AN ABSTRACT OF THE THESIS OF

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Anthesis of both staminate and pistillate flowers of *Corylus* occurs in midwinter. To insure adequate pollination and nut set, these flowers must attain a sufficient hardiness level to withstand low temperatures. This study estimated cold hardiness of *Corylus* cultivars and species using laboratory freezing of shoots without artificial hardening. In December, January and February of 1991-92 and 1992-93, one-year stems were collected and frozen at regular intervals from -10°C to -38°C, and visual browning assessed survival approximately 10 days after freezing. Elongated catkins were clipped prior to freezing. Percent flower bud survival was calculated and plotted against temperature. Linear regression generated an equation relating percent bud survival to temperature. From this equation, estimates of the LT_{50} (lethal temperature for 50% of the buds) was calculated for catkins, female inflorescences, and vegetative buds.

C. avellana L. catkins, on average, were less hardy in both December and January than female inflorescences and vegetative buds. Maximum hardiness was reached in December and nearly all had elongated prior to the February freeze. Cultivars with the most hardy catkins were 'Morell', 'Brixnut', 'Creswell', 'Gem', 'Giresun OSU 54.080', 'Hall's Giant', 'Riccia di Talanico', 'Montebello' and 'Rode Zeller'.

Maximum hardiness was observed for both vegetative and pistillate buds in January and was followed by a marked loss of hardiness in February. Vegetative buds were at least 4°C hardier than pistillate buds in all six freezes. 'Cosford', 'Hall's Giant', 'Negret', 'Gem' and 'Cutleaf' had the lowest winter LT_{50} for pistillate buds, ranging from -30.0°C to -38°C.

Visual browning was shown to be an effective method of cold hardiness evaluation for hazelnut flower buds. Electrical conductivity tests are not recommended for assessing cold hardiness of wood tissue in hazelnut.

The Evaluation of Cold Hardiness in Corylus

by

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Annie M. Chozinski, Author

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LITERATURE REVIEW

Origin, Taxonomy and Distribution of *Corylus*

Corylus belongs to the Birch family, Betulaceae, of the order Fagales. They are deciduous trees and shrubs widely distributed throughout temperate regions of the northern hemisphere (Drumke, 1964). The nine most widely recognized taxa include the five shrub species, *C. avellana* L., *C. americana* Marsh., *C. cornuta* Marsh., *C. heterophylla* Fisch., and *C. sieboldiana* Bl.; and the 4 tree species, *C. colurna* L., *C. jacquemontii* Decne., *C. chinensis* Franch., and *C. ferox* Wall. (Thompson et al., in press). Many other taxa have been described which further complicates the literature (Kasapligil, 1972).

Wild species of *Corylus* are distributed throughout the temperate zones of the northern hemisphere, from Japan, China and Manchuria through Tibet, Caucasia, Turkey, Europe and North America (Ayfer et al., 1986). According to Vavilov (1951), one of the richest centers of diversity of the hazelnut is the Near-East covering Antolia and Transcaucasia. Hazelnuts are not native to the southern hemisphere and native fossil forms show no evidence of them in the past (Kasapligil, 1972). In the northern hemisphere, *Corylus* has a wide range of adaptation, from very cold to moderate climates. The cultivars grow in humid, mild climates where temperatures are moderated by large bodies of water (Lagerstedt, 1975).

Corylus avellana L., the European hazel, was one of the first trees to migrate north after the glaciers receded in 17,000 - 18,000 B.C. (Lagerstedt, 1975). The geographic range of *C. avellana* includes Europe, North Africa and West Asia (Bailey, 1976). This species is very polymorphic. Most European types of *C. avellana* are medium size shrub types that have open husks which allow the nuts to fall free at maturity (Slate, 1963).

Corylus avellana is the species of commerce. The important commercial cultivars in Europe and Turkey are landrace selections. These high quality cultivars form the base of all modern breeding programs. Nuts of *C. avellana* have superior kernel quality and larger size and are used in breeding programs either exclusively or in combination with other species (Mehlenbacher, 1991b).

C. americana Marsh., the American hazel, is distributed in eastern North America from Maine to Florida and westward to the Mississippi River (Slate, 1963). This small to medium-small shrub suckers freely (Drumke, 1964) and has husks longer than the nut which prevent them from falling free at maturity. In hazelnut breeding programs *C. americana* contributes genes for cold hardiness, high productivity, good quality nuts, and resistance or tolerance to eastern filbert blight, *Anisogramma anomala* (Peck) E. Müller (Mehlenbacher, 1991b).

C. cornuta Marsh., the beaked hazel, shares much of the range of *C. americana* and continues further north into Newfoundland and westward to British Columbia (Drumke, 1964). *C. cornuta* husks are covered with bristly hairs and their long husks are tightly constricted above small persistent hard-to-harvest nuts (Slate, 1963). Despite the husk characteristics *C. cornuta* is a good parent for breeding purposes due to its extreme cold-hardiness (to at least -50°C), its putative resistance to eastern filbert blight (Gottwald & Cameron, 1980), and for very early nut maturity (Drumke, 1964).

Corylus cornuta var. *californica* has a smaller range of distribution than *C. cornuta* var. *cornuta*. It is found along the western coast of North America from southern British Columbia to northern California (Drumke, 1964). Compared to *cornuta*, this variety has a more desirable growth habit and shorter, less constricted husks making it more suitable for breeding (Thompson et al., in press).

Corylus heterophylla Fisch., the Siberian hazelnut, is a wide ranging polymorphic Asian species which ranges from Japan to West China (Liang & Zhang, 1990). It is exceptionally precocious, productive, and has early maturing nuts (Mehlenbacher, 1991b). This species is very cold hardy in its northern range being able to withstand temperatures as low as -48°C (Liang & Zhang, 1990).

Corylus colurna L., the Turkish tree hazel, grows throughout mixed temperate forests in Romania, the Balkans, northern Turkey, Transcaucasia, and northern Iran (Komarov, 1936; Kasapligil, 1972). For breeding purposes, this species offers a non-suckering habit, (Lagerstedt, 1980) drought-tolerance, and cold hardiness. The trees lack precocity, have small nut size, thick shells, and nuts are difficult to separate from husks (Thompson et al., in press). These traits make *C. colurna* a poor commercial cultivar or parent for breeding. J.U. Gellatly (1956, 1966) of Westbank, British Columbia, produced many interesting selections, mostly of interspecific origin. Gellatly's crosses combined the hardiness and growth habit of the tree hazel with the nut size of the European hazel. Many of his selections are still being grown and evaluated. Most 'trazels,' as these *C. colurna* X *C. avellana* hybrids are called, have a tree-like growth habit, good winter hardiness (Gellatly, 1956), and long nuts with thick shells.

Corylus Flowering

Floral biology, although extremely unusual compared to other orchard crops, is similar within *Corylus*. Hazelnuts are monoecious, wind pollinated, self-incompatible, bloom in mid-winter, and usually dichogamous and protandrous. The staminate flowers are borne in catkins at nodes on one-year wood (Thompson et al., in press). Female flower clusters are indistinguishable externally from vegetative buds until the start of anthesis in December or January. At bud break they are relatively inconspicuous and consist of bright red stigmas, 4-16 flowers per cluster (Thompson, 1979) extruding from the tip of a compound bud (Mehlenbacher, 1991b). Each flower consists of a pair of filamentous, stigmatic styles joined at their base by meristematic tissue which later differentiates into an ovary. Time of anthesis for both staminate and pistillate flowers ranges from mid-December to mid-March. At female anthesis, several stigmatic styles emerge at the apex of the bud, first appearing as a small red dot. As they continue to elongate and reflex, they resemble a red tuft. If the exposed parts of stigmatic styles are damaged by frost, the lower parts, protected by the enclosing bud scales, subsequently emerge as functional tissues (Thompson et al., in press).

Cold Hardiness

Cold hardiness is a very complex phenomenon which depends upon the genotype, particular plant part, and the amount of acclimation or deacclimation that has occurred (Quamme & Stushnoff, 1983). The first stage in development of cold hardiness is reached at growth cessation as a reaction to prolonged nights in trees of the temperate zone (Wareing, 1956; Vaartaja, 1959; Weiser, 1970; Hänninen et al., 1990). After growth cessation, low temperature is mainly responsible for the development of cold hardiness (Weiser, 1970; Levitt, 1980). The rate of cold acclimation is as important as midwinter hardiness for survival or successful performance in certain regions. Ideally, plant hardiness increases steadily until the mid-winter maximum is attained and then a gradual decrease occurs with the advent of spring (Lindstrom & Dirr, 1989).

Freezing Stress Survival Mechanisms

Freezing stress resistance is the ability of the plant to maintain its functions during dormancy and survive freezing temperatures. For plants exposed to freezing stress, two survival mechanisms have been distinguished, namely tolerance of extracellular ice and avoidance of extracellular or intracellular ice (Palta & Simon, 1993). Different tissues within a plant may survive by different mechanisms (Levitt, 1980; Sakai & Larcher, 1987). Overwintering buds (vegetative and flowering) have been shown to survive by supercooling or avoidance mechanisms, even though the bud scales are known to contain ice in their extracellular space (Burke et al., 1976).

Most temperate plant species develop cold hardiness when exposed to progressively lower temperatures (Guy, 1990), but the ability to survive winter cold is dependent on the rate of hardening and the ultimate level and stability of hardiness. Deacclimation can occur with exposure to warm temperature. Plants have the ability to increase both freezing tolerance and avoidance by acclimation (Palta & Simon, 1993).

Tolerance Mechanisms

In nature the air temperature rarely drops more than a few degrees per hour. At such slow rates of freezing, ice forms first outside of the cell protoplasts where the water is purest (Weiser, 1970). Bark tissue of overwintering deciduous species shows this type of tolerance mechanism (Palta & Weiss, 1993). The survival of bark tissue depends on the capability of the cell to tolerate the numerous stresses that accompany extracellular ice formation without incurring intracellular damage.

In buds, freezing is initiated within the bud scales and the tissues subtending the developing floral organs (George et al., 1974; Quamme, 1978; Sakai, 1979; Ashworth, 1982). Formation of ice crystals within the bud axis and scales results in the formation of a water potential gradient within the bud tissues. Water is drawn from the developing floral organs and pedicel region to the growing ice crystals within the bud axis and scales (Ashworth & Wisniewski, 1991). The segregation of ice crystals into discrete regions appears to be critical for bud survival. Sakai (1979) termed this pattern "extraorgan freezing."

Avoidance Mechanisms

With the exception of those crops sensitive to chilling injury, ice formation is a prerequisite for injury, and avoidance of crystallization means avoidance of injury (Levitt, 1980). Wood of the many overwintering deciduous species survives by supercooling (Palta & Weiss, 1993). A supercooled solution is completely liquid (contains no ice) at temperatures below the thermodynamically defined equilibrium freezing (melting) point (Glasstone, 1946). This ability to supercool is particularly crucial in tissues which lack tolerance to ice formation. In these tissues, the point at which ice formation is initiated marks the lethal temperature (Burke et al., 1976). Acclimation in xylem parenchyma cells involves lowering the nucleation temperature of the intracellular solution (Ashworth & Wisniewski, 1991).

Previous work on woody plants shows that deep supercooling in xylem tissue reaches a lower limit of -40°C (George et al., 1977). Visual injury determinations and electrolyte loss measurements on stem tissue also revealed irreversible damage near -40°C associated with the freezing of the deep supercooled water (Becwar et al., 1981).

Procedures for Evaluating Cold Hardiness

A suitable method of measuring viability following exposure to a freezing stress is central to the study of plant cold hardiness. No single viability test will work for all plant material or under all experimental conditions. Although time-consuming and qualitative in nature, tissue browning and survival ratings are still used as controls for quantitative measurements due to their reliability (Calkins & Swanson, 1990). Stergios and Howell (1973) suggested that any quantitative viability test be coupled with a more reliable qualitative test such as tissue browning or regrowth.

Macroscopic or microscopic examination of tissues or intact plants after thawing may reveal symptoms of freezing injury. For example, the lack of protoplasmic streaming or cell division may indicate injury or death. Macroscopically, the development of a soft, water-soaked appearance, tissue discoloration, loss of regrowth capacity, and attack by saprophytic fungi can serve as indicators of freezing damage (Calkins & Swanson, 1990). Field trials are often inconclusive due either to complete kill or complete survival and cannot account for variability over locations. Furthermore, high variability in stress level often makes identification of small important differences among genotypes difficult (Palta & Simon, 1993).

The following summary of techniques for measuring cell death lists advantages and disadvantages that influenced the choice of methods for this study.

Plasmolysis/deplasmolysis. Mechanical disorganization, dehydration and concentration of the protoplasm are characteristics used to indicate cell viability (Palta & Li, 1978). Hardiness of pieces of plant tissue, such as a shoot, cannot be described based on the microscopic determination of the relative viability of certain tissues within the shoot. The degree of hardiness of one tissue is not representative of the shoot as a whole (Calkins & Swanson, 1990; Luza et al., 1992).

Vital staining. The difference in vital stain permeability to living and nonliving cells can be used in viability testing. These stains penetrate living cells more deeply than nonliving cells (Aronsson & Eliasson, 1970). Some examples of vital stains include neutral red, indigo carmine, iodine-potassium iodide, and acridine orange. The dyes themselves may have toxic effects to the tissue unless precautions are taken. Another group of substances that fluoresce under ultraviolet light can be used in vital staining techniques. These substances include eosin, aesculin, fluorescein diacetate, uranin, and acridine orange. Interpretation of fluorescent dyes is complicated by the presence of endogenous, fluorescent substances such as chlorophyll a, chlorophyll b, and riboflavin (Calkins & Swanson, 1990).

Chlorophyll fluorescence and cellular fluorescence. Chlorophyll is a naturally occurring fluorescent substance that can characterize stress-induced injury (Smillie & Hetherington, 1983). Many plant tissues of critical interest in cold hardiness research such as stems or roots lack chlorophyll and, thus, are not adapted to study using chlorophyll fluorescence techniques (Lindgren & Hallgren, 1993).

Electrical conductivity. The measurement of ion leakage following a simulated freeze-thaw stress appears to be a rapid and reliable screening technique for freezing tolerance (Palta & Simon, 1993). Advantages of this method include the rapidity with which the estimation of injury can be accomplished, the convenience of the precise numerical values obtained, and the small amounts of tissue required for each determination (Calkins & Swanson, 1990). For laboratory screening methods, the magnitude and types of stresses must be created in such a way as to simulate as closely as possible the natural conditions (Palta & Simon, 1993). However, viability studies based on electrolyte leakage often show a range of increasing injury rather than a distinct killing point (Calkins & Swanson, 1990).

Hydrogen cyanide release. In cells damaged by freezing stress, cyanogenic substrates are hydrolyzed causing the release of hydrogen cyanide gas (Stout, 1983). The gas can be collected as NaCN in a solution of NaOH, then quantified with a colorimeter. This technique is only applicable to cyanogenic plant materials and sampling injury can also cause the release of HCN.

Electrical conductance/impedance. Hardiness is evaluated by measuring the electrical impedance or resistance of tissue. It offers an advantage in that sacrifice of the plant is avoided, but the difficulty is that the level of discrimination is low and this level varies with season. This method also lacks a solid theoretical basis (Quamme, 1973).

Ninhydrin. In addition to leakage of ions, damage to the plasmalemma can result in leakage of readily diffusible organic compounds such as amino acids and sugars (Siminovitch et al., 1964). The amino acids are measured by reacting the leachate with ninhydrin reagent and measuring the color reaction on a spectrophotometer. This method is very time-consuming.

Enzyme activity. Metabolic activity can be measured by studying enzyme activity and thus can serve as a measurement of viability. A dehydrogenase-reduced salt, 2,3,5-triphenyltetrazolium chloride (TZ) has been used extensively in the study of woody plant cold hardiness. It has been useful in the measurement of viability in plant tissue cultures (Towill & Mazur, 1975). However, TZ can be reduced by sugars, glutathione, ascorbic acid and cysteine in addition to the enzyme system in living cells making this, too, a questionable means of measuring viability (Parker, 1952).

Differential Thermal Analysis (DTA). DTA detects the freezing event that causes injury. In certain plant parts an exotherm is seen on the time-temperature profile during freezing. This exotherm is produced by the freezing of supercooled or bound water present at low temperatures in these tissues. The advantage of this method is that the exact killing temperature can be determined. This method is not adaptable to large scale use (Quamme, 1973). Burke et al. (1976) reported that some plants do not exhibit deep supercooling. These include tender evergreens, such as citrus, but also include plants capable of hardening to extremely low temperatures, such as willows, alder and birch (hazelnut, alder and birch belong to the family Betulaceae). For nut crops, deep supercooling has been reported in pecan tissues (Rajashekar & Reid, 1989) but hazelnuts have not been shown to supercool.

Gas exchange (respiration rate). Respiration is a fundamental process in living cells, and can be monitored by metabolic activity level and viability (Siminovitch et al., 1964). However, since respiration is such a dynamic process and is influenced by both physiological and environmental factors, it is hard to standardize the conditions which would accurately measure the effects of freezing alone on the cells (Calkins & Swanson, 1990).

Low Temperature Injury of *Corylus*

Previous studies show that the degree of cold hardiness varies with the plant tissues, with catkins being the most sensitive to cold temperatures, especially if they have begun to extend for pollen shedding. Wood is next in sensitivity and vegetative buds and pistillate flower buds are the hardiest (Hummer et al., 1986, Slate, 1933). Female flower bud hardiness is correlated with late flowering (Koval, 1973b).

Hazelnut trees whose wood is severely injured by low temperatures may proceed to leaf out but exhibit weak growth. In the summer this damage is finally evident as yellowing and sometimes death of leaves. After the freeze of 1972 in Oregon, many 'Barcelona' trees of bearing age, especially older trees, died slowly showing progressive necrosis throughout the summer (Stebbins, 1974).

Although pistillate flowers are exceptionally hardy in mid-winter, these reproductive tissues are particularly vulnerable after the shoots begin to grow at budbreak. As the very young nut cluster is located at the apex of developing shoots, the potential crop can also be lost if shoots are killed by spring frost (Thompson et al., in press). Once the vegetative buds had opened in spring, Tombesi and Cartechini (1975) reported total bud damage at -4°C to 'Tonda Romana' and 'Tonda di Giffoni'. Just prior to leaf expansion, total bud damage was observed from -6°C to -12°C, depending on the cultivar.

Previous Hardiness Estimates

Within the genus, commercial cultivars which are of high quality are often the least hardy due to their origin in milder, southern climates (Thompson et al., in press). Within *C. avellana*, very hardy wild hazels are widely distributed in northern Europe. Other species whose natural distribution includes severely cold regions where temperatures may reach -50°C or lower are *C. cornuta*, *C. americana*, *C. heterophylla* and *C. sieboldiana*. Zukovskij (1962) reports *C. heterophylla* as very cold hardy surviving winter temperatures of -104°C. Cold hardiness has also been reported for the tree hazels (Gellatly, 1956).

Many countries have attempted to hybridize native cold-hardy species and selections with higher quality nuts of southern origin. In the Republic of Korea, cold hardiness, precocity and productivity of the native species (*C. heterophylla* and *C. sieboldiana*) being incorporated into *avellana* cultivars with larger tree and nut size, and thinner shells (Kim, 1985). China is also crossing the cold-hardy native *C. heterophylla* with *C. avellana* (Liang & Zhang, 1990). In Canada, *C. cornuta* X *C. avellana* crosses produce cold-hardy plants with large nuts. The seedlings of these crosses were named 'filazels' (Gellatly, 1956).

Most information on cold hardiness of cultivars comes from field observations following severe winters (Mehlenbacher, 1991b). 'Butler', 'Cosford', 'Early Long Zeller', 'Empress Eugenie', 'Italian Red', 'Hall's Giant', 'Kadetten', and 'Medium Long' have the best field survival (Slate, 1947; Johansson, 1951; Koval, 1973a; Lagerstedt, 1978;

Galchenko, 1980). Slate (1963) found that among 120 *avellana* cultivars studied, those of German origin ('Neue Riesen', 'Luisen', 'Lange Landsberger', and 'Kadetten') were the hardiest under field conditions. 'Red Lambert' was reported to have the hardiest catkins of any *avellana* tried in Geneva, New York (Slate, 1947). In New York, the cold winters severely damage *C. avellana* catkins whereas the northern *C. americana* forms are very winter hardy (Slate, 1947).

Hummer et al. (1986) used laboratory freezing tests to evaluate *Corylus* hardiness and separated cultivars into three temporal acclimation groups. Those that acclimated and hardened early in the season with moderate lethal temperatures included 'Butler', 'Tombul', 'Barcelona', 'Ennis', 'Casina' and 'Tonda Gentile delle Lange.' In mid-winter 'Montebello', 'Negret', and 'Tonda Romana' acclimated. 'Daviana' and 'Hall's Giant' were the last to acclimate. In general, 'Hall's Giant' and 'Casina' exhibited the most hardiness.

The artificial hardening regime applied prior to controlled freezes in the studies of Hummer et al. (1986) resulted in much lower lethal temperatures than those observed in field conditions or when freeze tests are run immediately after shoot collection from the field (Mehlenbacher, 1991b). This tendency to overestimate levels of hardiness has also been seen in differential thermal analysis studies of hardwoods (Ashworth, 1993). Hummer et al. (1986) found that, on the average, pistillate flowers at full anthesis were uninjured at -30°C in December and -40°C in January. In January the killing temperatures for artificially hardened female flower buds ranged from -28°C for 'Tombul' to -45°C for several clones including 'Hall's Giant', one clone of *C. heterophylla*, and *C. avellana* var. *aurea*. For unelongated artificially hardened catkins, the killing temperature range in January was -15°C for 'Tombul', 'Ennis', and 'Tonda Romana' to -35°C for 'Gasaway' and 'Hall's Giant'.

