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Physical and chemical characteristics of fruits from different orange canopy/rootstock combinations grown in the brazilian semiarid

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Abstract

The orange tree combination 'Pera' x 'Cravo' lemon has prevailed in the national territory, and new orange rootstock combinations have been developed in citrus breeding programs in order to provide the productive sector with new alternatives. Therefore, the objective of this study was to evaluate the physical and chemical characteristics of fruits from different orange canopy/rootstock combinations grown in the Brazilian semiarid. The experimental design was in randomized blocks in a factorial scheme with three canopy and four rootstock cultivars, with three replications. The orange canopies cultivars used were 'Pera,' 'Natal,' and 'Sincorá', while the rootstock cultivars were 'Santa Cruz' Cravo lemon, the 'Sunki Tropical' tangerine selection, and the citrandarins 'Indio' and 'Riverside'. The results showed that the factors acted independently on fruit mass and diameter, number of seeds, juice yield, peel and pulp lightness, pulp chroma and hue angle, °Brix, and acid contents. However, it was different on peel thickness, peel chroma and hue angle, and SS/TA ratio. It was possible to conclude that the cultivar 'BRS 002–Sincorá' showed the best results for the physical and chemical analyses, while the 'Santa Cruz' Cravo lemon and the 'Sunki Tropical' tangerine selection influenced the best results in the physical and chemical analysis of the canopies, respectively. All combinations resulted in low juice yield.

Keywords: Citrandarins, postharvest, SS/TA ratio

Introduction

Within the diversity presented by the citrus group, oranges are the most important for commercial purposes, figuring as its most cultivated and appreciated fruits, with a worldwide production of 66,974.1 tons in 2016, of which 14,350 tons were produced in Brazil, with 11,180 tons destined for the processing industry (Erpen et al., 2018; FAO, 2017; IBGE, 2019; Kist, 2018), highlighting the country as the largest orange producer in the world. Nationally, the main combination present in citrus orchards consists of the 'Pera' orange canopy and the 'Cravo' lemon rootstock (Bastos et al., 2014). The predominance of this combination has raised concerns regarding phytopathology risks as it may make the crop vulnerable to attacks by pests and diseases and limit the market compared to other countries (Amorim et al., 2018).

Aiming at crop diversification in Brazil, national citrus breeding programs have invested in the obtainment and/or introduction of new cultivars (Medeiros et al., 2013); however, several aspects should be considered in order to introduce them in the market as the selection of the canopy must consider the demands regarding final fruit production, such as fruit color, flavor, size, and juice yield, the latter when destined for the processing industry (Medeiros et al., 2013). When selecting the rootstock, it is essential to consider the proper type of soil, local climate, irrigation availability, disease-tolerant or free material, the ability for reducing plant size and plant cycle, production improvement, and orchard longevity (Albrecht et al., 2019; Continella et al., 2018).

With that, the citrus breeding program developed by Embrapa Cassava and Fruits (Embrapa Mandioca e Fruticultura) has put forward the orange cultivars 'Natal CNPMF 112,' 'Pera D9,' and BRS 002 - 'Sincorá' as canopies aiming at widening the harvest window of orange orchards, favoring juice processing

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through a longer period, and supplying the internal fresh fruit market. As rootstocks, other cultivars such as 'Indio, 'Cravo' lemon and the 'Sunki Tropical' tangerine selection are recommended for showing compatibility with sweet orange, lemon, mandarin, and grapefruit canopies, besides showing adaptability to tropical conditions and resistance or tolerance to diseases such as gummosis and the Citrus Tristeza Virus (Bastos et al., 2014).

Knowing the importance of the diversification of canopy and rootstock cultivars in orange orchards, this study aimed to evaluate the physical and chemical characteristics of orange fruits resulting from different canopy/rootstock combinations grown in the brazilian semiarid region.

