Postharvest Decline Symptoms after Simulated Shipping and During Shelf Life of 21 Cultivars of Vegetative Annuals

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ADDITIONAL INDEX WORDS. bacopa, marguerite daisy, strawflower

SUMMARY. Twenty-one cultivars from nine species of vegetative annuals were grown under optimum greenhouse production practices until maturity. At harvest, they were subjected to 0, 1, or 2 days of simulated shipping. After shipping, plants were rated for quality, and flower abscission was counted postship and weekly for 3 weeks in a simulated retail environment. There were few decreases in flower number and quality directly postship, but decline symptoms became evident as time lapsed in the postharvest environment. Flower abscission resulting from increased shipping duration occurred on 'Sun Chimes Coral' diascia (*Diascia* × *hybrida*) and 'Aromatica White' nemesia (*Nemesia* × *hybrida*). During the postharvest evaluation, 'Dreamtime Copper' bracteantha (*Bracteantha bracteata*), 'Superbells Trailing Blue' calibrachoa (*Calibrachoa hybrid*), 'Aromatica White' nemesia, and 'Candy Floss Blue' sutera (*Sutera cordata*) were the only cultivars to abscise all flowers (<0.4 flowers) by the end of the first week. Five cultivars still had flowers at termination of the experiment. Of these five, four were bracteantha cultivars including 'Florabella White', 'Florabella Gold', 'Dreamtime Cream', and 'Sundaze Golden Yellow', and 'Cascadias Pink' petunia. After 2 weeks postharvest, 12 of the 21 cultivars that were shipped 1 or 2 days did not have a high enough quality rating (<3.0 points) to be considered marketable. Each species in this study had one or two postharvest decline symptoms common to all cultivars of that species. However, cultivars within species also varied in their postharvest decline symptoms and longevity. More optimum environmental conditions, better care, and faster turnover in the retail market are needed to improve shelf life of vegetative annuals sold in containers.

Vegetative annuals are garden plants propagated asexually and marketed to the consumers to be grown in landscape beds or containers. Some vegetative annuals are cool-season crops that are best grown during early spring or fall with cool temperatures. Others are warm season, and the warmer temperatures in late spring and summer are optimum. Because many of the cultivars

of vegetative annuals have vigorous growth habits, they are often sold in 10-cm-diameter pots or larger pots, rather than in bedding plant flats. Vegetative annuals in large containers are well-suited to patio planters, window boxes, and decorative containers in outdoor rooms. These larger pots are ideal for giving today's consumer, living in houses and apartments, the instant color they are demanding for decorating their small outside spaces.

Losses can be as great as 30% as a result of improper postproduction and handling of floriculture crops (Jones, 2002). Postharvest shelf life responses and factors that influence them have not been studied for vegetative annual crops grown as small

containerized garden plants. Vegetative annuals in these containers are shipped and handled much the same as potted flowering plants. For long-distance shipping, they are packed into boxes at the production greenhouse and transported in trucks to market. They may stay in the boxes for 1 or 2 d until they are unpacked and put on the shelves in the garden center. In the shipping box, plants are subjected to increased stress from high temperature, low light, and increased exposure to ethylene gas (Jones, 2002). In the dark environment, photosynthesis shuts down and respiration continues, and speeds up if the temperature increases, with a subsequent loss of carbohydrates. Reduction in carbohydrates will decrease shelf life, and extended periods in the dark cause plants to stretch, leaves to yellow, and buds and flowers to abscise (Jones, 2002).

After being unpacked, the garden center environment may be less than ideal and plants are usually subjected to low light, inadequate irrigation and fertilization, and warm temperatures. The retail area for marketing garden plants varies from an extension of the greenhouse, to well-ventilated polyethylene or glass structures, to sidewalks. Outlets for garden plants are many times staffed by unqualified employees, and the plants suffer from neglect. Large chain-type retailers use pay-by-scan and the grower only gets paid for product that lasts through the marketing channels from production greenhouse to consumer's doorstep. Cultivars that are more resistant to the adverse effect of shipping or retail displays will provide consumers with a higher quality product. Unfortunately, detailed postproduction information is not available for all species, and there is considerable variability between species and cultivars (Jones, 2002). Increased information would make growers more conversant to help retailers care for plants, and

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
10.7639	fc	lx	0.0929
29.5735	fl oz	mL	0.0338
2.54	inch(es)	cm	0.3937
1	ppm	mg·L ⁻¹	1
(°F - 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

retailers would be more knowledgeable in designing retail spaces for marketing potted garden plants. Production practices keeping postharvest longevity in mind would also give consumers longer lasting products and would make them more satisfied, repeat customers.

Past postharvest research efforts on garden plants have been directed toward seed-propagated plants grown in bedding plant flats or storage of plug flats (Armitage, 1993). Studies of flowering potted plants have shown reduced postharvest longevity as a result of high temperatures during shipping and long shipping durations. Nell and Barrett (1986) simulated shipping of 'Gutbier V-10 Amy' poinsettia (*Euphorbia pulcherrima*) at 4, 16, or 24 °C for 1, 4, or 7 d. After shipping, plants were placed in a simulated interior at 21 °C, 50% relative humidity (RH), and 20 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ photosynthetic photon flux (PPF) for 30 d. Plants shipped for 7 d at the two higher temperatures had the highest amount of leaf abscission (36 leaves compared with 12 and 0 respectively as the length of simulated shipping decreased). Cyathia abscission was greater on treatments shipped for 4 or 7 d at 16 or 24 °C. Those shipped for 1 d at any temperature had a maximum of one cyathia abscised per plant and no leaves abscised.

