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PLUG STORAGE

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COLD STORAGE OF PLUG SEEDLINGS

Consider cold storage of plugs as an alternative to other means of growth regulation. Make better use of your greenhouse space, and time crops more efficiently by holding plugs in cold storage for short periods of time when they're ready to transplant too early.

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PLUG STORAGE A TO Z

Holding bedding plant plugs in cold storage until transplant can help you schedule greenhouse time and spacing better.

by ROYAL HEINS, NATHAN LANGE, THOMAS F. WALLACE JR., and WILL CARLSON

MOST bedding plant seedlings are produced as plugs. Ideally, plants are transplanted when they reach the correct size, but plugs are often ready before growers can transplant them. Growth must therefore be slowed or delayed.

Traditional methods of slowing plug growth include using water and nutrient stress and chemical growth regulators. All of these methods can stress plants and potentially delay growth after transplanting. If plugs are held in a greenhouse, bench space is unavailable for other crops, decreasing total production and profits.

An alternate growth regulator is low temperature, which can be used in the plug production area; but other plants' growth will also be retarded. It is best to isolate plugs in another greenhouse, a walkway, the headhouse, or a cooler, all of which will probably have quite different light and temperature conditions than does the plug production area.

Storing plugs in coolers facilitates scheduling management because they can be held for several days or even weeks before transplanting. Storage refers to short- and long-term holding at low temperature.

The grower must understand how holding plugs under variable light and temperature conditions will affect seedling growth after transplanting.

There is an ideal combination of temperature and light for each bedding plant species, and there are negative consequences when plugs are stored under suboptimal conditions.

Growers may want to store species with different storage requirements in the same cooling facility, so a compromise will have to be made. If only short-term storage is necessary, a temperature warmer than the optimum may be more economical.

We conducted our research to determine how long plugs could be stored under various light and temperature combinations without adversely affecting growth and forcing time after transplanting.

This booklet discusses the optimum light and temperature conditions for plug storage of the major bedding plant crops. While the majority of the information has already been presented in GREENHOUSE GROWER magazine, six other crops have been added for this booklet (tomato, dahlia, celosia, lobelia, portulaca, and verbena).

Table 1. Optimal plug storage temperatures and maximum storage durations for selected bedding plant species stored in the dark or under a minimum of 5 footcandles of light.

Species	Optimal storage temperature (°F)	Maximum weeks storage in the dark	Maximum weeks storage in the light
Alyssum	36°	5	6
Cyclamen	36°	6	6
Geranium	36°	4	4
Pansy	36°	6	6
Petunia	36°	6	6
Begonia, fibrous	41°	6	6
Begonia, tuberous	41°	3	6
Dahlia	41°	2	5
Lobelia	41°	6	6
Marigold, French	41°	3	6
Salvia	41°	6	6
Ageratum	45°	6	6
Impatiens	45°	6	6
Portulaca	45°	5	5
Tomato	45°	3	3
Verbena	45°	1	1
Celosia	50°	2	[illegible]
Vinca	50°	5	6
New Guniea impatiens	55°	2	3

RESEARCH METHODS

Twenty-five plug sheets of each crop were obtained from a commercial grower when plugs were at a transplantable stage (for a list of cultivars that were tested, see Table 5, page 19). These plants were held in a glass greenhouse at 68°F for 1 week prior to the start of the storage treatments to remove possible side effects from shipping.

One plug sheet was placed under each of either 18 or 24 different temperature and light-level combinations. Temperatures were 32°, 36°, 41°, 45°, 50°, and 55°F (0°, 2.5°, 5°, 7.5°, 10°, and 12.5°C). Light levels for some species were 0, 5, 25, and 50 footcandles; for others 0, 5, and 25 footcandles.

Light levels were provided by cool-white fluorescent bulbs 24 hours per day. Darkness (0 footcandles) was provided by placing a plug sheet in a closed cardboard plug shipping box.

All plugs were subirrigated with clear water as needed during storage because the plants' nutritional needs are minimal under low temperatures.

The frequency of irrigations varied from 2 to 10 days, depending on the temperature treatment and relative humidity of each cooler. Contact between the foliage and water was minimized to avoid fungal infection.

Ten representative plants were removed from each plug sheet of each temperature/irradiance treatment after 1, 2, 3, 4, 5, and 6 weeks. A representative plant from each treatment was used for a photograph, and all plants were then potted in 4-inch pots using a commercial soilless mix. The plants were forced into flower in a glass greenhouse with a minimum temperature of 68°F.

We recorded the date of first flower for each plant surviving storage. We also determined the average number of days from the start of forcing until first flower and the percentage of plant survival for each treatment.

RATING THE TREATMENTS

We rated the storage treatments as satisfactory or unsatisfactory. In satisfactory storage treatments, no more than one out of 10 plants died after storage, and plants did not exhibit a delay in flowering of more than 5 days compared to that of control plants, which were potted without any storage.

MAKING THE MOVE TO WARMER CONDITIONS

Moving the plugs from a cool storage environment to a warm, high-light greenhouse was not a problem for us as long as the plugs were moist.

In one trial set up to simulate extreme conditions, we placed pansy seedlings that had been stored for 3 weeks at 36°F directly into a sunny glass greenhouse set at 100°F. There was some leaf damage on the seedlings at the edge of the plug sheet; they were dry and wilted rapidly. Seedlings in moist plugs did not wilt and showed no damage.

We suggest warming the plugs for a few hours in a low-light, moderate temperature (60°–70°F) environment. Irrigate if plugs are to be placed into an especially bright, hot environment.

A MAJOR PROBLEM: BOTRYTIS

Botrytis is a major problem during storage of some crops at cool temperatures. Damage can be minimized by maintaining a low relative humidity

Table 2. Maximum storage durations, in weeks, for 19 species stored in the dark.

Species	0°C (32°F)	2.5°C (36°F)	5°C (41°F)	7.5°C (45°F)	10°C (50°F)	12.5°C (55°F)
Ageratum	1	1	5	6	3	3
Alyssum	5	4	4	2	1	1
Begonia (fibrous)	0	4	6	5	5	0
Begonia (tuberous)	3	3	3	4	3	3
Celosia	0	1	1	1	2	2
Cyclamen	6	6	6	5	5	4
Dahlia	1	2	2	2	2	2
Geranium	4	4	4	4	4	2
Impatiens	0	2	3	6	5	4
Lobelia	0	5	6	5	4	0
Marigold, French	0	1	3	3	2	2
New Guinea impatiens	0	0	0	0	0	2
Pansy	6	6	6	6	6	6
Petunia	6	6	6	5	5	4
Portulaca	1	3	5	5	6	6
Salvia	0	0	6	6	4	4
Tomato	0	1	2	3	1	1
Verbena	1	2	1	1	1	1
Vinca	0	2	3	4	5	5

Table 3. Maximum storage durations, in weeks, for 19 species stored under 5 footcandles of light.

Species	0°C (32°F)	2.5°C (36°F)	5°C (41°F)	7.5°C (45°F)	10°C (50°F)	12.5°C (55°F)
Ageratum	1	2	6	6	6	6
Alyssum	6	6	6	6	3	3
Begonia (fibrous)	0	6	6	6	6	4
Begonia (tuberous)	3	4	6	6	4	4
Celosia	0	1	1	1	3	3
Cyclamen	6	6	6	6	6	6
Dahlia	1	4	5	6	6	5
Geranium	4	4	4	4	4	4
Impatiens	0	2	3	6	6	6
Lobelia	0	5	6	5	4	4
Marigold, French	0	3	6	6	5	3
New Guinea impatiens	0	0	0	0	0	3
Pansy	6	6	6	6	6	6
Petunia	6	6	6	6	6	6
Portulaca	1	3	5	5	6	4
Salvia	0	0	6	6	6	6
Tomato	0	1	2	3	1	1
Verbena	3	2	1	1	4	4
Vinca	0	2	3	6	6	6

during storage. However, low humidity causes plugs to dry out quickly. Maintaining a high relative humidity in a cooler decreases the frequency of watering but favors the rapid spread of Botrytis (Figure A).

Be aware of this dilemma before you implement a plug storage program in a cooler — especially if irrigation may be difficult.

Susceptibility to Botrytis is also influenced by crop "lushness." In one experiment, we irrigated petunia plugs with 0, 200, or 400 ppm nitrogen and potassium from ammonium and potassium nitrate for 1 week prior to storage. The amount of disease increased as the amount of applied fertilizer increased (Figure B). Very soft, lush crops will not store as well as those that are more toned.

We do not have sufficient experience with different fungicides under storage conditions to know if they will adequately control Botrytis under high humidity during extended storage. Therefore, we are currently recommending that crops be stored under low humidity. We still suggest applying a fungicide before storage to help ensure that Botrytis does not become a problem.

Figure A (above, left): Example of Botrytis infection on petunia plugs stored under conditions of high humidity.

Figure B (above, right): Difference in disease incidence on petunia plugs stored for 2 weeks at 7.5°C (45°F) in the dark under high humidity. Top row of plants was sprayed with water weekly, while foliage was dry on bottom row of plants. Plants were pretreated for 1 week with 0, 200, or 400 ppm N and K from ammonium and potassium nitrate.

Figures C and D (top): Ageratum 'Blue Danube' (top left) and salvia 'Red Hot Sally' (top right) plants after 6 weeks of storage at 5°C (41°F) and 6 weeks of forcing. Plants on the right in each figure, labeled "Greenhouse," were held in a 20°C (68°F) greenhouse in the plug sheet during the time the left and center plants were in the cooler.

Figures E and F (bottom): Ageratum 'Blue Danube' (bottom left) plants and salvia 'Red Hot Sally' (bottom right) plants following 4–10 weeks of forcing after 0–6 weeks of storage at 5°C (41°F).

Optimal Storage Temperatures

All species can be stored at a range of temperatures. However, one temperature is optimal: The lowest temperature at which plants can be held without experiencing chilling or freezing injury.

As temperature deviates from the optimum, chilling injury occurs as temperature is lowered and metabolism increases as temperature is raised. Both can decrease plant quality.

Table 1 lists the optimal storage temperature of the species studied. In general, plants of each listed species should not be stored at temperatures less than those shown in the table unless the duration of storage is equal to or less than that listed for the species and temperature in Table 2 (dark storage) and Table 3 (light storage).

Alyssum, cyclamen, geranium, pansy, and petunia can tolerate temperatures as low as 32°F without damage. There is little advantage to using temperatures below 36°F for these species, however, since cooling costs will increase and plants may be severely damaged if temperatures drop below freezing. Storing at cooler than optimum temperatures increases the chance of chilling injury.