Material and Methods

The study was conducted in an experimental area in the municipality of Juazeiro-BA (9° 24" S, 40° 26" W, 365.5 m of elevation) at Embrapa Semiarid. The soil is classified as a Haplic Vertisol with clayey texture. The climate of the study area is classified according to the Köppen classification as BSwh (tropical semiarid), with a rainy season from January to April and mean annual rainfall of 400 mm, mean air temperature of 26.4 °C, and air relative humidity of 62 % (Alvares et al., 2014). Throughout the experiment, the weather conditions were monitored by a weather station installed within the Mandacaru Experimental Field through the mean and maximum air temperatures, air relative humidity (Figure 1), and rainfall data (Figure 2).

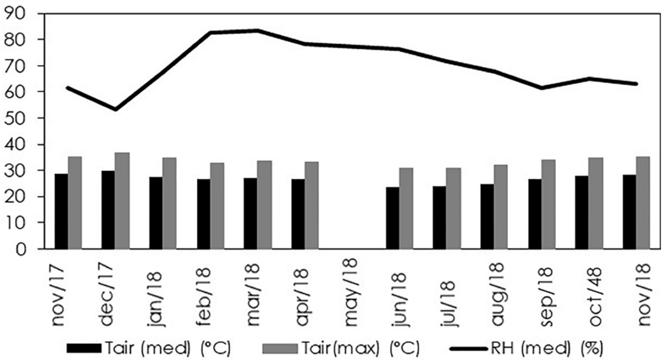

Figure 1. Mean (T_{air} med °C) and maximum air temperatures (T_{air} max °C) and air relative humidity data (RH med %) from November 2017 to November 2018, Embrapa Semiarid, Juazeiro, BA.

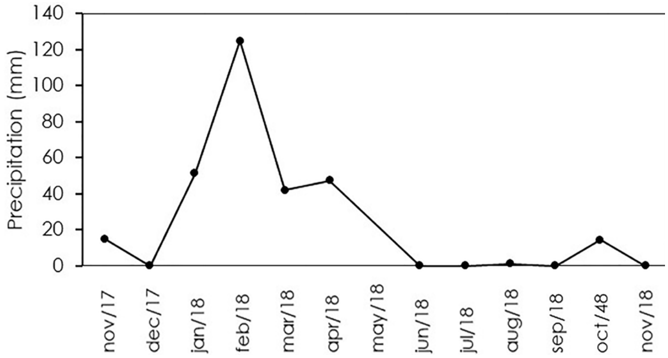

Figure 2. Precipitation (mm) from November 2017 to November 2018, Embrapa Semiarid, Juazeiro, BA.

The canopy cultivars used the 'Pera CNPMF D9,' 'Natal CNPMF 112,' and 'BRS 002 – Sincorá,' all grafted onto the 'Santa Cruz' Cravo lemon (*C. limonia*) (LCR), 'Sunki Tropical' tangerine selection [*C. sunki* (Hayata) hort. ex Tanaka] (SKT), and the citrandarins 'Indio' ['Sunki' mandarin x *Poncirus trifoliata* (L.) Raf. selection 'English' - 256] and 'Riverside' rootstocks ('Sunki' mandarin x *P. trifoliata* selection 'English' - 264), with the combinations being evaluated at five years of age. All fruits from the studied combinations were harvested on the same day regardless of their maturation stage, in November 2018, after eleven months from the beginning of the cycle. Eighteen fruits were collected per treatment, placed in plastic bags, and stored in a cold room (±15 °C) until the evaluation day.

The evaluations were performed in the Post-Harvest Laboratory of Embrapa Semiarid by determining the fruit weight (g), juice weight (g), transverse and longitudinal fruit diameters, peel thickness (mm), and the number of seeds per fruit. Fruit color was analyzed using a colorimeter by employing the CIE L*a*b method, thus allowing to obtain the lightness (L*) and to calculate the chroma (C*) and the hue angle (*h**) through one reading in the peel and through the average of two readings in the pulp (Azeredo et al., 2016). Juice yield was evaluated by the relationship between juice mass and fruit mass [(juice weight/fruit weight) x 100].