Cushman et al. (1998) found an interaction between shipping temperatures (4, 16, or 28 °C) and simulated shipping durations (2, 4, or 6 d) on pot rose (*Rosa hybrida*). At 28 °C, plants shipped for more than 2 d had decreased floral longevity. At 16 °C, floral longevity decreased and leaf abscission increased when plants were shipped for more than 4 d. Plants shipped at 4 °C at all shipping durations had the longest floral longevity, the best flower quality, and the least leaf abscission.

The objective of this experiment was to simulate shipping for 0, 1, or 2 d to determine qualitative and quantitative shelf life longevity of 21 cultivars of cool- and warm-season vegetative annuals to determine the effect of shipping duration and to characterize postharvest decline symptoms. This study was designed to lead to further investigation of production methods and postproduction environment parameters to increase

postharvest longevity of vegetative annual garden plants grown in small containers.

Materials and methods

COOL-SEASON VEGETATIVE ANNUALS. Twenty-milliliter rooted liners (105 rooted liners/tray) from Flower Fields (Paul Ecke Ranch, Encinitas, CA) were received on 7 Jan. 2003 and planted on 10 and 13 Jan. Twenty-seven-milliliter rooted liners (34 rooted liners/strip, three strips/tray) from Simply Beautiful (Ball FloraPlant; Ball Horticulture, Chicago) were received on 14 Jan. and planted on 15 and 16 Jan. Plant cultivars included 'Comet White' and 'Sunlight' argyranthemum or marguerite daisy (*Argyranthemum frutescens*); 'Liricashowers Deep Blue Imp', 'Starlette Trailing Purple', and 'Superbells Trailing Blue' calibrachoa; 'Sun Chimes Coral' diascia; 'Aromatica White' and 'Vanilla Sacht' nemesia; and 'Bridal Showers' and 'Candy Floss Blue' sutera or bacopa (*Sutera hybrida*).

All were planted in soilless media (Pro Mix BX; Premier Brands, Quakertown, PA) in 4.5-inch-diameter (415-mL) geranium pots (Dillon Products, Middlefield, OH). Plants were hand watered with reverse osmosis water and fertilized each time they were irrigated. From planting to 28 Jan., 15N-5.4P-14.1K (Peter's Professional; Scotts-Sierra Horticultural Products Co., Marysville, OH) water-soluble fertilizer was used at 200 $\text{mg}\cdot\text{L}^{-1}$. From 29 Jan. to 11 Feb., fertilizer rate was increased to 300 $\text{mg}\cdot\text{L}^{-1}$. From 12 Feb. until harvest, 20N-3.4P-16.6K (Peter's Professional) fertilizer was applied at 300 $\text{mg}\cdot\text{L}^{-1}$. On 31 Jan. and at 4-week intervals from this date, Soluble Trace Element Mixture (STEM, Peter's Professional) drench was applied to the plants at 30 $\text{mg}\cdot\text{L}^{-1}$. On 11 Mar., calibrachoa and petunia cultivars received a 20% iron sulfate drench to lower substrate pH and prevent iron deficiency symptoms (i.e., chlorosis of new foliage).

Plants were grown in a glass and polycarbonate greenhouse at 18/13 °C day/night temperature set points. The measured day/night temperatures were 18.0 ± 6.2 °C/ 13.3 ± 6.1 °C. Actual greenhouse temperatures were measured using HOBO H8 loggers (Onset Computer Corp., Bourne,

MA). Average noontime light levels were measured at $145.44 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ PPF using an Integrated Spectrum Datalogger (Apogee Instruments Inc., Logan, UT).

Petunia cultivars had been sporadically pinched by the grower; any petunia plants not pinched previously were pinched on 31 Jan. 'Bridal Showers' and 'Candy Floss Blue' sutera were pinched on 7 Feb. For height control, a tank mix of paclobutrazol (Bonzi; Uniroyal Chemical, Middlebury, CT) (40 $\text{mg}\cdot\text{L}^{-1}$) and daminozide (Uniroyal Chemical) (2500 $\text{mg}\cdot\text{L}^{-1}$) was applied as a foliar spray to runoff (≈ 10 mL/pot) to 'Sunlight' argyranthemum on 31 Jan. and to 'Comet White' argyranthemum on 5 Feb.

WARM-SEASON VEGETATIVE ANNUALS. Twenty-seven-milliliter rooted liners from Simply Beautiful, 20-mL rooted liners (84 rooted liners/tray) from Flower Fields and from Proven Winners (EuroAmerican Propagators, Bonsall, CA) were received on 26 and 27 Feb. and planted on 12 Mar. Plant cultivars included 'Caritas Lavender' angelonia (*Angelonia angustifolia*); 'Dreamtime Copper', 'Dreamtime Cream', 'Florabella White', 'Florabella Gold', 'Sundaze Bronze', and 'Sundaze Golden Yellow' bracteantha or strawflower; 'Lucky Lemon Cream' and 'Lucky Peach Sunrise' lantana (*Lantana camara*); and 'Cascadias Pink' and 'Suncatcher Pink' petunia.

