PAB
Pesquisa Agropecuária Brasileira

ISSN 1678-3921

Journal homepage: www.embrapa.br/pab

For manuscript submission and journal contents, access: www.scielo.br/pab

Pomology/ Original Article

Performance of 'Jaffa' sweet orange on different rootstocks for orchards in the Brazilian Northeast

Abstract – The objective of this work was to evaluate the effect of nine rootstocks on 'Jaffa' sweet orange (*Citrus sinensis*) for its vegetative, productive, and qualitative traits, and for its susceptibility to three pest mites (*Eutetranychus banksi*, *Tetranychus mexicanus* and *Phyllocoptruta oleivora*). The following parameters were evaluated: vegetative growth, yield, physiochemical characteristics of fruit, and density of pest mites. 'Sunki Tropical' mandarin conferred high cumulative yields whereas 'Orlando' tangelo and 'Rugoso Vermelho' lemon imparted bigger fruit with low brix, and less acidity to 'Jaffa'. Indio and 'Riverside' citrandarins induced more acid fruit of smaller sizes, as well as low-cumulated yields and canopy volumes. Also, the 'Cravo Santa Cruz' lime, 'San Diego' citrandarin, and the hybrids HTR-051 and LVK x LCR-010 conferred lower-cumulated yields to 'Jaffa'. The rootstocks did not influence the population levels of the evaluated mites. 'Sunki Tropical' mandarin, 'Cravo Santa Cruz' lime and 'Rugoso Vermelho' lemon stand up as excellent rootstock options for 'Jaffa' sweet orange in the Northeastern Brazil.

Index terms: *Citrus sinensis,* juice content, yield, phytophagous mites.

Desempenho da laranjeira 'Jaffa' em diferentes porta-enxertos para pomares do nordeste Brasileiro

Resumo – O objetivo deste trabalho foi avaliar o efeito de nove porta-enxertos sobre os parâmetros vegetativos, produtivos e qualitativos da laranjeira-doce 'Jaffa' (*Citrus sinensis*) e sobre a sua suscetibilidade a três ácaros-praga (*Eutetranychus banksi*, *Tetranychus mexicanus* e *Phyllocoptruta oleivora*). Os seguintes parâmetros foram avaliados: crescimento vegetativo, produtividade, características fisioquímicas dos frutos e densidade de ácaros-praga. A tangerineira 'Sunki Tropical' conferiu elevada produtividade à laranjeira 'Jaffa', enquanto o tangeleiro 'Orlando' e o limoeiro 'Rugoso Vermelho' induziram frutos maiores, com baixos valores Brix e menos ácidos à laranjeira 'Jaffa'. Os citrandarins 'Indio' e 'Riverside' induziram frutos mais ácidos e de tamanhos menores, assim como baixa produtividade acumulada e menor copa. Adicionalmente, o limoeiro 'Cravo Santa Cruz', o citrandarin 'San Diego' e os híbridos HTR-051 e LVK x LCR–010 conferiram menor produção acumulada à laranjeira 'Jaffa'. Os porta-enxertos não influenciaram os níveis populacionais dos ácaros avaliados. A tangerineira 'Sunki Tropical', o limoeiro 'Cravo Santa Cruz' e o limoeiro 'Rugoso Vermelho' se destacam como excelentes opções de porta-enxertos para a laranjeira 'Jaffa' na região Nordeste do Brasil.

Termos para indexação: *Citrus sinensis,* conteúdo de suco, produtividade, ácaros fitófagos.

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Received
October 15, 2018

Accepted
November 6, 2019

How to cite
TEODORO, A.V.; CARVALHO, H.W.L. de; BARROS, I. de; CARVALHO, L.M. de; MARTINS, C.R.; SOARES FILHO, W. dos S.; GIRARDI, E.A.; PASSOS, O.S. Performance of 'Jaffa' sweet orange on different rootstocks for orchards in the Brazilian Northeast. **Pesquisa Agropecuária Brasileira**, v.55, e01665, 2020. DOI: https://doi.org/10.1590/S1678-3921.pab2020.v55.01665.