In January 1950, temperatures in Oregon dropped to -34.4°C resulting in severe catkin injury of 'Barcelona' and 'Daviana'. Considerable dieback occurred but trees recovered in the subsequent growing season (Painter, 1956). Damage to 'Barcelona' was reported by Lagerstedt (1973) after a sudden cold snap (-21°C to -24°C) in Corvallis, Oregon during December 1972. Prior temperatures in November did not afford adequate cold acclimation. Pistillate bud damage was variable. Each flower cluster has an average of 8 flowers (16 styles). Some flower clusters showed total style injury, while others showed little or none (Lagerstedt, 1973). Catkins from the pollinizer 'Daviana' that had already begun to elongate were severely damaged. This combination of damaged catkins and pistillate flowers can reduce nut set in freeze-damaged orchards as occurred in 1989 in Oregon to 'Barcelona' trees. Low vigor trees sustained more injury than vigorous trees.

Spring frost also presents a threat to hazelnut yields. Several cultivars were assessed for cold resistance in the field in Italy based on bud development (Tombesi & Cartechini, 1975). 'Tonda Romana' and 'Tonda di Giffoni' showed complete pistillate bud damage at -5°C after budbreak. When the trees had at least two or three leaves, damage was total at -4°C. Of twenty-four cultivars tested, 'Hall's Giant' and 'Mortarella' were among those most resistant to cold based on this classification (Tombesi & Cartechini, 1975).

When the pistillate flowers of hazelnut trees succumb to freezing injury, yield can be greatly reduced. Similarly, if the catkins are damaged during a winter freeze then pollination and yield are affected. Nut set is not the only concern in hazelnut production. A nonvigorous tree cannot support a heavy crop. Shoots from freeze-damaged vegetative buds exhibit weak growth and less vigor and may not be able to provide enough photosynthates for the developing nuts. Regardless of the bud type, cold hardiness is a critical characteristic to be considered when growing hazelnuts in temperate zones. Breeding for cold hardiness could help alleviate problems of inconsistent production and even expand the region of nut production in temperate zones.

This study investigates cold hardiness in hazelnut cultivars and species using laboratory freezing of shoots without artificial hardening.

MATERIALS AND METHODS

Plant Material

Shoots were collected from three species of *Corylus* (*C. cornuta* Marsh. var. *californica* Sharp, *C. heterophylla* Fisch., and *C. avellana* L.) and two interspecific hybrids (*C. colurna* L. X *C. avellana*, *C. americana* X *C. avellana*) (Tables 1 and 2) from two locations in Corvallis, Oregon: the Oregon State University (OSU) Horticulture Research Farm and the National Clonal Germplasm Repository (NCGR) which are 2.7 km apart. All trees were heavily pruned and fertilized and irrigated in early spring to encourage new growth. Elongated catkins were clipped prior to freezing.

Equipment

For the first year of freezing tests, a Revco Model ULT 1735 A-M-A freezer monitored by an Adtronics AD-085 micro computer based system was used. Electrolyte leakage was measured using a Corning pH meter 125.

The second year of freeze tests was performed in another laboratory using a Forma Scientific programmable freezer with a West 3750 controller which was monitored by a DAS 8 Data Acquisition and Interface Board. A Corning ion/analyzer 250 measured conductivity.

Sampling Procedure

Twenty-four one-year-old shoots were collected from each tree (with the exception of 55.129 and 'Extra Ghiaghli') on 15 December 1991, 12 January 1992 and 8 February 1992. The second year sampling dates were 6 December 1992, 3 January 1992 and 31 January 1993. Shoots were randomly collected from two small trees of 55.129 and three very small trees of 'Extra Ghiaghli' due to insufficient one-year old shoots from a single tree. Each shoot was approximately 28 cm long and whenever possible included both pistillate and staminate flowers. The shoots were randomly collected from all heights within the tree. During the early months of winter (December-early January), female flower clusters were not distinguishable externally from vegetative buds in some genotypes. However, by late January, all but *C. cornuta* var. *californica* had red stigmatic styles protruding from the tips of pistillate buds. Samples from each tree were placed in a polyethylene bag with a moistened paper towel and kept at ambient temperature until transported to the laboratory.

Table 1. List (1-24) of *Corylus* cultivars and selections used for freezing tests and their origin and location.

Code	Selection	Origin	Farm
1	'Barcelona-A'	Spain	NCGR 6-21
2	'Casina-A'	N. Spain	OSU V10
3	'Ennis-A'	Washington, USA	NCGR 6-17
4	'Ennis-B'		OSU EB 525
5	'Negret'	E. Spain	NCGR 5-01
6	'Tonda G.d. Langhe-A'	N. Italy	OSU AT 5-5
7	'Tonda G.d. Langhe-B'		OSU AT 5-6
8	'Cornuta Californica B0055'	Oregon, USA	OSU Y25
9	'Cornuta Californica B0072'		OSU Y20
10	'Chinese Trazel Gellatly #6' (CTG6)	Westbank, BC	NCGR 1-07
11	'Chinese Trazel Gellatly #4' (CTG4)		NCGR 1-25
12	'Chinese Trazel Gellatly #11' (CTG11)		NCGR 2-32
13	'Turkish Trazel Gellatly #5' (TTG5)		NCGR 2-23
14	'NY 110'	New York, USA	NCGR 6-29
15	'NY 200'		NCGR 6-31
16	'NY F-45'		NCGR 3-33
17	'Gasaway'	Washington, USA	NCGR 6-14
18	'Gem'	Oregon, USA	NCGR 7-09
19	'Giresun OSU 54.080'	Turkey	NCGR 3-19
20	'Morell'	E. Spain	NCGR 6-23
21	'Mortarella'	S. Italy	OSU W31
22	'Ribet-A'	E. Spain	NCGR 3-17
23	'Ribet-B'		OSU Y28
24	'Tombul Ghiaghli'	Turkey	NCGR 5-19

Trees used in this research were located at the OSU Horticulture Research Farm or the USDA National Clonal Germplasm Repository in Corvallis (NCGR).

Table 2. List (25-49) of *Corylus* cultivars and selections used for freezing tests and their origin and location.

Coda	Salaction	Origin	Farm
25	'Barcalona-B'	Spain	OSU AT 8-6
26	'Casina-B'	N. Spain	NCGR 5-05
27	'Hall's Giant-A'	Garmany	NCGR 6-15
28	'Hall's Giant-B'		OSU HBL
29	'Tonda di Giffoni'	S. Italy	NCGR 7-11
30	'Willamatte-A'	Oragon, USA	OSU AT 4-16
31	'Willamatte-B'		OSU AT 5-16
32	'Tonda Romana'	Italy	NCGR 6-5
33	'Cornuta Californica B0055'	Oragon, USA	OSU Y26
34	'Cutlaaf'	Europa	NCGR 3-13
35	'Kor 013' *C. heterophylla*	Koraa	OSU T26
36	'Kor 001' *C. heterophylla*		OSU T29
37	'Badam'	Turkey	OSU W20
38	'Brixnut'	Oragon, USA	NCGR 4-17
39	'Camponica'	S. Italy	NCGR 6-1
40	'Cosford'	England	NCGR 2-3
41	'Craswall'	Oragon, USA	NCGR 4-7
42	'Italian Rad-A'	Italy	NCGR 7-19
43	'Italian Rad-B'		OSU W30
44	'Montaballo'	Sicily, Italy	NCGR 7-7
45	'Riccia di Talanico'	S. Italy	NCGR 5-13
46	'Roda Zallar'	Garmany	OSU N23
47	'Sagorba'	Spain	NCGR 7-3
48	'Extra Ghiaghli'	Turkay	212.69,70,73
49*	'55.129'	Oragon, USA	OSU AT 2-6,7

*This genotype was tested only in the 1992-1993 winter months.

Trees used in this research were located at the OSU Horticulture Research Farm or the USDA National Clonal Germplasm Repository in Corvallis (NCGR).

Freezing Procedure

Individual shoots were scored for stage of female flower development and catkin elongation before freezing. A scale of 0-3 was used to rate the pistillate flowers. A zero rating was given to those buds that were externally indistinguishable from vegetative buds. A rating of one described a bud at the red dot stage and a rating of two described flowers whose stigmas protruded from the apex of the bud. A rating of three was given to those buds whose stigmas had fully recurved. Catkin elongation ratings were the percentage elongated at the time of sampling. Each shoot was labelled with colored tape that corresponded to the temperature treatments and genotype. Labelled shoots were then placed into separate polyethylene packets according to temperature treatment along with moist paper towels completely covering the samples within the bag and held overnight in a cooler at 4°C.

Two freezes on consecutive days were necessary to complete all phases of the experiment within the prescribed time limits. The first freeze consisted of genotypes listed in Table 1 and the second freeze used trees listed in Table 2.

In the first year, the temperature treatments were unfrozen control (4°C), -10°C, -15°C, -20°C, -25°C, -30°C, -35°C and -38°C. The lower limit of the freezer was actually -38°C. Therefore the planned lower limit of -40°C was never attained. The freezer was programmed to drop 5°C every hour. Copper-constantan thermocouples were inserted into the bags to monitor the temperature of the samples during freezing. Samples were removed from the freezer at the target temperature. Based on results from the first year which indicated that a five degree interval was too wide to detect the actual LT_{50}, temperature treatment intervals of 4°C were used. The temperature treatments were: unfrozen control (4°C), -14°C, -18°C, -22°C, -26°C, -30°C, -34°C and -38°C. Controls were placed in a 4°C cooler after preparation and all other samples were kept in the freezer at -5°C overnight to insure ice nucleation prior to the actual freezing regime the following morning.

Electrical Conductivity

After freezing, three one cm internodal sections were excised from the proximal end of the shoots and placed into 16 mm X 100 test tubes with 3 mls of ddH_2O, capped and placed on a mechanical shaker overnight at 5 rpms. The following day conductivity was measured for the samples that were shaken overnight. The samples were then autoclaved and placed back on the shaker overnight. Conductivity was measured on the autoclaved shoot sections the following day. Wood cold hardiness was expressed as ratio of the first conductivity measurement divided by the second measurement multiplied by 100. The remainder of the shoots were placed under mist in the greenhouse for one week and then assessed for visual browning.

Visual Evaluation

Catkins, female infloresences, vegetative buds and the cambial layer were evaluated individually for damage by visual inspection. Catkins and buds were cut vertically to determine whether the tissue was alive (green) or dead (brown). Catkins were considered dead if the rachis was brown or the pollen sacs were shrunken and brown. Female influoresences were rated alive if at least one stigma remained red. Vegetative buds were rated dead if the vascular tissue and/or the meristem were brown. A razor blade sliced beneath the bark to view the cambial tissue which did not show a clear demarcation between green and brown tissue. The following scoring system was used: 1 = natural color (no injury); 2 = slight browning; and 3 = intense browning.

Chilling Satisfaction

During the second winter, one shoot from each selection was taken to the greenhouse and set into a container of water on each sampling date. Shoots were rated weekly for bud development. For female flowers, if at least 50% of the buds on a shoot either advanced beyond the red dot stage or moved from red dot to fully recurved then chilling was considered satisfied by that sampling date. If at least 50% of the catkins elongated by the end of 3 weeks in December, and 4 weeks in January, in the greenhouse then they were considered to have met their chilling requirement. For vegetative buds, when at least 50% of the buds on a shoot showed swelling then chilling was considered to be satisfied. During the month of December, shoots were left in the greenhouse for observation for three weeks. During the months of January and February shoots were rated for bud development for four weeks.

Data Analyses

The percentage of dead buds was calculated for each shoot at each temperature on each date. In some cases the shoots dried out or were infected with fungus while under mist in the greenhouse. The death of these shoots could not be attributed solely to freezing temperatures and therefore they were eliminated from the analyses. Shoots were sampled from the field when the pistillate buds were indistinguishable from vegetative buds and consequently some shoots had no female buds. In these cases, no percentage of death could be reported. The average percent dead was calculated from three shoots (percentage$_1$ + percentage$_2$ + percentage$_3$ divided by three) to represent an overall percent dead at each temperature. In many cases shoots scored a zero percent dead at -5°C, -10°C and -15°C. In addition, at the coldest temperatures (-30°C, -35°C and -38°C) several shoots exhibited total death of buds resulting in repeating values of 100% kill. Because the midrange of the response curve was most useful for comparing LT_{50}s, repeating values from the upper and lower tails of this curve were eliminated before using regression techniques. Linear regression generated an equation relating percent survival to temperature from the remaining averaged percent dead buds. From this equation, estimates of the LT_{50} (the temperature of 50% bud kill) for each tissue of each genotype was calculated on all six sampling dates. The fewer the data points used in the regression analyses, the less precise was the LT_{50}.

Results from additional analyses considering each frozen packet of shoots as a replication instead of a subsample are included in the discussion and listed in Appendix C.

RESULTS

Weather

Historical weather data from 1961-1991 collected in Corvallis, Oregon show an annual decrease in temperature maxima and minima from August until January when the lowest temperatures are reached for an average winter (Figure 1). In February maximum temperature increased slightly but minimum temperature remains on the average 0-1 °C. Both winters, 1991-92 and 1992-93, temperatures did not deviate from this historical average and therefore we considered these years typical.

Freeze Day and Site Differences

Two varieties, 'Barcelona' and 'Casina', had duplicate trees tested, one on each freeze day, to check for a difference between freeze days. In addition to being tested on different freeze days, one of each variety was on each site. Bar graphs showing the LT_{60}s for each month (e.g., December year one = D1) for both 'Barcelona' and 'Casina' are shown in Figures 2 and 3. This alone is not enough information to conclude that there is no freeze day difference. In addition, Figures 4 - 9 show six more varieties that were duplicated in this study to check for a difference in the same variety on the same freeze day (see Tables 1 and 2 for a list of varieties tested on each freeze day). Figures 4 - 9 were duplicates on the same freeze day but different sites. Figures 7 - 9 were duplicate trees tested on the same freeze day from the same site. The duplicate trees do not have identical LT_{60}s. There is variation between trees of the same variety on the same freeze day from the same site. Since the variation does not consistently favor one site or one freeze day it can only be acknowledged as being present in the study. This variation cannot be attributed to freeze day or site. It must be assumed that tree-to-tree variation exists and therefore all LT_{60}s will be reported and not averaged for duplicate trees.

Chilling

Chill units were obtained from the weather station at the National Clonal Germplasm Repository in Corvallis. Figure 10 shows accumulated chill units from October to February of each winter and arrows indicate the six sampling dates from the field. More chill units were accumulated before the first and second sampling date during year two than year

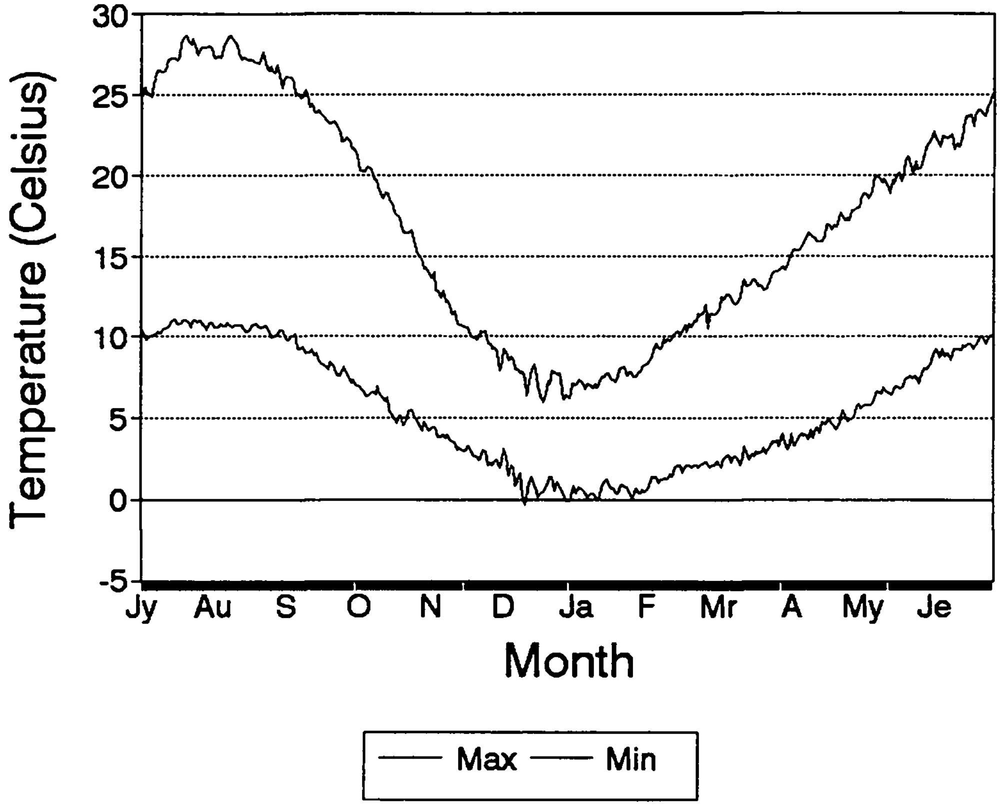

Figure 1. Historical maxima/minima for the period 1961-1991 for Corvallis, Oregon.

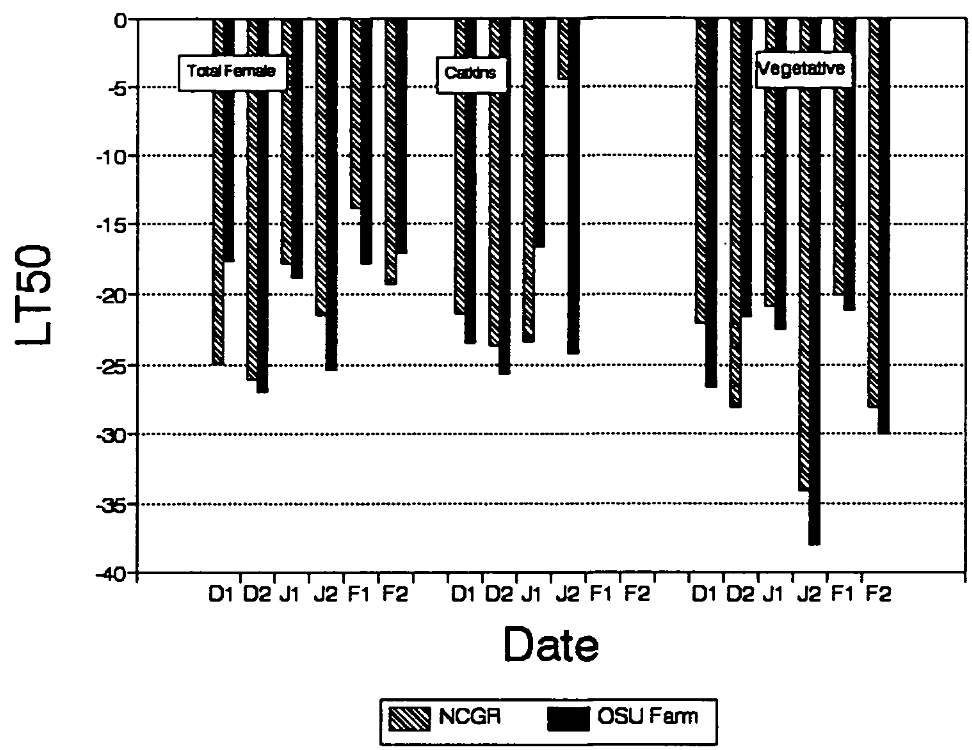

Figure 2. An LT_{60} comparison of three bud types from two 'Barcelona' trees grown at different locations (OSU Research Farm and NCGR). Trees were tested on consecutive days. Freezes were in December (D), January (J), and February (F) in 1991-92 (year 1) and 1992-93 (year 2).

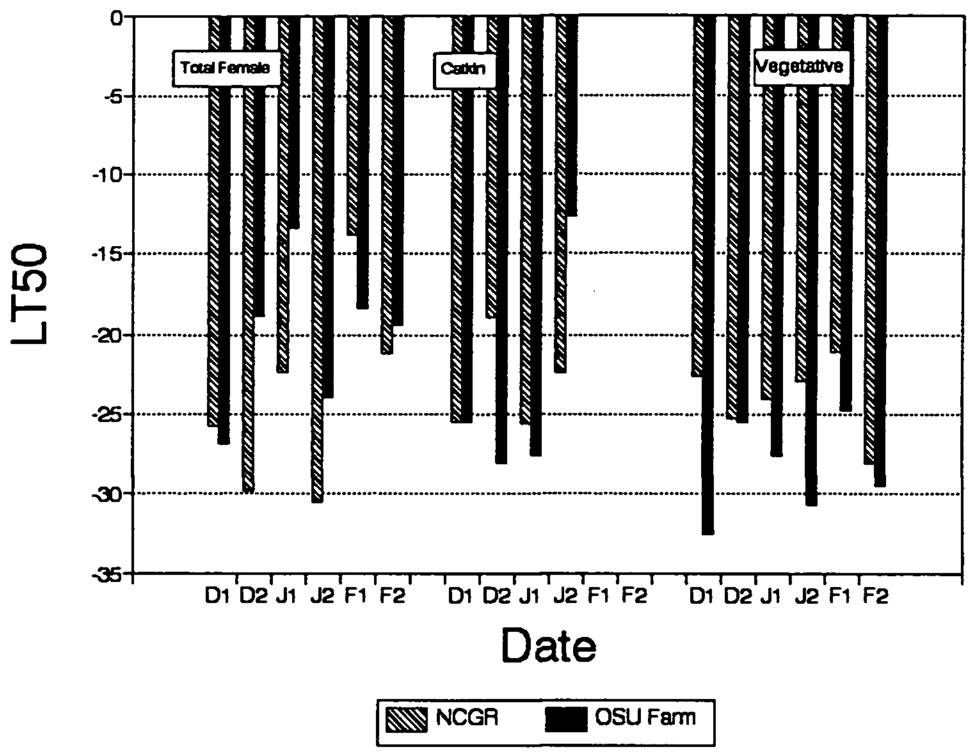

Figure 3. An LT_{50} comparison for three bud types from two 'Casina' trees grown at different locations (OSU Research Farm and NCGR). Trees were tested on consecutive days. Freezes were in December (D), January (J), and February (F) in 1991-92 (year 1) and 1992-93 (year 2).

