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US-812 Citrus Rootstock

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'US-812' is a new citrus rootstock released May 2001 by the Agricultural Research Service (ARS) of the U.S. Dept. of Agriculture (USDA). Compared to other citrus rootstocks used in Florida, US-812 is highly productive of good quality fruit on a moderate-sized tree and exhibits tolerance or resistance to citrus tristeza virus (CTV) and citrus blight. US-812 propagates uniformly from seed (by nucellar polyembryony) and is graft compatible with all scion cultivars examined, including sweet orange [*Citrus sinensis* (L.) Obsbeck], grapefruit (*C. paradisi* Macf.), mandarin (*C. reticulata* Blanco), tangelo (*C. reticulata* × *C. paradisi*), and other citrus hybrids.

Origin

US-812 is the result of a cross between Sunki mandarin (*C. reticulata*) and Benecke trifoliate orange (*Poncirus trifoliata* [L.] Raf.) completed at the USDA Indio Research Station, California. During the early stages of testing, this hybrid selection was moved as seed to the U.S. Horticultural Research Laboratory in Orlando, Florida for the rootstock evaluation process. While under test in Florida, the new rootstock selection was identified as Sunki × Benecke, HRS-812, or US-812. Seed for all greenhouse and field evaluations described below was obtained from the field source tree WFF 1-132-46.

Fruit for descriptive characteristics of US-812, Swingle citrumelo, and Carrizo citrange was collected from the USDA Whitmore Foundation Farm at fruit maturity during the 2002 and 2003 crop seasons. Leaf and spine descriptive characteristics were collected from young greenhouse seedlings of each clone during 2001-2002. Field trials conducted as part of the performance documentation for US-812 were established into the field sites between 1989 and 2000, and data collected using common methods. Details on trial locations, soils, management, and preliminary results were described in previous publications, as indicated. Evaluation of rootstock resistance to pests and disease were based on comparative field performance, greenhouse testing, or a combination of the two, as indicated.

For all experiments, the data were tested by analysis of variance using Statistica version 7.0 (StatSoft, Tulsa, Okla.). Duncan's multiple range test was used for mean comparison within columns or rows (as indicated) when the F test was significant at $P < 0.05$.

Description

As commonly used, US-812 forms the rootstock of the tree, with a good quality fruit cultivar grafted onto US-812 about 10 to 20 cm above the ground. Fruit of the US-812 rootstock clone are needed to produce seed for economical multiplication of the rootstock. For this purpose, mature US-812 shoots are budded onto another rootstock variety and grown to produce a fruiting tree. Characteristics of the US-812 fruit are similar to those of many hybrids from similar parentage, but distinctive from many other rootstocks in commercial use (Fig. 1). Quantitative fruit and seed traits of US-812 are clearly distinguished from Carrizo citrange (*C. sinensis* [L.] Osbeck × *P. trifoliata*) and Swingle citrumelo (*C. paradisi* Macf. × *P. trifoliata*) (Table 1).

US-812 seed produces seedlings that are predominantly derived from maternal tissue by apomixis and thus are clonally identical to US-812. In experimental populations of US-812 seedlings, frequency of off-type or zygotic seedlings has been less than five percent. Like many other first-generation hybrids of *Poncirus trifoliata* with *Citrus* spp., US-812 seedlings are vigorous, healthy, and possess trifoliolate leaves with winged petioles (Fig. 2). US-812 seedlings can be readily separated from seedlings of the two most common *P. trifoliata* hybrid rootstocks in commercial use, Swingle and Carrizo, based on leaf and spine characteristics (Table 2). Grafted trees of citrus cultivars on US-812 rootstock typically have some rootstock overgrowth of the scion (or

