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Superior sweet oranges for varietal diversification of tropical rainfed orchards

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Abstract: Citrus orchards in northeastern Brazil are mostly rainfed and comprised basically of 'Pera CNPMF D-6' sweet orange budded on 'Rangpur' lime, for the drought tolerance and productivity imparted by this rootstock. Therefore, the selection of new varieties is needed to broaden the genetic basis of citrus cultivated in this region. Accordingly, this study compared vegetative, productive, and fruit quality traits of eight sweet orange scions grafted on 'Rangpur' lime over eleven years under the tropical rainfed conditions of northeastern Brazil. 'Kona' trees excelled in yield performance associated with bulk canopy, precocity, sweet fruit with intermediate acidity, and high vitamin C contents in spite of proneness to alternate yields and low ratio (maturity index). 'Valencia Montemorelos' and 'Rubi' trees, in turn, had high yield performances coupled with intermediate canopies, sweet fruit, intermediate acidity ('Rubi') and vitamin C contents, low propensity for yield fluctuation ('Valencia Montemorelos'), and high precocity ('Rubi'), albeit low ratio. Overall, our results emphasize 'Kona,' 'Valencia Montemorelos,' and 'Rubi' as superior sweet orange varieties for diversification of tropical rainfed orchards for their outstanding yield performance and good fruit quality.

1. Introduction

Brazil is the largest producer of sweet oranges [*Citrus sinensis* (L.) Osbeck] worldwide, with 578,057 ha and 16.21 million tons of fruit harvested in 2021 (FAO, 2021). The country is also the world's top exporter of orange juice. Most orchards are rainfed, and the southeast and northeast regions are the main producers nationwide, with 421,171 ha and 98,475 ha, respectively. However, the yields in the northeast (11.40 $t \cdot ha^{-1}$)

are only a third of those in the southeast (IBGE, 2019).

Lower yields in northeastern Brazil stem mainly from soils with fertility restrictions and hardsetting layers that impair drainage and root development in addition to water deficits due to irregular rainfall distribution, low technology adoption, improper management practices, and aging plants (Gomes *et al.,* 2017; Carvalho *et al*., 2020; Martins *et al*., 2020). Despite water deficit negatively affecting citrus yields, citriculture in Brazil is predominantly rainfed (Carvalho *et al*., 2019 a, 2020, 2022). Water stress linked to climate change is predicted to increase and affect the citrus industry worldwide (Fares *et al.*, 2017). In addition to these constraints, most citrus orchards in this region comprise 'Pera CNPMF D-6' sweet orange (referred to as 'Pera') budded on 'Rangpur' lime (*C. limonia* Osbeck), which is a graft-compatible rootstock that confers good tolerance to drought, quality to fruits, and yield to scions (Carvalho *et al.*, 2020). 'Pera' has a medium-sized canopy and is classified as a mid-season maturating variety beginning in July with fruit suited for both *in natura* consumption and juice production (Carvalho *et al*., 2019 b).

However, broadening the genetic diversity of scions could increase the much-needed fruit yield and quality to enhance the competitiveness of farms in this region. Accordingly, in 2008, the Brazilian Agricultural Research Corporation (Embrapa) established a comprehensive research project aimed at varietal diversification with scion-rootstock combinations for rainfed citrus orchards in the coastal tablelands of northeastern Brazil. As a result, new combinations of sweet oranges and rootstocks have been selected for cultivation in this area (Carvalho *et al.*, 2019 b, 2020, 2022). Herein, we recommend new varieties of sweet oranges for the diversification of tropical rainfed orchards. To this end, we conducted comparative vegetative, productive, and fruit quality trait assessments among eight sweet orange scions grafted on 'Rangpur' lime over eleven years in Brazil's northeastern region.

