Cold Hardiness of Peaches and Nectarines Following a Test Winter

Richard E. C. Layne[1]

Abstract

Six distinct populations of peach and one of nectarine were assessed for cold injury to flower buds and shoot xylem following a test winter in which a minimum temperature of −26.0°C was recorded on January 17, 1982. The average bud mortality was high and the means ranged from 64.9 to 82.2%. Average injury to shoot xylem was moderate to high with injury ratings varying from a low of 3.04 to a high of 3.60. The correlation of bud hardiness with wood hardiness was inconsistent and usually low indicating the need to assess both types of hardiness separately. Individuals with hardy wood which also possessed hardy buds were identified. They were considered to be the most promising hardiness sources to use as parents in breeding.

In southern Ontario, peaches and nectarines (*Prunus persica* [L.] Batsch) seldom escape a winter without some cold injury. Usually the winters are not very severe in the major areas of peach production and only the most cold susceptible individuals are identified. Occasionally, some winters are so severe that only the most cold hardy individuals survive and little or nothing is learned about those with intermediate or low levels of cold hardiness. Neither is ideal for assessing the range of hardiness. Peach flower buds are more cold sensitive than shoot xylem (8), therefore, a typical winter is generally more useful for assessing bud hardiness than wood hardiness. Seldom is a given test winter almost ideal for assessing cold hardiness of flower buds as well as shoot xylem. Such a winter is one in which the full range of injury, or nearly so, is expressed in the particular population(s) under study. Test winters of this type are of great value to the plant breeder, providing unique opportunities to assess relative cold hardiness of virtually all plant material outdoors including cultivar collections, advanced selections in second test, selected seedling or even entire progenies of segregating, unselected seedlings. Such information is almost impossible to obtain otherwise. Controlled freezing tests are valuable in assessing cold hardiness (6, 7, 8) but limited to the amount of plant material that can be accommodated in the freezing chamber at any given time, and require a greater input of time, labor and plant material than that needed for hardiness determinations from natural cold stress. The winter of 1981-82 provided a rare opportunity to assess flower bud and wood hardiness of peach and nectarine breeding material at Harrow taken directly from outdoors. The results of that assessment form the basis of this report.

Materials and Methods

Weather. January and February, 1982 had mean monthly minimum temperatures that were 5.8 and 3.9°C colder than the corresponding 65 year means for these months at the Harrow Research Station. The lowest temperature recorded in January (−26.0°C) occurred on January 17. The only other potentially injurious temperature recorded before that date was −22.5°C on January 11. The lowest temperature recorded in February was −24.5°C which occurred on February 10. Only once in the last 23 years were January and February minimum temperatures as cold (−26.1°C on January 24, 1963, −23.5°C on February 11, 1979), and in both years there was severe winter injury to peaches in

[1]Research Station, Agriculture Canada, Harrow, Ontario, N0R 1G0.
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southwestern Ontario. Routine monitoring of injury to flower buds of Redhaven and Loring during the winter of 1981-82 revealed that most of the injury sustained in 1982 resulted from the low temperature stress on January 17 (−26.0°C). Detailed hourly records from Environment Canada, Windsor Airport (ca. 40 km north of Harrow) revealed that on January 17, 1982 the temperature was $\leqslant$ −20°C for 15 hours and was $\geqslant$ −25°C for 5 of those hours with a minimum temperature of −25.6°C being recorded. During the same period the prevailing wind direction was west-south-west and the wind speed varied from 19 to 32 km/h with gusts up to 43 km/h. Recent controlled freezing studies conducted at Harrow with detached shoots revealed that when peach shoots were artificially acclimated to attain maximum hardiness levels, the T_{20} and T_{90} for Redhaven flower buds were −24 and −29°C, respectively. Temperatures at which injury to leaf buds and shoot xylem were initiated were −25 and −30°C, respectively (8). It was expected, therefore, that a natural stress of −26.0°C without artificial acclimation to attain maximum hardiness would likely be even more injurious to flower buds than those reported and would also injure shoot xylem. Accordingly, various populations of peach and nectarine were sampled between January 19 and March 8 to assess injury to flower buds and shoot xylem.

