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Nonparametric indices for the selection of hybrid citrus as rootstocks grafted with 'Valência' sweet orange

Danilo Pereira Costa[(1)],
Lucas de Oliveira Ribeiro[(2)],
Maurício Antônio Coelho Filho[(3)],
Carlos Alberto da Silva Ledo[(3)],
Eduardo Sanches Stuchi[(3 ✉)],
Eduardo Augusto Girardi[(3)],
Abelmon da Silva Gesteira[(3)] and
Walter dos Santos Soares Filho[(3)]

[(1)] Universidade Estadual de Santa Cruz, Campus Soane Nazaré de Andrade, Rodovia Jorge Amado, Km 16, Salobrinho, CEP 45662-900 Ilhéus, BA, Brazil. E-mail: danilocosta_1739@hotmail.com

[(2)] Universidade Federal do Recôncavo da Bahia, Rua Rui Barbosa, nº 710, Centro, CEP 44380-000 Cruz das Almas, BA, Brazil. E-mail: lucasdeoliveira2@yahoo.com.br

[(3)] Embrapa Mandioca e Fruticultura, Rua Embrapa, s/nº, Centro, CEP 44380-000 Cruz das Almas, BA, Brazil. E-mail: mauricio-antonio.coelho@embrapa.br, carlos.ledo@embrapa.br, eduardo.stuchi@embrapa.br, eduardo.girardi@embrapa.br, abelmon.gesteira@embrapa.br, walter.soares@embrapa.br

✉ Corresponding author

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Abstract – The objective of this work was to evaluate five nonparametric selection indices for the selection of hybrid citrus rootstocks grafted with 'Valência' sweet orange, using horticultural traits relevant for the juice processing industry. Forty-six rootstocks were evaluated in a randomized complete block design, with three replicates and five trees in the plot, in the period from 2009–2015, in a rainfed cultivation. The means of the variables plant height, accumulated fruit yield, fruit yield efficiency, total soluble solids concentration, juice yield, and drought-tolerance were used to calculate the following indices: multiplicative index (I_{Ei}), sum of classification (I_{MMi}), genotype-ideotype distance (D_{iI}), and ranking indices (I_{RKi}, based on simple means; and I_{RKii}, based on linear normalization). The indices were efficient to classify the hybrids in relation to general performance. Spearman's correlation showed a high similarity between most nonparametric indices, notably between I_{RKi} and I_{RKii}. The ranking indices, mainly I_{RKii}, provide a more coherent classification of the hybrids, which allows of the selection of more productive and drought-tolerant rootstocks to produce high-quality fruit for processing.

Index terms: *Citrus*, *Poncirus trifoliata*, breeding, genetic variability, selection index.

Índices não paramétricos para seleção de citros híbridos como porta-enxertos, enxertados com laranjeira 'Valência'

Resumo – O objetivo deste trabalho foi avaliar cinco índices de seleção não paramétricos para a seleção de citros híbridos como porta-enxertos, enxertados com laranjeira 'Valência', com base em atributos horticulturais relevantes para a indústria de processamento de suco. Avaliaram-se 46 porta-enxertos em delineamento de blocos ao acaso, com três repetições e cinco plantas na parcela, no período de 2009–2015, em cultivo de sequeiro. As médias das variáveis altura de planta, produção acumulada de frutos, eficiência produtiva de frutos, concentração de sólidos solúveis totais, rendimento de suco e tolerância à seca foram utilizadas para calcular os seguintes índices: multiplicativo (I_{Ei}), soma de classificação (I_{MMi}), distância genótipo-ideótipo (D_{iI}) e ranqueamento (I_{RKi}, baseado em médias simples; e I_{RKii}, baseado em normalização linear). Os índices foram eficientes em classificar os híbridos em relação ao desempenho geral. A correlação de Spearman mostrou alta similaridade entre a maioria dos índices não paramétricos, notadamente entre I_{RKi} e I_{RKii}. Os índices de ranqueamento, principalmente o I_{RKii}, fornecem uma classificação mais coerente dos híbridos, o que permite a seleção de porta-enxertos mais produtivos e tolerantes à seca, para a produção de frutas de alta qualidade para processamento.

Termos de indexação: *Citrus*, *Poncirus trifoliata*, melhoramento, variabilidade genética, índice de seleção.

Introduction

Despite its socioeconomic importance, Brazilian citrus production is vulnerable to several abiotic and biotic stresses because of the low variability of the available genetic material, mainly of rootstock cultivars (Bastos et al., 2014). The citrus rootstock influences more than 20 characteristics of the scion variety, from drought-tolerance to pest resistance, tree size, and fruit traits (Castle, 2010). This fact poses a challenge for the appropriate selection of superior genotypes in breeding programs that, in turn, have been introducing hundreds of new hybrid rootstocks to promote varietal diversification (Soares Filho, 2012).

Traditionally, citrus rootstock breeding has been based on the massal selection of hybrid progenies obtained from crossing a female parental, preferably monoembryonic, which usually has lower-heterozygosis levels, and a male parental of *Poncirus trifoliata* (L.) Raf. (Schinor et al., 2013). However, due to the high genetic segregation of citrus (Navarro et al., 2002), obtaining hybrids that combine good performance in multiple traits is seldom an easy task. In this sense, nonparametric indices are auxiliary tools that involve the simultaneous combination of several attributes of interest, to allow a more efficient selection of promising genotypes (Vilarinho et al., 2003).

The nonparametric indices do not require the estimation of genetic parameters and can be used for random samples, selected genotypes, or hybrids, that is, fixed samples (Vilarinho et al., 2003). Some indices that are frequently used to assist the breeding of annual and perennial crops (Ferreira et al., 2005; Lessa et al., 2010; Dovale et al., 2011; Almeida et al., 2014; Lessa et al., 2017) are the following: the multiplicative index (Elston, 1963), the classification sum index (Mulamba & Mock, 1978), and the genotype-ideotype distance (Schwarzbach, 1972).

Few papers have reported the application of nonparametric indices to select citrus genotypes. Selection is commonly based on the empiric experience of the breeder, as well as on classic univariate analyses of extensive datasets and, in some cases, on multivariate analyses. However, the interest in indices to assist citrus breeding is increasing, as for instance, by the following authors: Caputo et al. (2012), who used a performance index to select early-ripening sweet orange cultivars; Yacomelo et al. (2018), who selected 'Margaritera' orange genotypes through an index based on fruit quality traits; and Costa et al. (2016), who classified hybrid citrus rootstocks according to a ranking index. Selection indices should consider variables that are highly relevant for the market acceptance, such as juice content and quality, fruit yield, a high-canopy production efficiency, dwarfism, and drought-tolerance (Auler et al., 2008; Tazima et al., 2008; Castle, 2010; Khalid et al., 2012). Therefore, different selection indices should be investigated for key traits, in order to assess and select citrus genotypes more precisely.

The objective of this work was to evaluate five nonparametric selection indices for the selection of hybrid citrus rootstocks grafted with 'Valência' sweet orange, using relevant horticultural traits for the juice processing industry.

Materials and Methods

The datasets come from an experiment that was planted in 2007, in the municipality of Colômbia, in the state of São Paulo, Brazil (20°19'22"S, 48°41'10"W, at 492 m altitude). The scion cultivar was 'Valência' IAC sweet orange [*Citrus sinensis* (L.) Osbeck], which was grafted onto 46 citrus rootstocks, most of them were hybrids introduced or obtained by the Citrus Breeding Program of Embrapa Mandioca e Fruticultura, in the municipality of Cruz das Almas, in the state of Bahia, Brazil (Tables 1 to 5). 'Cravo Santa Cruz' Rangpur lime (*Citrus limonia* Osbeck) was the commercial standard rootstock. The experimental design was carried out in randomized complete blocks, with 46 treatments, three replicates, and five trees per plot.

The local climate type is Aw, according to the Köppen-Geiger's classification (hot rainy summer, and dry winter typical of savannah), with 1,322 mm mean annual rainfall, and 26.3°C mean annual air temperature (Cepagri, 2018). Tree spacing was 6.0x2.5 m, in a rainfed orchard on a Latossolo Vermelho escuro (Oxisol), medium texture, with moderate A layer. Crop management followed the standard recommendations for orange trees in São Paulo (Mattos Jr. et al., 2014).

In the period 2009–2017, trees were assessed annually for the following variables, which are the most important ones to the juice processing industry: accumulated fruit production (AP), determined by weighing fruit from all trees on a digital scale (kg per tree, in 2009–2015); mean canopy production efficiency (EF), calculated by the mean ratio between the annual production per tree and the annual canopy volume per tree in 2009–2015 (kg m^{-3}), and volume calculated as described by Cantuarias-Avilés et al. (2011); mean soluble solids concentration in the juice (SS) in 2009–2015, measured (°Brix) with a refractometer Palette PR-101 (Atago, Tokyo, Japan); mean juice yield (JC) in 2009–2015, calculated by the ratio between juice weight and fruit weight (%), after extraction in a semi-commercial apparatus Otto 1800 juice extractor (OIC, Limeira, SP, Brazil); mean tree height (TH), measured with a ruler (m) from the rootstock collar end to the canopy tip; and drought-tolerance (DT), visually assessed from 2010 to 2017, except for 2015, using scores from 1 to 3 according to the intensity of leaf wilting during winter months (Stuchi et al., 2000; Schinor et al., 2013). Data were subjected to the analysis of variance, to obtain the coefficient of variation and significance ($p < 0.01$ and $p < 0.05$) of the variables used in the selection indices.

