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Winter Hardiness Measurements on 15 New Apple Cultivars[1]

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Abstract

Fifteen new cultivars from the 1995 NE-183 planting were evaluated for cold hardiness in November and February for three consecutive winters, relative to 'Golden Delicious' (winter tender) and 'Spartan' (hardy). Pieces of dormant current season's shoots were frozen to a series of test temperatures from -20°C to -36°C in a programmable freezer. In the final year, major scaffolds and trunks of certain cultivars from the NE-183 trial, plus 'Royal Gala' and 'Summerland McIntosh', were also tested, to establish the correlation between the hardiness of shoots and other parts of the tree. Ratings of tissue browning in the xylem and bark were used to assess injury after thawing. The temperature of incipient damage (TID), i.e. the warmest temperature at which a cultivar began to show injury, was obtained from survival curves by non-linear regression. TID varied significantly among cultivars, but not with sampling season. Overall, cultivars with shoots similar to 'Golden Delicious' in hardiness were: 'Arlet', 'Cameo', 'Orin', 'Golden Supreme' and 'Suncrisp.' 'Ginger Gold', 'GoldRush', 'Sunrise' and 'Braeburn' had TIDs intermediate between 'Golden Delicious' and 'Spartan'. Clones with shoots as hardy as 'Spartan' were: 'Pristine', 'Fortune', 'Honeycrisp', 'Yataka', 'Fuji' and NY 75414-1. Trunks were less hardy than shoots (had higher TID), and scaffolds tended to be intermediate. For the NE-183 trees, the TID of shoots and scaffolds, and the TID of trunks and scaffolds, from the same trees were significantly correlated. The TID for trunks and shoots was not correlated ($R=0.24$, $p=0.29$). This appeared to be attributable to deviations in the hardiness among tissues of several cultivars, especially 'Fuji' and 'Fortune', which had hardy shoots but tender trunks. In contrast, the TID for trunks, scaffolds and shoots of 'Royal Gala' and 'Summerland McIntosh' were all significantly and highly correlated ($R > 0.90$). The development of non-destructive methods to measure the hardiness of the trunk might improve the assessment of cultivar hardiness.

Introduction

Winter injury is a limitation to apple production in many regions, including Canada and the northern United States. In Canada, winter injury sufficient to damage apple trees has historically occurred once every five to seven years (16). In the Okanagan Valley of British Columbia (BC), Canada, the most vulnerable period is November, when outbreaks of Arctic air may flow southward and damage trees before they are fully acclimated (3). The second most vulnerable period is mid- to late winter, if unseasonably warm weather in early winter has induced premature de-hardening (3). Late winter freezes frequently damage apple trees in climates where freeze-thaw cycles are frequent and/or of high amplitude (6). Knowledge of cold hardiness during the period of greatest susceptibility is important to cultivar evaluation.

The hardiness of many woody species, including apple, varies seasonally. The first stage of acclimation is triggered by short days and low temperature, involves a translocatable substance, and proceeds at temperatures of 10 to 20°C (9, 19, 25). Apple trees can harden to withstand temperatures of -15°C to -20°C in the first stage (8, 11, 19). In the second stage, temperatures below 5°C, and especially temperatures below 0°C

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(25), induce further acclimation, down to -35 to -40°C in apple (17). The base of the trunk is typically the most tender tissue, as hardening proceeds from the periphery to the trunk, and from top to bottom of the tree (10, 16, 19). Damage appears after thawing as browning of the tissue caused by the oxidation of polyphenols.

Severe winters have been useful for assessing the relative hardiness of many cultivars (10, 15, 21, 22, 23). The hardiness of a particular cultivar is influenced by many factors, including the state of dormancy, climatic conditions leading up to the freeze event (which affect the tree's state of acclimation/de-acclimation), rootstock (5, 10, 16), tree age (14), and cultural practices, such as previous crop load, fertilization, pruning, irrigation, orchard floor management, and trunk treatments, and control of pests and diseases (14, 16, 24, 25, 26). Although the relative standing of cultivars may vary from event to event because of such factors, commonalities do occur. For example, 'McIntosh' and 'Spartan' are usually considered to be hardy, 'Golden Delicious' quite tender, and 'Delicious' intermediate (4, 7, 10, 11, 12, 22, 23).