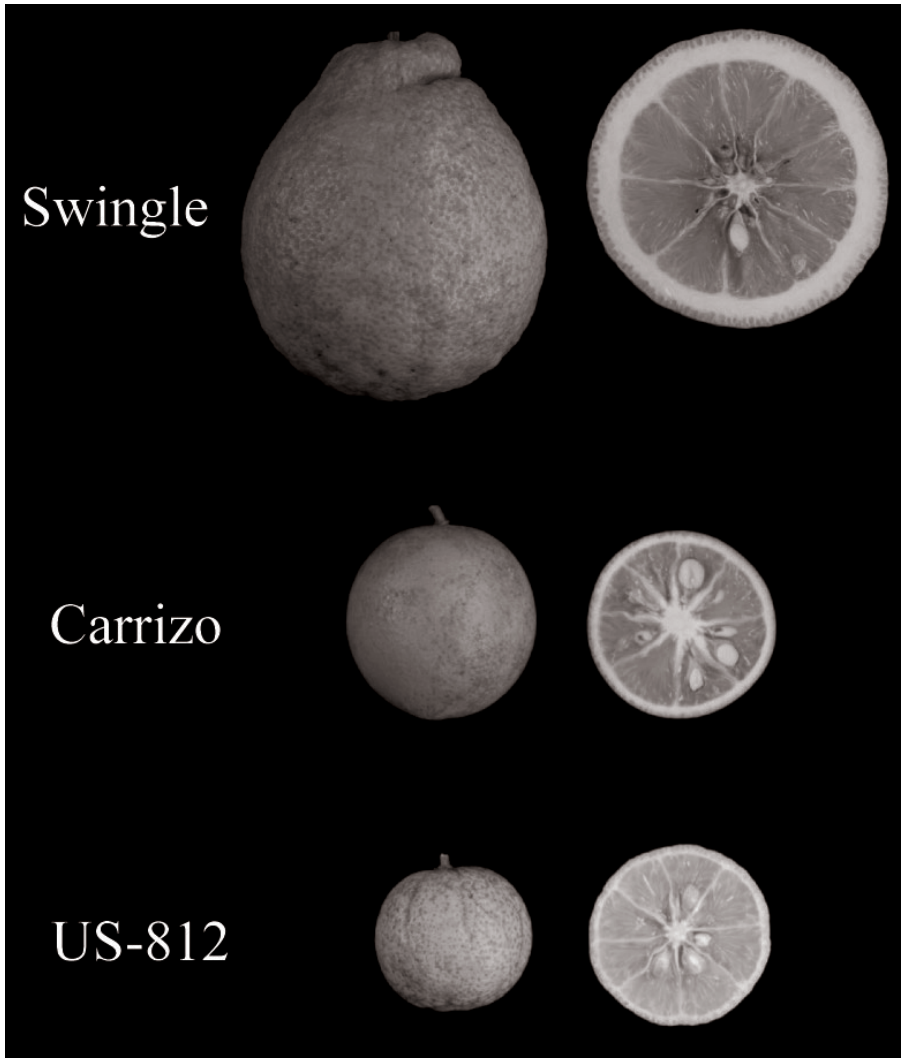

Fig. 1. Whole and cut fruit of Swingle, Carrizo, and US-812 at maturity.

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Table 1. Fruit and seed characteristics of US-812, compared with two common citrus rootstocks.

Trait	Swingle citrumelo	Carrizo citrange	US-812
Fruit weight (g)	289 A[z]	136 B	63 C
Fruit length (mm)	85 A	65 B	50 C
Fruit diameter (mm)	86 A	65 B	52 C
Seeds per fruit	26 A	23 A	15 B
Seed weight (mg)	23.2 B	35.3 A	18.3 C
Seed length (mm)	12.5 B	14.3 A	10.6 C
Seed diameter (mm)	6.9 B	8.8 A	6.5 C
Seeds per liter	3226 A	1942 B	3670 A

[z]Mean separations for significant ANOVA within rows were by Duncan's multiple range test at $P < 0.01$.

benching) similar to that of many other trifoliate hybrid rootstocks, and are not particularly distinctive in physical appearance (Fig. 3).

Performance

Field performance of US-812 was evaluated through 10 or more years of age in six Florida plantings. In each of these plantings, performance of US-812 was good or outstanding in comparison to other commercial rootstocks included in the planting. Several other field plantings were evaluated for shorter periods of time. Overall, performance in most field plantings was good, as described below.

Yield. Four long-term trials were conducted in well-drained Florida "ridge" sites. Trees were planted in a randomized manner with other comparison rootstocks and yield was carefully measured through at least six consecutive harvest seasons. In one rootstock trial in Polk County with 'Valencia' sweet orange on 21 rootstocks, US-812 was the first or second most productive rootstock through the fourth harvest season (Wutscher and Bowman, 1999), depending on the unit of yield measurement compared. When the yield comparison was continued through the sixth harvest season in this trial (Table 3), US-812 yield appeared clearly superior to all of the other commercial rootstocks in the trial, including Swingle, Carrizo, Gou Tou, Sun Chu Sha, and Vangasay lemon. In three Lake County trials, with 'Sunburst' (Table 4), 'Fallglo' (Table 5), and 'Ambersweet' (Table 6) citrus hybrid scions, yield of trees on US-812 through the first six harvest seasons was good or outstanding in comparison to other commercial rootstocks. Preliminary performance of US-812 in these trials was reported previously (Bowman, 1998; Bowman and Roman, 1999).