2. Materials and Methods

Site description and experimental design

The study was conducted from 2008 to 2019 at the experimental station of Embrapa in Umbaúba (11° 22' 37'' S, 37° 40'' 26'' W; 109 m a.s.l.), Sergipe State, in the coastal tablelands of northeastern Brazil. The study site soil is an Haplic Acrisol (Ultisol), which is a reddish-yellow acid soil with medium texture, a clay-rich B horizon (Kaolinite). According to soil analyses at 0-20 cm depth, the pH is 6.72, phosphorus 13.5 $mg \cdot dm^3$, organic matter 21.2 $g.kg^1$, potassium 0.23 $g.kg^1$, Calcium 2.22 $g.kg^1$, Magnesium 0.86 $g.kg^1$, and base saturation (74%). The climate is classified as "As" according to Köppen-Geiger, with a rainy period from May to September. Rainfall was recorded over the study period, with an annual mean of 1309 (±275) mm. The yearly rainfall and potential evapotranspiration patterns over the study period are shown in figure 1 a.

The experimental orchard consisted of eight sweet orange scions grafted onto 'Rangpur' lime in a randomized complete block design, with three replicates and three trees per plot. The orchard was planted at a density of 416 plants ha^{-1} (6.0×4.0 m) under rainfed conditions, but plants received 6 l of water weekly in the driest months. The orchard was annually fertilized according to the recommendation for sweet oranges in this region (Carvalho *et al.,* 2022). Pest and weed control treatments with registered pesticides as well as pruning were also conducted whenever necessary. The orchard was fertilized twice a yer based on soil analysis and soil acidity was corrected by the application of dolomitic limestone. The scions were 'Kona', 'Rubi', 'Valencia Montemorelos', 'Pera', 'Natal CNPMF-112', 'Sukkari', 'Lima Verde' and 'Lima', and were obtained from the Embrapa Mandioca e Fruticultura breeding program. These varieties hold potential for diversifying

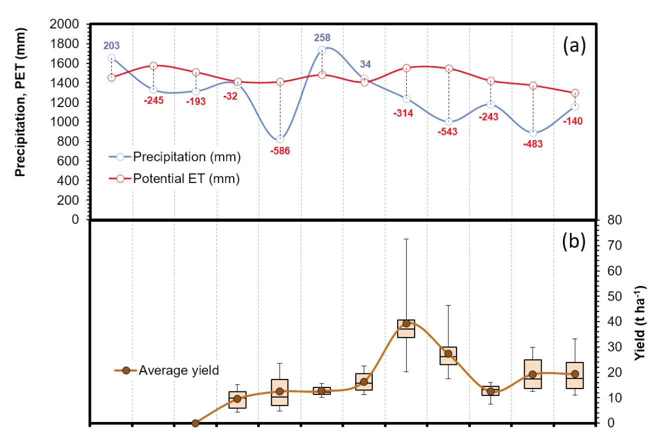

Fig. 1 - Water balance measured by the difference between rainfall and potential evapotranspiration (PET) (a) and box-plot chart of citrus yield for all observations during the experimental period (b) (2008-2019).

orchards in the study region that are dominated by 'Pera' sweet orange, therefore their agronomical performances under rainfed field conditions were assessed.

Vegetative performance and fruit yields

Vegetative growth of scions was evaluated in 8-year-old trees in 2016 by recording plant height (PH, in m), rootstock (RD, in m) and scion diameters (SD, in m), and by estimating canopy volume (CV, in m^3) as per Zekri (2000).

Productive performance was assessed by fruit yield (FY, in $t \cdot ha^{-1}$) from the first harvest in 2011 to 2019, and yield efficiency (YE, in $kg \cdot m^{-3}$) was estimated in 2016 by the quotient between per plant fruit production and canopy volume. The alternate bearing index (ABI) was estimated using FY from 2011 to 2019 using the following formula (Monselise and Goldschmidt, 1982):

$$ABI = \frac{\sum_{(i=2)}^{n} \frac{|Y_i - Y_{i-1}|}{(Y_{i+1} + Y_{i-1})}}{n-1} \qquad \text{Equation (1)}$$

where n denotes years and Y_i is the yield in year i. Precocity (Prec., in %) estimates considered the ratio between FY in the first two harvests and the cumulative yield (CY; 2011 to 2019).

