Responses of Five Container-grown Herbaceous Perennial Species to Laboratory Freezing

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Summary. The capacity of plant materials to resume normal growth after exposure to low temperature is the ultimate criterion of cold hardiness. We therefore determined the low-temperature tolerance of five commercially important herbaceous perennial species. Container-grown blanket flower (*Gaillardia ×grandiflora* Van Houtte. 'Goblin'), false dragonhead [*Physostegia virginiana* (L.) Benth. 'Summer Snow'], perennial salvia (*Salvia ×superba* Stapf. 'Stratford Blue'), painted daisy (*Tanacetum coccineum* Willd. 'Robinson's Mix'), and creeping veronica (*Veronica repens* Loisel.) were subjected to 0, -2, 4, -6, -8, -10, -12, -14, -16, and -18°C in a programmable freezer. The percentage of survival of most species was adequate when exposed to -10°C. Producers of container-grown perennials are advised to provide winter protection measures that prohibit root medium temperatures from falling below -10°C.

Field-grown herbaceous perennials and those established in the landscape survive low-temperature injury because regenerative growing points are located at or below the soil surface and thus are protected by soil heat and by insulation from snow (Burke et al., 1976). Because of

ease of handling and transplanting, container-grown perennials have become popular (Bing et al., 1987). Containerization often results in overwintering losses because the small container volume provides little low-temperature protection for meristematic plant tissues. Root medium temperatures of -20°C have been recorded in unprotected containers during winter in central Iowa (Iles et al., unpublished data). In order to make winter management decisions, perennial producers must know the low-temperature limits of their container-grown stock. Once identified, tender species could be given appropriate freeze protection, whereas more cold-hardy perennials would require less protection. Root-killing temperatures have been identified for many woody landscape plants (Havis, 1976; Studer et al., 1978); however, similar information has not been determined for herbaceous perennials.

Several methods have been used for measuring plant cold hardiness (Calkins and Swanson, 1990), yet the capacity of plant materials to resume normal growth after exposure to low temperatures remains the ultimate criterion of viability (Palta et al., 1978). Exposure to low temperatures in the natural environment is perhaps the oldest test, but unreproducibility of chance low-temperature events and variability of soil moisture conditions, rate of freezing, duration of exposure to low temperature, thawing rate, and postthaw conditions makes results difficult to interpret (Rieger, 1989). More-reliable methods for estimating plant cold-hardiness involve controlled environments in which plants can be subjected to broad ranges of temperatures at specified freezing rates (Johnson et al., 1987). Still et al. (1987) used a low-temperature freezer to expose 10 species of container-grown perennials to a range of freezing temperatures. None of their test species were rated salable after exposure to -12.6°C, and none were capable of surviving -14.3°C.

This study evaluated, qualitatively and quantitatively, the response of five container-grown herbaceous perennials to a broad range of controlled freezing temperatures.

Materials and Methods

Herbaceous perennials *Gaillardia ×grandiflora* 'Goblin', *Physostegia*

virginiana 'Summer Snow', *Salvia ×superba* 'Stratford Blue', *Tanacetum coccineum* 'Robinsons Mix', and *Veronica repens* were established in 0.4-liter (10-cm) square black plastic containers using a medium of 2 parts Canadian sphagnum peat, 2 parts perlite, and 1 part field soil (by volume) amended with ground calcitic limestone to pH 6.5. Plants were grown outdoors from 15 May to 13 Nov. 1990 under woven black polypropylene shade fabric (20% shade). Each plant received 4 g of 17N-2.6P-10K (17-6-12) Sierra fertilizer plus micronutrients (Grace-Sierra Chemical Company, Milpitas, Calif.) and was fertilized biweekly until 21 Aug. with an additional 150 ppm N from a 20N-4.4P-16.6K(20-10-20) water-soluble fertilizer (Grace-Sierra Horticultural Products, Allentown, Pa.). Plants were watered approximately twice daily during May, June, July, and August, and once daily during September, October, and November. Each plant was irrigated by hand until root medium moisture levels exceeded container capacity. On 13 Nov., plants were transferred to a walk-in freezer and held at $2 \pm 2^\circ\text{C}$ until freezing tests began on 28 Dec. 1990. A split-plot experimental design was used with temperature as the main plot and species as the sub-plot. Each temperature/species treatment combination was replicated three times over time. For each temperature treatment, 15 plants (three plants each of five species) were selected and arranged randomly in a Scientemp programmable freezer (Scientemp Corp., Adrian, Mich.) for exposure to 0, -2, -4, -6, -8, -10, -12, -14, -16, or -18°C. Because only one freezer was used, temperature treatments were performed over time and assigned randomly within each replication. Control plants remained in a walk-in freezer at 2°C during the freezing test. Test tube racks were used to suspend plants above the freezer floor to facilitate uniform cooling. Medium temperatures were monitored during the experiment using 20-gauge copper-constantan thermocouples (Type T; Omega Engineering, Stamford, Conn.) inserted 4 cm deep in the center of two additional containers filled with growing medium. Thermocouple output was recorded on a Honeywell Electronik 15 multipoint recorder (Honeywell Inc., Fort Washington, Pa.).