Artificial freeze tests have been used to gauge the cold hardiness of plants, including apple, in various stages of growth or under different treatments. Although trunks are the tissues most susceptible to winter injury in apple, sampling them requires sacrificing whole trees, so sub-sampling is common, especially the use of one-year-old shoots. Freeze test results using shoots can agree well with observations of winter survival in the field (12). Lapins (12) found that in apple, freeze damage was more closely related to tissue browning than the conductivity of leachates from the tissue. Quamme (unpublished data) verified these observations in a study involving twelve apple cultivars (three replications per cultivar, and 5 or 6 sub-samples per replication per test temperature). The Spearman rank correlation between the temperature of incipient damage (obtained from browning scores) and Lapins' (12) field survival values was 0.95, whereas the correlation was only 0.30 to 0.50 for different measures of conductivity (Quamme, unpublished data). Conductivity measurements were found to be unreliable for measuring the hardiness of sour cherry, strawberry and raspberry (20). Browning evaluation is less laborious than conductivity measurements for evaluating injury when the number of samples is large.

In 1995, a common planting of 22 new apple cultivars was undertaken at 28 sites across North America under the auspices of the NE-183 regional committee. The main objective of the present study was to assess the hardiness of 15 new apple cultivars from this trial in artificial freeze tests at the times they are most susceptible to winter injury. Measurements were compared to 'Golden Delicious' and 'Spartan', which are well-characterized with respect to hardiness. Another objective was to determine the relation between cold hardiness of the one-year-old wood and that of scaffold limbs and the tree trunk.

Materials & Methods

Description of planting. The trees used were a subset of the cultivars in the NE-183 trial planted in 1995 at the Pacific Agri-Food Research Centre (PARC) in Summerland, BC. The experimental design at our site was completely randomized with unequal replication (one to five trees per genotype). The tree spacing was 1.2 m x 3.7 m, and rows ran east-west. Tree training, fertilization and cultural practices followed the trial protocols. In brief, each tree was supported by a pressure-treated post (5-7.5 cm diameter, 2.4 m long) and trained as a slender spindle. The trees were drip-irrigated annually from April to October according to local commercial practices (1). Overhead irrigation supplemented the water supply in hot periods and was also used for evaporative cooling and watering the vegetation in the alleys. Swards of 'Alke' ryegrass (*Lolium perenne* L.) were planted between the rows, and a weed-free strip 1.5 m wide was maintained under the trees with herbicide applications. Fertilization and pest control followed current commercial recommendations for the region (1), except that no calcium was provided, in keeping with the NE-183 protocol.

Freeze tests were initiated in November 1999, at which time the trees were fully grown. Sixteen cultivars that were represented by at least three replicate trees on M.9 T337 rootstock were chosen for the study. An exception was made for 'Braeburn' (two replicates) because of its regional commercial importance. The cultivars and number of available replicate trees were: 'Arlet' (n=5), 'Braeburn' (n=2), 'Cameo' (n=3), 'Fortune' (n=3), 'Fuji' strain BC # 2 (n=4), 'Golden Supreme' (n=4), 'Ginger Gold' (n=5), 'Golden Delicious' Gibson strain (n=5), 'GoldRush' (n=4), 'Honeycrisp' (n=4), NY 75414-1 (n=3), 'Orin' (n=3), 'Pristine' (n=3), 'Suncrisp' (n=4), 'Sunrise' (n=5) and 'Yataka' (n=4). 'Golden Delicious' was the standard of reference for the NE-183 trial, and served as our winter "tender" standard. Four 'Spartan' trees from the same field three rows over from the NE-183 trial were included as a cold hardy standard cultivar. The 'Spartan' trees were subjected to the same management, tree training and spacing, and were also on M.9 rootstock, but were one year older than the other trees.

Sample collection and preparation. One-year-old shoot samples from each tree were collected on 20 Nov. 1999, 14 Feb. 2000, 20 Nov. 2000, 12 Feb. 2001, 19 Nov. 2001 and 11 Feb. 2002. Because the sampling was destructive and data on horticultural performance were being collected concurrently, shoots on each tree were divided into two categories: those that were to remain after pruning, and those that could be removed for freeze tests. Of the latter, approximately half, or up to 15 shoots (15 -30 cm long) were removed for the November tests and the rest left for the February tests each year. In cases where weak tree growth limited the supply of one-year-old wood, the November sampling was given preference, as this is when damage is most likely to occur in our region (3). Shoots from all parts of the canopy were sampled. The shoots were cut, labeled, placed in a cooler over ice, and brought to the laboratory.

