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Research Reports

Stratification and Light Improve Germination of Katsura Tree Seed

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ADDITIONAL INDEX WORDS.

Cercidiphyllum japonicum, *Cercidiphyllum magnificum*, sexual propagation, dormancy, woody landscape plants

SUMMARY. Germinability of two, half-sib seed sources of *Cercidiphyllum japonicum* Sieb. & Zucc. and one seed source of *Cercidiphyllum magnificum* (Nakai) Nakai was determined after

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not stratifying or stratifying seeds at 3.5 ± 0.5 °C (38.3 ± 0.9 °F) for 8 days followed by germination for 21 days at 25 °C (77 °F) in darkness or under a 15-hour photoperiod. Stratification was not required for germination, but increased germination percentage, peak value, and germination value for both species. Stratification increased germination of *C. japonicum* from 42% to 75%, and germination of *C. magnificum* from 12% to 24%. Light enhanced germination of nonstratified seeds of one source of *C. japonicum* and of *C. magnificum* from 34% to 52% and from 8% to 15%, respectively. Stratification improved germinability of both species and obviated any preexisting light requirements the seeds may have had.

Cercidiphyllum comprises two species, both known as katsura tree. The common katsura (*Cercidiphyllum japonicum*) is endemic to China and Japan, although the survival of the species is threatened in China where it has been classified as rare (Chien, 1992). The species is a stunning specimen tree, valued for its pyramidal to broadly spreading form, apricot-yellow autumn leaves, and slightly furrowed bark. The second species, *Cercidiphyllum magnificum*, has a diminutive range in isolated mountainous regions of Japan and, although it is rare in commercial nurseries, has much potential merit as a landscape tree. Additional information on the genus can be found in recent reviews by Andrews (1998) and Dosmann (1999).

Cercidiphyllum japonicum can be vegetatively propagated by softwood cuttings (Dirr and Heuser, 1987), but commercial propagation is typically by seed. Information about the pretreatment and germination requirements of

katsura seeds is limited to a single report that states that the optimal temperature range for seed germination of *C. japonicum* is from 21 to 25 °C (69.8 to 77 °F) (Rohde, 1977). While katsura is not regarded as difficult to propagate by seed, general recommendations for seed germination of *C. japonicum* vary, as do reports of germination success. Reports on the germination of *C. magnificum* do not exist.

Dirr and Heuser (1987) note that stratification is not required for germination. Yet, for maximum germination, some nurseries sow seeds in spring after stratification for up to 60 d (H. Kunkel, personal communication). Seeds sown outdoors immediately after ripening in autumn germinate near capacity the following spring (D. Hinkley, personal communication). Other nurseries have found stratification unnecessary and sow seed outdoors directly in spring (M. Anderson, personal communication). Conservationists from the Xi'an Botanical Garden, China, reported that sowing seeds of *C. japonicum* in fall yielded only 23% germination, while spring sowing of stratified seed (temperature and duration not reported) increased germination percentage to 70% (Wang et al., 1990).

Effects of light on katsura seed germination are unknown. Seeds are small [about 5 mm (0.20 inches) long in *C. japonicum* and about 6 mm (0.24 inches) long in *C. magnificum*] with thin seed coats, both characteristics associated with light sensitivity (Bewley and Black, 1982; Li et al., 1994). Our objectives were to determine the effects of stratification and light on seed germination of the two species of katsura, and generate information of value for commercial production and conservation efforts, where some difficulty in production has been noted.

Materials and Methods

Cercidiphyllum japonicum. On 26 Sept. 1996, ripened follicles were obtained from two open-pollinated trees of *C. japonicum* growing at the Arnold Arboretum of Harvard Univ. (Jamaica Plain, Mass.), identified by the accession numbers of the maternal parent trees, 1150-67 and 882. Upon receipt, follicles were dried in shallow trays on a glasshouse bench for 3 weeks. After drying, seeds were shaken from their follicles, sealed in airtight plastic containers, and stored in darkness at about 7 °C (44.6 °F) to maintain dor-

mancy until the initiation of treatments.

Treatments began on 2 Dec. 1996. Seeds were placed (25/dish) in 100 × 15 mm (3.9 × 0.6 inch) plastic petri dishes (Fisherbrand, Pittsburgh, Pa.) on one piece of germination paper (Anchor Paper, Hudson, Wis.) moistened with 5 mL (0.17 fl oz) of deionized water. Seeds were stratified in darkness at 3.5 ± 0.5 °C (38.3 ± 0.9 °F) for 8 d in a ScienTemp programmable freezer (ScienTemp Corp., Adrian, Mich.). Temperature and duration of stratification were based on preliminary research that indicated that a short period of stratification was necessary to remove dormancy. Because of the limited quantity of seeds available, additional stratification treatments were not used. After stratification, nonstratified seeds were placed in dishes in the same manner as the stratified seeds.