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Freezer temperatures were lowered from the storage temperature (2C) at a rate of 2C/h. Plants remained in the freezer until thermocouple readings indicated medium temperatures had stabilized at the desired temperature. Due to the freezing of water in the container medium and subsequent release of heat, a minimum of 3 h was required for temperatures to stabilize at 0C. For the medium to stabilize at lower treatment temperatures, 12 to 16 h were required. After cold treatment, plants were removed from the freezer and placed in a low-temperature cooler (2C) to thaw gradually. After a 24-h thawing period, plants were transferred to a 21 C greenhouse for forcing under natural daylength.

After a regrowth period of 45 days, plants were rated visually using a qualitative scale. Shoot regrowth was harvested, dried (67C) for 72 h, and weighed. Because similar trends were found between visual ratings and dry weight measurements, quality rating data are not presented. Dead plants were treated as missing data and a least-squares method within the general linear model procedure of SAS (SAS Institute, Inc., Cary, N.C.) was used to analyze dry weights of surviving plants.

Results and discussion

An important factor to consider when studying freezing injury and cold acclimation of plants is accurate injury assessment (Steponkus and Lanphear, 1967). Although survival percentages alone are poor indicators of regrowth quality after exposure to low temperatures, it is noteworthy that most test plants survived the -10C treatment (Table 1). Exposure to temperatures below -10C resulted in considerable variation in the capacity to resume growth among species used in this study. All *Physostegia* survived temperatures as low as -16C, whereas only 44% of *Tanacetum* survived -12C. Very

few test plants survived the -18C treatment. Still et al. (1987), working with 10 perennial species, found none capable of surviving -14.3C.

After exposure to freezing temperatures, plants can be classified as uninjured, injured but living, or dead (Palta et al., 1978). However, it is difficult to ascertain the recovery ability of injured plants. Larcher (1980) emphasizes the importance of differentiating between the activity limit, at which the vital processes are only slowed, and the lethal limit, at which permanent injury is sustained. This determination is simplified by examining regrowth dry weights. But, greater attention should be given to regrowth trends than absolute dry weight measurements because of differences in growth habits and differences in vigor and quality of regrowing vegetative tissue between species.

For *Gaillardia*, temperatures below -8C resulted in observable crown injury (tissue browning) and poor regrowth dry weights (Fig. 1). Although survival percentages were high for *Gaillardia* exposed to -10C, -12C, -14C, and -16C treatments (Table 1), vegetative regrowth originating from surviving rhizomes was weak. Interestingly, shoot regrowth dry weights were low among control plants and for the 0C treatment, perhaps indicating a critical low-temperature requirement that must be met before resumption of vigorous regrowth.

Physostegia, regrowing from a network of storage tubers, was affected very little by treatment temperatures as low as -10C (Fig. 1). A reduction in regrowth dry weight was observed after exposure to -12C, with substantial injury occurring after exposure to -14C.

Both *Salvia* and *Tanacetum* resumed growth from surviving crown tissue and regrew acceptably after exposure to -10C (Fig. 1). Regrowth dry weights dropped precipitously af-

ter these species received a -12C treatment, indicating a well-defined low-temperature injury threshold.