Introduction

Brazil ranks first in the production of sweet orange in the world, and Brazilian Southeast and Northeast are the main producing regions (IBGE, 2016). In Northeastern Brazil, the majority of orchards cultivate 'Pera' sweet orange [*Citrus sinensis* (L.) Osbeck] grafted on 'Rangpur' lime (*C. limonia* Osbeck) because of fruit with good quality and drought tolerance imparted from the rootstock (Almeida & Passos, 2011). However, such a narrow genetic diversity could lead to losses caused by biotic and abiotic stresses, threatening the whole citrus chain in this region (Carvalho et al., 2019). Accordingly, Embrapa (Brazilian Agricultural Research Corporation) begun field trials to select new scion-rootstock combinations for rainfed citrus groves of the Brazilian Northeast, which resulted in the indication of some cultivars (Carvalho et al., 2016a, 2016b, 2019).

'Jaffa' orange originates from Israel, where it is the most cultivated scion cultivar (Ishfaq et al., 1999). It is characterized by medium-sized plants, with open branches, satisfactory yields, tendency to production alternation, precocious maturation, and fruit suited for both in natura consumption and juice production (Bacar et al., 2017).

Some pests, among which the Texas citrus mite *Eutetranychus banksi* and the tetranychid *Tetranychus mexicanus* (Acari: Tetranychidae), as well as the rust mite *Phyllocoptruta oleivora* (Acari: Eriophyidae) attack citrus orchards in Northeastern Brazil (Teodoro et al., 2014; Silva et al., 2016). While *E. banksi* and *T. mexicanus* feed upon leaves of citrus trees, *P. oleivora* is a fruit-attacking pest that leads to reduced yield and aesthetic damage to the fruit that is similar to rust (Teodoro et al., 2014). Therefore, assessing the influence of rootstocks on the susceptibility of scions to pests is highly recommended, as cultivars show distinct genetic characteristics (Vendramim & Guzzo, 2012; Silva et al., 2016). For instance, densities of *P. oleivora* and *T. mexicanus* on 'Pera CNPMF D-6' and 'Valencia Tuxpan' sweet oranges were influenced by some rootstocks (Silva et al., 2016).

The objective of this work was to evaluate nine rootstocks on the vegetative, productive, and qualitative traits of 'Jaffa' sweet orange, as well as on the susceptibility of this cultivar to three pest mites.

Materials and Methods

The experimental orchard was installed in 2008 in an Argissolo Amarelo distrófico (Santos et al., 2013), i.e., a Haplic Acrisol, at the experimental station of Embrapa, located in the municipality of Umbaúba (11°22'37"S, 37°40'26"W, at 109 m altitude), in the state of Sergipe, Brazil. Chemical analyses (0–40 cm soil depth) showed the following soil characteristics: 5.04 pH (H_2O), 12.79 g kg^{-1} OM, 2.66 $mmol_c$ dm^{-3} aluminum, 25.49 $mmol_c$ dm^{-3} calcium, 2.85 $mmol_c$ dm^{-3} magnesium, 45.19 mg dm^{-3} phosphorus, 81.25 mg dm^{-3} potassium, 6.16 mg dm^{-3} sodium, 56.91 mg dm^{-3} iron, copper 0.14 mg dm^{-3}, 1.43 mg dm^{-3} manganese, and 0.36 mg dm^{-3} zinc. The climate is classified as rainy tropical with a dry summer according to the Köppen-Geiger's classification. Average annual temperature, relative humidity, and rainfall over the experimental period (2008–2016) were 24.6°C, 83%, and 1,274 mm, respectively.

The experiment consisted of 'Jaffa' sweet orange grafted on nine rootstocks, as follows: 'Cravo Santa Cruz' lime (whose common name is Rangpur lime), 'Rugoso Vermelho' lemon (*C. jambhiri* Lush.), 'Orlando' tangelo (*C. paradisi* Macfad. x *C. tangerina* hort. ex Tanaka), 'Sunki Tropical' mandarin [*C. sunki* (Hayata) hort. ex Tanaka], 'Indio, 'Riverside', and 'San Diego' citrandarins [*C. sunki* x *Poncirus trifoliata* (L.) Raf.]), and the hybrids HTR-051 (trifoliate hybrid obtained by using *P. trifoliata*) and LVK x LCR-010 [*C. volkameriana* V. Ten. & Pasq. x 'Rangpur' lime], which were generated in the breeding program of Embrapa Mandioca e Fruticultura. Plant spacing were 6.0 m x 4.0 m (416 plants ha^{-1}) and conventionally managed without irrigation. Management practices included fertilization, control of diseases and weeds, as well as pruning. No control for mites was performed. The experiment consisted of a completely randomized block design, with 9 treatments (rootstocks), 4 replicates, and 4 plants per plot.