The chemical analyses (Azeredo et al., 2016) were performed using the juice from the same fruits used for the physical analyses, extracted with an automatic juice extractor (250 watts). Total soluble solids (SS) in °Brix were determined by direct reading using a portable digital refractometer with automatic temperature compensation and measurement range from 0.0 % to 53.0 % °Brix. Total titratable acidity (TA) in % was determined in 5 mL of juice diluted in 50 mL of distilled water and titrated with a 0.1N NaOH solution using a Titrino Plus® - Metrohm automatic titrator, while the SS/TA was determined as the ratio of soluble solids to titratable acidity. The ascorbic acid content was determined using a 2.6-Dichlorophenolindophenol solution (DPIP) as the titrating agent, expressed as mg/100g using Tillmans' method.

The experimental design was in randomized blocks in a factorial arrangement with three canopy cultivars x four rootstock cultivars, with three replications. The data obtained were subjected to analysis of variance and to the Shapiro-Wilk normality test, and the means were compared by Student's t-test (LSD) at 5 % probability. This analysis was performed using the package Exp.Des 1.2.0 (Ferreira et al., 2018), available in the software R Core Team 3.5.3. (R Core Team, 2019).

Results and Discussion

The physical variables such as fruit mass, transverse diameter, longitudinal diameter, number of seeds, and those related to internal and external fruit color showed independent responses for the canopy and rootstock factors (Table 1). Among canopies, the fruits of the cultivar 'Pera' showed the lowest mass and the lowest transverse diameter (252 g and 75.86 mm, respectively). Regarding the longitudinal diameter, the fruits of the cultivar 'Sincorá' stood out (89.88 mm), also showing the lowest number of seeds (2.26). The 'Cravo' lemon rootstock induced the largest transverse (81.11 mm) and longitudinal fruit diameters (89.18 mm) in all canopies. For the cultivar 'Sincorá,' the fruits showed the highest peel lightness and pulp hue angle values (68.43 and 96.30, respectively). For pulp chroma, the highest mean value was found with the cultivar 'Pera' (22.17). All cultivars showed higher pulp lightness and chroma when grown on the 'Cravo' lemon rootstock (47.08 and 21.41, respectively).

Stuchi et al. (2018), evaluating orange performance, found a fruit mass of 171.86 g and a longitudinal diameter of 66.6 mm for the cultivar 'Pera,' values below those found in the present study, with the same cultivar. The authors also found lower values for fruit mass and transverse and longitudinal fruit diameters for the cultivar 'Natal.' Still, in the present study, similar values to those obtained with the cultivar 'Sincorá' were found for fruit mass and diameters, but with fewer seeds. Even with a different canopy, Cruz et al. (2019) found very similar values for orange canopies grafted onto 'Cravo' lemon rootstock compared to the present study, obtaining 282.5 g of fruit mass, 79.4 mm of transverse fruit diameter, and 86.3 mm of longitudinal diameter. It is highlighted that, in all treatments, the fruits showed large transverse diameters according to the standards by Ceagesp (2011), which classify fruits as large when the diameter is larger than 71 mm.

Close values were found by Couto et al. (2018) for the lightness variable in fruits of the cultivars 'Pera' (57.59) and 'Natal' (58.20). Even with significant statistical differences between the pulp hue angle, the values obtained are above 90, demonstrating that all fruits had an internal yellow coloration. These characteristics followed the same trend observed for the fresh fruit mass and fruit diameters (Table 1), with higher values obtained for the fruits produced in the canopies grafted onto the 'Cravo' lemon rootstock.

Table 1. Fruit weight (FW in g), transverse diameter (TD in mm), longitudinal diameter (LD in mm), number of seeds (N), peel lightness (LC), pulp lightness (LP), pulp chroma (CP), and pulp hue angle (HP) of orange fruits grown on different rootstocks, Embrapa Semiarid, Juazeiro, BA, 2018.

