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REVIEW

Evaluation of citrus rootstocks for the high pH, calcareous soils of South Texas

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Abstract *Citrus tristeza virus* (CTV) is one of the most devastating disease in areas where sweet orange or grapefruit are budded onto sour orange rootstock. In Texas, the citrus industry is located in the far south of the state in a high pH and calcareous soils region, which makes sour orange the best rootstock option. The Texas industry has been under a threat since the arrival in Florida and Mexico of the most efficient vector of CTV, the Brown Citrus Aphid. In an attempt to find a suitable replacement for sour orange rootstock a field trial was performed to evaluate 10 rootstocks with Rio Red grapefruit scion. Trees on C35 and Carrizo citranges, and Swingle citrumelo became very chlorotic and died. The other rootstocks also showed slight to severe chlorosis but were able to recover. C22 outperformed all rootstocks during the 6 years, producing more than 1.5 times the yield of sour orange, and $\approx$2-fold the production of Goutou which was the rootstock with the lowest production. Although significantly lower than C22, the cumulative production of trees on C57 and C146 rootstocks were excellent and their yearly fruit productions were similar to that of C22 in four (2001, 2003, 2004, and 2005) out of the 6 years of study. All three rootstocks originated from the same cross (Sunki mandarin × Swingle trifoliate orange). In all years, sour orange rootstock yielded the highest percentage of soluble solids (SS) and Troyer and Goutou rootstocks the lowest. Although the SS varied with rootstocks, the ratio of the SS and the percentage of acid did not significantly vary with rootstock type. Considering that C22, C57, and C146 are tolerant to CTV and other important diseases, these rootstocks are good options to replace Sour orange in Texas.

Keywords *Citrus tristeza virus* · Brown citrus aphid · Salinity · Sour orange · Grapefruit

Introduction

Sour orange has been the most desirable citrus rootstock in the world because of its adaptability to a range of soil conditions and the excellent fruit quality induced. However, due to its susceptibility to the *Citrus tristeza virus* (CTV), when used as rootstock for sweet orange and grapefruit, sour orange uses is now restricted to a few areas in the world.

Citrus tristeza virus, which causes quick decline, stem-pitting, and seedling yellows in susceptible citrus species, is one of the most devastating viruses affecting citrus, and a threat for the producing areas

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where sour orange is the predominant rootstock. The worldwide economic losses caused by this virus are enormous considering the millions of trees that were killed by CTV epidemics (Bar-Joseph et al. 1989). In the Valencia Community (Spain), more than 40 million trees grafted on sour orange rootstock were removed because of CTV infection since 1935, one of the best examples of the devastation that this virus can cause (Cambra et al. 2000).

Among all the aphid vectors of CTV, the brown citrus aphid (BrCA), *Toxoptera citricida* (Kirkaldy) is the most efficient one, but this vector is currently not present in the commercial citrus producing area of South Texas (Da Graça et al. 2007). Since BrCA has been reported in Florida in 1995 (Hardy 1995) and in Mexico in 2000 (Michaud and Alvarez 2000) the Texas citrus industry is threatened by this disease. Despite of the fact that the incidence of CTV in commercial groves is low in the Lower Rio Grande Valley (LRGV), Texas, the incidence is high in east Texas (Solís-Gracia et al. 2001), and severe isolates were found in noncommercial citrus (Herron et al. 2006). Furthermore, the majority of the grapefruit and oranges in the LRGV are on sour orange rootstock. Considering this situation, it is just a matter of time before BrCA is introduced and becomes established in Texas and starts a damaging epidemic. Two years after the introduction of the BrCA in Florida, the incidence of CTV increased significantly in the southern part of the state with severe strains increasing more than the mild one (Halbert et al. 2004). Powell et al. (2005) reported that strategies to control the BrCA are ineffective in delaying the movement of decline or non-decline strains of CTV; therefore, the future of the Texas citrus industry depends on finding a suitable replacement for sour orange rootstock which can survive in the high pH and calcareous soils widespread in the LRGV of Texas.

The objective of the present research was to evaluate several rootstocks in an attempt to find an adequate replacement for sour orange as rootstock for Rio Red grapefruit in a high pH, calcareous soil in South Texas.

