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COLD HARDINESS OF CITRUS TREES DURING THE 1981 FREEZE IN FLORIDA

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Abstract. **The January 1981 freeze was one of the coldest to occur in central Florida with minimums as low as 8°F in low-lying areas. Citrus trees were largely devastated in low areas in contrast to surrounding trees on apparently warmer, higher elevations. Prefreeze weather conditions were sufficiently favorable, as in 1977, to cold harden trees and this helped the trees to survive. Orange trees were less injured than grapefruit trees in comparable plantings. In some instances, differences in tree injury were noted among different rootstocks. Trees on some experimental rootstocks were less injured than trees on commercial selections. Traits of dwarfism and tetraploidy in rootstocks did not increase cold hardiness of the trees. Exceptional freeze tolerance was noted in experimental selections of** Eremocitrus, **hybrids of** Poncirus, **progeny from hybridizations of King, Changsha, and Satsuma mandarins, and one off-type seedling tree from OPS-Citrumelo 4481.**

The January 12-13, 1981 freeze in Florida was one of the coldest to ever occur in the state. Temperatures less than 11°F in citrus-producing areas were strikingly visualized on Geostationary Orbital Environmental Satellite (GOES) temperature maps (5) obtained from the Fruit Crops Department, University of Florida. In many areas, temperatures were lower than those reported for 2 of Florida's most damaging freezes to citrus, December 1962 (3, 4) and the winter of 1894-95 (6). The 1981 freeze had a weak advection component, but the radiation phase was devastating in low-lying areas.

This report primarily summarizes observations of citrus trees that survived the 1977 freeze (7) and describes their tolerance of the colder 1981 freeze. Instances of exceptional freeze tolerance in new citrus varieties are reported as part of the USDA program to improve citrus cold hardiness in Florida.

Materials and Methods

Freeze injury to citrus trees was observed from January to July 1981. Sites visited were cold hardiness test plantings near Astatula, Dade City, Leesburg, Orlando, and Weirsdale. Scion types were sweet orange, *Citrus sinensis* (L.) Osbeck cvs. Valencia, Hamlin and Pineapple; grapefruit, *C. paradisi* Macf. cvs. Marsh, Florida Red, and Star Ruby; hybrids (*C. paradisi* X *C. reticulata* Blanco) X *C. reticulata* cv. Page, and *C. reticulata* X (*C. paradisi* X *C. reticulata*) cvs. Robinson, Nova, Osceola, Sunburst, and 1-16-5 (Robinson X Osceola); tangelo *C. paradisi* X *C. reticulata* cv. Orlando, and hybrids 1-57-73 and 1-57-105 (Temple X Orlando). Rootstocks were Chase rough lemon, *C. limon* Burm. f.; sour orange No. 2, *C. aurantium* L.; trifoliate orange, *Poncirus trifoliata* (L.) Raf. cvs. Chambers, Davis, English Large, English Small, Flying Dragon, Jacobsen, Kryder 15-3, Large Flower, Pomeroy, Rich 22-2, Ronnse, Rubidoux, Small Flower, Swingle, and a tetraploid; Cleopatra mandarin, *C. reticulata*; citrumelos, *C. paradisi* X *P. trifoliata* cvs. Swingle (CPB-4475), Sacaton, Winter Haven, and 4481; citranges, *C. sinensis* X *P. trifoliata* cvs. Cunningham, Carrizo, Morton, Rusk, Savage, Troyer, Uvalde, Willits, Jaffa X Gotha Road (trifoliate orange), 'Pineapple' X Gotha Road, and hybrids, Pee Wee and Rubidoux X Carrizo; citrangors, (*C. sinensis* X *P. trifoliata*) X *C. sinensis*, Nos. 42681, 43728, and 43732; citremon, *P. trifoliata* X *C. limon*, No. 46216; citrandarin, *P. trifoliata* X *C. reticulata* No. 40208; citrangedin, (*C. sinensis* X *P. trifoliata*) X (*C. reticulata* X *Fortunella* sp.), cvs. Glen, No. 48039; citrangequat, (*C. sinensis* X *P. trifoliata*) X *Ci reticulata* X *Fortunella* sp. cvs. Telfair, Sinton; *C. volkameriana; Severinia buxifolia* (Poir.) Ten.; ('Temple' X Gotha Road trifoliate orange) X 'Valencia' orange; Rangpur lime, *C. reticulata* var. *austera* Swing. hybrid; and open pollinated seedlings of hybrids 61-118 and 61-182-6. *Eremocitrus glauca* (Lindl.), *Poncirus* hybrids and other types used in cold hardiness breeding work were also observed.

Trees were visually rated on severity of leaf and wood kill. Injury ratings were coded numerically which are indicated in the tables. Bark splitting, gumming, and other signs of freeze injury were also noted. Air temperatures were measured on site and inside standard weather shelters containing hygrothermographs calibrated to the nearest 1°F. Additional temperatures were taken with minimum thermometers located throughout certain areas, and in localized instances, 24-gauge copper-constantan thermocouples connected to a multi-point recorder. In the same planting where thermocouples were located, 100 leaves were taken from each of 4 'Valencia' trees to obtain estimates of water content and concentration of total sugars and proline, indices of cold hardening of citrus previously reported (10).