Sampling Procedure. We have established from earlier work that sampling 5 and preferably 10 shoots per tree taken at random was satisfactory in assessing natural bud mortality and tissue injury to peaches (6, 7). Accordingly, at least 5 and usually 10 shoots per tree were collected from each individual in each population being studied. Each shoot included all of the growth made in the previous season. We have also learned from earlier work (unpublished) that weak or diseased trees of a given cultivar usually furnished underestimates of hardiness of that cultivar. Thus, only the healthiest trees in the populations of interest were selected for assessment of cold injury. The shoots of a given individual were placed in the same plastic bag and all bags containing shoots from a given population were placed in a large plastic bag which was then placed in an insulated container and brought to the laboratory where they were slowly warmed to room temperature (ca. 22°C) overnight to allow full development of oxidative browning in the tissues that had been cold injured (1, 6, 7, 8). The shoots were then examined directly for injury. It was established from earlier work that detached shoots could be held for several weeks at 5°C and high relative humidity with no change in the level and/or intensity of oxidative browning resulting from freeze injury (6, 7, 8). This made possible the collection of a large amount of plant material on a given date.

The number and percentage of dead flower buds were determined for each shoot by dissection of the flower buds using a sharp scalpel or razor blade under an illuminated magnifier (2X) work station. A flower bud was counted as dead if the flower bud primordium was brown instead of the normal bright green color typical of a healthy primordium. The same shoots were then used to assess xylem injury. There was a marked gradient in shoot xylem injury from the apex to the base with the apex being most cold sensitive. Accordingly, xylem injury was assessed at the midpoint of each shoot since this region was considered the best indicator of hardiness for the whole shoot. A freehand cross section 1 to 2 mm thick was taken from the internode closest to the midpoint of each shoot using a sharp scalpel or razor blade. The section was immediately mounted in a drop of water on a glass slide and examined under a dissecting microscope (50X magnification) using incident illumination. Injury to the xylem was rated on a scale of 1 to 5 where a rating of 1 represented an absence of oxidative browning in the xylem and indicated no apparent cold injury. A rating of 2 indicated that portions of the xylem were injured but injury was patchy and discontinuous and browning intensity was light to moderate. A rating of 3 indicated that injury was continuous around the xylem cylinder but usually did not include all of the xylem and browning intensity was moderate. A rating of 4 indicated that all of the xylem was injured and browning intensity was moderate to severe. A rating of 5 indicated that all of the xylem tissue was severely injured and browning was intense. Ratings from 3 on would show progressive dieback up to 100% from the apex.

Data Analysis. The individuals comprising each group (population) were the treatments and a 1-way analysis of variance for a completely random design was used to analyze the bud mortality and xylem injury data (10). $LSD_{.05}$ values were determined from the appropriate error mean squares and are given in the summary tables. The grand mean of each population was taken to be indicative of the average cold hardiness level of that population. Thus, it was used to make general comparisons of hardiness among each of the populations studied. In each table, the individuals are ranked separately in order of their bud and wood hardiness with the hardiest listed first. Individuals listed above the solid line are significantly (P = .05) more hardy than the corresponding population mean, while those listed above the broken line are significantly more hardy than the hardy standard which is enclosed in brackets. The separate groupings were based primarily on tree age, orchard location and rootstocks to minimize the effect of these factors on assessment of cold hardiness.

Results and Discussion

The largest single group studied consisted of 46 cultivars and advanced selections from the same orchard which were thought to be representative of the full range of cold hardiness present in the working collection used for peach cultivar improvement (Table 1). The individuals comprising this population all had the melting flesh gene (M) and had either white (Wh) or yellow (wh) flesh. They differed significantly (P = .01) in flower bud and wood hardiness and the overall correlation of bud hardiness with wood hardiness was low although significant (r = 0.412, P = .01). Redhaven is the most important and generally the best adapted cultivar grown in Ontario and is used as the standard of hardiness by which other cultivars are compared (4, 5). If this criterion were used to assess the hardiness of the cultivars ranked in Table 1, then 20 were found to be significantly (P = .05) more bud hardy than Redhaven and 20 were found to be more wood hardy but they were not necessarily the same cultivars. Wood hardiness is considered to be more important than bud hardiness because it is crucial for tree survival and longevity. Bud hardiness has a greater influence on annual productivity but is not crucial for tree survival (7, 8). Cultivars more wood hardy than Redhaven that were also more bud hardy included: Chui Lum Tao, Siberian C, Tzim Pee Tao, Newhaven, Reliance, Madison, Harrow Blood, Bailey, and HW 206. Of these, only Newhaven, Reliance, Madison and HW 206 have yellow flesh and commercially acceptable fruit type or nearly so. The remaining cultivars in the hardiest group have small fruit with white flesh of poor eating quality and lack commercial acceptability. When they are used as hardiness sources in breeding three generations of backcrossing to parents with good fruit type and high flavor quality are required to recover commercial phenotype. Invariably, this is accompanied by some loss of the hardiness originally contributed by the hardy parent (5). Evidence from controlled freezing studies indicate that bud hardiness (Layne, unpublished) and wood hardiness (1) are quantitatively inherited and several breeding procedures have been proposed to incorporate these into commercial peaches (1, 5).