Stratified and nonstratified seeds were randomly arranged on the same rack within a Sherer CEL-8 incubator (Conviron, Asheville, N.C.) at 25 °C (77 °F) (Rohde, 1977) under a photoperiod of 15 h or complete darkness. Light was provided by cool-white fluorescent lamps (64 ± 8 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ photosynthetically active radiation measured at dish level with a quantum radiometer [LI-COR, Lincoln, Neb.]), and complete darkness was obtained by placing dishes in light-proof containers. Throughout the study, filter paper was remoistened as needed with deionized water. Dishes in the dark treatment were opened only briefly to remoisten paper and count germinated seeds. The experiment was terminated after 21 d.

Germination percentage was computed daily for each dish, and was de-

termined as the percentage of seeds that showed radicle emergence, without correction for nonviable seeds. At the conclusion of the experiment, peak and germination values (Czabator, 1962) and final germination percentages were calculated. Peak value is an index of vigor and is obtained by dividing, for each day of measurement, the cumulative germination percentage by the number of days from the beginning of the germination test. The maximum daily value is defined as the peak value. Germination value is the product of peak value and the mean daily germination percentage, which is determined by dividing final germination percentage by the number of days for completion of germination. Germination value combines speed and totality of germination in a single index.

The factorial arrangement for statistical analysis consisted of two seed sources, two stratification treatments (stratified and nonstratified), and two light conditions (light and dark). Each dish of 25 seeds was considered an experimental unit. Each treatment combination was replicated three times, and the experiment was conducted three times. Data were analyzed with the Statistical Analysis System (SAS Institute, Cary, N.C.). Analyses of variance, performed with the General Linear Model (PROC GLM), tested for significance of seed sources, stratification treatments, and light effects for the measured response variables. High-order interactions (replication over time × seed source × stratification treatment × photoperiod × within treatment replication) were included as a measure of experimental error. Means were separated by using

Fisher's least significant difference (LSD) test at $P \leq 0.05$.

Cercidiphyllum magnificum. On 16 Dec. 1996, a limited supply of seeds of *C. magnificum* was received from the Forest Experimental Station of the Warsaw Agricultural Univ. Arboretum (Rogów, Poland). The seeds had been collected from four open-pollinated female trees during the first half of September 1996, dried, and stored in sealed containers at -3 to 10 °C (26.6 to 50 °F). Upon receipt, seeds were resealed in plastic containers and held at about 7 °C (44.6 °F).

Tests similar to those for *C. japonicum* were initiated on 5 Mar. 1997, except that a fourth replication over time was added. Experimental error during analysis of variance included the interaction of replication over time × stratification treatment × photoperiod × within treatment replication.

Results

Cercidiphyllum japonicum. Germination was complete for all treatments 7 to 11 d after placing seeds in the incubator. No further germination was observed, despite continued observation. Germination percentage, peak value, and germination value differed between trees ($P > F = 0.0001$). A tree × stratification treatment interaction was significant for germination percentage, peak value, and germination value ($P > F = 0.0001$). For all three variables, stratification increased germination in tree 1150-67 more than in tree 882 (Table 1). Germination percentage, peak value, and germination value for tree 1150-67 were unaffected by photoperiod. However, germination percent-

Table 1. Mean germination percentage, peak value, and germination value of seeds of *Cercidiphyllum japonicum* (sources 1150-67 and 882) and *C. magnificum* nonstratified or stratified at 3.5 ± 0.5 °C (38.3 ± 0.9 °F) for 8 d and germinated under complete darkness or 15 h photoperiod. Values for *C. japonicum* and *C. magnificum* are the means of nine or 12 replications, respectively, each consisting of 25 seeds.

Pregermination treatment	Photoperiod (h)	Seed source						Germination %	Peak value	Germination value
		<i>C. japonicum</i> (accession no.)				<i>C. magnificum</i>				
		1150-67	882	1150-67	882	1150-67	882			
Nonstratified	0	39	34	6.7	6.2	42	33	8	1.4	2.1
	15	42	52	7.3	9.2	50	71	15	2.0	3.7
Stratified	0	90	60	19.5	13.2	294	138	23	4.3	18.5
	15	89	59	18.8	13.0	285	128	24	4.5	18.6
LSD ^w		10		2.3		47		5	0.9	6.2

^zPercentage of seeds showing radicle emergence without correction for nonviable seeds.