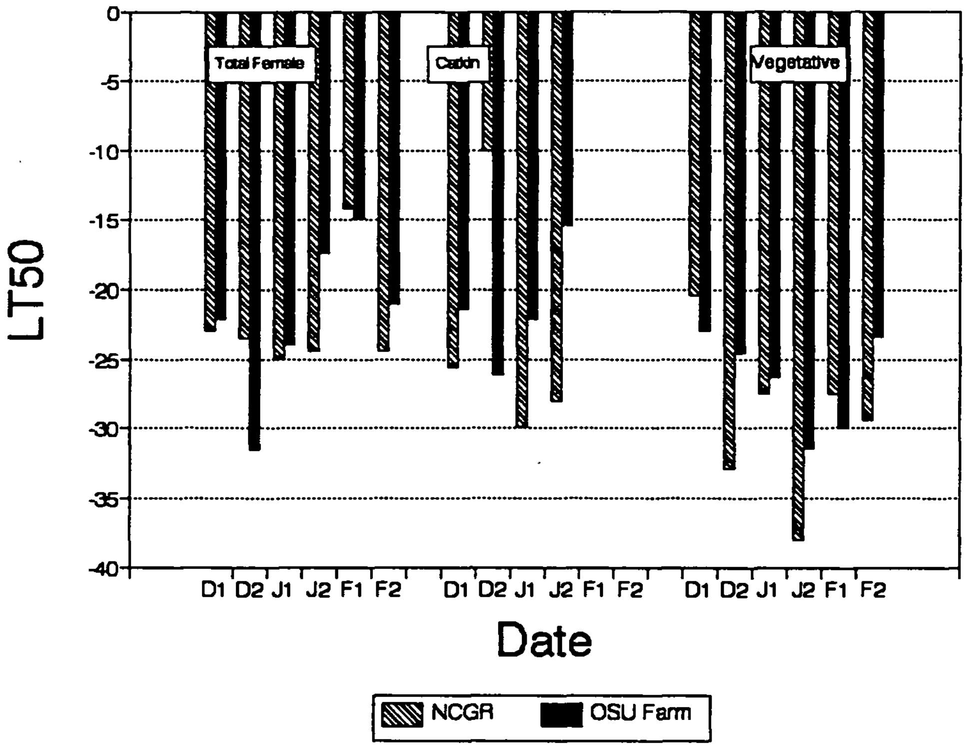

Figure 4. An LT_{50} comparison for three bud types from two 'Ennis' trees grown in different locations (OSU Research Farm and NCGR). Both trees were tested in the same freeze. Freezes were in December (D), January (J), and February (F) in 1991-92 (year 1) and 1992-93 (year 2).

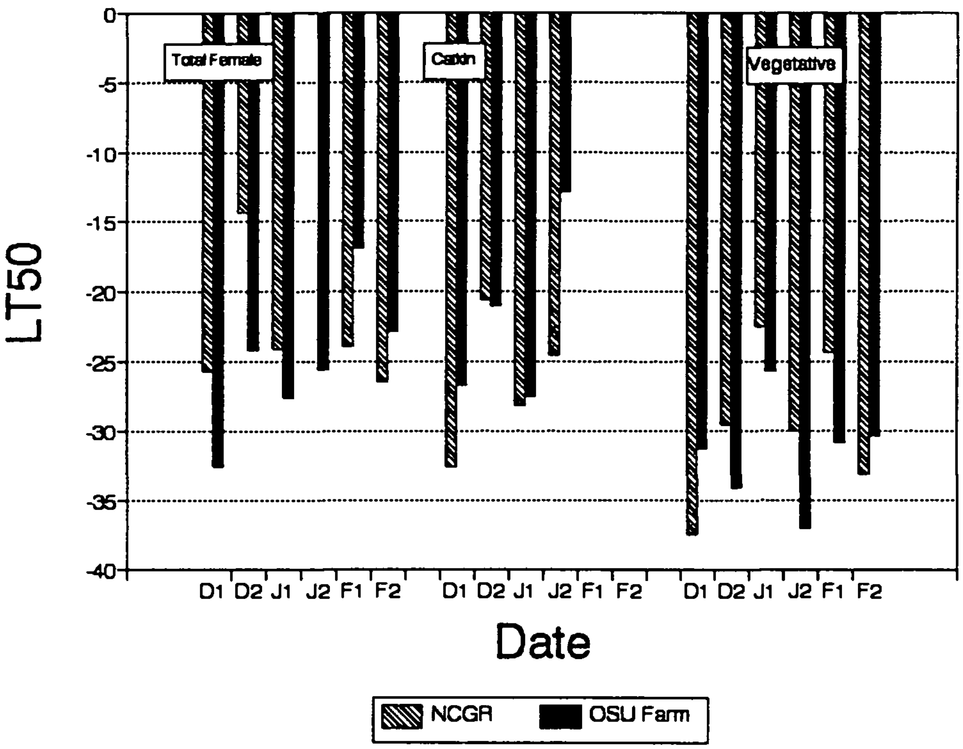

Figure 5. An LT_{50} comparison for three bud types from two 'Hall's Giant' trees grown in different locations (OSU Research Farm and NCGR). Both trees were tested in the same freeze. Freezes were in December (D), January (J), and February (F) in 1991-92 (year 1) and 1992-93 (year 2).

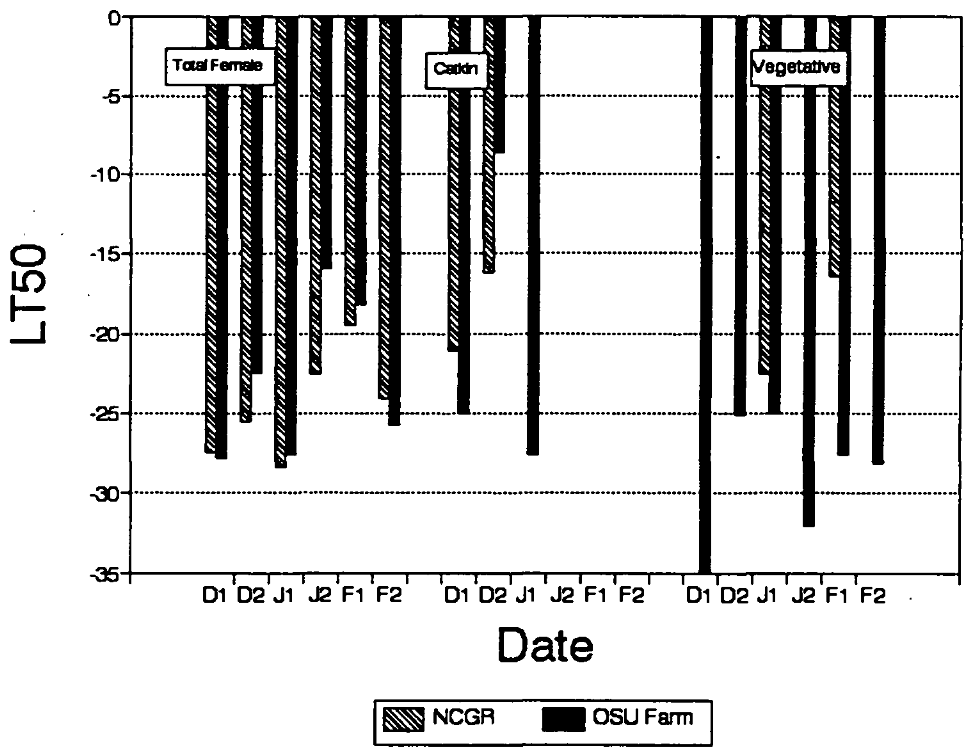

Figure 6. An LT_{60} comparison for three bud types from two 'Italian Red' trees grown at different locations (OSU Research Farm and NCGR). Both trees were tested in the same freeze. Freezes were in December (D), January (J), and February (F) in 1991-92 (year 1) and 1992-93 (year 2).

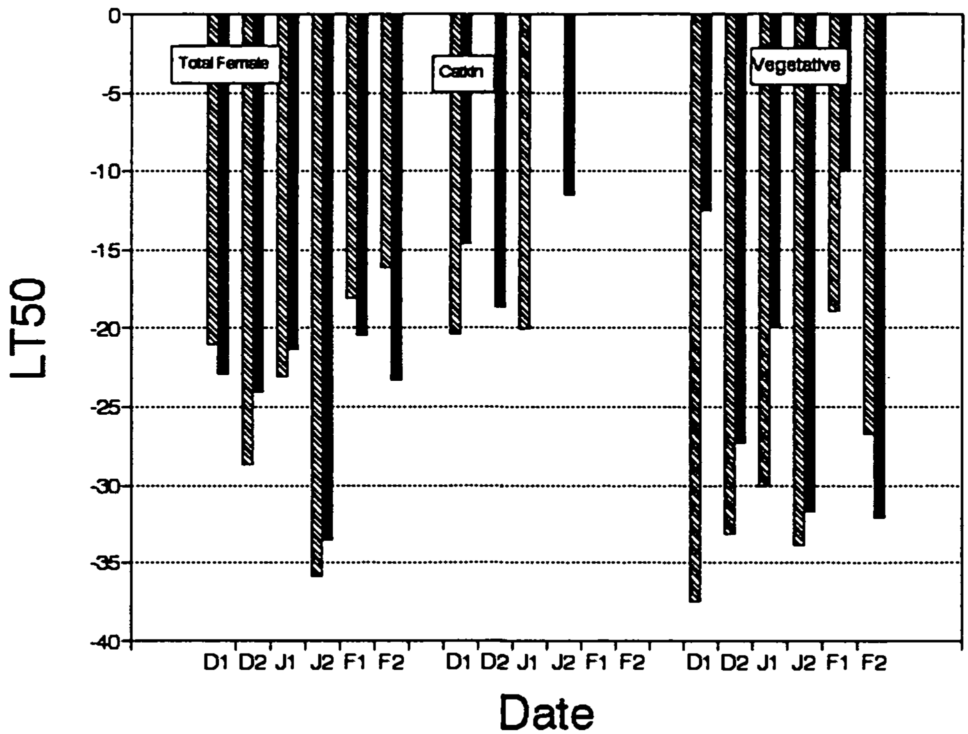

Figure 7. An LT_{60} comparison of three bud types from two 'Ribet' trees both grown at the NCGR. Both trees were tested in the same freeze. Freezes were in December (D), January (J), and February (F) in 1991-92 (year 1) and 1992-93 (year 2).

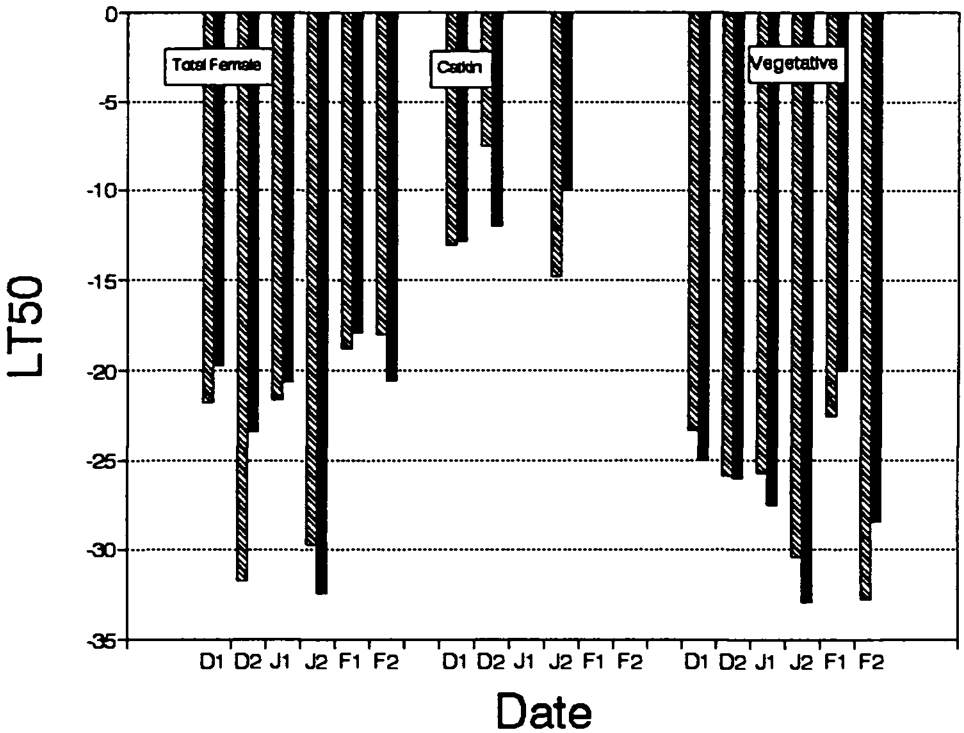

Figure 8. A LT_{50} comparison of three bud types from two 'TGDL' trees both grown at the OSU Research Farm. Both trees were tested in the same freeze. Freezes were in December (D), January (J), and February (F) in 1991-92 (year 1) and 1992-93 (year 2).

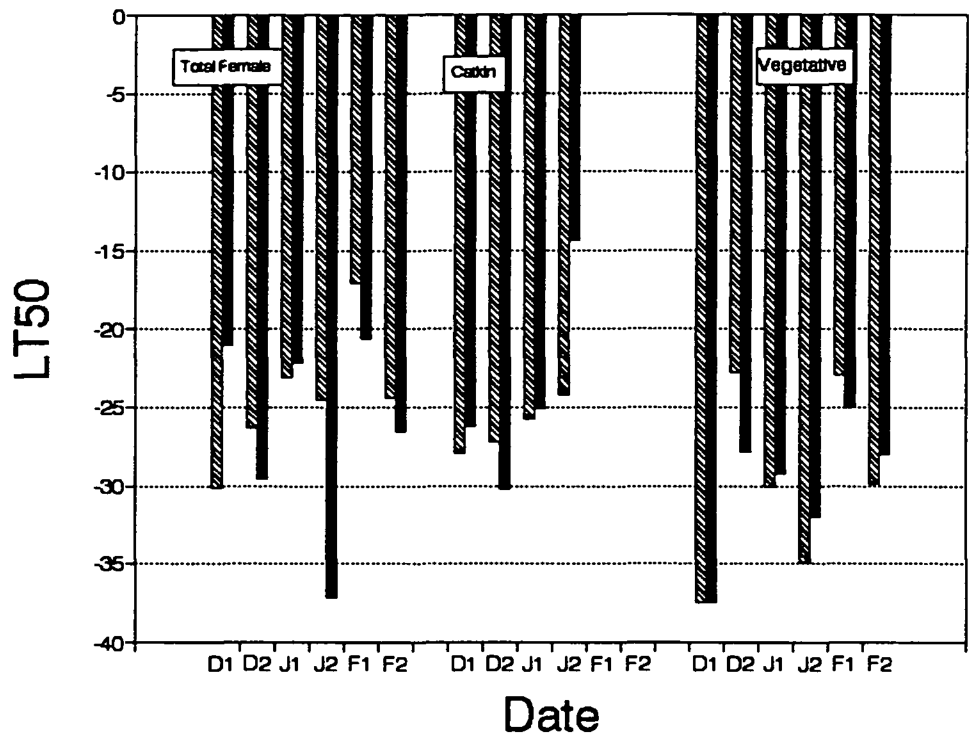

Figure 9. An LT_{50} comparison of three bud types from two 'Willamette' trees both grown at the OSU Research Farm. Both trees were tested in the same freeze. Freezes were in December (D), January (J), and February (F) in 1991-92 (year 1) and 1992-93 (year 2).

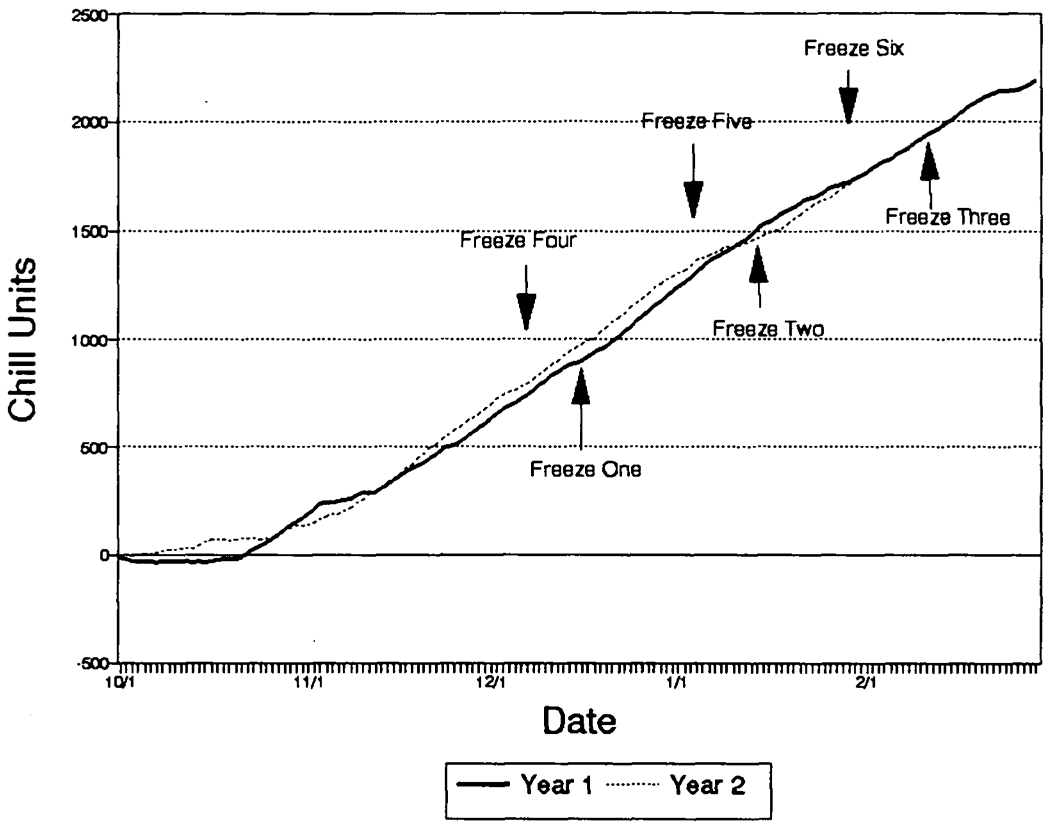

Figure 10. Cumulative chill units for both winters of freezing tests. Arrows indicate sampling dates. Freezes one through three occurred during year one. Freezes four through six occurred during the second year.

one. However, by the third sampling date at the beginning of February, both years showed the same number of chill units accumulated.

Prior to the December sampling date in year one (1991-92), four varieties, 'Badem', 'Camponica', 'Extra Ghiaghli' and 'Tombul Ghiaghli' accumulated enough chill units to satisfy their chilling requirements for pistillate flowers (Mehlenbacher, 1991a), however, 'Badem' was the only selection at the red dot stage in the field. In year two (1992-93), eight varieties had reached the red dot stage by the first sampling date. 'Tombul Ghiaghli' and 'Segorbe', even though theoretically should have accumulated enough chilling units to begin stigma exsertion, failed to develop in the greenhouse during December (Appendix A). This may have been due to pollination in the field. Once a pistillate flower is pollinated there is no further development until late spring. By the second sampling date of year two all but six varieties had satisfied their putative chilling requirements, however, 19 varieties had not yet reached the red dot stage in the field. All selections except *C. cornuta* var. *californica* and 'NY F-45' developed in the greenhouse to beyond the red dot stage. By the third sampling date in February, all varieties should have had their chilling requirements satisfied. However, '*C. cornuta*', 'NY F-45', 'NY 110' and 'CTG6' persisted in a pre-red dot stage on the February sampling date but showed progression beyond that stage in the greenhouse when forced.

All varieties except 'Gasaway' and 'Gem' satisfied their reported chilling requirements for catkins for both years by the December sampling date. 'TGDL' and 'Italian Red' were the first to show this by having greater than 50% catkin elongation in the field on this date. In the greenhouse chilling studies, 18 selections showed catkin elongation after three weeks indicating that chilling had been satisfied (Appendix A). By the January sampling date all varieties should have satisfied their requirement in theory. Still, in addition to those mentioned for December, only 'Badem', 'Barcelona', 'Ennis', 'Italian Red', 'Montebello', 'Negret' and 'Extra Ghiaghli' actually showed catkin elongation in the field. However, in the greenhouse studies, all selections except *C. cornuta* had shown at least 50% catkin elongation after four weeks (Appendix A) which indicates that elongation occurs after both chilling is met and warm temperatures occur. There were still a few varieties that did not show elongation in the field even by the February sampling date: '*C. cornuta*', 'CTG6', 'Cutleaf', 'Gem', 'Kor 001', 'Kor 013', 'NY F-45' and 'Rode Zeller'. However, catkins of all selections successfully elongated in the greenhouse during February.