All plants can be satisfactorily stored at warmer than optimal temperatures if light is supplied during storage. Light does not protect plants from the chilling injury just described, but it greatly improves plant quality and regrowth (Figures C and D) as storage duration is extended at the optimal temperature and as temperature rises above the optimum.

As little as 5 footcandles of light will reduce chlorosis and etiolation, which occur during dark storage at temperatures above the optimum. The greater the temperature deviation above the optimum, the greater the amount of light that will be necessary to maintain plant quality.

The easiest way to add light is to mount fluorescent fixtures vertically on the walls of the cooler. Light then shines between the shelves. If shelves are very tightly spaced, or if many racks of plants are placed in the cooler, lights may need to be mounted in the middle of the cooler as well.

The time to flower was not affected by storage unless plants experienced chilling injury when stored at too low a temperature or deteriorated when stored at too warm a temperature.

When stored at or near optimal temperatures, plants transplanted 1 week apart throughout the experiment developed and flowered 1 week apart (Figures E and F).

Cool 'Em Before Shipping

Our results show that cooling plugs prior to shipping will improve their postharvest condition when they reach their final destination.

We have heard of pansy plugs shipped from northern states to southern states arriving with elongated petioles. Based on our observations of the length of time pansies can be held under low temperatures with no petiole elongation, plants arriving with elongated petioles must have been shipped at temperatures above 50°F.

Removing field heat by cooling is a common practice after harvest in fruit and vegetable crops to prevent loss of quality during shipping. Likewise, cooling the plug soil and seedlings to remove greenhouse heat will help prevent loss of bedding plant plug quality during shipping.

A Few Words Of Warning

The impact of storage on plugs may vary depending on the specific storage conditions, age, species, cultivar, and physiological state of the plugs. There is also evidence that the environmental conditions before and after storage may have an influence on the growth of the plugs following storage.

We believe storage of plugs is a viable management tool. However, as with anything new, experiment with plug storage before you commit large quantities into storage.

Keep in mind there are differences in acceptable temperatures among different plant species. Remember, for instance, that pansies, geraniums, and petunias can tolerate lower temperatures than impatiens.

Environmental conditions before and after storage may have an effect on plug growth following storage.

AGERATUM

The optimum dark-storage temperature is 45°F.

The optimum long-term, light-storage temperature range is between 45° and 55°F.

Although ageratum could be held successfully for 1 week at 32°F, we do not recommend storing the crop at temperatures less than 41°F because of the potential for chilling injury.

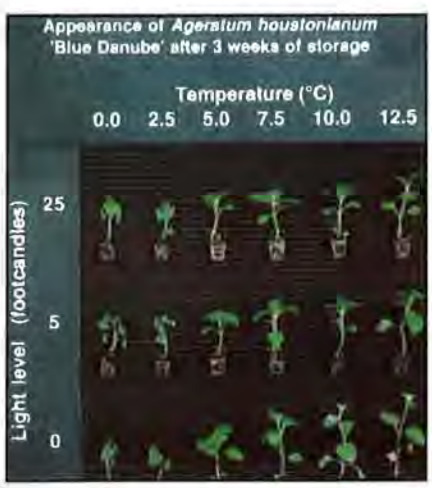
Temperatures of 32° and 36°F caused chilling injury and plant death in ageratum. Delayed flowering was the first sign of chilling injury at 32° and 36°F. As storage continued, plants died.

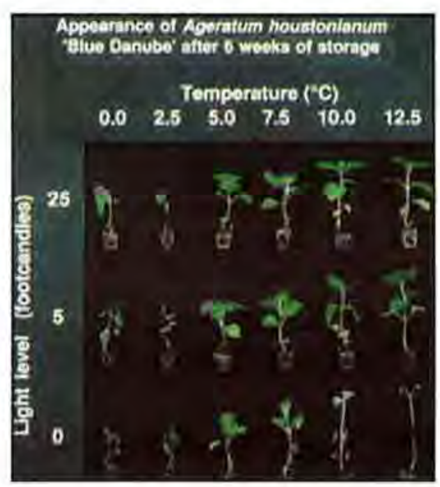
Ageratum seedlings were much less tolerant of dark storage than other crops. Plants first elongated, then became chlorotic, and finally died when stored for progressively longer periods at 50° and 55°F. The only temperature at which ageratum successfully stored for 6 weeks in the dark was 45°F.

The addition of light dramatically improved the ability to store ageratum seedling plugs at temperatures from

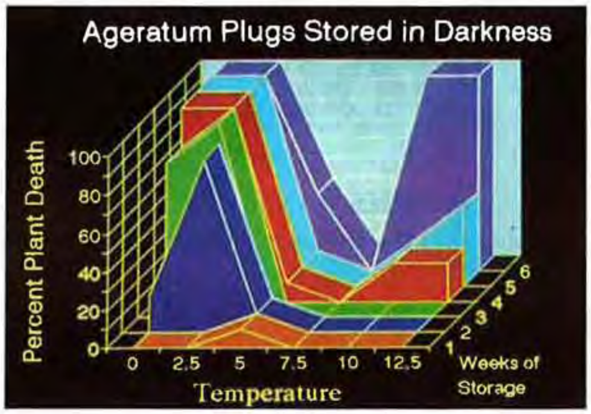
Figure 1 (left): Ageratum plugs immediately after 3 weeks' storage at 0–25 footcandles and 0°–12.5°C (32°–55°F).

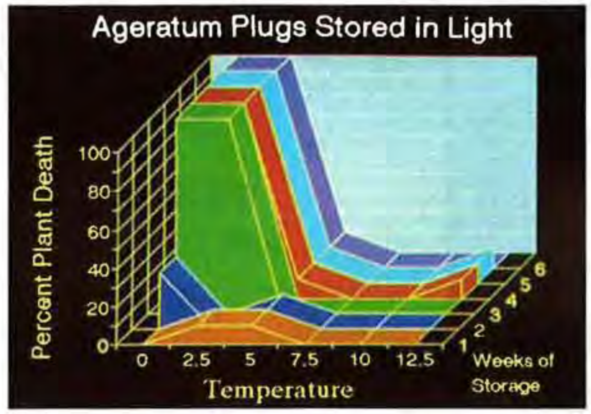
Figure 2 (right): Ageratum plugs immediately after 6 weeks' storage at 0–25 footcandles and 0°–12.5°C (32°–55°F).





Figures 3 and 4: Percent plant death of ageratum after 0–6 weeks of dark storage (left) and light storage (right) at 0°–12.5°C (32°–55°F).





41° to 55°F. The difference was significant — death of all plants after 6 weeks of storage in the dark at 50° and 55°F versus survival of all plants after 6 weeks storage in the light at the same temperatures.

There was no significant difference in plant performance with 5 versus 25 footcandles of light during storage.

● ALYSSUM

Alyssum plugs stored best in light under low temperatures (41°F or lower). The optimal storage temperature is 36°F. Store them in light when storage exceeds 2 weeks; they do not tolerate dark storage well.

At warmer temperatures (45°F or higher), acceptable storage duration significantly increased when a small amount of light (5 footcandles) was added. Etiolation, elongation, and plant mortality were all reduced.

There was no chilling injury at any temperature. Plants tolerated 1 week of storage under any of the temperatures in either light or dark, but as dark-storage duration increased, plants first elongated and etiolated, then died.

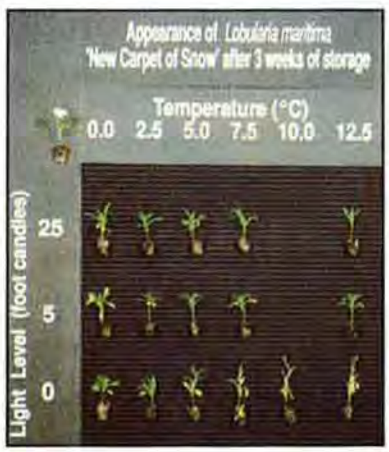
All plants stored for more than 3 weeks in the dark at 45°F or higher died.

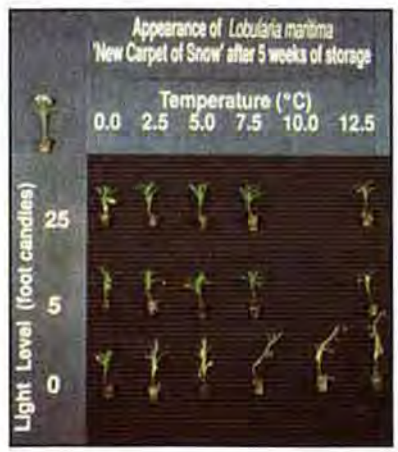
Plants stored in light did not elongate and etiolate, and compared to plants stored in darkness, the percentage of plants that died was lower at temperatures between 45°F and 55°F.

Regrowth potential after storage was determined by calculating the time it took a transplant to reach a 3-inch diameter.

No significant growth trend was observed in plants stored in light; however, time to achieve a 3-inch diameter increased for surviving plants as dark-storage temperature and duration increased.

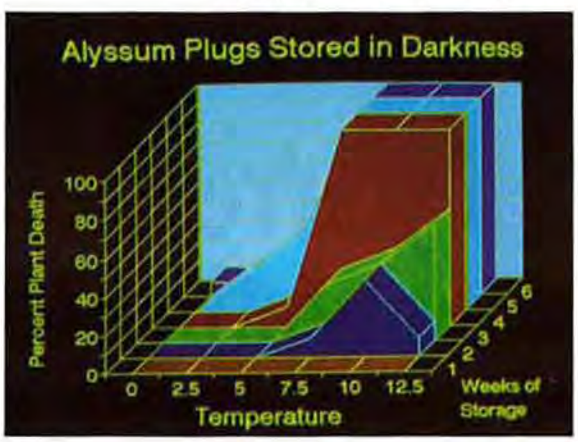
Plants stored for 1 and 5 weeks looked similar after 6 weeks of forcing, although plugs held in the greenhouse for 5 weeks were smaller than those held in cold storage.