Fruit quality

The quality was appraised in nine randomly chosen fruits per plant from the 2015 and 2016 harvests as follows: fruit weight (FW, in $g \cdot fruit^{-1}$), diameter (FD, in mm), and height (FH, in mm), as well as rind thickness (RT, in mm) as measured by a caliper, juice content (JC, in $g \cdot 100\ g^{-1}$ of fruit mass), total titratable acidity (TTA) was measured with 0.1 mol L^{-1} NaOH as titrant and given in g of citric acid per 100 mL of juice, total soluble solids (TSS, in °Brix) using a refractometer, and vitamin C content (Vit. C, in $mg \cdot 100\ mL^{-1}$ of juice) as measured by the oxidation-reduction volumetric technique using potassium iodate solution. The ratio, or maturity index, was estimated as the quotient between TSS and TTA. All measurements followed the methods described by França *et al*. (2016).

Statistical procedures

Data were subjected to ANOVA, and means were grouped by Scott-Knott analysis. Multivariate analyses were also performed using XLSTAT to identify homogenous groups of scions, considering only the variables that were significant in univariate analyses. Briefly, a principal component analysis (PCA) was used to shorten the dataset into synthetic and uncorrelated variables, that is, the first principal component (Carvalho *et al*., 2019 a). Afterwards, the scions were grouped by agglomerative hierarchical clustering analysis (AHC) applied to the PCA scores that complied with the Kaiser criterion, that is, those whose eigenvalues were ≥1.0. Euclidean distance was used as a measure of dissimilarity, and Ward's minimum variance was used to identify clusters. The automatic truncation option was used for cluster splitting. This approach creates homogenous groups based on the largest decrease in Shannon's entropy between a node and the next one. The resulting clusters were interpreted using PCA results and put into perspective with the results of univariate analyses of variance (Carvalho *et al*., 2019 a).

3. Results

Vegetative performance

PH, RD, SD, and RD/SD girth ratio were not influenced by scions (data not shown, $p < 0.05$). Although not significantly different, PH varied from 2.5 m ('Lima') to 3.5 m ('Kona'), and RD/SD girth ratio from 1.19 ('Valencia Montemorelos') to 1.68 ('Lima'). However, 'Kona' trees were characterized by the largest CVs (26.3 m^3); 'Valencia Montemorelos' (19.0 m^3), 'Rubi' (18.5 m^3), and 'Sukkari' (17.1 m^3) had intermediate values, while 'Pera' (15.5 m^3), 'Lima Verde' (15.1 m^3), 'Natal CNPMF-112' (14.3 m^3), and 'Lima' (11.4 m^3) presented the smallest canopy volumes (p<0.0001).

Fruit yields

The annual water balance over the experimental period was predominantly negative, reaching deficits of 586 and 543 mm in the driest years of 2012 and 2016, respectively (Fig. 1 a). Considering yield performance, the production peak of sweet oranges was generally achieved in the fifth harvest (2015), decreased until 2017, and stabilized thereafter (Fig. 1 b, Table 1). 'Kona' trees exhibited the highest mean yields over nine years, followed by 'Valencia Montemorelos' and 'Rubi'. 'Pera' which is the main sweet orange grown in the study region, had intermediate yields while 'Lima' and 'Lima Verde' were the least productive (Table 1). Except for 'Lima Verde' with the lowest values, all varieties had similar yield efficiencies. 'Lima Verde', Natal CNPMF-112',

Table 1 - Yield performance of eight sweet orange varieties budded on 'Rangpur' lime (2008-2019)