Results and Discussion

The probability is very low that such low temperatures as occurred during the January freeze will occur in any one year in central Florida (2). Some of the coldest conditions that we found were in a 'Valencia' orange planting on the A. H. Whitmore Foundation Farm near Leesburg. Temperatures of 'Valencia' orange leaves exposed to the open sky were as low as 8°F, while temperatures in the fruit were 21°F immediately underneath the peel and 23°F in the center. Durations of 26°F and colder approximated 13 hours. Under these conditions fruit were severely damaged, all leaves were killed, and terminal wood was lost, with wood kill extending into 3-inch diameter stems. As in 1977, growers are faced with major costs in grove rehabilitation made more difficult because of below normal rainfall following the freeze. Near Leesburg, rainfall averaged only 2 inches per month from January to June with no rain in April.

The 1981 freeze had 2 major traits working against the growers. One was that the freeze occurred when most of the 1980-81 crop was still on the trees, the other was that rapidly falling temperatures (as much as 5°F per hr in certain instances) were reaching record lows with long durations of lethal conditions. In contrast, there were 2 compensating factors. One was that the freeze was largely the radiation-type which devastated citrus in low ground areas but not higher ground plantings and, also, helped to in-

crease the effectiveness of applying water for freeze protection. The other favorable factor was cool temperatures before and after the freeze. This helped to cold harden the trees and also allowed more time to salvage frozen fruit. It is unclear how much additional damage was due to 18°F on January 13-14 and 4 nights later, January 17-18, 1981.

Prefreeze cold hardening conditions (A. H. Whitmore Foundation Farm)

Longer durations of cooler temperatures prevailed during the 4 weeks immediately before the 1981 than the 1977 freeze at the A. H. Whitmore Foundation Farm (Tables 1, 2). Therefore, cold hardening weather conditions were as favorable in 1981 as in 1977. Partial confirmation of cold hardening, as suggested in controlled environment studies (10), was indicated more by proline than total sugar concentrations in 'Valencia' leaves sampled from 4 trees at 9 PM on January 12, 1981. Proline levels averaged 13 to 16 mg/g of oven-dry leaf weight while sugar levels were 40 to 54 mg. The moisture content averaged 53% on a fresh weight basis and 1.12 g of water/g of oven-dry weight. These moisture levels were associated with both cold hardened and/or water stressed 'Valencia' leaves in controlled studies (11) and result not only in higher proline concentrations but also in increased supercooling. Supercooling, which is an expression of freeze avoidance and a noninjurious situation, was indicated in our research plantings when water soaking was difficult to find in 'Valencia' leaves until temperatures were 20°F or colder. Non-water-soaked leaves became water soaked when misted with water at 25°, 23°, and 21°F during the freeze night.

Table 1. Average weekly temperatures and rainfall preceding the January 18-20, 1977 and January 12-13, 1981 freezes at the A. H. Whitmore Foundation Farm near Leesburg, Florida.

Wk before the freeze	Year	Max (°F)	Min (°F)	Range (°F)	Rainfall (inches)
11	1977	69	47	72 to 37	0.20
	1981	80	58	86 to 45	1.02
10	1977	70	50	79 to 30	0.00
	1981	79	52	86 to 38	0.00
9	1977	67	54	75 to 41	0.00
	1981	77	58	82 to 50	1.00
8	1977	69	47	82 to 32	2.05
	1981	70	50	79 to 41	0.67
7	1977	58	44	67 to 36	1.23
	1981	67	46	77 to 32	1.81
6	1977	71	55	80 to 35	0.65
	1981	73	47	75 to 42	0.00
5	1977	68	48	76 to 37	1.49
	1981	72	41	78 to 36	0.00
4	1977	61	39	75 to 29	0.78
	1981	65	38	70 to 30	0.00
3	1977	64	45	74 to 36	0.69
	1981	57	34	68 to 34	0.22
2	1977	65	46	72 to 36	1.06
	1981	62	32	66 to 24	0.00
1	1977	61	41	75 to 28	1.22
	1981	60	29	73 to 23	0.00

The effects of favorable weather conditions and cold hardening of the trees enabled them to survive, but did not prevent severe damage in areas where 8 to 12°F occurred. In some of the low-lying areas, there were apparent differences in freeze injury among trees on different rootstocks, but the biggest differences in injury were observed between trees that were virtually devastated in low areas in contrast to considerably less injured trees on surrounding and apparently warmer, higher elevations.

Table 2. Temperature durations during 11 weeks immediately preceding the January 18-20, 1977 and January 12-13, 1981 freezes at the A. H. Whitmore Foundation Farm near Leesburg, Florida.