Material and methods

Ten rootstocks, i.e., C-22, C-146, C-57, C-35, Troyer, and Carrizo citranges, Swingle citrumelo, sour orange, African Shaddock × Rubidoux trifoliate orange and Goutou sour orange, were evaluated with Rio Red grapefruit (*Citrus paradisi* Macf.) as scion in the Lower Rio Grande Valley of Texas. The three hybrids C-22, C-146, and C-57, originated from a cross of Sunki mandarin × Swingle trifoliate orange (*C. sunki* Hort. Ex Tan. × *Poncirus trifoliata* L. Raf. 'Swingle'), African Shaddock × Rubidoux trifoliate orange, and C-35 citrange were all kindly donated by Dr Mikeal L. Roose from the University of California, Riverside. The trial was established in July 1997 in Mission, South Texas, in a Hidalgo fine sand loam soil (Jacobs 1981), known to contain high lime levels (pH 8.2, Na^{+} 325 ppm, Ca^{2+} 1251 ppm, and Mg^{2+} 154 ppm), in a completely randomized design with 20 replications per rootstock and a spacing of 7.6 × 5.5 m. Two guard rows of Rio Red grapefruit grafted on sour orange were planted around the experimental plot. The experimental plot was considered as part of the commercial operation of Rio Queen Farms and all grove cares were performed together with that of their commercial groves. The first harvest was performed 4 years after planting, and each year thereafter, and the following parameters were measured: yield (kg $tree^{-1}$ and tons ha^{-1}), fruit size (commercial classification), acid, and percentage of soluble solids (SS). The yield was measured by weighing all fruits of individual trees in a plot, and fruit sizes were measured as a bulk in the 20 replications, at the Rio Queen Packinghouse using an Integra Grader (Colour Vision System, Victoria, Australia). In late January of each year, ten randomly selected fruits from each tree were used for the determination of juice acidity, SS, and percentage of juice. Juice was extracted using a juice extractor (Sunkist Groves Inc., Overland, KS). Percentage of acid was determined using a DL 50 Grafix (Mettler Toledo, Columbus, OH), and the amount of SS using a Bausch & Lomb refractometer (Bausch & Lomb, Rochester, NY). Fruit size was classified as the number of fruits that fitted in an "18.15" kg carton. The distribution of fruit among size classes is reported as 56, 48, 40, 36, 32, 27, 23, and larger than 23 so that fruit size is inversely proportional to the numeric value.

The effects of rootstock and time (year) on fruit quality and yield data were determined by a two-way analysis of variance (ANOVA) and treatment means were separated using the PROC GLM of SAS (SAS Institute Inc. 1999). In addition, the cumulative yield data was subjected to one-way ANOVA to test for treatment means and separated using the Student-Newman-Keuls' test (Zar 1999). Fruits size was regrouped in the five most common size (≤48, 40, 36, 32, and ≥27). The numbers of fruits in each category were compared between rootstock treatments by a log-likelihood test (*G*-test; Zar 1999) on the 7 × 5 contingency table.

Results and discussion

In an attempt to find a rootstock to replace sour orange, 10 rootstocks were evaluated. Severe iron chlorosis were observed during the first 2 years in C35, Carrizo and Troyer (TR) citranges, Swingle citrumelo, Goutou (GT), African Shaddock × Rubidoux trifoliate orange (ASRT), and light chlorosis on C22, C57, C-146, and sour orange (SO). All replications of C35, Carrizo, and Swingle died and they were replaced by USDA-HRS 809 (Changsha mandarin × English large flowered trifoliata orange) and by USDA-HRS 896 (Cleopatra mandarin × Rubidoux trifoliate orange). These two replacements were slow to grow, displayed severe chlorosis and a few died, and, therefore they are not included in the analysis presented herein. All GT, ASRT, C22, C57, C-146, TR, and SO recovered from the chlorosis and had normal development. GT, ASRT, and TR recovered slower than the other rootstocks, which affected their first year production. Grapefruit trees on C22, C57, and C-146 were initially smaller than those on sour orange but after 7 years there was no visible distinction among them. African Shaddock × Rubidoux trifoliate orange produced the largest trees.