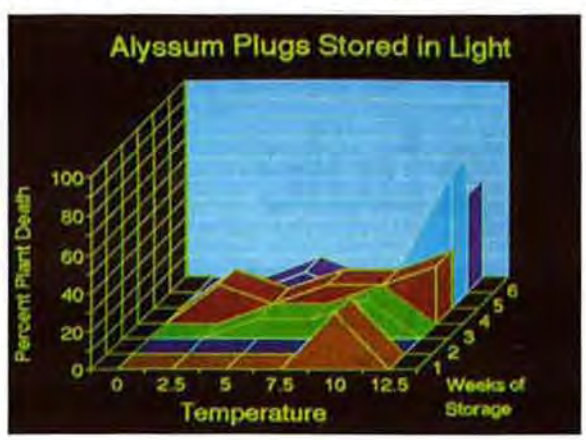


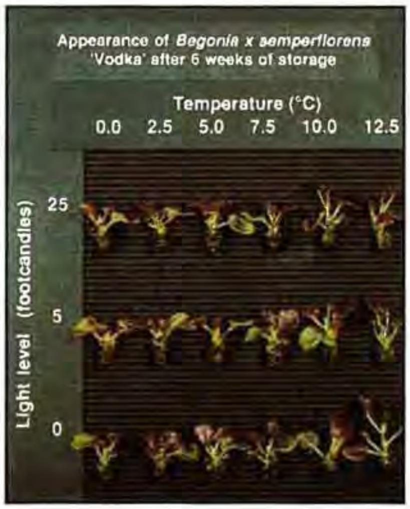


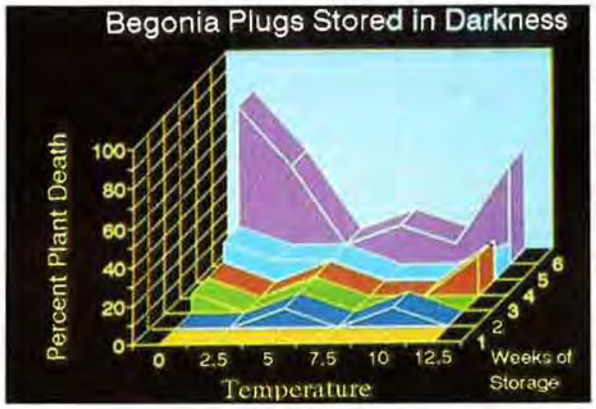
Figures 5 and 6: Alyssum plugs immediately after 3 weeks' (above, left) and 5 weeks' (above, right) storage at 0–25 footcandles and 0°–12.5°C (32°–55°F).

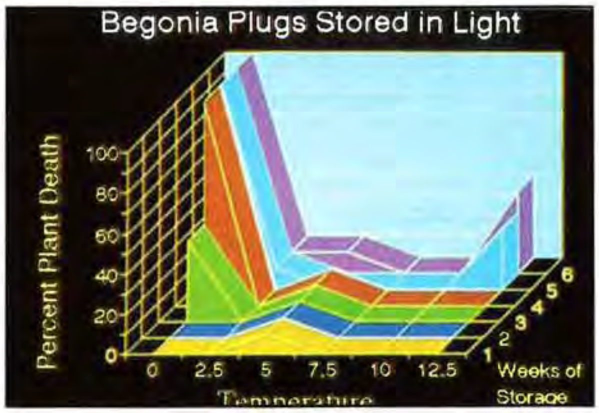
Figures 7 and 8: Percent plant death of alyssum after 0–6 weeks of dark storage (below, left) and light storage (below, right) at 0°–12.5°C (32°–55°F).











Figures 9 and 10 (far left): Begonia plugs immediately after 3 weeks' (top) and 6 weeks' (bottom) storage at 0–25 footcandles of light and 0°–12.5°C (32°–55°F).

Figures 11 and 12 (near left): Percent plant death of begonia after 0–6 weeks of dark storage (top) and light storage (bottom) at 0°–12.5°C (32°–55°F).

FIBROUS BEGONIA

The optimum temperature range for begonia plug storage was 41°–45°F. The acceptable range widened to 36°–50°F when the storage duration was 4 weeks or less and when light was added during storage.

Leaf spotting was evident within a few days on plugs stored at 32°F and to a lesser extent on plugs stored at 36°F. Long-term effects of chilling injury were first manifested by delayed flowering and, as storage continued, plant death.

Flowering delay was more pronounced at 32°F. The percentage of dead plants increased when plugs were stored in the light rather than the dark.

While the effects were not as severe at 36°F, flowering delay and the percentage of dead plants became progressively greater as plugs were stored for longer time periods.

Begonia seedlings elongated when held at 50° and 55°F. Elongation was more pronounced on plugs held in the dark and was not entirely prevented by storage in the light. Flowering was significantly delayed on plants stored in the dark at 55°F for any duration.

Begonias tolerated storage in the dark for 4 weeks at 36°F, 6 weeks at 41°F, and 5 weeks at 45°–50°F when judged by time to flower and percentage of plants surviving. Temperatures of 32° and 55°F were unacceptable for dark storage.

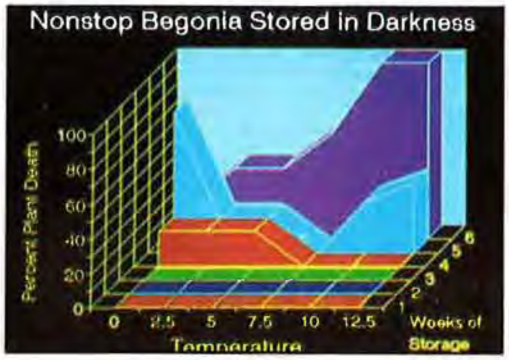
The duration of acceptable storage was 6 weeks at 36°–50°F when as little as 5 footcandles of light was added to the plants during storage. Even with the addition of 5 and 25 footcandles of light, however, the acceptable storage duration was limited to 4 and 5 weeks, respectively, at 55°F.

TUBEROUS BEGONIA

The optimum storage temperature range for tuberous begonias is 41°–45°F, but plants tolerate 32°–55°F for up to 3 weeks. Plants are susceptible to chilling injury at 36°F or lower and do not tolerate dark storage for more than 4 weeks at any temperature.

Plants tolerated light or dark storage at all temperatures for 3 weeks. After that time, chilling injury became evident at 32°F in both dark and light,

Figures 13 and 14: Tuberous begonia 'Nonstop Scarlet' plugs immediately after 1 week (left) and 5 weeks (right) of storage at 0–25 footcandles of light and 0°–12.5°C (32°–55°F).



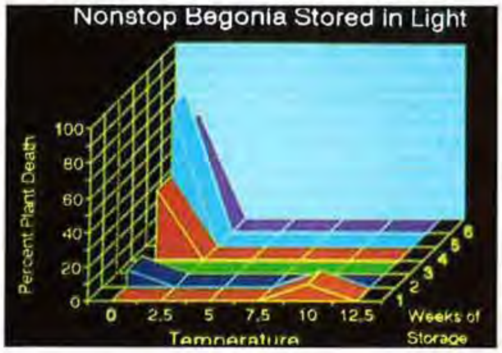


Figure 15 (top): Percent plant death of 'Nonstop Scarlet' tuberous begonias after 0–6 weeks of dark storage at 0°–12.5°C (32°–55°F).

Figure 16 (bottom): Percent plant death of 'Nonstop Scarlet' tuberous begonias after 0–6 weeks of light storage at 0°–12.5°C (32°–55°F).

and percent mortality increased as dark-storage duration and temperature increased.

Time to flower after transplanting was unaffected by light storage but increased as temperature increased and dark-storage duration surpassed 3 weeks.

Stem height did not increase significantly during storage at any temperature or in the dark. However, leaf petioles elongated at warmer storage temperatures, especially in the light. Plant size and height at first flower were unaffected by light-storage treatment, but the size of dark-stored plants increased as storage duration and temperature increased.

Appearance after 6 weeks of forcing was similar for plants stored 1 week in the cooler or held in the greenhouse. However, development of plants stored for 5 weeks in the dark or held in the greenhouse was delayed compared to that of plants stored at 41°F in the light.

CELOSIA

Optimal storage temperature was 50°F. Celosia stored poorly in both dark and light. All plants died after 2 weeks' storage at 32°F.

During storage there was severe disease pressure from Botrytis and bacterial infection. Because flowering was difficult to quantify, celosia were rated by survival of the shoot tip.

Although celosia survived dark storage at all temperatures and light storage at 36°F or warmer for 1 week, they did not tolerate longer storage well. As storage duration increased, percent mortality increased. Some plants died in all treatments after 5 weeks' storage in the light and 4 in the dark.

Some plants survived storage treatments, but their shoot tips aborted, especially at lower temperatures. All shoot tips aborted on plants stored at 32°F whether in light or darkness. The shoot tip aborted on most plants stored from 36° to 45°F in darkness or under 5 footcandles, and some aborted at 50°F in the dark. Plants stored at 45°F under 25 footcandles survived but did not look good after storage. Following storage, the healthiest looking plants were those that were held at 50°–55°F in light.

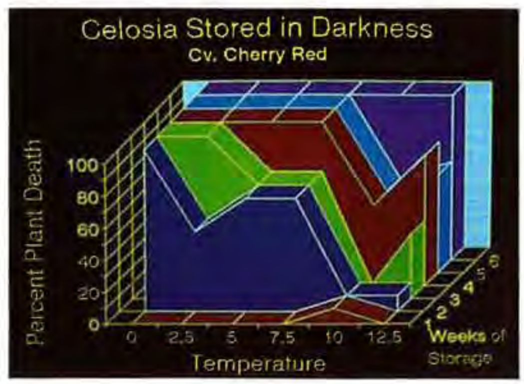
CYCLAMEN

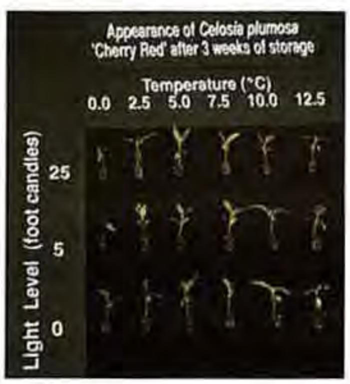
The optimum storage temperature range for cyclamen is 36°F–41°F. The results show cyclamen plugs can be stored in this range for up to 6 weeks, although some flowering delay (5–7 days) may occur if plugs are stored in the dark.

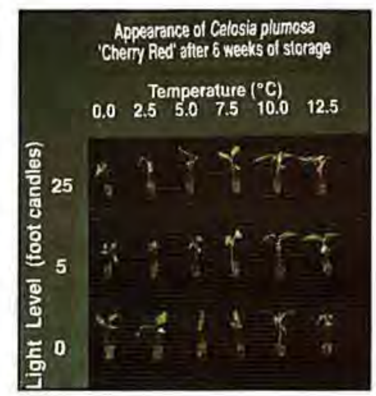
There was no significant petiole elongation in either 'Sylvia' or 'Giselle' when plants were stored in darkness

Figures 17 and 18 (below): Celosia plugs after 3 weeks' (below, left) and 6 weeks' (below, right) storage at 0–25 footcandles and 0°–12.5°C (32°–55°F).

