Effects of different pre-sowing seed treatments on germination of 10 *Calligonum* species

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Abstract

A greenhouse experiment was conducted to study the effects of abrasion, sulphuric acid, boiling water, cold stratification and seed exudate treatments on the germination of 10 *Calligonum* species. That are dominant shrubs used for restoration of desert vegetation in mobile sand dunes and stabilized sand fields in the northern desert of China. Little is known about their germination characteristics. In August–September 1998, seeds of *Calligonum* were collected and were treated by five pre-sowing treatments before the germination experiments. The results show that the germination response of seeds to the different pretreatments was more or less similar for all 10 *Calligonum* species. The germination percent of seed from the 10 species was lowest for exudate treatments and highest for abrasion treatments. The abrasion, sulphuric acid and cold stratification treatments significantly promoted overall germination. Compared with the control, the exudate treatment significantly hampered germination, rate of germination and bolstered dormancy for almost all species. The cold stratification treatment can break the dormancy of viable *Calligonum* seeds and increase the germination, but it has lethal effect on viable seeds probably as well as the boiling water treatments. Almost all germination parameters showed significant difference between the pre-sowing treatments for all 10 *Calligonum* species. The speed and percent germination of the *Calligonum* species can be greatly increased by mechanical scarification or acid treatments. The results show that seeds of *C. junceum* have good germination potential. These conclusions are very important because *Calligonum* species can be propagated by seed in the arid desert regions.

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Keywords: *Calligonum*; Pre-sowing treatments; Germination; Dormancy

1. Introduction

*Calligonum* species are dominant perennial shrubs in active sand dunes and stabilized sand fields in the northern desert of China (Mao and Pan, 1986; Tao, 2000). They can exist in mobile sand dunes in conditions of extreme drought (Liu, 1985–1990; Mao and Pan, 1986). They have a reputation for high tolerance to water deficit. They appear to be suitable for revegetation of desert (Mao et al., 1983; Mao and Pan, 1986; Zhang, 1992; Tao, 2000). They have great potential to provide different products and services such as forage, traditional medicine, halting desert encroachment and stabilizing sand dune (Liu, 1985–1990; Tao, 2000). Because of their importance in providing many uses and services, they have attracted some attention. However, there has been little experimental research dealing with the seed germination and...
The available information about these species is their botany, cultivation method, taxonomy, genetic diversity, brief descriptions of their habitat conditions and the range of their geographical distribution (Mao et al., 1983; Mao, 1984; Liu, 1985–1990; Mao and Pan, 1986; Zhang, 1992; Yu and Wang, 1998; Tao, 2000; Tao et al., 2000).

One of the problems with these species is the difficulty of raising seedlings from seeds. The seeds have a hard impermeable testa which prevents imbibition of water and germination (Yu and Wang, 1998; Tao, 2000; Tao et al., 2000). Therefore, the seeds require seed treatments before sowing to obtain rapid, uniform and high germination (Demel, 1996, 1998; Demel and Mulualem, 1996; Schutz and Rave, 1999; Yang et al., 1999; Huang and Gutterman, 2000). The purpose of the present study was to investigate the germination responses of seeds of the 10 Calligonum species to different pre-sowing treatments. An understanding of these factors is crucial for successful regeneration and recruitment of these long-lived desert plant species.

### 2. Materials and methods

#### 2.1. Seed collection and preparation

Seeds of 10 Calligonum species (*C. junceum* (Fisch. Et Mey.) Litv., *C. leucocladum* (Schrenk) Bge., *C. rubicundum* Bge., *C. densum* Borszcz., *C. mongolicum* Turcz., *C. chinense* A. Los., *C. caput-medusae Schrenk, *C. arborescens* Litv., *C. alaschanicum* A. Los. and *C. potaninii* A. Los.) were collected from at least 10 plants per species in August and September 1998 at Shapotou Desert Research and Experimental Station of the Chinese Academy of Sciences (37°32′N, 105°02′E, 1339 m a.s.l.), Ningxia Province, China. Seeds were allowed to air-dry and were stored at room temperature (23–26 °C) until May 1999, when experimental pretreatments were initiated (storage in this manner did not affect the dormancy or viability of the seeds). For each species, seeds were mixed and then allocated at random. Aborted and predated seeds were discarded. Intact plump seeds were surface sterilized with Na-hypochlorite prior to any experimental usage. Seed viability is variable, but is generally between 30 and 50% (Tao, 2000; Yu and Wang, 1998).