Production in kg tree^{-1} for each of the 6 years and cumulative production in tons ha^{-1} are shown on Figs. 1 and 2 respectively for 6 years of harvest. Production was significantly affected by rootstock ($F = 48.55$; df = 6, 757; $P < 0.0001$) and year ($F = 158.81$; df = 5, 757; $P < 0.0001$). Because the rootstock by year interaction was significant ($F = 2.74$; df = 30, 757; $P < 0.0001$) treatment means were compared separately for each year. However, in the 6-year-period, C22 rootstock was the most productive and GT rootstock the least productive (Fig. 2). Consequently, the cumulative production (Fig. 2) indicates that C22 outperformed all rootstocks during the 6 years, producing more than 1.5 times the production of sour orange, which is the current rootstock used in Texas, and ≈2-fold the production of GT which was the rootstock with the lowest production. Although significantly lower than C22, the cumulative production of C57 and C146 rootstocks were also excellent and their yearly fruit productions was similar to that of C22 in four (2001, 2003, 2004, and 2005) out of the six years of study (Fig. 1). These results are not surprising since these three rootstocks (C22, C57 and, C146) originated from the same cross of Swingle trifoliate orange with Sunki mandarin. These three rootstocks also outperformed the other rootstocks. ASRT and Troyer rootstocks have intermediate cumulative production. The performance of sour orange rootstock was highly variable, being excellent in 2000, intermediate in 2001 and 2005, and poor in 2002, 2003, and 2004 (Fig. 1). Trees on C22 produced fruits inside the canopy which is very beneficial to reduce wind scar, a significant problem in many Texas groves.

Similar to the yield data, the percentage of soluble solids was significantly affected by rootstock ($F = 72.09$; df = 6, 656; $P < 0.0001$), year ($F = 424.16$; df = 4, 656; $P < 0.0001$) and the year by rootstock interaction ($F = 2.5$; df = 24, 656; $P < 0.0001$). In all years sour orange rootstock produced fruits with the highest SS and the Troyer and Goutou rootstocks the lowest. The SS gradually increased from 2001 to 2005 in all rootstocks (Fig. 3). Although the SS varied with rootstocks, the ratio of the SS and the percentage of acid did not significantly vary with rootstock type ($F = 0.68$; df = 6, 649; $P = 0.66$; Fig. 4). Percent juice of fruits