The multiplicative index [I_{Ei}] (Elston, 1963) was calculated as

$$I_{Ei} = \log \prod_{j=1}^{m} (X_{ij} - k_j) = \log [(X_{i1} - k_1)(X_{i2} - k_2) \ldots (X_{in} - k_n)],$$

in which: I_{Ei} is the multiplicative index; x_{ij} is the mean of the trait j, measured in genotype I; and k_j is the lowest value to select

$$K_j = (\frac{n(\text{mín}.x_{ij} - \text{máx}.x_{ij}}{n - 1}),$$

in which: n is the number of genotypes; and min. x_{ij} and max. x_{ij} are, respectively, the lowest and the highest mean of trait j.

The classification sum index [I_{MMi}] (Mulamba & Mock, 1978) was calculated by

$$I_{MMi} = \sum_{j=1}^{m} n_{ij}$$

in which: I_{MMi} is the classification sum indices; and n_{ij} is the number of classifications of genotype i in relation to trait j.

The ranking index (I_{RK}) was modified from Costa et al. (2016), and calculated by

$$I_{RK} = (AP\times0.2) + (EF\times0.2) + (SS\times0.15) + (JC\times0.15) + (DT\times0.2) + ((1/TH)\times0.1),$$

in which: AP is the accumulated production; EF is the canopy production efficiency; SS represents the concentration of soluble solids; JC is the juice yield; DT is the drought-tolerance; and TH is the tree height.

The weights of each variable were determined according to their relevance from researcher experience. I_{RK} was calculated in two manners: I_{RKi}, using the weight sum equal to 1 (simple means of data); and I_{RKii} – whose data were subjected to linear normalization for the interval [0, 1]) – was determined by $F(x_i) = (x_i - x_{min})/(x_{max} - x_{min})$, where x_i is the numerical value of the variable for each rootstock, and x_{min} and x_{max} are the minimum and maximum values of each variable.

The genotype-ideotype distance index [D_{iI}] was determined (Schwarzbach, 1972) by the Euclidean distance according to the following equation:

$$D_{iI} = \sqrt{\sum_{j=1}^{m} d_{ij}^2}$$

in which: D_{iI} is the Euclidean distance between genotype i and ideotype I; and d_{ij} is the standard deviation between the mean of trait j, measured in genotype i (x_{ij}), and the value given to the ideotype for this trait (x_{Ij}), that is, $d_{ij} = (x_{ij} - x_{Ij}) / \sigma_j$. The standardization prevents traits measured in greater units from having greater influence than other traits on the value of the indices, and, consequently, on the genotype classification (Lessa et al., 2017).

The values given to the ideotype were based on information provided by juice processors, according to our experience, as follows: SS > 11 ºBrix, JC > 50%, AP > 250 kg per tree, EF > 4 kg m^{-3}, DT ≥ 2, and TH < 3 m. The weight given to each variable in the formula followed the empirical relative importance of the variable for the selection, as AP = EF > SS = JC > DT > TH.

After the calculation of the indices, the genotypes were classified according to the recommendations of Garcia & Souza Júnior (1999). Spearman correlation coefficients among the evaluated indices were calculated to observe the degree of agreement; and the significance of the estimates was tested at 1% and 5% probabilities (Costa Neto, 2002).

Results and Discussion

All assessed variables showed significant differences, which allowed of the ranking of the hybrid citrus rootstocks, therefore confirming the variability within the evaluated genotypes. The coefficient of variation (CV) of the variables used to calculate the indices were AP (16.13%), EF (20.37%), SS (3.37%), JC (4.13%), DT (10.37%), and TH (6.33%) (Table 1). Not only this wide genetic variability reflects the diverse parental background of the evaluated genotypes, but it is also commonly reported within populations of hybrid citrus rootstocks (Raga et al., 2012; Schinor et al., 2013).

The application of the I_{Ei} to the dataset of the evaluated variables indicated that 52.17% of the hybrid citrus rootstocks were superior to the standard 'Santa Cruz' Rangpur lime (25th position), which was the Rangpur lime with highest position. The genotypes in the five first positions in the ranking were TSKC × (LCR x TR) – 059 (1st), TSKC × CTQT 1434 – 010 (2nd), TSKC × (LCR x TR) – 017 (3rd), TSK × TR 'Benecke' – CO (4th) and 'San Diego' citrandarin (5th). Therefore, the I_{Ei} led to the selection of rootstocks that combined lower-tree height (3.14 m), intermediate accumulated production (253.8 kg per tree), high-production efficiency (3.68 kg m^{-3}), good drought-tolerance (1.98), high-SS (11.88 ^{o}Brix), and juice yield close to that of the standard genotype (48.23%) (Table 1).For the I_{MMi}, the best ranked rootstocks were TSKC × (LCR x TR) – 059 (1st), TSKC × CTQT 1434 – 010 (2nd), TSKC × (LCR x TR) – 017 (3rd), TSK × TR 'Benecke' – CO (4th) and LCR × TR – 001 (5th), in comparison to 'Cravo Santa Cruz' Rangpur lime (11st) (Table 2). Therefore, the I_{MMi} led to the selection of rootstocks combining lower-tree height (3.07 m), intermediate accumulated yield (243.15 kg per tree), high-yield efficiency (3.81 kg m^{-3}), good drought-tolerance (2.02), high-SS (11.79 ^{o}Brix), and juice yield close to that of the standard genotype (47.82%). This ranking prioritized the concentration of soluble solids and the production efficiency in a similar way to that obtained with I_{Ei}; however, some selected hybrids showed low yield due to their smaller tree size. By contrast, large-size inducing rootstocks led to low-production efficiency (Cantuarias-Avilés et al., 2011). Lessa et al. (2010) studied diploid banana hybrids, and they pointed out that the multiplicative index (I_{Ei}) and the classification sum index (I_{MMi}) also provided an adequate selection with high correlation, which allowed of a better adequacy of the results that helped with decision making.

The index I_{RKi} classified the following rootstocks as the best ones: 'Indio' citrandarin (1st), 'Sunki' × 'English Palmira' – CO (2nd), 'San Diego' citrandarin (3rd), CNPMF – 004 Rangpur lime (4th), and TSKC × CTSW – 028 (5th), which ranked ahead of the standard 'Cravo Santa Cruz' Rangpur lime (8th) (Table 3). On average, these indices clearly selected rootstocks with higher-accumulated production (308.7 kg per tree), tall trees (3.7 m) with good drought-tolerance (2.0), and juice quality (11.75 ^{o}Brix), but with lower efficiency (3.18 kg m^{-3}). Or else, when normalized means were used, I_{RKii} selected the following genotypes: 'Sunki' × 'English Palmira' – CO (1st), TSKC × (LCR x TR) – 059 (2nd), 'Indio' citrandarin (3rd), 'San Diego' citrandarin (4th), and CNPMF – 004 (5^{o}), in comparison to 'Cravo Santa Cruz' Rangpur lime (7th) (Table 4). Therefore, in relation to I_{RKi}, the index I_{RKii} led to the selection of rootstocks that combined high-accumulated production (301.84 kg per tree), intermediate to large tree height (3.57 m), better production efficiency (3.4 kg m^{-3}), good drought-tolerance (2.04), high-SS (11.82 ^{o}Brix), and juice yield near that of the standard genotype (48.03%). For both ranking indices (I_{RK}), rootstocks with low yield and low-drought-tolerance, such as 'Sunki' × 'Alemow' – CO, were in the last positions. Caputo et al. (2012) also reported that a selection index using normalized data of phenotypic variables was useful to assess sweet orange varieties that were more promising for both fresh marketing and juice processing.

The rootstocks TSKC × CTARG – 001 (1st), 'Riverside' citrandarin (2nd), CNPMF – 004 Rangpur lime (3rd), 'Sunki' × 'English Palmira' – CO (4th), and 'Indio' citrandarin (5th) were superior to 'Cravo Santa Cruz' Rangpur lime (9th) by the D_{iI} (Table 5). On average, the selected rootstocks showed intermediate to high-accumulated yield (278.3 kg per tree), but with tall trees (3.83 m) and low-productive efficiency (2.68 kg m^{-3}). As to the ideotype used, 33, 13, 87, and 22% of the evaluated hybrid citrus showed higher means for AP, EF, SS, and DT, respectively, but all them had lower JC.

In each index ranking, the averages of the first five rootstocks were highlighted because they accounted for around 10% of the selection pressure on the 46 evaluated genotypes. 'Indio' and 'San Diego' citrandarin, 'Sunki'

Table 1. Original and centered (x_{ij}-k_j) means of the accumulated production per tree (AP), canopy production efficiency (EF), concentration of soluble solids (SS), juice yield (JC), drought-tolerance (DT) (visual scoring of leaf wilting), and tree height (TH), to calculate the multiplicative index (I_{Ei}) for the classification of hybrid citrus rootstocks grafted with 'Valência' sweet orange, in the north of São Paulo state, Brazil, 2009–2017.