Cultivars	FW (g)	TD (mm)	LD (mm)	Number of seeds	LC (L*)	LP (L*)	CP (C*)	HP (*h**)
				Canopies				
Natal	288a	79.94a	84.63b	3.74a	64.55b	46.15a	20.81b	93.58b
Pera	252b	75.86b	79.52c	3.82a	64.37b	44.96a	22.17a	92.09c
Sincorá	297a	79.80a	89.88a	2.26b	68.43a	44.45a	17.19c	96.30a
P-Value	0.018	0.023	0.000	0.000	0.016	0.263	0.000	0.000
CV (%)	13.27	4.80	5.57	26.41	5.41	5.62	6.67	1.42
				Rootstocks				
Indio	289a	79.79ab	86.31ab	3.68a	63.50a	43.58b	18.84c	93.75a
Cravo lemon	299a	81.11a	89.18a	3.06a	65.63a	47.08a	21.41a	94.22a
Riverside	266a	76.33b	82.01bc	3.17a	67.12a	44.27b	20.47ab	93.32a
Sunki Tropical tangerine	264a	76.90b	81.21c	3.18a	66.88a	45.82ab	19.50bc	94.65a
P-Value	0.149	0.039	0.005	0.442	0.152	0.034	0.003	0.199
CV (%)	13.27	4.80	5.57	26.41	5.41	5.62	6.67	1.42

Means followed by the same lowercase letter in the column do not differ statistically at 5% probability by Student's t-test. Canopies cultivars used: 'Natal,' 'Pera,' and 'Sincorá;' rootstocks cultivars used 'Indio', 'Cravo' lemon- LCR, 'Riverside,' and 'Sunki Tropical' tangerine.

Regarding juice yield and its chemical variables of soluble solids, titratable acidity, and ascorbic acid, the canopy and rootstock factors acted independently (Table 2). Juice yield did not differ between canopies; however, the 'Cravo' lemon rootstock induced the canopies to the lowest yield (28.13 %). Among the canopies, the fruits of the cultivars 'Pera' and 'Sincorá' showed the highest concentration of soluble solids (10.02 and 10.08 °Brix, respectively), with the fruits of the cultivar 'Sincorá' showing the highest titratable acidity (0.546 %). All canopies grafted onto the 'Riverside' and 'Sunki Tropical' tangerine rootstocks stood out in the production of fruits with a higher concentration of soluble solids (10.86 and 10.54 °Brix). The 'Sunki Tropical' tangerine rootstock influenced all canopies to produce fruits with higher titratable acidity (0.539 %).

According to data obtained from Ceagesp (2011) and Hortibrasil (2020), juice yield should be equivalent to 44 % for the cultivar 'Natal' and 45 % for the cultivar 'Pera', values above those found in the present study. The values recommended by these citrus classification standards were determined for the states of São Paulo and Minas Gerais. Citrus production is subjected to continuous and varied biotic and abiotic stress with different intensities, especially the climatic and edaphic conditions (Peixoto et al., 2006). Fruit growth depends on the supply of photosynthesized and accumulated substrate, which is favored by appropriate conditions to high photosynthesis rates, which, for *Citrus sinensis* (L.) Osbeck, occur at air temperatures from 22 °C to 25 °C (Machado et al., 2002). During the study, the mean temperature varied from 23.8 to 29.7 °C, while the maximum temperature reached 36.6 °C, with air relative humidity at 53.3 % (Figure 1) and total rainfall of 295.66 mm (Figure 2), affecting juice yield as high air temperatures and low air relative humidity values favor fruit water loss to the atmosphere, causing granulation. This physiological disorder reduces juice yield due to gel formation in the vesicles (Ritenour et al., 2004), which was observed in the fruits of the present study.

Table 2. Juice yield (%), soluble solids (°Brix), titratable acidity, and ascorbic acid in orange fruits grown on different rootstocks, Embrapa Semiarid, Juazeiro, BA, 2018.