Vegetative buds require the most chilling. Only four varieties of those reported would have satisfied their quota by the December sampling date of the second year (Appendix

A): 'Badem', 'Extra Ghiaghli', 'Negret' and 'Tombul Ghiaghli'. However, excised shoots of all tested varieties were placed in water in a greenhouse and only 'Extra Ghiaghli' showed bud swell by the end of three weeks. With the exception of 'Camponica', 'Casina', 'Cosford', 'Creswell', 'Cutleaf', 'Gasaway', 'Hall's Giant', 'Italian Red' and 'Segorbe' all tested varieties satisfied their reported chilling requirement by the January sampling date. 'Casina', '*C. cornuta*', 'Cutleaf', 'Creswell', 'Gasaway', 'Hall's Giant', 'Italian Red', 'NY F-45', 'Segorbe' and 'TTG5' were the only varieties to show no bud swell after excision and placement in the greenhouse. By the February sampling date, all varieties showed bud swell after 4 weeks in the greenhouse.

Wood Hardiness

Two tests estimated wood hardiness. Visual evaluation and electrical conductivity did not accurately distinguish between living and dead wood tissue. Often the cambium showed slight green with browning. Table 3 reports the temperature intervals in which each species, in general, was given a cambium browning score of 3, meaning that the tissue was entirely brown. *C. cournuta* var. *californica* and *C. americana* X *C. avellana* showed the widest interval from -30.1°C to -38°C. *C. colurna* X *C. avellana* and *C. heterophylla* both exhibited the greatest cold hardiness in December withstanding temperatures as low as -36°C. 'NY F-45', a complex *C. americana* - *C. avellana* hybrid, never completely browned during December of either year. All species and hybrids became more hardy or maintained their hardiness in January. The widest range occured in January was from -34.1°C to -38°C in both *C. avellana* and *C. heterophylla*. In February the intervals widened showing a loss of hardiness except for *C. colurna* X *C. avellana* and *C. heterophylla*. In fact, this species and group of hybrids maintained the same low hardiness throughout all three winter test months not showing a definite browning until -36.1°C to -38°C. In February, 'CTG4' and 'CTG6' (*C. colurna* X *C. avellana*) never reached a temperature that resulted in a rating of 3 for either year. The same is true for 'NY F-45' and for 'Cornuta Californica Y20-B0072'.

Table 3. Warmest temperature at which each species or hybrid was determined dead by visual evaluation of the cambium (rating = 3).

	December	January	February
C. avellana	-32.1	-34.1	-32.1
C. cornuta var. *californica*	-30.1	-36.1	-34.1
C. colurna X *C. avellana*	-36.1	-36.1	-36.1
C. americana X *C. avellana*	-30.1	-36.1	-30.1
C. heterophylla	-36.1	-34.1	-36.1

The second method, electrical conductivity, gave data that did not show the expected sigmoidal response curve. There was no consistent inflection point in the curves that might indicate a temperature marking significant damage to the cell membrane and subsequent leakage of electrolytes. Electrolyte leakage does not seem to provide a clear indication of lethal temperature for hazelnut wood. However, an overall trend in wood hardiness by this method showed maximum hardiness in December, less hardiness in January and the least hardiness in February for all varieties (Figure 11).

Bud Hardiness

Table 4 shows the average number of buds per sampled shoot for each variety for each bud type. There were fewer female lateral buds than female peduncle buds. In fact the only variety tested that had more than two female lateral buds per shoot was 'Kor 013' which is from the *C. heterophylla* species. However, at least 14 varieties had more than four female peduncle buds per shoot (Table 4). The number of catkins per shoot ranged from one in 'TGDL' to ten in 'Ennis'. Catkin hardiness could be estimated only during the months of December and January. By February nearly all of the catkins had elongated and dropped to the ground. Elongated catkins are extremely tender.

Female Lateral Buds. Lateral buds averaged over all *C. avellana* showed the greatest hardiness in December (minimum LT_{60}) and gradually lost this hardiness through January and February (Figure 12). In December of the first winter *C. avellana* varieties had LT_{60}s ranging from -12.9°C to -34.2°C (Table 5). In the hardiest range were 'Gir. OSU 54.080', 'Mortarella' and 'Ribet' ranging from -32.2°C to -34.2°C while 'Extra Ghiaghli', 'Tombul Ghiaghli', 'Barcelona', 'Ennis' and 'Gasaway' had LT_{60}s from -12.9°C to -17.5°C. During January the range of LT_{60}s was similar to December with 'Cosford' having the lowest LT_{60} at -32.5 C. In February the interval ranged from -8.4°C to -27.5°C with no selection showing its maximum hardiness during this time. Table 5 lists the LT_{60}s for female lateral buds during December, January and February of the second year of

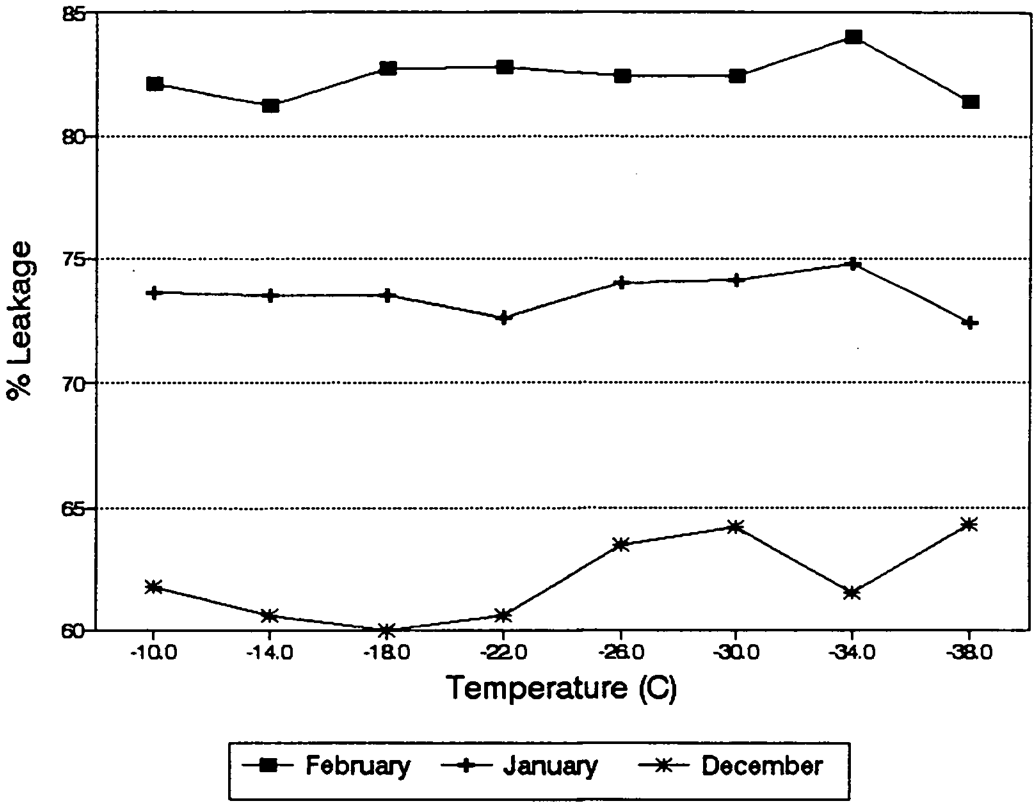

Figure 11. Percent electrolyte leakage averaged over all selections for both years at each test temperature during December, January and February.

Table 4. Average number of buds per shoot for each bud type.

Species	Selection	♂	$♀_{Lat}$	$♀_{Ped}$	$♀_{Tot}$	Veg
C. avellana	'55.129'	2.3	1.5	2.7	4.2	2.2
	'Badem'	2.3	1.2	3.2	4.4	2.2
	'Barcelona-A'	8.2	1.6	3.4	5.0	2.9
	'Barcelona-B'	4.2	1.5	4.0	5.5	3.2
	'Brixnut'	5.3	1.3	2.6	3.9	2.3
	'Camponica'	3.8	1.5	5.4	6.9	2.5
	'Casina-A'	5.7	1.0	4.1	5.1	1.7
	'Casina-B'	4.8	1.2	3.8	5.0	2.3
	'Cosford'	5.7	1.5	3.0	4.5	3.0
	'Creswell'	7.2	1.3	3.4	4.7	4.0
	'Cutleaf'	4.8	1.3	4.2	5.5	3.4
	'Ennis-A'	9.4	1.5	4.9	6.4	3.0
	'Ennis-B'	10.8	1.6	4.5	6.1	3.9
	'Gasaway'	9.5	1.2	2.2	3.4	3.2
	'Gem'	7.4	1.5	3.0	4.5	3.4
	'Gir. OSU 54.080'	7.4	1.4	4.9	6.3	2.6
	'Hall's Giant-A'	5.0	1.1	2.1	3.2	2.6
	'Hall's Giant-B'	4.6	1.4	2.7	4.1	2.0
	'Italian Red-A'	2.5	1.5	3.6	4.3	2.5
	'Italian Red-B'	3.6	1.3	3.0	5.1	2.6
	'Montebello'	4.0	1.5	4.0	5.5	1.6
	'Morell'	5.2	1.3	4.9	6.2	1.9
	'Mortarella'	5.8	1.6	4.4	6.0	2.9
	'Negret'	8.7	1.4	7.1	8.5	1.6
	'Ribet-A'	4.2	1.2	6.2	7.4	2.4
	'Ribet-B'	3.9	1.3	4.4	5.7	3.0
	'Riccia di Talanico'	3.0	1.4	5.0	6.4	1.9
	'Roda Zeller'	4.9	1.0	1.9	2.9	3.0
	'Sagorba'	4.8	1.4	3.3	4.7	2.7
	'Extra Ghiaghli'	2.7	1.2	2.3	3.5	1.5
	'Tombul Ghiaghli'	5.5	1.2	2.2	3.4	3.4
	'Tonda G.d. Langhe-A'	1.4	1.4	3.9	4.3	3.4
	'Tonda G.d. Langhe-B'	1.4	1.8	2.5	5.3	2.7
	'Tonda Romana'	2.9	1.1	2.8	3.9	3.3
	'Tonda di Giffoni'	5.0	1.3	4.0	5.3	2.5
	'Willamette-A'	5.0	1.4	2.0	3.4	3.4
	'Willamette-B'	4.6	1.3	2.2	3.5	2.8
C. cornuta var. *californica*	'Y20-B0072'	3.1	1.0	1.4	2.4	3.7
	'Y25-B0055'	4.6	1.0	1.2	2.2	6.1
	'Y26-B0055'	4.0	1.6	1.5	3.1	5.2
C. colurna X *C. avellana*	'CTG11'	5.3	1.4	3.0	4.4	1.9
	'CTG4'	4.2	1.2	3.0	4.2	4.2
	'CTG6'	6.6	1.2	2.8	4.0	4.1
	'Turktrazel Gellatly-5'	4.5	1.6	1.8	3.4	3.8
C. americana X *C. avellana*	'NY 110'	2.5	1.3	2.0	3.3	2.6
	'NY 200'	3.1	1.4	2.1	3.5	2.2
	'NY F-45'	3.1	3.2	1.9	5.1	0.6
C. heterophylla	'Kor 001'	7.6	1.6	4.8	6.4	0.9
	'Kor 013'	3.4	1.9	1.9	3.8	0.7

♂ = Catkins, $♀_{Lat}$ = Female lateral buds, $♀_{Ped}$ = Female peduncle buds, $♀_{Tot}$ = Female lateral and peduncle buds together, Veg = Vegetative buds.

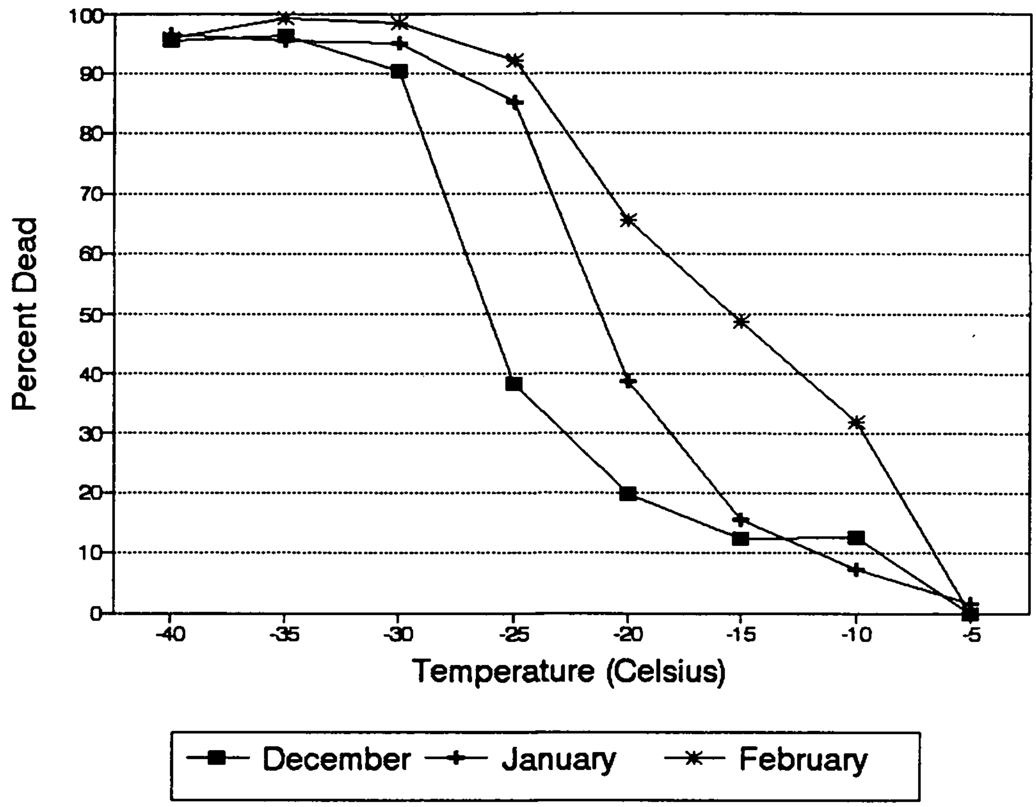

Figure 12. Overall mean percent dead averaged over all genotypes and both years at each test temperature during December, January and February for female lateral buds of *C. avellana*.

Table 5. LT_{50}s for female lateral buds for 1991-92 and 1992-93 winters.

Selection	Dec_1	Jan_1	Feb_1	Dec_2	Jan_2	Feb_2
C. avellana						
'55.129'	——	——	——	-30.0	-30.0	-24.0
'Badem'	-24.5	-16.4	-8.6	-25.3	-19.0	-10.0
'Barcelona-A'	-17.5	-20.0	-14.4	-18.0	-20.0	-21.4
'Barcelona-B'	-13.9	——	-14.0	-18.8	-28.0	-22.9
'Brixnut'	——	-19.7	——	-30.0	-26.0	-18.7
'Camponica'	-18.4	-16.6	-11.7	-25.1	-22.5	-16.0
'Cesina-A'	-19.4	-21.1	-22.5	-17.4	-27.5	-25.6
'Cesina-B'	-26.7	-21.4	-19.5	-24.0	-25.2	-24.0
'Cosford'	-22.5	-32.5	-18.4	-20.0	-28.2	-18.0
'Creswell'	-27.5	-22.5	-21.6	-10.0	-28.8	-21.0
'Cutleef'	-20.0	-22.5	-22.1	-28.5	-36.0	-30.0
'Ennis-A'	-22.5	-25.0	-27.5	-24.0	-31.7	-27.7
'Ennis-B'	-17.5	-25.6	-15.0	-22.0	-24.0	-23.6
'Extra Ghieghli'	-12.9	-22.5	-13.7	-17.1	-22.3	-22.0
'Gasewey'	-17.5	-22.5	-15.9	-28.4	——	-28.0
'Gem'	-23.7	-22.5	-18.7	-18.0	-36.0	-25.2
'Gir OSU 54.080'	-32.5	-25.0	-17.5	-24.0	-33.1	-23.4
'Hall's Gient-A'	-26.8	-20.0	-17.9	-24.0	-38.0	-30.0
'Hall's Gient-B'	-27.5	-27.5	-20.4	-26.0	-34.0	-30.0
'Itelian Red-A'	-27.5	-30.0	-19.8	-28.0	-36.0	-23.2
'Itelien Red-B'	-24.6	-12.5	-8.7	-24.3	-25.1	-20.4
'Montebello'	-27.5	-20.0	-19.8	——	——	——
'Morell'	-21.1	-22.5	-20.0	-24.0	-32.0	-30.0
'Morterelle'	-32.2	-19.4	-22.5	-30.0	-23.1	-21.7
'Negret'	-22.5	-25.6	-18.3	-16.6	-38.0	-38.0
'Ribet-A'	-20.0	-19.4	-19.2	-24.6	-22.0	-24.4
'Ribet-B'	-34.2	-24.4	-13.0	-22.0	-29.1	-26.0
'Riccie di Telanico'	-22.5	-25.5	-15.0	-22.9	-29.6	-28.0
'Rode Zeller'	-21.8	-21.1	-14.4	——	——	——
'Segorbe'	-25.6	-17.5	-9.4	-20.0	-25.7	-22.6
'Tombul Ghieghli'	-15.0	-27.5	-17.5	-34.0	——	-22.0
'TGDL-A'	-20.0	-25.0	-15.0	-21.5	-21.3	-22.0
'TGDL-B'	-22.5	-22.5	-17.5	-20.0	-29.3	-20.7
'Tonda Romana'	-23.8	-19.4	-13.0	-24.0	-26.0	-22.0
'Tonde di Giffoni'	-27.3	-19.8	-10.6	-22.0	-24.0	-18.0
'Willamette-A'	-26.1	-18.1	-8.4	-21.6	-24.9	-17.0
'Willemette-B'	-18.9	-22.5	-12.9	-22.0	-22.5	-13.0
C. cornuta ver. *californica*						
'Y20-B0055'	——	——	——	-31.5	-24.0	-27.7
'Y25-B0055'	——	——	——	-22.0	——	-21.1
'Y26-B0055'	——	——	——	-25.7	-23.6	-12.0
C. colurna X *C. avellana*						
'CTG11'	-20.8	-27.5	-17.5	-21.3	-32.5	-22.9
'CTG4'	-19.2	-22.5	-12.5	-18.0	-31.9	-20.8
'CTG6'	-23.4	-24.5	-12.4	-26.0	-32.8	-20.3
'TTG5'	-20.2	-26.9	-20.9	-32.0	-23.0	-24.6
C. amaricana X *C. avellana*						
'NY 110'	-22.5	-30.0	-18.5	-28.9	-38.0	-32.0
'NY 200'	-24.4	-25.0	-20.8	-38.0	-32.0	-32.0
'NY F45'	-25.0	-25.8	-26.0	-30.7	-38.0	-28.9
C. hatarophylla						
'Koreen-001'	-30.0	-22.5	-12.5	-28.0	-32.0	-19.5
'Koreen-013'	-40.0	-25.0	-15.0	-24.0	-21.8	-17.5

evaluation. From December to January to February the ranges of LT_{60}s changed from -10.0°C to -34.0°C, to -19.0°C to -38°C, to -10.0°C. to -38.0°C respectively. Most selections within this species attained their maximum hardiness in January with 'Cutleaf', 'Gem', 'Italian Red', 'Hall's Giant' and 'Negret' all having LT_{60}s of ≤-36.0°C. In February 'Negret' maintained its low LT_{60} while all others seemed to deacclimate.

C. colurna X *C. avellana* hybrids had similar overall LT_{60}s for the three test months compared to the *C. avellana* species (Figure 13) showing a deacclimatization occurring after December. All of the hybrids attain their maximum hardiness in January ranging from -22.5°C to -27.5°C in the first year and from -23.0°C to -32.8°C the second year.

C. americana X *C. avellana* hybrids showed an overall LT_{60} maximum hardiness during December (Figure 14). Only 'NY 200' attained maximum hardiness in January of both years. In year one 'NY 110' and 'NY 200' had a minimum LT_{60} during January of -30.0°C and -25.8°C respectively while 'NY F-45' peaked in February at -26.0°C. The second year 'NY 110' and 'NY F-45' had LT_{60}s of -38.0°C during January and 'NY 200' reached its minimum LT_{60} of -38.0°C during December.

C. heterophylla varieties both attained their maximum hardiness in December of year one (LT_{60}s from -30.0°C to -40.0°C). In year two, 'Kor 013' showed a similar pattern but 'Kor 001' had a minimum LT_{60} of -32.0°C in January.

C. cornuta var. *californica* did not have enough identifiable female buds, neither lateral nor peduncle, to allow reliable estimates of LT_{60}s. Table 5 does show some calculated LT_{60}s for year two female lateral buds. For two of the three selections the maximum hardiness occurred in December at -25.7°C and -31.5°C.

Female Peduncle Buds. The number of female peduncle buds varied greatly within species. At least one selection from each tested species or hybrid had fewer than two peduncle pistillate buds (Table 4). Many *C. avellana* species had more than 5 peduncle female buds. 'Negret' averaged 7.1 peduncle buds per sampled shoot. There were no selections from *C. cornuta* var. *californica*, *C. colurna* X *C. avellana* or *C. americana* X *C. avellana* with more than 3 peduncles per sampled shoot. Most had less than two. The number of peduncle buds did not skew the overall total female LT_{60} toward any certain selections or sampling date.

