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Determination of Cold Hardiness and Estimation of Potential Breeding Value of Apricot Germplasm

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Abstract

Controlled laboratory freezing tests were carried out on dormant apricot (*Prunus armeniaca* L.) shoots preconditioned to attain maximum cold hardiness. Determinations were made of the temperatures required to kill 50% of the flower buds [T_{50} (FB)] and 50% of the shoot xylem [T_{50} (SX)]. The 27 genotypes in this study differed significantly from each other in T_{50} (FB) and T_{50} (SX). Using 'Goldcot' as the climatically adapted hardy standard, 27 genotypes were placed in three hardiness classes; those more hardy than 'Goldcot,' those equally hardy as 'Goldcot' and those less hardy than 'Goldcot.' The mean T_{50} (FB) was -28.7C and the mean T_{50} (SX) was -35.3C, indicating that shoot xylem hardiness of apricots was at least several degrees greater than flower bud hardiness. The range in flower bud hardiness among the 27 genotypes was 2.8C while that for shoot xylem hardiness was 6.7C. Seven genotypes had hardier flower buds than 'Goldcot' including two named Harrow cultivars ('Harlayne' and 'Haggith'), four numbered Harrow selections (H7814180, HW-446, H8205044 and HW460) and one other cultivar ('Manchu'). Among 16 genotypes equally bud hardy as 'Goldcot,' four were named Harrow cultivars ('Harcot,' 'Harglow,' 'Hargrand' and 'Harogem') and eight were numbered Harrow selections. One named Harrow cultivar ('Hag-gith') was more wood hardy than 'Goldcot'; while three Harrow cultivars ('Harlayne,' 'Harcot' and 'Hargrand') and seven numbered Harrow selections were equally wood hardy. The goal of breeding apricot cultivars equal to or more cold hardy than 'Goldcot' was achieved because bud hardiness of six of the seven Harrow introductions was equal to or greater than 'Goldcot.' The potential breeding value of the 14 named cultivars was estimated by using their total long term performance ratings for 14 attributes, then applying the bud and wood hardiness classifications made here as additional factors. The ranking of breeding value for the 14 named cultivars from highest to lowest was as follows: 'Harlayne' > 'Harcot' = 'Hargrand' = 'Harval' > 'Harglow' = 'Harogem' > 'J.L. Budd' > 'Manchu' > 'Gibbs' = 'Sunglo' > 'Haggith' = 'Veecot' > 'Stella' > 'Goldcot.' The potential breeding value of the six named Harrow introductions for the fresh market exceeded that of the eight other cultivars, including 'Veecot' and 'Goldcot,' the two commercial standards. Consequently, they warrant greater use as parents and wider testing as cultivars.

Introduction

Apricot culture is greatly restricted by climatic limitations (3, 4). Cold hardiness is an important aspect of apricot cultivar adaptation, especially in Canada, one of the most northerly apricot growing regions in the world, where only Ontario and British Columbia have small commercial industries (1, 4, 14). The industry in Ontario is confined to areas near the shores of Lake Ontario and Lake Erie where these large bodies of water moderate the climate near the lakeshore sufficiently for apricots to be successfully grown (1, 14).

In 1964, an apricot breeding program was initiated at the Harrow Research Centre to develop cold hardy, productive, disease resistant, high quality cultivars for the fresh market. This program led to the introduction of seven fresh market cultivars: 'Harcot' (5), 'Harogem' (6), 'Harlayne' (7), 'Hargrand' (8), 'Harglow' (10), 'Laycot' (patented in France by Star Fruits) and 'Harval' (12); and one rootstock seed source 'Haggith' (15). 'Goldcot,' a hardy adapted cultivar from Michigan, and 'Veecot,' a less hardy adapted cultivar from Ontario were used as hardiness standards to establish effective selection levels for hardiness in the Harrow breeding program. Usually, breeding lines less hardy than 'Goldcot' were discarded and those equal to or hardier than 'Goldcot' were retained for further study and regional testing.

Controlled freezing tests have been routinely used for apricot parental selection, hybrid seedling selection, and final selection of advanced lines prior to cultivar release (7, 8, 10, 12, 14). A

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standardized protocol in breeding and selection for cold hardiness in peach and nectarine (11, 13) has also been routinely and effectively used for apricot since 1989 (12).