Plant height (PH), canopy volume (CV), rootstock/scion girth ratio (R/S), and yield efficiency (YE) were measured in 2016, as follows: PH (m) was recorded by using a ruler from the base of the trunk close to the soil up to the top of the plant; CV (m^3) was estimated using the expression $CV = (\pi/6) \times PH \times DR \times DP$, in which DR and DP are canopy diameters (m) along the row, and in the perpendicular direction to the row, respectively (Cantuarias-Avilés et al., 2012); yields and cumulative yields (CY, in kg ha^{-1}) were evaluated over 6 years (2011 to 2016), while yield efficiency (YE, in kg m^{-3}) was estimated by the quotient between the per plant fruit production and CV.

Fruit quality was assessed over 2 years (2014 and 2015) by collecting six fruits per plant (Carvalho et al., 2016a). Briefly, height, rind thickness (mm) and diameter of fruits were measured with a digital caliper (Carvalho et al., 2016a). Juice content was estimated with the equation JC = [(juice mass / sample mass) × 100] (Carvalho et al., 2019). Juice mass was obtained by the difference between sample weight and bagasse mass (that is, seeds, peels, and fragments retained in the sieve) (Carvalho et al., 2016a). Total soluble solids (TSS in ºBrix) were recorded with a digital refractometer with values corrected to 20°C (Carvalho et al., 2016a). Titratable acidity (TA, g citric acid 100 mL^{-1} juice) was determined with a semiautomatic burette with 0.1 mol L^{-1} NaOH (titrant) and a phenolphthalein indicator. The ratio was determined as the quotient between TSS and TA (Carvalho et al., 2016a). The content of vitamin C (mg 100 mL^{-1} of juice) was calculated using the oxidation-reduction volumetric technique, using 0.002 mol L^{-1} potassium iodate (KIO_3) and 1% starch indicator solutions (Carvalho et al., 2016a). Industrial yield was determined with the equation IY = 660/TI, in which TI (technological index) was obtained as juice content x TSS × 40.8/10.000, which is equivalent to the amount of TSS in the juice (kg) in a standard 40.8 kg industrial box of citrus (Carvalho et al., 2016a). Data were subjected to the analysis of variance, followed by Scott-Knott's tests, at 5% probability.

Multivariate analyses were also performed using XLSTAT (a statistical software for Excel) to identify homogenous groups of rootstocks, considering the universe of all variables that were significant by univariate analysis of variance. At first, a principal component analysis (PCA) was conducted to reduce the dataset into a few synthetic and uncorrelated variables, that is, the first principal components (Carvalho et al., 2019). Then, the rootstocks were grouped by agglomerative hierarchical clustering (AHC) applied on the PCA scores, using the Euclidean distance as a measure of dissimilarity and Ward's minimum-variance method for linkage to identify the clusters (Carvalho et al., 2019). The automatic truncation option was used for cluster splitting. This approach creates homogenous groups based on the largest decrease in the Shannon's entropy between a node and the next one (Carvalho et al., 2019). The resulting clusters were interpreted by means of the PCA results and put into perspective with the results of univariate analyses of variance.

The effect of rootstocks on the population levels of three regional pests of citrus, namely *E. banksi*, *T. mexicanus*, and *P. oleivora* was assessed. The number of adults of these mites were monthly recorded from June 2011 to February 2013 (counts of some months were excluded from the analyses as they were null to all rootstocks). In short, *E. banksi* and *T. mexicanus* were recorded in four randomly chosen leaves from two plants per plot, totaling 32 leaves per rootstock in each monthly evaluation. For *P. oleivora*, two randomly-chosen fruit taken from two plants per plot were evaluated, totaling 16 fruit per rootstock in each evaluation, and mites were counted in 1 cm^2 area. Repeated measures of the analyses of variation, followed by the post hoc Fisher's LSD tests, were carried out to evaluate the effect of rootstocks on the population levels of the pest mites, removing the variance explained by time, as evaluations were conducted monthly. Data were $\sqrt{(x)} + 0.5$ transformed. in order to adjust them for normal distribution (Silva et al., 2016).