	Fruit yield (t·ha^{-1})										YE[y]	ABI[x]	Prec.[w] (%)
	2011	2012	2013	2014	2015	2016	2017	2018	2019	Mean			
Kona	12.1 c [z]	23.5 a	11.7 b	19.1 b	72.5 a	46.4 a	14.0 b	29.8 a	33.2 a	29.2 a	4.27 a	0.33 c	13.6 c
Lima	4.3 f	4.7 e	10.1 b	12.0 d	34.4 c	17.6 d	7.4 d	13.8 d	13.9 d	13.1 e	3.73 a	0.27 b	7.6 e
Lima Verde	4.2 f	4.8 e	12.2 b	11.2 d	31.8 c	17.5 d	8.9 d	12.6 d	10.9 d	12.7 e	2.79 b	0.24 a	7.9 e
Natal CNPMF-112	13.5 b	7.6 d	10.3 b	15.2 c	20.1 d	24.8 c	11.6 c	13.2 d	23.2 b	15.5 d	4.26 a	0.20 a	15.2 b
Pera CNPMF D-6	8.0 d	15.4 b	13.8 a	15.9 c	39.4 b	25.4 c	15.5 a	14.0 d	12.8 d	17.8 c	3.98 a	0.19 a	14.6 b
Rubi	11.6 c	23.0 a	15.6 a	20.8 a	40.7 b	26.8 c	12.7 c	24.7 b	15.2 d	21.2 b	3.53 a	0.26 b	18.1 a
Sukkari	6.5 e	11.8 c	12.2 b	13.3 d	34.8 c	29.9 b	13.6 b	25.3 b	20.0 c	18.6 c	4.37 a	0.22 a	10.9 d
Valencia	15.2 a	8.9 d	15.0 a	22.5 e	40.8 b	30.1 b	15.9 a	20.7 c	25.9 b	21.7 b	3.83 a	0.21 a	12.3 c
CV (%)	10.9	14.7	15.4	8.9	9.9	5.8	8.7	10.7	17.4	4.3	13.5	8.6	7.8
F	51.3	50.4	3.32	24.8	44.2	99.7	23.7	32.3	15.6	135.0	2.99	14.9	40.5
p-value	<0.0001	<0.0001	0.027	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.038	<0.0001	<0.0001

[z] Means in the same column followed by the same letter are not significantly different according to the Scott-Knott analysis (p<0.05).
[y] Yield efficiency; [x] Alternate Bearing Index;
[w] Precocity.

'Pera', 'Sukkari' and 'Valencia Montemorelos' were less prone to alternate bearing. 'Rubi' appeared to have the highest precocity (Prec.) for the ratio between the first two harvests and the CY. However, 'Kona' and 'Rubi' presented the highest absolute yields in 2011-2012 with more than 30 t·ha^{-1} (Table 1).

Fruit quality

Regarding fruit quality, 'Lima' had a smaller fruit than the other scions. 'Rubi' fruit had the thickest rind in contrast to 'Lima Verde', which had the thinnest. Fruit of 'Natal CNPMF-112' and 'Valencia Montemorelos' showed the highest citric acid content, followed by those of 'Kona', while 'Lima', 'Lima Verde' and 'Sukkari' exhibited the least acid fruit. 'Kona', 'Lima', 'Natal CNPMF-112', 'Rubi', 'Sukkari' and 'Valencia Montemorelos' produced sweeter fruit than the remaining scion varieties (Table 2). Additionally, 'Kona' and 'Lima' had the highest vita-

Table 2 - Attributes of fruit quality of eight sweet orange varieties budded on 'Rangpur' lime (Average 2015-2016)

Orange varieties	Mean FW (g·fruit^{-1})	Fruit diameter (mm)	Fruit height (mm)	Rind thickness (mm)	Juice content (g·kg^{-1})	TTA (g·100 mL^{-1})	TSS (°Brix)	Vitamin C (g·100 g^{-1})	Ratio TSS/TTA
Kona	190	76.3	71.0 a [z]	3.81 b	545	0.798 b	11.5 a	60.0 a	14.5 c
Lima	193	70.0	60.8 b	3.34 c	544	0.128 d	11.3 a	58.3 a	88.0 b
Lima Verde	190	74.6	72.7 a	2.60 d	579	0.097 d	8.9 b	40.6 d	93.2 a
Natal CNPMF-112	180	72.9	69.8 a	3.59 b	572	1.208 a	12.3 a	52.3 b	10.4 c
Pera CNPMF D-6	205	74.9	75.6 a	3.12 c	548	0.670 c	8.9 b	43.5 d	14.7 c
Rubi	187	75.9	70.0 a	4.15 a	539	0.617 c	11.3 a	49.2 c	18.7 c
Sukkari	189	72.9	67.0 a	3.08 c	544	0.114 d	10.5 a	54.1 b	93.7 a
Valencia Montemorelos	188	72.1	69.6 a	2.99 c	549	1.180 a	11.0 a	53.4 b	9.6 c
CV (%)	8.2	3.5	5.9	6.0	4.2	11.0	7.2	7.1	8.2
F	0.63	2.01	3.38	18.62	1.15	142.1	7.56	10.00	397.2
p-value	0.723	0.126	0.025	<0.0001	0.385	<0.0001	0.0007	0.0002	<0.0001

[z] Means in the same column followed by the same letter are not significantly different according to the Scott-Knott analysis (p<0.05).
TTA= Total titratable acidity;
TSS = Total soluble solids.

min C contents, whereas 'Lima Verde' and 'Pera' had the lowest values. 'Sukkari' and 'Lima Verde' followed by 'Lima' had the highest values of ratio, a proxy for fruit maturity (Table 2). FW, FD, and JC were not affected by scions (Table 2).