This study was undertaken 1) to critically assess the cold hardiness of the named Harrow cultivar introductions against 'Goldcot,' the hardy standard, 2) to assess the relative hardiness of 12 Harrow numbered selections in relation to 'Goldcot' and the named Harrow introductions, and 3) to assess hardiness of several other cultivars that had demonstrated good hardiness in the field but whose relative hardiness had not been critically established by controlled freezing tests. Long term performance ratings of the 14 named cultivars were also used in conjunction with cold hardiness determinations to estimate potential breeding values of these cultivars.

Materials and Methods

This study, conducted at the Harrow Research Centre in southwestern Ontario (~42°N, 82°54'W), involved mature bearing trees of 27 genotypes in a conventionally-managed apricot orchard (Ontario Ministry of Agriculture and Food, Fruit Production Recommendations, 1994-1995, Publ. 360).

Thirty dormant shoots (~30 cm long) per genotype were collected at random on 12 Dec. 1994. Shoots were taken from around the periphery of each tree in the fruiting zone about 1.5 to 2.5 m above ground. All 30 shoots per genotype were bundled together with elastic bands and placed in large plastic bags containing moist paper towels to prevent desiccation. The samples were prepared at -3C in a cold room by randomly selecting five shoots per genotype for each of six preselected test temperatures. All 135 shoots per test temperature were placed in a plastic bag containing moist paper towels, then all six bags were placed in a large insulated cooler and preconditioned to attain maximum hardiness: 21 days at -3C, 7 days at -5C, then 7 days at -10C according to a standard protocol used in our laboratory (11, 13). On 16 Jan. 1995, these shoots were removed from the plastic bags and placed in a specially constructed chest-type freezing chamber cooled by liquid nitrogen, the prototype of one previously reported (2). A Bristol Temperature Controller (Model IT500FT-IB) regulated by a cam controller provided a constant cooling rate of 5C per hour. To monitor tissue temperatures, copper constantan 27 gauge thermocouples connected to an Omega 32 Channel Recorder/Data Logger (Model 272) were inserted at the nodal swelling beneath the bud plate of randomly selected shoots.

The freezing test began at -10C and ended at -38C. As soon as each test temperature (i.e. -23, -26, -29, -32, -35, and -38C) was attained, the shoots assigned to that temperature were removed from the freezing chamber, placed in their original plastic bags, and held at -10C until the freezing run was completed for all test temperatures. All samples in their original plastic bags were placed in an insulated cooler and slowly warmed overnight to 3C, then brought to the laboratory and held at room temperature (~23C) for 24 hours to permit full development of oxidative browning symptoms associated with freeze-injured tissues. The shoot samples were then held at 5C until they were assessed for flower bud mortality and shoot xylem tissue injury as previously described (9, 11, 13). T_{50} values calculated for the flower bud mortality and xylem injury data (11, 13) were analyzed as a 1-way ANOVA for a completely randomized design with 5 replications using PROC GLM (SAS Institute, Cary NC).

Genotypes were ranked from least to most hardy on the basis of the T_{50} hardiness values calculated for flower buds and shoot xylem as had been done earlier for peaches (11). Three classes of flower bud hardiness were established in relation to 'Goldcot,' the hardy standard: genotypes significantly ($p \leq 0.05$) more hardy than 'Goldcot,' not different from 'Goldcot,' and those significantly less hardy than 'Goldcot.' Shoot xylem hardiness was similarly classified in relation to 'Goldcot.'

Pearson's coefficient of linear correlation (r) was calculated to test the relationship of flower bud hardiness with shoot xylem hardiness. Spearman's rank correlation coefficient (r_s) was calculated to test the rank order of genotypes for flower bud hardiness against that for shoot xylem hardiness.

For the 14 named cultivars, existing records were used based on annual subjective ratings of long-term performance records. The 14 named cultivars were summarized on a scale of 1 = least desirable to 10 = most desirable. The total score per cultivar based on these ratings provides a general measure of the relative pomological value of each cultivar. The flower bud and shoot xylem hardiness data were used to provide additional factors which, when added to the total score, would give a measure of the potential breeding value of these cultivars. Cultivars less bud hardy than 'Goldcot' were given a weighting of 1, those equally as hardy as 'Goldcot' had a weighting of 4 and those hardier than 'Goldcot' had a weighting of 7. Similarly, cultivars with shoot xylem less wood hardy than 'Goldcot' had a weighting of 1, those equally as hardy as 'Goldcot' had a weighting of 2, and those hardier than 'Goldcot' had a weighting of 3. Higher weightings were given for flower bud than for shoot xylem hardiness because it played a greater role in annual productivity of apricots in Ontario. Potential breeding value was calculated using the formula: PBV = T + FBHF + SXHF, where PBV = potential breeding value, T = total of long term ratings, FBHF = flower bud hardiness factor, and SXHF = shoot xylem hardiness factor. Cultivars were then ranked from highest to lowest according to their potential breeding value.