Performance of US-812 in Florida flatwoods sites was evaluated in one long-term randomized trial and one nonrandomized planting in St. Lucie County, one long-term nonrandomized planting in Hendry County, and several other shorter-term randomized trials at other sites. Performance in some of these plantings and in Puerto Rico was described previously (Bowman and Roman, 1999; Bowman and Wutscher, 2001). At all the plantings where data were recorded, yield performance of US-812 has been good.

Yield of several sweet orange scions on US-812 was compared to that on three other rootstocks in a Collier County trial at the University of Florida, Southwest Florida Research & Education Center near Immokalee. For trees with 'Hamlin' scions, yield on US-812 was significantly better than that of trees on X-639 (a commercially available hybrid of *C. reticulata* × *Poncirus trifoliata*) through the four seasons from age five to eight (Table 7). During the same time period, 'Valencia' scion yield on US-812 was equal to that of X-639 and US-1001 (another USDA hybrid that has not been released) and significantly better than yield on Kinkoji (*C. obovoideae*), another new commercially available rootstock (Table 8). Yield of midseason sweet oranges on US-812 in the trial was good but not statistically different from that of trees on the other rootstocks in the test (data not shown).

In two young 'Flame' grapefruit trials in St. Lucie and Indian River Counties, yield of trees on US-812 was good in comparison to trees on other rootstocks (Table 9). During the first harvest season for the St. Lucie County trial, yield of trees on US-812 was similar to that on the highest yielding rootstock, rough lemon (*C. jambiri* Lush.), and significantly better than that on Swingle, Sun Chu Sha, US-802 (an unreleased USDA hybrid), and Flying Dragon rootstocks. Although yield of grapefruit trees on US-812 in the Indian River County trial was good in comparison to Carrizo, Swingle, and Cleopatra rootstocks, its overall performance at that site would probably be judged poor. Further discussion of the likely explanation for this poor performance is given in the disease resistance section below.

Tree size. Comparative height of trees on US-812 at 6-10 years was evaluated in four trials, all on Florida "ridge" sites (Table 10). Trunk Cross Sectional Area is also a measure of relative trees size and was compared for different rootstocks in the Indian River County grapefruit trial. Some variability was observed by trial and should be expected in response to different scions, soils, growing conditions, and disease pressure. In general, under good growing conditions trees on US-812 were smaller those on rough lemon and Carrizo, similar in size to those on Swingle and Sun Chu Sha, and larger than trees on Flying Dragon.

Fruit quality. Measurements of fruit quality

Fig. 2. Greenhouse-grown seedling shoots of Swingle, Carrizo, and US-812.

Table 2. Seedling leaf and spine characteristics of US-812, compared with two common citrus rootstocks.

Trait	Swingle citrumelo	Carrizo citrange	US-812
Center leaflet length (mm)	55.5 A[z]	41.1 C	44.7 B
Center leaflet width (mm)	24.6 A	19.1 C	21.0 B
Side leaflet length (mm)	32.8 A	22.4 C	25.4 B
Side leaflet width (mm)	15.1 A	10.3 C	11.4 B
Petiole length (mm)	20.0 AB	21.4 A	18.5 B
Petiole width (mm)	3.9 A	4.1 A	2.9 B
Spine length (mm)	5.3 B	7.9 A	8.8 A

[z]Mean separations for significant ANOVA within rows were by Duncan's multiple range test at $P < 0.01$.

Fig. 3. Base of mature 'Valencia' sweet orange tree on US-812 rootstock showing typical graft union on a field tree.

Table 3. Yield of Valencia sweet orange on US-812 and other rootstocks in Polk County, 1996–2001.

	Fruit yield (kg/tree)						Yearly
Rootstock	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	avg[z]
US-812	41 b[y]	61 a	90 b	114 a	122 a	103 a	107 a
Vangasay lemon	54 a	51 a	120 a	92 b	119 ab	68 c	100 a
Swingle	38 bc	39 b	75 c	87 b	90 c	91 ab	86 ab
Carrizo	25 c	29 bc	75 c	86 b	109 ab	82 bc	88 ab
Sun Chu Sha	29 bc	29 c	66 c	60 c	105 bc	63 c	74 b
Sour orange #2	7 d	3 d	21 d	23 d	21 d	29 d	23 c

[z]Yearly average based on years 5 to 8.
[y]Mean separations for significant ANOVA within rows were by Duncan's multiple range test at $P < 0.05$.