Samples were removed from the cooler and cut into lengths of about 4 cm that included at least one vegetative bud. The wood segments were mixed in a plastic tub and six to eight pieces were sealed into each of eight polyethylene zip top bags pre-labeled with sample code number and target test temperature. Cultivar name was not on the label. Previous work has shown a sample size of 5 to 7 pieces to be practical for screening studies (13). Sample preparation took 2-3 min per tree and was done in the laboratory. The sealed bags were kept on ice until all sample preparation was complete, then transferred to two metal carts in the freeze chamber (-3 °C) where they remained overnight. T-type thermocouples were attached to the surface of one of the wood pieces, using an elastic band to ensure close contact.

Freezing cycle and injury assessment. Samples were cooled to a series of test temperatures 2 °C apart in the range of injury. The eight target temperatures spanned the range from -20 °C to -36 °C and included a control (i.e. the warmest subzero sampling temperature, where no tissue damage was anticipated). Samples were frozen in a custom-built Conviron walk-in programmable freezer (2.5 m x 2.5 m) equipped with circulation fans and having a cold pre-chamber anteroom (Conviron, Winnipeg, MB, Canada). The freezer has an operating range of +5 °C to -50 °C and was controlled by a Conviron CMP 3244 firmware controller operated in ramp mode at a temperature reduction rate of 1 °C per hour. Samples were monitored with a CR10 data logger (Campbell Scientific, Edmonton, AB, Canada) with T-type thermocouple leads, connected to a laptop computer running PC208 software (Campbell Scientific). The equipment displayed a reading onscreen every 10 seconds. Six thermocouples on sample pieces were monitored, and a set of samples comprised of all cultivars for a particular target temperature were removed when the average of the six leads reached the target temperature. The temperature variation across the room is < 1 °C but some temperature stratification occurs from top to bottom, and samples were placed on the carts so that all would be at about the same height.

Samples removed from the freezing chamber were immediately transferred to a cooler over ice in the antechamber (-3 °C, dark), and then held at 1 °C for a day. Samples were kept at 22 °C for 60-72 h at 100% relative humidity to allow tissue browning to occur, then stored at 1 °C in darkness to prevent decay over the two to four weeks required to complete sample scoring. Previous work has demonstrated that visual injuries reach their maximum extent within 2 to 3 days (19). Controls remain free from discoloration during such handling.

Tissue browning was rated as described previously (17). Each shoot piece was re-cut and viewed in cross-section with a stereomicroscope (Zeiss STEMI SV8, Carl Zeiss Canada, Don Mills, Ontario). Ratings for browning of both xylem and "bark" (actually all living tissues external to the cambium) were made using a scale of 0 to 5 where 0=no visible damage or discoloration, tissue white or green; 1=a trace of injury visible; 2.5=50% of tissue shows browning; 5=completely brown, tissue is dead. Color images of the ratings are available from the senior author on request. Two people scored the samples, with one person scoring an individual replicate tree.

Supplemental freeze tests were run to establish the correlation in hardiness between one-year-old shoots and other parts of the tree. Major scaffolds and trunks of selected cultivars ('Arlet', 'Fortune', 'Fuji', 'Golden Delicious', 'GoldRush', 'Honeycrisp', NY 75414-1, 'Sunrise', 'Spartan') were destructively sampled in the final year. The scaffolds used (originating at trunk about 0.5 m above soil) had completed seven growing seasons and were roughly 10 cm in basal diameter. Two scaffolds were sampled on 4 Dec. 2001, and then two scaffolds and the lower portion of trunks (above the graft union) in late February 2002. Cross-sections (2 to 4 cm thick) were cut for sampling, using two pieces per test temperature for scaffolds and one for trunks. No winter injury (blackheart) symptoms were seen in the trunks when the trees were cut down. Freeze tests and sample scoring were done as described for shoots.

The correlation in hardiness between tree parts was studied further, using 11-year-old slender spindle trees from another orchard at PARC. These trees were sampled in Dec. 2002 ('Royal Gala') and Jan. 2003 ('Summerland Red McIntosh'). The trees were cut off at the bud union and some branches were removed to allow them all to be fit into the freezing chamber. The temperature of the trunk bark was monitored. Samples from four trees per cultivar were removed at each of seven test temperatures (from -21 °C to -39 °C at 3 °C intervals). The trees were cooled over four days allowing a temperature drop of 9 °C per day. They were thawed at 1 °C and left for 10 days prior to injury assessment. Xylem and bark of upper and lower portions of one-year-old shoots and scaffold limbs, and the trunk, were assessed as described above.

