Scientia Horticulturae 243 (2019) 169–176

Contents lists available at ScienceDirect

Scientia Horticulturae

journal homepage: www.elsevier.com/locate/scihorti

New scion-rootstock combinations for diversification of sweet orange orchards in tropical hardsetting soils

Luciana M. de Carvalho[a,*], Hélio W.L. de Carvalho[a], Inácio de Barros[a], Carlos R. Martins[b], Walter dos S. Soares Filho[c], Eduardo A. Girardi[c], Orlando S. Passos[c]

[a] Embrapa Coastal Tablelands, Aracaju, SE, Brazil
[b] Embrapa Temperate Agriculture, Pelotas, RS, Brazil
[c] Embrapa Cassava and Fruits, Cruz das Almas, BA, Brazil

ARTICLE INFO

Keywords:
Citrus
Poncirus trifoliate
Dwarfism
Fruit
Quality
Survival
Yield

ABSTRACT

Naturally occurring subsoil horizon restricting root development and a narrow genetic base of scion-rootstock combinations make the citriculture in Brazilian Northeast prone to biotic and abiotic stresses. The diversification of citrus orchards through the introduction of new scion-rootstocks combinations is an important strategy to reduce the risks associated with these constraints. Three experiments aiming at identifying appropriate scion-rootstock combinations for enhancing genetic diversification in citrus orchards under rainfed conditions in tropical hardsetting soils were established in Sergipe state in 2008. In each one, a different sweet orange ('Sincora', 'Valencia Tuxpan' and 'Pineapple') was grafted on six rootstocks ('Santa Cruz' Rangpur lime, 'Red Rough' lemon, 'Orlando' tangelo, 'Sunki Tropical' mandarin, HTR–051 and VKLxRPL–010 hybrids). After eight years the experiments were evaluated for plant development, yield performance and fruit quality. In general, all sweet oranges grafted on 'Red Rough' lemon showed great development and cumulative yield as does with 'Santa Cruz' Rangpur lime, with the later showing better fruit quality as an advantage. Inversely, HTR-051 hybrid displayed low yields despite high yield efficiency, for this rootstock induces dwarfism. 'Sunki Tropical' mandarin brought high yields of medium quality fruits, while the VKLxRPL-010 hybrid induced productive precocity, especially for 'Sincora' sweet oranges. Based upon these results, all tested scions grafted on 'Red Rough' lemon and 'Santa Cruz' Rangpur lime, followed by 'Sunki Tropical' mandarin are indicated for genetic diversification of groves, when planted at conventional density. On the other hand, the hybrid HTR-051 seems to have great potential for high density orchards, since it shows high yield efficiency and good quality of fruit.

1. Introduction

With 744,400 ha and 18.16 million tons of fruits produced in 2016, Brazil is the largest producer and accounts for a quarter of the worlds' production of sweet oranges [*Citrus sinensis* (L.) Osbeck]. However, the Country ranks only as the twelfth most productive, with just 24.4 t ha^{-1} (FAO, 2017). One reason for this poor performance is water deficit because citriculture in Brazil is predominantly rainfed (Erismann et al., 2008).

With 132 thousand ha and production of 1.9 million tons of sweet oranges the Brazilian Northeast shows even lower yield (14 t ha^{-1}; IBGE, 2016). Besides the water deficit, limitations to yields in this area are largely attributed to the presence of naturally occurring compacted subsoil horizon (5–20 cm) (Araujo et al., 2005; Soares et al., 2015; Gomes et al., 2017). Such hardsetting soils are found in every. In contrast to permanently cemented soils, they lose strength when wet, but develop very high strength with little observable structure when dry, leading to poor drainage and restricting root development (Daniells, 2012; Gomes et al., 2017). Restrictions to root development are also considered one of the major edaphic limitation to citrus production in Northwest India; San Joaquin Valley, USA; Aegean region, Turkey; Yaracuy, Venezuela; Concordia and Entre Rios provinces, Argentina; Nelspruit, South Africa (Srivastava and Singh, 2009) among others. Furthermore, it is also important to consider the effects that ageing, inadequate management and lack of investments have in the performance of the orchards, especially the ones in smallholder farms, which predominant in the region.

Nowadays, the most commonly used scion-rootstock combination in the Brazilian Northeast' orchards is 'Pera' sweet orange [*Citrus sinensis* (L.) Osbeck] grafted on 'Rangpur' lime (*C. limonia* Osbeck) because of

* Corresponding author.
E-mail address: luciana.carvalho@embrapa.br (L.M.d. Carvalho).

https://doi.org/10.1016/j.scienta.2018.07.032
Received 28 March 2018; Received in revised form 26 July 2018; Accepted 31 July 2018

the good fruit quality, several blossoms of this scion variety and also because this rootstocks has already been reported as drought tolerant (Almeida and Passos, 2011). However, this narrow genetic diversity increases the risks that abiotic and biotic stresses causes important economic impacts, threatening the entire production chain in the region. Diversification of scion-rootstock combinations may contribute to increase yield and fruit quality and extend the harvest season. Based on this corollary, the Brazilian Agricultural Research Corporation (EMBRAPA) started in 2008 several studies aiming at evaluating scion-rootstock combinations under field condition in hardsetting soils of Brazilian Northeast. In this work, the objective was to identify appropriate scion-rootstock combinations for enhancing genetic diversification in citrus orchards under rainfed conditions in tropical hardsetting soils.

2. Materials and methods

The study was carried out in the experimental station of Embrapa in Umbaúba, state of Sergipe (11°22′37″S, 37°40′26″W, 109 m above sea level). The soil in the experimental site is a sandy clay loam Haplic Lixisol with fragipan (Gomes et al., 2017), typical of orange groves in the region. The climate is tropical dry ("*As*") according to Köppen-Geiger classification, with rainy season between May and September. Rainfall was recorded daily during the experimental period and showed an average of 1324 mm year^{-1}. The annual totals are presented in Fig. 1.

Three experiments were settled up and, in each one, a different variety of sweet orange [*Citrus sinensis* (L.) Osbeck] was combined with six rootstocks genotypes. The scions tested were 'Valencia Tuxpan' (late-maturing), 'Sincora' and 'Pineapple' (medium-maturing) grafted on four commercial rootstocks: (i) 'Santa Cruz' Rangpur lime (*C. limonia* Osbeck), (ii) 'Red Rough' lemon (*C. jambhiri* Lush.), (iii) 'Orlando' tangelo (*C. paradisi* Macfad. x *C. tangerina* hort. ex Tanaka), (iv) 'Sunki' mandarin [*C. sunki* (Hayata) hort. ex Tanaka] Tropical selection and two unreleased Embrapa hybrids: (v) trifoliate HTR – 051 [a hybrid involving *Poncirus trifoliata* (L.) Raf.], and (vi) VKL ('Volkamerian' lemon, *C. volkameriana* V. Ten. & Pasq.) x RPL ('Rangpur' lime) - 010. All commercial genotypes used are accessions of the citrus Genebank and the hybrids developed by the Citrus Breeding Program of Embrapa Cassava & Fruits.