Rootstock	AP (kg per tree)	x_{ij} - k_j	EF (kg m^{-3})	x_{ij} - k_j	SS (°Brix)	x_{ij} - k_j	JC (%)	x_{ij} - k_j	DT	x_{ij} - k_j	TH (m)	x_{ij} - k_j	I_{Ei}	Rank
TSKC × (LCR x TR) – 059	262.34	1.60	4.20	1.69	12.02	1.50	47.68	1.56	2.22	1.70	3.16	1.49	15.970	1
TSKC × CTQT 1434 – 010	215.03	1.47	3.75	1.63	11.94	1.48	48.72	1.66	1.79	1.56	2.93	1.61	14.650	2
TSKC × (LCR x TR) – 017	275.88	1.63	4.08	1.67	11.58	1.35	47.43	1.54	1.96	1.62	3.13	1.50	13.812	3
TSK × TR Benecke – CO	210.47	1.45	2.88	1.46	12.50	1.61	48.10	1.61	1.92	1.61	3.12	1.51	13.350	4
San Diego citrandarin	305.22	1.68	3.51	1.60	11.38	1.27	49.23	1.70	1.99	1.63	3.35	1.37	12.846	5
TSKC × CTSW – 041	272.91	1.62	3.76	1.63	11.29	1.22	47.96	1.59	2.08	1.66	3.24	1.44	12.258	6
TSKC × (LCR x TR) – 001	241.65	1.55	3.76	1.63	11.75	1.42	46.48	1.41	1.51	1.40	2.97	1.59	11.241	7
LRF × (LCR x TR) – 005	265.43	1.60	2.57	1.37	11.94	1.48	47.22	1.51	1.87	1.59	3.31	1.40	10.900	8
TSKC × CTSW – 033	208.00	1.44	3.62	1.61	11.59	1.36	48.27	1.62	1.46	1.36	3.07	1.54	10.745	9
LCR × TR – 001	252.05	1.57	4.14	1.68	10.94	0.96	47.15	1.50	2.23	1.70	3.00	1.57	10.266	10
Sunki × English Palmira - CO	317.99	1.70	2.90	1.47	12.88	1.68	47.85	1.58	1.93	1.61	3.76	0.93	9.904	11
HTR – 053	287.26	1.65	3.87	1.65	11.27	1.21	45.94	1.32	2.05	1.65	3.34	1.37	9.869	12
TSKC x CTSW – 028	296.79	1.66	3.14	1.53	11.68	1.39	47.30	1.52	2.02	1.64	3.70	1.02	9.020	13
TSKC x CTQT 1439 – 026	188.45	1.35	3.54	1.60	12.23	1.55	48.14	1.61	1.19	1.00	2.87	1.64	8.806	14
CLEO x TR Rubidoux – CO	151.20	1.04	2.45	1.32	12.99	1.70	47.93	1.59	1.49	1.39	2.72	1.70	8.755	15
HTR – 051	244.33	1.56	3.48	1.59	11.58	1.36	45.21	1.16	1.78	1.55	3.28	1.42	8.559	16
CLEO x CTCZ – 226	230.46	1.52	3.06	1.51	11.77	1.43	45.40	1.21	1.52	1.41	3.22	1.45	8.057	17
Indio citrandarin	320.96	1.70	3.17	1.53	11.58	1.36	48.01	1.60	1.91	1.61	3.78	0.89	8.051	18
Sunki Tropical mandarin	291.21	1.65	2.72	1.42	11.52	1.33	48.09	1.61	1.97	1.62	3.73	0.97	7.883	19
TSKC × (LCR x TR) – 073	253.95	1.58	3.32	1.56	11.67	1.39	45.45	1.22	1.67	1.50	3.49	1.25	7.837	20
TSKC × CTSW – 064	205.34	1.43	3.92	1.65	11.45	1.30	45.92	1.32	1.35	1.25	3.08	1.53	7.828	21
TSKFL × CTC 25 – 010	197.38	1.40	3.76	1.63	11.42	1.29	45.11	1.13	1.46	1.36	2.87	1.64	7.355	22
TSKC × CTQT 1439 – 004	208.50	1.44	2.09	1.10	11.55	1.34	48.51	1.64	1.70	1.52	3.34	1.37	7.333	23
TSKC × LHA – 006	211.22	1.45	2.22	1.20	11.69	1.40	48.15	1.61	1.50	1.40	3.41	1.32	7.250	24
Cravo Santa Cruz Rangpur lime	276.19	1.63	3.41	1.58	10.85	0.86	49.07	1.69	2.03	1.65	3.59	1.15	7.060	25
TSKFL × CTTR – 012	193.10	1.38	3.52	1.60	10.98	1.00	46.40	1.40	1.65	1.49	3.11	1.52	6.948	26
CNPMF – 003 Rangpur lime	239.38	1.54	3.33	1.56	10.81	0.80	47.10	1.50	2.08	1.66	3.26	1.43	6.880	27
CNPMF – 004 Rangpur lime	302.69	1.67	3.19	1.54	11.23	1.19	47.36	1.53	2.15	1.68	3.81	0.83	6.526	28
TSK × CTTR – 002	218.36	1.48	2.76	1.43	11.15	1.13	44.99	1.09	2.16	1.68	3.31	1.40	6.150	29
LVK × LCR – 010	242.26	1.55	3.33	1.56	10.99	1.01	44.98	1.09	1.77	1.55	3.20	1.47	6.057	30
TSKFL × CTTR – 022	161.02	1.16	2.88	1.47	11.56	1.35	47.55	1.55	1.19	1.00	2.87	1.64	5.821	31
TSKC × (LCR x TR) – 018	213.01	1.46	3.31	1.56	11.04	1.05	45.25	1.17	1.48	1.38	3.13	1.50	5.799	32
LVK × LCR – 038	237.46	1.54	4.28	1.69	11.37	1.26	44.12	0.62	2.03	1.64	2.93	1.61	5.393	33
Riverside citrandarin	251.01	1.57	2.47	1.33	11.65	1.38	46.50	1.42	1.96	1.62	3.82	0.81	5.374	34
LVK × LVA – 009	215.68	1.47	2.72	1.42	12.39	1.59	44.21	0.70	1.77	1.55	3.27	1.42	5.120	35
TSKC × CTARG – 036	171.80	1.25	2.26	1.23	11.47	1.31	45.58	1.25	1.29	1.18	3.21	1.46	4.322	36
LCREEL × CTSW - 001	149.48	1.02	2.51	1.34	12.07	1.51	44.82	1.03	1.36	1.26	3.22	1.46	3.931	37
TSKC × LHA – 011	172.43	1.25	1.95	0.97	11.98	1.49	45.00	1.09	1.58	1.45	3.43	1.30	3.725	38
TSKC × CTRK – 001	145.00	0.95	2.00	1.02	12.06	1.51	47.03	1.49	1.07	0.52	3.32	1.39	1.576	39
Sunki Maravilha mandarin	174.12	1.26	1.72	0.44	11.79	1.43	45.80	1.30	1.08	0.55	3.34	1.37	0.783	40
HTR – 116	246.13	1.56	4.07	1.67	11.32	1.24	43.80	0.06	1.46	1.36	3.06	1.54	0.418	41
HTR – 069	215.20	1.47	4.33	1.70	10.58	0.04	46.05	1.34	1.85	1.58	3.07	1.54	0.301	42
TSKC × CTSW – 019	235.69	1.53	2.02	1.04	11.51	1.33	43.82	0.12	1.27	1.15	3.73	0.98	0.282	43
TSKFL × CTTR – 008	157.45	1.12	2.52	1.35	12.09	1.52	43.80	0.04	1.22	1.05	3.04	1.55	0.139	44
Sunki × Alemow – CO	124.79	0.04	2.62	1.39	11.34	1.25	45.65	1.27	1.04	0.04	3.01	1.57	0.005	45
TSKC × CTARG – 001	198.78	1.40	1.66	0.04	11.67	1.39	44.42	0.85	1.23	1.08	3.98	0.04	0.002	46
Minimum	124.79		1.66		10.58		43.80		1.04		2.72			
Maximum	320.96		4.33		12.99		49.23		2.23		3.98			
Kj	116.81		0.57		9.29		41.73		-0.01		1.64			
F	**		**		**		**		**		**			
Coefficient of variation (%)	16.55		20.37		3.37		4.13		10.37		6.32			
Mean	227.28		3.10		11.61		46.49		1.68		3.27			