Results and discussion

Rootstocks did not influence the height of 'Jaffa' sweet orange plants, in contrast with the highest-canopy volumes conferred by 'Sunki Tropical' mandarin, 'Rugoso Vermelho' lemon and the hybrid LVK x LCR-010 (Table 1). However, rootstocks did not affect the yield efficiency which considers the yield per volume of canopy.

'Riverside' citrandarin and LVK x LCR-010 induced precocity to 'Jaffa', as yields surpassed 9,500 kg ha^{-1} in the first harvest. 'Sunki Tropical' mandarin was related to higher yields throughout harvests and higher cumulative yields, followed by 'Cravo Santa Cruz' lime and 'Rugoso Vermelho' lemon. These results are in line a previous research of our group in the same region, showing that these rootstocks were also recommended for 'Pera CNPMF-D6' sweet orange and 'Piemonte' mandarin [*C. clementina* hort. ex Tanaka x tangor 'Murcott' (*C. reticulata* Blanco x *C. sinensis*)] (Carvalho et al., 2016a, 2016b).

Except for rind thickness and vitamin C, the rootstocks influenced all qualitative parameters of 'Jaffa' fruit (Table 2). For instance, fruit from trees grafted on HTR–051 yielded less juice, whereas

'Cravo Santa Cruz' lime induced the highest levels of total soluble solids, but the lowest industrial yield to fruit (Table 2). These results are in agreement with the literature, showing the influence of rootstocks on fruit physiochemical parameters (Carvalho et al., 2016a; Bacar et al., 2017). For instance, 'Cleopatra' (*C. reshni* hort ex Tanaka) and 'Sunki' mandarins, 'Fepagro C-13' citrange (*C. sinensis* x *P. trifoliata*), and 'Swingle' citrumelo induced sweeter fruit to 'Jaffa' than 'Rangpur' lime, in the Brazilian state of Paraná (Bacar et al., 2017).

Values of TA, a proxy for acidity, ranged from 0.86 ('Orlando' tangelo, least acid) to 1.05 ('Indio' citrandarin, most acid), and were similar to those found in Syria for 'Jaffa' (Al-Mouei & Choumane, 2014), and are within the acceptable limits for oranges (Bacar et al., 2017). Concerning TSS, values ranged from 9.99 °Brix ('Orlando' tangelo, least sweet) to 12.21 °Brix ('Cravo Santa Cruz' lime, most sweet), which are higher than those obtained by Bacar et al. (2017) for 'Jaffa' grafted on five rootstocks, in Paraná state, including 'Rangpur' lime (TSS = 9.10) and 'Sunki' mandarin (TSS = 9.46). Such differences may be related to the mean air temperatures during the production period, which is pivotal to form sugars during fruit ripening. Ratio values varied from 10.89 ('Indio' citrandarin) to 12.54 ('Cravo Santa Cruz' lime) and met acceptable standards for oranges (Ceagesp, 2011; Bacar et al., 2017).

'Cravo Santa Cruz' lime, 'Riverside' and 'Indio' citrandarins, 'Sunki Tropical' mandarin, and LVK x

Table 1. Plant height (PH), canopy volume (CV), rootstock/scion girth ratio (R/S), yield efficiency (YE), yield, and on the cumulative yield (CY) of 'Jaffa' sweet orange in relation to rootstocks[(1)].