The second group of cultivars (Table 2) consisted of 8 virus tested cultivars of peach and 2 nectarines (Harko, Hardired). The cultivars in this group differed significantly (P = .05) in bud hardiness amongst themselves but differences in wood hardiness were not significant. Only Harbrite was more bud hardy and only Harbinger and Cresthaven were more wood hardy than Redhaven. Cresthaven had the best combination of bud hardiness and wood hardiness. None of the cultivars in this group was significantly (P = .05) less hardy than Redhaven. With the exception of Cresthaven, Redhaven, Garnet Beauty and Loring, the remaining cultivars in this group were developed at Harrow and were previously judged to be equivalent to Redhaven in hardiness based on natural and controlled freezing tests (4, 5). The results reported here are indicative that the selection methods used previously were effective because none of the Harrow introductions in this test group was significantly less hardy than Redhaven.

The third group (Table 3) consisted of 8 cultivars and advanced selections of clingstone peaches with the non melting flesh characteristic (m). They differed significantly from each other in bud hardiness and wood hardiness (P = .01). As a group, they were more bud hardy and wood hardy than the second group (Table 2). Four were more bud hardy than Veecling including two Harrow selections (H6744005, HW 242) but none was more wood hardy. The same two bud hardy selections were also the most wood hardy but another Harrow selection (HW 240) although wood hardy was the least bud hardy of this group. The overall correlation of bud hardiness with wood hardiness was low (r = 0.397) and not significant.

The fourth group (Table 4) consisted of 8 nectarine cultivars. They were less hardy as a group than the clingstone peaches (Table 3), and bud hardiness was not correlated with wood hardiness. Two cultivars (Stark's Early Blaze, Hardired) were more bud hardy than Nectared 4, the hardy standard, but only one (Harko) was more wood hardy. However, both Harko and Hardired, developed at Harrow (2, 3), had satisfactory levels of bud hardiness and wood hardiness and are potentially useful as hardiness sources in nectarine breeding.

The fifth group (Table 5) consisted of 11 cultivars and advanced selections each with yellow, melting flesh. They compared in hardiness with the non melting flesh clingstones (Table 3). They differed significantly amongst themselves for bud hardiness and wood hardiness (P = .01) and bud hardiness was correlated with wood hardiness (r = 0.637, P = .05). The Harrow selections which comprised most of the entries in this group were selected earlier for a combination of bud and wood hardiness which may account for the improved correlation of bud hardiness with wood hardiness compared with the other groups where selection was based primarily on bud hardiness. Three Harrow selections exceeded the grand mean in bud hardiness (P = .05), 2 of which also exceeded (P = .05) the grand mean in wood hardiness (H7121084, HW 215). All 9 Harrow selections exceeded Biscoe in bud hardiness and

Table 1. Hardiness rank of 46 peach cultivars and advanced selections with melting flesh following a natural outdoor stress of −26°C on January 17, 1982.