TSK, 'Sunki' mandarin [*Citrus sunki* (Hayata) hort. ex Tanaka]; TSKC, common 'Sunki' mandarin (*C. sunki*); TR, trifoliate orange [*Poncirus trifoliata* (L.) Raf.]; LCR, Rangpur lime (*C. limonia* Osbeck); CTSW, 'Swingle' citrumelo (*C. paradisi* Macfad. x *P. trifoliata*); HTR, trifoliate hybrid (*P. trifoliata* x sp.); LRF, 'Florida' rough lemon (*C. jambhiri* Lush.); CTQT, 'Thomasville' citrangequat [*Fortunella margarita* (Lour.) Swingle x 'Willits' citrange]; LHA, 'Hamlin' sweet orange [*C. sinensis* (L.) Osbeck]; CTCZ, 'Carrizo' citrange (*C. sinensis* x *P. trifoliata*); CTTR, 'Troyer' citrange (*C. sinensis* x *P. trifoliata*); LVK, 'Volkamer' lemon (*C. volkameriana* (Risso) V. Ten. & Pasq.); LVA, 'Valência' sweet orange (*C. sinensis*); TSKFL, 'Florida Sunki' mandarin (*C. sunki*); CTC, citrange (*C. sinensis* x *P. trifoliata*); CLEO, 'Cleópatra' mandarin (*C. reshni* hort. ex Tanaka); CTARG, 'Argentina' citrange (*C. sinensis* x *P. trifoliata*); LCREEL, 'Santa Cruz' Rangpur lime (*C. Limonia*); CTRK, 'Rusk' citrange (*C. sinensis* x *P. trifoliata*); 'Alemow' (*C. macrophylla* Wester); English Palmira - CO: Sunki x English Palmira - CO is a selection of a USDA hybrid (*C. sunki* x *P. trifoliata* cv. English) introduced from the city of Palmira in Colombia; CNPMF, Embrapa Mandioca e Fruticultura. **Significant at 1% probability. The calculation of the multiplicative index was based on the methodology described by Elston (1963), where, x_{ij} is the mean of the character j, measured in the genotype i, and k_j is the lowest selectable value.

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Table 2. Original means of the accumulated production (AP), canopy production efficiency (EF), soluble solids concentration (SS), juice yield (JC), drought-tolerance (DT) (visual scoring of leaf wilting), and tree height (TH) for the determination of the classification sum index (I_{MMi}), to rank the hybrid citrus rootstocks grafted with 'Valência' sweet orange, in the north of São Paulo state, Brazil, 2009–2017.

Rootstock	AP (kg per tree)	Rank	EF (kg m^{-3})	Rank	SS (°Brix)	Rank	JC (%)	Rank	DT	Rank	TH (m)	Rank	I_{MMi}	Rank
TSKC × (LCR x TR) – 059	262.34	12	4.20	3	12.02	9	47.68	14	2.22	2	3.16	19	59.000	1
TSKC × CTQT 1434 – 010	215.03	27	3.75	9	11.94	12	48.72	3	1.79	20	2.93	6	77.000	2
TSKC × (LCR x TR) – 017	275.88	9	4.08	1	11.58	24	47.43	16	1.96	13	3.13	17	80.000	3
TSK × TR Benecke – CO	210.47	30	2.88	15	12.50	3	48.10	8	1.92	16	3.12	16	88.000	4
LCR × TR – 001	252.05	14	4.14	4	10.94	43	47.15	20	2.23	1	3.00	8	90.000	5
TSKC × CTSW – 041	272.91	10	3.76	7	11.29	36	47.96	11	2.08	5	3.24	24	93.000	6
San Diego citrandarin	305.22	3	3.51	17	11.38	32	49.23	1	1.99	11	3.35	34	98.000	7
Sunki × English Palmira – CO	317.99	2	2.90	25	12.88	2	47.85	13	1.93	15	3.76	42	99.000	8
TSKC × (LCR x TR) – 001	241.65	19	3.76	10	11.75	15	46.48	24	1.51	29	2.97	7	104.000	9
TSKC × CTSW – 028	296.79	5	3.14	23	11.68	17	47.30	18	2.02	10	3.70	39	112.000	10
Cravo Santa Cruz Rangpur lime	276.19	8	3.41	13	10.85	44	49.07	2	2.03	8	3.59	38	113.000	11
Indio citrandarin	320.96	1	3.17	21	11.58	23	48.01	10	1.91	17	3.78	43	115.000	12
HTR – 053	287.26	7	3.87	6	11.27	37	45.94	27	2.05	7	3.34	31	115.000	12
LVK × LCR – 038	237.46	21	4.28	5	11.37	33	44.12	43	2.03	9	2.93	5	116.000	14
TSKC × CTSW – 033	208.00	32	3.62	12	11.59	21	48.27	5	1.46	33	3.07	13	116.000	14
TSKC × CTQT 1439 – 026	188.45	37	3.54	26	12.23	5	48.14	7	1.19	43	2.87	4	122.000	16
LRF × (LCR x TR) – 005	265.43	11	2.57	35	11.94	11	47.22	19	1.87	18	3.31	29	123.000	17
CLEO × TR Rubidoux – CO	151.20	43	2.45	36	12.99	1	47.93	12	1.49	31	2.72	1	124.000	18
Sunki Tropical mandarin	291.21	6	2.72	30	11.52	27	48.09	9	1.97	12	3.73	41	125.000	19
CNPMF – 004 Rangpur lime	302.69	4	3.19	20	11.23	38	47.36	17	2.15	4	3.81	44	127.000	20
HTR – 069	215.20	26	4.33	2	10.58	46	46.05	26	1.85	19	3.07	12	131.000	21
HTR – 051	244.33	17	3.48	11	11.58	22	45.21	35	1.78	21	3.28	27	133.000	22
CNPMF – 003 Rangpur lime	239.38	20	3.33	19	10.81	45	47.10	21	2.08	6	3.26	25	136.000	23
TSKC × (LCR x TR) – 073	253.95	13	3.32	16	11.67	18	45.45	32	1.67	25	3.49	37	141.000	24
CLEO × CTCZ – 226	230.46	23	3.06	28	11.77	14	45.40	33	1.52	28	3.22	23	149.000	25
Riverside citrandarin	251.01	15	2.47	32	11.65	20	46.50	23	1.96	14	3.82	45	149.000	25
HTR – 116	246.13	16	4.07	8	11.32	35	43.80	45	1.46	35	3.06	11	150.000	27
LVK × LVA – 009	215.68	25	2.72	33	12.39	4	44.21	42	1.77	22	3.27	26	152.000	28
TSKFL × CTC 25 – 010	197.38	35	3.76	14	11.42	31	45.11	36	1.46	34	2.87	3	153.000	29
TSKFL × CTTR – 022	161.02	41	2.88	31	11.56	25	47.55	15	1.19	42	2.87	2	156.000	30
TSKC × LHA – 006	211.22	29	2.22	41	11.69	16	48.15	6	1.50	30	3.41	35	157.000	31
TSKC × CTSW – 064	205.34	33	3.92	18	11.45	30	45.92	28	1.35	37	3.08	14	160.000	32
TSKC × CTQT 1439 – 004	208.50	31	2.09	42	11.55	26	48.51	4	1.70	24	3.34	33	160.000	32
TSK × CTTR – 002	218.36	24	2.76	29	11.15	39	44.99	38	2.16	3	3.31	28	161.000	34
LVK × LCR – 010	242.26	18	3.33	24	10.99	41	44.98	39	1.77	23	3.20	20	165.000	35
TSKFL × CTTR – 012	193.10	36	3.52	27	10.98	42	46.40	25	1.65	26	3.11	15	171.000	36
TSKC × (LCR x TR) – 018	213.01	28	3.31	22	11.04	40	45.25	34	1.48	32	3.13	18	174.000	37
LCREEL × CTSW – 001	149.48	44	2.51	34	12.07	7	44.82	40	1.36	36	3.22	22	183.000	38
TSKFL × CTTR – 008	157.45	42	2.52	38	12.09	6	43.80	46	1.22	41	3.04	10	183.000	38
TSKC × LHA – 011	172.43	39	1.95	39	11.98	10	45.00	37	1.58	27	3.43	36	188.000	40
TSKC × CTRK – 001	145.00	45	2.00	44	12.06	8	47.03	22	1.07	45	3.32	30	194.000	41
TSKC × CTARG – 036	171.80	40	2.26	40	11.47	29	45.58	31	1.29	38	3.21	21	199.000	42
Sunki × Alemow – CO	124.79	46	2.62	37	11.34	34	45.65	30	1.04	46	3.01	9	202.000	43
Sunki Maravilha mandarin	174.12	38	1.72	46	11.79	13	45.80	29	1.08	44	3.34	32	202.000	43
TSKC × CTSW – 019	235.69	22	2.02	43	11.51	28	43.82	44	1.27	39	3.73	40	216.000	45
TSKC × CTARG – 001	198.78	34	1.66	45	11.67	19	44.42	41	1.23	40	3.98	46	225.000	46
F	**		**		**		**		**		**			
Coefficient of variation (%)	16.55		20.37		3.37		4.13		10.37		6.32			
Mean	227.28		3.10		11.61		46.49		1.68		3.27			