Seedlings were produced in a commercial nursery facility by seeding rootstocks in black plastic bags and subsequently bud grafted with the scions to be tested. Transplanting occurred in June 2008, when seedlings reached 12 months old and about 40 cm height, and planting

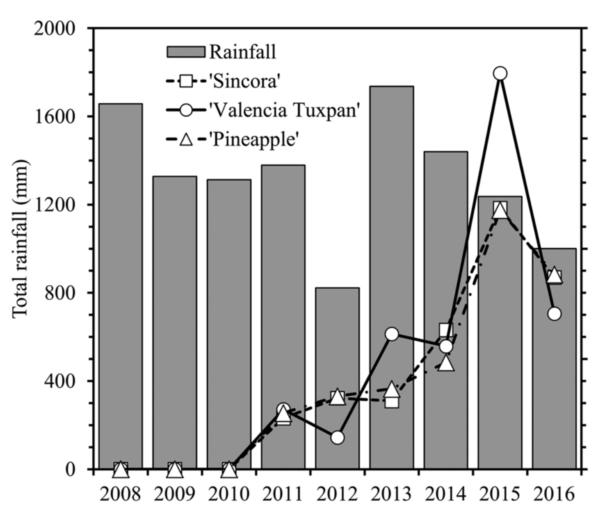

Fig. 1. Total rainfall and average yields of the varieties of sweet oranges [*Citrus sinensis* (L.) Osbeck] 'Sincorá', 'Valencia Tuxpan' and 'Pineapple' in the experimental site in Umbauba, state of Sergipe, Brazil from 2008 to 2016.

spacing was 6 m × 4 m (416 plants ha^{-1}) using pits of 40 × 40 × 40 cm. Border rows on each side of the harvest trees as well as border plants on each end of the plots were planted using trees of the same scion variety as the one being tested. Similarly to commercial orchards in the region, the orange trees were conducted without irrigation, except in the driest months, when each plant received a weekly salvation irrigation of 3 L. Soil preparation and fertilizer application were performed according to Sobral et al. (2007) while all other management practices followed the recommendations from Mattos Junior et al. (2005).

The effects of rootstocks on plant development were appraised when the orchards reached eight years old (2016), and the following variables were estimated: plant height (PH, in m), canopy volume (CV, in m^3) and survival rate (SR, in %) as the percentage of remaining plants related to initial plant density. Yield performance was evaluated through fruit yield (FY, in t. ha^{-1}) recorded from 2011 (first harvest) to 2016 and summed up to estimate the cumulative yield (CY, in t. ha^{-1}) as well as by yield efficiency (YE, in kg·m^{-3}), calculated for 2016 only. Furthermore, fruit quality was assessed in 2014 and 2015 through juice content (JC, in %); titratable acidity (TA, in g of citric acid per 100 ml of juice), measured by titration with NaOH 0.1 N; total soluble solids (SS, in °Brix), estimated by refractometer; 'ratio' (maturity index), calculated as SS/TA; ascorbic acid (AA) content (in mg.L^{-1}), measured by redox titration using iodate solution; and technological index (TI, in kg of SS per standard box of 40.8 kg), calculated as TI = yield × SS × 40.8 / 100. All these attributes were evaluated according to França et al. (2016).

For each trial, the experimental design was randomized complete block with six treatments (rootstocks), four repetitions and data collected in the three central plants per plot. For univariate analysis, the recorded data were submitted to ANOVA and rootstocks were grouped using Scott-Knott test when significant effects were detected by F-test ($p < 0.05$). Moreover, root square transformations were used for all data that did not follow normal distribution.

Multivariate analyses were also performed for each experiment (scion variety) so as to identify relatively homogenous groups of rootstocks considering the universe of all variables and rootstocks. First, a Principal Component Analysis (PCA) was applied to evaluate the variability and relationships among values of the aforementioned variables for plant development, yield performance and fruit quality. Rootstocks were then grouped by Agglomerative Hierarchical Clustering (AHC) using the Euclidean distance as a measure of dissimilarity and the Ward method for linkage. The threshold considered for truncation between clusters was 10 units of rescaled distance cluster combine based on visual inspection of the dendrograms.

3. Results

3.1. Plant growth

Plants of 'Valencia Tuxpan' sweet orange grafted on any of the four commercial rootstocks were taller than those grafted on any of the two experimental hybrids. Likewise, shorter plants of 'Sincora' were observed when grafted on HTR-051 trifoliate hybrid (Table 1). Regarding the canopy volume, no significant differences were observed between 'Red Rough' lemon, 'Orlando' tangelo, 'Sunki Tropical' mandarin, and the hybrid VKL x RPL - 010 for 'Sincora' sweet oranges; and between 'Red Rough' lemon, 'Santa Cruz' Rangpur lime, 'Orlando' tangelo and 'Sunki Tropical' mandarin for 'Valencia Tuxpan' sweet oranges, while for 'Pineapple' sweet oranges, 'Red Rough' lemon showed a significantly larger canopy volume than other rootstocks (Table 1). Regardless of the scion variety, the smallest canopy volumes (5.74–7.88 m^3) were observed on plants grafted on HTR-051 hybrid. Contrariwise, the largest canopy volumes (16.99–18.94 m^3) were obtained with 'Red Rough' lemon for all scion varieties (Table 1).

Concerning survival rates, sweet oranges budded on 'Santa Cruz'

Table 1
Plant height, canopy volume and survival rate of three varieties of sweet oranges [*Citrus sinensis* (L.) Osbeck] grafted on six rootstock genotypes at eighth year in Umbauba, state of Sergipe, Brazil, 2016 (means ± standard error).

Scion variety	Rootstock genotype[a]	Plant height (m)	Canopy volume (m^{-3})	Survival rate (%)
'Sincora'	'Red Rough' lemon	2.83 ± 0.07a	17.0 ± 0.4a	100
	'Santa Cruz' Rangpur lime	2.63 ± 0.14a	11.0 ± 2.0b	100
	'Orlando' tangelo	3.00 ± 0.04a	15.6 ± 0.4a	88
	'Sunki' Tropical mandarin	2.89 ± 0.11a	13.3 ± 0.9a	88
	VKL x RPL-010 hybrid	2.95 ± 0.07a	15.2 ± 1.2a	100
	HTR-051 hybrid	1.98 ± 0.05b	5.7 ± 0.4c	100
'Valencia Tuxpan'	'Red Rough' lemon	3.03 ± 0.13a	18.9 ± 1.2a	100
	'Santa Cruz' Rangpur lime	3.01 ± 0.19a	16.7 ± 1.0a	100
	'Orlando' tangelo	3.18 ± 0.05a	16.2 ± 0.6a	75
	'Sunki' Tropical mandarin	3.13 ± 0.17a	16.5 ± 1.6a	100
	VKL x RPL-010 hybrid	2.65 ± 0.35b	12.0 ± 2.9b	100
	HTR-051 hybrid	2.10 ± 0.08c	7.9 ± 1.0c	100
'Pineapple'	'Red Rough' lemon	3.04 ± 0.09	17.7 ± 0.4a	75
	'Santa Cruz' Rangpur lime	2.51 ± 0.22	13.6 ± 0.8b	100
	'Orlando' tangelo	2.74 ± 0.06	14.3 ± 1.3b	100
	'Sunki' Tropical mandarin	2.73 ± 0.10	14.2 ± 0.8b	88
	VKL x RPL-010 hybrid	2.60 ± 0.18	12.2 ± 1.4b	100
	HTR-051 hybrid	2.30 ± 0.22	7.2 ± 0.5c	100

Means followed by the same letter in each column, belonging to the same scion variety did not differ by the Scott-Knott test ($p < 0.05$).
[a] 'Red Rough' lemon (*C. jambhiri* Lush.), 'Santa Cruz' Rangpur lime (*C. limonia* Osbeck), 'Orlando' tangelo (*C. paradisi* Macfad. x *C. tangerina* hort. ex Tanaka), 'Sunki' Tropical mandarin [*C. sunki* (Hayata) hort. ex Tanaka], VKL ('Volkamer' lemon *C. volkameriana* V. Ten. et Pasq.) x RPL ('Rangpur' lime) - 010 hybrid and HTR [trifoliate hybrid involving *Poncirus trifoliata* (L.) Raf.] - 051.