Results

The 27 genotypes (Table 1) differed significantly ($p \leq 0.001$) for flower bud [T_{50}(FB)] and shoot xylem [T_{50}(SX)] cold hardiness in the F test. There was a 2.8C range among genotypes from least ('Harval') to most ('Harlayne') hardy and the mean bud hardiness of the 27 genotypes was -28.7C. Of the seven named Harrow introductions tested, 'Harlayne' and 'Haggith' were hardier than 'Goldcot' while 'Harcot,' 'Harglow,' 'Hargrand' and 'Harogem' equalled 'Goldcot.' Only one of the Harrow cultivars tested, 'Harval,' was less bud hardy than 'Goldcot' (Table 1). Four Harrow selections were more bud hardy than 'Goldcot,' eight were equally hardy and only one was less hardy than 'Goldcot.' Of these, all seven of the Harrow advanced selections were equal to or more bud hardy than 'Goldcot,' and included in descending order of hardiness: HW446, HW460, HW459, HW436, HW458, HW441 and HW457. Among cultivars developed elsewhere, 'Veecot' was the only one less bud hardy than 'Goldcot' while 'J. L. Budd,' 'Gibbs,' 'Stella,' and 'Sunglo' were equally hardy, and only 'Manchu' was more bud hardy than 'Goldcot.'

Shoot xylem hardiness among the 27 genotypes also differed significantly ($p \leq 0.001$) in the F test, with a 6.7C range from the least to the most hardy and a mean among the 27 genotypes of -35.3C (Table 1). Among the seven named Harrow introductions, only 'Haggith' exceeded 'Goldcot'; 'Harlayne,' 'Harcot' and 'Hargrand' equalled 'Goldcot'; and 'Harval,' 'Harogem,' and 'Harglow' were less hardy than 'Goldcot.' None of the Harrow selections was more shoot xylem hardy than 'Goldcot,' seven were equally hardy and six were less hardy than 'Goldcot.' Harrow advanced selections that equalled 'Goldcot' in shoot xylem

Table 1. Hardiness rank of 27 apricot cultivars and numbered Harrow selections at maximum hardiness (1994-1995).

Cultivar or selection	T_{50} (FB)[z] (°C)	Cultivar or selection	T_{50} (SX)[y] (°C)
Harlayne	-29.83	Manchu	-38.15
H7814180	-29.71	Haggith	-36.80 x
Haggith	-29.62	HW460	-36.20
Manchu	-29.58	Stella	-36.05
HW446	-29.15	H7809028	-36.05
H8205044	-29.14	H7814180	-35.90
HW460	-29.05 x	HW436	-35.90
Sunglo	-29.01	[Goldcot	-35.75][w]
HW459	-28.97	Sunglo	-35.60
Stella	-28.96	Gibbs	-35.60
Gibbs	-28.95	HW446	-35.60
Harcot	-28.90	Veecot	-35.45
Harglow	-28.87	Harlayne	-35.30
H7809028	-28.81	J. L. Budd	-35.30
J. L. Budd	-28.73	H8208044	-35.15
HW436	-28.65	HW441	-35.00
Hargrand	-28.61	Harcot	-35.00
H8208004	-28.40	Harval	-34.55 v
[Goldcot	-28.40][w]	Hargrand	-34.85
HW458	-28.35	H8205044	-34.55
Harogem	-28.31	HW459	-34.55
HW441	-27.95	H7821077	-34.55
H7821077	-27.84	Harogem	-34.40
HW457	-27.79 v	Harglow	-34.40
Veecot	-27.60	HW458	-34.25
H8204231	-27.45	H8204231	-34.25
Harval	-27.06	HW457	-34.10
Mean	-28.66	Mean	-35.30
F test	8.42***	F test	5.91***
LSD (5%)	0.677	LSD (5%)	1.047

[z]Estimated temperature required to kill 50% of the flower buds.
[y]Estimated temperature required to kill 50% of the shoot xylem.
[x]Cultivars above the solid lines are significantly ($p \leq 0.05$) more hardy than 'Goldcot.'
[w]Cultivar enclosed in parenthesis is the hardy standard.
[v]Cultivars below the broken line are significantly ($p \leq 0.05$) less hardy than 'Goldcot.'

hardiness included: HW460, HW436, HW446, and HW441. Among cultivars developed elsewhere, only Manchu' was hardier than 'Goldcot,' while 'Stella,' 'Sunglo,' 'Gibbs,' 'Veecot,' and 'J. L. Budd' were equally hardy, and none was less hardy than 'Goldcot.'