Table 4. Yield of Sunburst tangerine on US-812 and other rootstocks in Lake County, years 1996–2001.

	Fruit yield (kg/tree)						Yearly
Rootstock	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	avg[z]
US-812	19	66 a[y]	22 ab	108 a	66	158 a	84
Carrizo	36	54 a	39 a	116 a	53	147 a	82
Cleopatra	34	43 ab	44 a	84 ab	48	101 b	64
Swingle	19	45 ab	13 b	81 ab	44	101 b	57
Sun Chu Sha	31	22 bc	25 ab	65 bc	33	90 bc	47
US-937	19	10 c	8 b	32 c	24	55 c	26

[z]Yearly average based on years 5 to 9.
[y]Mean separations for significant ANOVA within rows were by Duncan's multiple range test at $P < 0.05$.

were taken in all the trials described. Although there was variability between trials and between years, in general, the influence of US-812 rootstock on the scion fruit quality was good, especially as relates to fruit for juice production. When sweet orange fruit is grown for use in orange juice concentrate (a major part of Florida orange production), quantity of soluble solids per 40.9 kg box of fruit is probably the most important component of fruit quality. Fruit quality data from trials with 'Valencia' (Table 11) and 'Hamlin' oranges (Table 12), indicated that production of soluble solids by US-812 is similar to the best of the commercially used rootstocks and often significantly better than that on X-639 and Vangasay lemon. Influence of US-812 on fresh fruit internal quality (brix, acid, juice, color) was also generally good, such as with 'Sunburst' tangerine (Table 13). However, individual fruit size on US-812 was often smaller than on many other rootstocks. In cases where large fruit size is important for successful marketing of the crop, US-812 may not be suitable. Preliminary studies have indicated that US-812 imparts a moderate to favorable effect on post-harvest storage life of grapefruit (McCollum et al., 2002) and Valencia orange (Ritenour et al., in press).

Disease and pest resistance. Health, growth, and survival of trees on US-812 were generally good in trials conducted in Florida. Evidence on tolerance of important disease threats can be derived from performance in some of these trials. In the Polk County Valencia trial, trees on sour orange were unproductive (Table 3) and severely stunted (Table 10), in addition to having a high proportion of tree loss. This extremely poor performance of sour orange rootstock provides clear evidence for a severe challenge in that trial from citrus tristeza virus (CTV) (Bowman and Garnsey, 2001). In contrast, trees on US-812 in the trial were uniformly healthy, moderately vigorous, and highly productive. This evidence, combined with the presence of flanking markers for the citrus tristeza virus (CTV resistance gene from *Poncirus trifoliata* in US-812 (data not presented), provide evidence that US-812 has resistance or tolerance to CTV infection and decline.

There was also good survival of trees on US-812 in long-term plantings in Hendry and St. Lucie Counties, while neighboring trees on other rootstocks failed. Many of these trees losses on other rootstocks were probably due to blight (Wutscher et al., 1977) or blight-like soil disease problems. The St. Lucie County Valencia trial was under conditions of high soil pH (8.1 to 8.3) and the good performance of US-812 there may be indicative of some tolerance of high alkalinity.

Good performance of trees on US-812 at many sites also suggests some resistance to *Phytophthora nicotianae* diseases, which are common in most production areas. However, greenhouse inoculation tests of US-812 alongside other rootstocks have indicated that US-812 is relatively susceptible to *Phytophthora palmivora*, especially in soils with poor drainage (Bowman et al., 2002). In addition, greenhouse testing of US-812 for resistance to the Diaprepes root weevil (*Diaprepes abbreviatus*) has indicated that US-812 is as susceptible as most other common rootstocks in commercial use (Bowman et al., 2001). These greenhouse test results are reinforced by field observations at a young trial with grapefruit in Indian River County infested by *Diaprepes* weevil and *P. palmivora* on heavy Winder soil (Bowman et

Table 5. Fallglo scion in Lake County, years 1996–2001.