#### 2.2. Pre-sowing seed treatments

**Abrasion of testa:** The mechanical scarification treatment was carried out by grinding seeds in a mortar with a pinch of clean silica sand until all seta of testa are removed and the testa was broken.

**Sulphuric acid immersion:** Although seeds from the 10 species varied apparently in size (Table 1) and degree of hardness of their testas (based on visual inspection), they received the same sulphuric acid treatments. Seeds were immersed in 96% sulphuric acid for 30 min, and then rinsed thoroughly in running water for 45 min.

**Hot water treatment:** Each replicate of seeds was enclosed in a coffee filter bag which was then folded

### Table 1

Month and year of seed collection, as well as seed size and dry mass of 10 Calligonum species

<table>
<thead>
<tr>
<th>Species</th>
<th>Date of seed collection</th>
<th>Length of seed (mm) (mean ± S.D.)</th>
<th>Diameter of seed (mm) (mean ± S.D.)</th>
<th>Seed mass (mg) (mean ± S.D.)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>C. junceum</em></td>
<td>24 August 1998</td>
<td>11.07 ± 0.76</td>
<td>9.24 ± 0.99</td>
<td>0.08 ± 0.01</td>
</tr>
<tr>
<td><em>C. leucocladum</em></td>
<td>13 August 1998</td>
<td>12.53 ± 0.97</td>
<td>9.95 ± 1.81</td>
<td>0.07 ± 0.01</td>
</tr>
<tr>
<td><em>C. rubicundum</em></td>
<td>3 September 1998</td>
<td>16.70 ± 1.62</td>
<td>14.17 ± 1.43</td>
<td>0.16 ± 0.02</td>
</tr>
<tr>
<td><em>C. densum</em></td>
<td>3 September 1998</td>
<td>16.09 ± 2.05</td>
<td>14.77 ± 1.83</td>
<td>0.10 ± 0.01</td>
</tr>
<tr>
<td><em>C. mongolicum</em></td>
<td>24 August 1998</td>
<td>13.32 ± 1.35</td>
<td>9.32 ± 1.48</td>
<td>0.10 ± 0.02</td>
</tr>
<tr>
<td><em>C. chinense</em></td>
<td>29 August 1998</td>
<td>13.11 ± 0.90</td>
<td>11.85 ± 1.12</td>
<td>0.12 ± 0.01</td>
</tr>
<tr>
<td><em>C. caput-medusae</em></td>
<td>10 August 1998</td>
<td>21.66 ± 2.31</td>
<td>18.18 ± 3.05</td>
<td>0.15 ± 0.01</td>
</tr>
<tr>
<td><em>C. arborescens</em></td>
<td>10 August 1998</td>
<td>20.32 ± 4.42</td>
<td>16.34 ± 4.01</td>
<td>0.15 ± 0.03</td>
</tr>
<tr>
<td><em>C. alaschanicum</em></td>
<td>1 September 1998</td>
<td>19.78 ± 2.44</td>
<td>16.27 ± 2.17</td>
<td>0.11 ± 0.02</td>
</tr>
<tr>
<td><em>C. potaninii</em></td>
<td>1 September 1998</td>
<td>14.73 ± 1.93</td>
<td>12.23 ± 2.12</td>
<td>0.11 ± 0.01</td>
</tr>
</tbody>
</table>

Seed size and seed dry mass are mean ± S.D. of 10 randomly selected seeds from each species in Shapotou Desert Experiment and Research Station of Chinese Academy of Science (Tao, 2000).
and fastened with paper clips to prevent seed loss. The seeds were then immersed in boiling water for 10 min. After immersion, they were removed from the boiling water and left to cool on a table for about 5 min.