Cultivar or selection[1]	Flower bud mortality (%)[2]	Cultivar or selection[1]	Xylem injury rating scale (1 = none to 5 = severe)[2]
Bailey	22.56	Chui Lum Tao	1.00
Chui Lum Tao	30.96	Siberian C	1.10
Tzim Pee Tao	37.53	Tzim Pee Tao	1.20 [3]
Late Redhaven	42.27	Newhaven	2.60
Harrow Blood	53.47	Reliance	2.60
Troy	53.59	Loring	2.70
Reliance	58.83	Madison	2.70
Early Elberta	61.90	Harrow Blood	2.80
Siberian C	62.22	Sentinel	2.80
Kalamazoo	62.24	Redskin	2.90
Olinda	62.77	Harbelle	2.90
Whynot	63.54 [3]	Harbinger	2.90
Collins	64.72	Bailey	2.90
Early Redhaven	65.14	HW 201	2.90
Cresthaven	68.20	H 4219	2.90
Newhaven	69.08	HW 206	3.00
HW 206	72.08	Sweethaven	3.00
Madison	72.65	Late Redhaven	3.10
Pekin	73.06	H1102B	3.10
Vivid	74.72 [4]	Vivid	3.10 [4]
Harken	80.37	Harken	3.20
H 4219	80.99	Elberta	3.20
Reeces Early Haven	81.24	Pekin	3.20
Garnet Beauty	81.38	Sunhaven	3.20
Sweethaven	81.88	Glohaven	3.30
Earliglo	82.20	Olinda	3.30
Veeglow	82.35	Candor	3.30
Glohaven	83.11	Harland	3.30
Sunhaven	83.13	Garnet Beauty	3.40
Canadian Harmony	83.97	H2219	3.40
Velvet	84.58	Kalamazoo	3.40
[Redhaven	86.12]	Cresthaven	3.40
H 781	86.67	Cardinal	3.50
Elberta	87.71	Troy	3.50
HW 201	88.54	Canadian Harmony	3.60
H2219	89.60	H 781	3.60
Harbelle	90.32	[Redhaven	3.70]
Redskin	93.71	Early Elberta	3.70
Candor	94.21	Early Redhaven	3.70
Loring	94.44	Earliglo	3.70
H1102B	94.81	Velvet	3.70
Harland	95.11	Reeces Early Haven	3.70
Sentinel	96.47	HW 227	3.70
Harbinger	96.51	Veeglow	3.90

Table 1. (cont.)

Cultivar or selection[1]	Flower bud mortality (%)[2]	Cultivar or selection[1]	Xylem injury rating scale (1 = none to 5 = severe)[2]
HW 227	97.78	Collins	3.90
Cardinal	98.45	Whynot	4.10
Mean	75.37	Mean	3.13
F test	**	F test	**
LSD (.05)	11.33	LSD (.05)	0.56

[1]All trees were 7 or 8 years old and propagated on Siberian C peach seedling rootstock.
[2]Means were based on 10 shoots per tree collected and evaluated between January 21 and February 2, 1982. Each shoot included all of previous season's growth.
[3]Means above the solid line are signficantly (P = .05) different (more hardy) from the population mean.
[4]Means above the broken line are significantly (P = .05) different (more hardy) from 'Redhaven.'

Table 2. Hardiness rank of 10 fresh market peach and nectarine (N) cultivars in 4-year-old virus free orchard following a natural outdoor stress of −26°C on January 17, 1982.

Cultivar[2]	Flower bud mortality (%)[1]	Cultivar[2]	Xylem injury rating scale (1 = none to 5 = severe)[1]
Harbrite	62.78 [4]	Harbinger	2.87
Hardired	71.87	Cresthaven	3.00 [4]
Cresthaven	75.29	Garnet Beauty	3.27
[Redhaven	78.76] [3]	Loring	3.33
Canadian Harmony	85.62	Harbrite	3.53
Garnet Beauty	86.23	Canadian Harmony	3.60
Harbinger	87.50	Harko	3.73
Harko	90.74	Harbelle	3.80
Harbelle	91.16	Hardired	3.80
Loring	91.76	[Redhaven	3.93]
Mean	82.17	Mean	3.49
F test	**	F test	n.s.
LSD (.05)	13.79	LSD (.05)	0.73

[1]Means are based on 15 shoots per cultivar collected February 11, 1982. Each shoot consisted of all of the previous season's growth.
[2]All trees were propagated on virus free Siberian C peach seedling rootstock.
[3]Cultivars above the solid line are significantly (P = .05) different (more hardy) from the corresponding grand means.
[4]Cultivars above the broken lines are significantly (P = .05) more hardy than Redhaven.

wood hardiness and show promise as hardiness sources.