All were planted in soilless media (Sunshine Mix #1; SunGro Horticulture, Pine Bluff, AK) because of the lack of availability of the media used previously. Pot size depended on growth habit of the cultivar and included 4.5-inch-diameter (415-mL) geranium pots, 5.0-inch-diameter (535-mL) azalea pots (Dillon Products), or 4.5-inch-diameter (430-mL) azalea pots (ITML Horticultural Products, Brantford, Ont., Canada). The plants were grown at 24/18 °C day/night temperature set points with actual temperatures of 24.0 ± 3.6 °C/ 20.0 ± 4.7 °C day/night. The average noontime light levels measured were $216.59 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ PPF. A 50% interior shade cloth was applied on 2 Apr. for the remainder of the experiment. Plants were watered by hand and fertilized at each irrigation with 20N-3.4P-16.6K at 300 $\text{mg}\cdot\text{L}^{-1}$.

Soluble Trace Element Mixture was applied every 4 weeks. On 28 Mar., calibrachoa cultivars received a 20% iron sulfate drench. A paclobutrazol ($40 \text{ mg}\cdot\text{L}^{-1}$) and daminozide ($2500 \text{ mg}\cdot\text{L}^{-1}$) tank mix was applied as a foliar spray to runoff ($\approx 10 \text{ mL/pot}$) to bracteantha cultivars for height control. These cultivars were 'Floralbelle White' bracteantha treated on 24 Jan. and 'Floralbelle Gold' bracteantha treated on 31 Jan.

Plants were harvested when they were judged marketable (i.e., had enough foliage that the root substrate in the container was not visible and the plants looked full and were flowering). All plants of a cultivar were harvested at the same time. Cultivars of the same species were harvested either at the same time or when they reached a comparable, stipulated stage of development. Data taken at harvest included plant height, plant width index, and number of flowers. Plant height was measured from the base of the pot to the highest point on the plant. Plant width index was the mean of two plant width measurements taken perpendicular to each other across the plant canopy.

SHIPPING AND POSTHARVEST TREATMENTS AND EVALUATION. The three shipping durations used were 0 d, 1 d, or 2 d. Simulated shipping was in a growth chamber at $26.7 \pm 0.3^\circ\text{C}$, $0 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ PPF, and 50% RH. A postship flower number was counted, and quality ratings were given to each plant as they were moved from simulated shipping to simulated shelf life.

Simulated shelf life was in a growth room at $21.1 \pm 1.3^\circ\text{C}$ with an average light intensity of $30.05 \pm 4.79 \text{ fc}$ measured with a digital light meter (model FCM-10M+; Phyto-tronics, St. Louis). Lights were turned on from 0800 to 1700 HR for a 9-h photoperiod. Plants were watered by hand with plain reverse osmosis water during the 3 weeks they remained in the growth room. Flower number and quality rating were recorded weekly for each termed postharvest time of measurement (week 1 through week 3).

The plant quality rating was assessed on a point scale of 5 to 0 with 5 being highest quality. Postharvest quality ratings were defined as 5 points, plant is healthy with no visible decline symptoms; 4 points, <50% flower abscission or visible

change in flower color or <10% chlorotic lower leaves; 3 points, 100% flower abscission or <50% chlorotic lower leaves or <10% senesced lower leaves; 2 points >50% senesced lower leaves and 100% flower abscission or <10% dead stems; 1 point, >10% dead stems, 100% flowers abscised or 100% lower leaves senesced; and 0 point, total plant senescence. A plant was no longer considered marketable when the quality rating was lower than a rating of 3.0 points.

Each treatment consisted of six plants per cultivar. Harvest data were analyzed using analysis of variance and the LSD test at $P \leq 0.05$ by the SAS program (version 8.01; SAS Institute, Cary, NC). Postharvest flower data were analyzed using repeated-measure analysis conducted as a split plot design using the Mixed Model Procedure (PROC MIXED) in SAS with LSD for mean separation. Postharvest quality ratings were analyzed as repeated-measure categorical data with the General Model Procedure (PROC GENMOD) in SAS with a chi-square test at $P \leq 0.05$ for mean separation.

Results

Days to harvest varied among species and cultivars, and ranged from 41 to 87 d (Table 1). At harvest and before shipping duration treatments, plant height, width index, and number of flowers showed no differences among treatments. Lower leaf chlorosis manifested, as overall yellowing of entire leaves was the most common visually observed postharvest decline symptom and occurred on 81% of the vegetative annual cultivars (Table 2). Conversely, foliage on lantana and sutera cultivars remained dark green and healthy throughout the entire evaluation. Diascia lower leaf chlorosis was unique because it commenced as chlorotic spots that later progressed to the entire leaf.

