Effect of Cold Storage on the Germination Success of Four Stonecrop Species

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SUMMARY. Green roof construction is constrained by cost of labor to install the plant material. Optimizing seed germination and establishment could significantly reduce installation costs but would require specific growing conditions that are difficult to provide during installation. Plants of the stonecrop (*Sedum*) genus are commonly used for the roof top because they will tolerate the high temperatures. This study compared the germination rates of four stonecrop species {goldmoss sedum (*Sedum acre*), 'Oracle' sedum (*Sedum forsterianum*), blue spruce sedum (*Sedum reflexum*), and amur sedum [*Sedum selskianum* (synonym *Phedimus selskianum*)]} at two temperatures, 70 and 90 °F, following storage of seed in dry, cool (40 °F) conditions of different durations (54, 98, 157, 197, 255, or 343 days). At 70 °F seed of goldmoss sedum, 'Oracle' sedum, and blue spruce sedum produced minimum germination rates of 60% at 21 days in seed stored for 54, 98, 157, 197, 255, or 343 days. Goldmoss sedum, 'Oracle' sedum, and blue spruce sedum showed reduced germination in 90 °F, probably due to temperature-induced dormancy. Amur sedum had germination of at least 83% at 21 days in both temperatures tested. As amur sedum germination rates appear to be unaffected in the temperatures tested, it could provide an excellent seed for use on green roofs where ideal temperatures are rarely available.

Green roofs are being used throughout the United States to reduce storm water runoff, improve rain water and air quality, and reduce the effect of urban heat islands (Snodgrass and Snodgrass, 2006). One of the primary limitations to their use is the cost of installation. Traditional methods for plant installation are through the use of broadcast cuttings, plugs, or nursery containers. Seeds are rarely used due to low rates of germination when under nonoptimal conditions and the long time required for seedling establishment on a roof.

Recent research indicates that under optimal conditions on a green roof, seeds can provide a viable option for installation (Monterusso et al., 2005). Further research is needed to determine the best species to use for seed installation under diverse conditions. Traditional installation methods have shown that stonecrop species are

optimal for use on green roofs due to their high survival rates after establishment in the mid-Atlantic region of the United States (Heinz, 1985; Snodgrass and Snodgrass, 2006). Seeds of stonecrop species have been used as a green roof installation method under ideal temperature and moisture conditions (Monterusso et al., 2005).

Seeds stored for long periods undergo physiological changes leading to lower germination rates (Baskin and Baskin, 1998). Orthodox seeds, such as stonecrop species, can be stored at low moisture content for many years (Hartmann et al., 2011).

There is little information in scientific literature on the effects of storage or germination temperature on germination rates of stonecrop species. Bonde (1965) showed that lanceleaf sedum (*Sedum lanceolatum*) seed germinated at 92.5% using growth chambers set at 18 °C. Widow's cross sedum (*Sedum pulchellum*) seed, grown in 20 or 25 °C, had germination rates of 91% when seed was stored for 7 months and germination rates at or below 16%

when stored up to 5 months, proving a dormancy existed in the seed (Baskin and Baskin, 1977).

Four species were used in this study: goldmoss sedum, 'Oracle' sedum, blue spruce sedum, and amur sedum. These species were selected based on seed availability and their ability to germinate under a broad range of conditions in the mid-Atlantic region on green roofs. The study temperature of 70 °F was selected since it resulted in optimal germination in studies of stonecrop germination by Baskin and Baskin (1977) and Bonde (1965). Lundholm et al. (2010) suggested that nonvegetated green roof media can reach an average of 5.5 °F warmer than the ambient air temperatures at midday, therefore, this work evaluated germination of these four species at 90 °F as well. The objective of this study was to determine whether seed storage impacts germination rates at 70 or 90 °F of the four stonecrop species.

Materials and methods

Seeds of four stonecrop species (goldmoss sedum, 'Oracle' sedum, blue spruce sedum, and amur sedum) were received from Benary Seed (Dekalb, IL) on 20 Dec. 2010. Benary reported the seeds were viable with germination rates of at least 85% for each species when tested in late spring or early Summer 2010. Therefore, the seeds were at least 6 to 8 months old when received. The seeds were placed in dry, cool storage at 40 °F. Germination tests were performed at 54, 98, 157, 197, 255, or 343 d after receipt of the seeds. Due to a malfunction in a growth chamber, data for the 343 d storage treatment germinated in the 90 °F temperature was contaminated.

At each germination test, 100 seeds of each species were removed from storage and separated into groups of 25 for testing at each of the two temperatures. For each species, 25 seeds were placed on a petri dish with one piece of filter paper and 1.5 mL of deionized water, providing four replications per temperature treatment.