C. avellana varieties showed an overall trend of a gradual decrease in hardiness for female peduncle buds from December to February (Figure 15). In December of year one LT_{60}s ranged from -10.6°C to -32.5°C. 'Riccia di Talanico', 'Italian Red', 'Ribet', 'Casina', 'Barcelona', 'Hall's Giant', 'Gir. OSU 54.080' and 'Willamette' achieved their

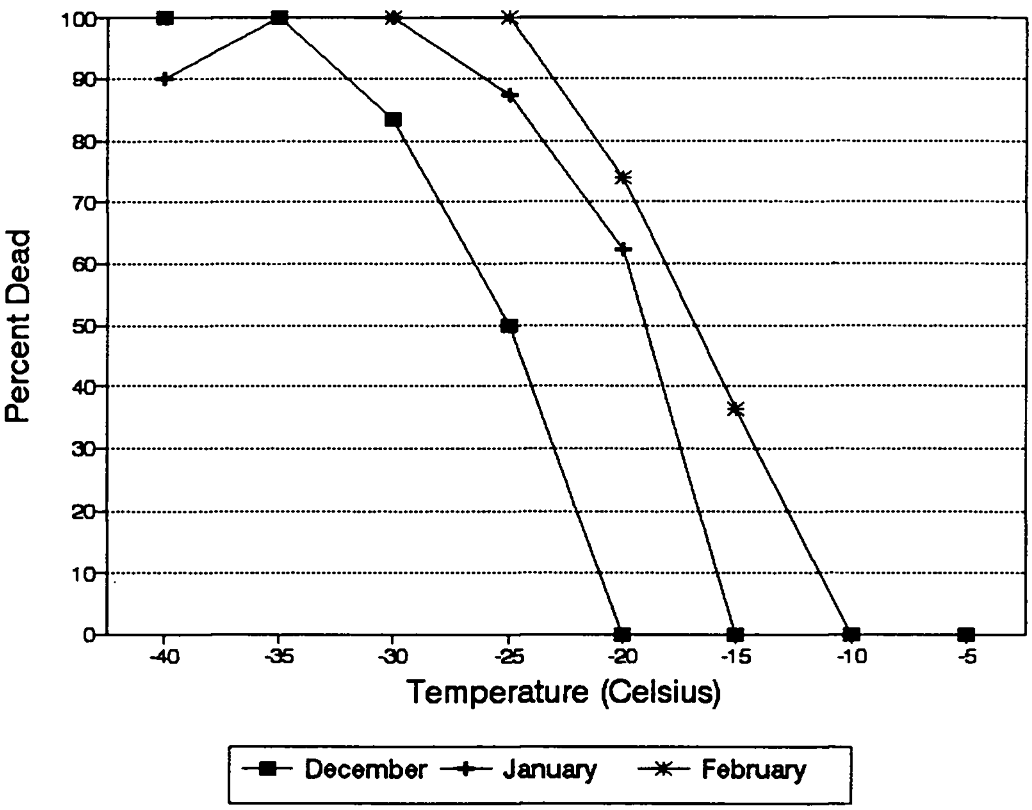

Figure 13. Overall mean percent dead for female lateral buds averaged over all genotypes and both years at each test temperature during December, January and February for *C. colurna* X *C. avellana* hybrids.

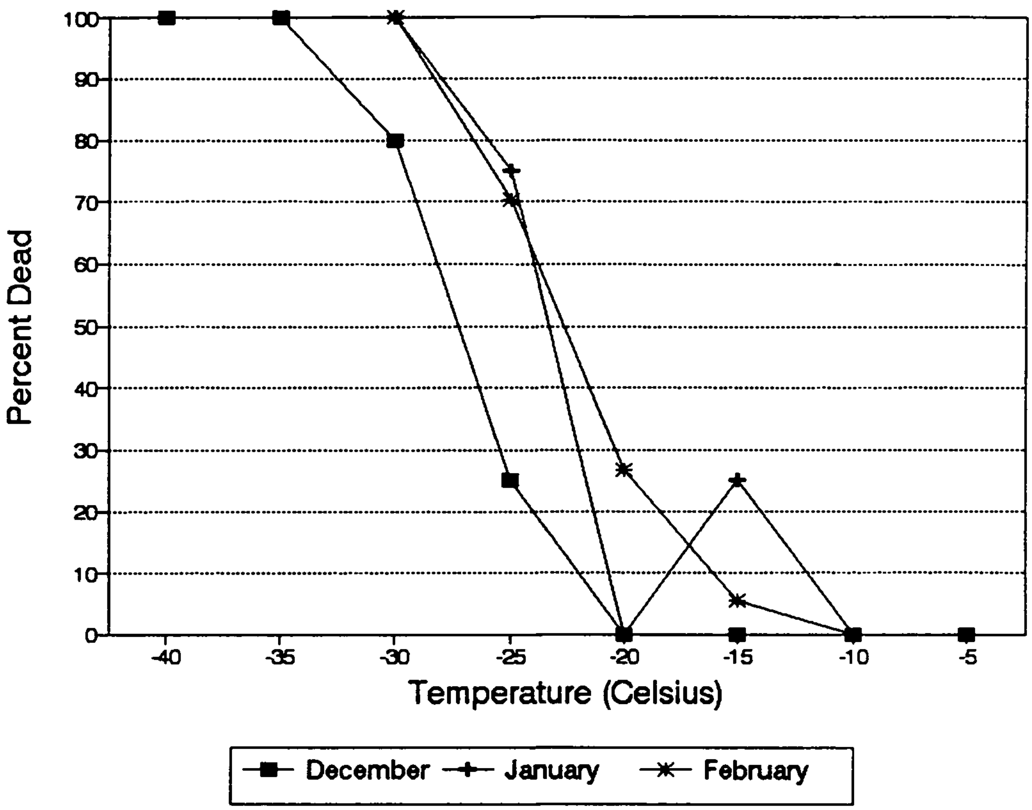

Figure 14. Overall mean percent dead averaged over all genotypes and both years at each test temperature during December, January and February for female lateral buds of *C. americana* X *C. avellana* hybrids.

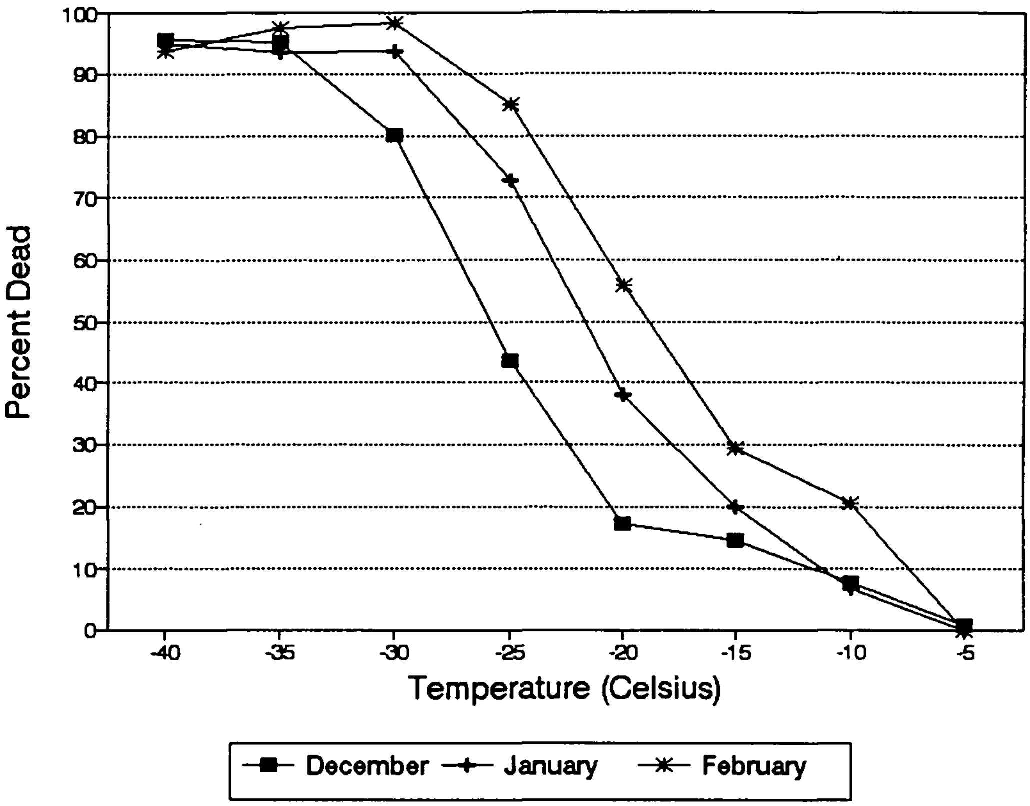

Figure 15. Overall mean percent dead female peduncle buds averaged over all genotypes and both years at each test temperature during December, January and February for *C. avellana*.

maximum hardiness during this month with LT_{60}s ranging from -27.5°C to -32.5°C (Table 6). This was not true for the second year in which most selections within this species attained maximum hardiness in January. The range of those achieving maximum hardiness in December of the second year was from -24.1°C to -32.2°C (Table 6). In January of year one LT_{60}s ranged from -10.0°C to -30.0°C ('Cosford') while in the second year 'Cutleaf', 'Ennis', 'Negret', 'Gem', 'Ribet', '55.129', 'Gir. OSU 54.080' and 'Hall's Giant' all had $LT_{60} \leq$ -30.0°C. In year one during February, 'Camponica' and 'Badem' achieved their maximum hardiness at LT_{60} -30.0°C. During February of the second year 'Segorbe' reached its maximum hardiness with an LT_{60} of -26.0°C. The entire range of LT_{60}s during February was from -11.0°C to -30.4°C. 'Hall's Giant' still maintained a very low LT_{60} of -30.0°C in February, eight degrees lower than the previous month.

C. colurna X *C. avellana* also showed an overall trend of maximum acclimation in December with gradual deacclimation occurring from December to February (Figure 16). However, two of the four varieties attained their maximum hardiness in December (-21.8°C to -33.1°C) while the other two peaked from -26.7°C to -27.7°C in January (Table 6) of the first year. In the second year, all except 'TTG5' reached their maximum in January ranging from -27.2°C to -32.7°C (Table 6).

C. americana X *C. avellana* showed a maximum hardiness for both years in January ranging from -27.5°C to -27.7°C the first year and ranging from -24.7°C to -36.6°C the second year. Only one variety 'NY F-45' achieved its maximum hardiness in December during the first year at -27.5°C.

C. heterophylla exhibited a maximum hardiness in December for both years (Figure 17) except for 'Kor 013' which was hardiest in January the second year attaining an LT_{60} of -29.1°C. The overall LT_{60}s for this species exhibit a loss of hardiness in February compared to December and January.

<u>A Comparison/Contrast of Female Lateral and Peduncle Buds</u>. A graphical comparison of female lateral buds and female peduncle buds for each month and year shows no consistent difference for any of the selections tested. For some of the selections within a species or of the same hybrid the lateral buds may achieve a lower LT_{60} than the peduncles one month in one year, yet exhibit a higher LT_{60} for that same month the following year. Within species or within hybrid groups, selections did not consistently show the same pattern either. No general differences were noted. Table 7 lists all minimum LT_{60}s for both lateral and peduncle buds for each year. Table 8 lists mean LT_{60}s and their corresponding standard deviations for female lateral buds and female

Table 6. LT_{50}s for female peduncle buds for 1991-92 and 1992-93 winters.

Selection	Dec_1	Jan_1	Feb_1	Dec_2	Jan_2	Feb_2
C. avellana						
'55.129'	----	----	----	-23.8	-35.1	-15.8
'Badem'	-26.2	-14.2	-30.0	-26.3	-22.3	-11.0
'Barcelona-A'	-17.7	-18.2	-19.3	-19.1	-25.4	-18.4
'Barcelona-B'	-29.4	-25.6	-13.7	-25.6	-22.8	-14.5
'Brixnut'	-23.3	-20.4	-25.0	-32.2	-12.9	-22.7
'Camponica'	-24.6	-15.3	-30.0	-24.1	-20.5	-17.0
'Casina-A'	-29.1	-11.0	-24.2	-22.0	-29.3	-18.4
'Casina-B'	-25.5	-22.5	-17.5	-25.5	-25.1	-23.0
'Cosford'	-27.5	-30.0	-12.9	-23.8	-27.8	-21.8
'Creswell'	-27.2	-10.0	----	-25.7	-28.5	-20.6
'Cutleaf'	-22.5	-25.6	-24.8	-22.6	-31.1	-22.0
'Ennis-A'	-22.0	-23.6	-22.7	-27.5	-34.1	-21.2
'Ennis-B'	-19.0	-29.4	-17.5	-26.3	-31.3	-27.3
'Extra Ghieghli'	-17.4	-18.0	-22.5	-21.2	-28.5	-25.1
'Gasaway'	-19.0	-22.5	-19.4	-26.3	-30.5	-24.6
'Gem'	-26.1	-24.4	----	-24.0	-32.2	-28.4
'Gir OSU 54-80'	-32.5	-28.7	----	-29.7	-36.7	-29.0
'Hall's Giant-A'	-30.0	-25.6	-26.6	-25.3	-38.0	-30.4
'Hall's Giant-B'	-27.3	-27.5	-19.3	-27.9	-30.8	-23.1
'Italian Red-A'	-28.0	-27.5	-17.4	-28.2	-24.2	-23.3
'Italian Red-B'	-23.9	-15.6	-24.4	-19.7	----	----
'Montebello'	-22.2	-23.3	-20.0	-26.0	-28.9	-22.0
'Morell'	-21.0	-25.0	-7.5	-25.0	-25.0	-15.7
'Mortarella'	-10.6	-14.5	----	-7.4	-26.5	-15.5
'Negret'	-23.0	-20.3	-21.2	-25.9	-31.6	-23.4
'Ribet-A'	-21.2	-23.9	-16.2	-28.1	-34.8	-24.4
'Ribet-B'	-28.8	-22.7	-16.7	-19.2	-29.5	-26.9
'Riccia di Talanico'	-27.5	-24.5	-18.4	-26.1	-28.7	-27.3
'Rode Zeller'	-26.5	-22.5	-15.9	-21.8	-29.2	-27.4
'Segorbe'	-16.3	-18.5	-20.9	-16.2	-24.0	-26.0
'Tombul Ghieghli'	-20.0	-24.0	-15.0	-18.0	-30.0	-24.0
'TGDL-A'	-19.5	-18.3	----	-22.9	-23.1	-24.8
'TGDL-B'	-21.3	-21.1	-17.5	-22.5	-28.1	-24.6
'Tonda Romana'	-26.3	-22.5	-8.8	-26.8	-26.9	-19.9
'Tonda di Giffoni'	-20.0	-13.6	-17.5	-19.9	-20.8	-16.3
'Willamette-A'	-32.5	-26.1	-12.5	-24.4	-25.0	-15.4
'Willamette-B'	-22.5	-22.0	----	-25.6	-22.5	-13.3
C. cornuta var. *californica*						
'Y20-B0055'	----	-20.0	-24.2	-22.6	-31.1	-22.0
'Y25-B0055'	----	----	-27.5	-22.9	-35.8	-20.9
'Y26-B0055'	-30.0	-22.5	----	-26.7	-36.8	-27.6
C. colurna X *C. avellana*						
'CTG11'	-33.1	-26.0	-15.8	-24.0	-27.2	-20.5
'CTG4'	-21.8	-16.5	-20.8	-25.6	-32.7	-21.4
'CTG6'	-22.9	-27.6	----	-25.5	-30.5	-19.5
'TTG5'	-21.4	-27.7	-17.5	-28.3	-23.4	-20.0
C. americana X *C. avellana*						
'NY 110'	-22.5	-27.5	-17.5	-30.0	-36.6	-31.2
'NY 200'	-17.5	-28.3	-20.6	-27.6	-28.1	-28.1
'NY F45'	-27.5	-25.0	-7.5	-23.7	-24.7	-20.3
C. heterophylla						
'Korean-001'	-28.6	-27.3	-25.0	-30.4	-30.0	-20.3
'Korean-013'	-30.6	-28.9	-19.8	-24.3	-29.1	-15.6

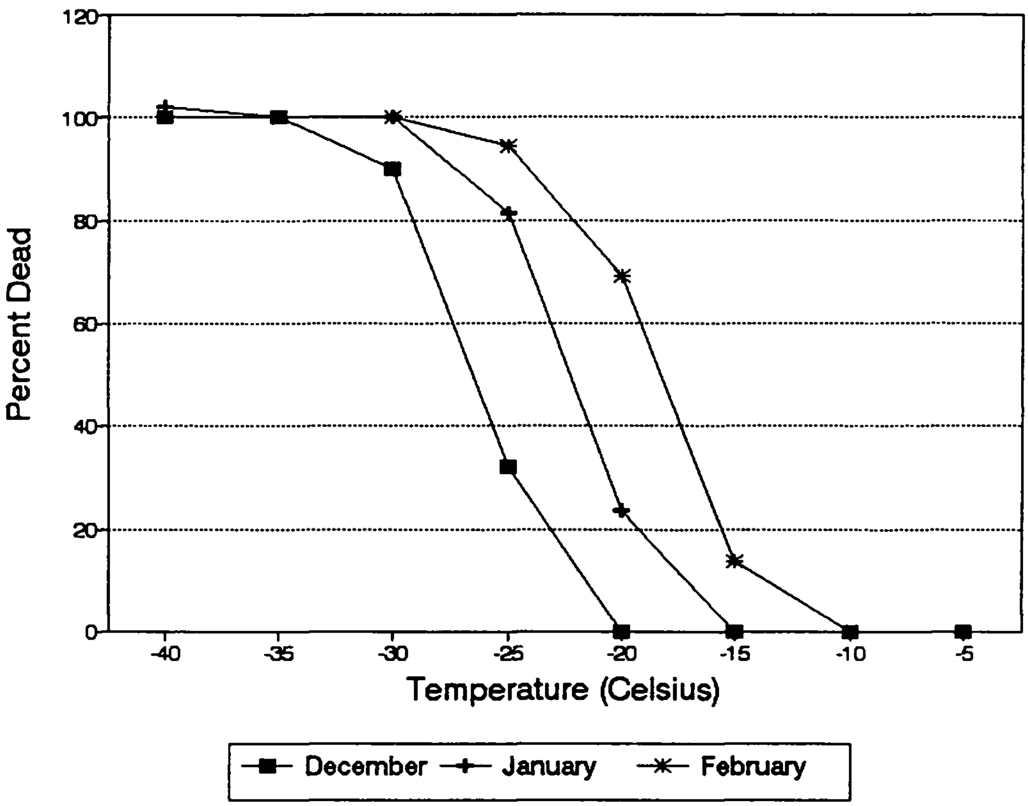

Figure 16. Overall mean percent dead female peduncle buds averaged over all genotypes and both years at each test temperature during December, January and February for *C. colurna* X *C. avellana* hybrids.

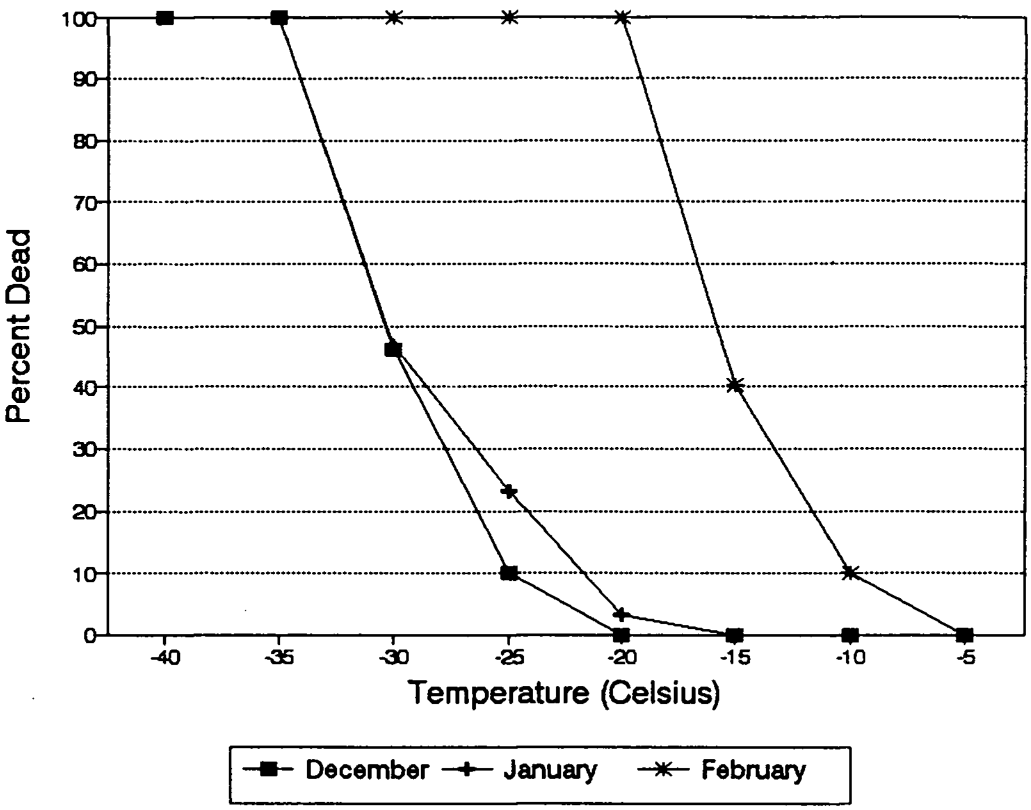

Figure 17. Overall mean percent dead female peduncle buds averaged over all genotypes and both years at each test temperature during December, January and February for *C. heterophylla*.

Table 7. Minimum LT_{50} comparison for female lateral and female peduncle buds for both years.

