# LOW-TEMPERATURE STORAGE OF BEDDING-PLANT PLUGS

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ABSTRACT. Ageratum, begonia, marigold, and salvia seedlings growing in individual cells were stored to determine the effects of temperature, irradiance, and storage time on growth and forcing time after transplanting. Photosynthetic photon flux densities of 0, 1, and 5 $\mu mol \cdot m^{-2} \cdot s^{-1}$ were combined with temperatures of 0.0, 2.5, 5.0, 7.5, 10.0, and 12.5C to create 18 unique storage environments. Sample plants were removed at 1-week intervals for a period of at least 6 weeks, and were forced into flower. In all four species, chilling injury increased as storage at 0.0 and 2.5C was extended, and surviving plants flowered late relative to controls. Ageratum was most sensitive to chilling injury, followed in order by salvia, marigold, and begonia. Plant deterioration and ultimately death occurred as dark storage duration increased at 10 and 12.5C. Greatest percent survival and highest quality of seedlings stored in the dark occurred at temperatures just above those that caused chilling injury. Exposure to 1 $\mu mol \cdot m^{-2} \cdot s^{-1}$ during storage greatly increased quality of plants held at warmer-than-optimal temperatures. No substantial differences were observed among plants stored with 1 versus 5 $\mu mol \cdot m^{-2} \cdot s^{-1}$. All four species could be stored for 6 weeks in the light, but their responses to storage temperatures and durations differed. Optimal temperatures were 5-7.5C for begonia, 5C for marigold, and 7.5C for salvia and ageratum.

## 1. Introduction

Formerly, most seed-propagated plants were germinated in flats and transplanted bare root. Today, the majority of plants propagated from seed in the United States are germinated in individual cells called plugs. When the seedling is the proper size, it is transplanted with the entire root ball to a finish container (pot or flat).

Plants are sometimes ready for transplanting before greenhouse space or labor is available, or the market is ready to accept them. The grower is forced to restrict growth under such circumstances to avoid overgrowth of the closely spaced seedlings (up to 5,000 seedlings $m^{-2}$). Holding techniques include water stress, nutrient stress, or treatment with growth retardants. Stress and growth retardants can harden seedlings and, after transplanting, adversely affect growth rate, time until flower, and/or size at flower.

An alternative to holding seedling-plug flats in the greenhouse is low-temperature storage of the seedlings in a cooler. Low-temperature storage is common for many fruit,



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vegetable, and nursery crops. Extensive research of these crops has provided data pertaining to temperature range, relative humidity, and storage diseases and durations (Hardenburg, et.al., 1986). In contrast, research of seedling storage is very limited. The only research we are aware of is that of Kumpf et. al. (1966), who found that seedlings growing in flats could be stored at 1.1 to 4.4C for 2 or more weeks if watered, placed in polyethylene bags, and kept under light 14 h per day. Ageratum, cineraria, cosmos, pepper, and tomato could be stored for 1 to 2 weeks; aster, browallia, dianthus, geranium, lobelia, and marigold for 2 weeks; and alyssum, petunia, salvia, and snapdragon for up to 6 weeks. Zinnia and coleus could not be stored at all.

Specific information about the effects of a range of temperatures and irradiances during storage is unavailable for seedlings of most bedding plants grown as plugs. We undertook this research to provide this information for ageratum, begonia, marigold, and salvia.

## 2. Materials and Methods

Size 406 plug sheets (2,570 plants $m^{-2}$, 406 plants per flat) of ageratum (*Ageratum houstonianum* 'Blue Danube'), begonia (*Begonia* x *semperflorens-cultorum* 'Vodka'), marigold (*Tagetes patula* 'Hero Yellow'), and salvia (*Salvia splendens* 'Red Hot Sally') were obtained from a commercial grower when the plugs had reached a transplantable size. One plug sheet from each species was placed in storage at each of 18 different temperature and irradiance combinations. Temperatures were 0, 2.5, 5, 7.5, 10, and 12C in the coolers and 20C in the greenhouse. Photosynthetic photon flux density (PPF) levels generated by cool white fluorescent bulbs were 0, 1, and 5 $\mu mol\ m^{-2}\ s^{-1}$. Darkness (0 $\mu mol\ m^{-2}\ s^{-1}$) was obtained by placing plug sheets in closed, corrugated-cardboard plug-shipping boxes. Relative humidity for seedlings stored in the light varied from 50 to 70%, but approached 100% for seedlings held in the dark.

All plants were subirrigated with water as needed during storage. Irrigation frequency varied from 3 to 20 days, depending on the temperature and humidity of each treatment environment. Contact between foliage and water was minimized to avoid fungal infection.

Ten representative plants were removed from each plug sheet after 1, 2, 3, 4, 5, and 6 weeks. One plug sheet, left in the greenhouse as a non-stored control, was used as a source of control seedlings. One plant per treatment was photographed immediately after removal, and then all the plants were measured before being potted in 10-cm pots. Initial plant height was measured from the root ball to the apical meristem. The plants were forced into flower in a glass greenhouse with a minimum temperature of 20C.

The date of first flower was recorded for each plant that survived storage. Plants were considered in flower when the buds reached anthesis. The average number of days from the start of forcing until first flower and the percentage of plant survival for each treatment was determined. Plant height for salvia, plant diameter for begonia, and plant diameter and height for ageratum and marigold were recorded at first flower. Plant area for begonia from diameter measurements and plant volume for ageratum and marigold from height and diameter was calculated by assuming that the plant was cylindrical.

# 3. Results

## 3.1 Ageratum

Height of ageratum seedlings stored in the dark increased as storage temperature and duration increased (Fig. 1). Plant height increased approximately 35 mm during the experiment on seedlings stored at 10 and 12.5C, but only 5 mm at 5C. In comparison, height of control seedlings (initial height 42 mm) increased 105 mm during the same 6-week period.

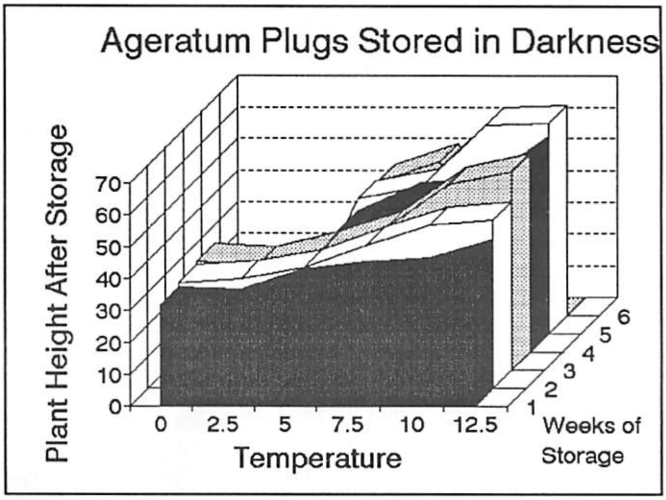


**Figure 1:** Influence of temperature on height (mm) of ageratum seedlings stored in the dark for 1 to 6 weeks.

The addition of 1 $\mu mol\ m^{-2}\ s^{-1}$ of light during storage slowed the rate of seedling elongation (Fig. 2). For example, seedlings 62 mm tall after 3 weeks' dark storage at 12.5C were only 46 mm tall after 3 weeks' light storage. Final heights after 6 weeks at 12.5C, however, were similar in both the dark and light. Plant height did not increase significantly during 6 weeks' storage at 5C.