Statistical analysis. The shape of a typical freeze survival curve is sigmoid, with high scores (major injury) at the lowest test temperatures. Raw scores for each tree were subjected to nonlinear regression with the SAS procedure NLIN and graphed with SAS/GRAPH (SAS Institute, Cary NC). Xylem and bark survival were analyzed separately. The temperature corresponding to a score of 1 (a trace of injury) was interpolated from each curve by SAS for each individual tree in the experiment at each of the six sampling dates. The higher of the two temperatures (xylem or bark) was designated as the "temperature of incipient damage" (TID), called minimum survival temperature in some previous publications (4). The TID for one-year-old wood was nearly always determined by the xylem scores, i.e. the xylem was more tender. In only 21 of 380 cases was the bark less hardy, and typically the two scores were less than 1 °C different when this happened. In a few cases, the survival curves for bark were flat (i.e. no browning down to -36 °C), and reliable interpolation of the score=1 point was impossible. In these cases the bark score was set to a missing value and the xylem score was used as the TID. Similarly for scaffold limbs, the bark was less hardy than the xylem in 6 of 61 cases. For trunks, in contrast, the bark was less hardy than the xylem in 13 of 29 cases.

The TID values for one-year-old wood were subjected to analysis of a mixed linear model using the MIXED procedure in SAS, employing the Satterthwaite option to determine degrees of freedom. Year and all interaction terms with year were deemed random effects, and cultivar, season and their interaction were fixed effects. Least-squares (LS) means were obtained and multiple t-tests run at the 5% level of significance for mean separation.

For scaffolds and trunks, separate ANOVAs were run on the TIDs for the two sampling seasons with the SAS procedure GLM. The design was completely random with cultivar as a fixed effect. Multiple t-tests were used for cultivar separation and the results compared to TIDs for the one-year-old shoots of the same trees in year 3 in each season. Pearson correlation coefficients were obtained for TIDs of one-year-old wood, scaffolds and trunks with the SAS procedure CORR.

Table 1. Least squares means for temperature of incipient damage (TID, in °C) to the vascular tissue of one-year-old shoots of 17 apple cultivars averaged over three years with two sampling times per year (November and February).

Cultivar	TID^z (°C)
Arlet	-24.0 a
Golden Delicious	-24.4 ab
Cameo	-24.8 abc
Orin	-25.1 abcd
Golden Supreme	-25.8 abcd
Suncrisp	-26.3 bcd
Ginger Gold	-26.7 cd
GoldRush	-26.8 cde
Sunrise	-26.9 de
Braeburn	-27.3 def
Pristine	-28.9 efg
Fortune	-29.5 fg
Spartan	-30.4 gh
Honeycrisp	-30.6 gh
Yataka	-30.9 gh
Fuji, BC #2	-32.0 h
NY 75414-1	-32.2 h

^{z} Means followed by the same letter are not significantly different (LSD, p = 0.05)

Results & Discussion

We determined the mean temperature of incipient damage (TID), defined here as the warmest temperature at which a trace of injury to the vascular tissue (bark or xylem) occurred, for each tree at each sample date. As expected, the absolute values of TID varied from year to year, probably because annual weather conditions affected acclimation and de-acclimation rates. Cultivars differed significantly in TID ($p < 0.0001$). November and February sampling times were not significantly different ($p=0.4688$), but year-to-year variance was about tenfold greater in November than February (9.36 November, 0.85 February). Emmert and Howlett (7) found that freeze tests in late winter showed a much narrower range among cultivars than in early winter. A similar trend was observed in our experiment (data not shown).

Cultivar x season interaction was not significant ($p=0.086$). In keeping with this finding, we observed some changes in the rank of cultivars, but also much consistency (Fig. 1). A low cultivar x date interaction was reported by Chilton et al. (4), who interpreted it to mean that more detailed work would be required to determine rates of acclimation and de-acclimation among cultivars. Emmert and Howlett (7) noted that the hardiness rank of some cultivars changed from fall to spring, and that while the fall rankings were more in keeping with observations of winter survival, such observations were usually based on early winter freezes. Similarly, Lapins (12) reported good agreement between freeze tests and known early and mid-winter hardiness, but he considered freeze tests in February and March to be less reliable, which may relate to Emmert and Howlett's (7) comments.