Wk before the freeze	Total number of hours: 70°F and >		<70°F but > 50°F		50°F and <	
	1977	1981	1977	1981	1977	1981
11	6	57	122	105	40	6
10	20	55	120	84	28	29
9	27	58	131	110	10	0
8	26	31	89	105	53	32
7	0	14	78	98	90	56
6	30	30	116	100	22	38
5	14	28	100	80	40	60
4	5	4	66	84	97	81
3	3	0	97	67	68	101
2	5	0	101	57	62	111
1	7	2	82	53	79	113
Total	143	279	1102	943	589	627
Last 4 wk	20	6	346	261	306	406

Injury in low-ground plantings

The potential of citrus trees to survive extreme freezes in Florida (8) was most evident in nonprotected plantings in low areas on the A. H. Whitmore Foundation Farm. A low of 8°F was found adjacent to sister plantings of 'Valencia' orange and 'Marsh' grapefruit on 12 different rootstocks. Trees were badly damaged and lost all their leaves and outer fruit-bearing wood (Tables 3 and 4). Overall injury greatly exceeded that of 1977, a less severe freeze (18° to 20° minimum), although the trees were 4 years younger in 1977 (7). As in 1977, orange trees were injured less than grapefruit trees, which required "buckhorned-pruning" into 3-inch wood. There was more tree injury on some rootstocks than others, especially of 'Valencia' orange trees. Visual examination and numerical rating of trees indicated the least injured trees were on citrangor, Swingle citrumelo, trifoliate orange (diploid 2N), and sour orange rootstocks. As in 1977, trees on Carrizo citrange (2N) seemed to tolerate the unusually cold conditions better than trees on rough lemon, but not as well as trees on sour orange. The most injured trees were on Rangpur lime, *Severinia*, OPS-61-118 hybrid, and the Pee Wee citrange. The less than 50% survival of 'Valencia' trees on rough lemon rootstock from the time trees were planted (Table 3) was not solely the result of freeze injury, but also included accidents during cultural practices, foot rot, and possible soil differences that adversely affect tree vigor. Pee Wee was the poorest of all rootstocks. This was also indicated in a low-ground planting on Hiawassee Farm near Orlando (Table 5). In both locations, polyploidy (4N) in rootstocks resulted in smaller but less cold-hardy trees. In all of the low-ground plantings, citrangor (CPB-43732) rootstock, along with the relatively recent release of Swingle citrumelo, rated comparatively well among standard types used in the industry. Trees on open-pollinated numbered hybrids, *Severinia*, Rangpur, Pee Wee, (Temple X Gotha Road) X 'Valencia' hybrid, and tetraploid types were not cold hardy.

The damaging effects of the unusually cold conditions, 8°F, were also evident in a 10-year-old planting of mandarin hybrids next to the 'Valencia' and 'Marsh' plantings. These were relatively little injured during the 1977 freeze (7). In 1981, wood kill often extended into 3-inch wood and some trees were lost. 'Page' on sour orange rootstock were the least injured trees, injury on Carrizo citrange was somewhat more severe. Regardless of rootstock, wood kill was

Table 3. Injury in a 6-year-old planting[z] of 'Valencia' orange on 12 different rootstocks on A. H. Whitmore Foundation Farm near Leesburg, Florida, after the 1981 January freeze.

Rootstocks	Trees planted (no.)	Trees missing (no.)	Tree height (ft)	Tree width (ft)	Leaf kill (%)	Approx diam (inches) of wood killed[y]					
						<0.5	0.5	1	2	3	Total
Citrangor (CPB-43732)	20	2	9.5 a[x]	8.6 a	100	5.0	4.0 b	2.9 e	1.3 e	1.1 b	14.2 d
Swingle (CPB-4475)	20	3	8.6 ab	8.1 ab	100	5.0	4.1 b	2.8 e	1.4 de	1.0 b	14.3 d
Rubidoux trifoliate (2N)	20	4	8.5 bc	7.2 bc	100	5.0	4.3 b	3.1 cd	1.3 de	1.0 b	14.8 d
Sour orange No. 2	20	1	9.2 ab	8.2 ab	100	5.0	4.3 b	3.2 cd	1.4 de	1.1 b	15.0 d
Rubidoux trifoliate (4N)	20	3	6.3 d	5.4 d	100	5.0	4.9 a	4.1 bc	2.1 cd	1.0 b	17.1 c
Carrizo citrange (2N)	20	4	9.8 a	8.9 a	100	5.0	4.8 a	3.9 c	2.6 bc	1.3 b	17.4 c
Carrizo citrange (4N)	20	6	8.3 c	6.5 c	100	5.0	5.0 a	4.0 bc	2.9 bc	1.1 b	17.8 bc
Chase rough lemon	20	14	8.3 abc	7.5 abc	100	5.0	5.0 a	3.2 cd	3.0 abc	2.5 a	19.3 abc
Rangpur lime	20	9	9.1 ab	7.9 ab	100	5.0	5.0 a	4.4 abc	3.1 ab	2.1 a	19.6 ab
Severinia buxifolia	20	8	7.4 c	6.6 c	100	5.0	4.9 a	4.8 ab	3.6 a	1.9 a	20.2 a
OPS 61-182 hybrid	20	1	9.0 ab	8.2 ab	100	5.0	5.0 a	4.9 a	3.5 a	1.7 a	20.2 a
Pee Wee citrange hybrid	20	20	—	—	—	—	—	—	—	—	—
All rootstocks	240	75	8.4	7.6	100	5.0	4.2	3.8	2.4	1.4	17.2

[z]8°F minimum temperature.
[y]1 = no injury, 2 = trace to 25%, 3 = 26 to 50%, 4 = 51 to 75%, 5 = 76 to 100%.
[x]Mean separation within columns by Duncan's multiple range test, 5% level.