Rangpur lime, HTR-051and the VKL x RPL – 010 hybrids and all plants of 'Valencia Tuxpan' and 'Sincora' sweet oranges grafted on 'Red Rough' lemon were alive after eight years (Table 1). Moderate mortality rates (75–88%) were observed in trees of the following scion-rootstock combinations: 'Sincora' grafted on 'Orlando' tangelo and 'Sunki Tropical' mandarin; 'Valencia Tuxpan' grafted on 'Orlando' tangelo; and 'Pineapple' grafted on 'Red Rough' lemon and 'Sunki Tropical' mandarin (Table 1).

3.2. Yield performance

Significant differences between rootstocks in yield were detected in all years for all scion varieties, except for 'Sincora' in 2012 (Table 2). The highest yields for all three scion varieties during the experimental period were observed in 2015 (Fig. 1), being the highest yield of all obtained with 'Valencia Tuxpan' trees grafted on 'Santa Cruz' Rangpur lime, reaching 76.83 t.ha^{-1} in 2015 (Table 2). It is also noteworthy the yield alternation observed with this scion variety. While decreases in yield of the other two tested scions were observed only in 2016, 'Valencia Tuxpan' sweet orange showed yield declines in alternate seasons (2012, 2014 and 2016) as shown in Fig. 1. Likewise, it is meaningful that the hybrid VKL x RPL – 010 showed the highest yield in the first four seasons for 'Sincora' and 'Pineapple' trees (except in 2011 for 'Pineapple') and that 'Orlando' tangelo was the only rootstock that did not show a yield decline for 'Valencia Tuxpan' in 2012 (Table 2).

Considering the long run, 'Red Rough' lemon showed the highest cumulative yield for all tested scions. Inversely, HTR-051 hybrid showed the lowest values (Table 2). On average, plants grafted on 'Red Rough' lemon showed twice as much cumulative yield than those grafted on HTR-051 hybrid. Notwithstanding, significant difference in cumulative yield was not detected between 'Red Rough' lemon and 'Santa Cruz' Rangpur lime rootstocks for 'Valencia Tuxpan' (Table 2).

The effect of rootstock on yield efficiency (2016 basis) was significant for 'Sincora' and 'Valencia Tuxpan', but not for 'Pineapple' trees (Table 2). The best yield efficiencies for 'Sincora' were obtained when grafted on 'Santa Cruz' Rangpur lime, 'Sunki Tropical' mandarin and the hybrid HTR-051, while the 'Red Rough' lemon promoted the best yield efficiency for 'Valencia Tuxpan'.

3.3. Fruit quality

In 2015 none of the attributes for assessing fruit quality show significant differences between rootstocks for 'Sincora' and 'Pineapple' (Table 3), while for 'Valencia Tuxpan', titratable acidity (TA), total soluble solids (SS) and 'ratio' differed significantly between rootstocks. Even though scions were not compared in this study, the highest juice content was obtained in fruits of 'Valencia Tuxpan' in both seasons (60%) and 'Santa Cruz' Rangpur lime and HTR-051 induced high total soluble solids (11.7–12.2° Brix) regardless the scion (Table 3).

In 2014, fruits from trees grafted on VKL x RPL – 010 produced less juice, whereas sweet oranges grafted on HTR-051 produced oranges with higher levels of total soluble solids, regardless the scion variety. Additionally, less juice content in fruits of 'Valencia Tuxpan' (56%) and 'Pineapple' (51%) sweet oranges and less total soluble solids in fruits of 'Sincora' (10.5° Brix) and 'Pineapple' (10.2° Brix) sweet oranges were observed in 2014 for 'Red Rough' lemon (Table 3).Titratable acidity varied greatly between rootstocks, particularly in 2014 as opposed to ascorbic acid content and 'ratio' that did not show significant variations.

3.4. Multivariate analysis

More than 60% of the variability could be explained by the first two principal components (PC1 and PC2) for all three sweet orange varieties (Fig. 2), and the factor loadings showed that PH, CV, YE, CY, TA, SS and TI contributed most to PC1, whereas SR, JC, and 'ratio' were associated with PC2 for 'Sincora' trees (Fig. 2). For 'Valencia Tuxpan' sweet oranges, the variables that contributed mostly to PC1 were PH, CV, JC and SS while TA and ratio were more important to PC2 (Fig. 2). And finally, PH, CV, CY, SR, TA, SS, AA and TI showed major contributions to PC1 and JC and 'ratio' to PC2 for 'Pineapple' (Fig. 2). These results indicate that the correlation between variables depends upon the scion and therefore, the groups of relatively homogenous rootstocks are expected to differ depending on the sweet orange variety considered.

For 'Sincora' trees, the AHC grouped the rootstocks in three clusters (see dendrogram in Fig. 2). The first cluster was characterized by taller plants with voluminous canopies, relatively low yield efficiency, high cumulative yield, and medium levels for most attributes related to fruit quality and was constituted by 'Red Rough' lemon, 'Orlando' tangelo

Table 2
Annual yield, cumulative yield (CY) and yield efficiency (YE) of three varieties of sweet oranges [*Citrus sinensis* (L.) Osbeck] grafted on six rootstock genotypes in Umbauba, state of Sergipe, Brazil from 2011 to 2016 (means ± standard error).