Cultivars	Juice yield %	Soluble solids (°Brix)	Titratable acidity (%)	Ascorbic acid (mg.100 g)
		Canopies		
Natal	31.46a	9.18b	0.372b	57.52a
Pera	38.83a	10.02a	0.418b	59.31a
Sincorá	34.33a	10.08a	0.546a	68.40a
P-Value	0.053	0.026	0.002	0.058
CV (%)	20.11	8.56	23.92	18.12
		Rootstocks		
Indio	35.44a	9.51b	0.377b	62.72a
Cravo lemon	28.13b	8.31c	0.471ab	60.00a
Riverside	38.36a	10.68a	0.395b	63.06a
Sunki Tropical tangerine	37.57a	10.54a	0.539a	61.19a
P-Value	0.021	0.000	0.015	0.932
CV (%)	20.11	8.56	23.92	18.12

Means followed by the same lowercase letter in the column do not differ statistically at 5% probability by Student's t-test. Canopies cultivars used: 'Natal,' 'Pera,' and 'Sincorá;' rootstocks

Regarding quality standards, the fruits of the cultivar 'Natal' were immature (Ceagesp, 2011; Hortibrasil, 2020). This may have occurred because this cultivar shows late maturation compared to the other cultivars used in the study, requiring more time for ripening (Bastos et al., 2014). The highest accumulation of °Brix in the fruits of the canopies grown on the 'Riverside' and 'Sunki Tropical' tangerine rootstocks may have caused early fruit ripening, influenced by these rootstocks (Bastos et al., 2014; Cruz et al., 2019). Titratable acidity is another chemical characteristic regarding fruit quality with importance for market acceptance, which should range from 0.5 % to 1 % (Bastos et al., 2014). The present study showed values well below the recommended and verified in the literature for all canopies, with 0.94 % for the cultivar 'Pera,' 0.9 % for 'Natal,' and 1.16 % for 'Sincorá.' The 'Sunki Tropical' tangerine rootstock was the one that most influenced all studied canopies, although with a value lower than the reported by Auler et al. (2008). The treatments did not influence ascorbic acid, and unlike this study, Couto et al. (2018) found lower values for this variable, while Lemos et al. (2012) also found lower concentrations of ascorbic acid in fruits of the orange cultivar 'Pera' (31.98 mg/100 g).

There was interaction between the canopy and rootstock factors regarding physical and chemical variables such as peel thickness, pulp chroma, pulp hue angle, and the ratio of soluble solids to titratable acidity (Tables 3 and 4). The combinations that showed the lowest peel thickness values were 'Natal' x 'Cravo' lemon, 'Pera' x 'Cravo' lemon, 'Pera' x 'Sunki Tropical' tangerine, 'Sincorá' x 'Indio,' and 'Sincorá' x 'Riverside' (4.07, 4.59, 3.40, 4.38, and 4.10 mm, respectively). Among the physical aspects, peel thickness (Table 3) should be lower in order to facilitate fruit peeling (Bastos et al., 2014). A similar value was found for the combination 'Pera' x 'Cravo' lemon by Lemos et al. (2012).

Regarding peel chroma (Table 3), a variable that shows the color intensity of the peel, the combinations 'Natal' x 'Sunki Tropical' tangerine (65.90), 'Pera' x 'Riverside' (67.96), 'Pera' x 'Sunki Tropical' tangerine (68.49), and 'Sincorá' x 'Cravo' lemon (80.22) are highlighted. In turn, the highest peel hue angle values (Table 4) were found with the combinations 'Natal' x 'Indio' (107.92), 'Natal' x 'Cravo' lemon (104.93), 'Pera' x 'Indio' (109.50), 'Sincorá' x 'Indio' (96.91), and 'Sincorá' x 'Sunki Tropical' tangerine (103.99). Hue angles above 100 indicate that the fruit peels contain a greenish-yellow color, while the remaining combinations in the present study showed a yellow-colored peel.