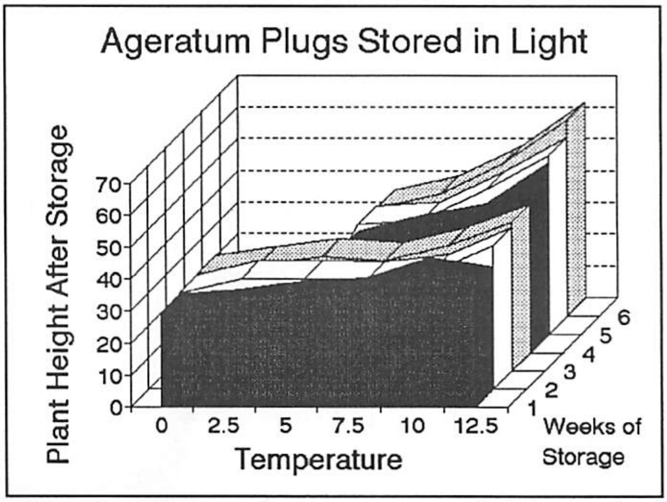


**Figure 2:** Influence of temperature on height (mm) of ageratum seedlings stored in the light for 1 to 6 weeks.

Plants stored at 0 and 2.5C showed signs of chilling injury after 2 weeks of storage. Percent mortality as a result of chilling injury at 0 and 2.5C increased from 0 to 100 as storage increased from 1 to 4 weeks in the dark (Fig. 3) and from 1 to 3 weeks in the light (Fig. 4). After dark storage, percent death of transplants increased correspondingly with the increase in plug-storage temperature and duration (Fig. 3). No plants survived after 6 weeks' dark storage at 10 and 12.5C, but 100% survived at 7.5C. The addition of 1 $\mu$mol $m^{-2}$ $s^{-1}$ of light dramatically decreased mortality at 10 and 12.5C (Fig. 4). All control plants survived.

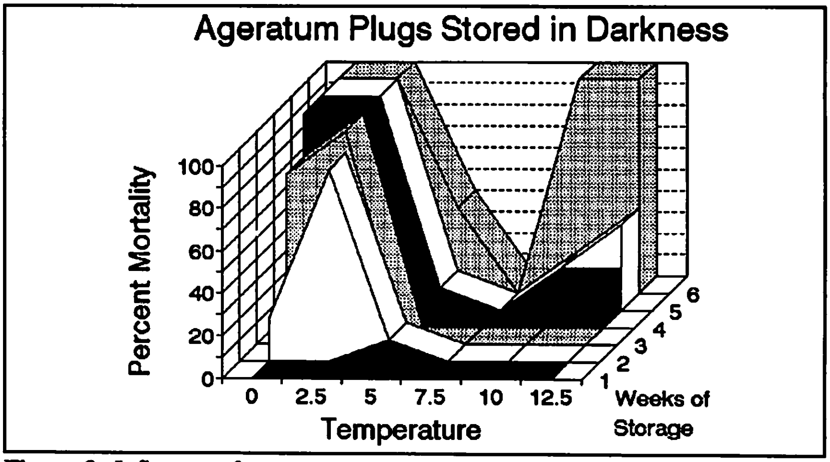


**Figure 3**: Influence of temperature on percent mortality of ageratum seedlings stored in the dark for 1 to 6 weeks.

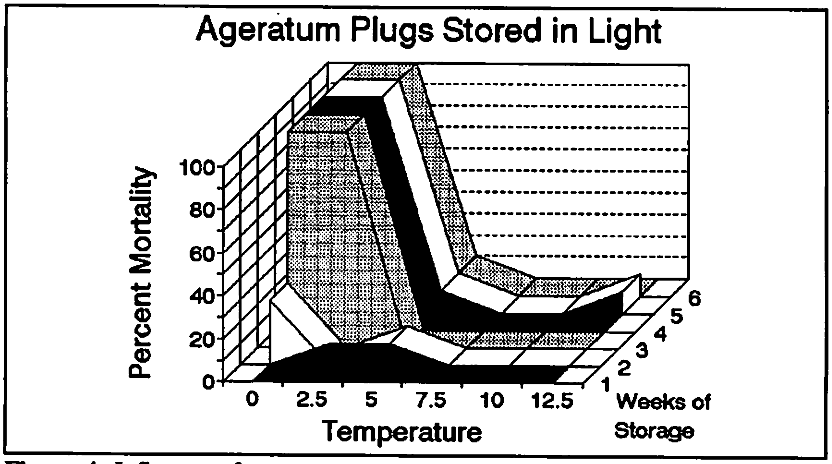


**Figure 4**: Influence of temperature on percent mortality of ageratum seedlings stored in the light for 1 to 6 weeks.

The time from transplant to flower was affected by storage in two ways. First, flowering was delayed on plants from treatments which caused chilling injury, but not death on all plants. For example, plants flowered in 86 and 65 days after 2 weeks' storage at 2.5C (Fig. 5) and 0C (Fig. 6), respectively, versus 46 days for unstored control plants. Second, flowering was also delayed on plants from dark storage at 10 and 12.5C after 5 weeks' storage, the longest duration plants survived at these two temperatures. The addition of 1 $\mu$mol m$^{-2}$ s$^{-1}$ did not prevent flowering delay on plants exposed to chilling-injury-inducing temperatures, but did prevent delayed flowering of plants held at 10 and 12.5C for up to 6 weeks (Fig. 6).

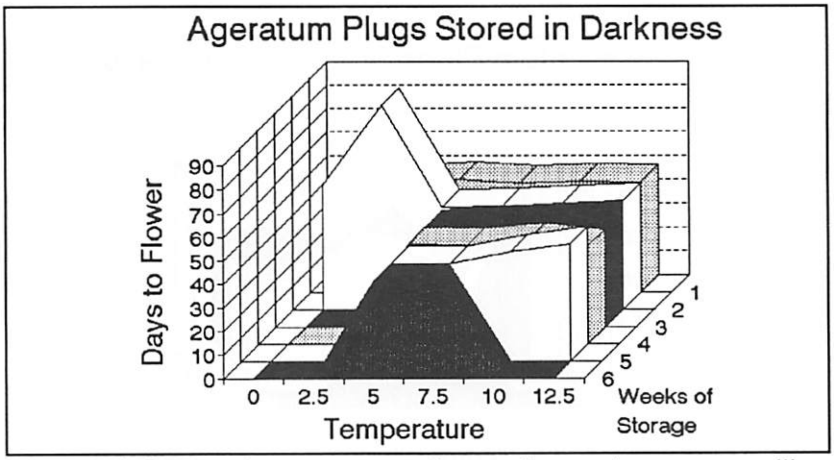


**Figure 5**: Influence of temperature on days to flower of ageratum seedlings stored in the dark for 1 to 6 weeks. Treatments with 0 days to flower are treatments where all plants died.

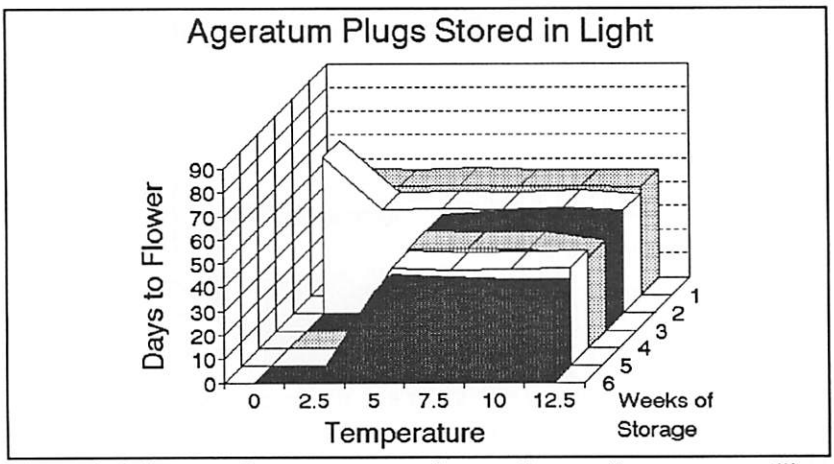


**Figure 6**: Influence of temperature on days to flower of ageratum seedlings stored in the light for 1 to 6 weeks.

There was no consistent storage-treatment effect on the size of plants when they flowered (Fig. 7 and 8). Flowering-plant size was more consistent across treatments on plants stored in the light (Fig. 8) than in the dark (Fig. 7). Size at flower tended to decrease as storage duration increased. Plants stored for only 1 week were significantly larger than those stored for 2 to 6 weeks. Size of control plants at flower decreased from 4050 $cm^3$ to 660 $cm^3$ as holding duration in the greenhouse increased from 0 to 6 weeks.