Cold stratification: Seeds were soaked in distilled water for 2 days, wrapped in paper bags, and then stored in plastic bags in a refrigerator (3°C), for 25 days. During the period of imbibition, water was replaced twice a day.

Exudate treatment: During preliminary studies it had been noted that a yellow, water-soluble material was exuded from soaking seeds that perhaps included water-soluble inhibitors from the testa (Yu and Wang, 1998). To examine the possible effect of this exudate on seed germination, a group of seeds was exposed to the exudate solution during the germination period, instead of clean distilled water.

2.3. Germination experiment

The germination experiments were conducted during May–June 1999. Controlled seeds and seeds that had undergone the pretreatments described above were placed on wet filter paper in glass Petri dishes (11.5 cm diameter × 2 cm depth). These were then placed into temperature-controlled chambers for germination, set at 14 h of daylight at 25°C and 10 h of darkness at 12°C, to approximate general springtime field conditions. To ensure no systematic effects due to position within the chamber, Petri dishes were rearranged at random every 2 days. All pre-sowing seed treatments consisted of five replicates of 40 seeds for each species. Visible radicle growth was used to define germination. Germination was recorded every 5 days and allowed to proceed for 9 weeks except where specified. Ungerminated seeds were soaked in water at 30°C for 24 h. Testa was cut and the embri was soaked in 1% tetrazolium chloride for 24 h at 30°C. Pink embryos were scored as alive. Germination was expressed as percentage of viable seeds germinated.

2.4. Data analysis

The results of the germination experiments were analyzed for statistical significance (ANOVA) from the STATISTICA software package for personal computer (Statsoft, 1993). All percent germination data were arcsine-square-root transformed prior to analysis. Arcsine-transformed means and standard errors were backtransformed for graphic presentation. Multiple comparisons of means were made with Duncan’s tests at 95%. The following parameters were determined:

\[
\text{germination} = \frac{\text{number of germinating seeds}}{\text{number of seeds initiated}} \times 100
\]

relative germination

\[
= \frac{\text{number of germinating seeds}}{\text{number of viable seeds initiated}} \times 100
\]

dormancy

\[
= \frac{\text{number of ungerminated but viable seeds}}{\text{number of seeds initiated}} \times 100
\]

relative dormancy

\[
= \frac{\text{number of ungerminated but viable seeds}}{\text{number of viable seeds initiated}} \times 100
\]

mortality

\[
= \frac{\text{number of inviable seeds}}{\text{number of seeds initiated}} \times 100
\]

index of germination rate:  \( \text{IGS} = \sum \frac{G}{t} \)

where \( G \) is the relative germination percentage at 5-day intervals, and \( t \) is the total germination period. This parameter characterizes the rate of germination for particular seed replicates.

3. Results

3.1. Seed quality of germination ecology

Table 2 summarizes mean values for germination, relative germination, dormancy, relative dormancy, mortality and IGS, prior to any pretreatment. It was clear that there was no significant correlation between these variables and seed size or weight (Tables 1 and 2). Germination and relative germination differed among the 10 species (one-way ANOVA: \( F_{9,36} = 14.94, P < 0.0001 \) for the former; \( F_{9,36} = 10.52, P < 0.0001 \) for the latter). C. leucocladum had the highest germination and relative germination (47 and 69.3%). C. leucocladum and C. mongolicum had significant poorer germination and relative germination (11.5 and 28.8% for the former, 14.5 and 31.3% for the latter) than the other species. Inversely,
Table 2
Overall seed germination qualities for 10 species of *Calligonum* following storage for 8 months at room temperature in Shapotou Desert Experiment and Research Station of Chinese Academy of Science