Internode elongation and flower senescence were each displayed by 38% of the cultivars (Table 2). 'Caritas Lavender' angelonia internode elongation was unique because it occurred only at the acropetal end of the stems on new growth. Calibrachoa cultivars had epinasty in addition to internode elongation. Nemesis cultivar's internode elongation occurred at the acropetal end of stems

and between flowers on the racemes. Specifically, bracteantha flower senescence was "bent neck" followed by necrosis of the peduncle at the base of the receptacle before the release of seeds. In lantana cultivars, flower senescence was the only postharvest decline symptom and occurred immediately after bud opening with no further flower development during shelf life.

Thirty-three percent of the cultivars had bud abortion during simulated shelf life (Table 2). In particular, argyranthemum bud abortion was characterized by necrosis of the peduncle at the base of the receptacle followed by necrosis of immature petals. Bracteantha bud abortion began with the peduncle curling and becoming necrotic while the bud drooped and failed to develop further. Flower color fading was a postharvest symptom of 19% of the cultivars. Distinctively, calibrachoa flowers that opened during shelf life were lighter purple or streaked with white and were smaller in size compared with larger, solid-dark-purple flowers that were typical of these cultivars. During shelf life, diascia's coral-color flowers faded to a pale cream. 'Suncatcher Pink' petunia had flower fading to a paler pink and a water-soaked texture. 'Bridal Showers' sutera had decreased size on flowers that developed postharvest. Late in the evaluation, calibrachoa, diascia, and sutera cultivars had stem dieback starting at the acropetal stem tips and advancing basipetally.

There was an interaction between shipping duration and postharvest time of measurement for number of flowers for eight of the cultivars: 'Caritas Lavender' angelonia, 'Dreamtime Cream', 'Floralbelle White', and 'Sundaze Bronze' bracteantha; 'Sun Chimes Coral' diascia; 'Aromatica White' nemesia; 'Suncatcher Pink' petunia; and 'Bridal Showers' sutera. For 'Caritas Lavender' angelonia, 'Suncatcher Pink' petunia, and 'Bridal Showers' sutera there was not a consistent affect of shipping duration on flower number and, regardless of shipping duration, after 3 weeks all flowers had abscised. 'Dreamtime Cream' (Fig. 1), 'Floralbelle White', and 'Sundaze Bronze' bracteantha flowers continued to open flowers during the postharvest evaluation sporadically among shipping durations.

Table 1. Common name, cultivar, days to harvest, and average plant height, plant width index, and number of flowers.

Common name	Cultivar	Time to harvest (d)	Plant ht (cm) ^z	Plant width index (cm)	Flowers (no.)
Angelonia	Carita Lavender	57	52.7	40.0	12
Argyranthemum	Comet White	69	25.2	21.9	3
Argyranthemum	Sunlight	69	26.0	15.5	1
Bracteantha	Florabella White	87	24.5	20.4	3 ^y
Bracteantha	Florabella Gold	87	26.5	23.5	3
Bracteantha	Dreamtime Copper	55	21.4	26.3	8
Bracteantha	Dreamtime Cream	62	22.4	19.4	5
Bracteantha	Sundaze Bronze	50	28.7	31.5	8
Bracteantha	Sundaze Golden Yellow	50	25.8	31.3	7
Calibrachoa	Liricashowers Deep Blue Imp	69	22.6	38.4	10
Calibrachoa	Starlette Trailing Purple	87	15.3	33.0	18
Calibrachoa	Superbells Trailing Blue	43	18.7	35.9	8
Diascia	Sun Chimes Coral	46	21.4	17.8	25
Lantana	Lucky Lemon Cream	43	26.9	27.2	7
Lantana	Lucky Peach Sunrise	43	25.8	25.3	3
Nemesia	Aromatica White	41	31.9	20.7	46
Nemesia	Vanilla Sachet	41	27.1	19.3	16
Petunia	Cascadias Pink	75	22.6	30.7	2
Petunia	Suncatcher Pink	53	21.6	31.3	5
Sutera	Bridal Showers	47	13.3	25.2	19
Sutera	Candy Floss Blue	47	14.7	26.8	46

^z1 cm = 0.3937 inch.

^yNumber of buds rather than flowers in all bracteantha cultivars.

All replications within a cultivar were harvested the same day. Measurements were taken at harvest and before shipping duration treatments. Among shipping treatment groups, differences in plant height, width index, and flower number were nonsignificant.

Table 2. Common name, cultivar, and postharvest decline symptoms of vegetative growth and flowers observed visually during 3 weeks of simulated shelf life for 21 cultivars of vegetative annuals.