Scion variety	Rootstock Genotype[b]	Yield						CY	YE[a]
		2011 (t. ha^{-1})	2012	2013	2014	2015	2016	(t. ha^{-1})	(kg. m^{-3})
'Sincora'	'Red Rough' lemon	7.62 ± 0.50b	9.28 ± 0.87	8.80 ± 0.74c	20.19 ± 0.82a	45.60 ± 2.49a	34.16 ± 1.16a	125.6 ± 1.5a	4,8[b] ± 0.09b
	'Santa Cruz' Rangpur lime	8.31 ± 0.59b	10.14 ± 0.85a	9.85 ± 0.85b	21.74 ± 1.48a	33.93 ± 0.86b	26.88 ± 1.59b	104.9 ± 1.9b	6.58 ± 0.53a
	'Orlando' tangelo	5.10 ± 0.42c	9.10 ± 0.46a	10.10 ± 0.19b	17.47 ± 0.93b	42.39 ± 1.76a	27.18 ± 1.76b	111.4 ± 2.9b	4.33 ± 0.12b
	'Sunki' Tropical mandarin	4.52 ± 0.39c	9.82 ± 0.36a	7.64 ± 0.66c	17.43 ± 0.61b	35.58 ± 2.21b	31.64 ± 0.39a	106.6 ± 1.8b	5.80 ± 0.38a
	VKLxRPL-010 hybrid	10.24 ± 0.60a	11.98 ± 0.62a	12.08 ± 0.52a	21.93 ± 0.52a	33.18 ± 1.92b	20.54 ± 0.82c	109.9 ± 3.1b	3.28 ± 0.14b
	HTR-051 hybrid	5.96 ± 0.52c	7.76 ± 0.43a	7.40 ± 0.82c	15.11 ± 0.60b	22.47 ± 1.91c	16.25 ± 0.62d	74.9 ± 2.6c	6.96 ± 0.58a
'Valencia Tuxpan'	'Red Rough' lemon	12.60 ± 0.69a	6.79 ± 0.34a	28.03 ± 2.69a	17.61 ± 0.82b	60.51 ± 3.47b	33.52 ± 1.80a	160.9 ± 5.5a	4.53 ± 0.16a
	'Santa Cruz' Rangpur lime	11.53 ± 2.91a	5.98 ± 0.98b	22.02 ± 4.36b	19.16 ± 1.08a	76.83 ± 3.01a	19.49 ± 5.33c	155.0 ± 14.5a	2.82 ± 0.15c
	'Orlando' tangelo	1.66 ± 3.12a	3.13 ± 0.98c	14.60 ± 5.55c	14.61 ± 0.84c	63.02 ± 1.41b	15.17 ± 5.90d	112.2 ± 14.8b	2.23 ± 0.21c
	'Sunki' Tropical mandarin	6.78 ± 2.38b	2.89 ± 0.82c	15.74 ± 5.59c	15.87 ± 0.83c	54.40 ± 2.74b	19.49 ± 5.52c	115.2 ± 13.4b	3,05 ± 0.50c
	VKLxRPL-010 hybrid	11.99 ± 0.12d	5.66 ± 0.16b	19.48 ± 1.17b	15.75 ± 0.54c	39.27 ± 2.25c	23.97 ± 1.26b	116.1 ± 3.7b	3,52 ± 1.42b
	HTR-051 hybrid	4.34 ± 2.54c	1.59 ± 0.67d	10.61 ± 1.82d	17.48 ± 1.21b	29.24 ± 2.40d	15.50 ± 1.47d	78.7 ± 8.5c	3,84 ± 0.67b
'Pineapple'	'Red Rough' lemon	9.01 ± 0.76a	10.93 ± 0.74a	12.08 ± 0.45a	19.54 ± 1.08a	47.90 ± 4.19a	35.14 ± 5.34a	126.1 ± 6.7a	4.75 ± 0.10a
	'Santa Cruz' Rangpur lime	8.26 ± 1.16a	11.44 ± 0.88a	13.13 ± 0.80a	16.20 ± 0.59a	34.31 ± 2.12b	25.03 ± 0.75c	106.5 ± 2.5b	4.70 ± 0.23a
	'Orlando' tangelo	6.71 ± 0.2b	8.97 ± 0.59b	8.84 ± 0.79b	11.45 ± 0.24b	36.22 ± 3.73b	28.34 ± 3.45b	93.4 ± 5.4b	5.15 ± 0.59a
	'Sunki' Tropical mandarin	9.23 ± 0.49a	8.83 ± 0.72b	9.36 ± 0.30b	14.53 ± 0.21a	38.64 ± 1.45b	28.53 ± 0.55b	109.1 ± 1.0b	6.20 ± 0.26a
	VKLxRPL-010 hybrid	6.14 ± 0.53b	13.38 ± 0.81a	12.69 ± 0.57a	14.95 ± 0.42a	36.51 ± 1.66b	30.21 ± 1.48b	107.3 ± 4.2b	5.89 ± 0.59a
	HTR-051 hybrid	6.60 ± 038b	6.06 ± 0.50c	9.65 ± 0.71b	10.62 ± 3.57b	17.95 ± 0.67c	11.75 ± 0.77d	62.6 ± 3.0c	4.55 ± 0.26a

Means followed by the same letter in each, belonging to the same scion variety, did not differ by the Scott-Knott test ($p < 0.05$).

[a] The calculated yield efficiencies correspond only to year 2016.

[b] 'Red Rough' lemon (*C. jambhiri* Lush.), 'Santa Cruz' Rangpur lime (*C. limonia* Osbeck), 'Orlando' tangelo (*C. paradisi* Macfad. x *C. tangerina* hort. ex Tanaka), 'Sunki Tropical' mandarin [*C. sunki* (Hayata) hort. ex Tanaka], VKL ('Volkamer' lemon *C. volkameriana* V. Ten. et Pasq.) x RPL ('Rangpur' lime) - 010 hybrid and HTR [trifoliate hybrid involving *Poncirus trifoliata* (L.) Raf.] - 051.

Table 3
Fruit quality attributes of three varieties of sweet oranges [*Citrus sinensis* (L.) Osbeck] grafted on six rootstock genotypes in Umbauba, state of Sergipe, Brazil in 2014 and 2015 (means ± standard error).