<table>
<thead>
<tr>
<th>Species</th>
<th>Germination percent ± S.D.</th>
<th>Relative germination percent ± S.D.</th>
<th>Dormancy percent ± S.D.</th>
<th>Relative dormancy percent ± S.D.</th>
<th>Mortality percent ± S.D.</th>
<th>IGS ± S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>C. junceum</em></td>
<td>47.0 ± 7.4 a</td>
<td>69.3 ± 13.4 a</td>
<td>21.5 ± 10.2 a</td>
<td>30.7 ± 13.4 a</td>
<td>31.5 ± 6.8 a</td>
<td>9.8 ± 2.4 a</td>
</tr>
<tr>
<td><em>C. leucolecladum</em></td>
<td>11.5 ± 5.2 b</td>
<td>28.8 ± 8.1 b</td>
<td>27.5 ± 7.7 a</td>
<td>71.2 ± 8.1 b</td>
<td>61.0 ± 11.0 b</td>
<td>4.2 ± 1.5 bd</td>
</tr>
<tr>
<td><em>C. rubicundum</em></td>
<td>37.5 ± 7.7 ac</td>
<td>58.9 ± 14.7 a</td>
<td>27.0 ± 11.0 a</td>
<td>41.1 ± 14.7 a</td>
<td>35.5 ± 6.9 a</td>
<td>7.6 ± 2.7 abc</td>
</tr>
<tr>
<td><em>C. densum</em></td>
<td>42.5 ± 3.1 ac</td>
<td>64.1 ± 9.6 a</td>
<td>24.5 ± 8.7 a</td>
<td>35.9 ± 9.6 a</td>
<td>33.0 ± 6.5 a</td>
<td>8.6 ± 1.5 a</td>
</tr>
<tr>
<td><em>C. mongolicum</em></td>
<td>14.5 ± 8.2 b</td>
<td>31.3 ± 8.7 b</td>
<td>30.0 ± 10.3 a</td>
<td>68.7 ± 8.7 b</td>
<td>55.5 ± 16.6 b</td>
<td>4.5 ± 0.8 cd</td>
</tr>
<tr>
<td><em>C. chinense</em></td>
<td>35.5 ± 4.1 ac</td>
<td>61.3 ± 6.2 a</td>
<td>22.5 ± 4.7 a</td>
<td>38.7 ± 6.2 a</td>
<td>42.0 ± 5.1 ab</td>
<td>7.6 ± 1.0 ac</td>
</tr>
<tr>
<td><em>C. caput-medusae</em></td>
<td>34.0 ± 8.4 ac</td>
<td>52.2 ± 12.9 a</td>
<td>31.5 ± 9.9 a</td>
<td>47.8 ± 12.9 a</td>
<td>34.5 ± 9.7 a</td>
<td>6.4 ± 1.9 ab</td>
</tr>
<tr>
<td><em>C. arborescens</em></td>
<td>29.5 ± 4.5 ac</td>
<td>58.5 ± 2.9 a</td>
<td>21.0 ± 3.8 a</td>
<td>41.5 ± 2.9 a</td>
<td>49.5 ± 7.8 ab</td>
<td>7.0 ± 1.0 abc</td>
</tr>
<tr>
<td><em>C. alaschanicum</em></td>
<td>26.0 ± 8.2 c</td>
<td>58.2 ± 12.6 a</td>
<td>19.5 ± 8.9 a</td>
<td>41.8 ± 12.6 a</td>
<td>54.5 ± 13.9 b</td>
<td>7.4 ± 2.3 a</td>
</tr>
<tr>
<td><em>C. potaninii</em></td>
<td>34.0 ± 4.5 ac</td>
<td>64.2 ± 7.1 a</td>
<td>19.0 ± 4.2 a</td>
<td>35.8 ± 7.1 a</td>
<td>47.0 ± 4.5 ab</td>
<td>8.0 ± 1.5 ac</td>
</tr>
</tbody>
</table>

Different letters indicate significant difference between the values of pairs of species in the same column (Duncan’s multiple comparison test, \( P < 0.05 \)).