Common name	Cultivar	Lower leaf chlorosis	Internode elongation	Flower senescence	Bud abortion	Flower color fading	Flower size decrease	Stem dieback
Angelonia	Caritas Lavender	X	X					
Argyranthemum	Comet White	X						
Argyranthemum	Sunlight	X			X			
Bracteantha	Dreamtime Copper	X			X			
Bracteantha	Dreamtime Cream	X			X			
Bracteantha	Florabella Gold	X	X	X	X			
Bracteantha	Florabella White	X	X	X	X			
Bracteantha	Sundaze Bronze	X			X			
Bracteantha	Sundaze Golden Yellow	X			X			
Calibrachoa	Liricashowers Deep Blue Imp	X	X			X	X	X
Calibrachoa	Starlette Trailing Purple	X	X	X				
Calibrachoa	Superbells Trailing Blue	X	X			X	X	
Diascia	Sun Chimes Coral	X				X		X
Lantana	Lucky Peach Sunrise and			X				
Lantana	Lucky Lemon Cream			X				
Nemesia	Vanilla Sachet	X	X					
Nemesia	Aromatica White	X	X					
Petunia	Cascadias Pink	X						
Petunia	Suncatcher Pink	X		X		X		
Sutera	Bridal Showers		X	X			X	
Sutera	Candy Floss Blue			X				X

‘Dreamtime Cream’ and ‘Florabella White’ had flowers at the end of the evaluation period. ‘Sundaze Bronze’ opened flowers until 2 weeks, at which time they senesced.

Postship, ‘Sun Chimes Coral’ diascia plants shipped 1 d had fewer flowers than plants shipped 0 or 2 d (Fig. 2). After 1 week, all treatments had the same number of flowers, and

after 2 weeks none had flowers. ‘Aromatica White’ nemesia plants shipped 0 or 1 d had no flower abscission postship whereas plants shipped 2 d lost half the flowers

Fig. 1. Effect of shipping duration and postharvest time of measurement on number of flowers on 'Dreamtime Cream' bracteantha. Mean separation within treatments (lowercase letters) and among treatments (uppercase letters) by LSD at $P \leq 0.05$. If no uppercase letters are present, then differences among treatments were nonsignificant.

Fig. 2. Effect of shipping duration and postharvest time of measurement on number of flowers on 'Sun Chimes Coral' diascia. Mean separation within treatments (lowercase letters) and among treatments (uppercase letters) by LSD at $P \leq 0.05$. If no uppercase letters are present, then differences among treatments were nonsignificant.

during shipping (Fig. 3). After 1 week, none of the nemesia plants had flowers, regardless of shipping duration.

There was no effect of shipping duration on number of flowers for 12 of the cultivars; however, there were differences in number of flowers

among postharvest times of measurement (Table 3). 'Superbells Trailing Blue' calibrachoa and 'Candy Floss Blue' sutera retained flowers from harvest through shipping, but virtually all flowers abscised after 1 week.

'Vanilla Sachet' nemesia opened flowers after shipping. Bracteantha cultivars' number of flowers increased postship as mature buds opened; however, the number of open flowers remained less than one throughout the evaluation for 'Dreamtime Copper' bracteantha, and 'Florabella Gold' bracteantha had only two flowers.

'Lucky Lemon Cream' and 'Lucky Peach Sunrise' lantana number of flowers never increased, but decreased to almost no flowers after 2 weeks.

'Comet White' and 'Sunlight' argyranthemum, 'Liricashowers Deep Blue Imp' and 'Starlette Trailing Purple' calibrachoa, and 'Cascadias Pink' petunia retained flowers after 2 weeks. The number of flowers in these cultivars increased from harvest to after 1 week, then decreased with the exception of 'Starlette Trailing Purple' calibrachoa, which had the same number of flowers from harvest until after 2 weeks, then decreased to almost 0 flowers after 3 weeks. 'Sundaze Golden Yellow' bracteantha was the only cultivar with a number of flowers that was unaffected by shipping duration or postharvest time of measurement; plants had an average of one flower throughout the evaluation (data not shown).

There were significant interactions between shipping duration and postharvest time of measurement on quality ratings of 11 cultivars (Table 4). 'Sunlight' argyranthemum plants shipped 2 d decreased in quality postship compared with those shipped 0 or 1 d, but their quality rating improved after 1 week. There was no difference among shipping treatments throughout the remainder of the evaluation. 'Florabella Gold' bracteantha plants shipped 0 d remained high quality postship compared with those shipped 1 or 2 d, but all treatments remained marketable throughout the evaluation. The increase in quality rating later in the evaluation may have been the result of new flowers opening up on plants. Although the interaction was significant, quality of all shipping treatments of 'Florabella White' bracteantha was not different each week.

No shipping treatment of ‘Sundaze Bronze’ bracteantha was marketable after 1 week.

‘Liricashowers Deep Blue Imp’ calibrachoa plants shipped 2 d were lower quality than those shipped 0 or 1 d after 2 weeks, but none were marketable (Table 4). ‘Sun Chimes Coral’ diascia quality ratings decreased after 1 week for all shipping durations, but plants shipped 0 or

1 d had a higher quality than plants shipped 2 d, which were not marketable by that time. ‘Lucky Lemon Cream’ lantana plants shipped 0 or 1 d maintained a quality of 5.0 points postship, but plants shipped 2 d did not. ‘Vanilla Sachet’ nemesia plants shipped 2 d decreased in quality postship, but recovered because new flowers developed. After 2 weeks, there was no difference among treatments.