Scion variety	Rootstock genotype[a]	Attributes											
		Juice content JC		Titratable acidity TA		Total soluble solids SS		Ascorbic acid AA		Technological index TI		'Ratio'	
		(%)		(g.100 mL^{-1})		(°Brix)		(mg.L^{-1})		(kg SS.box^{-1})		(SS.TA^{-1})	
		2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
'Sincora'	'Red Rough' lemon	51 ± 2.0a	60 ± 1.0a	0.79 ± 0.04b	0.98 ± 0.02a	10.5 ± 0.6b	12.3 ± 0.3a	55 ± 3.1a	52 ± 2.2a	2.17 ± 0.14b	3.00 ± 0.12a	13.4 ± 0.7a	12.5 ± 0.4a
	'Santa Cruz' Rangpur lime	54 ± 1.7a	58 ± 0.7a	0.92 ± 0.05a	0.93 ± 0.03a	12.2 ± 0.5a	12.7 ± 0.3a	58 ± 2.6a	55 ± 1.0a	2.68 ± 0.13a	2.99 ± 0.10a	13.3 ± 0.3a	13.6 ± 0.5a
	'Orlando' tangelo	53 ± 1.5a	59 ± 0.6a	0.87 ± 0.09a	0.94 ± 0.10a	10.4 ± 0.3	12.8 ± 0.5a	56 ± 1.1a	55 ± 2.2a	2.25 ± 0.05b	3.07 ± 0.15a	12.3 ± 0.9a	13.5 ± 1.0a
	'Sunki Tropical' mandarin	54 ± 1.3a	59 ± 0.8a	0.87 ± 0.10a	0.93 ± 0.02a	10.3 ± 0.2b	12.3 ± 0.2a	49 ± 2.8b	49 ± 1.8a	2.26 ± 0.09b	2.97 ± 0.03a	12.1 ± 1.0a	13.5 ± 0.2a
	VKLxRPL-010 hybrid	48 ± 1.2b	57 ± 0.7a	0.63 ± 0.03b	0.99 ± 0.04a	9.4 ± 0.3b	12.4 ± 0.2a	48 ± 1.2b	57 ± 1.9a	1.86 ± 0.07b	2.89 ± 0.05a	15.0 ± 0.5a	12.6 ± 0.5a
	HTR-051 hybrid	55 ± 2.3a	57 ± 2.1a	0.96 ± 0.08a	0.98 ± 0.08a	11.7 ± 0.4a	13.1 ± 0.3a	53 ± 1.0a	56 ± 1.9a	2.64 ± 0.17a	3.03 ± 0.13a	12.3 ± 0.6a	13.6 ± 1.0a
	Mean	54	58	0.85	0.94	10.9	12.4	51	51	2.42	2.94	13.1	13.2
	CV(%)	6.0	4.0	14.50	15.0	7.6	6.8	7.3	8.1	10.1	8.1	9.3	13.3
'Valencia Tuxpan'	'Red Rough' lemon	56 ± 0.5b	57 ± 1.4a	1.01 ± 0.06a	1.36 ± 0.05a	11.4 ± 0.2a	11.8 ± 0.5b	50 ± 2.2b	57 ± 1.2a	2.60 ± 0.07b	2.74 ± 0.15a	11.3 ± 0.6b	8.4 ± 0.1b
	'Santa Cruz' Rangpur lime	60 ± 0.6a	60 ± 4.1a	1.02 ± 0.01a	1.22 ± 0.07a	12.0 ± 0.3a	11.5 ± 0.4b	54 ± 1.2a	58 ± 1.2a	2.93 ± 0.09a	2.82 ± 0.19a	11.7 ± 0.3a	9.8 ± 0.7b
	'Orlando' tangelo	62 ± 1.3a	59 ± 0.7a	0.94 ± 0.05b	1.14 ± 0.22b	10.4 ± 0.6b	11.3 ± 1.0b	46 ± 0.6b	57 ± 3.7a	2.61 ± 0.14b	2.73 ± 0.27a	11.0 ± 0.3b	9.3 ± 0.8b
	'Sunki' Tropical mandarin	59 ± 1.0b	61 ± 2.7a	1.07 ± 0.02a	1.21 ± 0.06a	11.8 ± 0.3a	10.8 ± 0.8b	48 ± 1.0b	51 ± 3.3a	2.79 ± 0.10b	2.72 ± 0.25a	10.9 ± 0.3b	9.2 ± 0.4b
	VKLxRPL-010 hybrid	59 ± 1.4b	60 ± 0.5a	0.99 ± 0.03b	1.04 ± 0.04b	10.5 ± 0.2b	10.3 ± 0.4b	57 ± 1.3a	54 ± 2.5a	2.53 ± 0.02b	2.52 ± 0.12a	10.7 ± 0.1b	10.5 ± 0.1a
	HTR-051 hybrid	59 ± 1.6b	55 ± 2.5a	0.96 ± 0.03b	1.43 ± 0.06a	11.5 ± 0.5a	13.3 ± 0.6a	51 ± 2.4b	60 ± 2.0a	2.76 ± 0.07b	2.98 ± 0.03a	12.0 ± 0.2a	9.2 ± 0.1b
	Mean	60	60	1.00	1.24	12.0	11.7	51	56	3.0	2.85	11.0	9.8
	CV(%)	3.0	6.0	6.9	15.9	8.9	10.1	6.6	8.9	8.5	11.6	6.4	10.2
'Pineapple'	'Red Rough' lemon	51 ± 1.0b	56 ± 0.9a	0.77 ± 0.03b	0.67 ± 0.01a	10.2 ± 0.2b	11.3 ± 0.1a	59 ± 1.6a	67 ± 0.6a	2.10 ± 0.06b	2.55 ± 0.06a	13.2 ± 0.2a	16.7 ± 0.3a
	'Santa Cruz' Rangpur lime	52 ± 0.5b	56 ± 1.9a	0.86 ± 0.05b	0.70 ± 0.05a	11.4 ± 0.4a	11.1 ± 0.2a	67 ± 3.1a	66 ± 1.4a	2.44 ± 0.09a	2.52 ± 0.13a	13.1 ± 0.3a	15.9 ± 0.9a
	'Orlando' tangelo	57 ± 0.8a	58 ± 3.0a	0.87 ± 0.01b	0.84 ± 0.04a	10.9 ± 0.1b	12.1 ± 0.3a	63 ± 0.3a	72 ± 2.7a	2.56 ± 0.02a	2.86 ± 0.12a	12.8 ± 0.2a	14.7 ± 0.9a
	'Sunki' Tropical mandarin	53 ± 1.3a	61 ± 1.3a	0.75 ± 0.04b	0.73 ± 0.10a	10.1 ± 0.3b	11.5 ± 0.4a	59 ± 2.1a	65 ± 2.2a	2.18 ± 0.09b	2.86 ± 0.16a	13.4 ± 0.4a	15.8 ± 1.3a
	VKLxRPL-010 hybrid	52 ± 1.2b	57 ± 1.3a	0.95 ± 0.07a	0.69 ± 0.05a	12.3 ± 0.5a	12.2 ± 0.6a	67 ± 3.0a	69 ± 1.6a	2.58 ± 0.09a	2.81 ± 0.20a	13.2 ± 0.6a	17.8 ± 0.8a
	HTR-051 hybrid	55 ± 1.3a	59 ± 1.0a	1.03 ± 0.05a	0.71 ± 0.06a	11.7 ± 0.2a	12.0 ± 0.3a	67 ± 2.0a	66 ± 2.4a	2.60 ± 0.10a	2.90 ± 0.11a	11.4 ± 0.5b	17.3 ± 1.2a
	Mean	54	58	0.91	0.74	11.3	11.9	63.1	67	2.49	2.81	12.6	16.2
	CV(%)	4.0	5.0	10.4	15.5	6.8	6.6	6.5	5.6	7.1	9.4	7.6	11.3

Means followed by the same letter in each column, belonging to the same scion variety, did not differ by the Scott-Knott test ($p < 0.05$).

[a] 'Red Rough' lemon (*C. jambhiri* Lush.), 'Santa Cruz' Rangpur lime (*C. limonia* Osbeck), 'Orlando' tangelo (*C. paradisi* Macfad. x *C. tangerina* hort. ex Tanaka), 'Sunki Tropical' mandarin [*C. sunki* (Hayata) hort. ex Tanaka], VKL ('Volkamer' lemon *C. volkameriana* V. Ten. et Pasq.) x RPL ('Rangpur' lime) - 010 hybrid and HTR [trifoliate hybrid involving *Poncirus trifoliata* (L.) Raf.] - 051.