Table 4. Injury in a 6-year-old planting[z] of 'Marsh' grapefruit on 12 different rootstocks on A. H. Whitmore Foundation Farm near Leesburg, Florida, after the 1981 January freeze.

Rootstocks	Trees planted (no.)	Trees missing (no.)	Tree height (ft)	Tree width (ft)	Leaf kill (%)	Approx diam (inches) of wood killed[y]					
						<0.5	0.5	1	2	3	Total
Swingle (CPB-4475)	20	0	8.9 bc[x]	8.9 bcd	100	5.0	4.8 b	4.4 ab	2.6 e	1.0 d	17.8 e
Citrangor (CPB-43732)	20	2	9.4 ab	9.4 abc	100	5.0	5.0 a	4.2 b	2.9 cde	1.1 cd	18.3 de
Sour orange No. 2	20	0	9.4 ab	9.7 ab	100	5.0	5.0 a	4.5 ab	2.8 de	1.2 cd	18.5 de
Rubidoux trifoliate (2N)	20	1	8.3 c	8.2 d	100	5.0	5.0 a	4.6 ab	2.8 de	1.1 cd	18.5 de
Rubidoux trifoliate (4N)	20	3	6.2 e	5.8 f	100	5.0	5.0 a	4.8 a	3.4 bcd	1.0 d	18.7 cde
Carrizo citrange (2N)	20	6	9.9 a	10.2 a	100	5.0	5.0 a	5.0 a	3.1 bcde	1.4 bcd	19.5 bcd
Carrizo citrange (4N)	20	3	7.1 d	7.2 e	100	5.0	5.0 a	4.9 a	3.8 b	1.5 bcd	19.9 bc
OPS 61-182 hybrid	20	1	8.7 bc	9.0 bcd	100	5.0	5.0 a	5.0 a	3.6 bc	1.6 bc	20.1 bc
Severinia buxifolia	20	6	8.7 bc	8.4 cd	100	5.0	5.0 a	5.0 a	3.7 b	1.5 bcd	20.1 bc
Chase rough lemon	20	6	9.1 abc	9.3 abc	100	5.0	5.0 a	4.8 a	3.3 bcd	2.0 b	20.3 b
Rangpur lime	20	12	9.2 abc	9.1 abcd	100	5.0	5.0 a	5.0 a	3.6 bc	2.1 b	20.8 b
Pee Wee citrange hybrid	20	14	5.6 e	5.7 f	100	5.0	5.0 a	5.0 a	4.8 a	3.3 a	23.0 a
All rootstock	240	54	8.4	8.4	100	5.0	5.0	4.8	3.4	1.6	19.7

[z]8°F minimum temperature.
[y]1 = no injury, 2 = trace to 25%, 3 = 26 to 50%, 4 = 51 to 75%, 5 = 76 to 100%.
[x]Mean separation within columns by Duncan's multiple range test, 5% level.

Table 5. Injury in a 5.5-year-old planting[z] of 'Pineapple' orange on 8 different rootstocks on USDA Hiawassee Research Farm near Orlando, Florida, after the 1981 January freeze.

Rootstocks	Trees planted (no.)	Trees missing (no.)	Tree height (ft)	Tree width (ft)	Leaf kill (%)	Approx diam (inches) of wood killed[y]					
						<0.5	0.5	1	2	3	Total
Citrangor (CPB-43732)	17	8	7.2 abc[x]	6.0 abc	100	5.0	4.7 b	4.4 b	4.3 b	4.1 b	22.2 b
Carrizo citrange (2N)	25	7	8.3 a	6.9 a	100	5.0	5.0 a	5.0 a	4.9 ab	4.5 ab	24.4 ab
Morton citrange	25	8	6.4 bc	5.7 bc	100	5.0	5.0 a	5.0 a	4.9 ab	4.8 ab	24.7 ab
OPS 61-182-6 hybrid	15	5	7.7 ab	6.3 ab	100	5.0	5.0 a	5.0 a	5.0 a	4.8 ab	24.8 ab
Rubidoux trifoliate orange	26	6	5.7 cd	4.8 cd	100	5.0	5.0 a	5.0 a	5.0 a	5.0 a	25.0 a
Carrizo citrange (4N)	27	10	4.6 d	4.0 d	100	5.0	5.0 a	5.0 a	5.0 a	5.0 a	25.0 a
Pee Wee citrange hybrid	19	17	5.0 cd	4.0 d	100	5.0	5.0 a	5.0 a	5.0 a	5.0 a	25.0 a
(T x G) X Valencia hybrid[w]	11	10	6.0 bcd	4.0 d	100	5.0	5.0 a	5.0 a	5.0 a	5.0 a	25.0 a
All rootstocks	165	71	6.4	5.2	100	5.0	5.0	4.9	4.9	4.8	24.6

[z]8.5°F minimum temperature.
[y]1 = no injury, 2 = trace to 25%, 3 = 26 to 50%, 4 = 51 to 75%, 5 = 76 to 100%.
[x]Mean separation within columns by Duncan's multiple range test, 5% level.
[w]('Temple' orange X 'Gotha Road' trifoliate orange) X 'Valencia' orange.

limited to 1-inch diameter wood in 'Page' trees. Although there was little difference in injury between numbered hybrids, 1-57-73 appeared slightly less injured than 1-57-105, 1-16-5, and 1-16-8 'Sunburst'. Other injured selections included 'Robinson,' 'Nova,' and 'Osceola', with 'Osceola' the most severely damaged of the 3 selections. All of these trees had large yields of fruit in 1980-81, and most of the crop was on the trees at the time of the January 1981 freeze.