Genotypes that equalled or surpassed 'Goldcot' for both flower bud and shoot xylem hardiness included Harrow named introductions: 'Hargrand,' 'Harcot,' 'Haggith' and 'Harlayne'; Harrow advanced selections: HW436, HW441, HW446 and HW460; and two other

Table 2. Long-term mean performance rating of 14 characters, performance total, cold hardiness factors, potential breeding value and rank of 14 apricot cultivars.

Cultivar	Mean performance rating[z]																		
	Tree type	Winter injury	Canker	Bloom intensity	Fruit set	Ripening uniformity	Fruit size	Blush	Attractiveness	Firmness	Freeness	Quality	Bacterial leaf spot	Bacterial fruit spot	Total[y]	Bud hardiness[x]	Wood hardiness[w]	Potential Breeding value[v]	Rank
Harlayne	8	8	8	6	7	6	6	2	6	8	9	7	8	8	97	7	2	106	1
Harcot	7	7	8	5	6	7	7	3	7	8	7	8	8	8	96	4	2	102	3
Hargrand	8	8	9	6	5	6	8	2	5	8	10	7	7	7	96	4	2	102	3
Harval	9	8	8	5	6	6	7	4	8	8	9	7	8	7	100	1	1	102	3
Harglow	8	7	8	7	5	6	6	1	6	7	9	7	9	9	95	4	1	100	5.5
Harogem	7	7	8	4	6	7	6	6	8	9	9	7	6	5	95	4	1	100	5.5
J. L. Budd	10	8	9	7	6	6	3	1	4	6	9	4	10	10	93	4	2	99	7
Manchu	10	10	10	8	5	4	3	1	3	5	6	4	8	9	86	7	3	96	8
Gibbs	9	8	9	5	6	5	4	1	4	5	9	4	10	10	89	4	2	95	9.5
Sunglo	7	7	8	6	6	6	6	1	7	6	7	6	8	8	89	4	2	95	9.5
Haggith	7	8	8	6	6	5	4	1	3	4	9	4	9	9	83	7	3	93	11.5
Veecot	7	7	8	5	6	7	6	1	7	8	10	6	6	6	90	1	2	93	11.5
Stella	10	10	10	6	5	5	3	1	4	4	6	5	9	8	86	4	2	92	13
Goldcot	8	8	8	5	6	6	4	1	5	4	9	5	8	8	85	4	2	91	14

[z]Ratings were subjective on a scale of 1 (least desirable) to 10 (most desirable). Ratings <5 were unsatisfactory, 5 or 6 was satisfactory and ratings >7 were considered good and commercially desirable.
[y]Total obtained by summation of the 14 rated characters.
[x]Flower bud hardiness factor (FBHF) 1 = less hardy than 'Goldcot,' 4 = as hardy as 'Goldcot,' 7 = more hardy than 'Goldcot.'
[w]Shoot xylem hardiness factor (SXHF) 1 = less hardy than 'Goldcot,' 2 = as hardy as 'Goldcot,' 3 = more hardy than 'Goldcot.'
[v]Potential breeding value = Total + FBHF + SXHF.

numbered Harrow selections: H780-9208 and H7814180. Cultivars developed elsewhere that equalled or surpassed 'Goldcot' for flower bud and shoot xylem hardiness included: 'J. L. Budd,' 'Gibbs,' 'Stella,' 'Sunglo' and 'Manchu.'

There was a significant positive linear correlation between flower bud and shoot xylem hardiness for the 27 genotypes studied ($r = 0.58$, $p \leq 0.001$). Similarly, there was a significant correlation of rank order among the 27 genotypes for flower bud and shoot xylem hardiness ($r_s = 0.59$, $p \leq 0.001$).

Potential breeding value of the 14 named cultivars was estimated from long-term evaluation records by adding factors for flower bud and shoot xylem hardiness to overall performance scores based on 14 rated characters (Table 2). The rank order of potential breeding value from highest to lowest was as follows: 'Harlayne' > 'Harcot' = 'Hargrand' = 'Harval' > 'Harglow' = 'Harogem' > 'J. L. Budd' > 'Manchu' > 'Gibbs' = 'Sunglo' > 'Haggith' = 'Veecot' > 'Stella' > 'Goldcot.' The top ranked six cultivars for potential breeding value were all Harrow fresh market introductions (Table 2).

