.9 b	50.14ab
Hybrid 059	72.63ab	233.75ab	2.31ab	30.71b	8.42ab	48.03ab
Coefficient of variation (%)	5.87	15.12	12.63	8.08	9.18	11.56

Means followed by same letter in the columns are not different by the Duncan's test at $p<0.05$.

Cravo Santa Cruz lemon rootstocks, which present higher vigor, generated fruits with higher firmness than the Riverside citrandarin and Hybrid 059 rootstocks (Table 5). Swingle citrumelo rootstocks generated fruits with higher solid soluble contents than the Cravo Santa Cruz lemon, Riverside citrandarin, and Sunki Tropical tangerine rootstocks, and higher ascorbic acid contents than the Riverside citrandarin rootstocks (Table 5).

Solid soluble contents (SS) are predominantly composed of sugars, amino acids, and vitamins that are dissolved in the cell cytoplasm and vacuoles (Almeida, 2014). SS contents depend on the fruit maturation stage at harvesting and usually tend to increase as the fruit develops and ripens due to biosynthesis or degradation of polysaccharides (Duarte et al., 2011). In the present study, the Sicilian lemons from Swingle citrumelo rootstocks were smaller, which may have increased the solid soluble concentrations in these fruits. According to Lima et al. (2014), a high solid soluble content results in more pronounced sweet flavor, and can result in a greater consumption preference.

All Sicilian lemons presented ascorbic acid contents within the standards established by the Brazilian Table of Foods Composition (32.8 to 38.2 mg of per 100 g of juice) (Taco, 2011), regardless of the rootstock and planting density used.

The rootstocks and spacings tested had no significant effect on fruit length, juice yield, luminosity, hue angle, and chromaticity of peel and pulp, and pH, which presented the following overall means, respectively: 89.24 mm, 45.95%, 67.59, 56.57, 81.30, 85.91, 58.91, 24.72, and 2.83.

Conclusions

Most quality characteristics of Tahiti acid lime and Sicilian lemons are not affected by rootstocks and planting spacings; however, they present excellent quality for the Brazilian national and international markets when grown under irrigated conditions in the semi-arid region of Brazil.

The interaction between rootstocks and spacings is significant for fruit peel color of Tahiti acid lime, presenting higher effect when using Hybrid 059 rootstocks and spacing of 6 × 2 m.

Tahiti acid lime scions grown on less vigorous rootstocks and under denser spacings present fruits with higher pH, whereas those grown on more vigorous rootstocks present thicker mesocarp and lower solid soluble contents.

Sicilian lemons from Cravo Santa Cruz lemon rootstocks under spacing of 6 × 2 m and those from Sunki Tropical tangerine or Hybrid 059 rootstocks under spacing of 6 x 4 m present higher acidity.

Sicilian lemons from Sunki Tropical tangerine rootstocks are bigger, but have lower solid soluble contents, whereas Sicilian lemons from on Swingle citrumelo rootstocks are smaller and have higher solid soluble contents.

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