Injury in other plantings

Young 'Star Ruby' grapefruit trees on different rootstocks were severely injured in an area with 11°F minimum temperature. Some of the least injured trees were on Carrizo and citremon 1449 rootstocks (Table 6). Sour orange, Cleopatra, and Rangpur X Troyer rootstocks had similar ratings of total wood killed. *Citrus volkameriana* was comparable to rough lemon. But trees on *Volkameriana* survived better over the years, and were some of the largest trees in the planting. In this planting, trees on Swingle citrumelo were rated the worst among rootstocks which reinforces the contention that it is poor practice to stereotype cold hardiness ratings to meet all situations (7). An excessive amount of gumming associated with freeze cankers was of special concern in this planting in that localized gumming was associated with continued dieback of wood as late as June 1981. Similar observations were made in other grapefruit plantings and occasional orange plantings. Bark splitting, which was pronounced in this planting after 24°F on January 3, 1979 (9), was virtually absent after the 1981 freeze. Bark splitting was not found to any extent in any of the plantings surveyed. The dry conditions prior to the 1981 freeze could be considered a contributing factor, although firm evidence is lacking to substantiate this.

'Florida Red' grapefruit trees within 100 yards of the 'Star Ruby' planting also were severely injured with no obvious differences among rootstocks (Table 7). Active gumming and associated dieback of new growth were observed on all 92 trees surveyed in May 1981. It is unclear what further significance gumming has, other than that it is associated with localized freeze lesions that can girdle tree branches.

Of all the research plantings surveyed on the A. H. Whitmore Foundation Farm, the least injured was a 7-year-

Table 6. Injury in a 4-year-old planting[z] of 'Star Ruby' grapefruit on 8 different rootstocks on A. H. Whitmore Foundation Farm near Leesburg, Florida, after the 1981 January freeze.

Rootstocks	Trees planted (no.)	Trees missing (no.)	Tree height (ft)	Tree width (ft)	Leaf kill (%)	Approx diam (inches) of wood killed[y] <0.5	0.5	1	2	3	Total
Carrizo citrange	12	3	6.3 a[x]	6.1 a	100	5.0	4.7 a	3.9 a	2.2 b	1.1 bc	16.9 b
Citremon 1449	10	2	6.5 a	6.4 a	100	5.0	4.8 a	4.0 a	2.4 b	1.0 c	17.1 b
Sour orange No. 2	10	0	6.6 a	5.9 a	100	5.0	4.8 a	4.1 a	2.9 b	1.8 abc	18.6 ab
Cleopatra mandarin	10	4	6.7 a	6.0 a	100	5.0	5.0 a	4.5 a	2.8 b	1.3 abc	18.7 ab
Rangpur X Troyer	10	0	6.1 a	6.1 a	100	5.0	4.7 a	4.0 a	3.1 ab	1.8 abc	18.8 ab
Chase rough lemon	9	6	4.7 b	4.3 b	100	5.0	5.0 a	5.0 a	3.3 ab	1.3 abc	19.7 ab
Volkameriana	10	1	6.9 a	6.6 a	100	5.0	4.9 a	4.3 a	3.6 ab	2.3 a	20.1 ab
Swingle (CPB-4475)	9	0	6.7 a	6.3 a	100	5.0	5.0 a	5.0 a	4.4 a	2.2 ab	21.7 a
All rootstocks	80	16	6.3	6.0	100	5.0	4.9	4.4	3.0	1.5	18.9

[z]11°F minimum temperature.
[y]1 = no injury, 2 = trace to 25%, 3 = 26 to 50%, 4 = 51 to 75%, 5 = 76 to 100%.
[x]Mean separation within columns by Duncan's multiple range test, 5% level.

Table 7. Injury in a 7-year-old planting[z] of 'Florida Red' grapefruit and in an 8-year-old planting[z] of 'Valencia' orange on 4 different rootstocks on A. H. Whitmore Foundation Farm near Leesburg, Florida, after the 1981 January freeze.