Rootstocks	PH	CV	R/S	Yield (kg ha^{-1})							CY	YE
	(m)	(m³)		2011	2012	2013	2014	2015	2016	2017	(kg ha^{-1})	(kg m^{-3})
Cravo Santa Cruz lime	2.56	12.59b	1.58	8,072b	13,416a	13,498a	20,571a	43,169c	34,338b	12,739a	145,802b	6.79
Rugoso Vermelho lemon	2.86	16.13a	1.41	6,365c	11,879a	11,010b	17,942a	47,878b	35,547b	14,708a	145,328b	5.30
Orlando tangelo	2.73	13.46b	1.31	7,500d	7,614b	6,700c	9,591c	52,478a	25,736d	7,515c	110,383d	4.86
Sunki Tropical mandarin	3.19	17.15a	1.49	7,857b	13,745a	12,740a	17,456a	56,121a	38,861a	8,184c	157,965a	5.60
Indio citrandarin	2.65	12.44b	1.75	8,483b	9,254b	12,483a	16,031a	34,851d	24,651d	5,937c	111,689d	5.27
Riverside citrandarin	2.74	12.39b	1.48	10,784a	9,696b	10,123b	15,131b	31,432d	24,806d	8,016c	109,988d	4.93
San Diego citrandarin	2.41	10.21b	1.65	6,872c	8,384b	13,170a	19,111a	34,986d	21,324e	10,187b	114,034d	5.20
HTR - 051	2.40	9.75b	1.42	6,352c	5,732c	10,380b	13,928b	20,649e	20,003e	10,339b	87,383e	5.16
LVK x LCR - 010	2.79	14.26a	1.33	9,533a	15,519a	12,545a	17,732a	40,970c	30,999c	7,297c	134,593c	5.40
Means	2.70	13.15	1.49	7230	10.582	11.405	16.388	40.281	28.474	9.436	114.360	5.39
CV (%)	12.52	21.51	15.64	17.10	15.81	8.29	11.59	7.88	8.24	21.17	10.58	24.58
F	2.04^{ns}	3.00*	1.57^{ns}	21.02*	14.96*	20.54*	11.66*	49.06*	32.45*	8.04*	65.77*	0.74^{ns}

[(1)]Means followed by equal letters do not differ, by Scott-Knot's tests, at 5% probability. ^{ns}Nonsignificant. *Significant at 5% probability.

Table 2. Diameter (FD), height (FH), and rind thickness (RT) of fruit, juice content (JC), titratable acidity (TA), total soluble solids (TSS), vitamin C, technological index (TI), industrial yield (IY), and ratio of 'Jaffa' sweet orange in relation to rootstocks. Averages for 2014, 2015, and 2016 harvests[(1)].

Rootstocks	FD (mm)	Fruit height (mm)	RT (mm)	JC (%)	TA (%)	TSS (ºBrix)	Vitamin C (mg.L^{-1})	TI (kg SST.cx^{-1})	IY	Ratio TSS/TA
Cravo Santa Cruz lime	68.44b	44.47b	3.72	50.63a	0.99a	12.21a	57.59	2.52a	261.90a	12.54a
Rugoso Vermelho lemon	74.40a	70.37a	3.93	50.77a	0.92b	10.54c	54.37	2.18b	302.75b	11.73b
Orlando tangelo	73.65a	70.48a	3.56	51.83a	0.86c	9.99c	54.36	2.11b	312.79b	11.86b
Sunki Tropical mandarin	71.11a	67.92b	3.59	50.34a	0.95b	11.13b	54.19	2.28a	289.47b	11.80b
Indio citrandarin	68.63b	67.56b	3.42	50.36a	1.05a	11.38b	53.12	2.33a	283.26b	10.89c
Riverside citrandarin	71.95a	69.52a	3.50	51.40a	1.02a	10.96b	52.94	2.29a	288.20b	11.09c
San Diego citrandarin	70.99a	68.70b	3.68	48.64a	1.01a	11.06b	52.56	2.19b	301.36b	11.20c
HTR-051	71.94a	70.29a	3.89	44.19b	1.02a	11.51b	50.86	2.07b	318.84b	11.61b
LVK x LCR-010	72.10a	68.82b	3.59	52.12a	0.97a	11.01b	56.06	2.34a	282.05b	11.43c
Means	71.58	68.90	3.65	50.03	0.98	11.09	54.01	2.25	308.84	11.57
CV (%)	5.35	4.64	11.78	9.28	8.81	8.24	10.06	11.36	15.80	7.29
F	3.26*	2.30*	1.87^{ns}	3.25*	5.76*	5.49*	1.59^{ns}	3.24*	3.21*	4.10*

[(1)]Means followed by equal letters do not differ, by Scott-Knot's tests, at 5% probability. ^{ns}Nonsignificant. *Significant at 5% probability.

LCR-010 imparted higher TI values to 'Jaffa' than the remaining rootstocks. The average TI for all rootstocks was 2.25 kg TSS per box, which was higher than that obtained by Bacar et al. (2017).