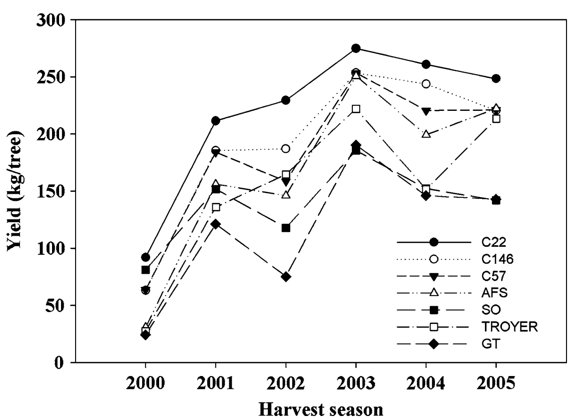

Fig. 1 Yield of Rio Red grapefruit in seven rootstocks during 6 years of harvest

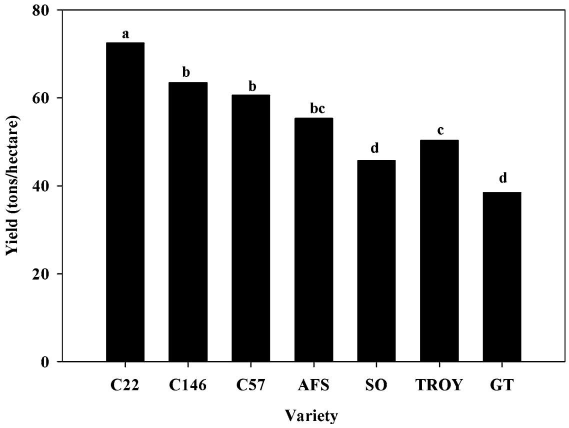

Fig. 2 Cumulative production of Rio Red grapefruit in seven rootstocks

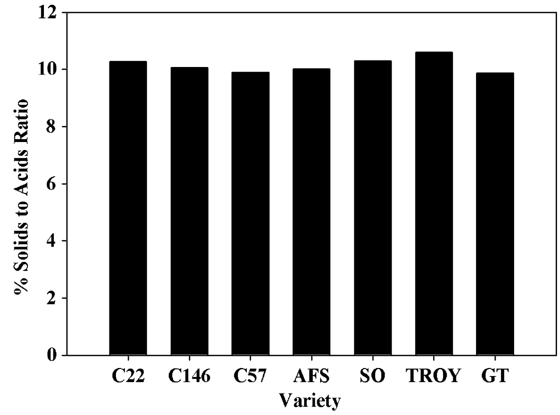

Fig. 4 Percentage of soluble solids to acid ratio in juice of Rio Red grapefruit grafted on seven different rootstocks

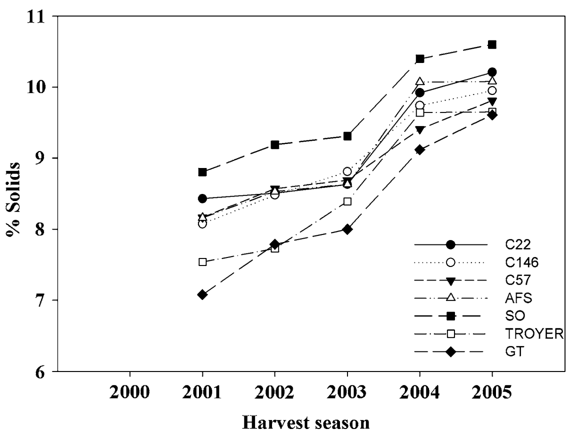

Fig. 3 Percentage of soluble solids in juice of Rio Red grapefruit grafted on seven different rootstocks

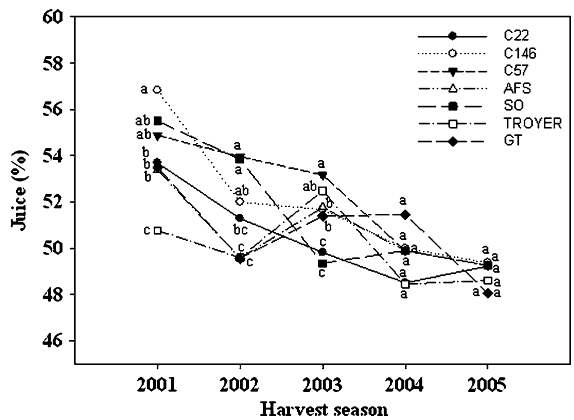

Fig. 5 Percentage juice of fruits of Rio Red grapefruit grafted on seven rootstocks

significantly varied with year ($F = 56.18$; df = 4, 654; $P < 0.0001$), rootstock ($F = 6.06$; df = 6, 654; $P < 0.0001$), and the rootstock by year interaction ($F = 3.54$; df = 24, 654; $P < 0.0001$; Fig. 6). Because of the significant rootstock by year interaction, mean of different rootstocks were compared within each year. During the early years of production (2001–2002), TR had the lowest percent juice in fruits while fruits from the C146 rootstock had the highest percent juice content. Percent juice content of all rootstocks declined with time and by 2004, no differences could be observed between the seven rootstocks (Fig. 5).

The fruit size is an important parameter for growers, since this will determine if the fruit goes to the fresh market or for juice. Smaller fruit size (classes 48–72) in most cases goes to juice even though there are customers for this size in the fresh market. Fruit size 40 and higher (40, 36, 32, 27) give more return, and 32 and higher are most preferred. With the exception of trees grafted on GT, all trees on the other rootstocks produced >80% of their fruits in sizes larger than 40 (Fig. 6). However, the log-likelihood ratio test did not detect significant differences between treatments in fruit size classification ($G = 10.26$, df = 24, $P = 0.993$) suggesting that crop yield is the most important parameter for marketability from the different rootstocks tested. When corrected for total fruit production per rootstock (tons ha^{-1}), C22 outperformed the other rootstocks, producing >20 tons ha^{-1} of fruits in size 40 higher than SO (Fig. 7). About 50% of these fruits were size 32 and higher (not shown). C146 and C57

