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The Interaction of Temperature on Flowering of *Alstroemeria* 'Regina'[1]

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Abstract. **When *Alstroemeria* 'Regina' plants were programmed to flower after 6 or 8 weeks at 5°C treatments, flowering was hastened by forcing plants at 18° vs. 13° greenhouse night air temperature. However, the 18° forcing temperature reduced flower production, flowers per shoot and shoot grade when compared to 13° forcing temperatures. Due to the decrease in flower production observed at 18° forcing temperature, a 13° temperature is recommended. When plants were grown for 16 weeks at 13°, an inductive temperature, or for 16 weeks at 21°, a non-inductive temperature, prior to the 5° inductive treatments, the 13° pretreatment without a 5° treatment was as effective as 8 weeks at 5° following the initial 21° pretreatment when forced at 18°. Thus, the cold requirement can be fulfilled either at 5° for a short period of time (6 to 8 weeks) or at 13° over an extended time span (16 weeks). Total shoot production during the flowering span decreased as the duration of the 5° treatment increased.**

A decrease in days to flower of *Alstroemeria* 'Regina' following a 5°C treatment for 4 to 6 weeks was demonstrated by our research group (5, 22). Vonk Noordegraaf (19) presented data showing that total shoot production was stimulated by air temperatures above 13°, but percentage of shoots that flowered decreased. His data were from plants which had been grown at 9°, 13°, 17°, 21°, or 25° from the beginning of the experiment. However, it was not clear what previous treatments these plants had received. Our previous work has shown that once rhizomes are induced to flower, flowering can be prolonged if the medium temperature is maintained below 20° (4).

Experiments were designed to determine whether rhizomes programmed to flower by a 5°C treatment, then forced at 18°, would flower earlier with increased flower stem production than those forced at 13°. We felt that increased flower production was based on promoting earlier flowering as plants ceased flowering at approximately the same time regardless of previous treatments (7, 20).

Materials and Methods

Alstroemeria 'Regina' plants were grown for 15 months at either 21°C minimum day/night (D/N) (Expt. I) or 13° minimum D/N (Expt. II) prior to rhizome division. All plants were divided on October 11, 1978. Each division consisted of a single rhizome with both storage roots and young vegetative shoots attached. These individual rhizome divisions were planted in 15 cm plastic pots filled with a 1 peat: 1 perlite: 1 soil (v/v/v) medium. Plants were allowed to resume growth under normal day lengths (ND) at the 45° north parallel in a glass greenhouse. Plants were continued at either 21°/18° D/N (Expt. I), or 13° D/N (Expt. II) until treatments began. Vegetative shoots were removed monthly to promote new shoot formation (6). Throughout the course of the experiment, fertilizer applications were based on weekly soil tests.

After 16 weeks of vegetative growth, plants for Expt. I and II were placed in a 5°C cooler irradiated with 3.5 W m^{-2} of Cool White fluorescent light (0800 to 1600). Every 2 weeks for the next 8 weeks, 8 plants from each experiment were removed from the cooler. Four plants were placed in a 21°/18° D/N (henceforth referred to as 18°) and 4 in a constant 13° D/N forcing greenhouse. The control plants (0 weeks at 5°) were placed in the 13° or 18° forcing greenhouses on the same day (February 14) as the first 5° treated plants. All plants in the greenhouse were irradiated with incandescent lights (10 W cm^{-2}) using a night interruption from 2200 to 0200. Irradiation was discontinued on April 15, 1979, when the normal daylength was 13½ hr (16). Temperatures were maintained at the specified range as long as possible with fan and pad cooling. Night temperature control of 13° was lost by July 1.

When plants were placed in the greenhouse at the respective forcing temperatures, the number of shoots present in each pot was recorded. On July 1, vegetative shoots were counted and final data taken on plants grown at the 18°C forcing temperature since these had ceased flowering by July 1. The experiment was terminated on September 7, 1979, and all reproductive shoots, whether in bud or flower, were recorded on plants which were grown at 13° D/N temperature.