TSK, 'Sunki' mandarin [*Citrus sunki* (Hayata) hort. ex Tanaka]; TSKC, common 'Sunki' mandarin (*C. sunki*); TR, trifoliate orange [*Poncirus trifoliata* (L.) Raf.]; LCR, Rangpur lime (*C. limonia* Osbeck); CTSW, 'Swingle' citrumelo (*C. paradisi* Macfad. x *P. trifoliata*); HTR, trifoliate hybrid (*P. trifoliata* x sp.); LRF, 'Florida' rough lemon (*C. jambhiri* Lush.); CTQT, 'Thomasville' citrangequat [*Fortunella margarita* (Lour.) Swingle x 'Willits' citrange]; LHA, 'Hamlin' sweet orange [*C. sinensis* (L.) Osbeck]; CTCZ, 'Carrizo' citrange (*C. sinensis* x *P. trifoliata*); CTTR, 'Troyer' citrange (*C. sinensis* x *P. trifoliata*); LVK, 'Volkamer' lemon (*C. volkameriana* (Risso) V. Ten. & Pasq.); LVA, 'Valência' sweet orange (*C. sinensis*); TSKFL, 'Florida Sunki' mandarin (*C. sunki*); CTC, citrange (*C. sinensis* x *P. trifoliata*); CLEO, 'Cleópatra' mandarin (*C. reshni* hort. ex Tanaka); CTARG, 'Argentina' citrange (*C. sinensis* x *P. trifoliata*); LCREEL, 'Santa Cruz' Rangpur lime (*C. Limonia*); CTRK, 'Rusk' citrange (*C. sinensis* x *P. trifoliata*); 'Alemow' (*C. macrophylla* Wester); English Palmira - CO: Sunki x English Palmira - CO is a selection of a USDA hybrid (*C. sunki* x *P. trifoliata* cv. English) introduced from the city of Palmira in Colombia; CNPMF, Embrapa Mandioca e Fruticultura. **Significant at 1% probability. The classification sum index was calculated based on the methodology described by Mulamba & Mock (1978).

Table 3. Original means of the accumulated production (AP), canopy production efficiency (EF), concentration of soluble solids (SS), juice yield (JC), drought-tolerance (DT) (visual scoring of leaf wilting), and tree height (TH) for the determination of the ranking index based on simple means (I_{RKi}), for the classification of hybrid citrus rootstocks grafted with 'Valência' sweet orange in the north of São Paulo state, Brazil, 2009–2017.

Rootstock	AP (kg per tree)	EF (kg m^{-3})	SS (°Brix)	JC (%)	DT	TH (m)	IRKi	Rank
Indio citrandarin	320.96	3.17	11.58	48.01	1.91	3.78	74.1719	1
Sunki × English Palmira – CO	317.99	2.90	12.88	47.85	1.93	3.76	73.7003	2
San Diego citrandarin	305.22	3.51	11.38	49.23	1.99	3.35	71.2656	3
CNPMF – 004 Rangpur lime	302.69	3.19	11.23	47.36	2.15	3.81	70.4214	4
TSKC × CTSW – 028	296.79	3.14	11.68	47.30	2.02	3.70	69.2661	5
Sunki Tropical mandarin	291.21	2.72	11.52	48.09	1.97	3.73	68.1472	6
HTR – 053	287.26	3.87	11.27	45.94	2.05	3.34	67.2465	7
Cravo Santa Cruz Rangpur lime	276.19	3.41	10.85	49.07	2.03	3.59	65.3446	8
TSKC × (LCR x TR) – 017	275.88	4.08	11.58	47.43	1.96	3.13	65.2682	9
TSKC × CTSW – 041	272.91	3.76	11.29	47.96	2.08	3.24	64.6683	10
LRF × (LCR x TR) – 005	265.43	2.57	11.94	47.22	1.87	3.31	63.7902	11
TSKC × (LCR x TR) – 073	253.95	3.32	11.67	45.45	1.67	3.49	62.8789	14
TSKC × (LCR x TR) – 059	262.34	4.20	12.02	47.68	2.22	3.16	62.7394	12
LCR × TR – 001	252.05	4.14	10.94	47.15	2.23	3.00	60.4305	13
Riverside citrandarin	251.01	2.47	11.65	46.50	1.96	3.82	59.8372	15
HTR – 116	246.13	4.07	11.32	43.80	1.46	3.06	58.6328	16
HTR – 051	244.33	3.48	11.58	45.21	1.78	3.28	58.4686	17
TSKC × (LCR x TR) – 001	241.65	3.76	11.75	46.48	1.51	2.97	58.1496	18
LVK × LCR – 010	242.26	3.33	10.99	44.98	1.77	3.20	57.8986	19
CNPMF – 003 Rangpur lime	239.38	3.33	10.81	47.10	2.08	3.26	57.6750	20
LVK × LCR – 038	237.46	4.28	11.37	44.12	2.03	2.93	57.1117	21
TSKC × CTSW – 019	235.69	2.02	11.51	43.82	1.27	3.73	56.1232	22
CLEO × CTCZ – 226	230.46	3.06	11.77	45.40	1.52	3.22	55.6152	23
TSKC × CTQT 1434 – 010	215.03	3.75	11.94	48.72	1.79	2.93	53.2449	24
TSK × CTTR – 002	218.36	2.76	11.15	44.99	2.16	3.31	53.1050	25
HTR – 069	215.20	4.33	10.58	46.05	1.85	3.07	52.8033	26
LVK × LVA – 009	215.68	2.72	12.39	44.21	1.77	3.27	52.5535	27
TSK × TR Benecke – CO	210.47	2.88	12.50	48.10	1.92	3.12	52.1767	28
TSKC × (LCR x TR) – 018	213.01	3.31	11.04	45.25	1.48	3.13	52.0340	29
TSKC × LHA – 006	211.22	2.22	11.69	48.15	1.50	3.41	51.9952	30
TSKC × CTSW – 033	208.00	3.62	11.59	48.27	1.46	3.07	51.6273	31
TSKC × CTQT 1439 – 004	208.50	2.09	11.55	48.51	1.70	3.34	51.4974	32
TSKC × CTSW – 064	205.34	3.92	11.45	45.92	1.35	3.08	50.7597	33
TSKFL × CTC 25 – 010	197.38	3.76	11.42	45.11	1.46	2.87	49.0329	34
TSKC × CTARG – 001	198.78	1.66	11.67	44.42	1.23	3.98	48.7740	35
TSKFL × CTTR – 012	193.10	3.52	10.98	46.40	1.65	3.11	48.2929	36
TSKC × CTQT 1439 – 026	188.45	3.54	12.23	48.14	1.19	2.87	47.7271	37
Sunki Maravilha mandarin	174.12	1.72	11.79	45.80	1.08	3.34	44.0520	38
TSKC × LHA – 011	172.43	1.95	11.98	45.00	1.58	3.43	43.7683	39
TSKC × CTARG – 036	171.80	2.26	11.47	45.58	1.29	3.21	43.6578	40
TSKFL × CTTR – 022	161.02	2.88	11.56	47.55	1.19	2.87	41.9213	41
TSKFL × CTTR – 008	157.45	2.52	12.09	43.80	1.22	3.04	40.6525	42
CLEO × TR Rubidoux – CO	151.20	2.45	12.99	47.93	1.49	2.72	40.2021	43
LCREEL × CTSW – 001	149.48	2.51	12.07	44.82	1.36	3.22	39.2338	44
TSKC × CTRK – 001	145.00	2.00	12.06	47.03	1.07	3.32	38.5086	45
Sunki × Alemow – CO	124.79	2.62	11.34	45.65	1.04	3.01	34.2706	46
F	**	**	**	**	**	**		
Coefficient of variation (%)	16.55	20.37	3.37	4.13	10.37	6.32		
Mean	227.28	3.10	11.61	46.49	1.68	3.27		

TSK, 'Sunki' mandarin [*Citrus sunki* (Hayata) hort. ex Tanaka]; TSKC, common 'Sunki' mandarin (*C. sunki*); TR, trifoliate orange [*Poncirus trifoliata* (L.) Raf.]; LCR, Rangpur lime (*C. limonia* Osbeck); CTSW, 'Swingle' citrumelo (*C. paradisi* Macfad. x *P. trifoliata*); HTR, trifoliate hybrid (*P. trifoliata* x sp.); LRF, 'Florida' rough lemon (*C. jambhiri* Lush.); CTQT, 'Thomasville' citrangequat [*Fortunella margarita* (Lour.) Swingle x 'Willits' citrange]; LHA, 'Hamlin' sweet orange [*C. sinensis* (L.) Osbeck]; CTCZ, 'Carrizo' citrange (*C. sinensis* x *P. trifoliata*); CTTR, 'Troyer' citrange (*C. sinensis* x *P. trifoliata*); LVK, 'Volkamer' lemon (*C. volkameriana* (Risso) V. Ten. & Pasq.); LVA, 'Valência' sweet orange (*C. sinensis*); TSKFL, 'Florida Sunki' mandarin (*C. sunki*); CTC, citrange (*C. sinensis* x *P. trifoliata*); CLEO, 'Cleópatra' mandarin (*C. reshni* hort. ex Tanaka); CTARG, 'Argentina' citrange (*C. sinensis* x *P. trifoliata*); LCREEL, 'Santa Cruz' Rangpur lime (*C. Limonia*); CTRK, 'Rusk' citrange (*C. sinensis* x *P. trifoliata*); 'Alemow' (*C. macrophylla* Wester); English Palmira - CO: Sunki x English Palmira - CO is a selection of a USDA hybrid (*C. sunki* x *P. trifoliata* cv. English) introduced from the city of Palmira in Colombia; CNPMF, Embrapa Mandioca e Fruticultura. **Significant at 1% probability. The ranking index (I_{RKi}) was adapted from Costa et al. (2016) using simple means as I_{RKi} = (AP×0.2) + (EF×0.2) + (SS×0.15) + (JC×0.15) + (DT×0.2) + ((1 / PH)× 0.1).