Figures 19 and 20 (right): Percent plant death of celosia after 0–6 weeks' dark storage (top) and light storage (bottom) at 0°–12.5°C (32°–55°F).







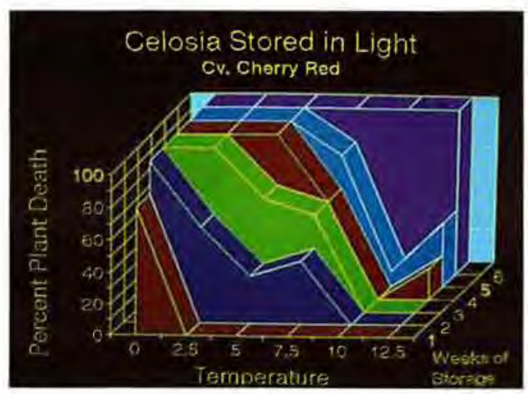


Figure 21 (left): Cyclamen 'Giselle' plugs immediately following 5 weeks of storage at 0–50 footcandles and 0°–12.5°C (32°–55°F).

Figure 22 (right): Cyclamen 'Sylvia' plugs immediately following 5 weeks of storage at 0–50 footcandles and 0°–12.5°C (32°–55°F).

or light at 36°F or 41°F. Elongation became more pronounced over time as storage temperature increased to 55°F.

Compared to temperature, light had much less effect on elongation, although petioles tended to elongate less at warmer temperatures as light levels increased.

Average time to flower was similar for both cultivars, varying little for plants stored up to 4 weeks. After that time, flowering was faster, especially for 'Sylvia' — plants stored for 6 weeks flowered an average of 11 days faster than those stored for 1 week.

The trend toward decreased time to flower with increased storage duration was probably a result of the higher greenhouse light levels and temperatures following the later plantings.

Storage temperature had no marked, consistent effect on time to flower. Plants held at 36°F flowered earliest. At 50°F and 55°F, plants stored for 4 weeks or more were slower to flower than those stored at lower temperatures.

Light levels had little effect on time to flower, particularly in 'Sylvia.' 'Giselle' plugs stored in the dark exhibited 5–7 days' flowering delay compared to those held in light.

Neither the presence nor absence of light affected the flowering time of 'Sylvia' stored for less than 4 weeks, but at 5 and 6 weeks, some delay was evident on plants stored in the dark compared to those stored in the light. The results suggest that, as with other species we have observed, the longer cyclamen plugs are stored, the more precise the conditions must be.

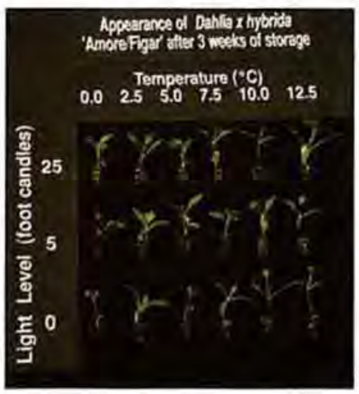
The optimum storage temperature range for 4 to 6 weeks was 36°F to 41°F. Adding light at lower temperatures yielded no significant benefits, but the opposite was true as the temperature increased. Plants stored in 5 footcandles of light always looked better at the end of 4 to 6 weeks' storage than those stored in darkness.

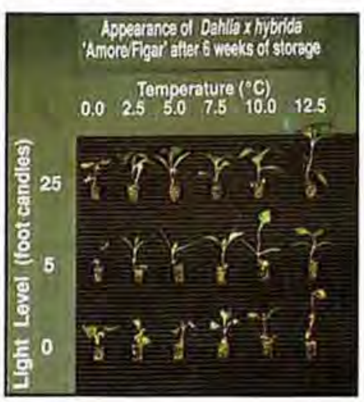
DAHLIA

Dahlias stored poorly in the dark. Botrytis and bacterial infections killed most of the plants, and those that survived were elongated. Plants stored in the dark at 50° and 55°F became extremely elongated and brittle as storage duration increased, and all died when stored for 4 weeks or longer.

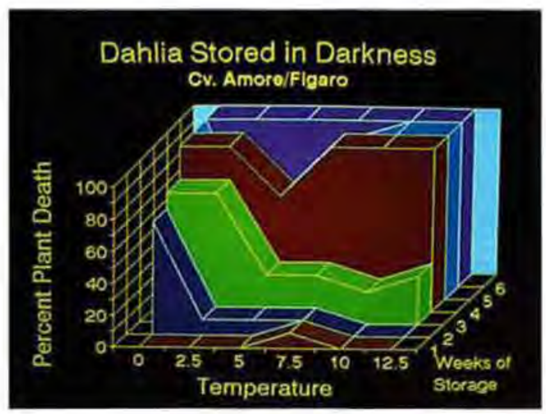
At least 70% of the plants stored at 32°F for more than 1 week died whether held in darkness or light. Most plants survived light storage at 36°F or higher.

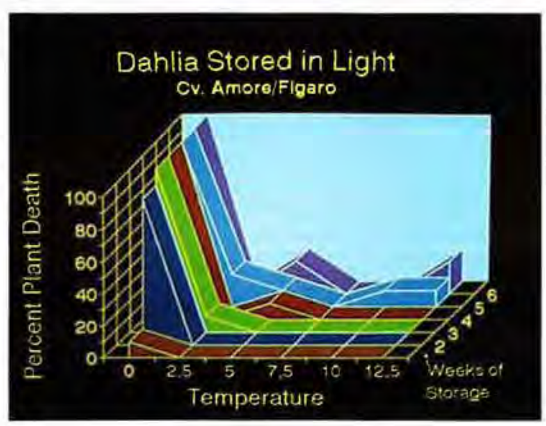
With increasing storage duration, plants looked better after storage



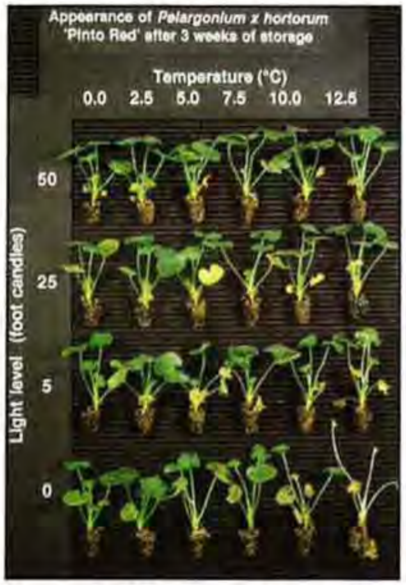


Figures 23 and 24 (left): Dahlia plugs after 3 weeks (top) and 6 weeks (bottom) of storage at 0–25 footcandles of light and 0°–12.5°C (32°–55°F).





Figures 25 and 26 (right): Percent plant death of dahlia after 0–6 weeks of dark storage (top) and light storage (bottom) at 0°–12.5°C (32°–55°F).



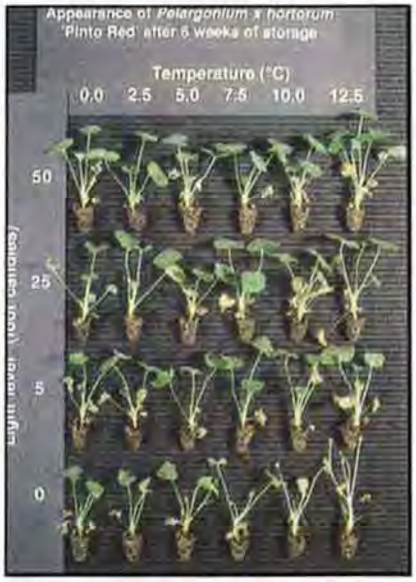


Figure 27 (left): Geranium plugs after storage for 3 weeks at 0°–12.5°C (32°–55°F) and 0–50 footcandles.

Figure 28 (right): Geranium plugs after storage for 6 weeks at 0°–12.5°C (32°–55°F) and 0–50 footcandles.

when held under 25 footcandles of light compared to 5, but all were still elongated at 50°F and especially at 55°F. Overall the best storage range was 41°–50°F in the light and 41°–45°F in the dark.

Time to flower increased as storage temperature increased for surviving plants held in darkness. With the exception of the few plants that survived 2 weeks' storage at 32°F, time to flower was unaffected by storage temperature or duration for plants stored in light.

Height of plants at flower was not significantly affected by storage.

Since plants do not tolerate dark storage well, use at least 5 footcandles of light if storage is expected to exceed 1 week.

GERANIUM

While geranium plugs stored satisfactorily for at least 4 weeks in the dark over a temperature range of 32°–50°F, we believe the optimum temperature for longest storage is near 36°F.

Geraniums tolerated freezing temperatures (32°F) and deteriorated in warmer temperatures.

Flowering data were collected on geraniums through 4 weeks of storage. A greenhouse cultural problem prevented flowering data from being collected on plants stored for 5 and 6 weeks.

With this limitation, geranium plugs stored satisfactorily for 4 weeks at temperatures from 41°F to 50°F in the dark. The addition of 5 footcandles of light increased the satisfactory temperature for 4 weeks of storage to 55°F.

Botrytis was a major problem on geraniums. We recommend storage under low-humidity conditions to prevent it. Irrigation will likely be necessary if plugs are stored longer than 1 week under low-humidity conditions.

IMPATIENS

Impatiens plugs could be stored for up to 6 weeks without delay in flowering if they were exposed to as little as 5 footcandles of light during storage.

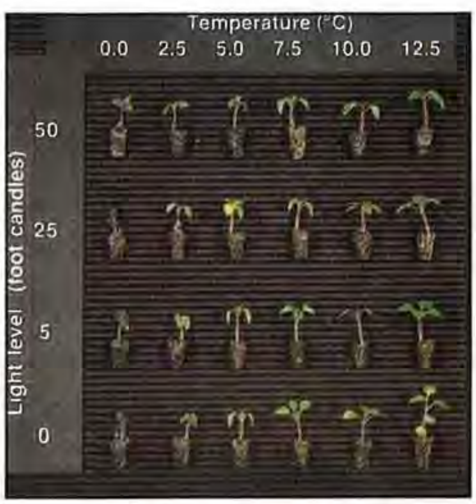
The optimum temperature for impatiens was 45°F. Storing impatiens plugs at 32°F for even 1 week killed all the plants.