Variables that were significant by the univariate analyses of variance and used for the multivariate analysis were: canopy volume (CV) and cumulative yield (CY, 2011-2017) for vegetative and productive performance and fruit diameter (FD); fruit height (FH); juice content (JC); titratable acidity (TA); total soluble solids (TSS); TSS/box; industrial yield (IY); and TSS/TA ratio (ratio) for fruit quality. About 75% of the total variability could be explained by the first two PCA axes (Figure 1), and the square cosine of the variables

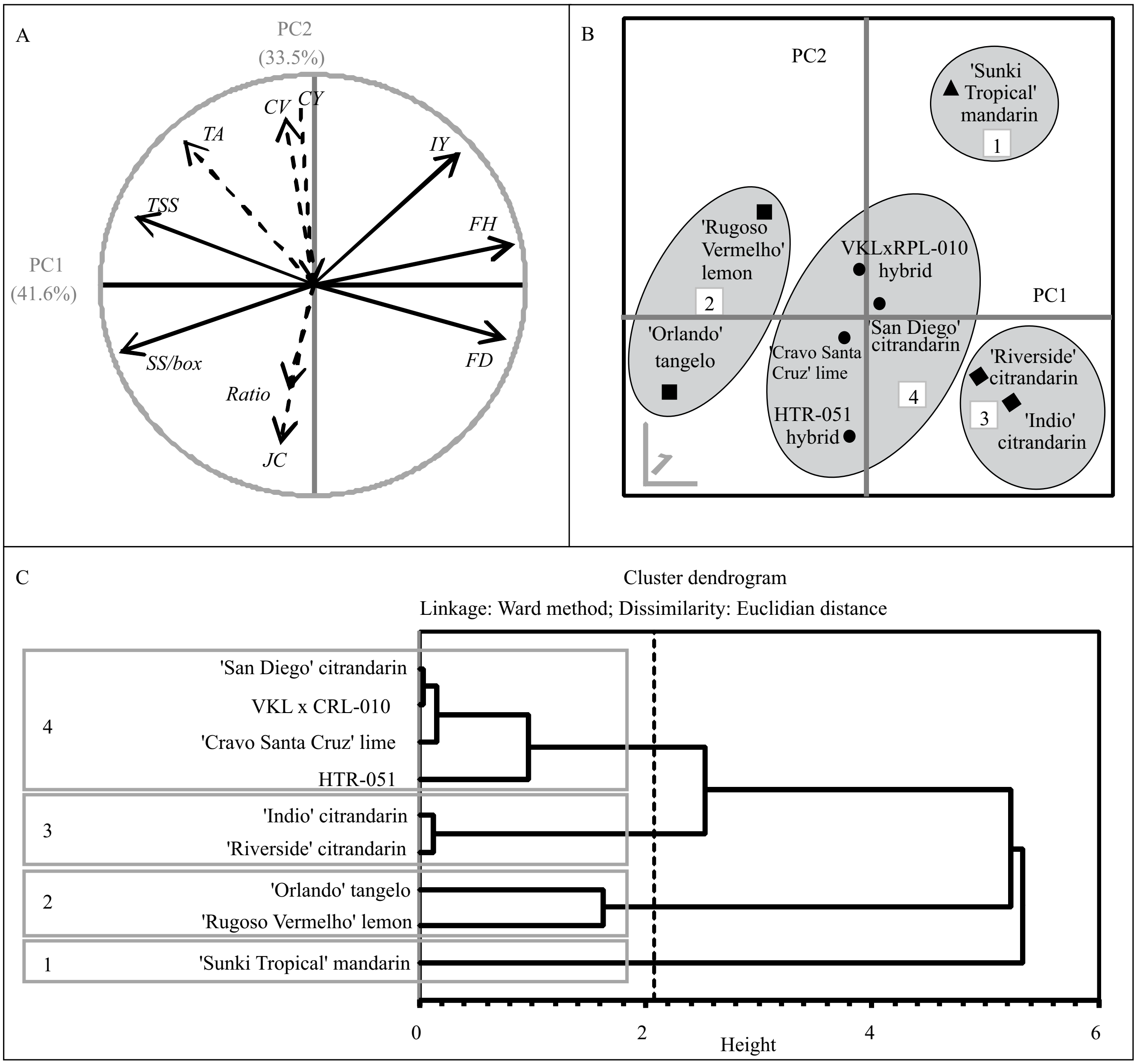

Figure 1. Representation of the four rootstock groups resulting from the principal component analysis and the agglomerative hierarchical clustering projected into the plane, defined by the first two principal component. In the correlation circle, straight lines represent variables that are the most explanatory of the PC1, while dashed lines represent variables that are the most explanatory of the PC2. A, correlation circle; B, Principal Component Analysis; and C, Agglomerative Hierarchical Clustering (AHC).