^yUnitless index of vigor; maximum daily value obtained by dividing cumulative germination percent by cumulative number of days of germination.

^xUnitless indication of speed and totality of germination; product of peak value and mean daily germination percentage.

^wFisher's least significant difference (LSD) within each dependent variable is at $P \leq 0.05$.

age and peak value were greater for nonstratified seeds of tree 882 exposed to light than those germinated in darkness. The same interaction was not significant for germination value. Light caused no significant differences in any of the response variables for stratified seeds of tree 882 (Table 1).

Cercidiphyllum magnificum. Germination was complete in 8 to 11 d. Similar to *C. japonicum*, stratification increased germination percentage, peak value, and germination value ($P > F = 0.0001$). Germination percentages and peak values for stratified seeds were more than two and three times greater, respectively, than those for nonstratified seeds germinated in darkness (Table 1). Germination value for stratified seeds was more than eight times that for nonstratified seeds germinated in darkness. Germination percentage for nonstratified seeds increased under light, but peak value and germination value for the nonstratified treatments were not different. Stratified seeds were unaffected by light (Table 1).

Discussion

Stratification was not required for germination of either *Cercidiphyllum* species, but stratifying seeds increased germination percentage, peak value, and germination value for both. Likewise, light was not required for germination, yet germination percentage for nonstratified seeds of *C. magnificum*, and germination percentage and peak value for nonstratified seeds of tree 882 of *C. japonicum* increased when exposed to light.

In a similar study, neither stratification nor light was required for germination of seeds of empress tree [*Paulownia tomentosa* (Thunb.) Steud.], but continuous irradiance improved germination of nonstratified seeds when compared with seeds germinated in darkness (Carpenter and Smith, 1981). While our study did not examine the effects of continuous light, we observed similar responses in tree 882 of *C. japonicum* and in *C. magnificum*. Furthermore, when seeds of empress tree were stratified for 2 weeks at 4 °C (39.2 °F), higher (and equal) germination percentages were observed in both light and dark than those that had not been stratified, indicating that light requirements had been removed by stratification (Carpenter and Smith, 1981). In our study, germination speed (peak value) in both species increased after stratification and

under light in nonstratified seeds of *C. japonicum* (tree 882). Germination value was unaffected by light, yet was increased by about 530%, 156%, and 540% in trees 1150-67 and 882 of *C. japonicum*, and *C. magnificum*, respectively, with stratification. This discovery suggests stratification is more important than light in seed germination of katsura. Similar responses to stratification and irradiance have been observed in downy birch (*Betula pubescens* Ehrh.) (Black and Wareing, 1955), canadian hemlock [*Tsuga canadensis* (L.) Carr.] (Stearns and Olsen, 1958), and longleaf pine (*Pinus palustris* Mill.) (McLemore and Hansbrough, 1970).

The dissimilar responses to stratification and light demonstrated by the two sources of *C. japonicum* in our study are difficult to explain. Differences may have been due to unique circumstances of the two parent trees at the Arnold Arboretum, including provenance or microclimate (Bewley and Black, 1982). Seed maturity and physiological status of the two sources also may account for the differences in seed performance. For these and other reasons, we emphasize that our results are based on only two individuals of *C. japonicum* and may not represent the characteristics of the species as a whole. Nevertheless, results from this study may help explain why plant propagators use various methods to produce katsura from seed. Because seeds from individual trees may respond differently to various methods used to overcome dormancy, growers propagating katsura from seed should monitor their seed sources carefully to maximize germination.

Germination percentages less than 25% emphasize the need for further study of *C. magnificum*. Because the parental trees of this species were open-pollinated, the possibility that cross-pollination occurred between this species and nearby *C. japonicum* cannot be ruled out, although to date, hybridization of the two taxa has not been observed. Future investigations with a larger number of sources of known provenance may help characterize the variability associated with geographic origin of both taxa.

Propagators that germinate seeds of katsura may find it beneficial to stratify seeds for a short period of time to improve germination. While our study did not test the effect of overwintering, seeds may have their dormancy requirements removed by sowing them in the

field in the autumn. Exposing the seeds to light is not necessary for germination, and does not improve germinability of stratified seeds.

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