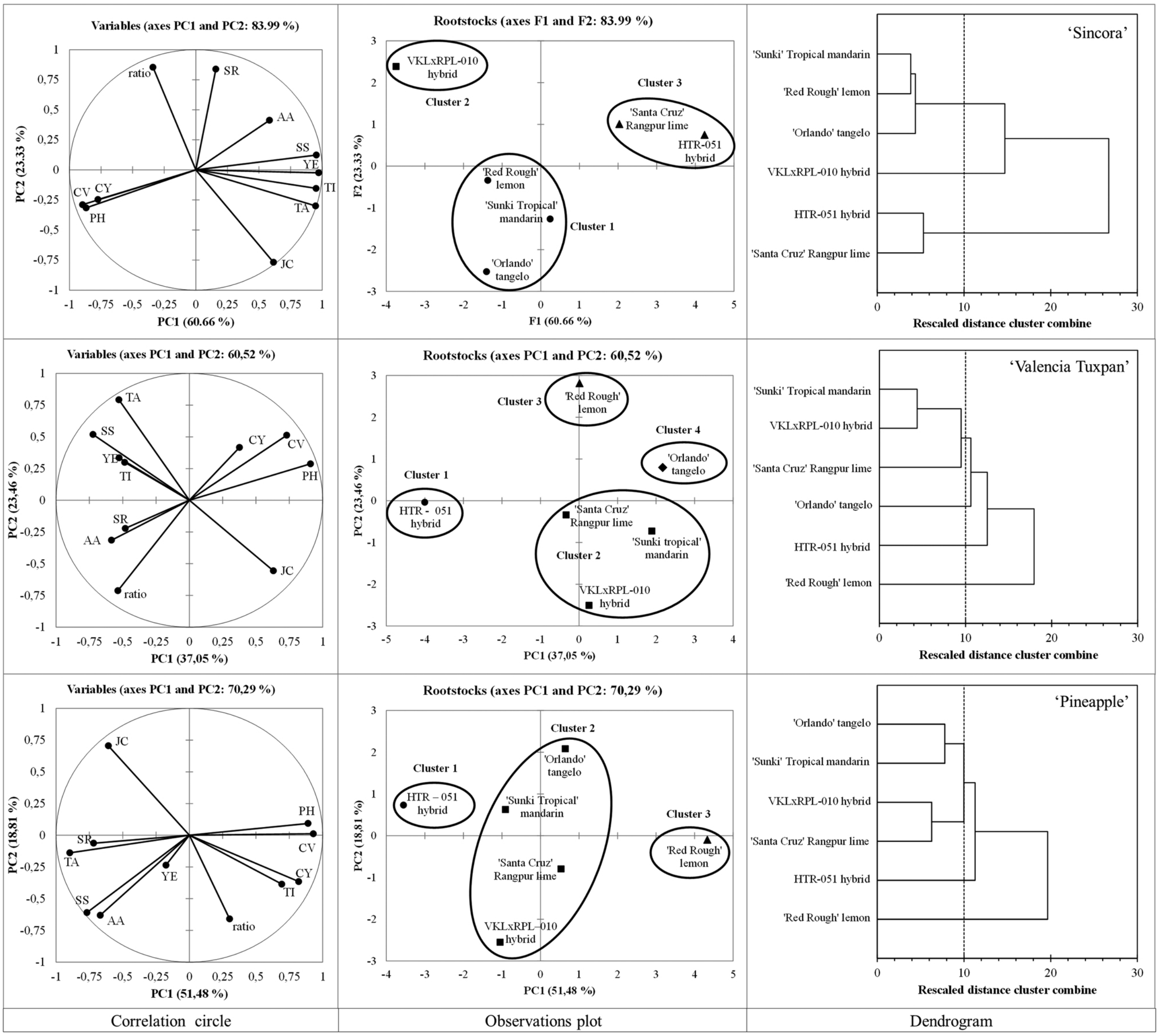

Fig. 2. Correlation circle and observations plot of the Principal Component Analysis (PCA) and dendrogram for four rootstock genotypes obtained by Ward method and the Agglomerative Hierarchical Clustering for the sweet oranges [*Citrus sinensis* (L.) Osbeck] varieties 'Sincorá', 'Valencia Tuxpan' and 'Pineapple' in Umbauba, state of Sergipe, Brazil.

and 'Sunki Tropical' mandarin. The second cluster, restricted to the hybrid VKL x RPL – 010, differed from the first cluster in relation to fruit quality, for it presented lower juice content, titratable acidity and total soluble solids. The third cluster, consisted by HTR-51 hybrid and 'Santa Cruz' Rangpur lime differed from the others by showing lower canopy volume and higher yield efficiency (Fig. 2).

The AHC performed for 'Valencia Tuxpan' sweet orange identified four clusters (Fig. 2). The first one comprised only the hybrid HTR-051 and was characterized by high yield efficiency associated with short plants of small canopy volumes that contributed to low cumulative yield. In addition, the fruits showed high total soluble solids, ascorbic acid content, titratable acidity and 'ratio'. The second cluster included 'Santa Cruz' Rangpur lime, the hybrid VKL x RPL – 010 and the 'Sunki Tropical' mandarin and was characterized by medium values for yield efficiency, plant high and canopy volume and high cumulative yield. Also, the fruits showed medium juice content and high titratable acidity, ascorbic acid and 'ratio'. The third cluster contained only the 'Red Rough' lemon and showed tall plants of medium canopy volume, which associated with medium cumulative yield, induced medium yield efficiency as consequence. The fruits, nonetheless, presented high contents of juice and ascorbic acid, medium titratable acidity, low total soluble solids and high 'ratio'. Finally, the fourth cluster, represented by the 'Orlando' tangelo alone, differed from the second cluster by showing low yield efficiency and large canopy volume.

Lastly, three clusters were identified by AHC for 'Pineapple' trees (Fig. 2). The first cluster contained only the hybrid HTR-051 and showed shorter plants, low canopy volume, and low cumulative yield as well as high juice content, titratable acidity, total soluble solids and ascorbic acid, similarly to what was observed with 'Sincora' trees. However, it differed from it by showing low yield efficiency and 'ratio'. The second cluster included: VKL x RPL – 010, 'Santa Cruz' Rangpur lime, 'Orlando' tangelo and 'Sunki Tropical' mandarin, and was characterized by plants with medium height, canopy volume and cumulative yield and high yield efficiency. Fruit quality showed high juice contents, total soluble solids and ascorbic acid as well as medium titratable acidity and 'ratio'. It is worth mentioning that this cluster included the rootstocks with the highest yield efficiencies. The last cluster was restricted to 'Red Rough' lemon that showed tall plants, bulky canopies and higher cumulative yield associated with medium yield efficiency together with low figures for almost all fruit quality attributes, except 'ratio'.

4. Discussion

Though sweet orange scions weren't compared here by statistical procedures, the highest yields were obtained with 'Valencia Tuxpan'. This high yield capacity may explain why this sweet orange is the most cultivated citrus variety. The highest cumulative yields for this scion were found when grafted on 'Red Rough' lemon and 'Santa Cruz' Rangpur lime (155-160 t·ha^{-1}), in contrast to HTR-051 hybrid that produced only half as much (78 t·ha^{-1}). Another peculiarity observed with this scion variety is the yield alternation (Fig. 1), a character that has already being reported by França et al. (2016), among others. Besides, the pronounced yield decreased from 2015 to 2016 in 'Valencia Tuxpan' sweet oranges (Fig. 1) suggests susceptibility to drought and agrees with Pedroso et al. (2014) that observed reductions in growth 'Valencia' orange trees as consequence of water deficit independent of the rootstock. Notwithstanding, this scion presented the highest average fruit yield, especially when grafted on 'Red Rough' lemon or 'Santa Cruz' Rangpur lime (Table 1) in 2015 (Fig. 1). Likewise, Castle et al. (2010) observed higher yields of 'Valencia' sweet oranges grafted on the vigorous 'Rough' lemon (and 'Volkamer' lemon) than on trifoliate hybrids and other rootstock species in hardsetting soils in Florida, USA, and França et al. (2016) also reported good performance of 'Santa Cruz' Rangpur lime in a hardsetting soil in Bahia, on the Brazilian Northeast.