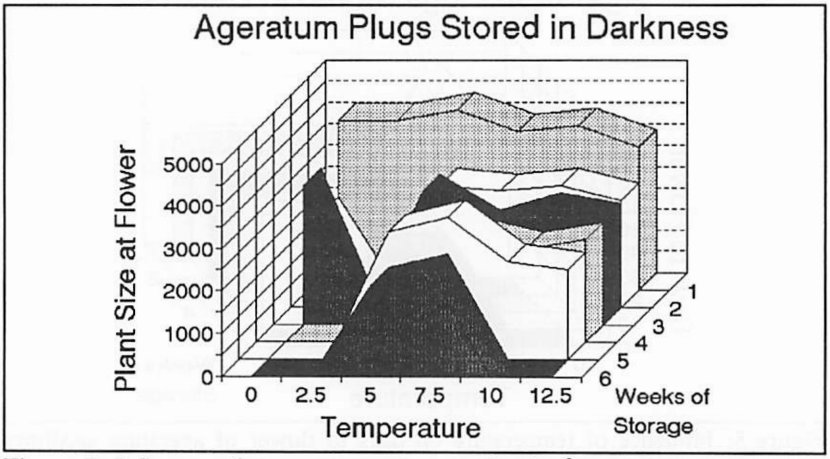


**Figure 7**: Influence of temperature on plant size ($cm^3$) at flower of ageratum seedlings stored in the dark for 1 to 6 weeks.

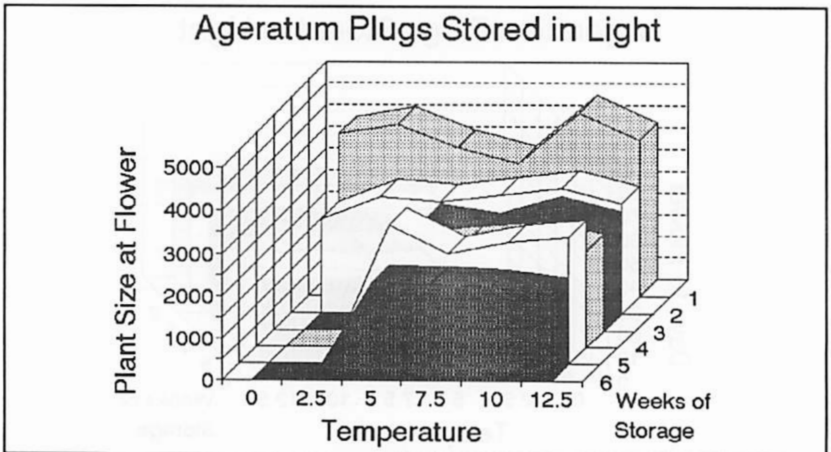


**Figure 8**: Influence of temperature on plant size ($cm^3$) at flower of ageratum seedlings stored in the light for 1 to 6 weeks.

## 3.2 Begonia

Height of begonia seedlings stored in the dark did not increase at 5C or lower, but increased as storage temperature and duration increased (Fig. 9); however, the gain in height was not great. More obvious than increased height was the etiolated appearance of plants stored at 10 and 12.5C. The addition of 1 $\mu$mol $m^{-2}$ $s^{-1}$ reduced, but did not prevent, petiole elongation during storage. Height of seedlings held in the plug sheet and maintained in the greenhouse increased from an initial height of 13 mm to 58 mm during the 6-week experiment period.

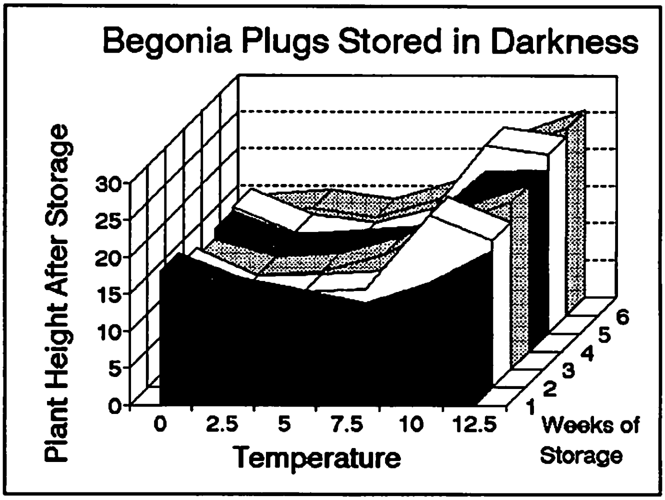


**Figure 9**: Influence of temperature on height of begonia seedlings stored in the dark for 1 to 6 weeks.

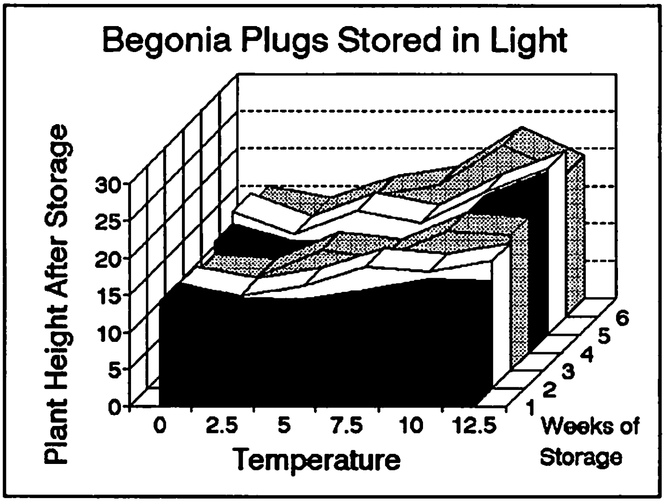


**Figure 10**: Influence of temperature on height of begonia seedlings stored in the light for 1 to 6 weeks.

Plants showed signs of chilling injury after 3 weeks' storage at 0C. Damage was not as severe on plants held in the dark (Fig. 11) as in the light (Fig. 12). All plants held at 0C for 4 weeks in the light died. Maximum mortality of plants held for 5 weeks in darkness was 20%; losses increased dramatically between weeks 5 and 6 (Fig. 11). The percentage of dead plants did not increase at 10 and 12.5C until plants had been stored at least 4 weeks, either in the dark or the light.