‘Suncatcher Pink’ petunia plants shipped 1 or 2 d remained marketable until after 1 week. All shipping durations were below marketable quality after 2 weeks. ‘Bridal Showers’ sutera shipped 1 or 2 d declined in quality postship, but had increased quality ratings compared with 0 d at the end of the evaluation. High-quality ratings for ‘Lucky Lemon Cream’ lantana and ‘Bridal Showers’ sutera were the result of the lack of vegetative decline symptoms. In retrospect, these high ratings at the end of the evaluation for the 1 and 2-d shipping treatments were probably inflated, considering there was extensive (lantana) or complete (sutera) flower abscission by this time.

Quality ratings decreased during shipping for ‘Caritas Lavender’ angelonia, ‘Aromatica White’ nemesia, and ‘Candy Floss Blue’ sutera (Table 5). All other cultivars went through simulated shipping unscathed. After shipping and the first week of simulated shelf life, quality declined for all but three cultivars: ‘Dreamtime Cream’ bracteantha, ‘Starlette Trailing Purple’ calibrachoa, and ‘Cascadias Pink’ petunia. After 1 week, ‘Caritas Lavender’ angelonia, ‘Sundaze Golden Yellow’ bracteantha, and ‘Candy Floss Blue’ sutera were rated below 3.0 points and not considered a marketable quality. After 2 weeks postharvest, quality had declined in all cultivars and ‘Superbells Trailing Blue’ calibrachoa and ‘Aromatica White’ nemesia were no longer marketable. ‘Dreamtime Copper’ and ‘Dreamtime Cream’ bracteantha, Starlette Trailing Purple’ calibrachoa, and ‘Cascadias Pink’

Fig. 3. Effect of shipping duration and postharvest time of measurement on number of flowers on ‘Aromatica White’ nemesia. Mean separation within treatments (lowercase letters) and among treatments (uppercase letters) by LSD at $P \leq 0.05$. If no uppercase letters are present, then differences among treatments were nonsignificant.

Table 3. Common name, cultivar and effect of postharvest time of measurement regardless of shipping duration on number of flowers measured at harvest, postship, and at weekly intervals for 3 weeks during postharvest evaluation.

		Time of postharvest measurement				
Common name	Cultivar	Harvest	Postship	1 wk	2 wk	3 wk
		Flowers (no.)				
Argyranthema	Comet White	2.6 c ^z	3.1 c	6.8 a	4.4 b	0.4 d
	Sunlight	0.9 b	1.1 b	1.6 a	0.8 b	0.1 c
Bracteantha	Dreamtime Copper	0.2 b	0.6 a	0.4 ab	0.4 ab	0.0 b
	Florabella Gold	0.3 c	0.4 c	1.5 b	2.1 a	2.0 a
Calibrachoa	Liricashower Deep Blue Imp	10.1 b	10.6 b	17.4 a	2.5 c	0.1 c
	Starlette Trailing Purple	18.9 a	17.1 a	21.5 a	22.9 a	0.3 b
	Superbells Trailing Blue	8.3 a	7.8 a	0.4 b	0.0 b	0.3 b
Lantana	Lucky Lemon Cream	6.5 a	5.1 a	0.5 b	0.1 b	0.1 b
	Lucky Peach Sunrise	2.6 ab	2.8 a	1.3 bc	0.2 c	0.1 c
Nemesia	Vanilla Sachet	16.1 b	20.2 a	3.6 c	0.0 d	0.0 d
Petunia	Cascadias Pink	2.3 c	2.3 c	8.9 a	6.2 b	1.3 d
Sutera	Candy Floss Blue	45.8 b	49.8 a	0.0 c	0.0 c	0.0 c

^zMean separation in rows by LSD at $P \leq 0.05$.

Table 4. Common name, cultivar and the effect of shipping duration and postharvest time of measurement on quality ratings measured at harvest, postship, and at weekly intervals for 3 weeks during postharvest evaluation.

