Improving Seed Germination of *Aquilegia chrysantha* by Temperature Manipulation

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Abstract. Seeds of *Aquilegia chrysantha* Gray were germinated under a variety of temperature regimes. Germination was nearly 90% under a day/night cycle of 25/20C, but was reduced to $\leq 40\%$ under constant 25C or a 25/10C day/night cycle. With days between 25 and 29C (night = 20C), germination percentage dropped gradually to $\approx 60\%$ with increasing temperature. With days $>29\text{C}$, germination declined dramatically such that no germination occurred at 31C. Neither kinetin (4.6 to 46 μM) nor ethephon (6.9 to 207 μM) was able to reverse the inhibitory effects of 33C days. Our results indicate that germination of *A. chrysantha* seed is sensitive to temperature and that germination $\approx 75\%$ can be obtained under a 25 to 27C day/20C night regime. Chemical names used: 2-chloroethylphosphonic acid (ethephon); 6-furfurylaminopurine (kinetin).

Aquilegia chrysantha, sometimes erroneously referred to as *A. hinckleyana* Gray (Lott, 1985), is a brilliant, yellow-flowered herbaceous perennial native to a very small area of southwestern Texas. The plant has excellent heat tolerance, particularly for an *Aquilegia* species, and considerable potential as a landscape plant (Welch, 1989). *Aquilegia* seeds often exhibit irregular germination patterns that complicate transplant production (Nau, 1989). Indeed, erratic seed germination is a serious obstacle to *A. chrysantha* commercial production. Although little is known about the seed biology of this species, germination ap-

pears to require relatively low temperatures. For example, Finnerty et al. (1992) obtained 80% to 90% germination at constant 20C, but almost no germination at 26C. Temperatures near 20C maybe difficult to maintain in greenhouses in the southern United States. Furthermore, *A. chrysantha* seeds should be planted in late spring or early summer to produce transplants of suitable size and quality for fall planting outdoors. Maintaining the low temperatures required for germination during this period is often impossible or, at best, costly.

Because *A. chrysantha* is native to a region with considerable diurnal temperature fluctuation during the normal germination period (i.e., autumn), alternating temperatures might enhance seed germination. We hypothesized that the inhibitory effects of a high daytime temperature could be offset at least partially by cool nights. One objective of the research reported herein was to test this hypothesis. We also sought to determine the temperature range over which thermodormancy is induced. Finally, we tested whether two seed dormancy-breaking agents, kinetin and ethephon (Rao et al., 1975; Sankhla and Sankhla, 1973), would be useful in overcoming high-temperature-induced dormancy.

Aquilegia chrysantha seeds were collected in late Spring 1990 and 1991 (hereafter referred to as 1990 and 1991 seeds, respectively) from plants growing in a garden in San Antonio, Texas. A tetrazolium test (Hartmann et al., 1990) indicated that $\approx 95\%$ of the seeds were viable. Three separate experiments were conducted. In each experiment, seeds were placed on moistened filter paper inside clear plastic petri dishes (30 seeds per dish) and germinated in temperature-controlled chambers (H.5C). An 8-h photoperiod was used, during which the photosynthetically active radiation level at the top of the petri dishes was 50 to 100 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$. The filter paper was demoistened every 3 to 4 days. There were three dishes per treatment, and each experiment was conducted at least twice. The number of germinated seeds was recorded daily for 1 month. A seed was considered germinated when the radicle became visible to the naked eye. Means and standard errors were calculated for each treatment. Temperature response data were subjected to regression analysis.

In the first experiment, seeds were placed under the following four temperature regimes: 25C constant, 25C day/20C night, 25C day/15C night, and 25C day/10C night. For the second experiment, seeds were kept at 25, 27, 29, or 31C during the day, each with nights at 20C. In the final experiment, seeds were placed under a 33C day/20C night cycle on filter paper moistened with aqueous solutions of 0, 4.6, 23.2, or 46 μM kinetin or 0, 6.9, 34.5, 68.9, or 207 μM ethephon. The growth regulator dosage ranges were chosen based on our previous experience with other herbaceous species (Rao et al., 1975; Sankhla and Sankhla, 1973).