Rootstocks	Trees planted (no.)	Trees missing (no.)	Tree height (ft)	Tree width (ft)	Leaf kill (%)	Approx diam (inches) of wood killed[y] <0.5	0.5	1	2	3	Total
Grapefruit planting											
Cleopatra mandarin	27	6	10.9 bc[x]	11.4 b	100	5.0	5.0	4.4 b	3.3 b	1.7 a	19.3 ab
Chase rough lemon	27	7	10.4 c	12.4 a	100	5.0	5.0	4.3 b	3.3 b	2.2 a	19.8 ab
Sour orange No. 2	27	1	11.2 ab	12.4 a	100	5.0	5.0	4.7 ab	3.5 b	1.8 a	20.0 ab
Carrizo citrange	27	2	11.6 a	12.9 a	100	5.0	5.0	4.8 a	4.0 a	2.3 a	21.1 a
All rootstocks	108	16	11.0	12.3	100	5.0	5.0	4.5	3.5	2.0	20.0
Valencia planting											
Chase rough lemon	24	0.0			5.0	5.0	2.5 b	1.0 b	1.0	1.0	10.5 abc
Cleopatra mandarin	25	0.0			5.0	5.0	2.6 ab	1.1 b	1.0	1.0	10.7 ab
Sour orange No. 2	24	0.0			5.0	5.0	2.8 a	1.3 ab	1.0	1.0	11.1 ab
Carrizo citrange	25	0.0			5.0	5.0	2.9 a	1.4 a	1.0	1.0	11.3 a
All rootstocks	98	0.0	5.0	5.0	2.7	1.2	1.0	1.0	10.9		

[z]10.5°F minimum temperature.
[y]1 = no injury, 2 = trace to 25%, 3 = 25 to 50%, 4 = 51 to 75%, 5 = 76 to 100%.
[x]Mean separation within columns by Duncan's multiple range test. 5% level.

old planting of 'Valencia' trees on 4 different rootstocks. This planting was within 50 yards of the previously mentioned 'Star Ruby' trees which were severely damaged during 11°F minimum temperatures. The overall damage to the 'Valencia' planting was confined largely to leaves and outer wood (Table 7). Bark splits were not found and gumming was rarely seen. There were no apparent differences in injury among the trees on different rootstocks, sour orange, Cleopatra mandarin, Carrizo citrange, and rough lemon.

Injury in high ground plantings (Weirsdale and Dade City)

Both of our research plantings on elevated sites were less injured than those at lower elevations. Temperatures were not measured in the Weirsdale plantings, but estimates from different sources indicate minimums between 18 and 21°F. In this 21-year-old 'Pineapple' orange planting, some of the leaves survived and wood kill was confined largely to diameters less than 0.5 inches (Table 8). Numerical ratings and general observations indicated that there was no difference between trees on sour orange considered cold hardy and trees on rough lemon considered cold-sensitive. In contrast, the smaller trees on the allegedly very cold-hardy trifoliate orange showed more injury and were poorer in overall appearance. Of the citranges, trees on Morton were some of the least injured, while trees on Willits, Jaffa X Gotha Road trifoliate, and Pineapple X Gotha Road trifoliate did as well as trees on Carrizo, Savage, and Troyer. Some of the most injured trees were on Rusk, Uvalde, and Cunningham. Relatively favorable injury ratings were also obtained for the 3 citrumelos, 4481, Sacaton, and Winter Haven, citrangor 43728, citremon 46216, citrandarin 40208, and citrangedin 48039. The most injured trees were on Telfair citrangequat and Glen citrangedin. The worst rootstock was citrangor 42681 where 10 of the 11 original trees were missing for unexplained reasons and the one remaining tree was one of the smallest in the planting and was badly injured during the 1981 freeze. This planting was only slightly injured during the 1977 freeze (7).

Another planting on high ground was a 7-year-old grove of 'Hamlin' orange trees on 23 rootstocks near Dade City. Trees were severely damaged during 15°F minimum temperatures (Table 9), but trees survived relatively well considering that they were probably more vulnerable because of extensive injury by the 1977 (7) and 1979 (9) freezes. The popular saying in the industry that "no 2 freezes are alike" seemingly applies in this instance, in that some of the trees rated the best in 1977 were among the most injured in 1981, i.e. trees on Rusk, Carrizo, and Swingle citrumelo (CPB-4475). Trees rated among the least injured were those on the trifoliate orange selection Ronnse, along with trees on Large and Small Flower trifoliate orange. The apparent differences in the rating of the trees after the 1977 and 1981 freezes are considered partially the result of the unusually cold temperatures in 1981, plus the previous damage done in 1977 and 1979. However, there are considerable inherent weaknesses in visual observations and more objective guidelines need to be developed in the ratings of freeze-injured trees in the field. More definitive measurements and utilization of computer facilities to analyze pre-freeze weather conditions and tree condition along with freeze injury would be helpful.

Table 8. Injury in a 21-year-old planting[z] of nucellar 'Pineapple' orange on 26 different rootstocks near Weirsdale, Florida, after the 1981 January freeze.

