source of Mg for container production allowing growers to raise or lower Mg concentrations in the media without affecting Ca supply or pH. However, further research is needed to determine the proper combination of rate and particle size.

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Flower Bud Hardiness of Forsythia Cultivars[1]

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Abstract

Winter hardiness profiles were developed for six *Forsythia* cultivars introduced in the last 10–15 years for superior flower bud hardiness. The cultivars 'Meadowlark', 'Northern Gold', 'Northern Sun', 'New Hampshire Gold', 'Sunrise', and 'Vermont Sun' were at least 2–4°C (4–7°F) more hardy than *F.* × *intermedia* and *F. ovata* cultivars on most sampling dates. All cultivars acclimated sufficiently to withstand early-season minimum temperatures in most years. By mid-winter, five of the six new introductions obtained maximum hardiness levels of −36°C (−33°F). 'Sunrise' was 2–4°C (4–7°F) less hardy than the other cultivars in mid-winter but was one of the most hardy cultivars in late-winter. With the exception of 'Vermont Sun', there was little difference among the new cultivars in timing of deacclimation. 'Vermont Sun' deacclimated earliest and was less hardy than the other cultivars by mid-March. While these new introductions have experienced little flower-bud injury in field trials over the past decade, nearly 100% of the flower buds of these cultivars were killed in two of three winters encompassed by this study. The climatic conditions that resulted in injury were distinctly different for the two years.

Index Words: Cold acclimation, winter injury

Significance to the Nursery Industry

The limited flower-bud hardiness of Forsythia precludes more wide-spread use of this landscape shrub in northern landscapes. Many cultivars presently available in the nursery trade often experience winter injury in the northern United States. This study characterized the cold hardiness of six recent Forsythia introductions that have exhibited flower-bud hardiness in the field. Our findings indicate that improvements in flower-bud hardiness and plant form might be realized by hybridization of several of the cultivars tested.

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Introduction

Many Forsythia cultivars lack sufficient flower bud hardiness for use in northern climates. Flower buds of popular *F.* × *intermedia* cultivars are completely killed above the

snowline in most years (6). *Forsythia ovata* (early forsythia) cultivars possess greater flower bud hardiness (1, 6) but frequently experience injury in Minnesota. Efforts to breed hardier Forsythia varieties would benefit from an improved understanding of the hardiness characteristics of potential parent materials. Several cultivars introduced in the last 10–15 years have exhibited flower bud hardiness in the field (5, 6), but relatively little is known about the acclimation cycle and the maximum hardiness potential of these cultivars (1).

Comparative evaluations of cold hardiness must consider potential genotype × date interactions. Studies on other woody plant genera have demonstrated that hardiness rankings of related taxa vary throughout the fall and winter (1, 4, 8). Lindstrom and Dirr (8) suggested that seasonal low-temperature tolerance profiles be developed for new varieties taking into account not only maximum mid-winter hardiness levels but also the timing and rates of acclimation/deacclimation occurring in response to environmental cues. This information can help determine the suitability of new material for different geographic regions and facilitates selection of parent materials for breeding programs.

The objective of this study was to develop winter hardiness profiles for six recent *Forsythia* introductions selected for flower-bud hardiness. Three cultivars that have not been reliably hardy in our field trials were included for comparison. Data were collected over several seasons to provide a more complete picture of how annual variation in meteorological conditions might affect the development of cold hardiness.

Materials and Methods

Plants used in this study were growing in a field plot at the University of Minnesota Landscape Arboretum located in Chanhassen, Minnesota (44° 50' N latitude). The six recent introductions evaluated in this study were 'Meadowlark', 'New Hampshire Gold', 'Northern Gold', 'Northern Sun', 'Sunrise', and 'Vermont Sun'. 'Meadowlark' and 'Northern Gold' are F1 hybrids of *F. ovata* and *F. europaea* (Albanian forsythia) (5, 11). 'Northern Sun' is believed to be a natural hybrid with the same parentage (10). 'New Hampshire Gold' resulted from a cross between *F. ovata* and *F.* × *intermedia* Lynwood (7). 'Sunrise' is the result of a cross between *F. ovata* and a comparably hardy plant purchased as *F. ovata* but possessing a distinctly different growth habit (12). 'Vermont Sun' is a selection of *F. mandschurica* Uyeki (9). The less-hardy early introductions included for comparison were *Forsythia* × *intermedia* 'Beatrix Farrand', *Forsythia ovata* 'Ottawa', and *Forsythia ovata* 'Robusta'.