Multivariate analyses

Multivariate analysis helped to identify scion groups that performed homogeneously, considering the universe of all significant attributes. The first two PCA principal components explained more than 66% of the total observed variability, and the square cosine of the variables showed that, while average yield, CV, TTA, Prec., RT, TSS, and ratio were mostly associated with PC1, FH, alternate bearing, and vitamin C contributed to most of the variation along PC2 (Fig. 2 a).

Multi-correlation analysis indicated that average yield correlated positively with CV and that Prec. exhibited a positive correlation with total acidity, but both correlated negatively with ratio. In addition, while alternate bearing correlated positively with vitamin C, it had a negative correlation with FH (Fig. 2 a).

Agglomerative hierarchical clustering analysis (AHC) using Shannon entropy for grouping all observations that showed similar results for the entire set of variables identified three distinct clusters (Fig. 2 c) with the following characteristics, as observed through the visual inspection of the observation cloud projection in the plane of the first two principal components of the PCA (Fig. 2 b). The heatmap of the results for all variables is shown in figure 2 c.

The first cluster grouped all observations of 'Kona' and its main characteristics were high and alternate yields associated with bulk canopy and high vitamin C content; intermediate values for TSS, RT, Prec., acidity, FH, and low ratio.

The second cluster included the observations of 'Valencia Montemorelos', 'Rubi', 'Pera' and 'Natal CNPMF-112'. In general, these varieties showed intermediate values for all evaluated variables except ratio, which were mostly low for this cluster.

Finally, the third cluster encompassed all observations of 'Sukkari', 'Lima Verde', and 'Lima'. In contrast to the first and second clusters, the main characteristic was that the ratio was high for all observations and average yield, CV, RT, and acidity were predominantly low. Intermediate values were observed for alternate bearing, vitamin C, TSS, and FH.