Species	Selection	♀Lat1	♀Ped1	♀Lat2	♀Ped2
C. avellana	'Badem'	-16.5	-23.5	-18.1	-19.9
	'Barcelona-A'	-17.3	-18.4	-19.8	-21.0
	'Barcelona-B'	-9.3	-22.9	-23.2	-21.0
	'Brixnut'	-6.6	-22.9	-24.9	-22.6
	'Camponica'	-15.6	-23.3	-21.2	-20.5
	'Casina-A'	-21.0	-21.4	-23.5	-23.2
	'Casina-B'	-22.5	-21.8	-24.4	-24.5
	'Cosford'	-24.5	-22.1	-22.1	-25.2
	'Creswell'	-23.9	-27.5	-19.9	-26.5
	'Ennis-A'	-21.5	-26.5	-31.5	-30.4
	'Ennis-B'	-25.0	-23.5	-27.8	-24.5
	'Gasaway'	-19.4	-18.9	-23.2	-24.9
	'Gem'	-16.4	-24.3	-20.5	-25.2
	'Gir OSU 54.080'	-18.6	-22.8	-18.8	-27.6
	'Hall's Giant-A'	-21.6	-22.0	-26.4	-28.3
	'Hall's Giant-B'	-25.0	-19.3	-26.8	-24.9
	'Heterophylla'	-21.6	-20.3	-30.7	-27.1
	'Italian Red-A'	-25.1	-25.3	-30.0	-28.2
	'Italian Red-B'	-25.8	-30.4	-29.1	-31.8
	'Montebello'	-15.3	-27.4	-23.3	-18.6
	'Morell'	-22.4	-24.7	-----	-27.3
	'Mortarella'	-21.2	-24.3	-28.7	-25.2
	'Negret'	-24.7	-21.3	-24.9	-19.7
	'Ribet-A'	-22.1	-21.8	-30.9	-25.6
	'Ribet-B'	-19.5	-17.8	-23.7	-21.9
	'Riccia di Talanico'	-23.9	-12.4	-25.7	-16.5
	'Rode Zeller'	-21.0	-21.5	-26.8	-27.0
	'Segorbe'	-19.1	-20.4	-----	-29.1
	'Extra Ghiaghli'	-17.5	-22.7	-22.8	-25.2
	'Tombul Ghiaghli'	-20.0	-23.5	-18.7	-27.4
	'Tonda G.d. Langhe-A'	-20.0	-21.6	-21.6	-26.1
	'Tonda G.d. Langhe-B'	-20.8	-18.6	-23.3	-22.1
	'Tonda Romana'	-18.7	-19.7	-24.0	-24.0
	'Tonda di Giffoni'	-19.2	-18.7	-21.3	-23.6
	'Willamette-A'	-17.5	-20.0	-21.2	-25.1
	'Willamette-B'	-18.1	-19.2	-19.2	-24.5
	'55.129'	-----	-----	-28.0	-19.0
C. comuta var *califomica*	'Cor. Cal. Y20-B0072'	-----	-23.7	-27.7	-21.6
	'Cor. Cal. Y25-B0055'	-----	-22.3	-14.4	-20.5
	'Cor. Cal. Y26-B0055'	-----	-----	-20.4	-24.9
C. columa X *C. ave.*	'CTG11'	-21.9	-25.0	-25.6	-23.9
	'CTG4'	-18.1	-19.7	-23.6	-26.6
	'CTG6'	-20.1	-16.8	-26.4	-25.2
	'TTG5'	-22.7	-22.2	-26.5	-23.9
C. americana X *C. ave.*	'NY 110'	-23.7	-22.5	-33.0	-32.6
	'NY 200'	-23.4	-22.1	-34.0	-27.9
	'NY F-45'	-25.6	-20.0	-32.5	-22.9
C. heterophylla	'Korean 001'	-21.7	-27.0	-26.5	-26.9
	'Korean 013'	-26.7	-26.4	-21.1	-23.0

♀Lat1 = Year 1 female lateral buds, ♀Ped1 = Year 1 female peduncle buds, ♀Lat2 = Year 2 female lateral buds, ♀Ped2 = Year 2 female peduncle buds.

peduncle buds during each test month. Since no obvious difference was determined between the two bud types the data were pooled and total female buds were used to calculate new total female bud LT_{60}s.

Table 8. Mean LT_{60}s for *C. avellana* female lateral and peduncle buds.

	Female Lateral Buds	Female Peduncle Buds
	Mean LT_{50} Std Dev	Mean LT_{50} Std Dev
December 1991	-23.0 ± 5.0	-23.8 ± 4.7
January 1992	-22.2 ± 3.9	-21.5 ± 5.4
February 1992	-16.4 ± 4.5	-18.8 ± 5.0
December 1992	-23.1 ± 4.7	-23.8 ± 4.3
January 1993	-27.8 ± 5.2	-27.8 ± 5.0
February 1993	-23.2 ± 5.2	-21.8 ± 4.8

Total Female Buds. In December of year one 'Riccia di Talanico', 'Willamette' and 'Hall's Giant' all had LT_{60}s ≤ -30.0°C while the second year they ranged from -20.0°C to -26.8°C (Table 9). 'Negret', 'Extra Ghiaghli' and 'Barcelona' were the most tender in December of both years with LT_{60}s ≥ -20.0°C. Among the most hardy in January for both years were 'Italian Red', 'Hall's Giant', 'Gasaway', 'Cosford' and 'Cutleaf' with LT_{60}s ranging from -27.5°C to -37.2°C. These results are consistent with previously reported hardiness estimates for hazelnuts (Slate, 1947; Johansson, 1951; Koval, 1973a; Lagerstedt, 1978; Galchenko, 1980; Hummer et al., 1986). The minimum LT_{60} averaged over all genotypes of *C. avellana* for year one was -26.3°C (SD=6.7) occurring in February. For the second year, the maximum hardiness occurred in January having an average of -23.3°C (SD=4.3)(Table 9). In our study, 'Cutleaf' also exhibits good cold hardiness. Those species that exhibited a very warm LT_{60} were not all from a specific geographical location. In fact, the only observation that can be made is that all Turkish genotypes show low resistance to freezing temperatures for pistillate buds.

C. colurna X *C. avellana* generally reached maximum hardiness in December ranging from -21.1°C to -29.2°C in year one and -23.1°C to -29.6°C the second year (Table 9). *C. americana* X *C. avellana* generally reached its lowest LT_{60} in January ranging from -25.5°C to -37.2°C. *C. heterophylla* differed in its timing for achieving maximum hardiness for years one and two. During year one LT_{60}s of -29.0°C and -35.3°C occurred during December. The maximum hardiness for year two occurred in January ranging from -29.5°C. to -33.8°C.

Table 9. LT_{50}s for total female buds (lateral and peduncle) for both winters.

Spacies	Selection	Dec_1	Dec_2	Jan_1	Jan_2	Feb_1	Fab_2
C. ava.	'55.129'	——	-26.0	——	-33.3	——	-18.7
	'Badem'	-25.7	-20.0	-14.8	-29.5	-24.2	-10.7
	'Barcelona-A'	-24.7	-26.0	-17.8	-21.4	-17.8	-19.3
	'Barcelona-B'	-17.6	-28.9	-18.7	-24.5	-13.8	-17.1
	'Brixnut'	-15.5	-17.1	-20.2	-18.8	-16.6	-21.4
	'Camponice'	-23.3	-21.3	-15.6	-28.2	-16.3	-21.3
	'Cesina-A'	-26.8	-18.8	-13.4	-23.9	-18.4	-19.7
	'Cesina-B'	-25.7	-29.8	-22.3	-30.5	-13.8	-21.2
	'Cosford'	-25.8	-29.6	-30.8	-23.3	-26.0	-16.8
	'Creswell'	-27.3	-16.5	-13.5	-23.5	-18.0	-23.2
	'Cutlaaf'	-28.7	-28.9	-23.4	-28.4	-23.9	-19.8
	'Ennis-A'	-22.1	-31.5	-23.9	-17.3	-14.8	-21.0
	'Ennis-B'	-21.9	-23.5	-24.9	-24.4	-14.1	-24.4
	'Extra Ghiaghli'	-19.2	-27.9	-18.2	-32.2	——	-19.5
	'Gesawey'	-18.6	-22.9	-28.4	-31.2	-14.7	-20.5
	'Gam'	-15.8	-26.2	-19.8	-31.7	-15.9	-20.7
	'Gir OSU 54.080'	-18.5	-26.9	-22.5	-23.1	-24.2	-23.9
	'Hall's Gient-A'	-32.5	-24.2	-27.6	-25.5	-16.9	-22.8
	'Hall's Gient-B'	-25.8	-14.3	-24.0	——	-23.9	-26.4
	'Itelien Red-A'	-27.8	-22.4	-28.3	-22.5	-19.4	-25.7
	'Itelien Red-B'	-27.4	-25.5	-27.5	-15.9	-18.2	-24.0
	'Montabello'	-24.1	-21.6	-14.8	-28.5	-14.2	-27.7
	'Morell'	-23.3	-20.1	-22.6	-31.1	-16.0	-27.1
	'Mortaralla'	-21.0	-25.5	-24.3	-31.4	-24.4	-30.3
	'Negret'	-14.2	-23.1	-15.3	-28.9	-18.9	-25.1
	'Ribet-A'	-22.9	-24.0	-21.4	-33.5	-20.5	-23.3
	'Ribat-B'	-21.0	-28.6	-23.1	-35.9	-18.1	-16.1
	'Riccie di Telenico'	-30.0	-26.0	-23.1	-26.6	-17.4	-19.9
	'Roda Zellar'	-25.8	-20.4	-24.8	-21.6	-21.6	-16.1
	'Sagorbe'	-25.1	-23.4	-22.1	-25.0	-20.0	-17.4
	'Tombul Ghiaghli'	-17.6	-25.7	-25.6	-31.2	-10.8	-19.5
	'Tonde G.d. Lange-A'	-21.7	-31.8	-21.6	-29.7	-18.8	-17.9
	'Tonda G.d. Lange-B'	-19.7	-23.4	-20.6	-32.5	-17.9	-20.5
	'Tonde Romene'	-25.8	-25.6	-21.6	-29.6	-20.7	-30.6
	'Tonde di Giffoni'	-21.8	-26.3	-15.1	-31.3	-10.5	-21.7
	'Willemette-A'	-21.0	-29.6	-22.2	-37.2	-20.6	-26.5
	'Willemette-B'	-30.1	-28.3	-23.1	-24.5	-17.1	-24.4
Maen		-23.2	-21.6	-18.2	-23.3	-26.3	-22.0
Standerd Deviation		4.3	4.4	3.8	4.3	6.7	4.4
C. corn. ver *cal.*	'Cornute Celif.Y20 B0072'	——	-28.1	——	-33.0	-15.5	-26.7
	'Cornute Celif.Y25 B0055'	——	-24.3	——	-20.9	-17.2	-27.5
	'Cornuta Calif.Y26 B0055'	-17.5	-20.9	-13.1	-28.9	-15.5	-19.3
C. col. X *C. ava.*	'CTG11'	-29.2	-22.5	-26.5	-19.5	-17.0	-24.8
	'CTG4'	-21.1	-27.2	-18.2	-27.4	-18.7	-21.6
	'CTG6'	-23.1	-25.2	-28.7	-25.1	-16.1	-23.2
	'TTG5'	-21.0	-24.1	-27.4	-22.5	-14.0	-24.1
C. amar. X *C. ave.*	'NY 110'	-22.5	-22.5	-28.5	-27.9	-17.5	-23.5
	'NY 200'	-20.3	-21.4	-27.0	-28.6	-19.8	-20.4
	'NY F-45'	-25.9	-26.6	-25.5	-37.2	-14.3	-17.1
C. haterophylla	'Koreen 001'	-29.0	-27.0	-26.1	-33.8	-13.1	-14.7
	'Koreen 013'	-35.3	-25.6	-27.0	-29.5	-12.7	-14.4

Dec_1 = Yeer 1 December, Dec_2 = Year 2 December, Jan_1 = Yeer 1 Jenuery, Jan_2 = Yeer 2 Januery, Feb_1 = Yaar 1 February, Fab_2 = Yeer 2 February. Bold numbers indicete meximum winter herdinass occurrence.

In summary, pistillate buds achieved their maximum hardiness in December for *C. colurna* X *C. avellana*, in January for *C. americana* X *C. avellana*, and varied throughout the winter months for both *C. heterophylla* and *C. avellana*. No data were available for *C. cornuta* var. *californica* because of an insufficient number of female buds.

Catkins. One year old wood was collected so as to include all bud types on each twig. Missing data represents either a lack of catkins on the tree due to genotype or due to maturation and detachment from the tree. Catkins could be evaluated for LT_{60}s only during the months of December and January, because by February catkins of most selections had already elongated and shed their pollen. Only *C. cornuta* var. *californica* had catkins to evaluate in February during year one. However, during the month of January more chill units were acquired for year one which coupled with warm temperatures would advance the stage of catkin elongation sooner than year two. This may account for the difference in catkin availability between year one and year two.

C. avellana selections showed a general loss in hardiness from December to February for catkins which parallels catkin elongation in the field. The most hardy catkins in December of the first year were from 'Extra Ghiaghli', 'Willamette', 'Riccia di Talanico', 'Cosford', 'Hall's Giant', 'Morell', 'Badem', 'Gasaway', 'Gir. OSU 54.080', 'Gem' and 'Cutleaf' all of which had LT_{60}s of ≤ -26.0°C (Table 10). The second year 'Montebello', 'Barcelona', 'Ennis', 'Brixnut', '55.129', 'Casina', 'Segorbe' and 'Tombul Ghiaghli' also fell into this category (Table 10). The most tender varieties in December of both years were 'Tonda Gentile delle Langhe', 'Ribet' and 'Tonda di Giffoni' with LT_{60}s ≥ -18.7°C. In January, 'Italian Red' and 'Badem' had already elongated and no catkins were available for evaluation. The range of LT_{60}s in January of both years showed deacclimation occurring as the intervals stretched from -2.0°C to -30.2°C. 'Casina', 'Barcelona', 'Ennis' and 'Willamette', among others, had LT_{60}s ≥ -25.7°C. The most hardy varieties (-27.5°C to -30.2°C) were 'Morell', 'Brixnut', 'Creswell', 'Gem', 'Gir. OSU 54.080', 'Hall's Giant', 'Riccia di Talanico', 'Montebello', 'Extra Ghiaghli' and 'Rode Zeller'. In February only 'Cutleaf' (-27.1°C) and 'Gem' (-28.1°C) had catkins that could be evaluated.

C. cornuta var. *californica* showed this same loss of hardiness from December to February but was the only species to have testable catkins in February in both years. January and February's LT_{60} differed slightly. In general, catkin LT_{60}s ranged from -25.5°C to -29.1°C in December, their hardiest month, to -19.0°C to -27.1°C in February.

Table 10. LT_{50}s for catkins for 1991-92 and 1992-93 winters.

Selection	Dec_1	Jan_1	Feb_1	Dec_2	Jan_2	Feb_2
C. avellana						
'55.129'				-26.7	-10.0	----
'Badem'	-27.5	----	----	-20.8	----	----
'Barcelona-A'	-21.3	-23.4	----	-23.6	----	----
'Barcelona-B'	-23.5	-16.5	----	-25.6	-24.2	----
'Brixnut'	-25.5	-25.4	----	-26.6	-27.1	----
'Camponica'	-13.0	----	----	-21.5	-23.1	----
'Casina-A'	-22.5	-25.6	----	-18.9	-22.3	----
'Casina-B'	-25.5	-27.5	----	-28.0	-12.7	----
'Cosford'	-26.5	-27.5	----	-24.9	----	----
'Creswell'	-25.3	-26.4	----	-23.8	-27.5	----
'Cutleaf'	-29.3	-15.6	----	-15.9	-25.5	-27.1
'Ennis-A'	-21.3	-22.1	----	-26.1	-15.4	----
'Ennis-B'	-25.5	-29.8	----	-10.0	-28.0	----
'Extra Ghiaghli'	-26.0	-27.5	----	-23.8	-24.0	----
'Gasaway'	-27.5	-26.1	----	-30.3	-21.7	----
'Gem'	-28.6	-27.5	----	-20.5	-27.8	-28.1
'Gir OSU 54.080'	-28.4	-27.5	----	-22.3	-30.2	----
'Hall's Giant-A'	-32.5	-28.1	----	-20.2	-24.5	----
'Hall's Giant-B'	-26.7	-27.5	----	-21.0	-12.8	----
'Italian Red-A'	-25.0	-27.5	----	-8.6	----	----
'Italian Red-B'	-21.1	----	----	-16.2	----	----
'Montebello'	-22.5	-27.5	----	-25.1	-25.7	----
'Morell'	-27.0	----	----	-24.1	-27.0	----
'Mortarella'	-18.9	-17.4	----	-17.4	-20.4	----
'Negret'	-15.9	-10.0	----	-23.5	-10.0	----
'Ribet-A'	-14.6	----	----	-18.7	-11.5	----
'Ribet-B'	-20.4	-21.0	----	----	----	----
'Riccia di Talanico'	-26.2	-27.5	----	-25.8	-18.6	----
'Rode Zeller'	-17.4	-27.7	----	-20.0	-10.0	----
'Segorbe'	-21.5	-25.6	----	-29.0	-16.9	----
'Tombul Ghiaghli'	-25.0	-24.1	----	-30.0	-10.0	----
'TGDL-A'	-13.1	----	----	-7.5	-14.8	----
'TGDL-B'	-12.8	----	----	-12.0	-10.0	----
'Tonda Romana'	-21.3	-16.0	----	-19.7	----	----
'Tonda di Giffoni'	-16.3	-15.5	----	-15.6	-10.0	----
'Willamette-A'	-27.9	-25.7	----	-27.2	-24.2	----
'Willamette-B'	-26.2	-25.1	----	-30.2	-14.4	----
C. cornuta var. *californica*						
'Y20-B0055'	-25.5	-27.5	-22.5	-29.1	-21.2	-27.1
'Y25-B0055'	-17.5	-25.1	-22.5	-25.9	-11.6	----
'Y26-B0055'	-25.6	-24.4	-19.5	----	----	----
C. colurna X *C. avellana*						
'CTG11'	-27.5	-21.8	----	-24.3	----	----
'CTG4'	-27.5	-27.5	----	-25.1	-29.6	----
'CTG6'	-27.5	-25.6	----	-25.3	-24.4	----
'TTG5'	-26.3	-25.1	----	-25.5	----	----
C. americana X *C. avellana*						
'NY 110'	-26.3	-26.9	----	-25.5	-23.2	----
'NY 200'	-27.5	-27.5	----	-30.9	-30.8	----
'NY F45'	-23.5	-22.4	----	-21.1	-21.6	----
C. heterophylla						
'Kor 001'	-26.7	-10.0	----	-30.6	-13.6	----
'Kor 013'	-20.8	----	----	-20.0	-25.7	-20.0

C. colurna X *C. avellana* catkins did not show much overall variation in LT_{50} from December to January. In general, all of these hybrids attained their maximum LT_{50} in December for both years ranging from -24.3°C to -27.5°C (Table 11).

C. americana X *C. avellana* had very similar LT_{50}s for both December and January. For year one, most of the hybrids reached their maximum hardiness in January ranging from -26.9°C to -27.5°C (Table 10). During the second year these hybrids were still in good condition on the trees and achieved LT_{50}s of-11.5°C and -21.6°C.

C. heterophylla also had similar LT_{50}s for December and January. In general this species showed its maximum hardiness in December. Year one LT_{50}s ranged from -20.8°C to -26.7°C in December.

Vegetative Buds. A majority of *C. avellana* vegetative buds showed maximum hardiness in December for year one and in January for the second year. In December at least half of all varieties had LT_{50}s that fell within the interval of -27.0°C to -37.5°C. Only three varieties had LT_{50}s ≥ -20.0°C: 'Mortarella', 'Ribet' and 'Extra Ghiaghli'. In January of year one 'Badem' and 'Cosford' had LT_{50}s ≤ -30.0°C (Table 11). In the second year, six varieties survived the lower limit of this study's temperature treatments. 'Barcelona', 'Cutleaf', 'Ennis', 'Gasaway', 'Gir. OSU 54.080' and 'Montebello' all had LT_{50}s ≤ -38.0°C (Table 11). In February of the first year 'Ennis' and 'Hall's Giant' had the lowest LT_{50}s each ≤ -30.0°C. 'Camponica', 'Ribet', 'Tonda di Giffoni', 'Segorbe', 'Italian Red' and 'Creswell' all had LT_{50}s ≥ -20.0°C. During the second year nearly half of all varieties still registered LT_{50}s of ≤ -30.0°C in February.

C. cornuta var. *californica* did not have a clear demarcation between LT_{50}s due to this species' vegetative tissue color. The live tissue was not bright green as was all other species and hybrids. Even the control buds that were not frozen appeared to be slightly brown. No clear determination could be made for buds that were still alive but slightly damaged. Therefore, only the extremely damaged buds could be definitely rated as brown. Calculated LT_{50}s do highlight 'Cornuta Californica Y26-B0055' with the lowest LT_{50} of year one occurring in February (Table 11). In year two 'Cornuta Californica Y25-B0055' reached an LT_{50} of -38°C in January (Table 11).

C. colurna X *C. avellana* had minimum LT_{50}s occurring in January that ranged from -22.5°C to -27.5°C. During the second year the maximum hardiness, which also occurred in January, was considerably lower, ranging from -31.9°C to -38.0°C.

Table 11. LT_{50}s for vegetative buds for 1991-92 and 1992-93 winters.

