J. AMER. SOC. HORT. SCI. 118(3):326-329. 1993.

Growth, Yield, and Fruit Quality of Nucellar Frost 'Marsh' Grapefruit on Fifteen Rootstocks in Cyprus

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Additional index words. Citrus paradisi, fruit weight, juice content, rind thickness, total acids, soluble solids concentration

Abstract. **Tree growth, yield, and fruit quality of nucellar 'Frost Marsh Seedless' grapefruit *(Citrus paradisi* Macf.) on 15 rootstocks were evaluated under Cyprus conditions. Over the 9-year production period, trees on Palestine sweet lime, the group of rough lemon, and *Citrus volkameriana* Pasq. were more productive per unit of tree size, and their cumulative yields per tree were significantly higher than those of trees on sour orange, which is the standard rootstock commercially used in Cyprus. Rootstocks affected fruit size and weight, rind thickness, juice content, total soluble solids concentration (SSC), and total acids, but the differences were not large enough to affect the market value of the fruit, On the basis of the results of this trial and because sour orange is highly susceptible to tristeza, the *C. volkameriana* and rough lemon group, which are tolerant to tristeza, should be included in further trial plantings as a potential commercial rootstock.**

The Mediterranean basin is one of the citrus growing areas that has been less affected by tristeza virus than several other citrus-producing areas. Tristeza was first reported to exist in Italy in 1955 on Meyer lemon and satsuma mandarin (Russo, 1956). Subsequently, other citrus species were found to be infected in various locations (Davino et al., 1984). In Israel, the disease has been spreading since 1970, 20,000 tristeza-infected trees have been uprooted, and the estimations are that 50,000 to 100,000 more trees are infected (Moreno, 1988). In Spain, between 1956 and 1992, ≈ 15 million trees grafted on sour orange died from tristeza infection, and 7 to 8 million more trees are infected and in different stages of decline (Chambra et al., 1982).

In Cyprus, the presence of tristeza was reported in 1968 by Papasolomontos and Economides (1968) who found 26 trees of four species infected. All diseased trees were eradicated. The use of sour orange as the main rootstock and reports of the spread of tristeza in neighboring countries have necessitated the initiation of indexing work for tristeza. Indexing work on Clementine mandarin trees in the main citrus producing area showed 190 trees infected out of 332 trees tested (Kyriacou and Polycarpou, 1989). A routine indexing and eradication program for tristeza is undertaken in the island's citrus industry.

As an assurance for future plantings, research programs were started in Cyprus (Economides, 1976a, 1976b; Economides, 1977) to find new rootstocks to replace sour orange in case of tristeza outbreak. The rootstocks used in these trials have shown promise in other areas. Performance was measured by growth, yield, and fruit quality of the 'Marsh Seedless' grapefruit as the scion.

Materials and Methods

The rootstocks included sour orange (C. *aurantium* L.), Palestine sweet lime (C. *limettioides* Tan.), rough lemon, Red rough lemon and Estes rough lemon (C. jambhiri Lush.), Rangpur lime *(C. limonia* Osbeck.), Troyer and Carrizo citrange (C. *sinensis* (L.) Osbeck × *Poncirus trifoliata* (L.) Raf), Yuma citrange *(P. trifoliata* × *C. sinensis),* Morton citrange *(P. trifoliata* × *C. sinensis),* 'Swingle' citrumelo *(C. paradisi* × *P. trifoliata), Volkameriana (C. volkameriana* Pasq.), Taiwanica *(C. taiwanica* Tan.), Amblycarpa *(C. limonellus* var. amblycarpa Hassk.), and Cleopatra mandarin *(C. reticulata* Blanko.). Seeds were obtained from California, except those of sour orange and Palestine sweet lime, which were obtained locally from selected healthy trees. All were planted in Spring 1976. The seedlings were transplanted in the nursery row at the Citrus Experiment Station at Akhelia, Paphos, in Spring 1977, and were budded in Mar. 1978 with buds from a single tree of nucellar 'Frost Marsh Seedless' grapefruit raised from budwood imported from California in 1975. The scion of all the trees were of the same clonal strain.