'Golden Delicious' and 'Spartan' differed significantly in TID (Table 1), with 'Spartan' being hardier, in accordance with previous freeze tests (4, 12, 13) and observations of damage after severe winters (23). Overall, cultivars with hardiness similar to 'Golden Delicious' were 'Arlet', 'Cameo', 'Orin', 'Golden Supreme' and 'Suncrisp'. None of

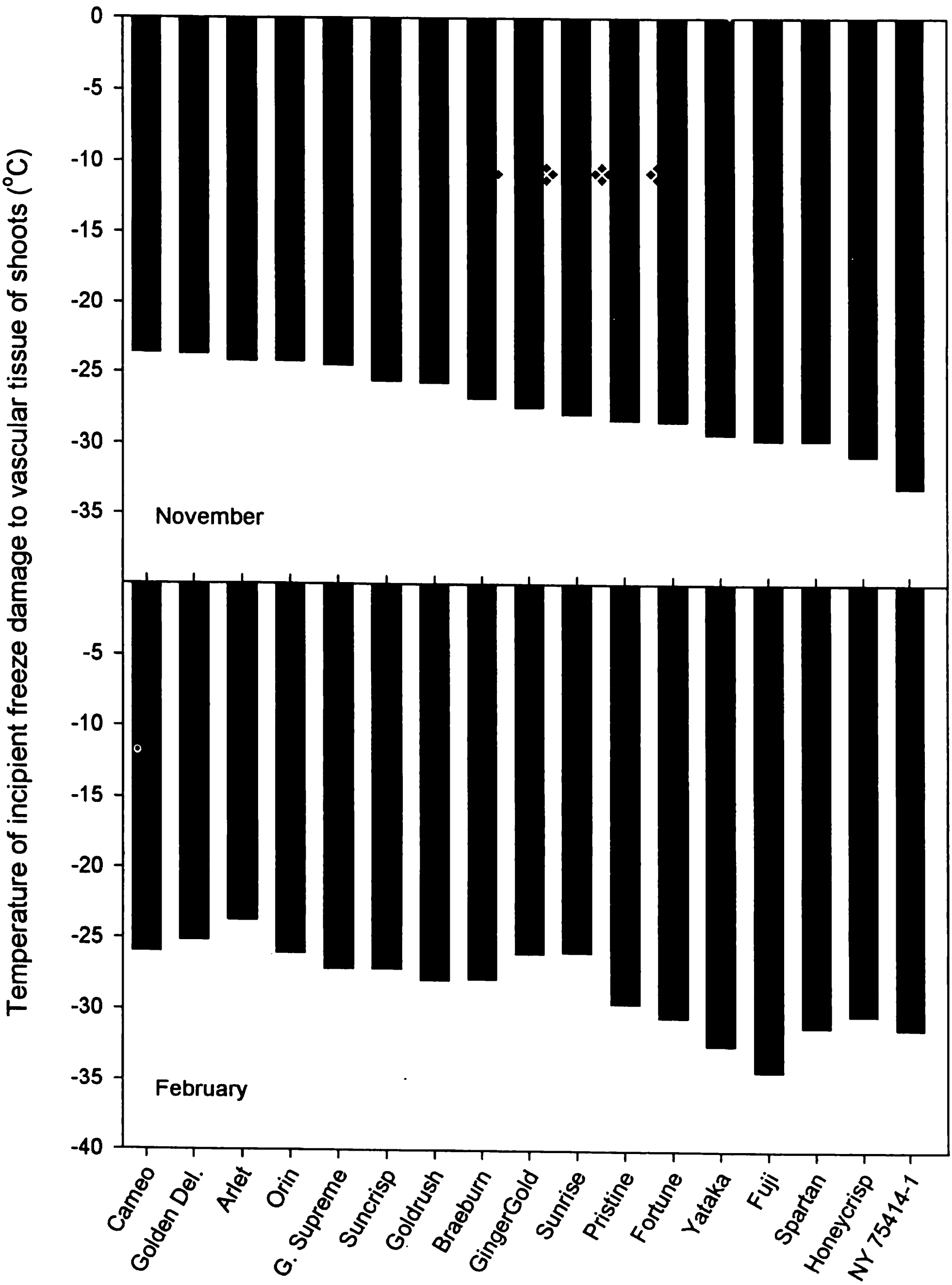

Figure 1. Three-year mean TID (c)of seventeen different apple cultivars in early and late winter.