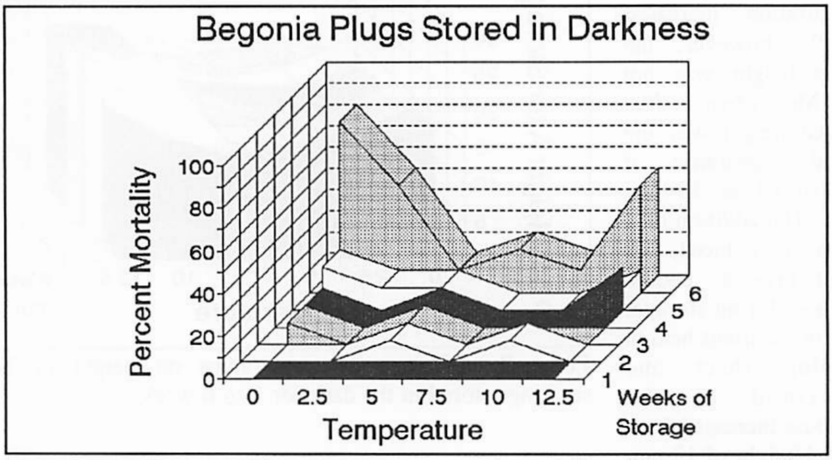


**Figure 11**: Influence of temperature on percent mortality of begonia seedlings stored in the dark for 1 to 6 weeks.

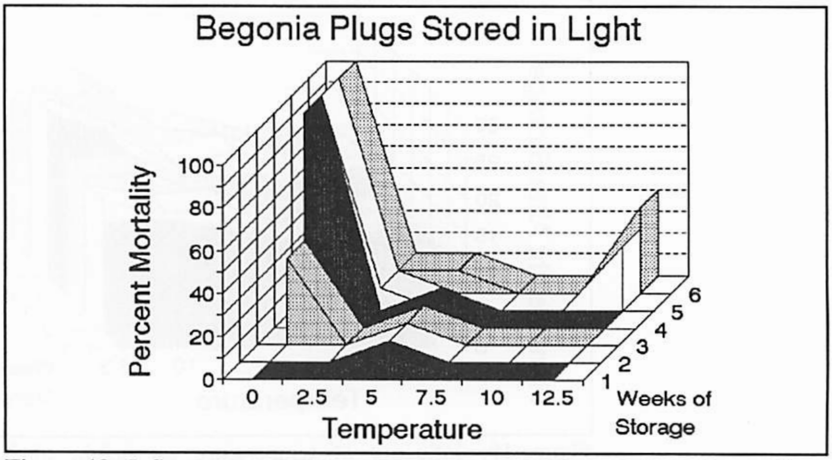


**Figure 12**: Influence of temperature on percent mortality of begonia seedlings stored in the light for 1 to 6 weeks.

Flowering was delayed in plants from treatments that caused chilling injury, but not death (Fig. 13 and 14). Compared to unstored control plants which flowered in 41 days, flowering was delayed 13 days for plants stored for 6 weeks in the dark at 0C (Fig 13), and 17 days for plants stored 3 weeks in the light (Fig 14). Flowering was also delayed 13 days on plants stored for 6 weeks in the dark at 12.5C (Fig. 13). There was no consistent pattern or delay in flowering of plants from other storage treatments.

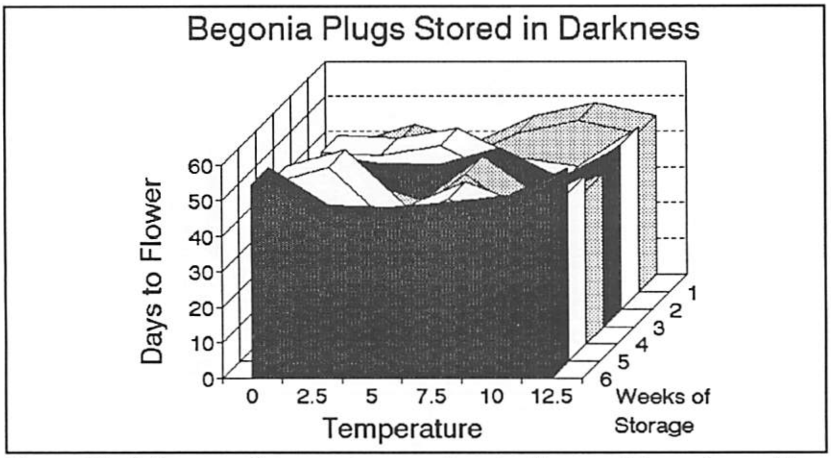


**Figure 13**: Influence of temperature on days to flower of begonia seedlings stored in the dark for 1 to 6 weeks.

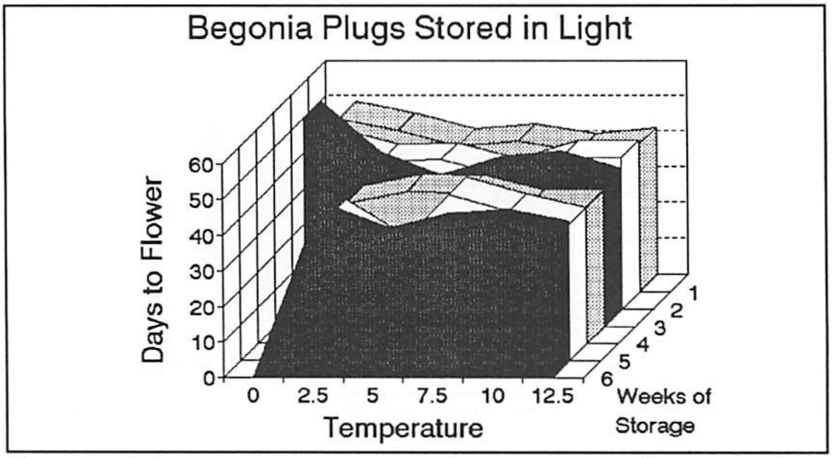


**Figure 14**: Influence of temperature on days to flower of begonia seedlings stored in the light for 1 to 6 weeks.

Plant size at flower followed no consistent pattern (Fig. 15 and 16), with the exception of plants stored for 6 weeks in the dark; plant size increased as storage temperature decreased. Size of control plants at flower decreased from 155 $cm^2$ to 115 $cm^2$ as holding duration in the greenhouse increased from 0 to 6 weeks.

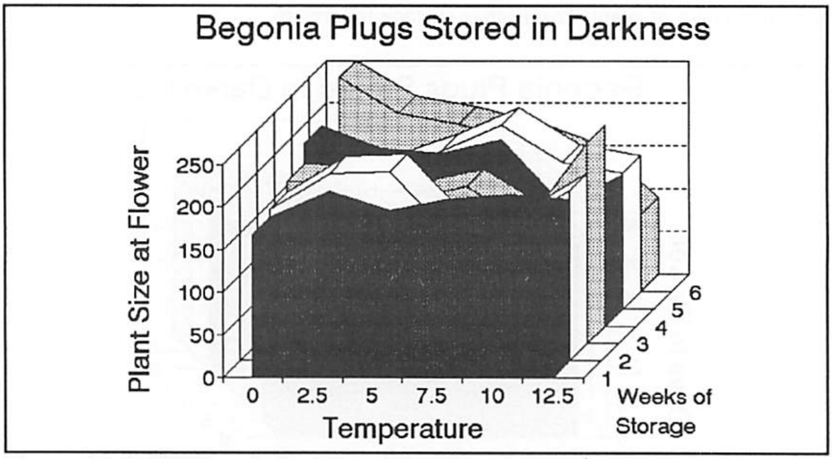


**Figure 15**: Influence of temperature on plant size ($cm^2$) at flower of begonia seedlings stored in the dark for 1 to 6 weeks.

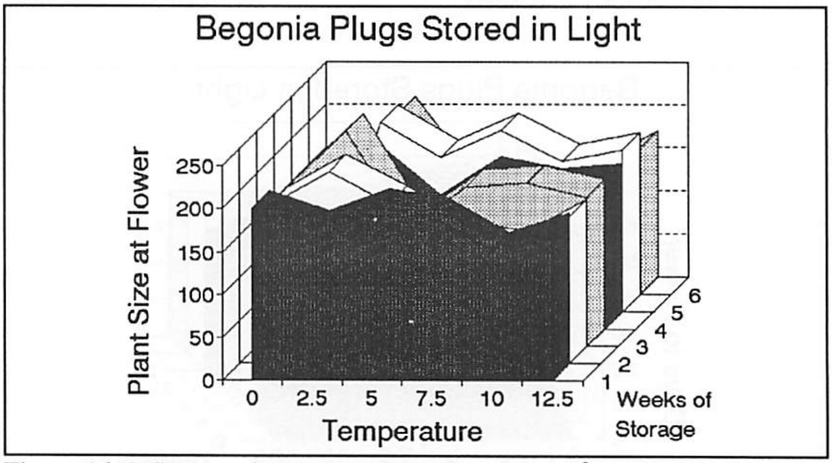


**Figure 16**: Influence of temperature on plant size ($cm^2$) at flower of begonia seedlings stored in the light for 1 to 6 weeks.