The trees were raised by standard cultural practices. Uniform 1-year-old budded trees were planted in Mar. 1979 at the Citrus Experiment Station at Akhelia in a complete randomized block design with two-tree plots of each rootstock and six replications. The spacing was 6.6 × 4.2 m.

The soil was clayey (60% clay, 25% silt, 15% sand), contained 20% $CaCO_3$, had a pH value of 8.0 (1 soil : 2.5 water), and an EC, value of 1.5 $dS \cdot m^{-1}$ throughout the profile.

Orchard care was similar to commercial practice in the area. The orchard was irrigated by under-tree minisprinklers at 25 weekly intervals per year giving ≈700 mm of water. The water had a pH of 7.6 and an electrical conductivity of 0.7 $dS \cdot m^{-1}$ and contained an average of 450 ppm total soluble salts, including 53 ppm Cl^-, 57 ppm Na^+, 58 ppm Ca^{+2}, 20 ppm Mg^{+2}, 134 ppm SO_4, and 129 ppm HCO_3.

The area has an average yearly rainfall of 420 mm, occurring mainly from October to April. Mean maximum air temperature ranges from 17C in January to 33C in July, with mean minima from 9 to 21C. Relative humidity ranges from 50% to 80% during the winter months and from 60% to 70% in the summer.

Annual applications of ammonium sulphate, triple superphosphate, and potassium sulphate were applied in spring, a month before flowering, the amounts increasing progressively each year to reach 3.0, 0.5, and 1.0 kg per tree, respectively. The orchard was cultivated, pruned, and sprayed with insecticides, fungicides, and nutritional sprays as needed,

In Oct. 1990, the trunk circumference of each tree was measured at a point 15 cm above the bud union. These measurements have been converted to trunk cross-sectional area (TCSA) (square centimeters), which better depicts relative sizes.

Yields were measured as kilograms of fruit per tree, harvested in the middle of December each year, when the crop was fully

Received for publication 1 Apr. 1992. Accepted for publication 24 Oct. 1993. Research conducted at Akhelia Research Station of the Agricultural Research Institute. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

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Table 1. Effect of rootstock on trunk cross-sectional area (TCSA) and yield of nucellar 'Marsh Seedless' grapefruit trees.

Rootstock	TCSA (1990) (cm^2)[z]	Average annual yield per tree (kg) 1982	1983	1984	1985	1986	1987	1988	1989	1990	Cumulative yield per tree (kg) 1982–90	Cumulative yeild per TCSA ($kg \cdot cm^{-2}$)
Sour orange	195 abcd	12 bcde[*]	46 cd	93 cde	143 efg	90 ghi	173[NS]	252 bcd	273 ab	181 cde	1263 c	6.5 def
Palestine sweet lime	176 cde	23 ab	71 ab	132 a	185 abcd	191 a	204	279 ab	287 a	236 a	1607 a	9.1 a
Rough lemon	203 abc	18 abc	72 ab	122 ab	182 abc	153 bcd	156	292 ab	286 a	225 ab	1505 b	7.4 bcd
Red rough lemon	210 ab	11 cdef	61 bc	106 bc	162 bcd	163 abc	146	277 ab	274 ab	219 ab	1419 b	6.8 cde
Estes rough lemon	192 abcd	23 a	83 a	141 a	194 a	180 ab	206	297 a	281 a	201 bc	1607 a	8.4 ab
Rangpur lime	174 de	4 def	35 def	84 def	147 def	126 def	163	252 bcd	240 bc	184 cd	1235 cd	7.1 cde
Troyer citrange	181 bcde	1 ef	18 g	56 hi	109 h	116 efg	173	206 ef	220 c	149 efgh	1048 e	5.8 fg
Carrizo citrange	174 cde	15 abcd	53 c	104 bcd	144 defg	156 bcd	155	226 cde	218 c	165 defg	1236 cd	7.1 cde
Yuma citrange	130 f	0 f	15 g	38 i	74 i	68 i	164	141 g	161 d	122 h	783 f	6.0 efg
Morton citrange	159 e	12 bcde	55 c	104 bcd	159 cde	145 cde	158	255 bcd	231 c	185 cd	1304 c	8.2 b
Swingle citrumelo	159 e	9 cdef	39 de	79 efg	127 fgh	154 bcd	174	223 de	218 c	140 gh	1163 d	7.3 bc
Volkameriana	169 de	25 a	76 a	126 a	187 ab	175 abc	183	267 abc	247 abc	174 cdef	1461 b	8.7 b
Taiwanica	171 de	8 cdef	37 de	69 fgh	119 gh	82 hi	157	209 ef	237 bc	155 efgh	1073 e	6.3 ef
Amblycarpa	207 ab	2 ef	28 efg	73 efgh	133 efgh	101 fgh	178	192 ef	218 c	134 gh	1059 e	5.1 gh
Cleopatra mandarin	212 a	1 ef	23 fg	60 gh	106 h	72 hi	179	182 f	221 c	142 fgh	986 e	4.7 h
CV (%)	12	79	24	18	14	19	25	13	13	14		