Material was collected from the same three to six plants of each cultivar for all sampling dates listed in Table 1. *Forsythia* 'New Hampshire Gold' plants were newly planted when the study was initiated and were not included on the earliest dates due to lack of material. Plants of the other cultivars ranged from five to eight years of age. Cultural practices in the nursery consisted of an annual spring application of a pre-emergent herbicide (Rout) and clean cultivation tillage practices thereafter. No supplemental irrigation was provided.

On each sampling date, shoots were collected in the morning from the current year's growth and placed in polyethylene bags for transport to the laboratory. Cuttings approximately 20 cm (7.87 in) in length and containing a minimum of three nodes were prepared after discarding the terminal 10 cm (3.9 in) of the shoot. Leaves that were still attached at the earliest sampling dates were excised at the base of the petiole with a razor blade. All material was prepared within two hours of collection and no material was exposed to ambient temperature of the laboratory for longer than four minutes. Eleven polyethylene bags were prepared containing five cuttings of each cultivar in contact with an ice nucleating agent (moist paper toweling). A copper-constantan thermocouple was inserted into a bud cluster in each bag and the bags were placed in an ultralow temperature freezer. The samples were held overnight in the freezer at a temperature approximating the previous night's minimum temperature. A twelfth bag of cuttings was held overnight under refrigeration at 2°C (3.6°F) and served as a control. The following day the temperature in the freezer was dropped at a rate of 5°C (9°F) per hour. Sample temperatures were monitored on a strip-chart recorder. The

Table 1. Lowest temperature [°C and (°F)] at which 30% of flower buds survived.

Sampling Date	Early Introductions			Recent Introductions					
	BF[z]	OT	RB	ML	NH	NG	NS	SR	VS
01/27/89	F[y]	−26(−15)	—	−30(−22)	—	−30(−22)	−30(−22)	−32(−26)	−30(−22)
03/02/89	F	F	F	F	—	F	F	F	F
11/02/89	−22(−8)	−22(−8)	−22(−8)	−24(−11)	—	−26(−15)	−24(−11)	−24(−11)	−24(−11)
11/20/89	−26(−15)	−28(−18)	−26(−15)	−28(−18)	—	−28(−18)	−30(−22)	−26(−15)	−26(−11)
12/14/89	−28(−18)	−34(−29)	−32(−26)	−36(−33)	−36(−33)	−36(−33)	−36(−33)	−32(−26)	−36(−33)
01/11/90	F	−30(−22)	−30(−22)	−32(−26)	−32(−26)	−32(−26)	−32(−26)	−32(−26)	−32(−26)
01/29/90	F	−28(−18)	−30(−22)	−32(−26)	−32(−26)	−32(−26)	−30(−22)	−32(−26)	−30(−22)
03/15/90	F	−20(−4)	−22(−8)	−22(−8)	−22(−8)	−22(−8)	−20(−4)	−22(−8)	−14(7)
10/12/90	−16(3)	−14(7)	−16(3)	−14(7)	−18(0)	−20(−4)	−16(3)	−16(3)	−16(3)
11/05/90	−20(−4)	−24(−11)	−22(−8)	−20(−4)	−24(−11)	−24(−11)	−24(−11)	−22(−8)	−24(−11)
11/28/90	−22(−8)	—	−24(−11)	−24(−11)	−24(−11)	−26(−15)	−24(−11)	−24(−11)	−24(−11)
12/18/90	−26(−15)	—	−28(−18)	−30(−22)	−30(−22)	−30(−22)	−30(−22)	−28(−18)	−30(−22)
01/13/91	F	F	F	F	F	F	F	F	F