The sixth group (Table 6), consisting of 8 peach cultivars and advanced selections with yellow, melting flesh, differed significantly from one another (P = .01) for bud hardiness and wood hardiness and bud hardiness was correlated with wood hardiness (r = 0.726, P = .05). HW 229, a Harrow selection, was outstanding in terms of bud hardiness and wood hardiness and differed significantly (P = .05) from the mean of this group. This selection was also outstanding in terms of cold hardiness when tested earlier as a seedling. Fayette was the least hardy of this group as expected, because it was developed in California and was not selected for cold hardiness.

Table 3. Hardiness rank of eight canning clingstone peach cultivars and selections 3 to 8 years old following a natural outdoor stress of −26°C on January 17, 1982.

Cultivar or selection[1]	Flower bud mortality[2] (%)	Cultivar or selection[1]	Xylem injury rating scale[2] (1 = none to 5 = severe)
Babygold 5	39.95 [3]	HW 242	2.80
H6744005	53.16	H6744005	2.90
HW 242	53.51	HW 240	2.90
Babygold 6	62.72 [4]	Babygold 7	3.00
Babygold 7	66.76	H6730013	3.00
H6730013	72.13	[Veecling	3.10]
[Veecling	79.97]	Babygold 5	3.80
HW 240	96.92	Babygold 6	3.80
Mean	65.64	Mean	3.16
F test	**	F test	**
LSD (.05)	14.60	LSD (.05)	0.49

[1]With the exception of Veecling which was on Bailey rootstock all other entries were on Siberian C rootstock.
[2]Values are based on 10 randomly selected shoots from the healthiest tree of each clone. Shoots were collected on January 21, 1982 and consisted of all of the previous season's growth.
[3]Clones above the solid line are significantly (P = .05) different (more hardy) from the corresponding grand means.
[4]Clones above the broken line are significantly more bud hardy than Veecling.

Table 4. Hardiness rank of eight nectarine cultivars 7 or 8 years old on Siberian C rootstock exposed to a natural outdoors stress of −26.0°C on January 17, 1982.

Cultivar	Flower bud mortality (%)[1]	Cultivar	Xylem injury rating scale (1 = none to 5 = severe)[1]
Stark's Early Blaze	44.80	Harko	2.70 [2]
Hardired	70.60 [2, 3]	Hardired	3.10
Fantasia	81.56	Nectared 2	3.40
Harko	85.18	Fantasia	3.50
Nectared 2	89.31	Nectared 3	3.70
[Nectared 4	90.82]	Nectared 6	3.80
Nectared 6	91.00	Stark's Early Blaze	3.90 [3]
Nectared 3	95.25	[Nectared 4	4.70]
Mean	81.07	Mean	3.60
F test	**	F test	**
LSD (.05)	9.25	LSD (.05)	0.58

[1]Values are the average of 10 shoots randomly selected from the healthiest tree of each entry. Shoots were collected on January 21, 1982 and consisted of all of the previous season's growth.
[2]Cultivars above the solid lines are significantly (P = .05) more hardy than the population mean.
[3]Cultivars above the broken line are significantly (P = .05) more hardy than Nectared 4.

Table 5. Hardiness rank of 11 peach cultivars and advanced selections with yellow, melting flesh following a natural outdoor stress of −26°C on January 17, 1982.

Cultivar or selection[1]	Flower bud mortality[2] (%)	Cultivar or selection[1]	Xylem injury rating scale[2] (1 = none to 5 = severe)
HW 213	43.10	H7121084	2.10
H7121084	46.63	HW 215	2.50 [3]
HW 225	48.32 [3]	H7107027	2.70
H7114176	56.42	H7108033	2.90
HW 233	57.49	HW 225	3.00
H7107027	64.28	HW 213	3.00
HW 215	65.37	H7121044	3.00
H7121044	69.35	HW 233	3.10
H7108033	83.12 [4]	H7114176	3.20 [4]
V55061	89.61	[Biscoe	3.70]
[Biscoe	90.11]	V55061	4.20
Mean	64.89	Mean	3.04
F test	**	F test	**
LSD (.05)	11.09	LSD (.05)	0.49

[1]Trees were 5 to 8 years old and were all propagated on Siberian C rootstock with the exception of Biscoe which was on Harrow Blood.
[2]Values in table are the mean of 10 shoots per entry randomly selected from the healthiest tree of each entry, collected on January 21, 1982, with each shoot consisting of all of the previous season's growth.
[3]Clones above the solid lines are significantly (P = .05) different (more hardy) from the corresponding grand mean.
[4]Clones above the broken lines are significantly (P = .05) more hardy than Biscoe.

