Angelika Marble' cuttings, regardless of the treatment of the stock plants (Tables 1 and 2).

Although the reaction to extended photoperiods of stock plants varies among species, it is widely accepted that long days during the stock plant stage is an important factor in the subsequent rooting of individual poinsettia cuttings (Hansen and Ernstsén, 1982). Poinsettias typically require short days to initiate flowering. The critical photoperiod for the initiation of flowering for most poinsettia cultivars has been established at 12 h 20 min (Ecke et al., 1990), which at 40° 35' N latitude, occurred naturally on 19 Sept. 1995. However, to our knowledge, there has been no research performed on the critical photoperiod of modern poinsettia cultivars to verify the difference in flower initiation dates (D. Hartley, personal communication).

While the stock plants under natural lighting would have initiated flowering, it is most likely that the critical dark period for 'V-17 Angelika Marble' is longer than that for 'Freedom Red' or 'Monet', and flowering initiation had not yet occurred. Consequently, there may not have been any physiological difference between the cuttings taken from 'V-17 Angelika' stock plants grown under natural and night-break treatments. For 'Freedom Red' and 'Monet', there was a physiological difference between the cuttings, perhaps due to the flower initiation of the stock plants under a natural daylength.

In short-day and long-day plants, flower initiation within the stock plants appears to inhibit rooting of the cuttings (Heide, 1965; Moe 1976). A short-day species, *Dendranthema* spp., produced superior cuttings using long-day treatments on the stock plants to block the initiation of flowering (Heins et al., 1980). Similar stock plant photoperiodic effects have been reported

on *Salix* spp., *Abelia* × *grandiflora*, *Kalanchoe tubiflora*, *Crassula argentea*, *Ilex crenata*, *Pinus sylvestris* using short days to increase rooting, whereas *Begonia* × *cheimanthus*, *Vigna radiata*, and *Rhododendron* spp. exhibited increased rooting under long days (Hansen, 1987).

Many studies have produced evidence showing that herbaceous stock plants in a vegetative stage produce cuttings that root quickly and yield more root mass. More systematic research is required to identify the critical photoperiod of individual poinsettia cultivars. Identifying the critical daylength of a specific cultivar for flowering is important when deciding whether lighting the stock plant is a necessary treatment for photoperiodic control. If the critical day length occurred before cuttings were harvested or rooting occurs, it would be necessary to extend the photoperiod to inhibit flower initiation, thereby producing a cutting capable of rooting. However, lighting would be unnecessary if rooting occurred before the critical daylength was reached and flower initiation had not yet occurred.

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Influence of Freeze Acclimation Procedure on Survival and Regrowth of Container-grown *Campanula takesimana* Nakai.

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ADDITIONAL INDEX WORDS. bellflower, *Campanulaceae*, cold acclimation, cold hardiness, overwintering, perennials

SUMMARY. Crown divisions of *Campanula takesimana* were potted 1 Sept. 1994 and were grown under natural conditions until 19 Nov., when they were moved into a 3 °C greenhouse. On 15 Feb. 1995, 10 plants were randomly assigned to each of four temperature treatments (-5, -8, -11, and -14 °C), using each of four freeze acclimation procedures designated A through D: group A plants were held at treatment temperatures for 30 minutes; group B plants were first subjected to three alternating freeze-thaw cycles (-3 °C for 24 hours, 3 °C for 24 hours), then held at treatment temperatures for 30 min; plants in group C were held at -1 °C for 14 days and subsequently were exposed to treatment temperatures for 30 minutes; group D plants

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were held at treatment temperatures for 48 hours. A control group was held at 3 °C for the duration of the study. Following 6 weeks regrowth at 15 °C, plants were rated for survival and regrowth quality relative to unfrozen controls. At treatment temperatures of -8 °C and less, acclimation procedure significantly influenced survival and regrowth quality. Plants exposed to three freeze-thaw cycles had the highest regrowth ratings at treatment temperatures less than -5 °C, with no loss in marketability following exposure to -11 °C. In addition, all plants exposed to freeze-thaw cycles thrived following controlled freezing, whereas those in each of the other groups displayed a decline in survival with decreasing treatment temperatures. Holding plants for 14 d at -1 °C had no beneficial effect on survival or regrowth quality relative to plants held at constant above-freezing temperatures. Increasing exposure duration from 30 minutes to 48 hours significantly reduced regrowth quality at treatment temperatures of -8 °C and -11 °C.