*C. leucolecladum* and *C. mongolicum* had highest relative dormancy (71.2 and 68.7%). The one-way ANOVA showed that the percentage of dormant seeds was not significantly affected by species (\( F_{0.36} = 2.12, P = 0.53 \)). There are significant differences among species for seed mortality and IGS (one-way ANOVA: \( F_{9.36} = 7.70, P < 0.0001 \) for mortality; \( F_{9.36} = 6.87, P < 0.0001 \) for IGS). *C. leucolecladum, C. mongolicum* and *C. alaschanicum* had significantly greater mortality (61.55 and 54.5%). The IGS were lowest for *C. leucolecladum* (4.2) and *C. mongolicum* (4.5; Table 2).

3.2. Effect of pretreatment on germination

For all 10 species, germination differed significantly for seeds given the different pretreatments (one-way ANOVA: \( F_{5.20} = 35.57, P < 0.0001 \) for *C. junceum*; \( F_{5.20} = 30.40, P < 0.0001 \) for *C. leucolecladum*; \( F_{5.20} = 38.46, P < 0.0001 \) for *C. rubicundum*; \( F_{5.20} = 49.41, P < 0.0001 \) for *C. densum*; \( F_{5.20} = 87.17, P < 0.0001 \) for *C. mongolicum*; \( F_{5.20} = 29.55, P < 0.0001 \) for *C. chinense*; \( F_{5.20} = 49.30, P < 0.0001 \) for *C. caput-medusae*; \( F_{5.20} = 65.21, P < 0.0001 \) for *C. arborescens*; \( F_{5.20} = 13.90, P < 0.0001 \) for *C. alaschanicum*; \( F_{5.20} = 48.26, P < 0.0001 \) for *C. potaninii*). For most species, the lowest germination percent occurred in the exudate treatment and the highest occurred in the abrasion treatment. Compared with the control, seeds of all species that had undergone the boiling water treatment had poorer germination, the abrasion, sulphuric acid and cold stratification treatments significantly increased the germination of all species (Fig. 1).

For all species, the relative germination differed significantly for seeds given different pretreatments (one-way ANOVA: \( F_{5.20} = 5.03, P = 0.0038 \) for *C. junceum; F\(_{5.20} = 24.50, P < 0.0001 \) for *C. leucolecladum; F\(_{5.20} = 6.85, P = 0.0007 \) for *C. rubicundum; F\(_{5.20} = 12.76, P < 0.0001 \) for *C. densum; F\(_{5.20} = 32.22, P < 0.0001 \) for *C. mongolicum; F\(_{5.20} = 3.32, P = 0.0240 \) for *C. chinense; F\(_{5.20} = 38.36, P < 0.0001 \) for *C. caput-medusae; F\(_{5.20} = 26.58, P < 0.0001 \) for *C. caput-medusae; F\(_{5.20} = 16.51, P < 0.0001 \) for *C. leucolecladum; F\(_{5.20} = 3.41, P = 0.0217 \) for *C. rubicundum; F\(_{5.20} = 6.61, P < 0.0001 \) for *C. densum; F\(_{5.20} = 12.97, P < 0.0001 \) for *C. caput-medusae; F\(_{5.20} = 7.09, P < 0.0001 \) for *C. arborescens; F\(_{5.20} = 19.19, P < 0.0001 \) for *C. alaschanicum*; F\(_{5.20} = 7.48, P < 0.0001 \) for *C. potaninii*).
P < 0.001 for C. potaninii) and no significant difference in three species ($F_{5,20} = 2.37, P = 0.0767$ for C. mongolicum; $F_{5,20} = 1.44, P = 0.2533$ for C. chinense). The percent dormancy responses of seeds to the yellow water-soluble exudate differed in between species. In the case of C. potaninii, the exudate treatment had no significant effects on dormancy (Fig. 3). For C. leucocladum, C. densum, C. caput-medusae, C. arborescens and C. alaschanicum, the exudate treatment significantly increased dormancy relative to the control and all other pretreatments. For C. leucocladum, C. densum, C. caput-medusae, C. arborescens and C. alaschanicum, the exudate treatment significantly increased dormancy relative to the control and all other pretreatments (Fig. 3).