[z]Measured 15 cm above bud union.
[*]Mean separation within the same column at $P = 0.05$ by Duncan's multiple range test.
NS = nonsignificant.

mature. Fruit samples for quality studies, taken from 1986 to 1990, consisted of a composite of 40 fruits picked at random from the two trees of each replication. Each fruit was weighed and cut in half. Rind thickness was measured with a digital caliper, and the juice was extracted with an electric juicer. Total SSC was measured with a temperature-compensated refractometer, and total acids were determined (as citric acid equivalent) by titrating with Na0H.

Results and Discussion

After 11 years, the rootstocks had a striking effect on the TCSA (Table 1). The difference between the most vigorous and the least vigorous trees was ≈63%, the largest being on Cleopatra mandarin and the smallest on Yuma citrange. Trees on rough lemons, sour orange, and *C. amblycarpa* were larger in general than the trees on citranges and *C. volkameriana.*

The trees on 'Swingle' citrumelo developed a severe overgrowth of the rootstock as compared to the trees on Troyer, Carrizo, Yuma, and Morton citranges on which the overgrowth was slight. The overgrowth of the rootstock did not affect the yield. Some overgrowth of Morton citrange, when used with 'Washington navel', has been reported in California, but the trees looked normal and their performance has not been affected (Batchelor and Rounds, 1948).

Trees on Palestine sweet lime and Troyer citrange showed a general yield increase until 1989 and a decrease in 1990, whereas trees on 'Swingle' citrumelo showed a general yield increase until 1988 and a decrease in the following 2 years (Table 1). Trees on the other rootstocks showed a general yield increase until 1985 and variability in production during the following years. This variability in production of trees on the various rootstocks probably reflects a tendency to biennial bearing. However, trees on Palestine sweet lime, rough lemons, and *C. volkameriana* had significantly higher yield in almost all years than trees on the other rootstocks.

The cumulative yields over the 9 years from 1982 to 1990 indicate a difference in productivity between the high and the low yielding rootstocks of 105% (Table 1). The trees on Palestine sweet lime, the rough lemons, and *C. volkameriana* produced significantly higher yields than those on sour orange, the citranges group, and the other rootstocks. The relatively small tree size and low yield of trees on the citranges and 'Swingle' citrumelo were probably due to the high soil pH and $CaC0_3$ content.

The correlation coefficient between average tree size and cumulative yield was not significant *($r = 0.3$, $P = 0.25$).* In general, the largest trees did not produce the highest yields. Productivity per square centimeters of TCSA on the various rootstocks was higher for Palestine sweet lime and *C. volkameriana* and lowest for Cleopatra mandarin and *C. amblycarpa* (Table 1). The trees on Palestine sweet lime and *C. volkameriana* were medium-sized and could have been planted more closely than the larger trees. With more trees per unit area, the production from medium-sized trees on a per hectare basis may equal or exceed that from trees planted further apart. There are also other disadvantages, including extra cultural costs in handling large trees.