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
29.5735	fl oz	mL	0.0338
(°F - 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

The petri dishes were double wrapped with plastic paraffin film (parafilm; Beemis NA, Neenah, WI) randomized, and placed in sets of four in clear, resealable plastic bags. The petri dishes were then placed in a growth chamber (Hoffman Manufacturing, Albany, OR; Percival Scientific, Boone, IA; or Controlled Environments, Winnipeg, MB, Canada) in a completely randomized design at either 70 or 90 °F (± 1.5 °F) with 12-h light/dark cycles. Deionized water was added to the petri dishes as necessary to provide free water without floating the seeds.

Using dissecting microscopes, data were collected every day for 21 d and seeds were considered germinated when radicle emergence was at least one quarter the size of the seed. The petri dishes were rerandomized each day after data collection. Within each species, an analysis of variance was conducted using the PROC MIXED procedure in SAS (version 9.3; SAS Institute, Cary, NC) based on a completely randomized design for each temperature on the final germination rate at 21 d and on the time to 50% germination (T50). Main effect means (storage time) were separated using Tukey's test and a probability value of 0.05.

Results and discussion

GOLDMOSS SEDUM. At 70 and 90 °F, there were significant differences between time of storage and either germination rate or T50. When temperatures are close to 70 °F, such as in late spring or early summer in the mid-Atlantic region, seed stored for 157, 255, or 343 d after receipt of seed is recommended as they produced the highest day 21 germination percentages at 92%, 78%, and 89%, respectively (Table 1).

In contrast, day 21 germination percentages decreased as the seeds matured when grown in a 90 °F growth chamber. Under higher temperatures, such as observed later in the summer, seed stored for shorter periods (54, 98, or 157 d) is recommended for use, even though the highest germination on day 21 for any treatment was less than 60%. The lower germination rates under the higher temperature could indicate a mild temperature-induced dormancy; Bewley and Black (1982) suggest continuing germination tests at even higher temperatures to produce the temperature that would cause full dormancy.

Together with the T50 data, at 70 °F, seed stored for 157 d is recommended for the fastest and highest germination with a T50 of 1.500 d and 92% germination on day 21. Seed stored for 255 and 343 d had similar day 21 germination but it took significantly longer to reach T50 (4.250 and 4.375 d, respectively). In the 90 °F temperature, seeds stored for 54 or 157 d provided the highest (58% and 29%, respectively) and quickest (4.250 and 2.250 d, respectively) final germination rates.

'ORACLE' SEDUM. There were no significant differences in day 21 germination percentages for 'Oracle' sedum seeds germinated in the 70 °F growth chamber. After 21 d in the growth chamber, seeds at all ages showed final germination between 82% and 98% (Table 2). Germination percentages in the 90 °F growth chamber were below 10% for all seed ages, with seed stored for 255 d showing the lowest final germination rate on day 21 at 0%. These results demonstrate that 'Oracle' sedum seeds are sensitive to increased temperatures and the potential for high temperatures to cause dormancy within the seeds. This physiological response may ensure that

the seeds only germinate in the cooler months of the year to ensure germination and plant success. Similar temperature-induced dormancy has been shown in widow's cross sedum as seeds germinated over 90% in 20.0 °C day/10.0 °C night temperatures and under 10% in 35 °C day/20.0 °C night temperatures (Baskin and Baskin, 1977). If consistent temperatures around 70 °F could be provided, all seed would produce successful germination; unfortunately, it is nearly impossible to provide such optimal temperature conditions on a green roof, except for a short period in late spring or early summer (Snodgrass and Snodgrass, 2006).

Significant differences occurred in the T50 data in seeds grown in the 70 °F growth chamber. Seed stored for 157 d showed the quickest T50 at 2.250 d and is recommended for the fastest and highest germination if temperatures can be provided around 70 °F. The T50 in the 90 °F showed no statistically significant differences between storage times, but due to the low final germination rates at 21 d (less than 10%), 'Oracle' sedum is not recommended for use.

Table 1. Final germination percentage at 21 d and time to 50% germination (T50) of goldmoss sedum after different durations of storage grown in a 70 or 90 °F (21.1 or 32.2 °C) growth chamber with a 12-h photoperiod.

Storage time (d)	Final germination (%)		T50 (d)	
	70 °F	90 °F	70 °F	90 °F
54	63.0 c ^z	58.0 a	4.250 b	4.250 ab
98	66.0 bc	34.0 ab	6.375 c	5.125 b
157	92.0 a	29.0 ab	1.500 a	2.250 a
197	72.0 bc	13.0 b	3.500 ab	2.625 ab
255	78.0 ab	23.0 b	4.250 b	4.625 ab
343	89.0 a	—	4.375 bc	—

^zWithin the columns, means (n = 4) followed by different letters are significantly different (Tukey's multiple comparison test at $P < 0.05$).

Table 2. Final germination percentage at 21 d and time to 50% germination (T50) of 'Oracle' sedum after different durations of storage grown in a 70 or 90 °F (21.1 or 32.2 °C) growth chamber with a 12-h photoperiod.