Two prerequisites necessary for the development of cold hardiness in plants are 1) the genetic capacity to tolerate freezing temperatures and 2) exposure to conditions that will induce its expression (Steponkus, 1969). In cold climates, herbaceous perennials with overwintering storage organs display periodicity in their resistance to freezing stress, adjusting their development and metabolic activity to the changing seasons (Sakai and Larcher, 1987; Steponkus, 1978). Although there is agreement that low temperature and light are necessary during acclimation of herbaceous plants (Kacperska-Palacz, 1978), low temperature generally is considered the environmental stimulus of greatest importance (Li, 1984; Sakai and Larcher, 1987). Low temperature treatments required to induce maximum hardiness vary among species (Bula and Smith, 1954; Chen and Li, 1980; Chen et al., 1979; Devay and Paldi, 1977; Gusta et al., 1982; Hodgson, 1964; Kacperska-Palacz, 1978; Kohn and Levitt, 1965; Olien, 1967; Paquin and Pelletier, 1980). Some research has shown that diurnal freezing and thawing temperatures are more effective than constant above-freezing temperatures in achieving

maximum hardiness (Andrews et al., 1974).

To date, there has been little published information regarding the acclimation requirements of ornamental herbaceous perennials. *Campanula takesimana* is a lesser-known but attractive groundcover species with large, pendulous, lilac flowers and glossy, rosetted foliage. This species is native to Korea and designated as hardy to USDA zone 5 (Thomas, 1990). Although its popularity is increasing among New England growers, research is needed to determine its hardiness limitations and adaptability in the northeast. Our purpose was to examine the influence of a number of freeze acclimation procedures on survival and regrowth quality of containerized *Campanula takesimana*.

Materials and Methods

On 1 Sept. 1994, uniform crown divisions of *Campanula takesimana* Nakai. were potted into 0.4-L containers (4 inches, Kord Ultra) using ProMix BX (Premier Horticultural Products, Red Hill, Pa.) and placed outdoors in full sun on raised wire racks behind the Univ. of Vermont greenhouse in Burlington, Vt. All received 150 ppm N from a water soluble 20N-4.4P-16.6K fertilizer (20-10-20, The Scott's Co., Milpitas, Calif.) every other watering until 1 Oct. 1994, after which time they received only unfertilized water. On 19 Nov., plants were transferred into a glass greenhouse with exhaust fans set to 3 ± 1 °C. Ambient light intensity and photoperiod were maintained throughout the storage period.

On 15 Feb. 1995, plants were randomized and subjected to 20 factor-level combinations of a two-factor experiment involving four freeze acclimation procedures and five treatment temperatures. Acclimation procedures, herein designated as groups A through D, varied either in freezing procedure or duration held at each ultimate freezing temperature. The five temperature levels included one 3 °C unfrozen control, -5, -8, -11, and -14 °C. Ten uniform plants were randomly assigned to each factor-level combination.

Freezing took place in insulated chest freezers (Wood's model UWC15-ZL/E; W.C. Wood Co., Guelph, Canada) equipped with DynaSense Mark III programmable controllers (Scientific Instruments, Skokie,

Ill.). To ensure adequate air circulation, circulating fans (model E89061; Tandy Corp., Ft. Worth, Texas) were placed on the floor of each freezer, and plants were layered in flats suspended by wooden shelves. To minimize differences in moisture between pots, plants were watered to capacity 48 h before freezing. Freezer accuracy at setpoint temperatures was within 1 °C, and substrate temperatures at each setpoint were verified using thermometers placed in pots randomly scattered throughout the freezers.