Rootstocks affected fruit size, weight, and rind thickness (Table 2). The largest and heaviest fruit was produced by the trees on the rough lemon group, Palestine sweet lime, Rangpur lime, Carrizo citrange, and *C. volkameriana,* although these did not differ significantly from those of all others. Trees on Cleopatra mandarin, *C. amblycarpa, C. taiwanica,* and Yuma citrange produced

Table 2. Effect of rootstock on fruit size, weight, and rind thickness of nucellar 'Marsh Seedless' grapefruit (average 1986–90).

Rootstock	Average fruit diam (cm)	Average fruit wt (g)	Average rind thickness (mm)
Sour orange	9.5 ab*	315 bcd	7.8 abc
Palestine sweet lime	9.7 ab	346 ab	7.1 c
Rough lemon	9.8 a	360 a	7.6 bc
Red rough lemon	9.5 ab	339 ab	8.0 abc
Estes rough lemon	9.7 ab	335 abc	7.5 c
Rangpur lime	9.6 ab	344 ab	7.5 c
Troyer citrange	9.0 cd	297 cde	7.8 abc
Carrizo citrange	9.5 ab	338 ab	7.0 c
Yuma citrange	9.2 bc	311 bcde	8.5 ab
Morton citrange	9.5 ab	341 ab	7.6 bc
Swingle citrumelo	8.9 cd	285 de	7.3 c
Volkameriana	9.6 ab	332 abc	7.8 abc
Taiwanica	9.3 abc	316 bcd	8.7 a
Amblycarpa	9.0 cd	276 e	8.7 a
Cleopatra mandarin	8.7 d	277 e	8.5 ab
CV (%)	4.0	9.3	9.3

*Mean separation within columns at $P = 0.05$ by Duncan's multiple range test.

Table 3. Effect of rootstock on fruit quality of nucellar 'Marsh Seedless' grapefruit (average 1986–90).

Rootstock	Juice by wt (%)	Total soluble solids (SSC) (%)	Total acids (TA) (%)	SSC : TA ratio
Sour orange	45.5 a*	12.2 abc	2.3 bc	5.35 bcd
Palestine sweet lime	44.8 ab	10.1 f	2.0 d	5.07 de
Rough lemon	40. 4 cdef	11.1 def	2.0 d	5.55 bc
Red rough lemon	41.5 bcde	10.7 ef	2.0 d	5.26 bcd
Estes rough lemon	38.7 efg	11.3 cde	2.1 cd	5.35 bcd
Rangpur lime	41.6 bcde	10.7 ef	2.1 cd	5.18 cd
Troyer citrange	40.4 cdef	11.7 abcde	2.3 bcd	5.19 cd
Carrizo citrange	39 .2 defg	11.4 bcde	2.1 cd	5.34 bcd
Yuma citrange	41.5 bcde	11.7 abcd	2.2 bcd	5.29 bcd
Morton citrange	43.9 abc	12.0 abcd	2.0 d	5.93 a
Swingle citrumelo	42.9 abcd	12.4 ab	2.3 bc	5.40 bcd
Volkameriana	37.2 fg	11.5 bcde	2.1 cd	5.58 b
Taiwanica	40.6 cdef	11.2 cde	2.2 bcd	5.17 d
Amblycarpa	37.1 fg	12.6 a	2.7 a	4.77 e
Cleopatra mandarin	36.4 g	12.3 abc	2.4 b	5.15 d
CV (%)	6.2	6.8	8.7	5.3

*Mean separation within columns at $P = 0.05$ by Duncan's multiple range test.

fruit with thicker rinds than trees on other rootstocks, but they were similar to those of fruit on others.