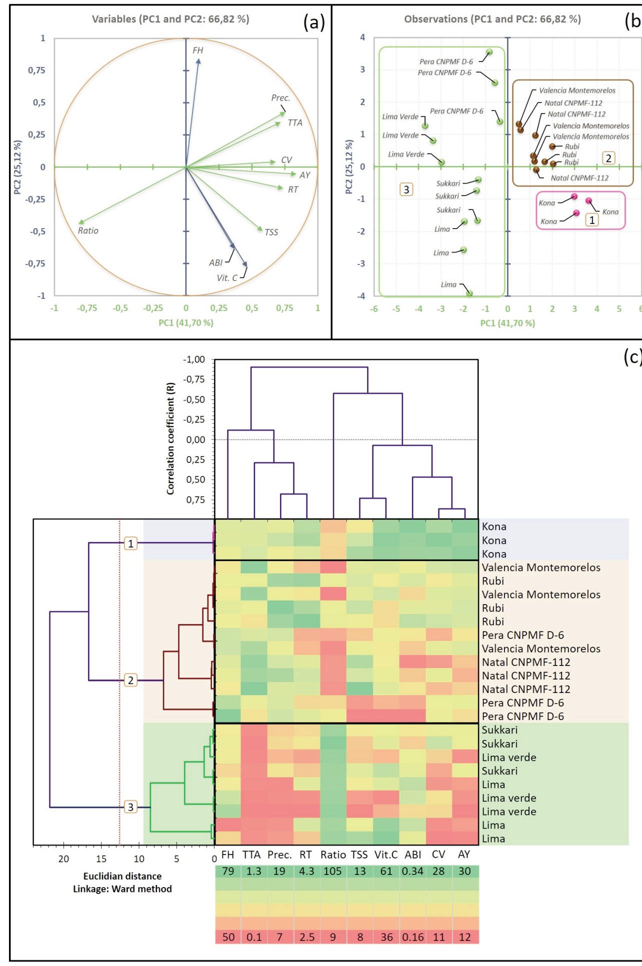

Fig. 2 - Principal Component and Agglomerative Hierarchical Clustering Analysis. (a) Correlation Circle of the variables; (b) Score plot of the observations in the plane of the two first Principal Components and (c) Heatmap of the relative values of all observations for all variables and group separation by the Agglomerative Hierarchical Clustering analysis (AHC). The first two axes (PC1 and PC2) accounted for 66.82% of the total variance. Arrows in green represent variables associated with PC1 whereas those in blue are associated with PC2 in figure a. Observations belonging to different groups by the AHC analysis were delineated (boxes) in figure b. CV: Canopy volume; AY: Average yield; ABI: Alternate Bearing Index; Vit.C: Vitamin C content; TSS: Total soluble solids content; RT: Rind thickness; Prec.: Precocity; TTA: Total titratable acidity; FH: Fruit height.

4. Discussion and Conclusions

Here, we comparatively assessed vegetative, productive, and fruit quality traits among eight sweet orange scions grafted on 'Rangpur' lime for enhancing orchard varietal diversification under the tropical rainfed conditions of northeastern Brazil. Overall, the varieties reached peak yields in the fifth harvest, and subsequently decreased. The same pattern was observed for 'Sincora,' 'Valencia Tuxpan,' and 'Pineapple' sweet oranges in the same study region (Carvalho *et al*., 2019 a; Martins *et al*., 2020). As the experimental orchard was cultivated under rainfed conditions, predominantly negative yearly water balances possibly interfered with the productive potential of the different varieties. Major drought spells occurred in 2012, 2016, and 2018, with water deficits exceeding 480 mm. Water stress strongly impairs growth and development of citrus trees and sweet orange varieties commonly present water deficiency symptoms throughout the study region even when scions are grafted on drought-tolerant 'Rangpur' lime, which emphasizes the severe seasonal drought rainfed orchards face (Soares *et al*., 2015; Carvalho *et al*., 2016). As we did not specifically evaluate drought tolerance, further studies are needed to shed light on the susceptibility of sweet orange varieties to drought.

Comparatively, 'Kona' was the most productive variety, with an annual average of 29.2 $t{\cdot}ha^{-1}$ of fruit. 'Valencia Montemorelos' (21.7 $t{\cdot}ha^{-1}$) and 'Rubi' (21.2 $t{\cdot}ha^{-1}$) also had remarkable yield performances. The high fruit yield of 'Valencia Tuxpan' grafted on 'Santa Cruz Rangpur' lime was also verified by Carvalho *et al*. (2019 a). Similarly, 'CNPMF 003 Rangpur' lime and 'Santa Cruz Rangpur' lime rootstocks conferred high yields to 'Valencia' in Brazil's southeastern state of São Paulo (Fadel *et al*., 2018). The dominantly grown 'Pera', however, was characterized by intermediate yields. 'Kona' trees produced 72.5 $t{\cdot}ha^{-1}$ at its peak, and alongside 'Rubi' excelled in precocity, with yields that surpassed 23 $t{\cdot}ha^{-1}$ in the second harvest. Apart from 'Lima Verde' with lower values, all varieties had similar yield efficiencies despite the sharp differences in canopy volumesCVs. For instance, 'Kona' trees had the largest canopies (26.3 m^3) in contrast with 'Lima' (11.4 m^3) and 'Pera' (15.5 m^3). This is consistent with similar yield efficiencies of 'Pineapple' sweet orange irrespective of the grafted rootstock in the same study region (Martins *et al*., 2020). It is noteworthy that after the two driest years (2012 and 2016), the most productive varieties were 'Pera' and 'Valencia Montemorelos'. Melgar *et al.* (2010) showed that 'Valencia' sweet orange trees [grafted on 'Swingle' citrumelo *C. paradisi* Macfad. x *Poncirus trifoliata* (L.) Raf.] that experienced drought for a hundred days and were well irrigated in subsequent months produced more fruit than those that were not subjected to water stress.