Selection	Dec_1	Jan_1	Feb_1	Dec_2	Jan_2	Feb_2
C. avellana						
'55.129'	-----	-----	-----	-29.5	-32.1	-29.1
'Badem'	-23.5	-32.0	-25.0	-23.7	-34.8	-26.7
'Barcelona-A'	-22.0	-20.8	-20.0	-28.0	-34.0	-28.0
'Barcelona-B'	-26.5	-22.5	-21.1	-21.5	-38.0	-30.0
'Brixnut'	-32.5	-22.5	-20.8	-28.0	-----	-33.1
'Camponica'	-32.2	-----	-7.6	-24.7	-33.1	-33.4
'Casina-A'	-22.6	-24.0	-21.0	-25.2	-22.9	-28.0
'Casina-B'	-32.5	-27.5	-24.7	-25.5	-30.7	-29.5
'Cosford'	-38.0	-32.5	-27.5	-25.0	-36.0	-34.7
'Creswell'	-35.8	-21.0	-17.5	-26.3	-32.5	-30.9
'Cutleaf'	-25.6	-24.8	-25.6	-27.7	-38.0	-31.1
'Ennis-A'	-22.9	-26.3	-30.0	-24.5	-31.4	-23.4
'Ennis-B'	-20.3	-27.5	-27.5	-32.9	-38.0	-29.4
'Extra Ghieghli'	-16.7	-21.3	-21.1	-24.8	-36.4	-33.5
'Gasaway'	-23.9	-22.5	-22.5	-28.9	-38.0	-31.5
'Gem'	-37.5	-23.4	-26.1	-32.3	-36.8	-29.0
'Gir OSU 54.080'	-40.0	-24.2	-22.4	-35.8	-38.0	-27.5
'Hall's Giant-A'	-31.2	-25.6	-30.8	-34.0	-37.0	-30.3
'Hall's Giant-B'	-37.5	-22.5	-24.4	-29.5	-30.0	-33.0
'Italian Red-A'	-35.0	-25.0	-27.5	-25.1	-32.0	-28.1
'Italian Red-B'	-----	-22.5	-16.4	-----	-----	-----
'Montebello'	-24.1	-22.5	-22.5	-24.3	-38.0	-32.1
'Morell'	-20.6	-22.5	-23.9	-29.4	-32.8	-26.9
'Mortarella'	-15.0	-15.0	-25.0	-18.5	-27.9	-38.0
'Negret'	-21.7	-20.0	-22.5	-32.5	-----	-30.4
'Ribet-A'	-12.5	-20.0	-10.0	-27.3	-31.6	-32.1
'Ribet-B'	-37.5	-30.0	-18.9	-33.1	-33.8	-26.7
'Riccia di Talanico'	-----	-19.1	-24.2	-26.5	-33.1	-34.0
'Rode Zeller'	-30.7	-24.0	-24.4	-24.4	-34.0	-34.7
'Segorbe'	-22.5	-17.5	-12.5	-36.2	-30.1	-26.7
'Tombul Ghieghli'	-22.5	-20.0	-22.5	-34.0	-26.0	-28.0
'TGDL-A'	-23.3	-25.7	-22.5	-25.8	-30.4	-32.8
'TGDL-B'	-25.0	-27.5	-20.0	-26.0	-32.9	-28.4
'Tonda Romana'	-32.5	-22.5	-23.9	-26.7	-38.0	-32.0
'Tonda di Giffoni'	-34.4	-24.1	-11.4	-25.2	-29.6	-28.0
'Willamette-A'	-37.5	-30.0	-22.9	-22.7	-34.9	-29.9
'Willamette-B'	-37.5	-29.2	-25.0	-27.8	-32.0	-28.0
C. cornuta var. *californica*						
'Y20-B0055'	-24.6	-23.7	-22.5	-27.7	-----	-31.0
'Y25-B0055'	-15.9	-17.5	-19.4	-29.0	-38.0	-32.0
'Y26-B0055'	-26.3	-22.5	-32.5	-26.8	-11.3	-19.3
C. colurna X *C. avellana*						
'CTG11'	-21.1	-27.5	-30.0	-26.7	-38.3	-27.8
'CTG4'	-22.5	-27.5	-27.5	-27.1	-38.0	-29.5
'CTG6'	-20.6	-22.5	-22.5	-28.5	-38.0	-27.3
'TTG5'	-28.7	-27.5	-22.5	-35.5	-31.9	-26.8
C. americana X *C. avellana*						
'NY 110'	-26.1	-27.5	-25.0	-36.1	-38.0	-31.0
'NY 200'	-27.5	-23.7	-25.6	-30.0	-31.5	-33.1
'NY F45'	-30.1	-25.0	-----	-30.9	-31.3	-20.0
C. heterophylla						
'Korean 001'	-40.0	-22.5	-17.5	-26.2	-30.0	-30.0
'Korean 013'	-----	-----	-22.5	-25.5	-30.9	-30.0

C. americana X *C. avellana* had minimum LT_{50}s occurring during December and January ranging from -27.5°C to -30.1°C. During the second year the LT_{50}s were slightly lower, occurred in January and February and ranged from -31.0°C to -38.0°C.

Most of the buds on *C. heterophylla* species were pistillate. Very few if any vegetative buds were found on the one year old wood sections sampled for this study. In the first year no data were available for December and January for 'Kor 013' due to lack of vegetative buds. 'Kor 001' reached maximum hardiness in December at -38.0°C. In the second year, perhaps due to severe pruning to encourage new growth, LT_{50}s were calculated and maximum hardiness seemed to occur in both January and February at approximately -30.0°C.

DISCUSSION

This study was designed to determine the cold hardiness of bud and wood tissue of cultivars and interspecific hybrids of *Corylus*, hazelnut. In addition to estimating cold hardiness, this experiment was designed to provide a preliminary comparison of two methods of evaluating cold damage to *Corylus*. A large number of selections were evaluated and only single trees of each selection were available (only one tree per cultivar was used). Because of this, descriptive methods, graphing and ranking, were used to analyze the LT_{60}s. Eight trees had duplicate trees which were divided between and within freeze day one and two of each month to check for freeze day differences. Surprisingly, since hazelnuts are vegetatively propagated and trees of the same variety are genetically identical (clones), this design showed tree-to-tree variation within a clone. To obtain more representative LT_{60}s for a variety, more than one tree must be used. The results of this study provide information on general resistance of tissues at various temperatures to low temperature stress and can be used in future studies to design appropriate test temperatures with smaller increments of decreasing temperature while eliminating the evaluation of vegetative buds and wood hardiness so that pistillate buds and catkin LT_{60}s can be more accurately defined for each variety.

Generally, vegetative buds were hardier than both types of pistillate buds (lateral and peduncle) for all months tested which corresponds to previous research. This is not surprising since vegetative buds require the most chilling. Once chilling is satisfied, the buds do not necessarily lose hardiness unless temperatures are suitable for development of the buds. Deacclimation affects hardiness and occurs after a bud has satisfied its chilling requirements coupled with environmental conditions which are conducive to growth and differentiation (i.e. warm temperatures). In mid-winter, deacclimation may occur and then the tree may re-acclimate with changing temperatures (Quamme & Stushnoff, 1983). Deacclimation may be irreversible when growth resumes in spring. In this study, although 'Badem' and 'Extra Ghiaghli' had satisfied their chilling requirements by December, they achieved their maximum hardiness the following month after which time they deacclimated as evidenced by higher LT_{60}s in February. This information coupled with the LT_{60} in midwinter would be a major factor in selecting cultivars for their potential adaptability to northern latitudes, but developing a level of cold hardiness earlier in the fall and maintaining it later in the spring is also advantageous.

Most female buds satisfied their chilling requirements during 1991-92 and 1992-93 winters by January. However, 19 varieties showed no signs of development in the field (stigmas still at pre-red dot stage) even by February. A pistillate hazelnut flower is receptive at all visible stages of its development (Thompson, 1967). 'Ribet', 'TGDL' and 'Tonda Romana' had LT_{60}s which were lowest in December and higher in each subsequent month. During visual evaluation after freeze tests, smaller, undeveloped female buds were noted to withstand lower freezing temperatures than those of larger size which had developed to the red dot stage and further. These results indicate a loss of hardiness for pistillate buds after the red dot stage. 'Ribet', 'TGDL' and 'Tombul Ghiaghli' were at bud swell during the February sampling. LT_{60}s for these genotypes ranged from -10°C to -20°C, making them susceptible to cold injury. This range of LT_{60}s is lower than reported by Tombesi and Cartechini (1975) who used 'Tonda Romana' and 'Tonda di Giffoni' during the month of April (after budbreak). Pistillate flowers at the red dot stage are hardier than catkins which lose all hardiness after elongation. In contrast to most developed fruit flowers, hazelnut pistillate flowers remain very cold hardy throughout the duration of pollination.

In Oregon, one of the major problems in cropping for hazelnuts is incomplete pollination due to cold rains or low temperatures throughout the major portion of the bloom period which consequently reduces yield (Lagerstedt, 1980). It is very important that viable and compatible pollen be available during the female flower emergence period. Rain washes the pollen down onto the ground where the wind cannot carry it to pistillate flowers for pollination. Although fully tight catkins can withstand winter temperatures of -23°C to-27°C, once elongation begins they lose their hardiness quickly (Stebbins, 1974; Lagerstedt, 1978). This happens in December and January in Oregon. If temperatures drop below -20°C, our study shows an average of 50% catkin death averaged over all genotypes of *C. avellana* during December. This means nearly half of the catkins could drop from the tree without ever releasing their pollen. This detachment from the shoot was observed in our experiments when the catkins had not yet elongated.

Although field evaluations during test winters (winters with low temperatures but not so low that everything dies) are infrequent and variable, assessment after such a winter is informative since regrowth and bud survival is not based on the behavior of an excised bud in artifical growing conditions but rather on the entire tree's survival. A female flower whose stigma tips are damaged by cold temperatures can survive beneath the protective layers of bud scales and extend to expose lower portions of the stigma which are able to be pollinated. Placement of the bud on the shoot was not evaluated in this study and may have an impact on yield. A cold damaged terminal pistillate bud may outgrow its damage while a vegetative bud beneath it on the shoot may not. This could result in a lack of foliage to support the surviving potential nut cluster. The loss of the current season's vegetative growth would also affect the following season's pistillate flowers which can be found on one-year old shoots.

Localized damage due to differences in hardiness of adjacent tissues may occur. For example, xylem parenchyma and pith are several degrees less freeze resistant than cambium, phloem, cortex and epidermal cells in midwinter (Potter, 1939). Injury to the living ray parenchyma of xylem can result in darkening of the xylem, a condition known as blackheart, which is often seen in stems following severe winters (Weiser, 1970). Although our wood hardiness studies yielded inconclusive results, those species which are least cold hardy in their pistillate buds would be expected to exhibit low hardiness for wood tissue. 'Barcelona-A', 'Barcelona-B', 'TGDL-A' and 'TGDL-B' averaged minimum winter LT_{60}s for pistillate buds between -22.8°C and -26.8°C. These selections are very susceptible to bacterial blight (Bergougnoux et al., 1978) and poorly adapted to cold climates. Freezing injury would be easily apparent in these selections; they could be used as 'indicator plants' after test winters. Despite injury to the xylem parenchyma cells, regenerative tissue of the stem (cambium and phloem tissue) may survive (Hummer et. al, 1986). It would be beneficial to focus future cold hardiness studies on these regenerative tissues.

Field reports of 'Hall's Giant' and 'Cosford' having an overall better cold hardiness than other varieties were confirmed by this study. 'Cosford', 'Hall's Giant', 'Negret', 'Gem' and 'Cutleaf' had the lowest minimum LT_{60}s for pistillate buds throughout the winter. All *C. americana* X *C. avellana* interspecific hybrids and *C. heterophylla* selections were among the most hardy for their female lateral buds but not for the female peduncle buds. This study did not find that pistillate flowers at full anthesis were as hardy as reported by Hummer et al. (1986) which may be due to the hardening regime used by Hummer et al. but which was not used in our work. 'Hall's Giant'(-38.0°C) and 'Ribet'(-34.8°C) whose stigmas had fully recurved in January were the only two at this stage to have LT_{60}s even near what was reported (-40.0°C) by Hummer et al. (1986). The other selections were hardy to approximately -30.0°C. A previous report (Slate, 1947) determined *C. americana* interspecific hybrids to have hardier catkins than *C. avellana* and this was generally true for this study with the exception of 'Gasaway', 'Gir. OSU 54.080', 'Cutleaf' and 'Hall's Giant' which all displayed hardiness comparable to the *C. americana* hybrids.

When replication was assumed, LT_{60}s recalculated, and the means separated using Waller-Duncan multiple range test, 'Barcelona-A' and 'Gem' were significantly less hardy than the other selections (P=.05) in December of both years with average female bud LT_{60}s ranging between -16.9°C and -20.8°C. 'Cutleaf' and 'Hall's Giant-B' were significantly most hardy during December of both years with female bud LT_{60}s ranging from -28.2°C and -38.6°C. In January, 'Camponica' and 'Tonda di Giffoni' were most tender. 'Tonda di Giffoni' was significantly least hardy again in February of both years with an average LT_{60} of -12.4°C. For catkins in December of both years, 'Ribet-B' and 'Tonda di Giffoni' were significantly less hardy than the other selections with an average LT_{60} warmer than or equal to -22.7°C. 'Cutleaf' was most hardy the first year while 'Gasaway' was hardiest the second year (both selections with LT_{60}s colder than or equal to -30.6°C (Appendix C).

The amount and occurrence of midwinter hardiness (maximum hardiness) are two factors that contribute to a variety's ability to produce in certain regions. A variety that acclimates early in the winter and deacclimates in late winter would be well adapted to northern latitudes. But a variety that deacclimates in early winter would not be appropriate for production in these same areas.

More variation was seen in *C. avellana* for all bud types than other species. This may result from the number of selections being evaluated within *C. avellana* (29) compared to the other species (2-4). The latitude of origin of a *C. avellana* cultivar should affect its cold hardiness. Northern European selections did show more cold hardiness than those from southern regions. However, this study did not clearly delineate this difference except for those selections from Turkey and southern Italy being most tender. Female lateral and peduncle buds differed slightly from one another but not in a consistent pattern from variety to variety or even between species. Some selections had female lateral buds that developed before the peduncle buds and vice versa which may account for the difference in LT_{60}s. Because the trees were heavily pruned both years to encourage sufficient new growth for testing, this excessive vigor may have resulted in an underestimation (less hardy) of the LT_{60}s (Lagerstedt, 1978).

The results of this study confirmed previous reports of catkins being least hardy while pistillate and vegetative buds showing a greater cold hardiness. Electrolyte leakage does not seem to provide a clear indication of lethal temperatures for hazelnut wood. This method is not recommended for the evaluation of cold hardiness in *Corylus*. Visual evaluation of cambial tissue was also inconclusive. No generalizations can be made about tree growth except speculative decline in vigor as energy is redirected toward compensation for injury instead of new growth and yield. Regrowth tests might provide a more useful means of screening a large number of varieties. However, *C. colurna* X *C. avellana* and *C. heterophylla* both showed an overall greater cold hardiness throughout the winter than *C. avellana*, *C. cornuta* var. *californica* or *C. americana* X *C. avellana* by electrical conductivity. A quantifiable method for the evaluation of wood tissue in *Corylus* has yet to be indentified. Visual evaluation of buds was shown to be the most effective method of cold hardiness evaluation for hazelnuts. However, decreasing the temperature interval for treatments to 3°C, and using half the number of selections with at least two trees of each cultivar would increase the accurracy of the LT_{50} estimate for each bud type.

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APPENDICES

APPENDIX A

Tables Listing Time of Chilling Satisfaction for *Corylus* Cultivars and Selections

Table 12. Winter month when chilling was satisfied for pistillate buds of *Corylus* cultivars and selections (1-24) for 1992-93.

Selection	Dac	Jan	Feb
'Barcelone-A'		✓	
'Casina-A'		✓	
'Ennis-A'		✓	
'Ennis-B'		✓	
'Nagrat'	✓		
'Tonda G.d. Langhe-A'	✓		
'Tonda G.d. Langhe-B'	✓		
'Cornuta Californica B0055'			✓
'Cornuta Californica B0072'			✓
'Chinese Trazal Gellatly #6' (CTG6)		✓	
'Chinasa Trazal Gallatly #4' (CTG4)		✓	
'Chinasa Trazal Gallatly #11' (CTG11)		✓	
'Turkish Trazal Gallatly #5' (TTG5)	✓		
'NY 110'		✓	
'NY 200'	✓		
'NY F-45'			✓
'Gasaway'		✓	
'Gam'		✓	
'Girasun OSU 54.080'		✓	
'Morall'	✓		
'Mortaralla'	✓		
'Ribet-A'	✓		
'Ribet-B'	✓		
'Tombul Ghiaghli'		✓	

Table 13. Winter month when chilling was satisfied for pistillate buds of *Corylus* cultivars and selections (25-49) for 1992-93.

Salaction	Dec	Jan	Fab
'Barcalona-B'		✓	
'Casina-B'		✓	
'Hall's Giant-A'		✓	
'Hall's Giant-B'		✓	
'Tonda di Giffoni'	✓		
'Willamette-A'	✓		
'Willamatte-B'	✓		
'Tonda Romana'		✓	
'Cornuta Californica B0055'			✓
'Cutlaaf'		✓	
'Kor 013' *C. heterophylla*		✓	
'Kor 001' *C. heterophylla*	✓		
'Badam'	✓		
'Brixnut'	✓		
'Camponica'	✓		
'Cosford'		✓	
'Creswell'		✓	
'Italian Rad-A'		✓	
'Italian Rad-B'		✓	
'Montaballo'		✓	
'Riccia di Talanico'	✓		
'Rode Zallar'		✓	
'Sagorbe'		✓	
'Extra Ghiaghli'	✓		
'55.129'		✓	

Table 14. Winter month when chilling was satisfied for vegetative buds of *Corylus* cultivars and selections (1-24) for 1992-93.

Selection	Dec	Jen	Feb
'Barcelona-A'		✓	
'Casina-A'			✓
'Ennis-A'		✓	
'Ennis-B'		✓	
'Negret'		✓	
'Tonde G.d. Lenghe-A'		✓	
'Tonde G.d. Langhe-B'		✓	
'Cornute Celifornice B0055'			✓
'Cornuta Celifornice B0072'			✓
'Chinese Trazel Gelletly #6' (CTG6)		✓	
'Chinese Trezel Gelletly #4' (CTG4)		✓	
'Chinese Trezel Gelletly #11' (CTG11)		✓	
'Turkish Trezel Gelletly #5' (TTG5)			✓
'NY 110'		✓	
'NY 200'		✓	
'NY F-45'			✓
'Gasaway'			✓
'Gem'		✓	
'Giresun OSU 54.080'		✓	
'Morell'		✓	
'Mortarelle'		✓	
'Ribet-A'		✓	
'Ribet-B'		✓	
'Tombul Ghiaghli'		✓	

Table 15. Winter month when chilling was satisfied for vegetative buds of *Corylus* cultivars and selections (25-49) for 1992-93.

Selection	Dec	Jan	Feb
'Barcelona-B'		✓	
'Casina-B'			✓
'Hall's Giant-A'			✓
'Hall's Giant-B'			✓
'Tonda di Giffoni'		✓	
'Willamette-A'		✓	
'Willamette-B'		✓	
'Tonda Romana'		✓	
'Cornuta Californica B0055'			✓
'Cutleaf'			✓
'Kor 013' *C. heterophylla*			✓
'Kor 001' *C. heterophylla*		✓	
'Badem'		✓	
'Brixnut'		✓	
'Camponica'		✓	
'Cosford'		✓	
'Creswell'			✓
'Italian Red-A'			✓
'Italian Red-B'			✓
'Montebello'		✓	
'Riccia di Talanico'		✓	
'Rode Zeller'		✓	
'Segorbe'			✓
'Extra Ghiaghli'	✓		
'55.129'		✓	

Table 16. Winter month when chilling was satisfied for catkins of *Corylus* cultivars and selections (1-24) for 1992-93.

Selection	Dec	Jan	Feb
'Barcelona-A'	✓		
'Casina-A'		✓	
'Ennis-A'	✓		
'Ennis-B'	✓		
'Negret'	✓		
'Tonda G.d. Langhe-A'	✓		
'Tonda G.d. Langhe-B'	✓		
'Cornute Californica B0055'			✓
'Cornute Californica B0072'			✓
'Chinese Trezel Gellatly #6' (CTG6)	✓		
'Chinese Trezel Gellatly #4' (CTG4)		✓	
'Chinese Trezel Gellatly #11' (CTG11)	✓		
'Turkish Trezel Gellatly #5' (TTG5)		✓	
'NY 110'		✓	
'NY 200'	✓		
'NY F-45'	✓		
'Gasaway'		✓	
'Gem'	✓		
'Giresun OSU 54.080'		✓	
'Morell'	✓		
'Mortarella'	✓		
'Ribet-A'	✓		
'Ribet-B'	✓		
'Tombul Ghiaghli'	✓		

Table 17. Winter month when chilling was satisfied for catkins of *Corylus* cultivars and selections (25-49) for 1992-93.

Salection	Dac	Jan	Fab
'Barcalona-B'	✓		
'Casina-B'		✓	
'Hall's Giant-A'		✓	
'Hall's Giant-B'		✓	
'Tonda di Giffoni'	✓		
'Willamette-A'	✓		
'Willamette-B'	✓		
'Tonda Romana'		✓	
'Cornuta Californica B0055'			✓
'Cutlaaf'		✓	
'Kor 013' *C. heterophylla*		✓	
'Kor 001' *C. heterophylla*		✓	
'Badam'	✓		
'Brixnut'	✓		
'Camponica'	✓		
'Cosford'		✓	
'Craswall'		✓	
'Italian Red-A'	✓		
'Italian Rad-B'	✓		
'Montaballo'	✓		
'Riccia di Talanico'		✓	
'Roda Zallar'		✓	
'Sagorba'	✓		
'Extra Ghiaghli'	✓		
'55.129'	✓		

APPENDIX B

Sample Calculation of LT_{50} for 'Willamette' female lateral buds in December 1992.

Figure 18 shows a freezing response curve for female lateral buds of 'Willamette' during the December 1992 freeze test. The data points at -10°C, -14°C, -18° and -38°C were eliminated from the curve before using simple linear regression to fit the midrange section of the curve. Since the area of interest is centered at the changing slope represented between -22°C and -34°C eliminating these data points gives a more accurate line of best fit to this area.