Storing impatiens at 36°F for more than 2 weeks or 41°F for more than 3 weeks resulted in severe chilling injury and subsequent plant death regardless of irradiance.

Chilling injury is defined as damage to plants by low temperatures above freezing. Interestingly, impatiens satisfactorily tolerated 3 weeks of storage at 36°F in the dark and at 5 footcandles, but not at the higher irradiances of 25 and 50 footcandles.

The coldest temperature that impatiens plugs could tolerate beyond 3 weeks without chilling injury was 45°F. Impatiens satisfactorily tolerated 6 weeks' storage at 45°F at all light levels, including darkness.

The longest satisfactory duration



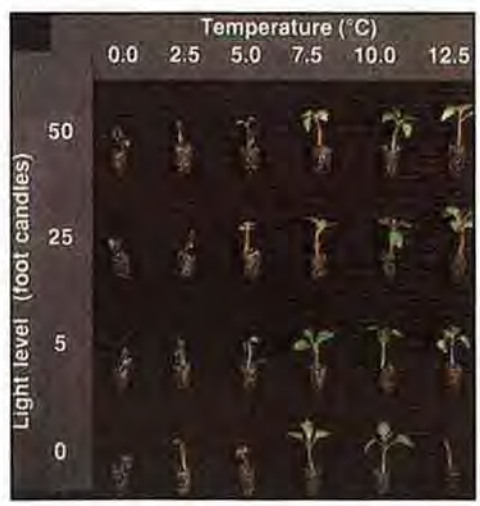
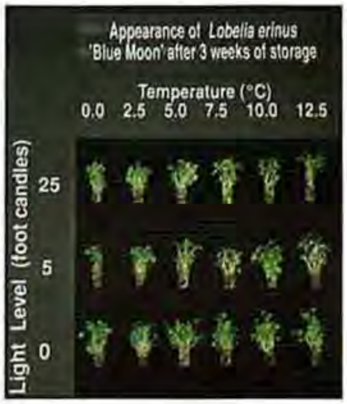
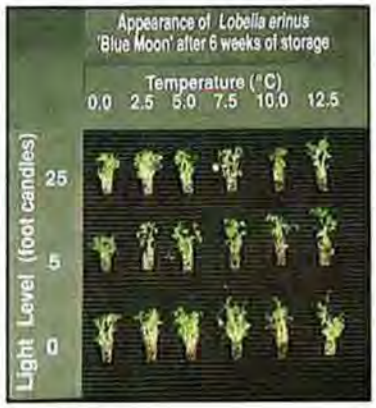


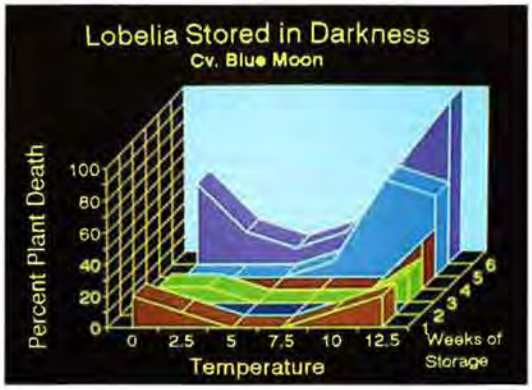
Figure 29 (left): Impatiens plugs immediately after storage for 3 weeks at 0°–12.5°C (32°–55°F) and 0–50 footcandles.

Figure 30 (right): Impatiens plugs immediately after storage for 6 weeks at 0°–12.5°C (32°–55°F) and 0–50 footcandles.

Figures 31 and 32: Lobelia plugs after 3 weeks' (near right) and 6 weeks' (far right) storage at 0–25 footcandles and 0°–12.5°C (32°–55°F).







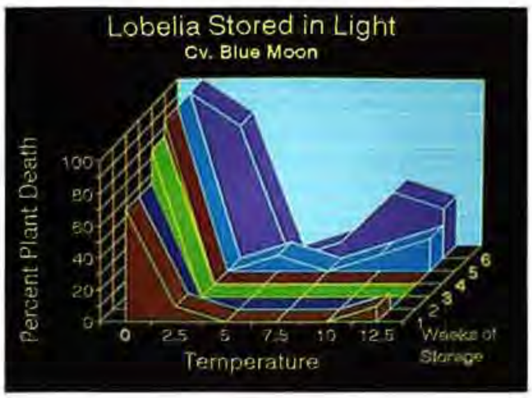


Figure 33 (left, top): Percent plant death of lobelia after 0–6 weeks of dark storage at 0°–12.5°C (32°–55°F).

Figure 34 (left, bottom): Percent plant death of lobelia after 0–6 weeks of light storage at 0°–12.5°C (32°–55°F).

for which impatiens plugs could be stored in the dark at 50°F and 55°F was 5 and 4 weeks, respectively. Storage at 55°F for more than 4 weeks in the dark delayed flowering.

LOBELIA

Lobelia survived dark but not light storage at 32°F; however, dark-stored plants became more chlorotic and percent plant mortality increased as storage duration and temperature increased. The optimum temperature for storage of lobelia was 41°F.

Plants stored in light did not become chlorotic, and percent mortality increased to a lesser extent as storage duration and temperature increased. However, as storage duration increased, plants held at 50° and 55°F in the light became slightly elongated, some developed dried foliage, and all were weak rooted.

The lobelia that looked best at the end of 6 weeks' storage were those stored at 41°–45°F under 25 footcandles.

Time to flower was not delayed by increasing storage duration in either light or darkness.

Lobelia, therefore, stored acceptably from 36° to 55°F with light and from 36° to 50°F in the dark, with an optimum at 41°F. If storing longer than 4 weeks, keep plants at 41°F and at least 5 footcandles.

FRENCH MARIGOLD

The optimum temperature for marigold storage was 41°F. However, even at that temperature, marigolds stored poorly in the dark. The maximum length of time they can be stored in total darkness is 3 weeks.

Temperatures of 32° and 36°F caused injury and death in marigold. As was typical for salvia, ageratum, and begonia, delayed flowering was the first sign of chilling injury. As storage continued, plants died.

Marigolds were very susceptible to chilling injury at 32°F, a temperature at which flowering was delayed after only 1 week of storage. Chilling injury was less noticeable at 36°F, but all plants were dead after 4 weeks of storage. Most plants survived at 41°F, but flowering was delayed when the storage duration exceeded 3 weeks.

Marigolds did not store well in the dark as temperatures increased from 45° to 55°F. Maximum storage duration was 2 weeks at 50°–55°F and 3 weeks at 45°F.

The combination of chilling injury at low temperatures (32°–36°F) and delayed flowering and death at warmer temperatures (45°–55°F) resulted in a short acceptable dark-storage time (maximum of 3 weeks).

The addition of light dramatically improved the quality of stored marigold plugs at temperatures of 41°–45°F. All plants died after 6 weeks' storage in the dark at 50°F and 55°F, while 100% of the plants survived after 6 weeks' storage in the light at the same temperatures.

However, even though plants survived storage in the light at 50°F and 55°F, there was variable flowering delay at these temperatures. We do not suggest storing marigolds beyond 5 weeks at 50°F and 3 weeks at 55°F.

NEW GUINEA IMPATIENS

Two experiments were conducted on New Guinea impatiens. The first experiment was conducted as with all other species. A second experiment was conducted because a storage test by Tom Smith and Tom McKeegan at Four Star Greenhouses in Carleton, MI, was only partially successful.

They observed that 'Celerio,' the cultivar used in our 1992 experiment, performed as expected. However, many other cultivars died under storage conditions in which 'Celerio' survived. The results suggested the temperatures that caused chilling injury varied among cultivars.

To test this hypothesis, we obtained rooted cuttings of 23 cultivars in 84-cell plug sheets. 'Celerio' sur-

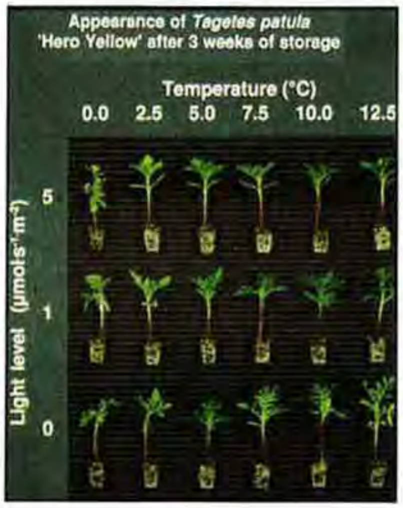
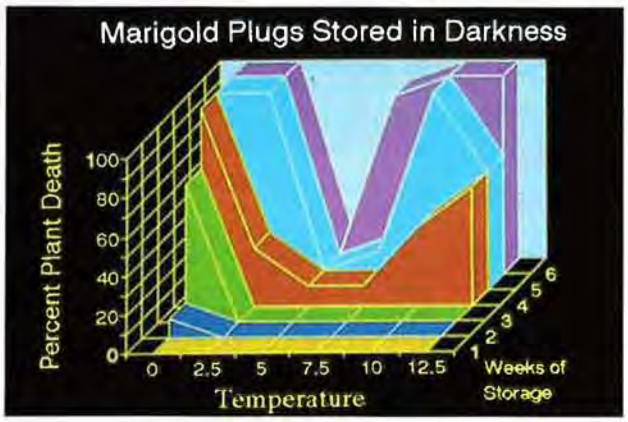


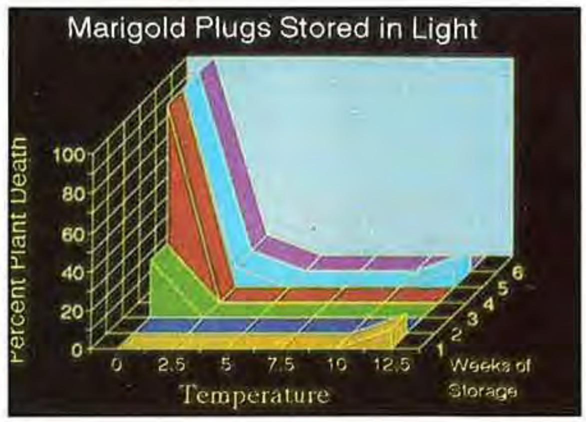
Figure 35 (far left): Marigold plugs immediately after 3 weeks of storage at 0–25 footcandles and 0°–12.5°C (32°–55°F).

Figure 36 (near left): Marigold plugs immediately after 6 weeks of storage at 0–25 footcandles and 0°–12.5°C (32°–55°F).

Figure 37 (below, left): Percent plant death of marigold after 0–6 weeks of dark storage at 0°–12.5°C (32°–55°F).