DOI: 10.1590/S1678-3921.pab2020.v55.01665

showed that fruit diameter (FD), fruit height (FH), TSS, TSS/box, and IY were the most explanatory variables of PC1, whereas JC, TA, CV, and CY were the most explanatory variables of PC2. A significant positive correlation was observed between cumulative yields and canopy volumes, indicating that the greater the canopy, the higher the yield, especially because rootstocks did not significantly affect the yield efficiency of 'Jaffa'. Working with three different orange scions, Carvalho et al. (2019) identified that while the trifoliate rootstock HTR-051 induced dwarfism in 'Sincora', 'Valencia Tuxpan', and 'Pineapple', such dwarfism was associated with an increased yield efficiency (that is, mass of fruit per volume of canopy) only for 'Sincora', concluding that the adequacy to high-density plantings depends upon a scion/rootstock combination. In the present work, even though some rootstocks induced plants of small volumes, such dwarfism was not followed by an increased yield efficiency, which indicates that 'Jaffa' is not a sweet orange scion adapted to high-density plantings.

In general, fruit size [small diameter (FD), and height (FH)] were negatively correlated with TSS, TSS/box, and TA, indicating that bigger fruit normally showed low-Brix values and less acidity. Even though the correlation between fruit size (FD and FH) and CY or JC could not be detected in the present study, the rootstocks that induced higher cumulative yields were also those that showed lower-juice contents in the fruit. The AHC grouped the rootstocks into four groups. The first group comprised only 'Sunki Tropical' mandarin, and was characterized by high cumulative yields. The second group included 'Orlando' tangelo and 'Rugoso Vermelho' lemon, and showed bigger fruit with low-Brix, low-SST/box, and less acid values. On the opposite, the third group, that included the 'Indio' and 'Riverside' citrandarins, tended to show more acid fruit, as well as low-cumulated yields and canopy volumes. Finally, the fourth group, that contained 'Cravo Santa Cruz' lime, 'San Diego' citrandarin, as well as the hybrids HTR-051 and LVK x LCR-010, shows mostly lower cumulative yields than the group 1, and intermediate values for the other evaluated variables. This result indicates that while 'Sunki Tropical' mandarin is the best rootstock for promoting vegetative development and yield, the group composed by 'Cravo Santa Cruz' lime, 'San Diego' citrandarin, and the trifoliate hybrids HTR-051 and LVK x LCR-010 induced fruit of better quality.

The rootstocks evaluated did not influence the population levels of the pest mites *E. banksi* ($F_{8,27}$ = 1.248; P = 0.3107), *T. mexicanus* ($F_{8,27}$ = 0.957; P = 0.488), and *P. oleivora* ($F_{8,26}$ 1.330; P = 0.272) in 'Jaffa'. Carvalho et al. (2016a) also did not found influence of rootstocks on the abundance of these mites in 'Piemonte' mandarin. In contrast, Silva et al. (2016) found high densities of *P. oleivora* on 'Pera CNPMF D-6' sweet orange grafted on x LCR-010, 'Cravo Santa Cruz' lime, and 'Rugoso Vermelho' lemon, which did not influence the population levels of the three pest mites in the present study.

Conclusions

1. 'Sunki Tropical' mandarin, 'Cravo Santa Cruz' lime, and 'Rugoso Vermelho' lemon are adequate rootstock options for 'Jaffa' sweet orange cultivation in Northeast Brazil, considering the vegetative, productive, and qualitative traits of 'Jaffa'.
2. The evaluated rootstocks do not influence the population levels of the pest mites *E. banksi*, *T. mexicanus*, and *P. oleivora* in 'Jaffa' sweet orange.

Acknowledgments

To Empresa Brasileira de Pesquisa Agropecuária (Embrapa), for financial support (SEG number 02.13.03.005.00.00).

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