Fruit quality was also influenced by rootstock (Table 3). Juice content per unit fruit weight was higher for trees on sour orange and Palestine sweet lime and lower for those on *C. volkameriana, C. amblycarpa,* and Cleopatra mandarin than for most others. Total SSC was higher in fruit from trees on sour orange, 'Swingle' citrumelo, *C. amblycarpa,* Cleopatra mandarin and lower from trees on Rangpur lime, Red rough lemon, Palestine sweet lime, and Rough lemon than for most others. There was no great variation in total acids content in fruit from trees on various rootstocks. In general, the differences in total SSC and total acids were not large enough to be likely to affect the market value of the fruit when harvested at dates used in this study.

Cyprus citriculture is threatened by tristeza, and the tristeza-susceptible sour orange rootstock should be replaced by other rootstock(s) resistant to the disease. Choice of a rootstock becomes a matter of individual judgment when the merit of a rootstock depends on several characteristics and when none is superior in all respects. *Citrus volkameriana* and the rough lemons, which are tolerant to tristeza, would appear to be the best of those evaluated. Trees on these rootstocks produce large yields of fruit (per tree) of excellent size and of average total SSC and total acids content. Although juice content per unit fruit weight was low for trees on *C. volkameriana,* this rootstock is adaptable to a wide range of soils and would be suitable for use under most conditions (Castle et al., 1989).

On the basis of these results, *C. volkameriana* and the rough lemons deserve further evaluations as potential commercial rootstocks to replace the tristeza-susceptible sour orange root-

stock. Risks are of course unavoidable in the adoption of any new fruit rootstocks, and final conclusion will emerge only after extended trials and experience under a range of commercial growing conditions.

Literature Cited

Batchelor, L.D. and M.D. Rounds. 1948. Choice of rootstocks, p. 169-222. In: L.D. Batchelor and H.J. Webber (eds.). The Citrus Ind. vol II, Univ. of California Press, Berkeley.

Castle, S.W., D.P.H. Tucker, H.A. Krezdorn, and C.O. Youtsey. 1989. Rootstocks for Florida Citrus. Inst. Food Agr. Sci., Univ. of Florida, Gainesville, pp. 47.

Chambra, M., A. Hermoso, P. Moreno, and L. Navarro. 1982. Use of enzyme-linked immunosorbent assay (ELISA) for detection of citrus tristeza virus (CTV) in different aphid. Proc. Intl. Soc. Citricult. 1:444-448.

Daviono, M., A. Catara, F. Russo, G. Terranova, and G. Carbone. 1984. A survey for citrus tristeza virus in Italy by the use of enzyme-linked immunosorbent assay. Proc. 9th Conf. Intl. Organization Citrus Virologists, Riverside, 66-69.

Economides, C.V. 1976a. Performance of Marsh seedless grapefruit on six rootstocks in Cyprus. J. Hort. Sci. 51:393-400.

Economides, C.V. 1976b. Growth and productivity of Washington navel orange trees on six rootstocks in Cyprus. Hort. Res. 16:83-88.

Economides, C.V. 1977. The influence of rootstocks on tree growth, yield and fruit quality of Valencia oranges in Cyprus. J. Hort. Sci. 52:29-36.

Kyriacou, A. and D. Polycarpou. 1989. Detection of Citrus tristeza in Cyprus. Mediterranean Crop Improvement Council, News 12:3-4.

Moreno, P. 1988. Citrus tristeza virus (CTV). A major threat to the Mediterranean area. Working group. Integrated control in citrus fruit crops. Intl. Union Biol. Sci. 100-108.

Papasolomontos, A and C.V. Economides. 1968. The presence of tristeza virus in certain species of citrus in Cyprus. Food Agr. Organization Plant Protection Bul. 16 (1):8-9.

Russo, F. 1956. La presenza del virus della tristeza su limon “Dwarf Meyer” emandarino “Satsuma”riscontrata in Sicilia. Riv Agromicoltura 1:7-8,281-289.