## 3.3 Marigold

Height of marigold seedlings increased slightly during storage in the dark (Fig. 17) (maximum 5 mm, or about 10% of the initial height). In the light (Fig. 18), height increased only at temperatures of 10C or greater. Height of control plants increased from 50 mm to 120 mm as holding duration in the greenhouse increased from 0 to 6 weeks.

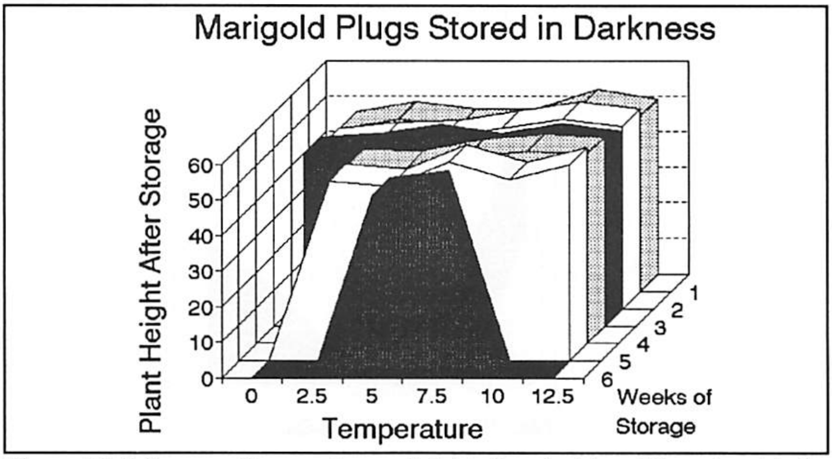


**Figure 17**: Influence of temperature on height of marigold seedlings stored in the dark for 1 to 6 weeks.

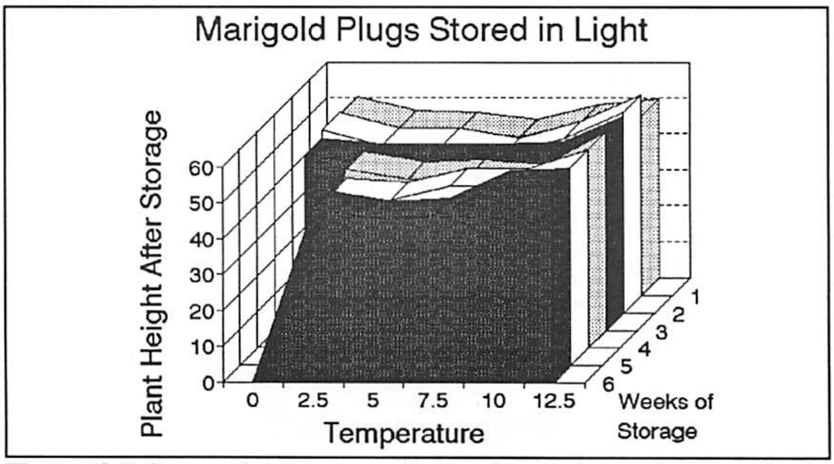


**Figure 18**: Influence of temperature on height of marigold seedlings stored in the light for 1 to 6 weeks.

Chilling injury was evident within 2 weeks of storage at 0C. Percent mortality increased from 0 or 10 after 2 weeks' light or dark storage at 0C to 100% after 4 weeks' storage at 0C (Fig. 19 and 20). At 2.5C, 4 or 5 weeks of storage were required to induce chilling injury in the dark (Fig. 19) or light (Fig. 20), respectively. Percent mortality at 2.5C was much greater in the dark than in the light, and increased as storage temperature and duration increased above 5C and 3 weeks' storage. In the dark, 5C was the only temperature at which substantial numbers of plants were able to survive for 6 weeks (Fig. 19). The addition of 1 $\mu mol \cdot m^{-2} \cdot s^{-1}$ dramatically decreased percent mortality at temperatures above 5C (Fig. 20). All control plants survived.

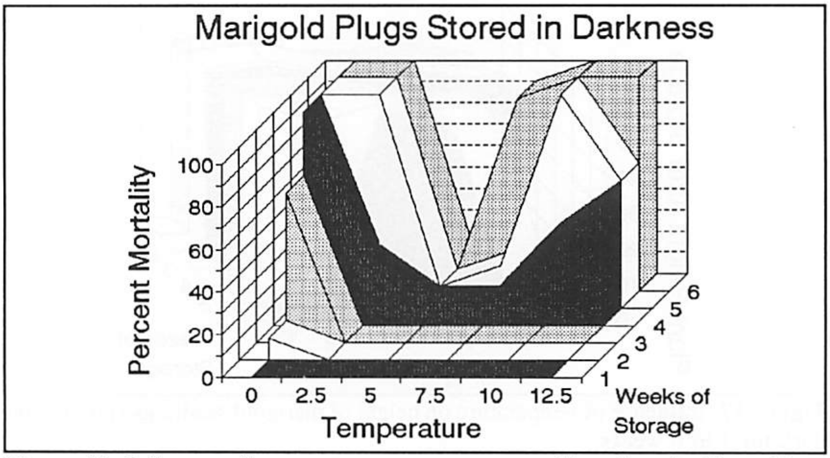


**Figure 19**: Influence of temperature on percent mortality of marigold seedlings stored in the dark for 1 to 6 weeks.

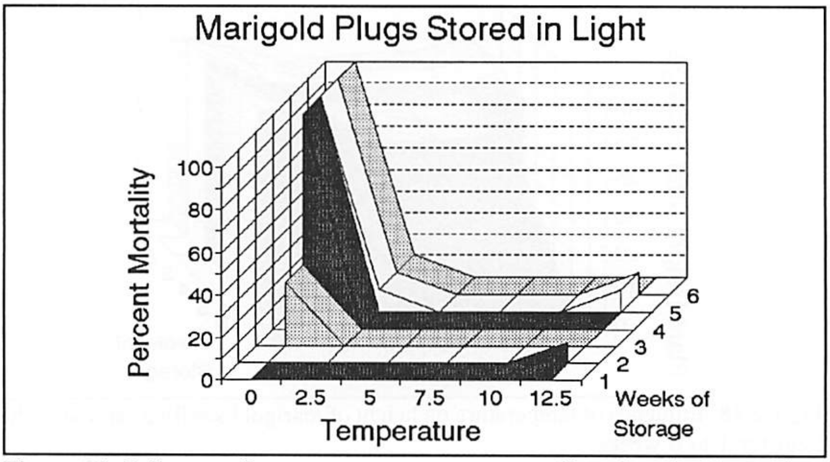


**Figure 20**: Influence of temperature on percent mortality of marigold seedlings stored in the light for 1 to 6 weeks.

The time from transplanting to flower was affected by storage in two ways. Treatments that induced chilling injury, but not death, caused flower-bud abortion and a subsequent flowering delay. Nonstored control plants flowered in 20 days. Flowering was delayed 28 or 24 days after 1 week's storage at 0C in the dark (Fig. 21) or light (Fig. 22), respectively. Plants stored in the dark at 10 and 12.5C also exhibited delayed flowering as storage duration increased. Flowering was delayed 25 days on surviving plants stored at 12.5C for 4 weeks (Fig. 21). Light did not prevent delayed flowering caused by chilling injury, but did reduce flowering delay on plants held at 10 and 12.5C (Fig. 22). Unstored plants in the greenhouse flowered in the plug sheets prior to transplanting within 4 weeks.