The SS/TA values (Table 4) did not differ across rootstocks for the 'Natal' scion, while for the 'Pera' and 'Sincorá' canopies, the highest SS/TA ratio was found with the 'Riverside' rootstock (32.90 and 27.28, respectively). The SS/TA ratio is expressed by the balance between these components in the juice in order to balance the flavor, which may be more or less acid depending on the producing region and/or the characteristics of the cultivar (Couto & Canniatti, 2010).

Table 3. Peel thickness (mm), peel chroma (C*), peel hue angle (*h**), and ratio of soluble solids to titratable acidity (SS/TA) of orange fruits grown on different rootstocks, Embrapa Semiarid, Juazeiro, BA, 2018.

Rootstocks	Canopies		
	Natal	Pera	Sincorá
	Peel thickness (mm)		
Indio	4.92Aa	3.99Aa	4.38Ab
Cravo lemon	4.07Ba	4.59Ba	5.77Aa
Riverside	4.93Aa	4.21Aa	4.10Ab
Sunki Tropical tangerine	4.16ABa	3.40Ba	4.94Aab
P-Value		0.043	
CV (%)		15.08	
	Peel chroma (C*)		
Indio	48.11Ac	48.20Ab	57.18Ab
Cravo lemon	49.54Cbc	63.43Ba	80.22Aa
Riverside	62.81Aab	67.96Aa	65.14Ab
Sunki Tropical tangerine	65.90Aa	68.49Aa	56.49Ab
P-Value		0.010	
CV (%)		13.08	

Means followed by the same lowercase letter in the column do not differ statistically at 5% probability by Student's t-test. Canopies cultivars used: 'Natal,' 'Pera,' and 'Sincorá;' rootstocks cultivars used 'Indio', 'Cravo' lemon- LCR, 'Riverside,' and 'Sunki Tropical' tangerine.

Table 4. Peel hue angle (*h**) and ratio of soluble solids to titratable acidity (SS/TA) of orange fruits grown on different rootstocks, Embrapa Semiarid, Juazeiro, BA, 2018.

	Peel hue angle (*h**)		
Indio	107.92Aa	109.50Aa	96.91Aa
Cravo lemon	104.93Aa	83.33Bb	80.48Bb
Riverside	89.09Ab	84.61Ab	92.55Aab
Sunki Tropical tangerine	87.21Bb	86.52Bb	103.99Aa
P-Value		0.011	
CV (%)		9.63	
	SS/TA		
Indio	25.74Aa	26.76Aab	24.29Aab
Cravo lemon	21.88Aa	22.55Ab	13.26Ac
Riverside	23.60Aa	32.90Aa	27.28Aa
Sunki Tropical tangerine	30.54Aa	18.99Bb	18.41Bbc
P-Value		0.041	
CV (%)		21.33	

Means followed by the same lowercase letter in the column do not differ statistically at 5% probability by Student's t-test. Canopies cultivars used: 'Natal,' 'Pera,' and 'Sincorá;' rootstocks cultivars used 'Indio', 'Cravo' lemon- LCR, 'Riverside,' and 'Sunki Tropical' tangerine.

The minimum SS/TA ratio required for the internal market is 9.5 (Ceagesp, 2011; Hortibrasil, 2020). In turn, the SS/TA ratio should be around 14 for juice processing (Bastos et al., 2014). However, a high ratio was found in the present study (13.26 to 32.90), which was provided by the low contents of titratable acidity, common for orange fruits produced in tropical regions, where the high temperatures promote the degradation of acids (Beber et al., 2018).

Conclusions

Regardless of the rootstocks, the 'Sincorá' scion showed the best physical and chemical fruit characteristics, while the rootstock cultivars that better influenced the fruits of the canopy cultivars were 'Cravo' lemon, for the physical analyses, and 'Sunki Tropical' tangerine, for the chemical analyses. All canopy and rootstock combinations met the market demands except for juice yield, showing new possibilities for citrus farming, both regarding its diversification and expansion to semiarid regions.

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