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Requirements for Seed Germination of Mexican Redbud, Evergreen Sumac, and Mealy Sage

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Abstract. **Seed scarification and stratification (moist-prechilling) requirements of Mexican redbud [*Cercis canadensis* var. *mexicana* (Rose) M. Hopk.] and evergreen sumac *(Rhus virens* Gray) and the effects of temperature on final percent germination, maximum germination rate, and inflection time (time to maximum germination rate) for the above species plus seeds of mealy sage *(Salvia farinacea* Benth.) were investigated. Maximum predicted germination from a quadratic response surface was 95% after 62 minutes of concentrated sulfuric acid scarification plus *35* days of stratification for Mexican redbud, and 59% after 52 minutes of scarification plus 73 days of stratification for evergreen sumac. Mexican redbud germinated at 24 to 31C. Predicted optima for final percent germination, maximum germination rate, and inflection time were 100% at 28C, 30% germination per day at 31C, and 4 days at 29C, respectively. Evergreen sumac germinated at 21 to 31C. Final percent germination for this species declined with increasing temperature from a predicted maximum of 52% at 21C, whereas maximum germination rate increased with temperature to a predicted maximum of 69% germination per day at 31C. Inflection time was high at both extremes with a predicted minimum of 10 days at 25C. Mealy sage germinated at 21 to 34C. Predicted optima for final percent germination, maximum germination rate, and inflection time were 96% at 25C, 104% germination per day at 27C, and 3 days at 28C, respectively.**

Mexican redbud and evergreen sumac are two southwestern shrubs with ornamental potential (Nokes, 1986; Raulston, 1990). Leaves of Mexican redbud are smaller than those of the eastern redbud *[Cercis canadensis* var. *canadensis* (L.) M. Hopk.] and are coriaceous and shiny with a thick cuticle. Seeds of eastern redbud require concentrated sulfuric acid scarification for 15 to 60 min followed by stratification (moist-prechilling) for 30 to 60 days (Afanasiev, 1944; Frett and Dirr, 1979; Geneve, 1991; Hamilton and Carpenter, 1975; Roy, 1974) to induce germination in vitro. Seed germination of eastern redbud occurs over the range of 0.6 to 38C, with optimum response at 21C (Roy, 1974). Unlike for eastern redbud, seed germination requirements of Mexican redbud have not been documented and could be influenced by the warmer and drier native habitat.

Sumacs also have an impermeable seedcoat requiring scarification in vitro. Brinkman (1974) reported acid scarification durations ranging from 1 to 6 h, depending

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Table 1. Analyses of variance for the effect of scarification and stratification durations on seed germination of Mexican redbud and evergreen sumac, and the effect of temperature on aced germination of Mexican redbud, evergreen sumac, and mealy sage. Data set for the effect of scarification and stratification on seed germination of Mexican redbud was restricted to facilitate fitting a model (see text).

	Scarification and stratification (% germination)		Temp: Final germination (%)		Temp: Maximum germination rate (% germination per day)		Temp: Inflection time (days)	
Source	df	MS	df	MS	df	MS	df	MS
Mexican redbud								
Model[z]	5	7,456.3**	2	5,280.8**	1	635.2*	2	52.4**
Lack of fit	3	456.9^{NS}			1	7.5^{NS}		
Pure error	63	198.0	21	1,147.2	15	145.2	15	5.2
Evergreen sumac								
Model	5	2,405.5**	1	3,631.1**	1	5,814.1*	2	21.8**
Lack of fit	19	240.0^{NS}	1	295.8^{NS}	1	122.5^{NS}		
Pure error	175	186.1	21	219.8	17	920.6	17	3.6
Mealy sage								
Model			2	3,416.7**	2	10,972.6*	2	39.3**
Lack of fit			1	1,229.6^{NS}	1	661.1^{NS}	1	0.4^{NS}
Pure error			28	339.9	27	2,739.8	27	2.8

