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Low-temperature Storage of Rooted Chrysanthemum Cuttings: Relationship to Carbohydrate Status of Cultivars

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Abstract. **Low-temperature storage potential of rooted cuttings of garden chrysanthemum [*Dendranthema ×grandiflorum* (Ramat.) Kitamura] cultivars and its relationship with carbohydrate reserves were evaluated. Storage of chrysanthemum cuttings at –1 and –3 °C resulted in freezing damage. Visual quality of rooted cuttings stored at 0 or 3 °C varied among cultivars. Quality of 'Emily' and 'Naomi' cuttings was reduced within a week by dark storage at 0 or 3 °C due to leaf necrosis, while 'Anna' and 'Debonair' cuttings could be held for 4 to 6 weeks without significant quality loss. In 'Anna' and 'Debonair', low-temperature storage reduced the number of days from planting to anthesis regardless of storage duration. However, flowers of plants grown from stored cuttings were smaller than those of nonstored cuttings. At the beginning of storage, 'Emily' and 'Naomi' had lower sucrose, glucose, and fructose (soluble sugars) content compared to 'Anna' and 'Debonair'. Regardless of temperature, leaf soluble sugar was significantly reduced by dark storage for 4 weeks. In stems, sucrose and glucose were reduced while fructose generally increased during low-temperature storage probably due to the breakdown of fructans. Depletion of soluble sugars and a fructan-containing substance during low-temperature dark storage was greater in 'Emily' and 'Naomi' than in 'Anna' and 'Debonair'. Low irradiance [about 10 $\mu mol \cdot m^{-2} \cdot s^{-1}$ photosynthetically active radiation (PAR) from cool-white fluorescent lamps] in storage greatly improved overall quality and delayed the development of leaf necrosis in 'Naomi'. Cuttings stored under light were darker green and had a higher chlorophyll content. Leaf and stem dry weights increased in plants stored under medium and high (25 to 35 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PAR) irradiance while no change in dry weight was observed under dark or low light. Results suggest that the low-temperature storage potential of chrysanthemum cultivars varies considerably, and provision of light is beneficial in delaying the development of leaf necrosis and maintaining quality of cultivars with short storage life at low temperatures.**

Due to the seasonal nature of the horticulture industry, peak demand for transplants fall during narrow market windows. Therefore, plant propagators are often faced with difficulties in meeting the high demand during this narrow window due to space and labor limitations. One alternative to avoid shortages of transplants is to produce cuttings a few weeks early and store them until markets are available.

A successful storage system must minimize growth and development during storage, sustain photosynthetic and regrowth potential while at the same time maintaining visual quality. Traditionally, chemical growth regulators are used extensively in the industry to reduce stem elongation and maintain visual quality of transplants and bedding plants during postproduction stages. However, due to perceived risks to humans and the environment, chemical growth regulators are being increasingly scrutinized. The restrictions on the use of chemical growth regulators on horticultural crops have tremendously increased the interest in the use of nonchemical alternatives.

Low temperature has been widely used for extending the life of harvested horticultural produce, but is rarely used as a means for restricting growth of transplants. In recent years however, low-temperature storage has gained interest as an alternative method to slow the growth of transplants. Numerous bedding plant species have been evaluated for their low-temperature storage potential in the dark, and storage for 3 to 6 weeks at 0 to 12 °C is feasible depending on the species (Lange et al., 1991).