Plants were arranged in a completely random design. Differences between treatments were determined using single degree F tests. Stems were harvested when the first primary flower was fully opened. Data collected on each flowering stem included: number of primary, secondary, tertiary and quartenary flowers on the cyme, stem length, days to flower (DTF) from the start of forcing temperature treatments and number of vegetative and flowering shoots per plant.

Results and Discussion

Days to flower. The number of days to flower was inversely related to the number of weeks the plants were subjected to 5°C.

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Table 1. Mean days to flower of the first 5 flowering stems, total shoot production, percentage of the total shoot production that flowered, and flowering shoot length when plants were pretreated for 16 weeks at 21°C (Expt. I) or 13° (Expt. II) prior to the 5° treatments which lasted 0, 2, 4, 6, or 8 weeks and then forced at 13° or 18° night temperatures.

	Pretreatment		Weeks at 5°C					Forcing temp	
Variable	13°	21°	0[z]	2	4	6	8	13°	18°
Days to flower	86.2	90.6*	99.6	92.2*	92.4*	76.6*	83.5*	99.1	76.3*
Total shoot production	59.1	69.2	78.8	70.4	62.7	62.6	46.6*	87.1	41.4*
Flowering (%)	45.7	41.5	47.3	39.7	42.6	47.2	42.7	50.3	21.9*
Flowering shoot length (cm)	68.1	64.2	66.7	60.3	60.0	71.5	73.1	69.8	62.4*

[z]Plants pretreated at 21° did not flower
*Significantly different at 5% by single degree level.

These data support our earlier work (5, 22) with *Alstroemeria* and work by others with *Dicentra* (9) and wheat (8). Further, plants which were pretreated at 13°, a temperature at which flowering does occur (7, 12, 17) (Table 1, Expt. II) flowered earlier than plants pretreated at 21° (Table 1, Expt. I), a temperature at which flowering does not occur (17). This suggests that the flower-inducing cold treatment may be an accumulated response and that it can be acquired over a period of time at some temperature below 20°, in this case slowly at 13° or rapidly at 5°. This response is similar to that observed with *Lilium longiflorum* (2) where flowering occurs at any temperature below 20°, but most rapidly if bulbs are given 6 weeks at 5°. This datum further demonstrates that once an adequate cold treatment has been received, at either 5° or 13°, flowering is delayed by low temperatures in the forcing greenhouse. Increasing the air temperatures from 13° to 18° accelerated flowering and compensated for any delay that occurred from prolonging the length of the 5° cold treatment. These same trends were observed by Wilkins, et al. with *Lilium longiflorum* (23, 24). Thus, once *Alstroemeria* are adequately programmed to flower, the rate of flower shoot development is governed by the forcing temperatures.

Shoot production. Total shoot production (vegetative and reproductive) was inversely proportional to the duration of the 5°C treatment (Table 1). When winter and spring wheat were vernalized for increasing periods of time, tiller production responded inversely to the length of the cold treatment (8). Just as DTF was decreased with a 13° pretreatment (Exp. II), total shoot production tended to be inhibited by a 13° pretreatment. Since flowering shoots are a major component of total shoot production, any decrease in total shoot production will affect flower production provided plants have been properly vernalized.

When the percentage of the total shoots produced that flowered was calculated, the effect of proper vernalization became evident along with the dominant influence of forcing temperature. Although increasing the duration of the 5°C treatment did not significantly affect the percentage of the total shoots that flowered, the interaction of pretreatment and forcing temperature did indicate a significant effect. When plants were pretreated at 21° and forced at 18° or pretreated at 13° and forced at 13°, the percentage of the total shoots that flowered was reduced compared to plants pretreated at 21° and forced at 13° or pretreated at 13° and forced at 21°. Upon observation of these data, the reduction in the percentage of the total shoots that flowered was strongly influenced by the pronounced reduction observed when plants were pretreated at 21° and forced at 18°. These data suggest that the percentage of the total shoots that flowered was related to the duration of inductive temperatures the plants perceived prior to, or subsequent to, the start of forcing. Thus, plants that have been properly vernalized prior to the commencement of flowering can be forced at higher temperatures, whereas, those plants that experienced non-inductive temperatures prior to the start of forcing can compensate for the insufficient vernalization by the use of lower forcing temperatures. Nevertheless, the forcing temperature ultimately will determine the percentage of the total shoots that flower. This is further supported by previous work that showed that 10° soil temperatures maintained plants in a flowering condition longer than 20° or 25° soil temperatures (4).