[z]Models for scarification and stratification effects were quadratic polynomials with two independent variables. Models for temperature effects were polynomials with a single independent variable. The degree of polynomial is indicated by the number of degrees of freedom.
^{NS,*,**}Nonsignificant or significant at $P = 0.05$ or 0.01, respectively.

on the species, and concluded that only *R. aromatica* Ait. (fragrant sumac) and *R. trilobata* Nutt. (skunkbush) had dormant embryos requiring stratification for 30 to 90 days. Nokes (1986) recommended 30 to 45 min of acid scarification for evergreen sumac and stated no stratification was required, but presented no data. Temperature requirements for seed germination of sumac are unknown, but most studies have been conducted at 20C or alternating 20/30C for 16/8 h (Brinkman, 1974). Lack of detailed seed germination information limits culture of Mexican redbud and evergreen sumac by the nursery industry.

Mealy sage is an established, southwestern herbaceous perennial ornamental with at least one recognized cultivar (Liberty Hyde Bailey Hortorium, 1976). Like most salvias, mealy sage requires no pregermination treatments to overcome dormancy, but optimum temperatures for seed germination are unknown (Nokes, 1986; Young and Young, 1986). Therefore, the objectives of this study were to 1) estimate the scarification and stratification requirements of Mexican redbud and evergreen sumac, and 2) estimate the effects of temperature on seed germination of Mexican redbud, evergreen sumac, and mealy sage.

Scarification and stratification requirements. This experiment was designed to estimate the optimum scarification and stratification durations for Mexican redbud and evergreen sumac. Seeds were harvested from individual cultivated plants of Mexican redbud and evergreen sumac growing at the Texas A&M Research and Extension Center, El Paso, in Aug. and Nov. 1987, respectively. The seeds were cleaned, sealed in airtight containers, and stored at room temperature until the experiment was initiated in December. The seeds of Mexican redbud were divided into five equal-size lots that were scarified in concentrated (≈36 N) sulfuric acid for 0, 30, 60, 90, or 120 rein, rinsed in deionized water, and subdivided into five equal-size lots. These seed lots were sealed in polyethylene bags with vermiculite that had been previously soaked in deionized water and allowed to drain for 24 h. Following stratification at 5C for 0, 15, 30, 45, or 60 days, the seeds were subdivided into eight lots (replications) of five seeds each, and each lot placed on one sheet of Whatman 1 filter paper (Whatman Paper, London) in a 50 × 9 mm seal-tight model 1006 plastic petri dish (Falcon Plastic, Oxnard, Calif.). After adding 2.1 ml deionized water, the petri dishes were placed in a germination chamber maintained at a constant 21C with a daily 18-h photoperiod provided by six cool-white fluorescent tubes positioned within 40 cm of the petri dishes. Germination, defined as the presence of a radicle as long as the seed, was counted daily for 14 days. Seeds of evergreen sumac were treated the same, except stratification durations ranged from 0 to 120 days at 30-day intervals.

Final percent germination (FPG) for each replication was transformed to $\sin^{-1}(\text{FPG}/100)^{1/2}$ and related to scarification and stratification durations by a quadratic polynomial response surface in an analysis of variance to estimate optima and confidence limits (Evans et al, 1982). Nonsignificant lack of fit sums of squares were combined with pure error sums of squares to test regression as described by Neter et al. (1983). Detransformed results are reported.

No seeds of Mexican redbud germinated without both scarification and stratification. For 30 min of scarification, germination also required 60 days of stratification. For 120 min of scarification, 30 days of stratification also was needed. To obtain a significant fit for a quadratic response surface, the data set was restricted to the region of 30 to 90 min of scarification and 15 to 45 days of stratification, which included the maximum response (Table 1). Maximum predicted germination was 95% after 62 min of scarification and 35 days of stratification (Fig. 1). The lower 99% mean confidence limit was 85%, which is predicted to occur within the region of 50 to 70 min of scarification followed by at least 20 days of stratification. These results are similar to those of Frett and Dirr (1979) for eastern redbud. Although they reported maximum germination after 15 min of scarification and 60 days of stratification, they also reported increased response to longer scarification when followed by only 30 days of stratification. Predictions for the maximum response differ from recommendations of Roy (1974) only in a slightly longer scarification duration.