the cultivars was less hardy than 'Golden Delicious.' Cultivars as hardy as 'Spartan' were 'Pristine', 'Fortune', 'Honeycrisp', 'Yataka', 'Fuji' and NY 75414-1. 'Ginger Gold', 'GoldRush', 'Sunrise' and 'Braeburn' were hardier than 'Golden Delicious' but not as hardy as 'Spartan'. 'Yataka' is a sport of 'Fuji' and was not significantly different from 'Fuji' in hardiness.

Previous tests of these cultivars are few but do support our findings. After a harsh winter, Warner and Nickerson (23) saw no injury on NY 75414-1. 'Honeycrisp' is reputed to be very hardy (18), and it was among the hardiest cultivars in our test. Chilton et al. (4) used protocols similar to ours and tested a few of the same cultivars. Their TIDs were lower than ours in absolute value, but in both cases 'Golden Delicious' was significantly more tender than 'Spartan', 'Sunrise' was intermediate between 'Spartan' and 'Golden Delicious', and 'Fuji' was as hardy as 'Spartan'.

Chilton et al. (4) found that 'Braeburn' and 'Spartan' did not differ significantly in TID, whereas we found 'Braeburn' to be slightly less hardy overall. This may have been related to the weak growth ("runting out") of the 'Braeburn' trees in the NE-183 trial at our site. Low carbohydrate reserves can reduce the level of hardening that trees attain (19). However on two of the six sample dates (November of year 1 and February of year 2), the TIDs for 'Spartan' and 'Braeburn' were similar. High crop loads have been implicated in reducing winter hardiness in some studies (2, 16, 24), but the crop load on our 'Braeburn' trees was moderate to low. On the other hand, 'Braeburn' has rated similar to 'Golden Delicious' or between 'Golden Delicious' and 'Spartan' in previous tests (Quamme, unpublished data). More work is needed to characterize the hardiness of 'Braeburn' with greater confidence. Lapins (12) found that some cultivars were simply inconsistent, both in artificial freeze tests and in their response to natural freezes.

These tests were conducted when the trees are at the greatest risk of winter injury in our region. Weather conditions at this time were likely not cold enough to induce maximal hardiness in the trees. Sakai and Larcher (19) note that full expression of hardiness may require a month or more of temperatures below -10°C. Also, early winter hardiness is usually greater than in autumn or mid- to late winter. For example, Chilton et al. (4) found the TID of 'Golden Delicious' to be about 7°C lower in December than in November.

Trees probably recover completely from an injury at the TID. The temperature of 50% damage, or LD_{50}, is reported in many studies instead of TID. Trees reportedly can recover from 50% blackheart injury (16), but growth retardation and reduced productivity are likely. We interpolated score=2.5 from some of our survival curves using 'Arlet' (tender), 'Pristine' (moderately hardy) and 'Fuji' (hardy). The values were well-correlated with TID ($R=0.94$, $n=61$, $p < 0.001$). We chose to analyze TID values for several reasons. (1) TID has a clear physiological significance. It is the warmest temperature at which tissue begins to show injury. (2) A rating of 1 represents a small area of browning and is easier to scale than higher ratings involving larger areas and different intensities of browning. (3) TID could be interpolated from all the survival curves whereas higher scores required extrapolation in many cases.

To see if the TIDs for one-year-old wood were correlated with those of the scaffolds and trunks, samples of the latter two organs were frozen in the final year. The correlations were positive and mostly statistically significant, but not very high (Table 2). The TID of trunks and one-year-old wood was not significantly related, an unfortunate finding because trunk assessments require sacrificing many trees. To clarify the low overall correlations, we present the mean TID for shoots, scaffolds and trunks in year three (Table 3). We re-analyzed the shoot TIDs for Table 3, using only the data from the trees that were also used for scaffold and trunk measurements. Trunks were usually less hardy than one-year-old wood. Scaffolds tended to be intermediate, at least in late winter.

If one looks at relative standings, the conclusions about the hardiness of new cultivars relative to 'Spartan' would be the same regardless of the tissue tested for the November sampling date, except for 'Sunrise,' 'GoldRush' and NY 75414-1 (Table

Table 2. Pearson correlation coefficients showing the relation among the temperatures of incipient damage (TID, in °C) to vascular tissue in different tree parts during the final year of the study.