Reduced plant quality and poor field/greenhouse establishment are often problems following low-temperature storage of transplants in dark conditions (Koranski et al., 1989). Unfavorable dark storage environment induces loss of chlorophyll (Conover, 1976), leaf abscission (Curtis and Rodney, 1952), use of carbohydrate reserves (Behrens, 1988; Hansen et al., 1978), and susceptibility to pathogens (van Doesburg, 1962; Smith, 1982). All of these factors can reduce appearance and field establishment of transplants. Paton and Schwabe (1987) reported that low temperature dark storage reduced rooting ability of *Pelargonium* cuttings while pretreatment of cuttings with sucrose or light in storage improved rooting ability. Light as low as 2 $\mu mol \cdot m^{-2} \cdot s^{-1}$ in low-temperature storage has been reported to maintain photosynthetic potential and quality of broccoli (*Brassica oleracea* L.) plantlets in tissue culture (Kubota and Kozai, 1994). These results suggest that maintaining photosynthetic ability and carbohydrate reserves during storage may play significant roles in quality maintenance during storage and subsequent field establishment of transplants. In an effort to develop better storage systems for rooted chrysanthemum cuttings, the objectives of the present study were to evaluate the low-temperature storage potential of rooted garden chrysanthemum cultivars and to investigate the relationship between their storage quality and carbohydrate reserves.

Materials and Methods

Low-temperature limit and storage potential of chrysanthemum cultivars. Unrooted cuttings of ten garden chrysanthemum cultivars ('Adorn', 'Anna', 'Bravo', 'Debonair', 'Emily', 'Naomi', 'Nicole', 'Rubi Mound', Tinkerbell,' and 'Yellow Illusion'; 480

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cuttings per cultivar) were obtained from Yoder Brothers, Inc., Alva, Fla., and shipped to their Pendleton, S.C., facility for rooting in plug trays (160 20-mL plugs per tray; three trays per cultivar) containing peat. At the end of the 3-week rooting period, plugs were transported to Clemson Univ., Clemson, S.C., watered, and held overnight in a glass greenhouse before placing in temperature-controlled storage chambers. One tray of each cultivar was stored at –3, –2, or 0 °C in the dark to determine the low-temperature limit to store rooted cuttings. Relative humidity inside storage chambers was 50% ± 10%. Plugs were examined daily and were subirrigated with tap water as necessary during the experiment. Plant quality was recorded at the end of the 4-week storage period. For quality evaluation, each plug tray was divided into six groups with 25 plugs and the appearance of each group was rated based on the following scale: 1 (very poor quality, severe leaf necrosis, leaf yellowing, not acceptable); 2 (poor quality, large areas of leaf necrosis, leaf yellowing, not acceptable); 3 (fair quality, small areas of leaf necrosis, leaf yellowing, marginal acceptability), 4 (good quality; very little leaf necrosis, no yellowing, acceptable); 5 (excellent quality, no leaf necrosis, no yellowing, acceptable). The experiment was arranged in a split plot design with temperature as whole-plot and cultivar as split-plot factors. Due to freezing damage, the experiment was not repeated at –3 or –2 °C.

Influence of storage temperature and duration on storage quality. Based on the results from the previous experiment, 'Anna', 'Debonair', 'Emily', and 'Naomi' were selected to study the influence of temperature and duration on storage quality. Unrooted cuttings were again obtained from Yoder Brothers, Inc. Two plug trays from each cultivar (54 plugs per tray) were placed in dark storage chambers maintained at 0 or 3 °C. Plugs were covered with a polybag to minimize water loss. Plugs were examined regularly and subirrigated as needed. Plant quality was recorded at weekly intervals for 6 weeks on two groups of 25 plugs in a tray of each cultivar. At the 4-, 5-, and 6-week evaluation periods, 10 plugs were removed from the second tray of each cultivar. Shoots from five cuttings were excised at soil level for fresh and dry weight measurements and carbohydrate analysis.

For carbohydrate analysis, leaves and stems were separated, immediately frozen in liquid nitrogen, and stored at –70 °C until lyophilization. Dry weights were then recorded and leaf and stem tissues were ground in a Wiley mill to pass through 20-mesh screen. Fifty milligrams of ground tissue was extracted with 12 methanol : 5 chloroform : 3 water (MCW; by volume) for soluble sugar analysis as described by Miller and Langhans (1989). Mannitol (1 mg) was added as internal standard. The extract was evaporated to dryness in vacuo at 60 °C, and the residue was dissolved in 2 mL of HPLC grade water. Sucrose, glucose, and fructose were separated and detected using a Waters HPLC system (Waters 600E system controller, 700 WISP autosampler, 410 refractive index detector and 810 baseline workstation, Waters Associates, Milford, Mass.) with a Bio-Rad HPX-87C column maintained at 85 °C. Starch was determined using enzymatic hydrolysis of dried residue following soluble sugar extraction as described by Haissig and Dickson (1979).