Rootstock	Fruit yield (kg/tree)						Yearly avg[z]
	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	
US-812	46 a[y]	82 a	73 a	159 a	109 a	140 a	113 a
Carrizo	19 b	65 ab	35 abc	128 a	92 ab	141 a	92 ab
Swingle	22 b	60 abc	35 abc	119 ab	69 abc	132 ab	83 ab
Cleopatra	23 b	60 abc	52 abc	66 bc	69 abc	105 ab	70 ab
Sun Chu Sha	18 b	30 c	22 bc	69 bc	48 bc	81 b	50 bc
US-953	12 b	26 c	9c	32 c	26 c	25 c	24 c

[z]Yearly average based on years 5 to 9.
[y]Mean separations for significant ANOVA within rows were by Duncan's multiple range test at $P < 0.05$.

Table 6. Ambersweet scion in Lake County, years 1996–2001.

Rootstock	Fruit yield (kg/tree)						Yearly avg[z]
	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	
Carrizo	25	78 a[y]	86 a	131 a	81 a	120 a	99 a
US-812	35	73 a	70 a	85 b	80 a	112 a	84 ab
Cleopatra	33	68 ab	65 ab	72 bc	61 ab	132 a	80 ab
Swingle	30	43 bc	42 bc	106 ab	56 bc	124 a	74 ab
Sun Chu Sha	16	41 bc	34 c	61 bc	23 d	92 ab	50 bc
US-937	19	24 c	17 c	32 c	38 cd	60 b	34 c

[z]Yearly average based on years 5 to 8.
[y]Mean separations for significant ANOVA within rows were by Duncan's multiple range test at $P < 0.05$.

Table 7. Yield of Hamlin sweet oranges on US-812 and three other rootstocks in a Collier County trial (kg fruit/tree/season), years 2000–04.

Hamlin clone	Season	US-812	*Citrus obovoideae*	US-1001	X-639
1-4-1	5	97	67	77	34
1-4-1	6	123 a	88 ab	130 a	51 b
1-4-1	7	123	59	106	68
1-4-1	8	172	180	124	96
8-4-1	5	82	81	60	66
8-4-1	6	129	113	104	79
8-4-1	7	144	103	85	88
8-4-1	8	209	230	105	169
Both	5–8	139 a	117 ab	102 ab	86 b

[z]Mean separations for significant ANOVA within rows were by Duncan's multiple range test at $P < 0.05$. Rows without letters were not significant.

Table 8. Yield of Valencia orange on US-812 and three other rootstocks in a Collier County trial (kg fruit per tree per season), years 2000–04.

Valencia clone	Seasons	US-812	US-1001	X-639	*Citrus obovoideae*
10-27-7	5–8	88	83	69	56
1-14-19	5–8	77	64	94	63
RR	5–8	75	77	50	50
55-28	5–8	71	66	48	63
51-3-3	5–8	75	60	43	62
All 5	5–8	77 a[z]	70 ab	61 ab	59 b

[z]Mean separations for significant ANOVA within rows were by Duncan's multiple range test at $P < 0.05$. Rows without letters were not significant.

Table 9. Truck cross sectional area and yield of grapefruit in two trials, 2003.

Rootstock	St. Lucie County Trial @ 4 years old		Indian River County Trial @ 3 years old	
	TCSA (mm^2)	Fruit yield (kg/tree)	TCSA (mm^2)	Fruit yield (kg/tree)
Rough lemon	10072 a	178 a	---	---
US-812	8930 ab	166 ab	1523 b	23 b
Carrizo	8892 ab	146 abc	987 c	8 c
Sour #2	8220 bc	135 bcd	---	---
Swingle	7118 c	126 cd	880 c	5 c
US-802	8999 ab	104 de	2284 a	38 a
Sun Chu Sha	9561 ab	98 de	---	---
Cleopatra	---	---	1897 ab	26 b
Flying Dragon	4759 d	78 e	---	---

[z]Mean separations for significant ANOVA within rows were by Duncan's multiple range test at $P < 0.05$.

al., 2003). Under these challenging conditions that severely damage many common rootstocks (Graham et al., 2003), performance of young trees on US-812 is relatively poor, while a few other new hybrid rootstocks appear much more promising. US-812 does not appear to be a good rootstock for locations infested by *Diaprepes* weevil and *P. palmivora* on heavy soil. Research is continuing to identify any other limitations in soil adaptation, disease tolerance, or scion compatibility of US-812 rootstock.

Table 10. Height (m) of trees on US-812 and other rootstocks in different trials at 6, 7, or 10 years of age, as indicated.