Common name	Cultivar	Shipping duration (d)	Time of postharvest measurement				
			Harvest	Postship	1 wk	2 wk	3 wk
Argyranthemum	Comet White	0	5.00 A a ^z	5.00 A a	4.67 A a	2.67 A b	—
		1	5.00 A a	5.00 A a	5.00 A a	3.00 A b	—
		2	5.00 A a	5.00 A a	4.33 A a	2.67 A b	—
	Sunlight	0	5.00 A a	5.00 A a	4.83 A a	3.67 A b	2.50 A c
		1	5.00 A a	5.00 A a	5.00 A a	3.50 A b	2.17 A c
		2	5.00 A a	4.00 B b	5.00 A a	3.50 A c	2.67 A d
Bracteantha	Florabella Gold	0	5.00 A a	5.00 A a	3.17 A b	4.83 A a	3.33 A b
		1	5.00 A a	4.50 B b	2.83 A d	4.17 B b	3.33 A c
		2	5.00 A a	3.00 C c	3.00 A c	3.50 B b	3.33 A c
	Florabella White	0	5.00 A a	5.00 A a	4.00 A b	3.67 A b	1.50 A c
		1	5.00 A a	4.67 A a	4.00 A b	4.00 A b	2.50 A c
		2	5.00 A a	5.00 A a	4.00 A b	3.33 A b	2.33 A c
	Sundaze Bronze	0	5.00 A a	5.00 A a	2.17 A b	0.50 AB c	0.00 B c
		1	5.00 A a	4.50 A a	1.33 A b	0.00 B c	0.00 B c
		2	5.00 A a	4.17 A a	2.17 A b	1.17 A b	0.50 A c
Calibrachoa	Liricashowers Deep Blue Imp	0	5.00 A a	5.00 A a	4.00 A b	2.67 A c	2.00 AB c
		1	5.00 A a	4.00 A b	4.00 A b	2.67 A c	2.83 A c
		2	5.00 A a	4.00 A b	3.83 A b	2.00 B c	1.33 B d
Diascia	Sunchimes Coral	0	5.00 A a ^z	—	3.17 A b	2.83 AB b	1.83 AB c
		1	5.00 A a	—	3.83 A b	3.33 A c	2.33 A d
		2	5.00 A a	—	2.17 B b	1.17 B c	1.17 B d
Lantana	Lucky Lemon Cream	0	5.00 A a	5.00 A a	3.67 B b	2.33 B c	1.67 B d
		1	5.00 A a	5.00 A a	4.33 A b	2.67 AB c	2.67 AB c
		2	5.00 A a	4.17 B b	4.00 AB b	4.00 A b	4.17 A b
Nemesia	Vanilla Sachet	0	5.00 A a	5.00 A a	4.17 A b	2.83 A c	0.83 B d
		1	5.00 A a	5.00 A a	4.33 A b	3.00 A c	2.50 A d
		2	5.00 A a	3.83 B b	4.50 A c	2.83 A d	1.83 AB e
Petunia	Suncatcher Pink	0	5.00 A a	5.00 A a	2.83 B b	2.17 A c	0.67 B d
		1	5.00 A a	4.00 A b	4.33 A b	2.67 A c	2.33 A c
		2	5.00 A a	4.00 A b	4.00 A b	2.67 A c	2.17 A d
Sutera	Bridal Showers	0	5.00 A a	5.00 A a	2.83 B b	2.67 B c	2.17 B c
		1	5.00 A a	4.00 B b	3.00 B c	4.00 A b	3.67 A b
		2	5.00 A a	4.00 B b	3.83 A b	4.00 A b	4.00 Ab

^zMean separation within cultivars in rows (lowercase letters) and within shipping durations (d) in columns (uppercase letters) by χ^2 at $P \leq 0.05$. Quality of 5 = best, <3 = not marketable, 0 = death.

Table 5. Common name, cultivar, and effect of postharvest time of measurement regardless of shipping duration on quality rating measured at harvest, postship, and at weekly intervals for 3 weeks during postharvest evaluation.

Common name	Cultivar	Time of postharvest measurement				
		Harvest	Postship	1 wk	2 wk	3 wk
Angelonia	Caritas Lavender	5.00 a ^z	4.83 b	2.89 c	2.06 d	1.78 e
Bracteantha	Dreamtime Copper	5.00 a	5.00 a	4.44 b	3.56 c	1.00 d
	Dreamtime Cream	5.00 a	5.00 a	4.89 a	4.67 b	2.72 c
	Sundaze Golden Yellow	5.00 a	5.00 a	2.67 b	0.89 c	0.06 d
Calibrachoa	Starlette Trailing Purple	5.00 a	5.00 a	5.00 a	4.06 b	2.28 c
	Superbells Trailing Blue	5.00 a	5.00 a	4.06 b	2.69 c	1.06 d
Lantana	Lucky Peach Sunrise	5.00 a	4.89 a	4.39 b	4.00 c	3.67 d
Nemesia	Aromatica White	5.00 a	4.33 b	4.00 c	2.00 d	1.17 e
Petunia	Cascadias Pink	5.00 a	5.00 a	5.00 a	3.72 b	2.72 c
Sutera	Candy Floss Blue	5.00 a	4.33 b	2.44 c	1.67 d	0.72 e

^zMean separation in rows by LSD at $P \leq 0.05$. Quality of 5 = best, <3 = not marketable, 0 = death.

petunia all had ratings of more than 3.0 points until after 3 weeks postharvest. Regardless of shipping duration, ‘Lucky Peach Sunrise’ was

marketable throughout the entire evaluation because the foliage remained healthy and green even though plants were without flowers.

Discussion

Postharvest decline symptoms in 21 cultivars of vegetative annuals after

simulated shipping and during shelf life were apparent postship or within 1 to 3 weeks, a reasonable time garden plants would be held in a commercial outlet. During simulated shelf life, cultivars showed postharvest symptoms of low light intensity, reduced fertilization, high temperature, and ethylene gas, as they would in a true retail environment. Lower leaf chlorosis was the most common postharvest decline symptom. Lower leaf chlorosis in shipping boxes and retail environments has been associated with decreased carbohydrates as a result of decreased photosynthesis or a buildup of ethylene gas (Armitage, 1993). The cessation of fertilization and movement of mobile nutrients such as nitrogen to new tissue by the plant also could have contributed to lower leaf chlorosis. Low light and ethylene would play a role in internode elongation, and ethylene would also contribute to flower and bud abortion.