Relative dormancy was significantly different between pretreatments in 10 species (one-way ANOVA: $F_{5,20} = 11.24, P < 0.0001$ for C. juncum; $F_{5,20} = 29.66, P < 0.0001$ for C. leucocladum; $F_{5,20} = 12.4329, P < 0.0001$ for C. rubicundum; $F_{5,20} = 17.89, P < 0.0001$ for C. densum; $F_{5,20} = 18.89, P < 0.0001$ for C. mongolicum; $F_{5,20} = 4.64, P = 0.0056$ for C. chinense; $F_{5,20} = 41.24, P < 0.0001$ for C. caput-medusae; $F_{5,20} = 30.87,$...
P < 0.0001 for C. caput-medusae; F_{5,20} = 17.65, P < 0.0001 for C. alaschanicum; F_{5,20} = 12.87, P < 0.0001 for C. potaninii. Compared with the control, the abrasion treatment significantly lowered overall dormancy except for C. chinense and C. potaninii. C. potaninii had significantly lower relative dormancy than the control and other treatments following cold stratification. Cold stratification treatment significantly reduced relative dormancy in C. leucocladum, C. rubicum, C. mongolicum, C. caput-medusae, C. arborescens, C. potaninii relative to the control (Fig. 4).

There were significant differences in percent seed mortality between the different seed pretreatments in 10 species (one-way ANOVA: F_{5,20} = 24.92, P < 0.0001 for C. junceum; F_{5,20} = 6.41, P = 0.0011 for C. leucocladum; F_{5,20} = 19.87, P < 0.0001 for C. rubicum; F_{5,20} = 7.84, P = 0.0003 for C. densum; F_{5,20} = 3.02, P = 0.0342 for C. mongolicum; F_{5,20} = 27.96, P < 0.0001 for C. chinense; F_{5,20} = 5.84,
$P = 0.0017$ for *C. caput-medusae*; $F_{5,20} = 8.39$, $P = 0.0002$ for *C. arborescens*; $F_{5,20} = 22.45$, $P < 0.0001$ for *C. alaschanicum*; $F_{5,20} = 36.82$, $P < 0.001$ for *C. potaninii*. For *C. junceum* and *C. rubicundum*, the exudate treatments applied resulted in significant effects on mortality than the control and other treatments (Fig. 5). Compared with the control, the abrasion treatment significantly lowered overall mortality except for *C. leucocladum* and *C. mongolicum*. Cold stratification tended to increase mortality, but such increases were not always significant (Fig. 5).

The index of germination of seeds (IGS) differed significantly between pretreatments for all species (one-way ANOVA: $F_{5,20} = 5.61$, $P = 0.0022$ for *C. junceum*; $F_{5,20} = 39.56$, $P < 0.0001$ for *C. leucocladum*; $F_{5,20} = 8.07$, $P = 0.0003$ for *C. rubicundum*; $F_{5,20} = 22.49$, $P < 0.0001$ for *C. densum*; $F_{5,20} = 59.6$, $P < 0.0001$ for *C. mongolicum*; $F_{5,20} = 8.8$, $P = 0.0002$ for *C. chinense*; $F_{5,20} = 44.4$, $P < 0.0001$ for *C. caput-medusae*; $F_{5,20} = 57.73$, $P < 0.0001$ for *C. arborescens*; $F_{5,20} = 14.88$, $P < 0.0001$ for *C. alaschanicum*; $F_{5,20} = 21.26$, $P < 0.0001$ for *C. potaninii*). For all species, highest IGS occurred following abrasion, sulphuric acid and boiling treatments. Compared with the control, the cold stratification and exudate treatments significantly decreased the IGS in *C. leucocladum*, *C. mongolicum*, *C. arborescens* and *C. potaninii*, the abrasion, sulphuric acid and boiling...
water treatments significantly increased the IGS in *C. leucocladum* and *C. mongolicum* (Fig. 6).