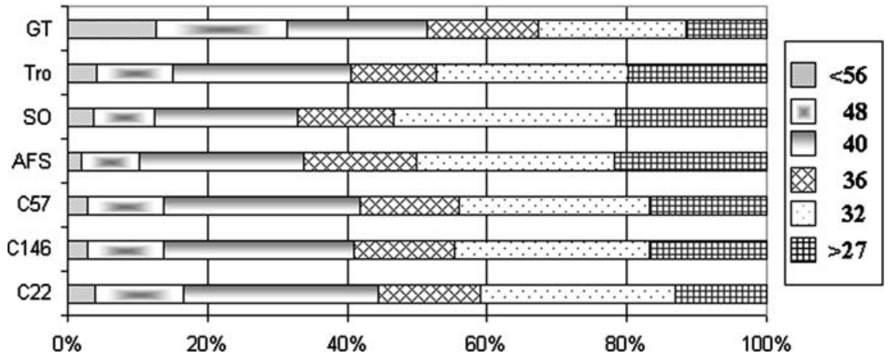

Fig. 6 Average size distribution of fruits of Rio Red grapefruit grafted on seven different rootstocks. The smaller the numbers, the larger the fruits

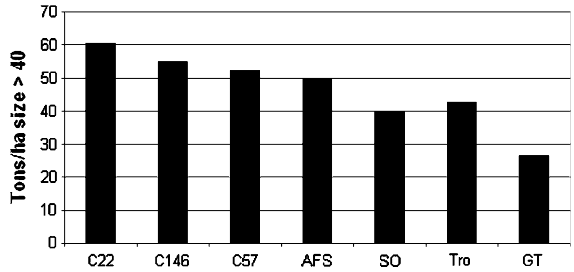

Fig. 7 Total of fruits, sizes 40 and higher (tons ha^{-1}), for each rootstock

were second and third in total production of fruits size 40 and larger (Fig. 7).

Conclusion

The Texas Citrus Industry is under constant threat not knowing when the Brown Citrus Aphid will accidentally be introduced from Florida and/or Mexico, therefore, the question is not "if", but "when" this will happen. Since Texas uses sour orange rootstock almost exclusively for its grapefruit and orange plantings, the risk of catastrophic losses is particularly high. In this study we tested 12 different rootstocks, counting the replacements for the ones that died, and we found that C22, C146, and C57 had the best performance compared to the other four discussed (ASRT, SO, TRO, and GT). These three rootstocks are offspring from a cross of Sunki mandarin with Swingle trifoliate orange. Trifoliate orange is well known for its resistance to CTV (Fang et al. 1998), while Sunki mandarin is highly salt tolerant (Spiegel-Roy and Goldschmidt 1996). The three rootstocks were shown to be well adapted to the high pH and calcareous soil normally found in South Texas, probably inheriting the iron chlorosis tolerance from Sunki. Furthermore, they are known to have acceptable tolerance to CTV, one of the concerns for Texas, while other hybrids from the same cross were found to be susceptible or very susceptible (Bitters 1972; Bitters et al. 1973) clearly demonstrating segregation for this character. They are also tolerant to *Phytophthora* and citrus nematode (M.L. Roose, personal communication). C22 had the best performance, producing >1.6 fold more fruits than SO, which means 26 tons ha^{-1} more than SO. Because of the lack of significant differences in fruit sizes between the different rootstocks, fruit yield, disease tolerance, and adaptability to the alkaline soil become the most important parameters for rootstock selection in Texas. Based on these criteria, C22, C146, and C57 rootstocks hold the most promise for Texas citrus industry. In ongoing studies, we are testing these rootstocks in large, solid block field trials in collaboration with commercial growers. Up to 4 ha of each rootstock is planted in different locations of the Lower Rio Grande Valley, South Texas, to validate the experimental data obtained in commercial settings. Additional experiments are planned to evaluate the three rootstocks in high density planting of up to 1,500 plants ha^{-1}. Seed source trees have been planted to provide for growers future needs.

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