Vonk Noordegraaf (19) reported that forcing temperatures stimulated shoot production with more shoots produced at 17°C than at 13°. Present data show greater total shoot production at 13° than at 18° (Fig. 1). Vonk Noordegraaf presumably did not use cold treated rhizomes, which could lead to his findings, as plants in our experiments that did not receive sufficient 5°, did not flower when forced at 18° and produced more total shoots than induced plants.

Previous work (4) reported that the soil temperature must be less than 10°C to maintain flowering for extended periods of time.

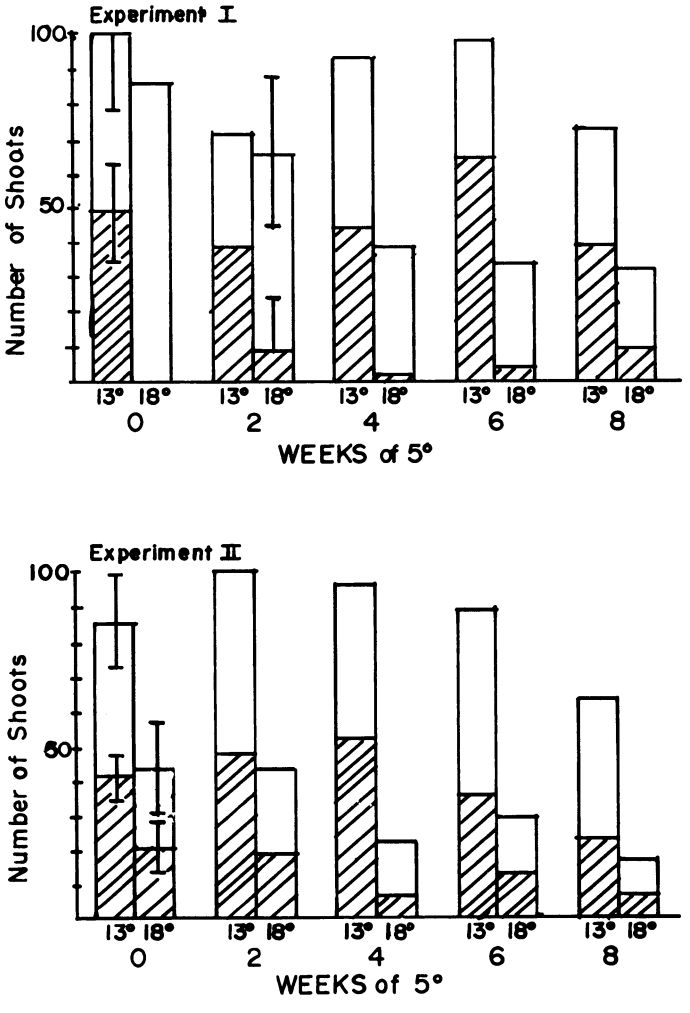

Fig. 1. Total shoot (clear bar) and flowering shoot (hatched bar) production when *Alstroemeria* 'Regina' were treated at 5°C for 0 to 8 weeks and then forced at 13° or 18° night temperatures. Plants were pretreated at 21° (Expt. I) or 13° (Expt. II) for 16 weeks prior to the start of the 5° treatment. HSD interval is at 5%.

The present data confirm those results and further suggest that once plants are induced to flower, the forcing temperature controls the ultimate flower production of the plant. The differences in total shoot production observed between pretreatments were accentuated at the 18° forcing temperatures (Fig. 1).