	Scaffold		Trunk
	November	February	February
One-year-old wood	R=0.54 p=0.0019 n=31	R=0.44 p=0.0158 n=29	R=0.24 p=0.2877 n=29
Scaffold	–	–	R=0.63 p=0.0001 n=31

Table 3. Temperature of incipient damage (TID, in °C) to the vascular tissue of nine cultivars of apple in year three for one-year old shoots, scaffolds and trunks at different sampling times.

	November			February			
Cultivar	Shoot[a]	Scaffold[a]	n[b]	Shoot[a]	Scaffold[a]	Trunk[a]	n[b]
Arlet	-22.2 a	-24.2 bc	4	-24.8 ab	-23.0 a	-23.3 ab	4
Golden Del.	-23.0 a	-20.9 a	4	-26.5 ab	-24.3 ab	-22.8 a	4
GoldRush	-27.0 b	-22.5 ab	3	-27.3 bc	-25.1 bc	-21.2 a	3
Sunrise	-27.9 b	-22.1 ab	4	-23.7 a	-24.6 abc	-21.7 a	4
Spartan	-28.1 b	-27.5 d	4	-30.2 cd	-28.7 d	-26.6 c	4
Fortune	-28.9 bc	-27.9 d	3	-30.2 cd	-28.9 d	-21.2 a	2
Fuji, BC #2	-29.0 bc	-26.1 cd	3	-33.2 d	-25.7 bc	-21.2 a	3
Honeycrisp	-30.4 bc	-27.9 d	3	-31.3 d	-28.9 d	-25.9 bc	3
NY 75414-1	-34.2 d	-26.4 cd	2	-30.7 cd	-26.8 cd	-24.0 abc	2

[a] Means within a column followed by the same letter are not significantly different (LSD, p = 0.05)
[b] Number of trees tested

3). The first two of these had shoots as hardy as 'Spartan' but scaffolds no hardier than 'Golden Delicious.' NY 75414-1 shoots were hardier than 'Spartan' but the scaffold hardiness was similar. In late winter, the hardiness of 'Arlet', 'Sunrise', and 'GoldRush' was similar to 'Golden Delicious', and 'Honeycrisp' and NY 75414-1 were about as hardy as 'Spartan' regardless of the tissue used for tests. For 'Fortune' and 'Fuji', scaffolds and especially trunks seemed to be more sensitive than shoots in late winter, but in early winter both scaffolds and shoots were as hardy as those of 'Spartan'. 'Fortune' and 'Fuji' may therefore be less hardy than they appeared from the shoot samples.

In another study with 'Royal Gala' and 'Summerland Red McIntosh', the hardiness of the trunk was closely related to hardiness of the other tissues (Table 4). 'McIntosh' was hardier than 'Gala' in accordance with previous findings (4). The correlations of TIDs among five different parts of the tree were high (R > 0.90 in all cases). In the absence of test winters, we can only state that hardiness determinations based on one-year-old wood may not be accurate for all cultivars. It would be interesting to know if the early winter hardiness of 'Fuji' and 'Fortune' trunks is also low. Since trunks are widely believed to be the most freeze-sensitive tissue, this question is an important one to answer. A large population of mature trees would need to be sacrificed for such a test. An alternative would be to develop a test based on excising bark and xylem samples from the tree trunk, using samples small enough not to harm the tree.

Table 4. Temperature of incipient damage (TID, in °C) to the vascular tissue of 'Royal Gala' and 'Summerland Red McIntosh' apple for one-year old shoots, scaffolds and trunks, and correlations between the tissue and trunk TID.

Tissue type	TID for McIntosh[z]	TID for Royal Gala[z]	Correlation to Trunk TID[y]
Lower 1-year shoot	-33.5	-24.7	0.97
Upper 1-year shoot	-31.9	-25.2	0.92
Lower scaffold	-29.1	-24.4	0.94
Upper scaffold	-30.5	-22.0	0.98
Trunk	-28.6	-23.2	1.00