Rootstocks	Trees planted (no.)	Trees missing (no.)	Tree height (ft)	Tree width (ft)	Leafy kill (%)	Approx diam (inches) of wood killed[y]					
						<0.5	0.5	1	2	3	Total
Rough lemon, Chase	10	2	15.5 a[x]	19.0 a	5.0 a	1.9 a	1.1 bc	1.0 c	1.0	1.0	6.0 b
Sour orange, No. 2	10	0	15.1 ab	19.3 a	4.4 ab	1.1 b	1.0 c	1.0 c	1.0	1.0	5.1 b
Trifoliate orange, Large Flower	12	1	11.8 defg	14.5 efgh	5.0 a	1.9 a	1.1 bc	1.0 c	1.0	1.0	6.0 b
Trifoliate orange, Small Flower	12	0	11.3 efgh	14.3 efghi	5.0 a	3.2 a	1.5 ab	1.1 b	1.0	1.0	7.4 a
Trifoliate orange, Rubidoux	13	0	10.7 ghi	14.5 efgh	5.0 a	2.2 a	1.1 bc	1.0 c	1.0	1.0	6.3 b
Citrange, Carrizo	16	1	13.9 c	18.4 a	4.9 a	1.9 a	1.0 c	1.0 c	1.0	1.0	5.9 b
Citrange, Cunningham	14	0	9.8 i	13.0 hi	5.0 a	2.4 a	1.1 bc	1.0 c	1.0	1.0	6.5 ab
Citrange, Morton	11	0	13.8 c	17.8 ab	4.8 a	1.5 ab	1.0 c	1.0 c	1.0	1.0	5.4 b
Citrange, Rusk	15	0	10.4 hi	14.6 efg	5.0 a	2.1 a	1.1 bc	1.0 c	1.0	1.0	6.2 b
Citrange, Savage	13	0	9.9 i	13.1 ghi	5.0 a	2.0 a	1.0 c	1.0 c	1.0	1.0	6.0 b
Citrange, Troyer	14	1	13.8 c	18.8 a	4.8 a	1.9 a	1.0 c	1.0 c	1.0	1.0	5.9 b
Citrange, Uvalde	18	1	12.0 def	15.2 def	5.0 a	2.1 a	1.0 c	1.0 c	1.0	1.0	6.1 b
Citrange, Willits	10	0	14.0 bc	18.2 ab	4.6 ab	1.7 ab	1.0 c	1.0 c	1.0	1.0	5.7 b
Citrange, Jaffa X Gotha Road	5	0	12.8 cde	16.2 bcde	5.0 a	1.8 a	1.0 c	1.0 c	1.0	1.0	5.8 b
Citrange, Pineapple X Gotha Road	11	0	12.9 cd	16.4 bcd	4.9 a	1.9 a	1.0 c	1.0 c	1.0	1.0	5.9 b
Citrumelo, 4481	5	0	10.6 ghi	13.4 fghi	5.0 a	1.8 ab	1.0 c	1.0 c	1.0	1.0	5.8 b
Citrumelo, Sacaton	10	0	14.0 bc	17.5 ab	4.4 ab	1.8 ab	1.0 c	1.0 c	1.0	1.0	6.0 b
Citrumelo, Winter Haven	6	0	13.8 c	18.0 ab	4.5 ab	2.0 a	1.0 c	1.0 c	1.0	1.0	6.0 b
Citrangor, 42681	11	10	8.0 i	8.0 j	5.0 a	3.0 a	1.0 c	1.0 c	1.0	1.0	7.0 ab
Citrangor, 43728	10	0	10.0 i	13.7 fghi	5.0 a	2.0 a	1.0 c	1.0 c	1.0	1.0	6.0 b
Citremon, 46216	16	1	11.8 defg	15.5 cde	5.0 a	2.1 a	1.0 c	1.0 c	1.0	1.0	6.1 b
Citrandarin, 40208	12	1	11.8 defg	15.1 def	4.8 a	1.7 ab	1.0 c	1.0 c	1.0	1.0	5.7 b
Citrangequat, Sinton	8	0	10.9 fghi	13.1 ghi	4.9 a	2.5 a	1.2 bc	1.0 c	1.0	1.0	6.7 ab
Citrangequat, Telfair	4	0	9.8 i	12.0 i	5.0 a	2.5 a	1.8 a	1.2 a	1.0	1.0	7.5 a
Citrangedin, 48039	16	0	13.4 c	16.6 bc	4.8 a	1.9 a	1.0 c	1.0 c	1.0	1.0	5.9 b
Citrangedin, Glen	5	0	11.2 efghi	14.4 efghi	5.0 a	2.6 a	1.4 ab	1.0 c	1.0	1.0	7.0 ab
All rootstocks	287	18	12	15	4.9	2.1	1.1	1.0	1.0	1.0	5.5

[z]Minimum temperatures estimated between 18 and 21°F.
[y]1 = no injury, 2 = trace to 25%, 3 = 26 to 50%, 4 = 51 to 75%, 5 = 76 to 100%.
[x]Mean separation within columns by Duncan's multiple range test, 5% level.

Table 9. Injury in a 6-year-old planting[z] of 'Hamlin' orange on 23 different rootstocks near Dade City, Florida after the 1981 January freeze.