The remaining five plugs were planted in 600-cm^3 (11-cm) square plastic pots containing a commercial potting mix (mix 3B; Fafard Inc., Anderson, S.C.), and were grown in a glass greenhouse until flowering. Plants were not pinched. Due to severe necrosis during storage at 0 or 3 °C, poststorage growth of 'Naomi' and 'Emily' was not evaluated. The plants were fertilized with 200 mg N/L from a commercial fertilizer at each watering. The average day and night temperatures during the greenhouse growing period were 28 ± 3 °C and 16 ± 2 °C, respectively. Average photosynthetic photon flux density (PPFD), as measured on a clear day between 1200 and 1300 HR inside the greenhouse, was 950 $\mu mol \cdot m^{-2} \cdot s^{-1}$ and average photoperiod was 10.5 ± 0.5 h during the greenhouse growth period. Days to flower (number of days from placing in greenhouse to first petal opening), number of flowers, number of flower buds, and diameter of terminal flowers (when flowers had four to six layers of petals open) were recorded to follow poststorage recovery. The experiment was arranged in a split plot design with storage temperature as the whole plot and cultivar as the split plot factor. Due to chamber limitations, the experiment was repeated once. Greenhouse growth following storage was not evaluated in the second replication of the experiment.

Influence of irradiance on storage quality. Based on the results from the previous experiment, 'Anna' and 'Naomi' were selected to study the influence of light on storage quality at 3 °C. Rooting of cuttings was similar to that described before (eight trays per cultivar). Two trays (54 plugs per tray) from each cultivar were placed under dark, low, medium or high irradiance (0, 11, 23, or 34 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD, respectively) continuously provided by cool-white fluorescent lamps. Average relative humidity during the experiment was 80%. When placed in polybags, plugs stored in medium or high irradiance reduced CO_2 levels inside the bag to about 2 $\mu mol \cdot L^{-1}$ within 3 to 4 h. Therefore, plants were not covered with polybags in the present experiment. Plants were subirrigated with tap water as needed. Plant quality (average of two groups of 25 plants in one tray), leaf and stem dry weight, and leaf chlorophyll content [on four leaf disks (0.28 cm^2/disk) from the third and fourth fully expanded leaves from the apex as described by Moran (1982) and Moran and Porath (1980)] were measured on 15 plants from the second tray of each cultivar at the beginning (control) and after 28 days of storage. The experiment was repeated. Light treatments were assigned randomly to four chambers in the cold room. Data were analyzed in a split-plot design with light level as the whole plot factor and cultivar as the split factor.

In a separate experiment, head space CO_2 concentration of 'Anna' and 'Naomi' plug trays sealed in polybags and stored in dark, low, medium, or high irradiance at 3 °C was measured. Plug trays were sealed in polybags and head space gas samples (1 mL) were withdrawn 24 h after sealing for CO_2 analysis by gas chromatography [Schimadzu 6A with a thermal conductivity detector and a Porapak R column (2 m long; 100/110 mesh), column and detector temperatures 40 and 100 °C, respectively]. Polybags were flushed with air and sealed again following the gas sampling. The procedure continued for 2 weeks and average head space CO_2 concentration after 24 h of sealing was calculated.

Data, except visual quality, were subjected to analysis of variance using PC version of SAS (SAS Institute, Cary, N.C.). Least square means were computed and difference among means were tested using single degree of freedom contrasts where appropriate. Regression analysis was used to determine the linear and quadratic effects of irradiance in storage.