Rootstock	Valencia in Polk Co. (10 years)	Sunburst in Lake Co. (7 years)	Ambersweet in Lake Co. (7 years)	Fallglo in Lake Co. (6 years)	Avg % of Carrizo tree ht
Vangasay lemon	4.08 a	---	---	---	109 a
Carrizo	3.75 ab	3.10 a	3.14 a	2.96 a	100 ab
Gou Tou	3.61 bc	---	---	---	96 ab
Cleopatra	---	2.71 b	2.79 ab	2.74 a	90 b
US-812	3.26 c	2.76 b	2.58 bc	2.97 a	90 b
Sun Chu Sha	3.99 a	2.64 b	2.48 bc	2.37 b	88 b
Swingle	3.46 bc	2.63 b	2.35 c	2.89 a	87 b
US-937	2.54 d	1.96 c	1.77 d	2.14 b	65 c
Sour orange #2	1.51 e	---	---	---	40 d

[z]Mean separations for significant ANOVA within rows were by Duncan's multiple range test at $P < 0.05$.

Table 11. Fruit quality of Valencia sweet orange on US-812 and other rootstocks in Polk County. Samples collected on 20 May 2003.

Rootstock	Fruit wt (g)	Degree Brix (%)	Total acid[z] (%)	Juice/ box[y] (kg)	Soluble solids/ box[y] (kg)
US-954	222 bc[x]	11.2 a	0.57 a	23.8 a	2.67 a
Sour orange #2	217 c	9.8 b	0.43 d	24.3 a	2.39 ab
US-812	285 a	9.7 b	0.56 ab	23.2 a	2.25 bc
Swingle	273 abc	9.5 b	0.56 ab	22.9 a	2.18 bcd
US-942	319 a	9.6 b	0.54 abc	22.0 ab	2.14 bcd
Carrizo	286 a	8.9 b	0.51 c	22.2 ab	1.98 bcd
Sun Chu Sha	284 a	8.9 b	0.52 bc	22.0 ab	1.95 cd
Gou Tou	278ab	8.6 b	0.50 c	21.9 ab	1.89 cd
Vangasay lemon	269 abc	8.9 b	0.53 abc	20.2 b	1.81 d

[z]Acid reported as citric acid.
[y]Box equals 40.9 kg of fruit.
[x]Mean separations for significant ANOVA within rows were by Duncan's multiple range test at $P < 0.05$.

Table 12. Fruit quality of Hamlin on US-812 and other rootstocks in Collier County. Quality evaluated in January each of three seasons for tree age 5 to 7 years.

Rootstock	Fruit wt (g)	Degree Brix (%)	Total acid[z] (%)	Juice/ box[y] (kg)	Soluble solids/ box[y] (kg)
US-812	161	10.7	0.57 a	21.53	2.30 a
C. obovoideae	173	10.2	0.55 ab	21.47	2.19 ab
US-1001	177	10.4	0.56 a	20.48	2.13 b
X-639	174	10.1	0.53 b	20.56	2.08 b

[z]Mean separations for significant ANOVA within rows were by Duncan's multiple range test at $P < 0.05$.

Table 13. Fruit quality of Sunburst tangerine on US-812 and other rootstocks in a Lake County Trial. Samples collected on 18 Nov. 2003. Tree age 7 years.

Rootstock	Fruit diam (mm)	Juice (%)	Degree Brix (%)	Total acid[z] (%)	Juice color (CN)[y]
US-896	68.2 c[x]	52.2 ab	10.18 a	0.95 a	43.3 a
US-812	68.9 bc	50.5 ab	10.12 b	0.94 ab	42.5 ab
Swingle	70.3 abc	53.2 a	10.10 bc	0.85 c	42.5 ab
Carrizo	70.7 ab	45.5 b	10.06 cd	0.88 bc	42.2 bc
Flying Dragon	71.4 a	46.0 b	10.04 d	0.76 d	41.5 c

[z]Acid reported as citric acid citric.
[y]CN = color number as measured in Greytag MacBeth Color Eye Spectrophotometer.
[x]Mean separations for significant ANOVA within columns were by Duncan's multiple range test at $P < 0.05$.

Availability

Disease-indexed budwood to establish seed trees is being distributed by Florida Department of Agriculture (Division of Plant Industry, 3027 Lake Alfred Road, Winter Haven, FL 33881) to registered Florida citrus nurseries. Requests for budwood from other states or countries should be sent to the USDA–ARS National Clonal Germplasm Repository for Citrus (1060 Martin Luther King Blvd., Riverside, CA 92507). Seed for commercial propagation may be available from commercial nurseries, Florida Department of Agriculture, or Florida Citrus Nurserymen's Association.

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