[z] n=4
[y] n=8; all values are significant at $p<0.001$

Literature Cited

1. British Columbia Ministry of Agriculture, Fisheries and Food.1996. Tree fruit production guide for interior districts for commercial growers. Government of British Columbia, Victoria, BC, Canada.
2. Brown, D.M. and W.J. Blackburn. 1987. Impacts of freezing temperatures on crop production in Canada. Can. J. Plant Sci. 67: 1167-1180.
3. Caprio, J.M. and H.A. Quamme. 1999. Weather conditions associated with apple production in the Okanagan Valley of British Columbia. Can. J. Plant Sci. 79: 129-137.
4. Chilton, R., H.A. Quamme and R. Brownlee. 1994. Winter hardiness evaluation project 1993-1994. Okanagan Valley Tree Fruit Authority Report, Summerland, BC, Canada. 10 pp.
5. Coleman, W.K. 1985. Variations in cold resistance among apple cultivars during deacclimation. J. Exp. Bot. 36: 1159-1171.
6. Coleman, W.K. and E.N. Estabrooks. 1985. Chemical modification of cold hardiness in apple trees. Can. J. Plant Sci. 65: 969-975.
7. Emmert, F.H. and F.S. Howlett. 1953. Electrolytic determinations of the resistance of fifty-five apple varieties to low temperatures. Proc. Amer. Soc. Hort. Sci. 62: 311-318.
8. Hong, S.-G. and E. Sucoff. 1982. Temperature effects on acclimation and deacclimation of supercooling in apple xylem. Pp. 341-356. In: P.H. Li and A. Sakai (eds). Plant cold hardiness and freezing stress, Vol. 2. Academic Press, New York. 694 pp.
9. Howell, G.S. and C.J. Weiser. 1970. The environmental control of cold acclimation in apple. Plant Physiol. 45: 390-394.
10. Kelley, V.W. and R.L. McMunn. 1942. November, 1940, cold damage to fruit plants in Illinois. Proc. Amer. Soc. Hort. Sci. 40: 220-224.
11. Ketchie, D.O. 1985. Cold resistance of apple trees through the year and its relationship to the physiological stages. Acta Hort. 168: 131-137.
12. Lapins, K. 1961. Artificial freezing of 1-year-old shoots of apple varieties. Can. J. Plant Sci. 41: 381-393.

13. Lapins, K. 1962. Artificial freezing as a routine test of cold hardiness of young apple seedlings. Proc. Amer. Soc. Hort. Sci. 81: 26-34.
14. Lindén, L., P. Palonen and M. Seppänen. 1999. Cold hardiness research on agricultural and horticultural crops in Finland. Agricultural and Food Science in Finland 8: 459-477.
15. Maney, T. J. 1942. Fruit tree injury resulting from the Midwest blizzard of November 1940. Proc. Amer. Soc. Hort. Sci. 40: 215-219.
16. Palonen, P. and D. Buszard. 1997. Current state of cold hardiness research on fruit crops. Can. J. Plant Sci. 77: 399-420.
17. Quamme, H.A. 1976. Relationship of the low temperature exotherm to apple and pear production in North America. Can. J. Plant Sci. 56: 493-500.
18. Regents of the University of Minnesota. 2001. 'Honeycrisp'. Plant Var. J. 14: 39-40.
19. Sakai, A. and W. Larcher. 1987. Frost survival of plants. Springer-Verlag, Berlin. 321 pp.
20. Stergio, B.G. and G.S. Howell, Jr. 1973. Evaluation of viability tests for cold stressed plants. J. Amer. Soc. Hort. Sci. 98: 325-330.
21. Strang, J.G. and C. Stushnoff. 1975. A classification of hardy North American apple cultivars based on hardiness zones. Fruit Var. J. 29: 78-108.
22. Warner, J. 1982. Winter injury to apple trees, 1980-1981. Fruit Var. J. 36: 99-103.
23. Warner, J. and C. Nickerson. 1996. Winter injury to apple trees, 1993-1994. Fruit Var. J. 50: 114-118.
24. Way, R.D. 1954. The effect of some cultural practices and of size of crop on the subsequent winter hardiness of apple trees. Proc. Amer. Soc. Hort. Sci. 63: 163-166.
25. Wisniewski, M. and R. Arora. 1993. Adaptation and response of fruit trees to freezing temperatures. Pp. 299-320. In: A.R. Biggs (ed). Handbook of cytology, histology and histochemistry of fruit tree diseases. CRC Press, Boca Raton, Florida. 330 pp.
26. Witney, G. 1996. Tree condition and cold tolerance. Good Fruit Grower 47(12): 24-26.