Results

Low-temperature limit and storage potential of chrysanthemum cultivars. All cuttings stored at –3 or –2 °C were frozen and removed after one day in storage. Within a week of storage at 0 °C, 'Emily' and 'Naomi' cuttings were not marketable (rating of 1; very poor quality) due to severe leaf necrosis. Cuttings of 'Yellow Illusion' were etiolated (rating of 3; fair quality) within 2 weeks of storage. After 4 weeks, 'Tinkerbell' and 'Ruby Mound' had small necrotic areas on the leaves but were of acceptable quality (rating of 3 to 4; fair to good quality, respectively). 'Anna', 'Adorn',

Table 1. Influence of storage temperature and duration on quality of rooted chrysanthemum cuttings.

Temp		Plant quality[z]				
		Time in storage (weeks)				
(°C)	Cultivar	1	2	3	4	6
0	Anna	5	5	5	5	4
	Debonair	5	5	4	4	2
	Emily	3	2	1	1	1
	Naomi	4	3	2	2	1
3	Anna	5	5	5	5	5
	Debonair	5	5	5	5	3
	Emily	3	2	2	1	1
	Naomi	3	2	2	1	1

[z]Plant quality scale: 0 (severely damaged, not acceptable); 1 (very poor quality, not acceptable); 2 (poor quality, not acceptable); 3 (fair quality, marginally acceptable); 4 (good quality, acceptable); 5 (excellent quality, acceptable).

'Debonair', and 'Nicole' maintained acceptable quality (rating of 5; excellent quality) for 4 weeks at 0 °C.

Influence of storage temperature and duration on storage quality. 'Anna' cuttings stored at 3 °C were of excellent marketable quality after 6 weeks of storage (Table 1). However, when stored at 0 °C for 6 weeks, leaves of 'Anna' cuttings had small necrotic spots (1 mm) which resulted in a slight reduction of visual quality. 'Debonair' cuttings stored at 0 or 3 °C were of acceptable quality after 4 weeks of storage but cuttings stored at 0 °C had small necrotic spots on leaves. In contrast to 'Anna', quality of 'Debonair' cuttings was reduced considerably when stored beyond 4 weeks. 'Emily' and 'Naomi' cuttings stored at 0 or 3 °C had large necrotic areas (5 mm) on the leaves after 1 week of storage and were unmarketable.

Storage duration of 4, 5, or 6 weeks (within a temperature) did not significantly influence growth, as measured by flower characteristics of plants subsequently flowered in the greenhouse (data not shown). Therefore, data for 4, 5 and 6 weeks were pooled for presentation in Table 2. Storage temperature did not significantly influence number of flowers, days to flower or average flower diameter in 'Anna' or 'Debonair' (Table 2). The number of flowers produced was not affected by storage at low temperature. However, in both cultivars, number of days to anthesis and average flower diameter were significantly reduced by low-temperature storage. Storage at 0 °C for 4 weeks aborted the terminal bud in 'Anna' cuttings (Fig. 1). As a result, 'Anna' cuttings stored at 0 °C produced more lateral shoots during greenhouse forcing and therefore, had a poor overall inflorescence appearance than cuttings stored at 3 °C.

In stems of all cultivars, an early eluting substance, (unknown) which eluted 7.6 min after injection, was present in relatively large quantities (assuming a similar general detector response as soluble sugars during HPLC) (Table 3). The absence of this early eluting peak and the corresponding large increase in fructose and small increase in glucose in acid hydrolyzed extracts (data not shown) confirmed that the early eluting substance contained a considerable amount of fructan. During storage, the amount of the fructan-containing substance decreased 75% to 95%, depending on cultivar.

Table 2. Effect of dark storage temperature on poststorage growth of 'Anna' and 'Debonair' chrysanthemum. Cuttings were removed after 4, 5, or 6 weeks of dark storage at 0 or 3 °C and grown in a greenhouse until flowering. Data for 4, 5, and 6 weeks at each temperature were pooled because there were no significant differences among storage duration within a temperature.