Alternate bearing is a widespread phenomenon among fruit trees in which high yield in one harvest is followed by low production in the subsequent harvest (Monselise and Goldschmidt, 1982). Alternate bearing is an undesirable trait from an economic standpoint, especially for mandarins and tangerines, but generally a minor to moderate problem for sweet oranges such as 'Valencia' (Monselise and Goldschmidt, 1982; Abobatta, 2019). Alternate bearing in citrus is caused by fruit load inhibiting return flowering (Abobatta, 2019) and seemed here to be variety-specific, as 'Kona' possessed high propensity for yield alternation in contrast with less-prone 'Lima Verde', 'Natal CNPMF-112', 'Pera', 'Sukkari' and 'Valencia Montemorelos'. 'Lima' and 'Rubi', in turn, had an intermediate degree of susceptibility to yield alternation. Nutrition, hormones, and abiotic stresses ranging from soil fertility and physical restrictions to drought susceptibility might also have played a role in yield fluctuation (Monselise and Goldschmidt, 1982; Abobatta, 2019; Carvalho *et al*., 2019 a, 2020).

Fruit quality is expressed by several parameters including the amount of juice, TSS content, acidity level, and the amount of vitamin C (França *et al*., 2016; Lado *et al*., 2018; Tirado-Corbalá *et al*., 2020). Moreover, the TSS content is the basis for the payment of a premium price differential for high-quality fruit (Zhang and Ritenour, 2016). The ratio, or maturity index, expresses fruit ripeness and is also an indicator of flavor (Lado *et al*., 2018; Ribeiro *et al*., 2020). These fruit quality traits may be influenced by the scion variety, management practices, maturity level, climate, and rootstocks (Al-Mohuei and Choumane, 2014; Carvalho *et al*., 2020; Ribeiro *et al*., 2020; Tirado-Corbalá *et al*., 2020). Here, we showed that FW, FD, and juice yield did not differ among the sweet orange varieties. However, 'Lima' trees produced smaller fruit than the other varieties. 'Rubi' produced the thickest and 'Lima Verde' the thinnest fruit rinds. 'Lima Verde' and 'Pera' produced the least sweet fruit, while 'Natal CNPMF-112' and 'Valencia Montemorelos' were the most acidic. The high fruit acidity of 'Valencia' grafted on 'Santa Cruz Rangpur' lime was also demonstrated by Rodrigues *et al*. (2019).

There is evidence that rainfed orchards generally produce sweeter fruit, as lower juice yields related to water deficits favor sugar concentration (Lado *et al*., 2018). This is in line with higher fruit sugar contents of ‘Valencia’ trees subjected to deficit irrigation treatments in Italy (Mossad *et al.*, 2020). The ratio, or maturity index, was highest for ‘Lima Verde’ and ‘Sukkari’, which can be related to their lower acidity levels. ‘Kona’ and ‘Lima’ fruit had the highest contents of vitamin C as opposed to the lowest values for ‘Lima Verde’ and ‘Pera’. Generally, the juice yields, TSS, and ratio values obtained here were within the minimal requirements for Brazilian fresh orange markets.

Multivariate analyses showed that fruit quality traits were mostly associated with PC1 (RT, TTA, TSS and ratio) while FH and Vit. C were strongly related to PC2. Ratio was negatively related to RT and especially to TTA. TSS, in turn, was associated with the majority of fruit quality traits, being negatively related to FH (smaller fruit, higher TSS) and positively with RT, TTA and Vit. C. However, TSS was not related to ratio. PC2, which accounted for 25% of variability, was negatively related with FH and Vit. C contents, suggesting that smaller fruit concentrate more Vit. C.

Collectively, our results obtained in northeastern Brazil highlight ‘Kona’, Valencia Montemorelos’ and ‘Rubi’ as superior sweet orange varieties for diversification of tropical rainfed orchards. ‘Kona’ excelled in productive performance combined with a voluminous canopy, precocity, sweet fruit with moderate acidity, and high levels of vitamin C despite the propensity for alternate yields and low ratio. ‘Valencia Montemorelos’ and ‘Rubi’ had high yield performances coupled with intermediate canopies, sweet fruit, moderate acidity (‘Rubi’) and vitamin C levels, low proneness for yield fluctuation (‘Valencia Montemorelos’), and high precocity (‘Rubi’), despite a low ratio.

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