Veronica, a prostrate perennial that regrows from a dense mat of stolons, demonstrated vigorous regrowth after exposure to -10C (Fig. 1). A slight reduction in dry weight was noted for the -12C treatment; however, plants did not suffer a large percentage decrease in survival until exposure to -14C. *Veronica* was seed-propagated for this study, which may partially explain the variability and poor regrowth dry weight after the -6C treatment. Genetically pure lines are preferred for study of plant cold hardness (Olien, 1967).

Determining plant viability after exposure to freezing temperatures remains a perplexing problem for researchers, as evidenced by the continued search for, and evaluation and refinement of, techniques for determination of tissue injury (Calkins and Swanson, 1990). Many viability assays provide information about the present status of certain tissues, but are unable to predict final performance of the entire plant. This fact is especially important in the study of herbaceous perennials, where a primary overwintering organ may be injured by cold, but other organs or tissues (rhizomes, stolons, tubers, etc.) may still be capable of growth. Although laborious, regrowth studies are very effective for determining percentage survival and quality of shoot regrowth after low-temperature episodes.

Except for *Gaillardia* $\times$ *grandiflora* 'Goblin', perennials used in this study sustained no significant injury when exposed to -10C. Regrowth dry weights of all species were unacceptable when plants were exposed to temperatures below -12C, although the degree of injury was quite variable. Producers of *Gaillardia* $\times$ *grandiflora*, *Physostegia virginiana*, *Salvia* $\times$ *superba*, *Tanacetum coccineum*, and *Veronica*

Table 1. Effect of low temperature on percentage survival of five herbaceous perennial species.

Herbaceous perennial	Treatment temperature (°C)									
	0	-2	-4	-6	-8	-10	-12	-14	-16	-18
<i>Gaillardia</i> $\times$ <i>grandiflora</i> 'Goblin'	78 ^z	100	100	88	100	100	78	88	78	33
<i>Physostegia virginiana</i> 'Summer Snow'	100	100	100	100	100	100	100	100	100	11
<i>Salvia</i> $\times$ <i>superba</i> 'Stratford Blue'	100	100	88	88	100	100	67	78	67	11
<i>Tanacetum coccineum</i> 'Robinson's Mix'	100	100	100	100	88	88	44	0	0	0
<i>Veronica repens</i>	100	100	100	100	100	100	78	22	22	0

^zPercentage (%) of test plants surviving (n=9).

Fig. 1. Effect of temperature on shoot regrowth dry weight (g) for five herbaceous perennial species surviving exposure to laboratory freezing. Standard error of the mean (SEM) dry weight for *Gaillardia* = 0.56; *Physostegia* = 0.19; *Salvia* = 0.38; *Tanacetum* = 0.49; *Veronica* = 0.26.

repens are advised to provide winter protection measures that prevent root medium temperatures from falling below -10C.

Identifying the overwintering organ(s) responsible for the perennial nature of these plants will help clarify how perennials withstand freezing temperatures. *Gaillardia*, *Salvia*, and *Tanacetum* regrow from crowns that consist of compressed basal stem tissue and have the capacity to form new growing points annually. Yet, after exposure to crown-injuring low temperature, *Gaillardia* demonstrated an ability to regrow using a network of rhizomes as secondary overwintering organs. This finding suggests that *Gaillardia* relies on comparatively hardy rhizomes rather than on a pe-

rennial crown to overwinter in cold climates successfully. There was no evidence of a similar mechanism among *Salvia* or *Tanacetum*. *Physostegia* and *Veronica*, the most cold-hardy species studied, did not regrow from a single crown. Instead, *Physostegia* resumed growth from a series of storage tubers located just below the soil surface, and *Veronica* regrew from a dense network of stolons. These numerous and widely distributed surviving growing points (tubers and stolons), vs. dependence on a single crown, may be responsible for the superior freeze tolerance demonstrated by *Physostegia* and, to a lesser extent, with *Veronica*. Future work will attempt to characterize the cold hardiness of specific plant tissues.

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