[z]BF = 'Beatrix Farrand', ML = 'Meadowlark', NH = 'New Hampshire Gold', NG = 'Northern Gold', NS = 'Northern Sun', OT = 'Ottawa', RB = 'Robusta', SR = 'Sunrise', VS = 'Vermont Sun'

[y]Flower buds were injured in the field prior to collection.

range of temperatures used was varied by season to bracket the estimated lethal temperature. Four samples of each cultivar were removed from the freezer at 2°C (3.6°F) intervals and allowed to thaw under refrigeration at 2°C (36°F) for 24 hr. The samples were then incubated at ambient room temperature (22 ± 2°C; 72 ± 4°F) for 7 days. Flower buds were bisected and evaluated for injury with the aid of a dissecting microscope. A minimum of 15 flower buds were evaluated per sample and the percent bud survival calculated. On each sampling date, the experiment was designed as a two-way factorial with 7–9 cultivars and 11 temperatures. Data were subjected to analysis of variance procedures following transformation by the arcsin square root. The cultivar × temperature interaction was significant on all sampling dates. Individual cultivar-temperature treatment means were analyzed using t-tests. The lowest surviving temperature (LST) was then determined for each cultivar as the minimum sampling temperature at which 30% of the flower buds survived (Table 1). This rating was based on the assumption that 30% flower bud survival would provide an attractive floral display in the landscape.

Results and Discussion

The flower bud hardiness of the new introductions ('Meadowlark', 'New Hampshire Gold', 'Northern Gold', 'Northern Sun', 'Sunrise', and 'Vermont Sun') was similar on most sampling dates with no one cultivar being consistently most hardy throughout an entire season (Table 1). These cultivars exhibited greater hardiness than the earlier introductions 'Beatrix Farrand', 'Ottawa', and 'Robusta' on all dates but March 15, 1990.

A substantial degree of acclimation had occurred by the earliest sampling date (October 12, 1990) when the least hardy varieties on this date were able to survive at −14°C (7°F) (Table 1). 'Northern Gold' appeared to acclimate slightly earlier in the fall than the other cultivars both in 1989 and 1990 and might perform better in years with uncommonly low early-season temperatures. All cultivars acclimated to −20°C (−4°F) or lower by the first week of November in both 1989 and 1990 and continued to acclimate through mid-December. Temperature records for the last 15 years at the University of Minnesota Landscape Arboretum in Chanhassen, MN, show that the lowest outdoor temperatures for the months of October and November averaged −5°C (23°F) and −16°C (3°F), respectively. Results of this research indicate that all cultivars tested, including those of *F.* × *intermedia* and *F. ovata*, acclimate sufficiently to survive October and November minimum temperatures in most years.

Maximum hardiness levels of all cultivars were obtained by mid-December in 1989 (Table 1). 'Meadowlark' and 'New Hampshire Gold' flower buds have reportedly withstood −37°C (−35°F) in the field (6, 7) while Meadowlark, 'Northern Gold', 'Northern Sun', and 'Vermont Sun' have all flowered well in our nurseries following exposure to −32°C (−26°F). Brainerd et al. (1) estimated a minimum field survival temperature of −32°C (−26F) for 'Vermont Sun' based upon laboratory determinations of hardiness. In the present study, these five cultivars achieved comparable mid-winter hardiness levels and, with few exceptions, were 2–4°C (4–7°F) hardier than Beatrix Farrand, 'Ottawa', and 'Robusta' by mid-December. All five had LSTs of −36°C (−33°F) on December 14, 1989, the maximum hardiness level recorded on any test date. Our findings corroborate observations of field survival of flower buds and indicate that Meadowlark, 'New Hampshire Gold', 'Northern Gold', 'Northern Sun', and 'Vermont Sun' are capable of withstanding midwinter minimum temperatures in Minnesota. It is interesting to note that the hybrid cultivars Meadowlark, 'New Hampshire Gold', 'Northern Gold', and 'Northern Sun' possess greater mid-winter hardiness than has been observed for either parent species (2). In previous field trials, the sixth recent introduction, 'Sunrise', was reported to lack the flower bud hardiness of other new cultivars (6, 7). In the current study 'Sunrise' was 2–4°C (4–7°F) less hardy than the other cultivars in mid-December.