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Table 4. Original and normalized (N) means of the accumulated production (AP), canopy production efficiency (EF), concentration of soluble solids (SS), juice yield (JC), drought-tolerance (DT) (visual scoring of leaf wilting), and tree height (TH), for the determination of the ranking index based on linearly normalized means (I_{RKii}), to classify hybrid citrus rootstocks grafted with 'Valência' sweet orange, in the north of São Paulo state, Brazil, 2009–2017.

Rootstock	AP	N_{AP}	EF	N_{EF}	SS	N_{SS}	JC	N_{JC}	DT	N_{DT}	TH	$N_{(1/TH)}$	I_{RKii}	Rank
	(kg per tree)	--------($kg\ m^{-3}$)--------			(°Brix)	------------------(%)------------------					(m)			
Sunki × English Palmira – CO	317.99	0.98	2.90	0.46	12.88	0.96	47.85	0.75	1.93	0.75	3.76	0.77	0.824	1
TSKC × (LCR x TR) – 059	262.34	0.70	4.20	0.95	12.02	0.60	47.68	0.72	2.22	0.99	3.16	1.80	0.782	2
Indio citrandarin	320.96	1.00	3.17	0.56	11.58	0.42	48.01	0.77	1.91	0.73	3.78	0.75	0.771	3
San Diego citrandarin	305.22	0.92	3.51	0.69	11.38	0.33	49.23	1.00	1.99	0.80	3.35	1.26	0.762	4
CNPMF – 004 Rangpur lime	302.69	0.91	3.19	0.57	11.23	0.27	47.36	0.66	2.15	0.93	3.81	0.73	0.758	5
TSKC × CTSW – 028	296.79	0.88	3.14	0.55	11.68	0.46	47.30	0.64	2.02	0.83	3.70	0.81	0.740	6
Cravo Santa Cruz Rangpur lime	276.19	0.77	3.41	0.66	10.85	0.11	49.07	0.97	2.03	0.84	3.59	0.91	0.725	7
Sunki Tropical mandarin	291.21	0.85	2.72	0.39	11.52	0.39	48.09	0.79	1.97	0.78	3.73	0.78	0.709	8
TSKC × CTSW – 041	272.91	0.76	3.76	0.79	11.29	0.29	47.96	0.77	2.08	0.88	3.24	1.52	0.709	9
TSKC × (LCR x TR) – 017	275.88	0.77	4.08	0.91	11.58	0.41	47.43	0.67	1.96	0.77	3.13	1.92	0.704	10
HTR – 053	287.26	0.83	3.87	0.83	11.27	0.29	45.94	0.39	2.05	0.85	3.34	1.28	0.680	11
LCR × TR – 001	252.05	0.65	4.14	0.93	10.94	0.15	47.15	0.62	2.23	1.00	3.00	2.84	0.666	12
Riverside citrandarin	251.01	0.64	2.47	0.30	11.65	0.44	46.50	0.50	1.96	0.77	3.82	0.72	0.623	13
TSKC × CTQT 1434 – 010	215.03	0.46	3.75	0.78	11.94	0.56	48.72	0.91	1.79	0.63	2.93	3.73	0.621	14
TSK × TR Benecke – CO	210.47	0.44	2.88	0.45	12.50	0.80	48.10	0.79	1.92	0.74	3.12	1.98	0.615	15
LRF × (LCR x TR) – 005	265.43	0.72	2.57	0.34	11.94	0.57	47.22	0.63	1.87	0.70	3.31	1.35	0.604	16
CNPMF – 003 Rangpur lime	239.38	0.58	3.33	0.62	10.81	0.10	47.10	0.61	2.08	0.87	3.26	1.47	0.590	17
TSKC × (LCR x TR) – 073	253.95	0.66	3.32	0.62	11.67	0.45	45.45	0.30	1.67	0.53	3.49	1.03	0.572	18
LVK × LCR – 038	237.46	0.57	4.28	0.98	11.37	0.33	44.12	0.06	2.03	0.83	2.93	3.83	0.562	19
HTR – 051	244.33	0.61	3.48	0.68	11.58	0.42	45.21	0.26	1.78	0.63	3.28	1.43	0.555	20
HTR – 069	215.20	0.46	4.33	1.00	10.58	0.00	46.05	0.41	1.85	0.68	3.07	2.26	0.535	21
TSKC × CTSW – 033	208.00	0.42	3.62	0.73	11.59	0.42	48.27	0.82	1.46	0.36	3.07	2.26	0.534	22
TSKC × (LCR x TR) – 001	241.65	0.60	3.76	0.78	11.75	0.48	46.48	0.49	1.51	0.39	2.97	3.15	0.533	23
TSK × CTTR – 002	218.36	0.48	2.76	0.41	11.15	0.24	44.99	0.22	2.16	0.94	3.31	1.36	0.507	24
TSKC × CTQT 1439 – 004	208.50	0.43	2.09	0.16	11.55	0.40	48.51	0.87	1.70	0.56	3.34	1.28	0.497	25
LVK × LVA – 009	215.68	0.46	2.72	0.40	12.39	0.75	44.21	0.08	1.77	0.61	3.27	1.46	0.487	26
LVK × LCR – 010	242.26	0.60	3.33	0.63	10.99	0.17	44.98	0.22	1.77	0.61	3.20	1.66	0.486	27
TSKC × LHA – 006	211.22	0.44	2.22	0.21	11.69	0.46	48.15	0.80	1.50	0.39	3.41	1.15	0.485	28
CLEO × CTCZ – 226	230.46	0.54	3.06	0.52	11.77	0.50	45.40	0.30	1.52	0.41	3.22	1.58	0.475	29
TSKC × CTQT 1439 – 026	188.45	0.32	3.54	0.70	12.23	0.69	48.14	0.80	1.19	0.13	2.87	5.22	0.473	30
HTR – 116	246.13	0.62	4.07	0.90	11.32	0.31	43.80	0.00	1.46	0.35	3.06	2.33	0.464	31
TSKC × CTSW – 064	205.34	0.41	3.92	0.85	11.45	0.36	45.92	0.39	1.35	0.26	3.08	2.22	0.462	32
TSKFL × CTTR – 012	193.10	0.35	3.52	0.70	10.98	0.17	46.40	0.48	1.65	0.51	3.11	2.03	0.457	33
CLEO × TR Rubidoux – CO	151.20	0.13	2.45	0.29	12.99	1.00	47.93	0.76	1.49	0.38	2.72	357.65	0.426	34
TSKFL × CTC 25 – 010	197.38	0.37	3.76	0.79	11.42	0.35	45.11	0.24	1.46	0.35	2.87	5.22	0.410	35
TSKC × (LCR x TR) – 018	213.01	0.45	3.31	0.62	11.04	0.19	45.25	0.27	1.48	0.37	3.13	1.92	0.408	36
TSKC × LHA – 011	172.43	0.24	1.95	0.11	11.98	0.58	45.00	0.22	1.58	0.46	3.43	1.11	0.372	37
TSKC × CTSW – 019	235.69	0.57	2.02	0.13	11.51	0.39	43.82	0.00	1.27	0.20	3.73	0.79	0.365	38
TSKC × CTARG – 001	198.78	0.38	1.66	0.00	11.67	0.45	44.42	0.12	1.23	0.16	3.98	0.63	0.351	39
TSKFL × CTTR – 022	161.02	0.18	2.88	0.46	11.56	0.41	47.55	0.69	1.19	0.13	2.87	5.42	0.338	40
LCREEL × CTSW – 001	149.48	0.13	2.51	0.32	12.07	0.62	44.82	0.19	1.36	0.27	3.22	1.60	0.326	41
TSKC × CTRK – 001	145.00	0.10	2.00	0.13	12.06	0.61	47.03	0.60	1.07	0.03	3.32	1.33	0.308	42
TSKC × CTARG – 036	171.80	0.24	2.26	0.22	11.47	0.37	45.58	0.33	1.29	0.22	3.21	1.64	0.301	43
Sunki Maravilha mandarin	174.12	0.25	1.72	0.02	11.79	0.50	45.80	0.37	1.08	0.03	3.34	1.28	0.270	44
TSKFL × CTTR – 008	157.45	0.17	2.52	0.32	12.09	0.63	43.80	0.00	1.22	0.15	3.04	2.49	0.261	45
Sunki × Alemow – CO	124.79	0.00	2.62	0.36	11.34	0.31	45.65	0.34	1.04	0.00	3.01	2.73	0.207	46
Mean	227.28		3.10		11.61		46.49		1.68		3.27			
Maximum	320.96		4.33		12.99		49.23		2.23		3.98			
Minimum	124.79		1.66		10.58		43.80		1.04		2.72			
F	**		**		**		**		**		**			
Coefficient of variation (%)	16.55		20.37		3.37		4.13		10.37		6.32			