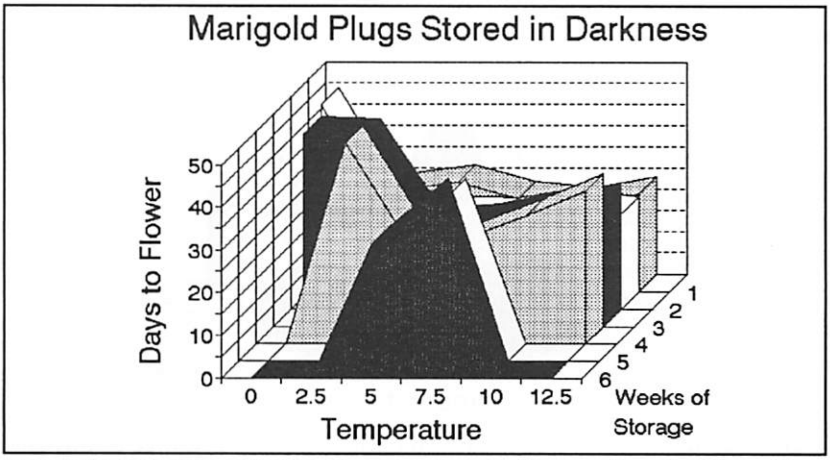


**Figure 21** Influence of temperature on days to flower of marigold seedlings stored in the dark for 1 to 6 weeks.

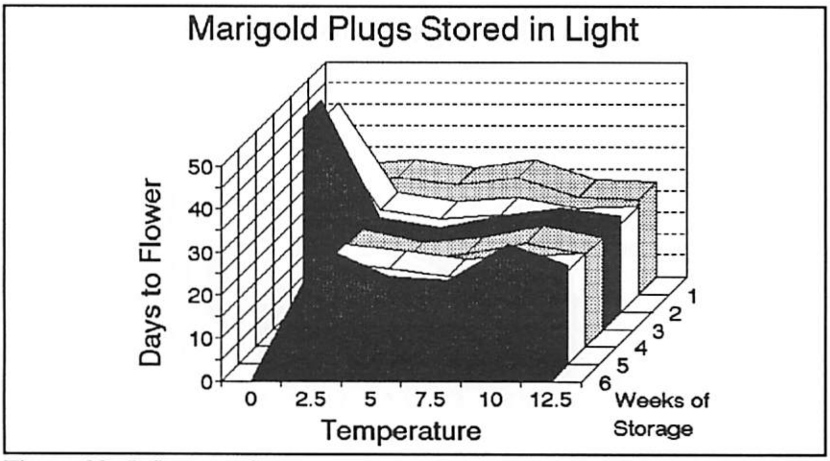


**Figure 22**: Influence of temperature on days to flower of marigold seedlings stored in the light for 1 to 6 weeks.

Plant size at flower was primarily related to the survival of the flower bud during storage. Plants in which flower buds aborted either because of chilling injury (e.g., 0C for 2 weeks) or because of extended storage (e.g., 7.5C for 5 and 6 weeks for plants in the dark [Fig. 23], 10 and 12.5C for plants in the light [Fig. 24]) were significantly larger at flower. The increased size was a result of the additional vegetative growth as lateral buds developed prior to flower. Plants held in the greenhouse flowered in the plug sheets and averaged only 20 cm$^3$ in volume at flower, whereas stored plants averaged 320 cm$^3$, and those that flowered after flower-bud abortion, up to 785 cm$^3$.

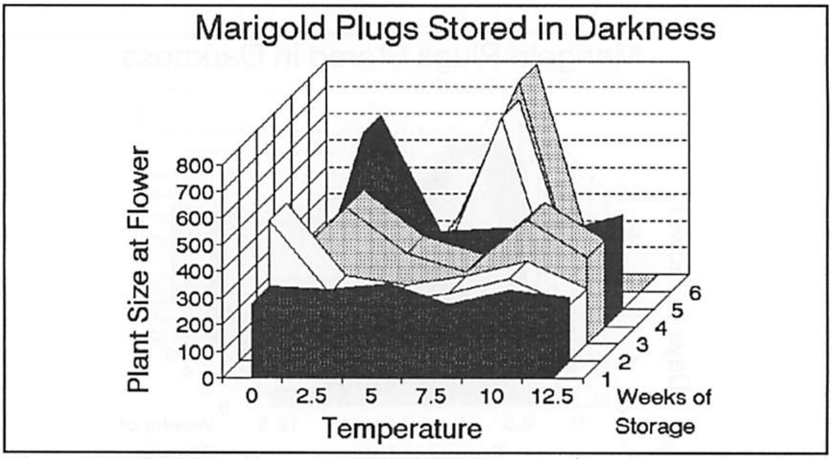


**Figure 23**: Influence of temperature on plant size (cm$^3$) at flower of marigold seedlings stored in the dark for 1 to 6 weeks.

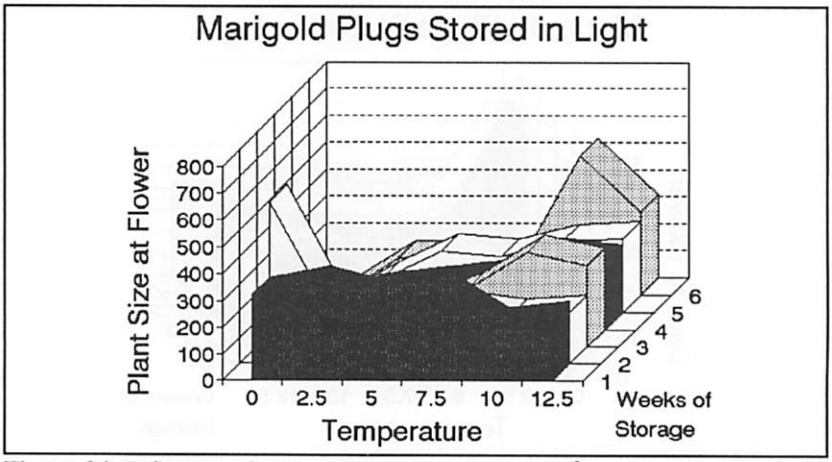


**Figure 24**: Influence of temperature on plant size (cm$^3$) at flower of marigold seedlings stored in the light for 1 to 6 weeks.

### 3.4 Salvia

Height of salvia seedlings stored in the dark increased as storage temperature and duration increased (Fig. 25). Seedling height increased approximately 15 mm at 10C, but at 5C, it increased only 3 mm. In comparison, height of seedlings held in the greenhouse increased 100 mm from an initial height of 54 mm during the same 6-week period.

Exposure to 1 $\mu$mol m$^{-2}$ s$^{-1}$ of light during storage slowed the rate of seedling elongation (Fig. 26). During 3 weeks' storage at 12.5C, seedlings grew 12 mm in the dark, but only 1 mm in the light.
No height increase occurred during 6 weeks' storage at 5C.