Buds of 'Beatrix Farrand', a *F.* × *intermedia* cultivar, were nearly 100% killed in the field by January 11, 1990. Flint (3) states that *F.* × *intermedia* flowers are usually killed between −25 and −27°C (−13 and −17°F) while Brainerd et al. (1) reported that *F.* × *intermedia* Lynwood flower buds were killed at −29°C (−20°F). 'Beatrix Farrand' had an LST of −28°C (−18°F) on December 14, 1989 and would have been susceptible to injury from the −28 to −32°C (−18 to −26°F) temperatures that occurred between December 19 and 22, 1989 (Fig. 2). These results are in agreement with previous studies (1, 3) and indicate that *F.* × *intermedia* cultivars lack sufficient mid-winter hardiness to survive average winter minimum temperatures in Minnesota.

'Robusta', a *F. ovata* selection, was the only other cultivar significantly affected by the extreme cold in December 1989. The percentage of buds injured in the field (i.e. percent injury in control samples) increased from an average of 22% on December 14 to 42% by January 11 (data not shown). 'Robusta' had an LST of −32°C (−26°F) in the December 14, 1989 test. However, in that same test, a temperature of −28°C (−18°F) was sufficient to kill approximately 33% of the buds examined. These less-hardy buds would have been susceptible to the extreme cold that occurred in the field later in December and may account for the higher levels of field injury observed on January 11. The other *F. ovata* cultivar, 'Ottawa', which experienced little injury at temperatures above −34°C (−29°F) in the December 14 freezer test, was not affected by the episode of extreme cold in the field.

All cultivars except 'Sunrise' experienced a loss of hardiness of 2-4°C (4–7°F) between the December 14, 1989 and January 11, 1990 dates (Table 1). One explanation for this phenomenon is that during the weeks preceding the January 11 sampling, daily maximum air temperatures in the field were frequently high enough to permit some degree of tissue thawing to occur. Between January 6 and January 11, 1990 daily maximum temperatures ranged from −0.5°C (31°F) to 8.0°C (46°F). Thus, while nighttime temperatures were always below freezing during this period (Fig. 1), the frequent daytime thawing of tissues may have resulted in some loss of hardiness.

There was little difference among the new introductions in the timing of deacclimation in late-winter. Most of these cultivars maintained sufficient levels of hardiness to survive typical ambient conditions for this period. The exception was 'Vermont Sun' which was substantially less hardy by March 15, 1990. This cultivar, which is the earliest to flower in spring, may be more susceptible to injury by late-season freezes.

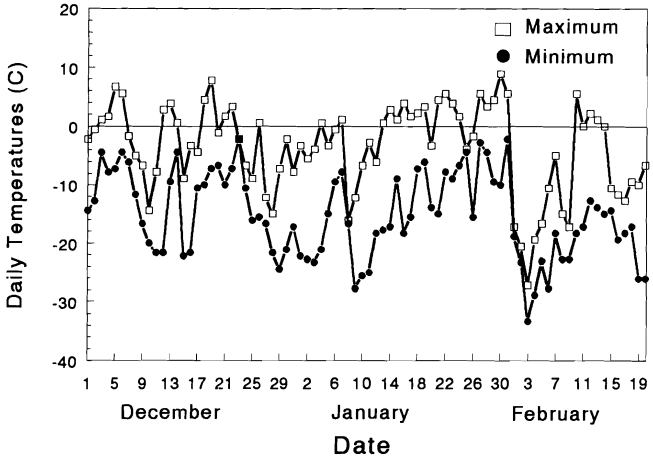

Fig. 1. Daily maximum and minimum air temperatures (°C) for the winter of 1988–89.