TSK, 'Sunki' mandarin [*Citrus sunki* (Hayata) hort. ex Tanaka]; TSKC, common 'Sunki' mandarin (*C. sunki*); TR, trifoliate orange [*Poncirus trifoliata* (L.) Raf.]; LCR, Rangpur lime (*C. limonia* Osbeck); CTSW, 'Swingle' citrumelo (*C. paradisi* Macfad. x *P. trifoliata*); HTR, trifoliate hybrid (*P. trifoliata* x sp.); LRF, 'Florida' rough lemon (*C. jambhiri* Lush.); CTQT, 'Thomasville' citrangequat [*Fortunella margarita* (Lour.) Swingle x 'Willits' citrange]; LHA, 'Hamlin' sweet orange [*C. sinensis* (L.) Osbeck]; CTCZ, 'Carrizo' citrange (*C. sinensis* x *P. trifoliata*); CTTR, 'Troyer' citrange (*C. sinensis* x *P. trifoliata*); LVK, 'Volkamer' lemon (*C. volkameriana* (Risso) V. Ten. & Pasq.); LVA, 'Valência' sweet orange (*C. sinensis*); TSKFL, 'Florida Sunki' mandarin (*C. sunki*); CTC, citrange (*C. sinensis* x *P. trifoliata*); CLEO, 'Cleópatra' mandarin (*C. reshni* hort. ex Tanaka); CTARG, 'Argentina' citrange (*C. sinensis* x *P. trifoliata*); LCREEL, 'Santa Cruz' Rangpur lime (*C. Limonia*); CTRK, 'Rusk' citrange (*C. sinensis* x *P. trifoliata*); 'Alemow' (*C. macrophylla* Wester); English Palmira - CO: Sunki x English Palmira - CO is a selection of a USDA hybrid (*C. sunki* x *P. trifoliata* cv. English) introduced from the city of Palmira in Colombia; CNPMF, Embrapa Mandioca e Fruticultura. **Significant at 1% probability. The ranking index (I_{RKii}) was adapted from Costa et al. (2016), with data subjected to linear normalization.

Table 5. Original means of the accumulated production (AP), canopy production efficiency (EF), concentration of soluble solids (SS), juice yield (JC), drought-tolerance (DT) visual scoring of leaf wilting, and tree height (TH) for the determination of the index (D_{iI}) based on the Euclidean distances (d_{ij}) between genotype and ideotype, to classify hybrid citrus rootstocks grafted with 'Valência' sweet orange, in the north of São Paulo state, Brazil, 2009–2017.

Rootstock	AP (kg per tree)	d_{ij}	EF (kg m^{-3})	d_{ij}	SS (°Brix)	d_{ij}	JC (%)	d_{ij}	DT	d_{ij}	TH (m)	d_{ij}	D_{iI}	Rank
TSKC × CTARG – 001	198.78	-1.04	1.66	-3.19	11.67	1.33	44.42	-3.60	1.23	-2.23	3.98	-101.59	101.7449	1
Riverside citrandarin	251.01	0.02	2.47	-2.08	11.65	1.29	46.50	-2.26	1.96	-0.12	3.82	-101.20	101.2554	2
CNPMF – 004 Rangpur lime	302.69	1.07	3.19	-1.11	11.23	0.46	47.36	-1.70	2.15	0.43	3.81	-101.17	101.2002	3
Sunki x English Palmira – CO	317.99	1.39	2.90	-1.51	12.88	3.75	47.85	-1.38	1.93	-0.21	3.76	-101.05	101.1464	4
Indio citrandarin	320.96	1.45	3.17	-1.14	11.58	1.15	48.01	-1.29	1.91	-0.25	3.78	-101.10	101.1326	5
TSKC × CTSW – 019	235.69	-0.29	2.02	-2.71	11.51	1.02	43.82	-3.98	1.27	-2.10	3.73	-100.97	101.1118	6
Sunki Tropical mandarin	291.21	0.84	2.72	-1.75	11.52	1.04	48.09	-1.23	1.97	-0.10	3.73	-100.98	101.0159	7
TSKC × CTSW – 028	296.79	0.95	3.14	-1.17	11.68	1.36	47.30	-1.74	2.02	0.07	3.70	-100.90	100.9306	8
Cravo Santa Cruz Rangpur lime	276.19	0.53	3.41	-0.80	10.85	-0.29	49.07	-0.60	2.03	0.10	3.59	-100.60	100.6086	9
TSKC × (TR x LCR) – 073	253.95	0.08	3.32	-0.93	11.67	1.33	45.45	-2.93	1.67	-0.97	3.49	-100.31	100.3680	10
TSKC × LHA – 011	172.43	-1.58	1.95	-2.80	11.98	1.96	45.00	-3.22	1.58	-1.22	3.43	-100.12	100.2491	11
TSKC × LHA – 006	211.22	-0.79	2.22	-2.43	11.69	1.38	48.15	-1.19	1.50	-1.44	3.41	-100.05	100.1086	12
Sunki Maravilha mandarin	174.12	-1.55	1.72	-3.12	11.79	1.58	45.80	-2.71	1.08	-2.67	3.34	-99.81	99.9602	13
TSKC × CTRK – 001	145.00	-2.14	2.00	-2.73	12.06	2.11	47.03	-1.91	1.07	-2.68	3.32	-99.74	99.8776	14
TSKC × CTQT 1439 – 004	208.50	-0.85	2.09	-2.61	11.55	1.09	48.51	-0.96	1.70	-0.86	3.34	-99.81	99.8668	15
San Diego citrandarin	305.22	1.13	3.51	-0.66	11.38	0.75	49.23	-0.50	1.99	-0.02	3.35	-99.85	99.8640	16
HTR – 053	287.26	0.76	3.87	-0.18	11.27	0.54	45.94	-2.62	2.05	0.14	3.34	-99.81	99.8536	17
TSK × CTTR – 002	218.36	-0.65	2.76	-1.69	11.15	0.29	44.99	-3.23	2.16	0.45	3.31	-99.70	99.7733	18
LRF × (LCR x TR) – 005	265.43	0.31	2.57	-1.95	11.94	1.88	47.22	-1.79	1.87	-0.39	3.31	-99.71	99.7665	19
LVK × LVA – 009	215.68	-0.70	2.72	-1.75	12.39	2.76	44.21	-3.73	1.77	-0.67	3.27	-99.57	99.6933	20
HTR – 051	244.33	-0.12	3.48	-0.72	11.58	1.16	45.21	-3.09	1.78	-0.63	3.28	-99.61	99.6675	21
CNPMF – 003 Rangpur lime	239.38	-0.22	3.33	-0.92	10.81	-0.37	47.10	-1.87	2.08	0.23	3.26	-99.55	99.5737	22
LCREEL × CTSW – 001	149.48	-2.05	2.51	-2.04	12.07	2.14	44.82	-3.34	1.36	-1.86	3.22	-99.39	99.5325	23
TSKC × CTSW – 041	272.91	0.47	3.76	-0.32	11.29	0.57	47.96	-1.32	2.08	0.24	3.24	-99.49	99.5047	24
CLEO × CTCZ – 226	230.46	-0.40	3.06	-1.29	11.77	1.54	45.40	-2.97	1.52	-1.39	3.22	-99.41	99.4888	25
TSKC × CTARG – 036	171.80	-1.59	2.26	-2.38	11.47	0.93	45.58	-2.85	1.29	-2.05	3.21	-99.35	99.4617	26
LVK × LCR – 010	242.26	-0.16	3.33	-0.91	10.99	-0.01	44.98	-3.24	1.77	-0.68	3.20	-99.33	99.3935	27
TSKC × (LCR x TR) – 059	262.34	0.25	4.20	0.27	12.02	2.03	47.68	-1.49	2.22	0.65	3.16	-99.19	99.2269	28
TSKC × (LCR x TR) – 018	213.01	-0.75	3.31	-0.95	11.04	0.07	45.25	-3.06	1.48	-1.51	3.13	-99.09	99.1546	29
TSK × TR Benecke – CO	210.47	-0.81	2.88	-1.53	12.50	2.98	48.10	-1.22	1.92	-0.23	3.12	-99.05	99.1144	30
TSKC × (LCR x TR) – 017	275.88	0.53	4.08	0.11	11.58	1.15	47.43	-1.65	1.96	-0.12	3.13	-99.09	99.1105	31
TSKFL × CTTR – 012	193.10	-1.16	3.52	-0.65	10.98	-0.04	46.40	-2.32	1.65	-1.02	3.11	-99.00	99.0457	32
TSKC × CTSW – 064	205.34	-0.91	3.92	-0.11	11.45	0.90	45.92	-2.63	1.35	-1.88	3.08	-98.88	98.9368	33
HTR – 116	246.13	-0.08	4.07	0.10	11.32	0.64	43.80	-3.99	1.46	-1.56	3.06	-98.81	98.9054	34
HTR – 069	215.20	-0.71	4.33	0.45	10.58	-0.84	46.05	-2.55	1.85	-0.42	3.07	-98.85	98.8948	35
TSKFL × CTTR – 008	157.45	-1.89	2.52	-2.03	12.09	2.16	43.80	-4.00	1.22	-2.27	3.04	-98.72	98.8913	36
TSKC × CTSW – 033	208.00	-0.86	3.62	-0.52	11.59	1.18	48.27	-1.12	1.46	-1.55	3.07	-98.85	98.8845	37
Sunki × Alemow – CO	124.79	-2.55	2.62	-1.89	11.34	0.67	45.65	-2.80	1.04	-2.79	3.01	-98.61	98.7422	38
LCR × TR – 001	252.05	0.04	4.14	0.19	10.94	-0.11	47.15	-1.84	2.23	0.67	3.00	-98.56	98.5839	39
TSKC × (LCR x TR) – 001	241.65	-0.17	3.76	-0.33	11.75	1.49	46.48	-2.27	1.51	-1.43	2.97	-98.45	98.4975	40
LVK × LCR – 038	237.46	-0.26	4.28	0.39	11.37	0.73	44.12	-3.79	2.03	0.09	2.93	-98.26	98.3372	41
TSKC × CTQT 1434 – 010	215.03	-0.71	3.75	-0.34	11.94	1.87	48.72	-0.83	1.79	-0.62	2.93	-98.28	98.3106	42
TSKC × CTQT 1439 – 026	188.45	-1.26	3.54	-0.63	12.23	2.45	48.14	-1.20	1.19	-2.35	2.87	-98.02	98.0922	43
TSKFL × CTC 25 – 010	197.38	-1.07	3.76	-0.33	11.42	0.83	45.11	-3.15	1.46	-1.56	2.87	-98.02	98.0892	44
TSKFL × CTTR – 022	161.02	-1.81	2.88	-1.53	11.56	1.11	47.55	-1.58	1.19	-2.34	2.87	-97.99	98.0667	45
CLEO × TR Rubidoux – CO	151.20	-2.01	2.45	-2.12	12.99	3.96	47.93	-1.33	1.49	-1.48	2.72	-97.31	97.4518	46
Xij = mean	227.28		3.10		11.61		46.49		1.68		3.27			
Variance	2405.23		0.54		0.25		2.41		0.12		0.09			
Standard deviation	49.04		0.73		0.50		1.55		0.35		0.30			
Ideotype	250.00		4.00		11.00		50.00		2.00		3.00			
F	**		**		**		**		**		**			
Coefficient of variation (%)	16.55		20.37		3.37		4.13		10.37		6.32			