Figure 38 (below, right): Percent plant death of marigold after 0–6 weeks of light storage at 0°–12.5°C (32°–55°F).





vived 3 weeks of dark storage at 45°F or warmer in the 1992 experiment. Therefore, plants were exposed to 45°, 50°, 55°, and 59°F for 3 weeks.

Plants in plug sheets were stored in a shipping box, a large plastic bag, or uncovered under 5 footcandles cool-white fluorescent light. Seven plants of each cultivar were stored in the box and under light, while 14 were stored in the plastic bag. All were drenched with Ornalin and Dithane prior to storage.

The data presented here reflect the number of surviving plants 2 weeks after storage ended.

Experiment One Results

Chilling injury of 'Celerio' occurred at 41°F or lower. Plants showed damage in the form of a water-soaked appearance after 1 week of storage at 32°F in either dark or light, and all transplants died.

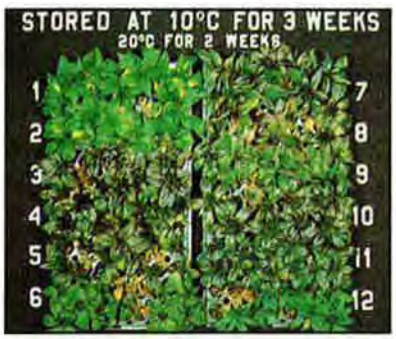
The temperature at which we saw chilling injury increased as storage duration increased. Neither light nor dark affected performance except after 5 weeks of storage; then the presence of light reduced it at 45°F or higher. After 6 weeks of storage, the plants that looked best were those held at 55°F under 25 footcandles of light.

For plants undamaged by chilling injury, the time to flower after transplanting was unaffected by storage treatment.

Plant height did not increase significantly during storage at any temperature, even in the dark. For plants

Figures 39 and 40 (Experiment One): New Guinea impatiens plugs immediately after 3 weeks (left) and 5 weeks (right) of storage at 0–25 footcandles and 0°–12.5°C (32°–55°F).

Figures 41 (above) and 42 (below): Appearance 2 weeks after termination of storage of New Guinea impatiens cultivars held at 7.5°C (45°F) for 3 weeks. There are two rows of each cultivar per flat. Numbers represent cultivar names (see Table 4).



Figures 43 (above) and 44 (below): Appearance 2 weeks after termination of storage of New Guinea impatiens cultivars held at 10°C (50°F) for 3 weeks. There are two rows of each cultivar per flat. Numbers represent cultivar names (see Table 4).

Table 4. New Guinea Impatiens Cultivars Tested in Experiment 2

Number	Cultivar
1	Kientzler Agua
2	Kientzler Anaea
3	Kientzler Apollon
4	Kientzler Celerio
5	Kientzler Celsia
6	Kientzler Eurema
7	Kientzler Marpesia
8	Kientzler Melissa
9	Kientzler Octavia
10	Kientzler Saturnia
11	Kientzler Sesia
12	Paradise Antigua
13	Paradise Aruba
14	Paradise Barbados
15	Paradise Bora-Bora
16	Paradise Lanai
17	Paradise Maui
18	Paradise Papete
19	Paradise Samoa
20	Paradise Tahiti
21	Paradise Tobago
22	Paradise Tonga
23	Paradise Trinidad

stored 1 week, size and appearance after 6 weeks' forcing were similar to those of unstored plants. Plants held in plug sheets for 5 weeks in the greenhouse continued to increase in size prior to transplanting; therefore, these plants were larger after 6 weeks' forcing than those stored under low temperatures. Plant size and height at first flower were unaffected by storage treatment.

Experiment Two Results

We observed major differences in tolerance to low-temperature storage among cultivars.

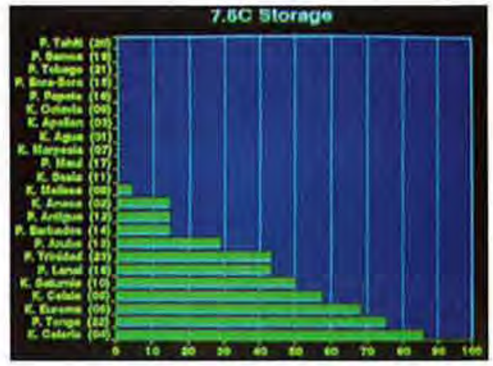
Eighty-six percent of 'Celerio' plants survived dark storage at 45°F; a lower percentage of all other cultivars survived the same storage conditions. No plants from 11 of the cultivars survived 45°F dark storage for 3 weeks.

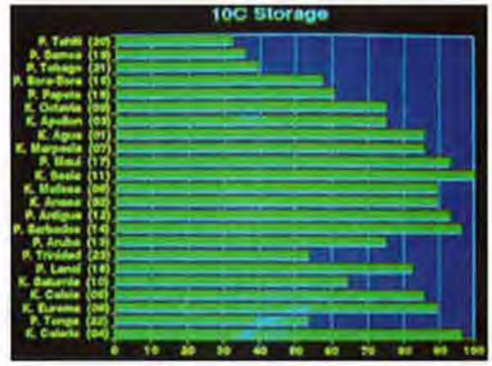
Increasing storage air settings to 50°F substantially increased the percentage of plants that survived dark storage for 3 weeks.

However, significant differences in tolerance to storage at 50°F still existed among cultivars; there was less than 60% survival for six of the cultivars. These differences were even more evident when average survival in the treatments at 50°, 55°, and 59°F was plotted against cultivar.

Plug sheets held in the dark were exposed to disease pressure from Botrytis. The mortality rate of certain cultivars stored above 50°F may be related to their susceptibility to Botrytis, not merely to cold temperatures.

These results show that most New Guinea impatiens cultivars are sensitive to chilling injury below 50°F and





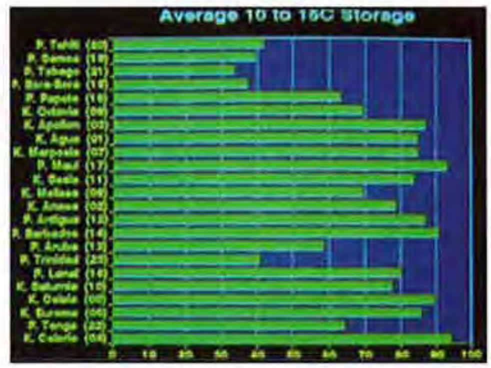
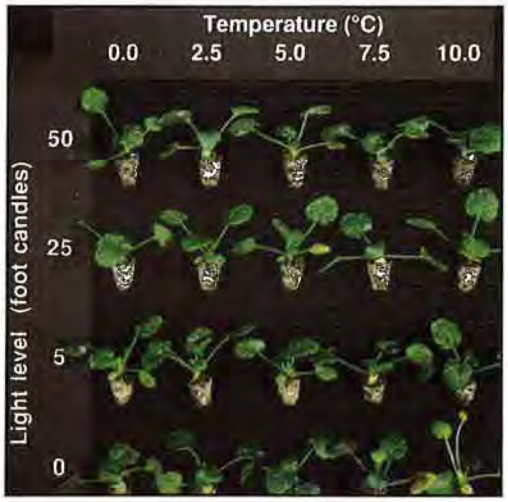


Figure 45 (top): Percent survival of New Guinea impatiens cultivars after 3 weeks of storage at 7.5°C (45°F).

Figure 46 (middle): Percent survival after 3 weeks at 10°C (50°F).

Figure 47 (bottom): Percent survival after 3 weeks at 10–15°C (50°–59°F).



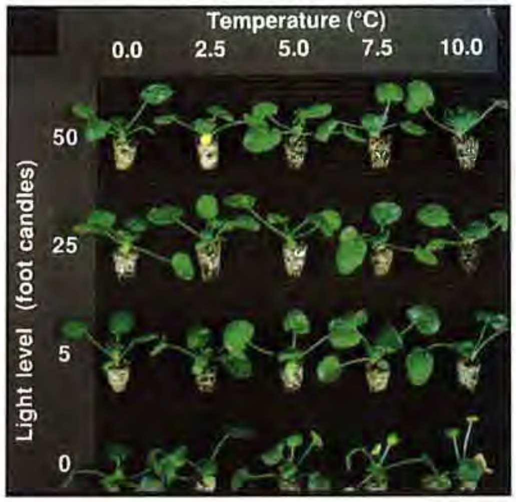
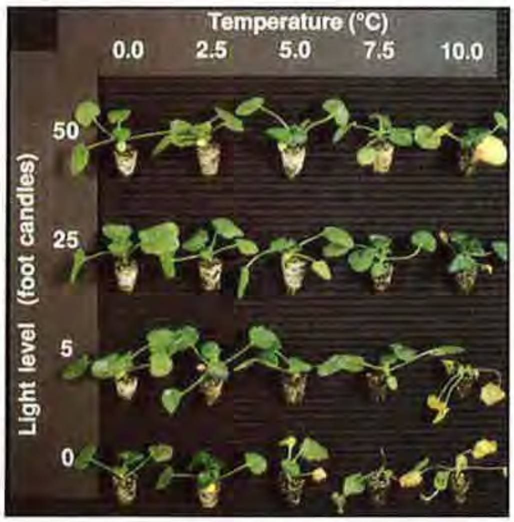


Figure 48 (far left): Appearance of pansy plugs immediately after storage for 4 weeks at 0–50 footcandles of light and 0°–12.5°C (32°–55°F).

Figure 49 (left): Appearance of pansy plugs immediately after storage for 8 weeks at 0–50 footcandles of light and 0°–12.5°C (32°–55°F).

Figure 50 (below, left): Appearance of pansy plugs immediately after storage for 16 weeks at 0–50 footcandles and 0°–12.5°C (32°–55°F).



some cultivars store poorly when kept below 59°F for extended periods.

Quality ratings were given to all the plants that survived. In general, the greater the survival rate, the higher the quality.

When Mixing Cultivars

If mixed cultivars of New Guinea impatiens must be held or stored, plants should not be held below 55°F. Most cultivars will store very well for up to 3 weeks at 55°F when exposed to light. However, be aware that some cultivars may not store well under these conditions.

● PANSY

Pansies were satisfactorily stored 16 weeks without flowering delay with light levels of 5 footcandles at 41°F and 45°F and 25 footcandles at 50°F.

Pansy plugs satisfactorily tolerated 16 weeks' storage at 32°F and 36°F at all light levels, including darkness.

Chilling injury was not observed on any of the pansy plugs. Satisfactory storage time in the dark decreased to 14, 10, and 6 weeks as the temperatures increased to 41°, 45°, and 50°F, respectively.