There were few decreases in flower number and quality immediately after shipping, and more decline symptoms occurred as time lapsed in the postharvest environment. Flower abscission directly postship occurred on 'Sun Chimes Coral' diascia and 'Aromatica White' nemesia. Both diascia and nemesia are members of Scrophulariaceae. Plants in that family, such as snapdragon (*Antirrhinum majus*) and spike speedwell (*Veronica spicata*), are ethylene sensitive and they abscise flowers in response to ethylene exposure (Woltering and van Doorn, 1988).

During the postharvest evaluation, 'Dreamtime Copper' bracteantha, 'Superbells Trailing Blue' calibrachoa, 'Aromatica White' nemesia, and 'Candy Floss Blue' sutera were the only cultivars to abscise all flowers (<0.4 flowers) by the end of the first week. By 2 weeks postharvest, four more of the 21 cultivars had abscised all flowers, including 'Sun Chimes Coral' diascia, the two lantana cultivars, and 'Vanilla Sachet' nemesia. Eight more cultivars abscised all flowers by the end of 3 weeks, and five cultivars still had flowers at termination of the experiment. Of these five, four were bracteantha cultivars including 'Florabella White', 'Florabella Gold', 'Dreamtime Cream', and

'Sundaze Golden Yellow', and 'Cascadias Pink' petunia.

After 1 week, 13 cultivars had decreased quality as a result of increased shipping duration of 1 or 2 d versus 0 d, but none were below a marketable quality (<3.0 points). After 2 weeks postharvest, 12 of the 21 cultivars that were shipped 1 or 2 d did not have a high enough quality rating (>3.0 points) to be considered marketable. Two weeks is the amount of time Nell and Hoyer (1995) stated as the minimum amount of time a flowering potted plant should live in an interior environment. These results indicate that plants produced optimum production practices then held inside a retail garden center, need to be sold within the first week of shelf life to have the consumer receive a high-quality plant. After 3 weeks, at least one shipping duration treatment of four cultivars was still judged marketable, including 'Florabella Gold' bracteantha, 'Lucky Lemon Cream' and 'Lucky Peach Sunrise' lantana, and 'Bridal Showers' sutera, albeit three of these cultivars were without flowers and whether they would have consumer acceptance is debatable.

Each species in this study had one or two postharvest decline symptoms common to all cultivars of that species. However, cultivars within species also varied in their postharvest decline symptoms and longevity. 'Comet White' argyranthemum retained flowers 1 week or more than 'Sunlight', although 'Sunlight' was of marketable quality 1 week longer as a result of less leaf chlorosis. 'Florabella White', 'Florabella Gold' and 'Dreamtime Cream' bracteantha opened flowers during shelf life regardless of shipping duration. 'Florabella Gold' was still marketable after 3 weeks, and 'Dreamtime Copper', 'Dreamtime Cream', and 'Florabella White' were marketable after 2 weeks. 'Sundaze Bronze' and 'Sundaze Golden Yellow' were no longer marketable after 1 week. 'Starlette Trailing Purple' calibrachoa retained 23 flowers and marketable quality for 2 weeks, 1 week longer than the other calibrachoa cultivars. 'Lucky Peach Sunrise' lantana, 'Vanilla Sachet' nemesia, 'Cascadias Pink' petunia, and 'Bridal Showers' sutera retained

flowers or were of marketable quality longer than the other cultivar of their species.

To maintain quality, the postharvest environment should be equipped with low light, shaded with 50% to 60% shade material, and have good air circulation (Nelson, 2003). The shading and air movement will help keep the temperature cooler. Experiments with seed-propagated bedding plants produced in flats have shown cool temperatures are the most important environmental factor in increasing shelf life (Armitage, 1993). Exposure to ethylene should be avoided during shipping and in the retail outlet. In addition, to prolong shelf life irrigation should occur at the onset of water stress. Higher quality material would sell more rapidly, and accelerated turnover would help to reduce shelf life problems. Our research is continuing to investigate effectiveness of production practices such as fertilizer toning and 1-methylcyclopropene treatments on prolonging shelf life and preventing flower abscission of vegetative annual garden plants.

Literature cited

- Armitage, A.M. 1993. Bedding plants: Prolonging shelf performance, postproduction care and handling. Ball Publishing, Batavia, IL.
- Cushman, L., H.B. Pemberton, J.C. Miller, and J.W. Kelly. 1998. Interaction of flower stage, cultivar, and shipping temperature and duration affect pot rose performance. *HortScience* 33:736-740.
- Jones, M.L. 2002. Postproduction care and handling. *Ohio Florists' Assn. Bul.* 872:15-16.
- Nell, T.A. and J.E. Barrett. 1986. Growth and incidence of bract necrosis in 'Gutbier V-14 Glory' poinsettias. *J. Amer. Soc. Hort. Sci.* 111:266-269.
- Nell, T.A. and L. Hoyer. 1995. Terminology and conditions for evaluation of flowering potted plant longevity. *Acta Hort.* 405:28-32.
- Nelson, P.V. 2003. Greenhouse operation and management. 6th ed. Simon and Schuster, Upper Saddle River, NJ.
- Woltering, E.J. and W.G. van Doorn. 1988. Role of ethylene in senescence of petals: Morphological and taxonomical relationships. *J. Expt. Bot.* 39:1605-1616.