Discussion

This study demonstrated that controlled freezing tests could be effectively used for objectively assessing the flower bud and shoot xylem hardiness of genetically diverse apricot germplasm (Table 1). The preconditioning and controlled freezing protocol reported here had been used in an earlier study of apricot cultivars (12), and is routinely used for selection of cold hardy apricots, peaches, and nectarines in the Harrow stone fruit breeding programs (11, 12, 13).

This study also confirmed a previous report (12) that apricot flower buds were several degrees less cold hardy than apricot shoot xylem. At maximum hardiness levels in the present study, flower bud hardiness was significantly correlated with shoot xylem hardiness, and the rank order among genotypes for bud hardiness was also significantly correlated with that for shoot xylem hardiness. Thus, selection for bud hardiness should lead to concomitant selection for wood hardiness and vice versa.

When the same preconditioning and freezing protocol is used, bud hardiness classification for a given set of genotypes in one year can generally be compared with hardiness classification data for common genotypes in another year although there is some year to year variability in relative hardiness. Thus, in 1991 (12), 'Goldcot' was equally bud hardy as 'Hargrand,' 'Harcot,' 'Harglow,' 'Harogem' and 'Harval,' but was less hardy than 'Harlayne.' In the present study (Table 1), the same classification of bud hardiness was obtained for these cultivars with only 'Harval' being less bud hardy than 'Goldcot.'

Controlled freezing tests were generally effective in selecting cold hardy apricots in the Harrow breeding program, thus, 19 of 21 Harrow genotypes equalled or surpassed the flower bud hardiness of 'Goldcot' (Table 1); and 12 of the same 21 Harrow genotypes equalled or exceeded the shoot xylem hardiness of 'Goldcot.' Estimated potential breeding value by combining hardiness data from this study with long-term performance ratings (Table 2), made it possible to identify cold hardy cultivars, and also to identify the ones most likely to be useful in breeding, not only for improved cold hardiness, but also for improvement of other characters needed for climatic adaptation and to satisfy market requirements. Progeny tests will be required to establish their actual breeding value as parents. Six of the seven named Harrow introductions (Table 2) exceeded other cultivars used in this study in potential breeding value. Consequently, they warrant further use as parents and wider testing as cultivars. They are currently recommended for commercial culture in Ontario (1).

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Lateral Shoot Development in Six Diverse Seedling Populations of Apple

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Abstract

Growth and branching habit of seedling populations originating from open-pollinated trees of *Malus prunifolia* Borkh., *M. ranetka* Borkh., and four cultivars of *M. domestica* Borkh. ('Antonovka,' 'Bittenfelder,' 'Borowinka,' 'Golden Delicious') were characterized. The decreased rate at which new lateral shoots developed was directly related to decreases in terminal growth rate, since all lateral budbreak throughout the growing season occurred within 20 cm of the shoot tip. 'Borowinka' sdlg., 'Golden Delicious' sdlg., and *M. ranetka* populations were most vigorous and, generally, had the greatest number of lateral budbreaks and branches. However, lateral budbreak and branching were not strongly related to terminal growth rate, evidenced by poor correlations with terminal shoot length. cross-sectional area, and internode length.

Introduction

Variation among commercial apple cultivars in vigor and tendency to branch is well documented (4, 5, 7). Many cultivars exhibit limited branching and are induced to branch, manually or chemically, in the nursery or immediately after planting. The early yields and high production potential of a high-density orchard can only be realized when a significant number of well-distributed branches develop. Knowledge of which traits are highly correlated with branch development would be beneficial in developing new cultivars which branch more freely than those currently available. The objectives of this study were: (1) to demonstrate the wide variation in growth and branching habit among a collection of genetically diverse seedling populations and (2) to examine the relationship between terminal shoot growth and lateral shoot development.

Materials and Methods

Study 1. In Nov. 1991, 20 one-year-old upright shoots were randomly selected from each of six sets of 9-year-old seedling trees. Each set of trees (seedling populations) originated from open-pollinated trees of either *Malus prunifolia* Borkh., *M. ranetka* Borkh., or one of four cultivars of *M. domestica* Borkh. ('Antonovka,' 'Bittenfelder,' 'Borowinka,' 'Golden Delicious'). The parent trees were grown together in a single block. The seedling populations were located in Raleigh, NC in a compact hedgerow consisting of a permanent network of horizontal

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