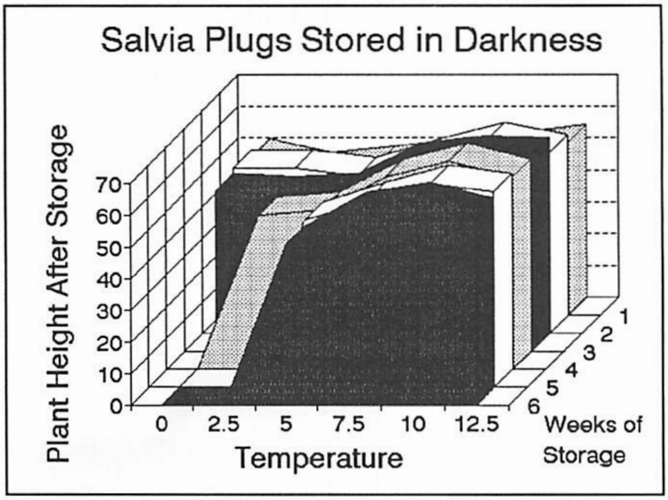


**Figure 25**: Influence of temperature on height (mm) of salvia seedlings stored in the dark for 1 to 6 weeks

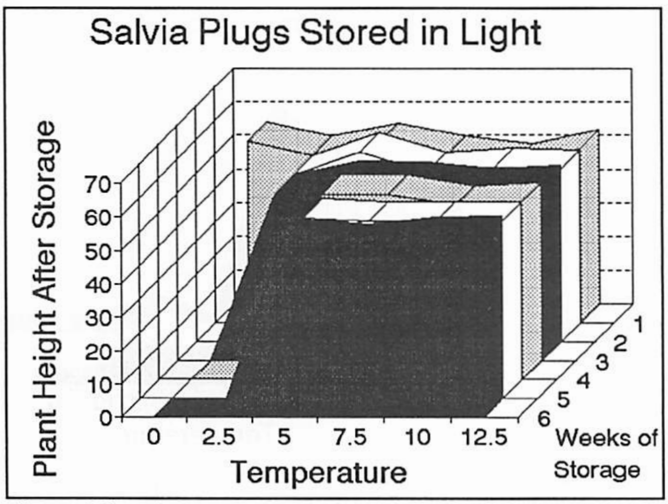


**Figure 26**: Influence of temperature on height (mm) of salvia seedlings stored in the light for 1 to 6 weeks.

Plants stored at 0 and 2.5C showed signs of chilling injury after 2 weeks of storage. Mortality as a result of chilling injury at 0 and 2.5C increased from 0 to 100% as storage time increased from 1 to 3 weeks in both the dark (Fig. 27) and the light (Fig. 28). Plants were more susceptible to chilling injury in the dark than in the light. Most plants survived 5 weeks' storage in light, but only 2 weeks' storage in darkness at 2.5C. Light prevented mortality at 10 and 12.5C (Fig. 28). All control plants survived.

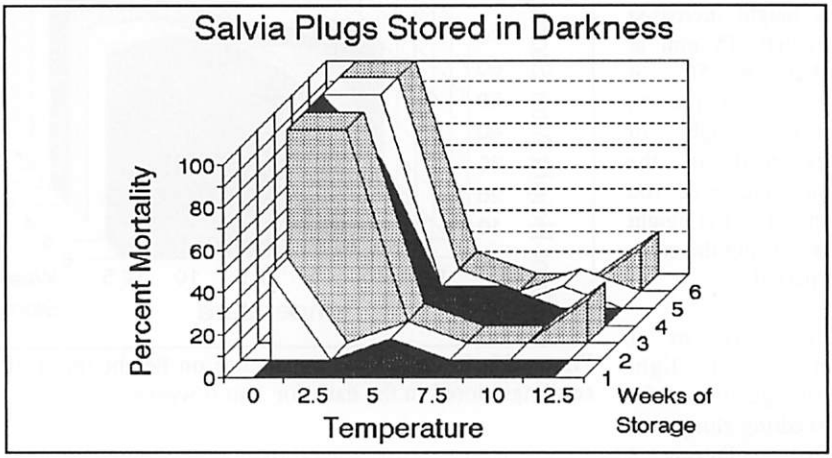


**Figure 27**: Influence of temperature on percent mortality of salvia seedlings stored in the dark for 1 to 6 weeks.

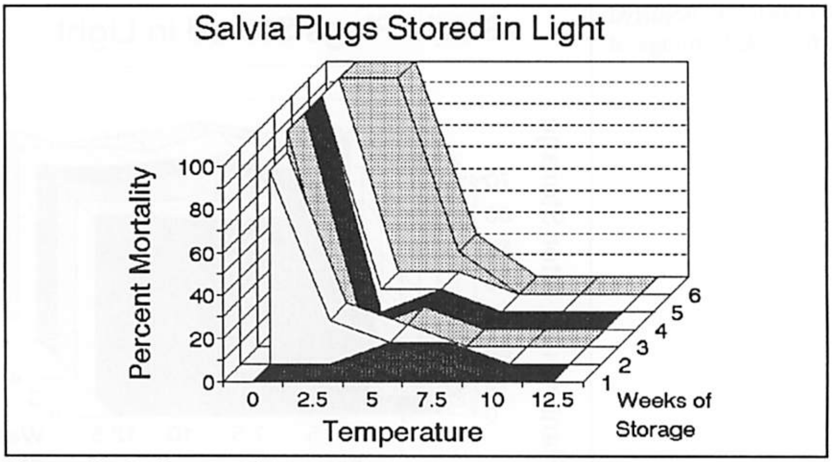


**Figure 28**: Influence of temperature on percent mortality of salvia seedlings stored in the light for 1 to 6 weeks.

The time from transplant to flower was affected by storage in two ways. First, flowering was delayed on plants that survived chilling injury from storage at 0 and 2.5C (Fig. 29 and 30). Compared to unstored control plants which flowed in 50 days, flowering was delayed up to 29 days on injured plants because of the abortion of the primary shoot axis. Second, flowering of plants held in the dark at 12.5C was delayed 18 days after 6 weeks' storage. Exposure to light during storage did not reduce the effect of chilling injury in delaying bloom (Fig. 30), but did prevent delayed flowering on plants held at 12.5C for 6 weeks.

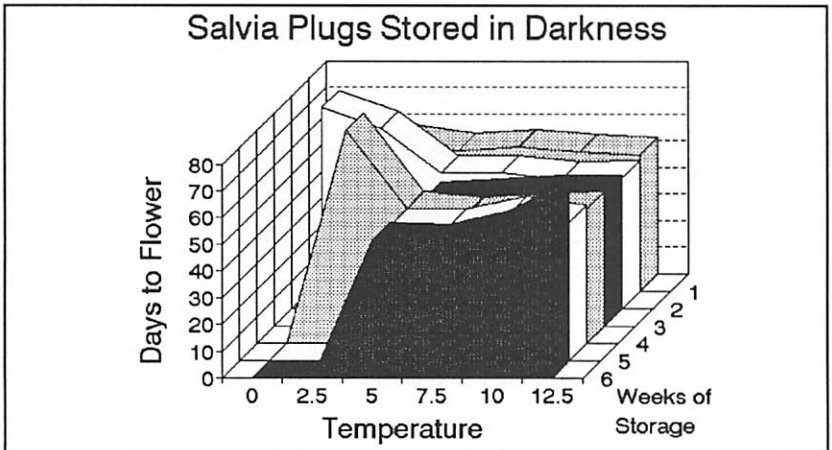


**Figure 29**: Influence of temperature on days to flower of salvia seedlings stored in the dark for 1 to 6 weeks.

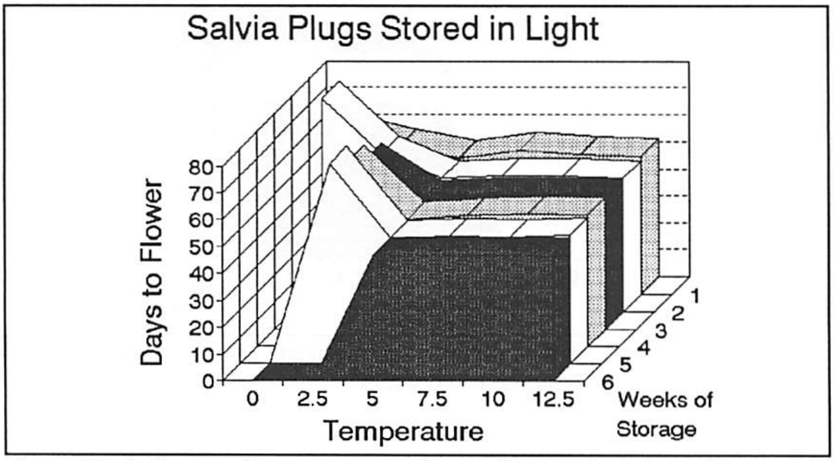


**Figure 30**: Influence of temperature on days to flower of salvia seedlings stored in the light for 1 to 6 weeks.

Chilling injury reduced plant height at flowering in both the dark and light (Fig. 31 and 32) because flowering lateral shoots were shorter than the primary shoot. In general, height at flower decreased as storage duration increased. For example, plants stored 1 week flowered at a height of approximately 35 cm, while those stored 6 weeks flowered at about 26 cm.

