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

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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

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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 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).

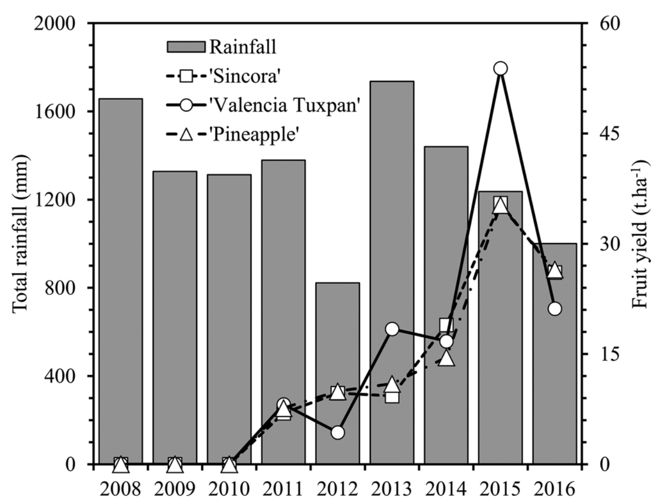

Fig. 1. Total rainfall and average yields of the varieties of sweet oranges [*Citrus sinensis* (L.) Osbeck] 'Sincorá', 'Valencia Tuxpan' and 'Pineapple' in the experimental site in Umbauba, state of Sergipe, Brazil from 2008 to 2016.

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'