These results indicated that diversification of sweet orange orchards using 'Sincora', 'Valencia Tuxpan' and 'Pineapple' scion varieties is a viable option for the edaphoclimatic conditions of the Brazilian Northeast. 'Red Rough' lemon rootstock was among the rootstocks that showed the highest yields in 2012 and 2016, the first and second driest years, respectively. Also, when pronounced declines in yield was observed for all scion varieties in 2016 (Fig. 1), the highest yields for all scions were observed with 'Red Rough' lemon. Similarly, Carvalho et al. (2016a); Carvalho et al. (2016b) also demonstrated that 'Red Rough' lemon showed better yield performance for 'Piemonte' mandarin and 'Pera CNPMF-D6′ orange scions than other rootstocks in the same edaphoclimatic conditions of this study. These results suggest that this rootstock is well adapted to local conditions and explains its acceptance by the growers and its adoption as the second most used rootstock in Sergipe (Prudente et al., 2004). However, except for 'Sincora' sweet oranges, 'Red Rough' lemon induced lower juice content and total soluble solids in fruits (Table 3). Similarly, Barry et al. (2004) verified lower soluble solids concentrations on 'Valencia' oranges harvested from trees grafted on 'Rough' lemon than those on 'Carrizzo' citrange rootstock, a trifoliate hybrid. This performance was attributed to a 'dilution effect' in those vigorous trees grafted on 'Rough' lemon by the same authors.

The use of 'Red Rough' lemon as rootstock for 'Sincora', 'Valencia Tuxpan', and 'Pineapple' sweet oranges induced high annual and cumulative fruit yields and, by the same token, promoted the development of trees with large canopy volumes (Table 2). According to Schäfer et al. (2001), large canopies are normally developed in plants with large root systems which, accordingly, have greater capacity to take up water and nutrients. The relatively low yield efficiencies found for this rootstock indicate that they produced little fruits for the size of their canopies. A possible explanation is that the large size created a shaded environment in the interior of the bulky canopies. According to Núñez et al. (2007), approximately 90% of the solar radiation is captured in the outer layer of the canopy, from its surface up to one meter in its interior.

The 'Santa Cruz' Rangpur lime, in turn, favored high-quality fruits for all sweet orange (Table 3) and, together with the hybrids VKL x RPL – 010 and HTR-051, stands out due to the greater tree survival rates after eight years, regardless the scion variety. However, the hybrid HTR-051 showed the shortest plants with tiniest canopies for all scions, implying in the lowest cumulative yield for all sweet orange varieties, averaging only half of that obtained with 'Red Rough' lemon (Table 2). Induction of dwarfism, also reported by Continella et al. (2018) for 'Tarocco Sciré' grafted on trifoliate rootstock, is characteristic of trifoliate [*Poncirus trifoliata* (L.) Raf.] rootstocks and this character favors high density plantings, facilitating orchard management and harvests (Lima et al., 2014). The benefits of the HTR-051 hybrid induced semi-dwarfism on scions could not be realized in this study as all three experiments were settled up in the same 6 m x 4 m conventional plant spacing. Despite the high yield efficiency obtained with HTR-051, very small canopies were also observed; besides low yields.

According to Auler et al. (2008), rootstocks that favor small canopies and induce high yield efficiencies may be as much or even more interesting than those that promotes large canopy volumes and high fruits yield plant, for it enables enhancing production by increasing planting density. In addition, it is worth mentioning that this rootstock produced fruits of all three scion varieties with high total soluble solids and of 'Sincora' and 'Pineapple' with high juice content (Tables 3).

The combination of the hybrid rootstock VKL x RPL – 010 with 'Sincora' and 'Pineapple' sweet oranges showed yields particularly high in the first harvest, suggesting precocity (Table 1 and Fig. 1), whereas 'Santa Cruz' Rangpur lime presented its better productive performance in the fifth harvest (2015 – Fig. 1), especially for 'Valencia Tuxpan' trees. Similarly to 'Santa Cruz' Rangpur lime, 'Sunki Tropical' mandarin induced high yield efficiencies and cumulative yields (except for 'Valencia Tuxpan' trees), but showed a lower survival rate after eight years than other rootstocks (Table 1).

Concerning fruit quality, significant differences between rootstocks were observed only in 2014 for all the three scion varieties and, in 2015, only 'Valencia Tuxpan' trees showed differences in just two variables (Table 3). In 2014, the fruits of trees grafted on VKL x RPL – 010 hybrid showed less juice, while those of trees grafted on HTR-051 hybrid presented higher total soluble solids than on other rootstocks, regardless the scion variety. Titratable acidity varied greatly among the rootstocks used, in contrast to ascorbic acid content and 'ratio' that did not show significant variations. França et al. (2016) also observed changes due to rootstocks in the juice content, total soluble solids and technological index in fruits of 'Valencia Tuxpan'. According to Castle (1995), rootstock effects on fruit juice quality are consistent, although dependent on annual climatic variations and edaphic conditions, for they seem to be dependent of water relations.

The rootstock HTR-051 induced similar characteristics to all three sweet oranges, especially in fruit quality (high juice content and total soluble solids). It induced low tree sizes and cumulative yields associated to high yield efficiencies for 'Sincora' and 'Valencia Tuxpan' sweet oranges, contrasting with 'Pineapple', where this rootstock did not increase the yield efficiency. On the other hand, 'Santa Cruz' Rangpur lime performed differently with each scion. Comparatively, it favored small plants, low cumulative yield and high yield efficiency for 'Sincora'; large plants and high yield for 'Valencia Tuxpan'; and medium height, canopy volume and cumulative yield for 'Pineapple'. 'Red Rough' lemon induced large plant sizes and medium values for all other variables for the most scions.

From a practical standpoint, survival rate is an important attribute of a scion-rootstock combination. Although difficult to determine the causes, some sweet oranges grafted on 'Red Rough' lemon, 'Orlando' tangelo and 'Sunki Tropical' mandarin (Table 1) seems to have died as consequence of Citrus Blight Disease. According to Srivastava and Singh (2009), a clay gradient and compaction hardpan in subsurface are among the abiotic factors that favor this disease. Such conditions are characteristic of hardsetting soils of Coastal Tablelands.