Rootstocks	Trees planted (no.)	Trees missing (no.)	Leaf kill (%)	Approx diam (inches) of wood killed[y]					
				<0.5	0.5	1	2	3	Total
Ronnse*	8	2	100	2.7 d[x]	1.3 d	1.0 f	1.0 d	1.0 d	7.0 e
Large Flower*	8	1	100	3.3 cd	2.4 cd	1.4 ef	1.0 cd	1.0 cd	9.1 de
Small Flower*	8	2	100	3.8 bcd	3.2 abcd	1.5 ef	1.0 cd	1.0 cd	10.5 de
Jacobsen*	8	1	100	3.4 cd	2.3 cd	1.6 def	1.6 cd	1.6 cd	10.8 de
Rich*	8	0	100	3.4 cd	2.4 cd	2.1 cdef	1.5 cd	1.5 cd	10.9 de
Rubidoux*	8	1	100	3.3 cd	2.3 cd	2.0 cdef	1.7 bd	1.7 bcd	11.0 de
English Large*	8	1	100	3.8 bcd	2.9 bcd	1.9 cdef	1.5 cd	1.5 cd	11.6 de
Davis*	8	0	100	3.5 cd	2.4 cd	2.1 cdef	2.0 bcd	2.0 bcd	12.0 cde
Cleopatra mandarin	8	0	100	3.9 bcd	3.0 bcd	2.2 cdef	1.5 cd	1.5 cd	12.1 cde
English Small*	8	1	100	3.7 bcd	2.7 cd	2.1 cdef	2.1 bcd	2.1 bcd	12.7 bcde
Pomeroy*	8	0	100	3.6 cd	2.9 bcd	2.6 bcdef	2.0 bcd	2.0 bcd	13.1 bcde
Swingle*	8	0	100	3.9 bcd	2.9 bcd	2.8 bcdef	2.5 abcd	2.5 bcd	14.6 bcde
Carrizo citrange	8	1	100	4.4 abc	3.4 abc	2.9 bcdef	2.1 bcd	2.1 bcd	14.9 abcde
Sour orange	8	1	100	4.0 bc	3.4 abc	3.0 abcdef	2.9 abcd	2.8 abcd	16.1 abcde
Tetraploid*	8	2	100	4.3 abc	3.5 abc	3.0 abcdef	3.0 abcd	3.0 abcd	16.3 abcde
Chambers*	8	1	100	4.6 abc	3.9 abc	3.6 abcd	2.7 abcd	2.7 abcd	17.4 abcd
Rough lemon	8	2	100	4.3 abc	3.8 abc	3.5 abcd	3.0 ab	3.0 abcd	17.7 abcd
Rusk citrange	8	1	100	4.9 ab	4.6 ab	4.0 abc	3.3 ab	3.3 abc	20.0 abc
Flying Dragon*	8	1	100	4.9 ab	4.6 ab	4.4 ab	3.3 ab	3.3 abc	20.3 abc
Citrumelo 4481	8	3	100	4.4 abc	4.2 abc	4.2 abc	4.2 ab	4.2 ab	21.2 abc
Kryder*	8	3	100	4.6 abc	4.2 abc	4.2 abc	4.2 ab	4.2 ab	21.4 ab
Rubidoux X Carrizo	8	0	100	5.0 a	5.0 a	4.9 a	4.0 ab	4.0 a	22.9 a
Swingle citrumelo	8	0	100	4.9 ab	4.7 a	4.5 ab	4.5 a	4.5 a	23.1 a
All rootstocks	184	24	100	4.0	3.3	2.8	2.4	2.4	15.1

[z]15°F minimum temperature.
[y]1 = no injury, 2 = trace to 25%, 3 = 26 to 50%, 4 = 51 to 75%, 5 = 76 to 100%.
[x]Mean separation within columns by Duncan's multiple range test, 5% level.
*Trifoliate orange selections.

Exceptional freeze tolerance

Exceptional freeze tolerance, little-to-no-injury, was noted for selections of *Eremocitrus* and its hybrids, and hybrids of trifoliate orange, all of which are being researched by USDA geneticists in Orlando. Other material in experimental plantings that tolerated exceptionally cold conditions with little or no injury included progeny from hybridization of King (*C. sinensis* X *C. reticulata* ?), Changsha, and Satsuma mandarins (*C. reticulata*), and one evergreen off-type seedling tree from OPS-Citrumelo 4481.

In summary, the results of our 1981 freeze survey continue to support the contention that citrus has considerable potential to survive freezes in Florida (8). The importance of favorable prefreeze cold-hardening weather conditions was reflected in the survival of 'Valencia' orange and 'Marsh' grapefruit trees under otherwise lethal freeze conditions. Orange trees continue to demonstrate more cold hardiness than grapefruit trees under severe conditions. 'Star Ruby' grapefruit has lacked hardiness during freezes in our research plantings. Variations in tree injury associated with different rootstocks were not clearly expressed in all instances to identify strong alternatives for some of the standard rootstocks of the industry, but trees on Swingle citrumelo and one citrangor rootstock did as well as trees on cold-hardy sour orange and trifoliate orange in a 'Valencia' planting exposed to 8°F. Carrizo citrange continues to be rated between sour orange and rough lemon. *Volkameriana* seemingly does as well and sometimes better than rough lemon, but not to the extent suggested by other researchers (1). The favorable results with Ronnse trifoliate orange encourages the use of this selection in future cold-hardiness trials. Tetraploid and dwarfing rootstocks do not appear promising in cold-hardiness trials. More fruitful areas seemingly are in continued research of *Eremocitrus* selections and hybrids, hybrids of trifoliate orange, and progeny from hybridization of cold-hardy mandarins.

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