Germination response of evergreen sumac to scarification and stratification fit a quadratic response surface without restricting the data set (Table 1). The maximum predicted germination was 59% after 52 min of scarification and 73 days of stratification (Fig. 2). The lower 99% mean confidence limit was 50%, which is predicted to occur within the region of 20 to 90 min scarification fol-

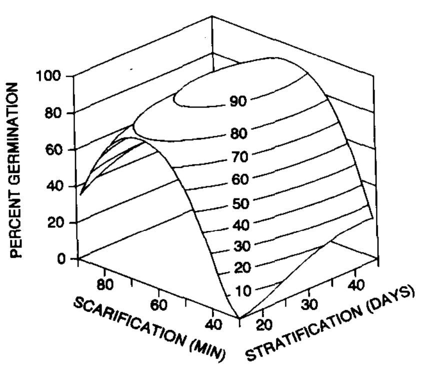

Fig. 1. Seed germination response of Mexican redbud to scarification and stratification durations. Model for the response is $\sin^{-1}(\text{FPG}/100)^{1/2} = -183.6 + 6.5\text{Sc} + 3.4\text{St} - 0.05\text{Sc}^2 - 0.04\text{St}^2 - 0.01\text{ScSt}$, where FPG = final percent germination, Sc = min of scarification in concentrated (≈ 36 N) sulfuric acid, and St = days of stratification at 5C.

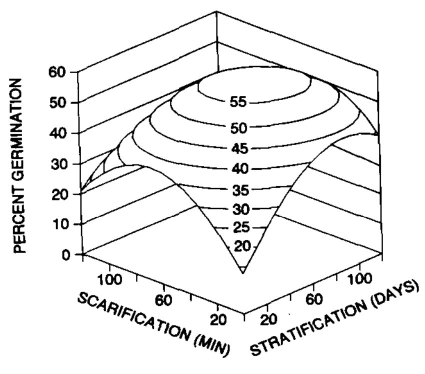

Fig. 2. Seed germination response of evergreen sumac to scarification and stratification durations. Model for the response is $\sin^{-1}(\text{FPG}/100)^{1/2} = 21.4 + 0.5\text{Sc} + 0.4\text{St} - 0.004\text{Sc}^2 - 0.003\text{St}^2 - 0.001\text{ScSt}$, where FPG = final percent germination, Sc = min scarification in concentrated (≈36 N) sulfuric acid and St = days of stratification at 5C.