5. Conclusions

(1) The sweet oranges 'Sincora', 'Valencia Tuxpan' and 'Pineapple', cultivated under rainfed system on tropical hardsetting soils of the

Brazilian Coastal Tablelands, have a productive potential depending on the used rootstock.
(2) 'Red Rough' lemon induces high cumulative yield to 'Sincora', 'Valencia Tuxpan' and 'Pineapple' sweet oranges in conventional planting density (416 plants ha^{-1});
(3) 'Santa Cruz' Rangpur lime induces high cumulative yield along with fruits of high quality in 'Sincora', 'Valencia Tuxpan' and 'Pineapple' sweet oranges in conventional planting density;
(4) 'Sunki Tropical' mandarin and VKL x RPL-010 hybrid induce, respectively, high juice content and survival rate;
(5) HTR-051 trifoliate hybrid induces low height and canopy volume, high yield efficiency, survival rate and fruits of superior quality in 'Sincora', 'Valencia Tuxpan' and 'Pineapple' sweet oranges, suggesting it's potential for being cultivated in orchards using high density plantings (more than 416 plants ha^{-1}).

Conflict of interest

The authors declare that they have no conflict of interest

Acknowledgments

This research was supported byEMBRAPA grant number 02.13.13.005.00.00.

References

Almeida, C.O. de, Passos, O.S., 2011. Citricultura brasileira em busca de novos rumos: Desafios e oportunidades na região nordeste. Embrapa Mandioca e Fruticultura, Cruz das Almas, pp. 145 2011.
Araujo, Q.R., Comerford, N.B., Ogram, A.V., Al-Agely, A., Santos Filho, L.P., Santos, J.G., 2005. Soil carbon and physical property changes in Brazilian Coastal Tableland soils with land use following deforestation. Agrofor. Syst. 63, 193–198. https://doi.org/10.1007/s10457-004-3198-7.
Auler, P.A.M., Fiori-Tutida, A.C.G., Tazima, Z.H., 2008. Comportamento da laranjeira 'Valencia' sobre seis porta-enxertos no noroeste do Paraná. Revista Brasileira de Fruticultura 30, 229–234. https://doi.org/10.1590/S0100-29452008000100042.
Barry, G.H., Castle, W.S., Davies, F.S., 2004. Rootstocks and plant water relations affect sugar accumulation of citrus fruit via osmotic adjustment. J. Am. Soc. Hortic. Sci. 129, 881–889.
Carvalho, L.M. de, Varvalho, H.W.L. de, Soares Filho, W. dos S., Martins, C.R., Passos, O.S., 2016a. Porta-enxertos promissores, alternativos ao limoeiro 'Cravo', nos Tabuleiros Costeiros de Sergipe. Pesquisa Agropecuária Brasileira 51, 132–141. https://doi.org/10.1590/S0100-204X2016000200005.
Carvalho, H.W.L. de, Martins, C.R., Teodoro, A.V., Soares Filho, W. dos S., Passos, O.S., 2016b. Agronomical performance of 'Piemonte' mandarin grafted on several rootstocks in the Brazilian Coastal Tablelands. Pesquisa Agropecuária Brasileira 51, 1830–1838. https://doi.org/10.1590/s0100-204x2016001100005.
Castle, W.S., 1995. Rootstock as a fruit quality factor in citrus and deciduous tree crops, New Zealand. J. Crop Hortic. Sci. 23, 383–394. https://doi.org/10.1080/01140671.1995.9513914.
Castle, W.S., Baldwin, J.C., Muraro, R.P., Littell, R., 2010. Performance of 'Valencia' sweet orange trees on 12 rootstocks at two locations and an economic interpretation as a basis for rootstock selection. HortScience (45), 523–533.
Continella, A., Pannitteri, C., Malfa, S.La, Legua, P., Distefano, G., Nicolosi, E., Gentile, A., 2018. Influence of different rootstocks on yield precocity and fruit quality of 'Tarocco Scirè' pigmented sweet orange. Sci. Hortic. 230, 62–67. https://doi.org/10.1016/J.SCIENTA.2017.11.006.
Daniells, I.G., 2012. Hardsetting soil: a review. Soil Res. 50, 349–359. https://doi.org/10.1071/SR11102.
Erismann, N.M., Machado, E.C., Tucci, M.L.S., 2008. Photosynthetic limitation by CO2 diffusion in drought stressed orange leaves on three rootstocks. Photosyn. Res. 96, 163–172.
Fao, 2017. Faostat. http://www.fao.org/faostat/en/#data/QC.
França, N.O. de, Amorim, M. da S., Girardi, E.A., Passos, O.A., Soares Filho, W. dos S., 2016. Performance of 'Valencia tuxpan' sweet orange grafted onto 14 rootstocks in northern Bahia, Brazil. Revista Brasileira de Fruticultura 38, e–684. https://doi.org/10.1590/0100-29452016684.
Gomes, J.B.V., Araújo Filho, J.C., Vidal-Torrado, P., Cooper, M., Silva, E.A., Curi, N., 2017. Cemented horizons and hardpans in the coastal tablelands of Northeastern Brazil. Revista Brasileira de Ciência de Solo 41, e0150453.
IBGE, 2016. Produção Agrícola Municipal. www.sidra.ibge.gov.br/bda/pesquisa.
Mattos Junior, de Negri, D., de Figueiredo, J.D., de Pompeu, J.O., Junior, J., 2005. Citros: principais informações e recomendações de cultivo. http://www.iac.sp.gov.br/imagem_informacoestecnologicas/43.pdf&.
Lima, C.F., Marinho, C.S., Costa, E.S., Almeida, T.R.V., Amaral, C.O., 2014. Qualidade dos frutos e eficiência produtiva da laranjeira 'Lima' enxertada sobre 'Trifoliata', em cultivo irrigado. Revista Brasileira de Ciências Agrárias 9, 401–405.
Núñez, E.E., Mourão Filho, F.A.A., Stuchi, E.S., 2007. Desenvolvimento vegetativo, produção e qualidade de frutos da tangerina 'Fremont' sobre quatro porta-enxertos. Revista Brasileira de Fruticultura 29, 308–312.
Pedroso, F.K.J.V., Prudente, D.A., Bueno, A.C.R., Machado, E.C., Ribeiro, R.V., 2014. Drought tolerance in citrus trees is enhanced by rootstock dependent changes in root growth and carbohydrate availability. Environ. Exp. Bot. 101, 26–35.
Prudente, R.M., Silva, L.M.S., Sobrinho, Cunha, da, A.P., 2004. Comportamento da laranjeira Pera D6 sobre cinco porta-enxertos em ecossistema de tabuleiros costeiros. Umbaúba-SE. Revista Brasileira de Fruticultura 26, 110–112.
Schäfer, G., Bastianel, M., Dornells, A.L.C., 2001. Porta enxertos utilizados na citricultura. Ciência Rural 31, 723–733.
Sobral, L.F., Viegas, P.R.A., Siqueira, O.J.W., 2007. Recomendações para o uso de corretivos e fertilizantes no Estado de Sergipe. Embrapa Tabuleiros Costeiros, Aracaju, pp. 251.
Soares, L.A. dos A., Brito, M.E.B., Fernandes, P.D., de Lima, G.S., dos S. Soares Filho, W., de Oliveira, E.S., 2015. Crescimento de combinações copa-porta-enxerto de citros sob estresse hídrico em casa de vegetação. Revista Brasileira de Engenharia Agrícola e Ambienta l19, 211–217. https://doi.org/10.1590/1807-1929/agriambi.v19n3p211-217.
Srivastava, A.K., Singh, S., 2009. Citrus decline: soil fertility and plant nutrition. J. Plant Nutr. 32, 197–245. https://doi.org/10.1080/01904160802592706.