Table 6. Hardiness rank of 8 peach cultivars and advanced selections with yellow, melting flesh following a natural outdoor stress of −26°C on January 17, 1982.

Cultivar or selection[1]	Flower bud mortality[2] (%)	Cultivar or selection[1]	Xylem injury rating scale[2] (1 = none to 5 = severe)
HW 229	37.83 [3]	HW 229	2.60 [3]
Correll	72.28	Jayhaven	2.80
HW 231	74.85	Hamlet	2.90
Hamlet	77.36	HW 228	3.00
HW 228	79.56	HW 231	3.40
Ellerbe	81.82	Ellerbe	3.50
Fayette	92.84	Fayette	4.10
Mean	73.73	Mean	3.15
F test	**	F test	**
LSD (.05)	9.27	LSD (.05)	0.47

[1]All trees were 3 or 4 years old and propagated on peach seedling rootstocks.
[2]Values in table are the mean of 10 shoots per clone randomly selected from the healthiest tree, collected on January 21, 1982 with each shoot consisting of all of the previous season's growth.
[3]Clones above the solid line are significantly different (P = .05) (more hardy) from the corresponding grand means.

The last group (not shown) consisted of 34 selected seedlings from crosses made in 1975 and 1976 where selection was based on a total of 16 tree and fruit characters including apparent cold hardiness in the field. These individuals differed significantly (P = .01) from each other in bud hardiness and wood hardiness. Seven were significantly (P = .05) more bud hardy than Redhaven and 11 were significantly (P = .05) more wood hardy. Those that exceeded the wood hardiness and bud hardiness of Redhaven included: H7504106, H7503238, H7606038 and H7514181.

In conclusion, it was possible as the result of a test winter to identify peaches and nectarines which possess useful levels of bud hardiness and wood hardiness. This information is especially useful in selecting seedlings to be advanced into second tests, but is also helpful in deciding which advanced selections should be considered for commercial introduction, and which named cultivars should be recommended for the different climatic zones (Zones 7b, 6b, 6a) where peaches are commercially grown in Canada (8, 9). Furthermore, it is of value to the breeder in choosing parents for improving cold hardiness of peach and nectarine. The lack of a consistent and close correlation between flower bud and shoot xylem hardiness indicates that the cold hardiness of these tissues may be inherited independently. Thus, separate assessment of bud hardiness and shoot xylem hardiness is essential to ensure selection of individuals that possess a desirable combination of both types of hardiness.

Literature Cited

1. Cain, D. W. and R. L. Andersen. 1980. Inheritance of wood hardiness among hybrids of commercial and wild Asian peach genotypes. J. Amer. Soc. Hort. Sci:. 105:349-354.
2. Layne, R. E. C. 1975. "Harko" nectarine. HortScience 10:532.
3. ————. 1975. 'Hardired' nectarine. HortScience 10:532-533.
4. ————. 1975. New developments in peach varieties and rootstocks. Compact Fruit Tree 8:69-77.
5. ————. 1980. Prospects of new hardy peach rootstocks and cultivars for the 1980's. Compact Fruit Tree 13: 117-122.
6. ————, H. O. Jackson and F. D. Stroud. 1977. Influence of peach seedling rootstocks on defoliation and cold hardiness of peach cultivars. J. Amer. Soc. Hort. Sci. 102-89-92.
7. Quamme, H. A., R. E. C. Layne, H. O. Jackson and G. A. Spearman 1975 An improved exotherm method for measuring cold hardiness of peach flower buds. HortScience 10:521-523.
8. ————, R. E. C. Layne and W. G. Ronald. 1982. Relationship of supercooling to cold hardiness and the northern distribution of several cultivated *Prunus* species and hybrids. Can. J. Plant Sci. 62:137-148.
9. Sherk, L. C. and A. R. Buckley. 1968. Ornamental shrubs for Canada. Agric. Canada Publ. No. 1286.
10. Steel, R. G. D. and J. H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill Book Co. 481 p.