Flowering shoot length. Stem length was greater when plants were forced at 13°C versus 18° (Table 1). The 5° treatments did not promote shoot elongation as was shown in *Dicentra* (9) or tulip (9). Thus, forcing temperature is a primary factor controlling stem length.

Flowers per shoot. Each flowering stem consists of a whorl of sympodial branched cymes (6). The total flowers produced per shoot is the sum of primary (1°), secondary (2°), tertiary (3°), and quartenary (4°) flowers on each cyme. The number of flowers per cyme was not influenced by 5°C treatments (Fig. 2). Plants forced at 13° consistently produced more flowers per stem than at 18° (Fig. 2). The difference in total flowers per shoot was due to the decrease in 2°, 3°, and 4° flowers initiated at the 18° forcing temperature. This suggests that the higher forcing temperatures inhibit floral initiation similar to what occurs in *Lilium longiflorum* (21).

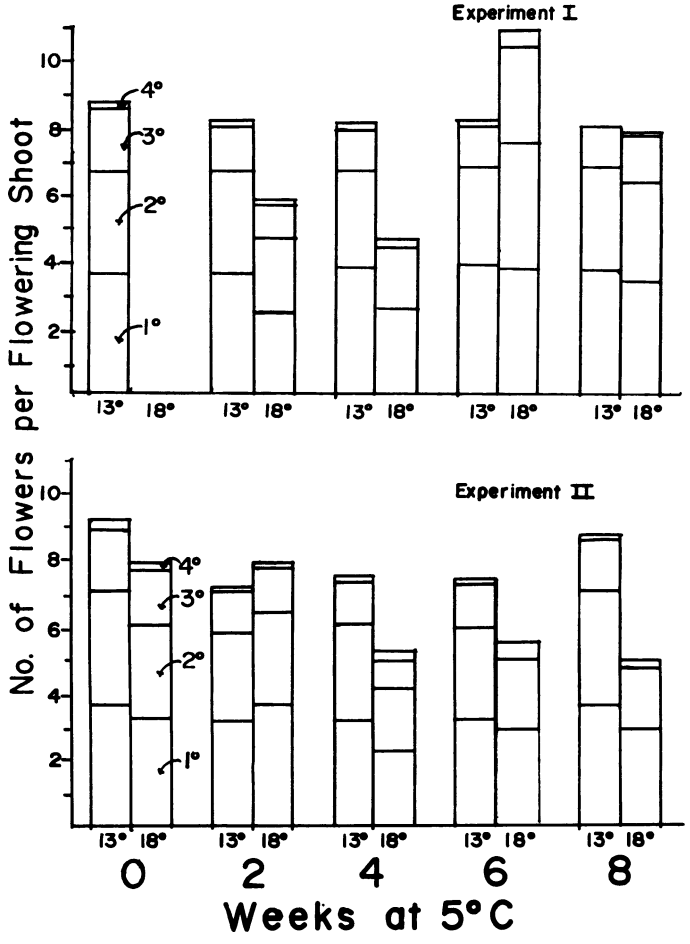

Fig. 2. Number of primary (1°), secondary (2°), tertiary (3°), and quartenary (4°) flowers initiated per flowering shoot when *Alstroemeria* 'Regina' were treated at 5°C for 0 to 8 weeks and then forced at 13° or 18° night temperature. Plans were pretreated for 16 weeks at 21° (Expt. I), or 13° (Expt. II) prior to the 5° treatments. For comparing means, the HSDs are Expt. I: T–1.8, 1°–1.3, 2°–0.6, 3°–0.52, 4°–0.23; Expt. II: T–1.3, 1°–0.6, 2°–0.5, 3°–0.4, 4°–0.2.

The flowering control mechanism in *Alstroemeria hybrida* 'Regina' is still not fully elucidated. There appears to be a primary cold requirement for floral induction as was proposed by Healy and Wilkins (5, 22), but a cold treatment either at 5°C for 6 weeks or 13° for 16 weeks, although equally inductive, will not promote rapid flowering. Once plants have perceived an adequate cold treatment, prolonging the cold treatment will only delay flowering with the forcing temperature (13° or 18°) accentuating the pretreatments (13° or 21°) and the subsequent actual cold treatment (5°). However, the period of time between the start of forcing and when flowering first begins may be too long to imply that the cold treatment alone stimulated earlier flowering.