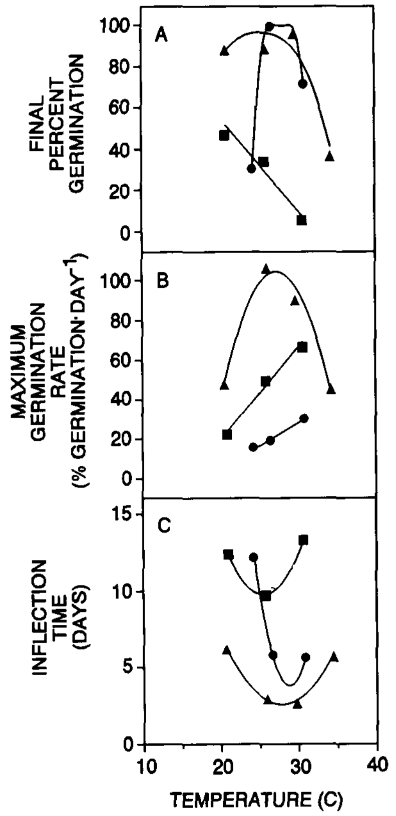

Fig.3. Observed means and polynomial regression **for(A)** final percent germination, **(B)** maximum germination rate, **and(C)** inflection time response to temperature for seeds of Mexican redbud (●), evergreen sumac (■), and mealy sage (▲) Mexican redbud models are: $\sin^{-1}(FPG/100)^{1/2} = -3259.5 + 239.5T - 4.3T^2$, $MGR = -41.7 + 2.3T$, $IT = 343.5 - 23.6T + 0.4T^2$. Evergreen sumac models are: $\sin^{-1}(FPG/100)^{1/2} = 110.1 - 3.1T$, $MGR = -73.4 + 4.6T$, $IT = 92.9 - 6.5T + 0.1T^2$. Mealy sage models are: $\sin^{-1}(FPG/100)^{1/2} = -237.1 + 24.9T - 0.5T^2$, $MGR = -818.2 + 67.6T - 1.2T^2$, $IT = 58.6 - 4T + 0.1T^2$, where FPG = final percent germination, MGR = maximum germination rate, IT = inflection time, and T = mean column temperature (C).

lowed by stratification for 30 to 110 days. While the results suggest some germination would occur following scarification alone, as suggested by Nokes (1986), stratification would enhance the response. The durations and variability of response are similar to those reported by Brinkman (1974) for other sumacs.

Temperature effecfts. This experiment was designed to estimate the effect of temperature on seed germination of Mexican redbud, evergreen sumac, and mealy sage. Seeds of Mexican redbud and evergreen sumac from the previously described harvest were scarified and stratified according to the predicted optima from the first experiment. Seeds of mealy sage were harvested during Aug. 1987 from several cultivated plants growing at the Texas A&M Research and Extension Center, El Paso. For a species, five seeds each were placed on one sheet of Whatman 1 filter paper in eighty-one 50 × 9 mm seal-tight model 1006 plastic petri dishes. After adding 2.1 ml deionized water, the petri dishes were arranged nine per column (replications) in nine columns 15 cm apart and perpendicular to the temperature gradient on a thermogradient plate. The aluminum thermogradient plate was 61 x 122 x *2.5* cm (width/length/thickness), insulated on the bottom and sides, and covered with a plexiglass shield. A 30 **x** 30 cm heat plate in contact with the bottom surface at one end provided heat while compressed freon circulating through eight 6.4-cm-diameter lateral holes in the opposite end removed heat. A daily 18-h photoperiod was provided by two cool-white fluorescent tubes positioned 40 cm above the plate surface. Seeds of mealy sage were placed on the thermogradient plate in Sept. 1987, seeds of evergreen sumac in June 1988, and seeds of Mexican redbud in July 1988.

A thermocouple was placed on a moistened filter paper in a petri dish in the center of each column. Temperature was recorded hourly by a data logger for the duration of each test. Fourier analysis (Bliss, 1958) (not shown) on a 24-h cycle with days as replications for each column indicated temperatures varied diurnally and daily with room temperature. There was little or no overlap among columns during the evergreen sumac and mealy sage tests. Temperatures were more variable during the Mexican redbud test, and there was some overlap among columns, probably due to a greater range in room temperature. Column means were uniform and linearly related to column location (analysis not shown), ranging from 14 to 48C during the Mexican redbud test, 3 to 37C during the evergreen sumac test, and 9 to 41C during the mealy sage test.

Germination, as previously defined, was counted daily for 14 days. Data for each replication were fit to Richard's function using the derivative-free algorithm of Ralston and Jennrich (1978). Richard's function is: Cumulative percent germination = $a\,[1 \pm \exp(b - kt)]^{-1/v}$ where a, b, k, and v are parameters and t is time (Causton and Venus, 1981; Lehle and Putnam, 1982; Moore et al., 1988). Parameter a gives the asymptotic maximum, v describes the shape of the curve (the presence and location of an inflection point), b describes the position of the curve in relation to the time axis, and k is a rate constant whose interpretation depends on the value of v (Causton and Venus, 1981). Maximum germination rate (MGR) and inflection time (IT) were calculated (Lehle and Putnam, 1982 Tipton, 1984):