With the 25C day/20C night regime, germination was first observed after 9 to 11 days (Table 1). In contrast, seeds at the lowest night temperature (25/10C) required at least 2 weeks before any germination occurred. The 1990 seeds germinated more rapidly and required less time to reach 50% germination than the 1991 seeds; nonetheless, the response of the two seed lots to the temperature regimes was similar. The highest germination percentage after 1 month ($\approx 87\%$) occurred in the 25/20C cycle. At constant 25C, germination was $\approx 34\%$. Thus, as with several non-*Aquilegia* species (Mayer and Poljakoff-Mayber, 1989; Thompson and Grime, 1983), alternating diurnal temperatures appear to promote germination of *A. chrysantha*. In any case, our results indicate

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Table 1. Influence of several temperature regimes on germination of *A. chrysantha* seeds produced in the years indicated.

Criterion	Temp			
	25C constant	25C day/ 20C night	25C day/ 15C night	25C day/ 10C night
Time to first seed germination (days)				
1990	11±1 ^z	9±1	10±1	14±1
1991	... ^y	11±2	16±1	22±4
T ₅₀ ^x (days)				
1990	... ^w	14±1	16±1	... ^w
1991	... ^w	19±3	22±1	... ^w
Total germination (%) after 1 month				
1990	34±7	87±3	73±7	38±3
1991	... ^y	88±5	71±1	10±3

^zValues indicate standard error of the mean.

^yOnly one seed germinated in this treatment.

^xTime until 50% of the seeds germinated.

^w50% Germination was not achieved in this treatment.

that days at 25C coupled with nights at 20C can yield relatively high germination percentages. With nights at 15C rather than 20C, germination was reduced slightly, but was still much higher after 1 month than that observed at constant 25C or when the night temperature was 10C (Table 1).

As in the first experiment, the 1990 and 1991 seeds responded similarly to temperature, and germination was relatively high (80% to 90%) with the 25/20C cycle in the second experiment (Fig. 1). As the day temperature was increased to between 25 and 29C, germination gradually declined quadratically, and no germination occurred at 31 C. Thus, *A. chrysantha* seeds exhibit a high-temperature-induced therm dormancy similar to several other species (Mayer and Poljakoff-Mayber, 1989; Rao et al., 1975; Sankhla and Sankhla, 1973). Our data indicate that day temperatures must be ≤ 29C to obtain >50% germination. Further, the quadratic response indicates that germination will decline precipitously above 29C.

Neither kinetin nor ethephon, at any of the concentrations used, promoted germination under the 33C day/20C night regime (data not shown). Under these conditions, none of the

Fig. 1. Germination (after 1 month) of *A. chrysantha* seeds in relation to day temperature. Night temperature was 20C for all treatments. Response to temperature was quadratic and significant at $P \leq 0.05$. Regression equation for 1990 seeds: $y = 173.15x - 3.31x^2 - 2182.4$, $r^2 = 0.980$. Regression equation for 1991 seeds: $y = 150.2x - 2.94x^2 - 1830.2$, $r^2 = 0.991$.

seeds germinated. Thus, at the concentrations tested, kinetin and ethephon do not appear to be of much potential value for overcoming high-temperature-induced therm dormancy of *A. chrysantha* seeds. In contrast, these compounds have promoted germination of lettuce (*Lactuca sativa* L.) at high temperature (Rao et

al., 1975; Sankhla and Sankhla, 1973; Sharples, 1973).

Finnerty et al. (1992) reported that cool, moist stratification slightly improved germination of *A. chrysantha* under constant 20C. At constant 26C, however, germination was <3% regardless of whether the seeds were stratified. In the present study, seeds were not stratified and were stored at 20 to 25C following harvest. Thus, stratification clearly was not essential for obtaining 80% to 90% germination, provided seeds were germinated under a 25 to 27C day/20C night cycle.

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