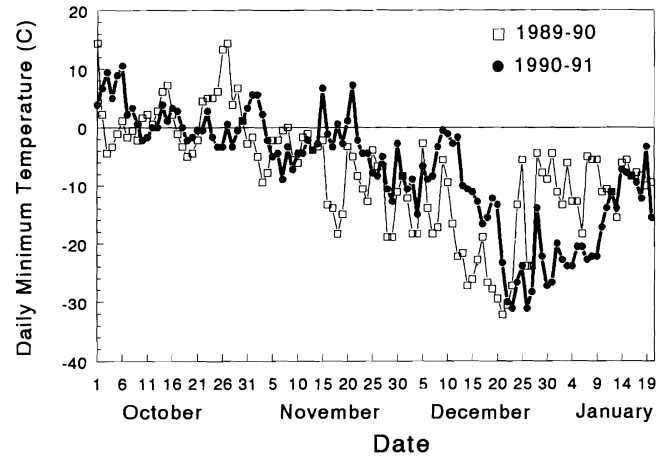

Fig. 2. Daily minimum air temperatures (°C) for the winters of 1989–90 and 1990–91.

While lacking the mid-winter hardiness of the other recent introductions, 'Sunrise' was one of the hardiest cultivars in late-January (1989 and 1990) and mid-March (1990). Our field observations also indicated that 'Sunrise' possessed good late-season hardiness. Following an unusually warm period in late-January of 1989 (Fig. 1), nearly 100% of the flower buds of all cultivars, except 'Sunrise', were killed when temperatures fell to −33°C (−27°F) on February 3rd. Based upon a March 2 sampling and observation of spring bloom, approximately 20% of 'Sunrise' flower buds survived this episode. Thus, it appears that 'Sunrise' deacclimates relatively slowly in late-winter and, as a consequence, is less susceptible to late-season thaw/freeze cycles. 'Sunrise' grows to only 1.5–2.0 m (5–6.5 ft) in height and has a more compact growth habit than most genotypes (12). The more ornamental nature of this variety, combined with its considerable late-season flower bud hardiness, suggest it might serve as a useful parent for future breeding efforts.

The results of this study illustrate the value of multiple-season evaluations in developing plant hardiness profiles. Flower buds of all cultivars acclimated more slowly in the Fall of 1990 compared to 1989. The hardiness of most cultivars increased by only a few degrees between November 5 and November 28 of 1990. Overall, buds were 2–6°C (4–11°F) less hardy in November and December of 1990 compared to 1989 even though the sampling dates chosen in 1990 were 3 to 8 days later than the corresponding sampling dates for 1989. This difference is at least partially explained by comparing ambient temperature conditions for the two years. We used the number of days on which ambient temperatures dropped below −3°C (27°F) as an index of hardening conditions in the field based upon observations in our laboratory freezing trials that indicate the initial freezing event for a range of plant material occurs at approximately this temperature. Using this criterion, the eight-week period ending December 24 was substantially colder in 1989 than in 1990 (44 days with minimum temperatures less than −3°C in 1989 vs. 32 days in 1990). Weekly average minimum air temperatures during this same period were also lower in most weeks in 1989 compared with 1990 (data not shown). The slower acclimation in 1990 proved to be critical as a December 23 field temperature of −31°C (−24°F) killed most of the flower buds on all cultivars. By contrast, a field temperature of −32°C (−26°F) on December 21 of 1989 had little effect on flower bud survival of most cultivars in this study.

The six cultivars evaluated here represent an improvement in flower bud hardiness and should be used in preference to other cultivars in northern climates. In particular, 'Meadowlark', 'New Hampshire Gold', 'Northern Gold', and 'Northern Sun' acquire and maintain adequate levels of hardiness to withstand average winter conditions at this latitude. However, the need for hardier selections still exists. In two of the three winters encompassed by this study, mid- or late-winter temperature fluctuations resulted in the loss of most flower buds on all varieties tested. We have observed substantial variation in the level of injury sustained by individual plants of a single cultivar growing at different sites at our research station. Such variation may be due to small microclimatic differences in air temperature. Thus, relatively small increases in hardiness achieved through hybridization have the potential to substantially improve flower bud survival.

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