For group A, the freezer was loaded and held at -1 °C for 40 h to ensure that all pots were uniformly frozen before dropping to target temperatures. The freezer temperature was then lowered at a rate of 2 ± 0.5 °C/h until reaching the first temperature setpoint (-5 °C) and then were held for 30 min before removing all plants for that treatment temperature. The temperature then was lowered to the next setpoint, and the process was repeated until all temperature treatments were completed. For group B, the freezer was loaded and held at -3 °C for 24 h, followed by 24 h at 3 °C. This was repeated two more times so that plants were exposed to three freeze-thaw cycles over a 6 d. On completion of the third cycle, all plants were held at -1 °C for 40 h, then frozen as described for group A. Group C plants were loaded and held at -1 °C for 14 d, after which temperatures were lowered at a rate of 2 ± 0.5 °C/h to setpoint temperatures, and plants were removed as described for group A. Group D plants were frozen as described for group A, with the exception that plants were held for 48 h at each setpoint temperature instead of 30 min. On removal from the freezer, all plants were immediately placed back in the greenhouse and held at 3 °C until 24 Mar. 1995, when the greenhouse temperature was raised to 15 °C.

After 6 weeks of regrowth, plants were evaluated for survival and regrowth quality relative to unfrozen controls. All were rated on a scale of 1 to 5 as follows: 1 = no regrowth (dead), 2 = trace to 25% regrowth, 3 = 26% to 50% regrowth, 4 = 51% to 75% regrowth, and 5 = 76% to 100% regrowth. Plants rated 3 and higher were considered marketable. Survival was defined in terms of visible shoot regrowth so that plants that lacked shoot

tissue after 6 weeks of regrowth were considered dead.

Regrowth means were subjected to two-way analysis of variance, and F-tests were performed on main factors and interaction between factors. Significant differences among regrowth means were determined using Tukey's test with a probability level of 0.05.

Results and discussion

All plants survived freezing treatment of -5°C regardless of acclimation procedure (Table 1). At treatment temperatures of -8°C and less, acclimation procedure significantly influenced survival and regrowth quality. Plants exposed to three freeze-thaw cycles (group B) had the highest regrowth ratings at treatment temperatures less than -5°C . This was the only freeze acclimation procedure that resulted in marketable plants following exposure to -11°C .

In addition, none of the plants exposed to freeze-thaw cycles displayed a decline in survival with decreasing treatment temperatures, as was observed in each of the other groups (Table 1).

Heiden (1987) observed that regrowth quality of bare root *Monarda*, *Hemerocallis*, *Lupinus* and *Hosta* showed little, if any, decline in quality following exposure to alternating freeze-thaw cycles. In contrast, a decrease in regrowth quality has been attributed to freeze-thaw cycles in *Fragaria* (Mader and Feldman, 1948), *Festuca* (Thomas and Lazenby, 1968), *Hordeum* (Olien, 1984), and *Geum* and *Coreopsis* (Heiden, 1987).

Holding plants for 14 d at -1°C (group C) had no significant benefit on regrowth quality relative to plants held in storage at 3°C and frozen without such pretreatment (group A) (Table 1). We anticipated that this group might attain a deeper level of hardiness than that obtained in above-freezing storage; however, results clearly showed no such benefit. While the absence of a significant effect might be attributed to the length of time plants were held at -1°C (14 d) or the time of year in which this research was conducted, it is noteworthy that plants exposed to freeze-thaw cycles showed a consistent, significant response using a treatment procedure applied in only 6 d (group B).

Increasing the exposure duration

at each temperature from 30 min (group A) to 48 h (group D) had a significant detrimental effect on regrowth quality at treatment temperatures of -8°C and -11°C . This group also had the lowest survival percentage at -8°C and -11°C (Table 1).

There is often a well-defined killing temperature that appears unaffected by exposure duration; however, in some cases, the degree of injury has been correlated with increasing length of exposure time (Ahrling and Irving, 1969; Burke and Stushnoff, 1979; Gusta and Fowler, 1979; Gusta et al., 1982; Paquin et al., 1987). The technique used in our study may have compounded this effect because plants exposed to the coldest treatment temperatures remained in the freezer longer than those at warmer treatment temperatures.

Our results indicate that survival and regrowth of containerized *Campanula takesimana* following controlled freezing were influenced by acclimation procedure and exposure duration. *Campanula takesimana* had an absolute killing temperature less than -14°C when pots were first exposed to a series of freeze-thaw cycles. Subsequently, we have observed regrowth in pots exposed to temperatures as low as -30°C following outdoor acclimation and unprotected storage. These results suggest that a USDA hardiness rating of zone 6 is somewhat conservative and that this species is well suited to climatic conditions found throughout the New England states.