$$MGR = k\,PG_i\,\frac{\left(\frac{a}{PG_i}\right)^{-v} - 1}{-v}$$

$$IT = \frac{b - \ln(\pm v)}{k}$$

where PG_i is the cumulative percent germination at IT. Thus, IT is the time to reach MGR, a measure of the delay in germination. Environmental stresses affect FPG, MGR, and IT differently in other species (Tipton, 1985, 1988). FPG, MGR, and IT were related to temperature by polynomial regression in an analysis of variance and tests of significance conducted as described above. To facilitate fitting a meaningful curve, only those columns in which germination occurred were included in the regression. Replications that lacked germination were treated as missing values for MGR and IT.

Extreme temperatures were inhibitory for all three species, germination occurring only in the middle three or four columns on the thermogradient plate. Where germination occurred, the Richard's function gave a highly significant fit in all cases, with coefficients of multiple determination ranging from 0.91 to 1. Mexican redbud had a narrow temperature range for germination, 24 to 31C, compared with the other species and with that reported for eastern redbud (Roy, 194) (Fig. 3). This species had a high FPG with a predicted optimum of 100% at 28C. MGR was low and increased with increasing temperature to 30% germination per day at 31C (Table 1, Fig. 3). The delay in germination (IT) was intermediate, with a predicted minimum of 4 days at 29C. These values suggest that germination would be high and occur rather quickly, but with roughly the same number germinating each day. The temperature range for predicted optima was 3C out of the 7C range in which germination occurred.

Evergreen sumac germinated at 21 to 31C, similar to that reported for other sumacs (Brinkman, 1974). This species exhibited anomalous and conflicting responses to temperature for FPG and MGR. Final percent germination declined linearly with increasing temperature from a predicted maximum of 52% at 21C, whereas MGR increased linearly with temperature to a predicted maximum of 69% germination per day at 31C (Table 1, Fig. 3). Inflection time was high at both extremes with a predicted minimum of 10 days at the midrange, 25C. These results predict that under low temperatures, germination would be delayed and slow but eventually yield more seedlings. Under high temperatures, germination would also be delayed but relatively rapid and yet yield few seedlings. The linear relationship between MGR and temperature exhibited by seeds of evergreen sumac and Mexican redbud has been documented for other species (Bewley and Black, 1982).

Mealy sage germinated over the widest temperature range, 21 to 34C. Final percent germination and MGR were high, with predicted maximums of 96% at 25C and 104% germination per day at 27C, respectively (Fig. 3). Inflection time was low with a predicted minimum of 3 days at 28C. The temperature range of predicted optima was only 2C out of a 14C range in which germination occurred. In the range 25-28C, germination is predicted to occur very quickly at a high rate and with a high percentage of success.

The degree of seedcoat hardness and embryo dormancy varies within and among seed lots for most applicable species (Copeland, 1976; Hartmann et al., 1990; Krugman et al., 1974). Scarification and stratification durations should be determined for each seed lot. While seeds used in these tests represent a limited genetic and environmental pool, the results establish initial values for testing the scarification and stratification requirements of subsequent seed lots. These values are 50 to 70 min of scarification followed by at least 20 days of stratification for Mexican redbud, and 20 to 90 min of scarification followed by 30 to 110 days of stratification for evergreen sumac. Sample limitations may also have influenced observed responses to temperatures. Nevertheless, the narrow temperature range of predicted optima for both Mexican redbud (28 to 31C) and mealy sage (25 to 28C) suggests starting points for additional studies. The lack of a differential temperature effect on FPG, MGR, and IT for these two species is in agreement with other studies that also show similar responses of percent germination and germination rate to temperature (Cluff and Roundy, 1988; Fulbright and Flenniken, 1986). In contrast, the differential responses of evergreen sumac are analogous to seed germination responses to drought stress in creosotebush *[Larrea tridentata* (D. C.) Cov.] (Tipton, 1985) and guayule *(Parthenium argentatum* Gray) (Tipton, 1988), and illustrate the benefits in examining all three parameters to understand environmental influences on seed germination.

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