Storage time (d)	Final germination (%)		T50 (d)	
	70 °F	90 °F	70 °F	90 °F
54	89.0	10.0 a ^z	8.625 b	9.000
98	87.0	8.0 a	13.250 c	9.250
157	98.0	10.0 a	2.250 a	11.875
197	91.0	3.0 ab	8.000 b	9.875
255	82.0	0.0 b	9.500 b	0.000
343	85.0	—	6.875 b	—

^zWithin the columns, means (n = 4) followed by different letters are significantly different (Tukey's multiple comparison test at $P < 0.05$).

BLUE SPRUCE SEDUM. There were no significant differences for the final germination of blue spruce sedum seeds in the 70 °F growth chamber, with data ranging between 84% and 94% (Table 3). In the 90 °F growth chamber, day 21 germination for blue spruce sedum seed showed a significant decrease in germination as the seeds were stored for longer periods. Similar to goldmoss sedum and ‘Oracle’ sedum, a temperature-induced dormancy was potentially activated within the seed when grown in the 90 °F growth chamber. The temperature-induced dormancy characteristics within goldmoss sedum, ‘Oracle’ sedum, blue spruce sedum, and widow’s cross sedum (Baskin and Baskin, 1977) may indicate that other closely related species within the stonecrop genus will also show a temperature-induced dormancy.

Seed stored for 157 d is recommended for use in 70 °F temperatures based on the final germination at 21 d (84%) and the T50 results, where seed stored for 157 d germinated the quickest at 2.500 d in the 70 °F growth chamber. In the 90 °F growth chamber, seed stored for 54 d is recommended for the quickest (5.125 d) and highest (40%) germination.

AMUR SEDUM. There were no significant differences due to storage for amur sedum seeds grown in the 70 °F growth chamber. Day 21 germination was between 88% and 98% (Table 4). Final germination on day 21 in the 90 °F temperature ranged between 83% and 94%.

In the 70 °F growth chamber, amur sedum seeds reached T50 the fastest when seeds were stored for 157 d (2.250 d), whereas seeds in the 90 °F growth chamber reached T50 the fastest when seeds were stored for 157, 197, or 255 d (2.750, 3.375, or 3.250 d, respectively).

Amur sedum seeds showed final germination rates on day 21 in both temperatures tested above 83%. Based on these final germination rates on day 21 in both temperatures and thus, their ability to be unaffected by the temperatures tested, amur sedum seeds would have the best potential for seed establishment on a green roof as the temperatures on a green roof vary throughout the day. Unlike the previous three stonecrop species studied, no temperature-induced dormancy was observed in this study, presumably due to the official scientific classification for amur sedum

being *Phedimus selskianus*, which results in a more distant relationship to the other stonecrop species tested. This name was officially changed in 1995 (Eggli, 2003), although many publications and commercial plant and seed sources still reference it as a stonecrop species.

Conclusion

Using a mixture of seeds, basing the mixture on germination data at several temperatures and seed ages, would provide a respectable and successful plant palette for seed installation on a green roof. A seeding mixture planted in the late spring or early summer could be drastically different from a seeding mixture being used in the blazing heat of summer. In late spring or early summer, when the high temperatures do not fluctuate much from 70 °F, a mixture of seed from any of the four species at any age in this study could be used to successfully install a green roof. However, as the high temperatures increase later in summer, amur sedum is the only species that is currently recommended for use at any seed age tested. Goldmoss sedum and blue spruce sedum seed could also be used in higher temperatures but must be used as soon as possible after receipt as increased storage time led to significantly lower germination rates.

Table 3. Final germination percentage at 21 d and time to 50% germination (T50) of blue spruce sedum after different durations of storage grown in a 70 or 90 °F (21.1 or 32.2 °C) growth chamber with a 12-h photoperiod.

Storage time (d)	Final germination (%)		T50 (d)	
	70 °F	90 °F	70 °F	90 °F
54	94.0	40.0 a ^z	3.000 ab	5.125 b
98	92.0	4.0 b	3.500 bc	2.250 ab
157	84.0	7.0 b	2.500 a	7.625 b
197	85.0	0.0 b	3.500 bc	0.000 a
255	90.0	0.0 b	4.250 c	0.000 a
343	92.0	—	4.250 c	—

^zWithin the columns, means (n = 4) followed by different letters are significantly different (Tukey’s multiple comparison test at $P < 0.05$).

Table 4. Final germination percentage at 21 d and time to 50% germination (T50) of amur sedum after different durations of storage grown in a 70 or 90 °F (21.1 or 32.2 °C) growth chamber with a 12-h photoperiod.

Storage time (d)	Final germination (%)		T50 (d)	
	70 °F	90 °F	70 °F	90 °F
54	89.0	89.0 ab ^z	3.500 b	4.000 b
98	95.0	88.0 ab	4.500 c	4.125 b
157	93.0	92.0 ab	2.250 a	2.750 a
197	94.0	83.0 b	3.500 b	3.375 ab
255	98.0	94.0 a	3.500 b	3.250 ab
343	88.0	—	3.875 bc	—

^zWithin the columns, means (n = 4) followed by different letters are significantly different (Tukey’s multiple comparison test at $P < 0.05$).

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