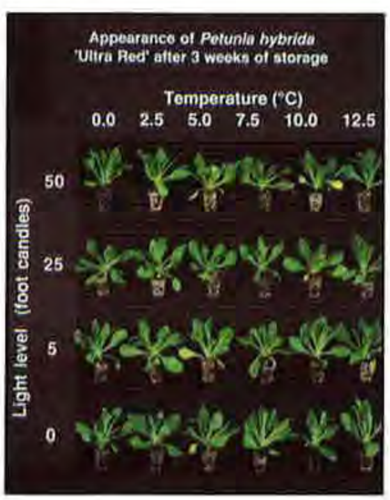
● PETUNIA

While petunia plugs stored satisfactorily for at least 4 weeks in the dark over a temperature range of 32°–50°F, we believe that the optimum temperature for the longest storage is near 36°F.

Petunias tolerated freezing temperatures (32°F) and deteriorated at warmer temperatures.

Petunia plugs stored satisfactorily for 6 weeks at temperatures ranging from 32°F to 41°F in the darkness. The addition of 5 footcandles of light increased the satisfactory temperature for 6 weeks of storage to 55°F.

Botrytis was a major problem. We recommend storage under low-humidity conditions to prevent the disease. Irrigation will likely be necessary if plugs are stored longer than 1 week under low-humidity conditions.



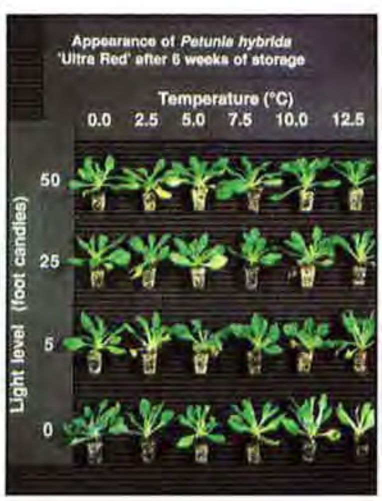


Figure 51 (far left): Appearance of petunia plugs immediately after storage for 3 weeks at 0–50 footcandles of light and 0°–12.5°C (32°–55°F).

Figure 52 (left): Appearance of petunia plugs immediately after storage for 6 weeks at 0–50 footcandles of light and 0°–12.5°C (32°–55°F).

PORTULACA

Plants stored acceptably at or above 32°F for 1 week, 36°F for 3 weeks, 41°F for 5 weeks, and 50°–55°F for 6 weeks. The optimum storage temperature range was 41°–45°F.

Plants died when stored for more than 1 week at 32°F. Although plants looked healthy when they came out of dark storage at 32°F, they died after transplanting.

Plants dropped leaves after both light and dark storage at 36° and 41°F. All plants stored in the dark were slightly chlorotic. Percent mortality increased as storage duration at less than 41°F increased.

Light was less critical for portulaca than for many other species tested. Time to flower was unaffected by storage treatment.

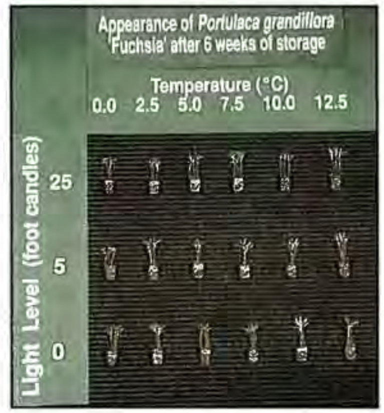
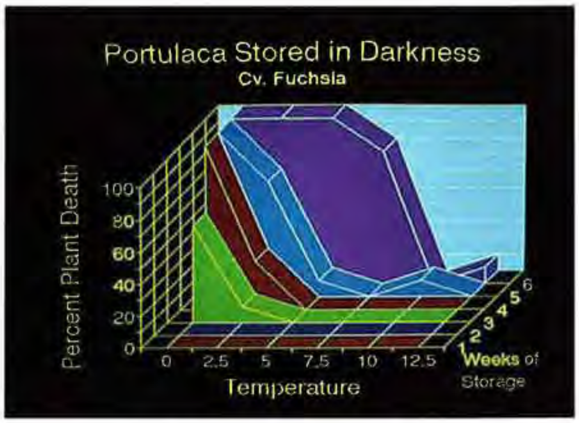
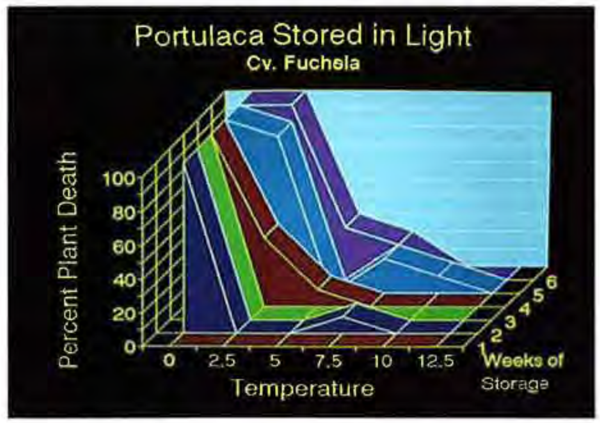


Figure 53 (above, left): Portulaca plugs immediately after storage for 3 weeks at 0–25 footcandles and 0°–12.5°C (32°–55°F).

Figure 54 (above, right): Portulaca plugs immediately after storage for 6 weeks at 0–25 footcandles and 0°–12.5°C (32°–55°F).





Figures 55 and 56 (above): Percent plant death of portulaca plugs after 0–6 weeks of dark storage (left) and light storage (right) at 0°–12.5°C (32°–55°F).

SALVIA

The optimum temperature for dark storage is 45°F. The optimum temperature range for long-term, light storage is between 45° and 55°F.

Temperatures of 32° and 36°F caused chilling injury and plant death in salvia. Delayed flowering was the first evidence of chilling injury at 32° and 36°F. As storage continued, plants died. These results indicate salvia plugs should not be stored at temperatures less than 41°F.

Salvia tolerated dark storage at temperatures of 41°–55°F for up to 4 weeks when judged by time to flower and percentage of plants surviving. However, plants elongated and leaves abscised during storage as temperature increased from 41° to 55°F.

The duration of acceptable storage increased to 6 weeks in the 41°–55°F temperature range when as little as 5 footcandles of light was added to the plants. Light also reduced seedling elongation during storage at all temperatures.

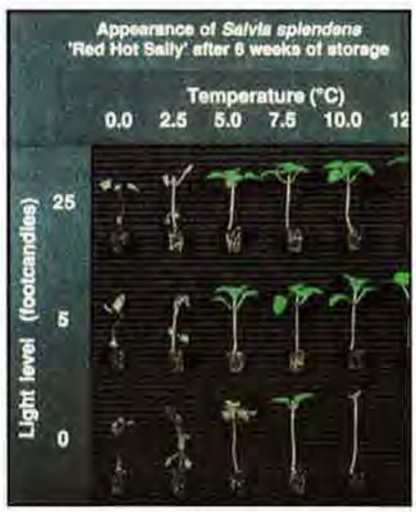
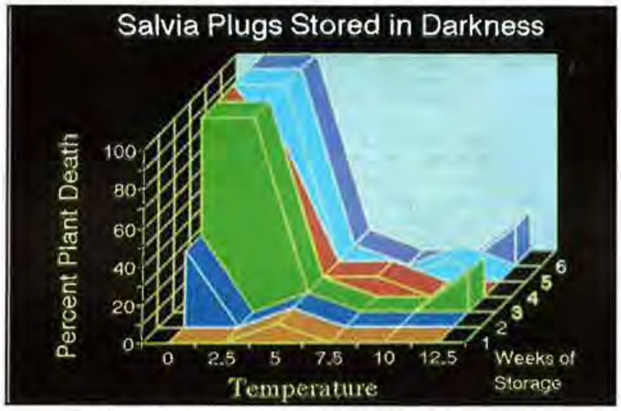


Figure 57 (left): Salvia plugs immediately after storage for 3 weeks at 0–25 footcandles and 0°–12.5°C (32°–55°F).

Figure 58 (right): Salvia plugs immediately after storage for 6 weeks at 0–25 footcandles and 0°–12.5°C (32°–55°F).



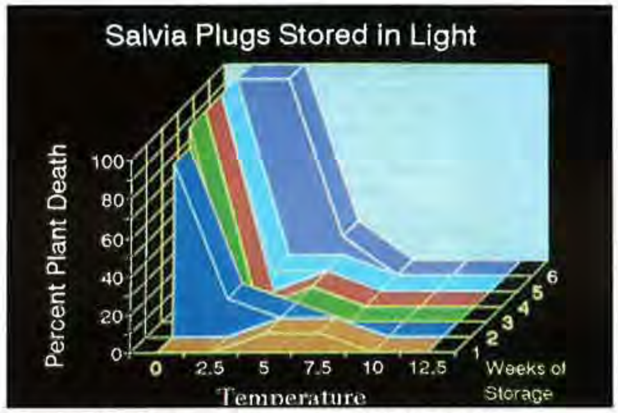
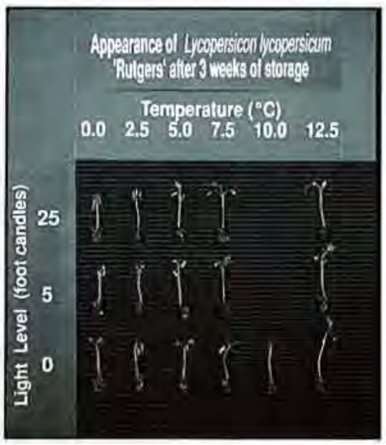


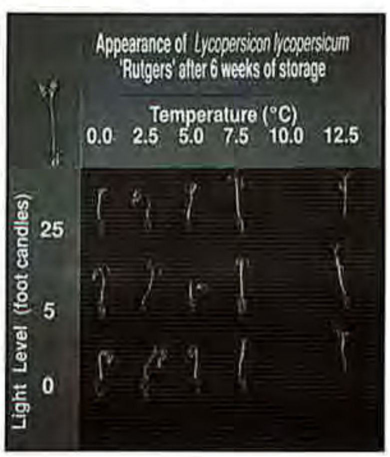
Figure 59 (left): Percent plant death of salvia plugs after 0–6 weeks of dark storage at 0°–12.5°C (32°–55°F).
Figure 60 (right): Percent plant death of salvia plugs after 0–6 weeks of light storage at 0°–12.5°C (32°–55°F).