4. Discussion

The hard testa of many desert plants has evolved to withstand unfavourable conditions such as heat caused by sunlight, the strong teeth of dispersing animals, severe drought and mechanical damage (Freas and Kemp, 1983; Washitani and Masuda, 1990; Fenner, 1991; Meyer and Monsen, 1991; Gutterman, 1993; Baskin and Baskin, 1998; Silvertown, 1999). In consequence, severe treatments are required to chance the testa permeability to water. Several pre-sowing treatments have been used to overcome hard testa imposed dormancy (Meyer et al., 1990; Ferasol et al., 1995; Broncano et al., 1998; Goslan and Gutterman, 1999; Rachel and Galatowitsch, 1999). The objective of all these treatments is to make the testa permeable to water by acting on specific weak spots of the hard testa. Of the different pre-sowing treatments, cold stratification, mechanical, acid and hot water treatments are widely used because they improve germination within a relatively short period of time.

In the present study, the germination response of seeds to different pretreatments was more or less similar for all 10 *Calligonum* species. Germination of seeds of the 10 species was poorest with the exudate treatment and best with the abrasion treatment. Compared with the control, seeds given boiling water treatment had poorer germination, and the abrasion, sulphuric acid and cold stratification treatments significantly improved germination. Exudates reduced seed germination except for *C. alaschanicum*. Seeds from all species showed an increase in relative germination after sulphuric acid and boiling water treatments relative to the control and other treatments. The exudate treatment had different effects on dormancy depending on species. Compared with the control, the exudate treatment significantly reduced percent germination and increased dormancy for almost all species. Germination inhibiting substance have been reported previously in the yellow water-soluble exudate of *Calligonum* seeds (Vleeshouwers et al., 1995; Schutz and Milberg, 1997; Yu and Wang, 1998). The abrasion treatment enhanced germination of all species. The cold stratification treatment can break the dormancy of viable *Calligonum* seeds and increased the germination, but it has a little lethal effect on viable seeds (Fig. 5). According to our observation during germination experiments, many seeds treated with boiling water rotted and succumbed to mold attacked, indicating that they are very sensitive to high temperature.

The positive responses of seeds to the pre-sowing scarification treatments (abrasion and sulphuric acid) suggests that the hard testa is responsible for the low percentage germination of untreated seeds by preventing imbibition of water. Prevention of germination by hard testa of *Calligonum* species has different ecological advantages (Tao, 2000). This feature favours the accumulation of persistent seed banks in the soil, spreads germination over time, suffers the extremely environmental condition and increases the chance that some seeds will germinate, survive and establish (Freas and Kemp, 1983; Fenner, 1991; Gutterman, 1993; Morgan, 1998; Wang et al., 1998). Overcoming dormancy, softening of the testa and water uptake are therefore, crucial matters in the life cycle of hard-seeded species (Wang et al., 1997; Yang et al., 1999).

The results from the present study provides evidence that almost all germination variables differed significantly between the pre-sowing treatments for all 10 *Calligonum* species. The speed and percent germination of the *Calligonum* species investigated can be greatly increased by subjecting the seeds to either mechanical scarification or acid treatments. The results show that seeds of *C. junceum* have strong ability of germinating (Table 3).

Improper seed pre-sowing treatment can lead to reduced seed germination. The implications of poor seed supply for restoration efforts are substantial. As viability rates are reduced, recommended seeding rates must be increased. Because the availability of *Calligonum* seeds is often limited by climate (rainfall), seasonal and site variability (Tao, 2000) obtaining sufficient seed may be difficult and the associated costs prohibitive. The formal standard recommended seed pre-sowing treatments for *Calligonum* species are sulphuric acid and cold stratification (Zhang, 1992). The results of the present study indicate that abrasion, cold stratification and sulphuric acid all are appropriate for the 10 *Calligonum* species under study. These conclusions are very meaningful because they indicated that *Calligonum* species can be propagated
by seed in the arid desert regions. Further work is required to develop seeding criteria for good seed pre-sowing practice to ensure germination in the field.

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