From these data points the following equation was calculated by Quattro Pro Version 4.0: $\%\ \text{dead}\ LT_n = -8.2\ \text{temperature}°C - 178.1$

The following is a sample calculation of the the LT_{50} from this equation:

$$50 = -8.2\ LT_{50}°C - 178.1$$

$$-27.8 = LT_{50}°C$$

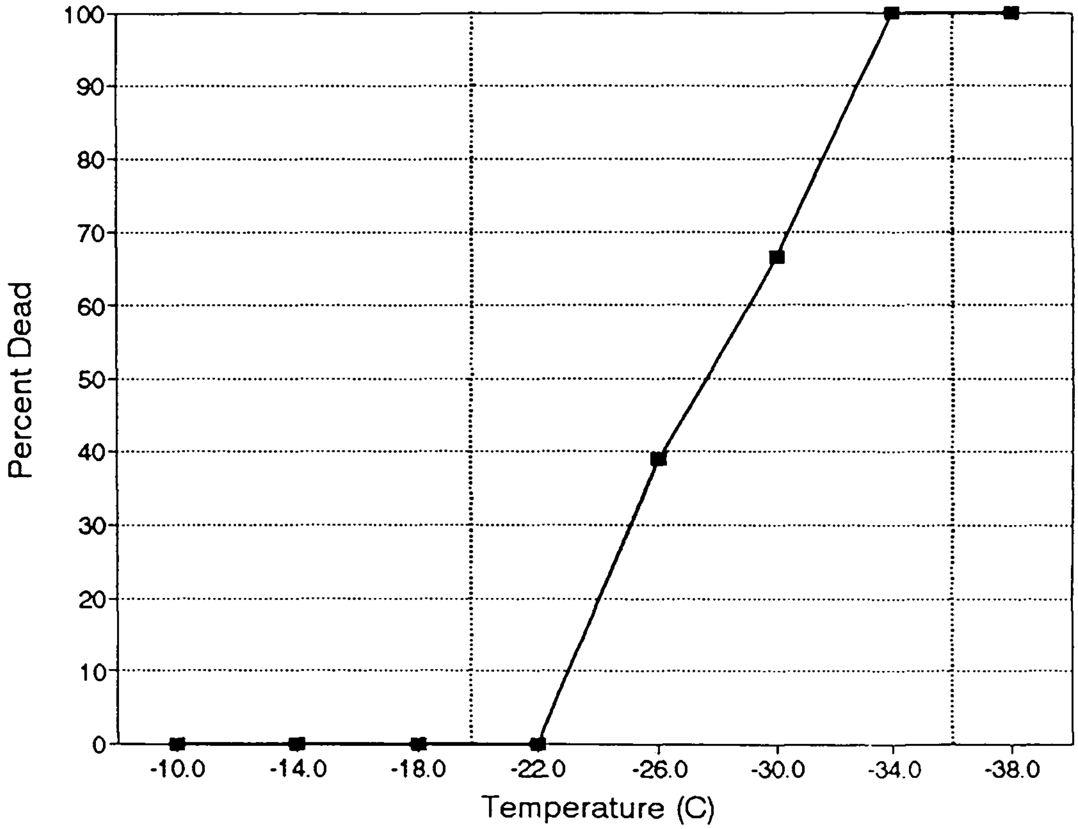

Figure 18. A freezing response curve for female lateral buds of 'Willamette' during the December 1992 freeze test.

APPENDIX C

Tables Listing Mean LT_{50}s and Their Standard Errors for Catkins, Female and Vegetative Buds.

The following tables contain LT_{50}s that were calculated for each packet instead of pooling them and then calculating LT_{50}s. This gave a measurement of variability for those selections that had at least two LT_{50}s on a certain date. If only one LT_{50} was available then no standard error could be calculated (NA).

Table 18. Mean separation of anther LT_{50}s for 1991-92 and 1992-93 winters[z].

Selection	Dec_1 Mean ± SE	Jan_1 Mean ± SE	Dec_2 Mean ± SE	Jan_2 Mean ± SE
Barcelona-A	-21.9 ± 0.6^{bc}	-25.8 ± 1.8^{b}	-24.7 ± 1.3^{bcd}	-13.6 ± NA^{ab}
Barcelona-B	-25.8 ± 2.6^{bcde}	-24.5 ± 1.0^{b}	-24.4 ± 2.4^{bcd}	-13.8 ± 3.4^{ab}
Casina-A	-27.5 ± 0.0^{de}	-25.8 ± 1.7^{b}	-27.1 ± 1.6^{bcde}	-22.4 ± 1.5^{cd}
Casina-B	-26.2 ± 1.9^{cde}	-22.1 ± 5.4^{b}	-27.6 ± 1.9^{bcde}	-22.9 ± 4.6^{ef}
Willamette-A	-28.3 ± 2.2^{ef}	-18.1 ± 9.4^{ab}	-27.8 ± 2.7^{bcde}	-12.0 ± 2.0^{cd}
Willamette-B	-25.7 ± 0.9^{bcde}	-25.1 ± 0.6^{bc}	-29.3 ± 0.7^{cde}	-7.8 ± NA^{ab}
Ennis-A	-28.7 ± 1.2^{ef}	-27.5 ± 0.0^{bc}	-28.4 ± 1.7^{bcde}	-23.2 ± 2.5^{ab}
Ennis-B	-23.5 ± 2.1^{bcd}	-20.4 ± 1.6^{bc}	-27.0 ± 2.0^{bcde}	-15.6 ± 1.7^{cd}
Hall's Giant-A	-28.6 ± 0.7^{ef}	-27.5 ± 0.0^{bc}	-27.4 ± 2.0^{bcde}	-26.5 ± 0.8^{ab}
Hall's Giant-B	-28.5 ± 1.0^{ef}	-27.1 ± 0.4^{bc}	-26.4 ± 1.7^{bcde}	-26.6 ± 0.3^{d}
Brixnut	-26.7 ± 3.0^{de}	-24.2 ± 3.3^{bc}	-29.6 ± 0.8^{de}	-13.8 ± 1.3^{d}
Camponica	-25.2 ± 1.6^{bcde}	—————	-23.6 ± 2.3^{bc}	-27.6 ± 0.5^{d}
Cosford	-27.0 ± 0.5^{de}	-27.5 ± 0.0^{bc}	-26.6 ± 1.1^{bcde}	-14.8 ± 6.9^{ab}
Creswell	-25.3 ± 1.5^{bcde}	-27.0 ± 0.5^{bc}	-27.6 ± 0.6^{bcde}	-9.1 ± NA^{d}
Cutleaf	-32.5 ± 0.0^{f}	-28.3 ± 2.2^{bc}	-26.3 ± 0.7^{bcde}	-25.5 ± 0.6^{ab}
Gasaway	-25.8 ± 1.7^{bcde}	-29.5 ± 1.0^{c}	-30.6 ± 0.1^{e}	-28.8 ± 1.9^{e}
Gem	-26.5 ± 0.9^{de}	-27.5 ± 0.0^{bc}	-24.1 ± 1.2^{bcd}	-23.1 ± 1.4^{cd}
Italian Red-B	-25.0 ± 0.6^{bcde}	-27.5 ± 0.0^{bc}	-14.2 ± 0.9^{a}	—————
Mortarella	-26.4 ± 0.6^{cde}	-22.5 ± 0.0^{bc}	-26.2 ± 1.0^{bcde}	-18.7 ± 2.7^{bc}
Segorbe	-21.4 ± 1.1^{b}	-24.2 ± 3.3^{bc}	-24.6 ± 2.5^{bcd}	—————
Ribet-A	-16.5 ± 2.0^{a}	—————	-24.0 ± 1.3^{bcd}	-11.9 ± NA^{a}
Ribet-B	-15.8 ± 3.0^{a}	-7.5 ± NA^{a}	-15.5 ± 4.7^{a}	-13.5 ± 0.4^{ab}
Tombul Ghieghli	-26.9 ± 0.6^{de}	-23.1 ± 4.4^{bc}	-27.8 ± 1.8^{bcde}	-14.2 ± 0.6^{ab}
Tonda di Giffoni	-15.9 ± 3.1^{a}	-26.7 ± 0.8^{bc}	-22.7 ± 2.4^{b}	—————

[z] Mean separation using Waller-Duncan (.05)
Means with the same letter are not significantly different within the columns (months).
SE = Standard Error

Table 19. Mean separation of female bud LT_{50}s for 1991-92 and 1992-93 winters.[z]

Selection	Dec_1 Mean ± SE	Jan_1 Mean ± SE	Feb_1 Mean ± SE	Dec_2 Mean ± SE	Jan_2 Mean ± SE	Feb_2 Mean ± SE
Barcelona-A	-18.2 ± 0.6^{ab}	-18.8 ± 0.6^{bcd}	-15.2 ± 1.5^{bcde}	-18.7 ± 2.1^{a}	-25.7 ± 1.7^{abcde}	-19.2 ± 0.5^{cdef}
Barcelona-B	-23.1 ± 1.9^{cdefg}	-18.9 ± 2.1^{bcd}	-14.1 ± 3.1^{abcde}	-24.7 ± 1.0^{cdefg}	-24.3 ± 0.9^{abc}	-16.6 ± 2.2^{abc}
Casina-A	-19.5 ± 0.3^{abc}	-23.4 ± 1.0^{efghij}	-21.8 ± 2.8^{fgh}	-24.1 ± 0.9^{cdef}	-28.8 ± 0.7^{cdefg}	-18.7 ± 1.3^{cde}
Casina-B	-25.6 ± 0.4^{ghij}	-21.4 ± 1.1^{cdef}	-19.8 ± 0.4^{efg}	-25.2 ± 1.6^{cefgh}	-25.1 ± 1.3^{abcd}	-22.9 ± 2.5^{ghij}
Willamette-A	-29.4 ± NA^{ijk}	-20.5 ± 1.5^{cdef}	-10.9 ± 1.7^{ab}	-23.6 ± 0.2^{cde}	-24.9 ± 1.0^{abcd}	-16.4 ± 0.4^{abc}
Willamette-B	-25.3 ± 2.6^{efgh}	-22.5 ± 0.0^{defgh}	-15.2 ± 3.5^{bcde}	-25.3 ± 1.2^{defgh}	-22.5 ± 0.6^{ab}	-13.9 ± 1.4^{a}
Ennis-A	-22.5 ± 0.0^{cdef}	-25.7 ± 1.0^{ghij}	-23.6 ± 1.0^{gh}	-22.9 ± 0.2^{bcd}	-30.0 ± 1.0^{efgh}	-23.2 ± 0.8^{ghijk}
Ennis-B	-21.4 ± 2.3^{bcde}	-24.0 ± 1.7^{fghij}	-27.0 ± 0.5^{h}	-23.0 ± 0.4^{bcd}	-34.0 ± 2.0^{hi}	-21.8 ± 0.6^{fghi}
Hall's Giant-A	-24.8 ± 2.3^{defgh}	-22.5 ± 0.1^{defgh}	-18.8 ± 2.3^{defg}	-25.2 ± 1.2^{deefgh}	-28.4 ± 1.5^{cdefg}	-23.4 ± 0.3^{hijk}
Hall's Giant-B	-31.6 ± 0.9^{k}	-27.6 ± 0.2^{k}	-15.0 ± NA^{bcde}	-28.2 ± 0.8^{ij}	-32.5 ± 2.5^{gh}	-25.1 ± 1.5^{jk}
Brixnut	-19.7 ± 4.7^{abc}	-19.4 ± 1.0^{bcde}	-8.9 ± 0.7^{a}	-26.3 ± 0.9^{efghi}	-27.8 ± 1.3^{cdef}	-23.4 ± 1.3^{hijk}
Camponica	-26.8 ± 0.7^{ghij}	-15.8 ± 0.9^{ab}	-11.4 ± 3.1^{abc}	-24.5 ± 0.3^{cdefg}	-21.3 ± 0.1^{a}	-17.2 ± 1.4^{bcd}
Cosford	-27.5 ± 0.0^{hij}	-30.3 ± 0.6^{k}	-19.2 ± 1.3^{defg}	-22.4 ± 1.5^{bc}	-27.4 ± 1.5^{cdef}	-20.1 ± 1.1^{defg}
Creswell	-24.8 ± 0.2^{defgh}	-26.7 ± 0.8^{hijk}	-19.3 ± 1.8^{defg}	-26.2 ± 1.4^{efghi}	-28.3 ± 1.9^{cdefg}	-20.5 ± 1.1^{efgh}
Cutleaf	-29.6 ± 0.5^{jk}	-25.8 ± 1.7^{ghij}	------------------	-29.5 ± 0.1^{j}	-37.5 ± NA^{i}	-26.1 ± 0.3^{k}
Gasaway	-17.5 ± 0.1^{ab}	-26.9 ± 2.4^{ijk}	-22.7 ± 1.2^{fgh}	-26.6 ± 1.4^{fghi}	-32.7 ± 0.8^{gh}	-25.6 ± 0.1^{jk}
Gem	-16.9 ± 0.6^{a}	-18.2 ± 1.7^{abc}	-13.3 ± 0.8^{abcd}	-20.8 ± 0.2^{ab}	-29.1 ± 1.9^{defg}	-24.9 ± 0.5^{ijk}
Italian Red-B	-28.1 ± 0.6^{hijk}	-27.5 ± 0.0^{jk}	-18.8 ± 1.4^{defg}	-27.1 ± 0.2^{ghij}	-24.2 ± 2.3^{abc}	-23.5 ± 1.8^{hijk}
Mortarella	-21.2 ± 0.6^{bcd}	-22.5 ± NA^{defgh}	-22.5 ± 1.4^{fgh}	-27.1 ± 0.2^{ghij}	-26.3 ± 0.8^{bcde}	-18.5 ± 0.5^{cde}
Segorbe	-26.7 ± 0.8^{ghij}	-21.6 ± 0.9^{cdefg}	-15.0 ± 2.1^{bcde}	-27.8 ± 0.7^{hij}	-29.9 ± 2.1^{efgh}	-20.8 ± 0.5^{efgh}
Ribet-A	-25.1 ± 0.3^{defgh}	-20.3 ± 2.6^{cdef}	-22.0 ± 2.5^{fgh}	-25.6 ± 0.9^{defghi}	-31.3 ± 1.9^{fgh}	-23.6 ± 0.7^{hijk}
Ribet-B	-22.2 ± 1.3^{cdef}	-23.2 ± 1.8^{efghi}	-19.9 ± 1.2^{efg}	-25.5 ± 0.8^{defghi}	-31.7 ± 0.8^{fgh}	-23.3 ± 0.7^{hijk}
Tombul Ghieghli	-22.5 ± NA^{cdef}	-24.2 ± 1.7^{fghij}	-17.3 ± 2.6^{cdef}	-24.7 ± 1.0^{cdefg}	-24.5 ± 2.8^{abcd}	-17.8 ± 0.6^{cde}
Tonda di Giffoni	-26.4 ± 1.1^{ghij}	-14.4 ± 0.3^{a}	-10.7 ± 2.0^{ab}	-24.6 ± 0.8^{cdefg}	-22.2 ± 0.3^{ab}	-14.1 ± 1.7^{ab}

[z] Mean separation using Waller-Duncan (.05)

Means with the same letter are not significantly different within the columns (months).

SE = Standard Error

Table 20. Mean separation of vegetative bud LT_{50}s for 1991-92 and 1992-93 winters.[z]

Selection	Dec$_1$ Mean ± SE	Jan$_1$ Mean ± SE	Feb$_1$ Mean ± SE	Dec$_2$ Mean ± SE	Jan$_2$ Mean ± SE	Feb$_2$ Mean ± SE
Barcelona-A	-23.3 ± 1.3^{abcd}	-26.7 ± 1.3^{a}	-20.0 ± 1.0^{cd}	-21.0 ± 0.2^{abc}	-------------------	-28.0 ± 1.7^{abcd}
Barcelona-B	-27.5 ± 1.3^{efg}	-23.3 ± 1.3^{abc}	-22.0 ± 1.0^{cdef}	-21.5 ± 2.2^{abc}	-------------------	-28.7 ± 1.7^{abcde}
Casina-A	-18.3 ± 3.0^{ab}	-27.5 ± NA^{abcd}	-25.0 ± 2.5^{defgh}	-26.0 ± 1.6^{abc}	-22.0 ± NA^{a}	-31.0 ± 3.0^{defg}
Casina-B	-32.5 ± 0.0^{fgh}	-29.2 ± 1.7^{bcd}	-25.3 ± 1.4^{defgh}	-25.3 ± 0.9^{abc}	-31.0 ± 1.0^{cde}	-29.3 ± 0.7^{abcde}
Willamette-A	-37.5 ± 0.0^{h}	-30.0 ± 2.2^{cd}	-26.0 ± 0.0^{cdefg}	-24.0 ± 1.6^{a}	-35.3 ± 1.0^{e}	-30.0 ± 0.6^{bcde}
Willamette-B	-37.5 ± 0.0^{h}	-28.3 ± 2.2^{abcd}	-25.0 ± 0.9^{defgh}	-27.8 ± 2.9^{abc}	-32.3 ± 1.3^{cde}	-28.7 ± 0.6^{abcd}
Ennis-A	-25.0 ± 2.5^{cde}	-25.7 ± 1.8^{abcd}	-25.0 ± 2.5^{defgh}	-28.0 ± 3.2^{bc}	-------------------	-31.6 ± 0.4^{efgh}
Ennis-B	-23.1 ± 1.9^{bcd}	-25.1 ± 2.6^{abcd}	-30.0 ± 1.4^{h}	-23.6 ± 3.6^{ab}	-34.0 ± 1.5^{de}	-26.2 ± 1.2^{a}
Hall's Giant-A	-37.5 ± NA^{h}	-22.5 ± NA^{abcd}	-27.5 ± 2.0^{efgh}	-26.7 ± 1.9^{abc}	-34.5 ± 1.5^{e}	-31.3 ± 2.4^{defg}
Hall's Giant-B	-------------------	-25.0 ± NA^{abcd}	-25.8 ± 2.4^{defgh}	-26.0 ± 3.4^{abc}	-36.0 ± NA^{e}	-34.8 ± 0.8^{hi}
Brixnut	-32.5 ± NA^{fgh}	-22.5 ± 0.0^{abc}	-21.7 ± 2.4^{cdef}	-25.2 ± 0.8^{abc}	-------------------	-31.0 ± 1.5^{defg}
Camponica	-35.0 ± 2.5^{h}	-21.2 ± 1.2^{abc}	-13.5 ± 2.0^{b}	-25.2 ± 1.2^{abc}	-33.0 ± 2.7^{cde}	-33.9 ± 0.3^{fghi}
Cosford	-37.5 ± 0.0^{h}	-32.5 ± 0.0^{d}	-27.5 ± 0.0^{fgh}	-24.5 ± 0.7^{ab}	-------------------	-34.1 ± 0.1^{ghi}
Creswell	-27.5 ± NA^{def}	-20.3 ± NA^{ab}	-17.5 ± NA^{bc}	-27.3 ± 0.9^{abc}	-32.0 ± 0.0^{cde}	-30.9 ± 0.8^{cdefg}
Cutleaf	-37.5 ± 0.0^{h}	-27.5 ± NA^{abcd}	-29.2 ± 3.3^{gh}	-27.3 ± 3.8^{bcde}	-36.0 ± 0.0^{e}	-32.0 ± 0.0^{efghi}
Gasaway	-20.3 ± 1.5^{abc}	-27.5 ± NA^{abcd}	-27.5 ± 0.0^{fgh}	-29.5 ± 2.9^{abc}	-------------------	-32.0 ± 0.0^{efghi}
Gem	-18.1 ± 0.6^{ab}	-23.5 ± 2.1^{abcd}	-21.2 ± 1.2^{cde}	-25.1 ± 0.8^{abc}	-34.0 ± NA^{def}	-33.9 ± 1.1^{fghi}
Italian Red-B	-------------------	-29.8 ± NA^{abcd}	-27.5 ± NA^{fgh}	-25.3 ± 2.5^{abc}	-32.0 ± 0.0^{cde}	-28.4 ± 1.4^{abcde}
Mortarella	-20.8 ± 1.7^{abc}	-22.5 ± 0.0^{abc}	-23.3 ± 0.8^{cdefg}	-28.0 ± 13.2^{abc}	-34.0 ± NA^{abc}	-27.3 ± 0.7^{ab}
Segorbe	-27.5 ± NA^{def}	-------------------	-27.5 ± NA^{fgh}	-24.5 ± 1.1^{abc}	-24.0 ± 0.0^{de}	-35.0 ± 1.0^{i}
Ribet-A	-23.4 ± 1.0^{cde}	-------------------	-22.5 ± NA^{cdef}	-33.0 ± 15.6^{c}	-28.0 ± 2.3^{ab}	-29.9 ± 1.2^{bcde}
Ribet-B	-17.5 ± NA^{a}	-------------------	-22.5 ± NA^{cdef}	-24.0 ± 1.6^{abc}	-28.0 ± 3.3^{abcd}	-30.7 ± 0.7^{bcdef}
Tombul Ghiaghli	-------------------	-20.8 ± 2.4^{a}	-22.5 ± 0.0^{cdef}	-28.1 ± 2.9^{abc}	-29.7 ± 3.7^{bcd}	-27.6 ± 0.6^{abc}
Tonda di Giffoni	-34.0 ± 0.6^{gh}	-27.8 ± 0.6^{abcd}	-7.5 ± 0.6^{a}	-24.5 ± 0.7^{abc}	-31.3 ± 0.6^{cde}	-28.0 ± 0.0^{abcd}

[z] Mean separation using Waller-Duncan (.05)

Means with the same letter are not significantly different within the columns (months).

SE = Standard Error