Heins and Wilkins (7) reported that shoots from actively flowering plants could develop at the rate of 20 cm/week. By calculating the DTF for a 72 cm stem (Table 1), there exists an interval of some 25 days for shoot development and some 14 days for flower development to occur (unpublished data). However, when we place plants in a greenhouse for forcing that have been given the optimum flower inducing treatments, some 76+ days are required for flowering to occur. Thus some other environmental factors must be interacting for rapid flowering to occur.

Long photoperiods have been shown to stimulate earlier flowering in *Alstroemeria* while short photoperiods inhibit flower production (7, 18). Our unpublished data have illustrated to us that long photoperiod treatments of high intensity light were not effective in promoting earlier flowering unless plants were grown at 13°C for at least 8 weeks. Further, there is no datum demonstrating that photoperiod treatments can substitute for cold treatments in *Alstroemeria* to induce flowering as has been shown in *Dicentra* (9), *Lilium longiflorum* (13) or wheat (8). This suggests that with *Alstroemeria* there exists a phasic flowering mechanism, where the thermophase must precede the photophase. Teleologically, a phasic flowering mechanism would allow *Alstroemeria* to compete more effectively in their native habitat. Plants would develop vegetatively during the cool rainy winter, then flower during periods of lengthening photoperiods and increasing temperatures until high temperatures inhibited flowering prior to the hot dry summers (7). During each of the phases, the speciofic precursors necessary for flowering could be accumulating.

When *Alstroemeria* were grown at temperatures less than 15°C, increased storage root growth and enlargement were observed (4). A marked increase in rhizome to shoot growth ratio was observed when *Agropyron* was grown at 15° versus 25° (10). When starch and carbohydrate storage patterns were followed in *Poa pratensis*, plants grown at temperatures of 13° exhibited enhanced storage compared to plants maintained at 18° or 24° night temperatures (11). Heins and Wilkins hypothesized that the starch stored in these storage roots was a possible source of carbon for rapid flower shoot development (7). Thus the thermophase may depress shoot growth (Table 1) while stimulating storage root filling.

The exact role of the photophase has not been fully explored in *Alstroemeria*. When *Dactylis* was grown at 10°C or 20° under 8 or 16 hr photoperiods, plants exposed to a 16 hr photoperiod showed a greater accumulation of dry matter in shoots compared to roots than did those grown under 8 hr photoperiods (3). Long photoperiods may also be enhancing plant growth substance (PGS) relationships within the *Alstroemeria* plants that could be promoting flowering. Some of the effects of gibberellic acid on shoot growth and leaf morphology with *Alstroemeria* have been discussed elsewhere (5). The interaction between long photoperiods and other PGS in *Alstroemeria* is still speculative. Other resear-

chers have shown that cytokinins in the nucleotide form were greater under long days when compared to short days (15). Alvim, *et al.* observed increased ABA levels under long days (1). The exact effect of the photophase and the interaction with PGS as it affects the *Alstroemeria* flowering mechanism needs additional work.

Our results (5, unpublished data) suggest that the flowering mechanism in *Alstroemeria* is of a phasic nature which has an obligatory thermophase followed by a photophase. The exact parameters controlling each phase and their interactions still remain to be elucidated.

Nevertheless, for commercial production of *Alstroemeria* 'Regina', plants should be divided annually at the end of summer flowering, grown at temperatures near or at 18°C until early November in order to increase shoot production (Table 1). Then temperatures can be reduced to 5° for 6 weeks after which the temperatures should be increased to 13° for rapid flower development and prolonged flowering (Table 1). Medium temperatures should be maintained under 15° for as long as possible (4). Photoperiod treatments as a night interruption should be used when photoperiods are less than 13 hr (7, 17).

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