Results also suggest that this species either failed to develop its full hardiness potential or lost a measur-

Table 1. Effect of treatment temperature and acclimation procedure on survival and regrowth quality of containerized *Campanula takesimana*.

Treatment temp ($^{\circ}\text{C}$)	Acclimation procedure ^a	Survival (%)	Regrowth quality ^b
3	A	100	4.7 a ^c
	B	100	4.7 a
	C	100	4.7 a
	D	100	4.7 a
-5	A	100	4.5 a
	B	100	4.8 a
	C	100	4.3 a
	D	100	4.4 a
-8	A	100	3.8 b
	B	100	4.5 a
	C	100	2.8 c
	D	80	2.1 d
-11	A	40	1.4 b
	B	100	3.2 a
	C	30	1.3 bc
	D	0	1.0 c
-14	A	0	1.0 b
	B	100	2.5 a
	C	0	1.0 b
	D	0	1.0 b

^aAcclimation procedures as follows: A plants held at 3°C before controlled freezing, B plants exposed to three freeze-thaw cycles (-3°C , 3°C) before controlled freezing, C plants held at -1°C for 14 d before controlled freezing, D plants exposed to each treatment temperature for 48 h.

^bMean of 10 replicates using the following rating scale: 1 = no regrowth, 2 = trace to 25% regrowth, 3 = 26% to 50% regrowth, 4 = 51% to 75% regrowth, 5 = 76% to 100% regrowth relative to unfrozen controls. Plants considered marketable if rated 3 or greater.

^cRegrowth means within treatment temperatures followed by different letters are significantly different using Tukey's test with $P = 0.05$.

able degree of hardiness in 3°C storage relative to those that were exposed to freeze-thaw cycles. Since a 14-d exposure to -1°C had no beneficial effect on hardiness relative to those held at 3°C , this would suggest that the physiological processes that lead to enhanced hardiness in this species depends on exposure to above- and below-freezing temperatures or that exposure to treatment temperatures colder than -1°C may be required to induce further hardening.

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Respiratory Rate and Vital Heat of Some Specialty Vegetables at Various Storage Temperatures

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ADDITIONAL INDEX WORDS. arugula, banana flower bud, bitter gourd, cassava, chayote, Chinese chive, Chinese water chestnut, drumstick, elephant garlic, giant garlic, guar, hyacinth bean, Jerusalem artichoke, jicama, methi, roquette, salsify, tindora, tomatillo, tumeric

SUMMARY. Respiratory rate was measured and vital heat calculated for 18 specialty vegetables {arugula or roquette [*Eruca sativa* Miller], banana flower bud [*Musa × paradisiaca* L. var. *paradisiaca*], bitter gourd [*Momordica charantia* L.], cassava [*Manihot esculanta* Crantz], chayote [*Sechium edule* (Jacq.) Swartz], Chinese chive [*Allium tuberosum* Rottler ex Sprengel], Chinese water chestnut [*Eleocharis dulcis* (Burm. f.) Trin. ex Henschel], drumstick [*Moringa oleifera* Lam.], giant or elephant garlic [*Allium scorodoprasum* L.], guar [*Cyamopsis tetragonoloba* (L.) Taub.], hyacinth bean [*Lablab purpureus* (L.) Sweet.], Jerusalem artichoke [*Helianthus tuberosus* L.], jicama [*Pachyrhizus erosus* (L.) Urban], methi [*Trigonella foenum-graecum* L.], salsify [*Tragopogon porrifolius* L.], tindora [*Coccinia grandis* (L.) Voigt], tomatillo [*Physalis ixocarpa* Brot. ex Hornem.], and tumeric [*Curcuma longa* L.]} at 0, 5, 10, and 20 °C. Respiration rates increased more or less exponentially with increasing storage temperature in all the vegetables tested, CO₂ varying from 28 to 302 mg·kg⁻¹·h⁻¹ at 20 °C for tumeric and drumstick, respectively. At 0 °C, the same products had the lowest and highest respiration rates of

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