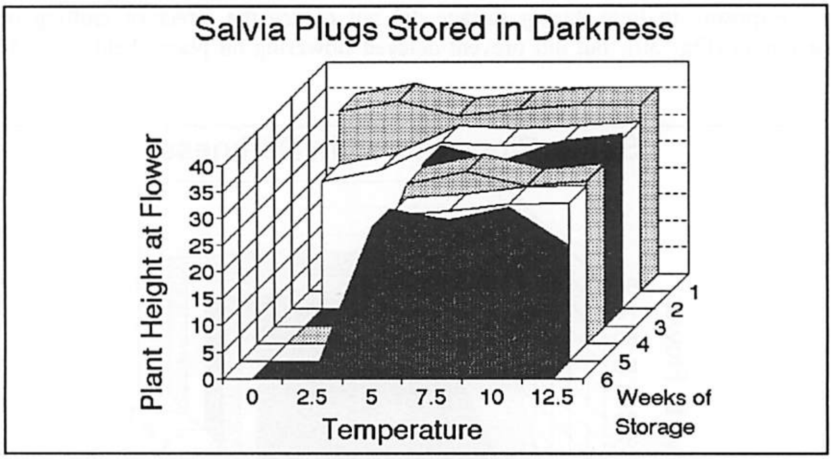


**Figure 31**: Influence of temperature on plant height (cm) at flower of salvia seedlings stored in the dark for 1 to 6 weeks.

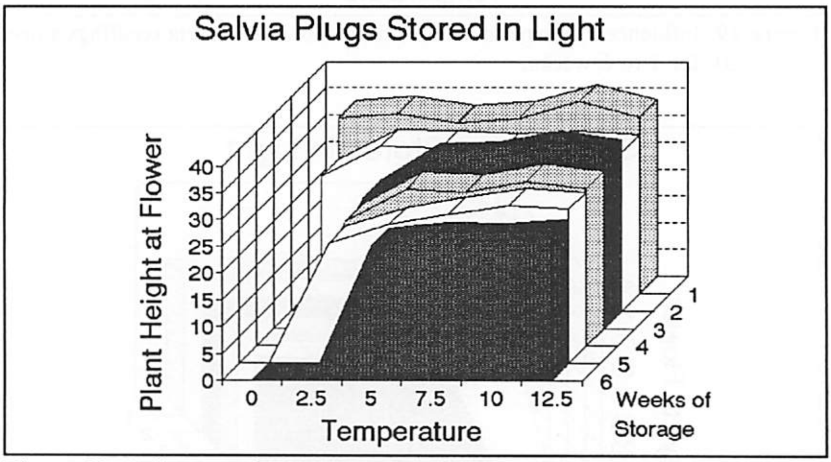


**Figure 32**: Influence of temperature on plant height (cm) at flower of salvia seedlings stored in the light for 1 to 6 weeks.

## 4. Discussion

Seedling survival and quality after storage depended on three storage parameters: temperature, presence or absence of light, and duration. The lowest treatment temperatures caused chilling injury, and the highest, plant deterioration and ultimately death as storage duration increased. Seedlings stored at 0 and 2.5C initially exhibited typical chilling-injury symptoms (Herner, 1990; Saltveit and Morris, 1990) of water-soaked leaf spotting, wilting, and death. In contrast, as storage temperature increased above 5C in the dark, deterioration occurred progressively faster and was exhibited by elongation, etiolation, leaf abscission, and flower and apical meristem abortion. Greatest percent survival and highest quality after dark storage occurred at temperatures just above those that caused chilling injury.

Exposure to light during storage had a dramatic effect on the quality of plants held at warmer-than-optimal temperatures. The amount of light necessary to improve quality was no more than 1 $\mu mol \cdot m^{-2} \cdot s^{-1}$. No substantial differences were observed among plants stored with 1 versus 5 $\mu mol \cdot m^{-2} s^{-1}$. In previous studies on geranium, pansy, petunia, and impatiens (Lange and Heins, 1991a,b), no significant differences in plant storability were evident among plants stored under 1, 5, and 25$\mu mol \cdot m^{-2} s^{-1}$, indicating that very low light levels are adequate to maintain plant quality during low-temperature storage.

All four species in this study were sensitive to chilling injury at temperatures less than 5C. Ageratum was most sensitive (Fig. 3 and 4,), followed by salvia (Fig. 27 and 28), marigold (Fig. 19 and 20), and begonia (Fig. 11 and 12). Kumpf, et. al. (1966) indicated salvia could be successfully stored at 1C for 2 weeks in the dark and 6 weeks at 4.5C in the light. Results from this study (Fig. 27 and 28) showed chilling injury on salvia seedlings after 2 weeks' storage at 0 and 2.5C, and therefore, storage is not recommended at temperatures less than 5C. Our results also suggest that 7.5C is superior to 5C for salvia storage in the dark or light (Fig. 27 and 28). Kumpf, et. al. (1966) also did not recommend marigold storage at 1C but did indicate marigold could be stored at 4.5C for 6 weeks in the light; both conclusions are in agreement with our observations.

Chilling injury occurs in many tropical plants (Morris, 1982) and in some temperate species (Bramlage, 1982) when the plants are exposed to temperatures above freezing, but below about 12.5C. The chilling injury on the species in this study is therefore not unexpected since ageratum originated in Mexico (Reilly, 1978), begonia and salvia in southern Brazil (Thompson and Thompson, 1981, and Reilly, 1978, respectively), and marigold in temperate and tropical Central and South America (Towner, 1961).

In salvia and marigold, percent mortality resulting from chilling injury was greater in the dark than in the light. The opposite was true for begonia and, to a lesser extent, ageratum (Fig. 12 and 13). While light interacts with temperature in some species to initiate or enhance chilling injury (van Hasselt, 1990), the interaction is dependent on light intensity. Little or no reduction in quantum yield occurred under conditions of 10% or less of full sunlight under chilling temperatures (Powles, et.al., 1983). Therefore, the lack of a strong response to light under chilling temperatures in this study is not unexpected.

Holding plants under 100% relative humidity during exposure to chilling temperatures reportedly prevents chilling injury in cucumber (Wright and Simon, 1973). However, in this experiment, exposure of plants to near 100% RH in the dark did not prevent chilling injury.

Apical meristems or flower buds aborted in some plants, leading to delayed flowering. These plants were typically larger at first flower than plants in which the apical meristem or flower buds did not abort. The increased size resulted from lateral shoot growth prior to flowering, a response which also occurs when apical meristems are pinched.

The value of storing seedling plugs at low temperatures is evident when greenhouse performance of optimally stored seedlings is compared to that of seedlings held in the greenhouse. In the most extreme example, marigold seedlings flowered in the plug sheet prior to transplanting. These plants were unacceptably small for commercial sale at time of flower. Similarly, size of ageratum, begonia, and salvia at flower decreased as duration of holding in the greenhouse increased.. Quality of the flowering plant was maintained by proper storage.

When plant death and time to flower were taken into consideration, the optimum temperature range for storage of both ageratum and salvia was 7.5C. The acceptable storage-temperature range widened to the 7.5 to 12.5C range when the storage duration was short and when light was added during storage. The optimum temperature range for begonia storage was 5 to 7.5C. The acceptable storage-temperature range widened to the 2.5 to 10C range when the storage duration was 4 weeks or less, and when light was added during storage. The optimum temperature for marigold storage was 5C. Even at 5C, however, marigold stored poorly in the dark. Although all 4 species could be stored successfully for 1 week at 0C, storage at temperatures less than 5C is not recommended for any of these species because of the potential for chilling injury.

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