TOMATO

Optimum storage temperature is near 45°F, but tomato plants do not tolerate storage well at any temperature when duration exceeds 3 weeks.



Figures 61 (above) and 62 (below): Tomato plugs immediately after storage for 3 and 6 weeks, respectively, at 0–25 footcandles and 0°–12.5°C (32°–55°F).



While tomato plants survived all storage temperature treatments for 1 week, their tolerance of longer storage was very poor. Plants were susceptible to chilling injury at 41°F or less. As time and storage duration increased, percent mortality increased whether plants were in darkness or light. Maximum dark-storage length was 3 weeks in a narrow temperature band of 45°–50°F. The addition of light decreased percent mortality at temperatures above 45°F but did not eliminate it.

No carry-over storage effects were observed. Days to flower, flower-bud number per inflorescence, and node number to first inflorescence were unaffected by storage treatment.

VERBENA

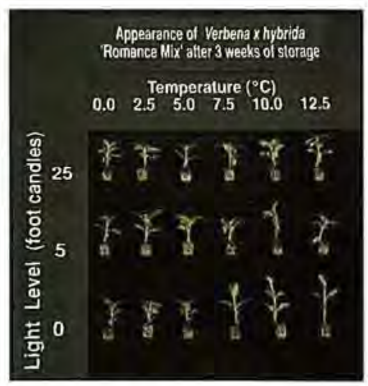
Verbena stored acceptably over the entire temperature range tested, but for no longer than 3–4 weeks. Best storage settings were 45°–55°F.

Verbena did not tolerate dark storage well. Plants stored in the darkness were infected by Botrytis and bacteria at all temperatures. As duration of dark storage increased at 50° and 55°F, plants elongated. At all light levels and temperatures, lower leaves dried as storage duration increased, particularly at 50° and 55°F.

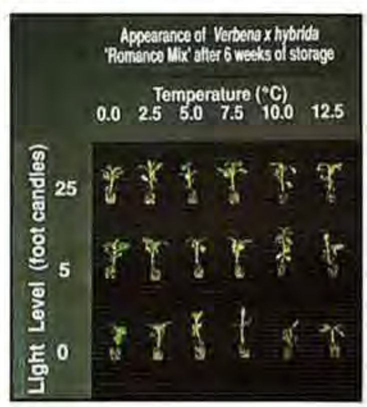
Percent mortality of plants stored in darkness was consistently higher than that of verbena stored in light. As storage duration increased, percent plant mortality increased in both light and dark conditions.

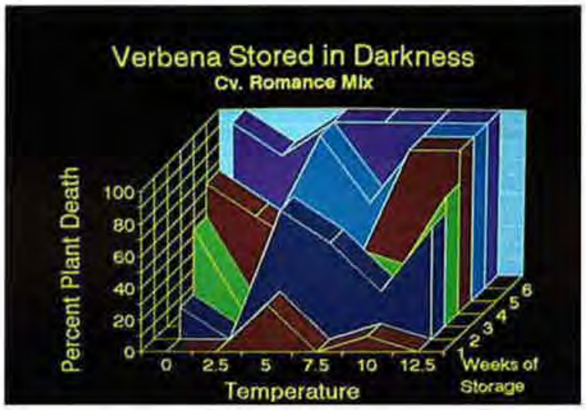
There was a slight increase in days to flower for plants stored in the dark at 32°F compared to those kept in light, but required time until flower was similar at all other temperatures.

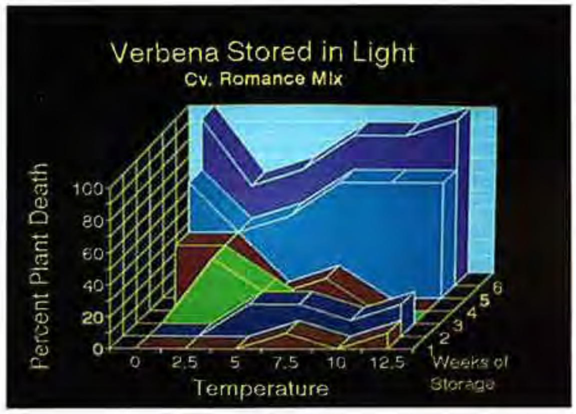
Size at flower was similar for plants stored in light or darkness except after 6 weeks' storage, when those held in light were bigger at flower.



Figures 63 (above) and 64 (below): Verbena plugs immediately after storage for 3 weeks and 6 weeks, respectively, at 0–25 footcandles and 0°–12.5°C (32°–55°F).







Figures 65 (far left) and 66 (left): Percent plant death of verbena plugs after 0–6 weeks of dark storage and light storage, respectively, at 0°–12.5°C (32°–55°F).

VINCA

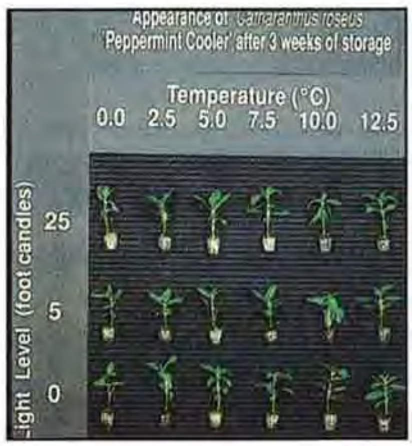
The best storage temperature range for vinca plugs is 45°–55°F, with a 50°F optimum. Plants are susceptible to chilling injury at 41°F or lower.

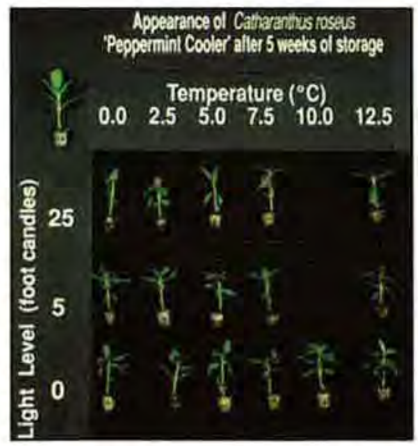
As temperature and storage duration increased, percent mortality of plants stored in darkness increased. No plants survived dark storage for 6 weeks because of Botrytis infection. Adding light eliminated plant death at 45°F and above.

Flowering of plants surviving temperatures that caused chilling injury (32°–41°F) was slightly delayed compared to flowering of plants stored at warmer temperatures. No flowering delay was observed on plants stored at temperatures above 41°F.

Plant size at flower was not consistent; however, plants surviving chilling injury were smaller at flower than those exposed to temperatures above 41°F. In addition, plants stored above 41°F were slightly smaller 6 weeks after the start of forcing than those held in the greenhouse in a plug sheet for 1 week. Nevertheless, there was no difference in plant size after 5 weeks of storage.

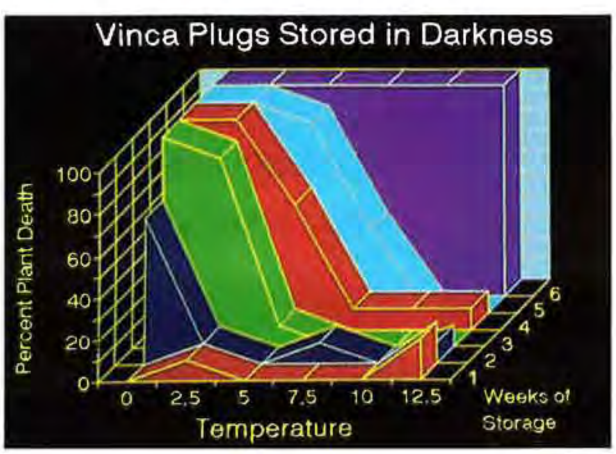
At warmer temperatures (45°F or higher), acceptable storage duration significantly increased when a small amount of light (5 footcandles) was added. Etiolation, elongation, and percent death were all reduced.





Figures 67 (above, left) and 68 (above, right): Vinca plugs immediately after storage for 3 and 5 weeks, respectively, at 0–25 footcandles and 0°–12.5°C (32°–55°F).

Figures 69 (below, left) and 70 (below, right): Percent plant death of vinca after 0–6 weeks of dark and light storage, respectively, at 0°–12.5°C (32°–55°F).



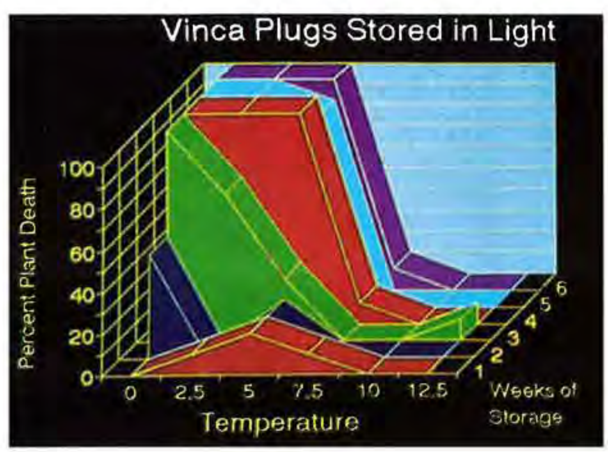


Table 5. Bedding Plant Species And Cultivars Used In Testing

Ageratum
'Blue Danube'

Alyssum
'New Carpet of Snow'

Fibrous Begonia
'Vodka'

Tuberous Begonia
'Nonstop Scarlet'

Celosia
'Cherry Red'

Cyclamen
'Giselle'
'Sylvia'

Dahlia
'Amore/Figaro'

Geranium
'Pinto Red'

Impatiens
'Accent Orange'

Lobelia
'Blue Moon'

French Marigold
'Hero Yellow'

New Guinea Impatiens
'Kientzler Agua'
'Kientzler Anaea'
'Kientzler Apollon'
'Kientzler Celerio'
'Kientzler Celsia'
'Kientzler Eurema'
'Kientzler Marpesia'
'Kientzler Melissa'
'Kientzler Octavia'
'Kientzler Saturnia'
'Kientzler Sesia'
'Paradise Antigua'
'Paradise Aruba'
'Paradise Barbados'
'Paradise Bora-Bora'
'Paradise Lanai'
'Paradise Maui'
'Paradise Papete'
'Paradise Samoa'
'Paradise Tahiti'

New Guinea Impatiens (cont.)
'Paradise Tobago'
'Paradise Tonga'
'Paradise Trinidad'

Pansy
'Majestic Yellow'

Petunia
'Ultra Red'

Portulaca
'Fuchsia'

Salvia
'Red Hot Sally'

Tomato
'Rutgers'

Verbena
'Romance Mix'

Vinca
'Peppermint Cooler'