TSK, 'Sunki' mandarin [*Citrus sunki* (Hayata) hort. ex Tanaka]; TSKC, common 'Sunki' mandarin (*C. sunki*); TR, trifoliate orange [*Poncirus trifoliata* (L.) Raf.]; LCR, Rangpur lime (*C. limonia* Osbeck); CTSW, 'Swingle' citrumelo (*C. paradisi* Macfad. x *P. trifoliata*); HTR, trifoliate hybrid (*P. trifoliata* x sp.); LRF, 'Florida' rough lemon (*C. jambhiri* Lush.); CTQT, 'Thomasville' citrangequat [*Fortunella margarita* (Lour.) Swingle x 'Willits' citrange]; LHA, 'Hamlin' sweet orange [*C. sinensis* (L.) Osbeck]; CTCZ, 'Carrizo' citrange (*C. sinensis* x *P. trifoliata*); CTTR, 'Troyer' citrange (*C. sinensis* x *P. trifoliata*); LVK, 'Volkamer' lemon (*C. volkameriana* (Risso) V. Ten. & Pasq.); LVA, 'Valência' sweet orange (*C. sinensis*); TSKFL, 'Florida Sunki' mandarin (*C. sunki*); CTC, citrange (*C. sinensis* x *P. trifoliata*); CLEO, 'Cleópatra' mandarin (*C. reshni* hort. ex Tanaka); CTARG, 'Argentina' citrange (*C. sinensis* x *P. trifoliata*); LCREEL, 'Santa Cruz' Rangpur lime (*C. Limonia*); CTRK, 'Rusk' citrange (*C. sinensis* x *P. trifoliata*); 'Alemow' (*C. macrophylla* Wester); English Palmira - CO: Sunki x English Palmira - CO is a selection of a USDA hybrid (*C. sunki* x *P. trifoliata* cv. English) introduced from the city of Palmira in Colombia; CNPMF, Embrapa Mandioca e Fruticultura. **Significant at 1% probability. The genotype-ideotype index was calculated based on the methodology described by Schwarzbach (1972).

× 'English Palmira' – CO, and TSKC × (LCR x TR) – 059 ranked very often among the best genotypes for all indices. CNPMF – 004 Rangpur lime also surpassed the standard 'Cravo Santa Cruz' Rangpur lime. These results confirm the initial good performance of these hybrids, which are promising rootstocks for 'Valência' orange in rainfed cultivation, in São Paulo, Brazil, as reported by Ramos et al. (2015).

The Spearman correlation indicated a high similarity among the nonparametric indices, except for D_{iI} (Table 6). The correlations were highly significant for I_{MMi} x I_{RKi}, I_{MMi} x I_{RKii}, I_{MMi} x I_{Ei}, I_{RKi} x I_{RKii}, I_{RKi} x I_{Ei}, I_{RKi} x D_{iI}, I_{RKii} x I_{Ei}, and I_{RKii} x D_{iI}. The multiplicative index, as well as the classification sum and the genotype-ideotype distance indices have been shown also to correlate well for other crops and to provide selection gains in hybrid populations (Lessa et al., 2010, 2017; Almeida et al., 2014). However, in the present work, the genotype-ideotype index was the most divergent because it prioritized relatively productive yet less efficient hybrid rootstocks. Nevertheless, D_{iI} indicated several hybrids ranking above the ideotype for most variables; hence, it still helped out with the selection of promising genotypes.

The selection of new citrus rootstocks is a lifelong challenge for horticulturists, since dozens of traits should be observed, considering all influences that come from climate, soil type, tree management, scion/rootstock combinations, occurrence of pests, and economic aspects (Castle, 2010). The highest yield of fruits that meet the industrial standards is still the most important criterion, although reduced tree size is increasing in importance (Bowman et al., 2016). Classic univariate analyses such as LSD and other mean comparison and grouping tests are usually used to support decisions; however, for citrus, the analyses are still difficult due to their large genetic variability within several attributes.

Table 6. Spearman's correlation among five nonparametric indices, using the variables accumulated fruit production, canopy production efficiency, concentration of soluble solids, juice yield, drought-tolerance (visual scoring of leaf wilting), and tree height of 'Valência' sweet orange grafted on 46 hybrid citrus rootstocks, in the north of São Paulo state, Brazil.

	I_{MMi}	I_{RKi}	I_{RKii}	I_{Ei}	D_{iI}
I_{MMi}	-				
I_{RKi}	0.68**	-			
I_{RKii}	0.85**	0.91**	-		
I_{Ei}	0.86**	0.53**	0.69**	-	
D_{iI}	0.16^{ns}	0.43**	0.30*	0.16^{ns}	-

I_{MMi}, classification sum index (Mulamba & Mock, 1978); I_{RKi}, ranking index using simple means (Costa et al., 2016); I_{RKii}, ranking index using linearly normalized means; I_{Ei}, multiplicative index (Elston, 1963); D_{iI}, genotype-ideotype distance index (Schwarzbach, 1972). *, **Significant at 5% and 1% probability, respectively. ^{ns}Nonsignificant.

The association of selection indices with other statistical tools was recommended, for more robust selection of genotypes (Ferreira et al., 2005). This is particularly important, since the indices discriminate, or should discriminate, the best genotypes, despite the challenges to attain a perfect correspondence because a single genotype will rarely satisfy all traits of interest (Lessa et al., 2010). Nonetheless, citrus breeders should choose the variables and indices that best fit the breeding objectives or economic interests, aiming at a more accurate selection gain, and further criteria can be applied, such as responses to diseases in the long term.

The five nonparametric indices were efficient to sort hybrid citrus rootstocks, even though each one prioritized different variables for selection. Moreover, the high correlations among indices showed that most of them can be similarly used to assist the selection of rootstocks with good overall performance. The ranking indices provided a more coherent classification of hybrids, particularly the I_{RKii}, which made it possible the ranking of the most productive genotypes with fair drought-tolerance and high-quality fruit for processing.

Conclusions

1. The use of nonparametric indices is suitable to assist the breeding programs for the selection of hybrid citrus rootstocks.
2. The ranking index based on the linear normalization of means allows of a more reliable classification of hybrid citrus rootstocks, since it highlights those presenting the greatest accumulated fruit production, in addition to good drought-tolerance, and efficient production of high-quality fruit to obtain juice.

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