Cultivar	Temp (°C)	Flowers (no.)	Days to flower	Flower diam[z] (cm)
Anna	Control[y]	23	48	6.9
	0	25	43	4.5
	3	26	41	4.6
Temperature		NS	NS	NS
Control vs. (0, 3)		NS	**	**
Debonair	Control	16	53	4.6
	0	16	41	3.6
	3	15	41	3.6
Temperature		NS	NS	NS
Control vs. (0, 3)		NS	**	**

[z]Average diameter of terminal flowers.
[y]Control plants were not stored; numbers are the mean of 10 plants.
[NS,*,**]Nonsignificant or significant at $P = 0.05$, or 0.01, respectively.

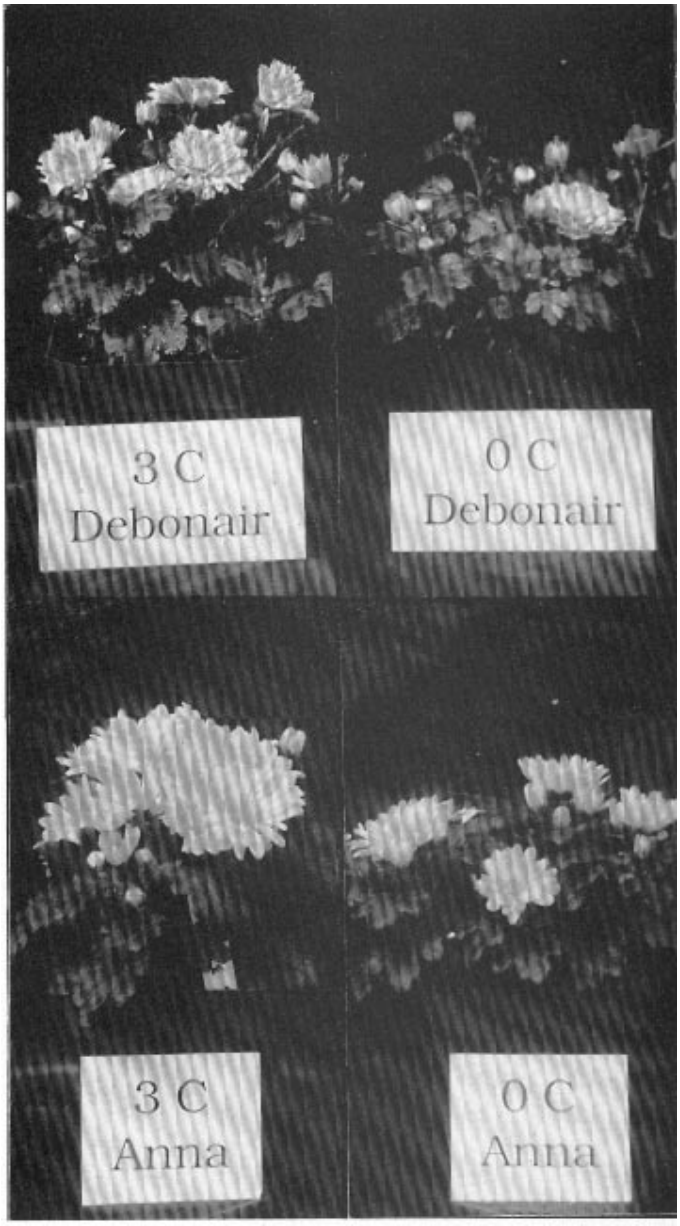

Fig. 1. 'Debonair' and 'Anna' cuttings stored for 4 weeks at 0 or 3 °C.

Table 3. Influence of dark storage temperature on leaf and stem soluble sugar and starch concentration of four chrysanthemum cultivars.

		Carbohydrate ($mg \cdot g^{-1}$)										
	Temp[z]	Sucrose		Glucose		Fructose		TSS[y]		Starch		Unknown
Cultivar	(°C)	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem	Stem
Anna	Control	5.6	27.8	7.0	40.6	11.0	12.6	23.6	81.0	28.5	47.2	136.5
	0	3.0	20.8	1.3	36.5	6.5	40.6	10.8	97.9	27.4	46.9	27.6
	3	4.1	18.2	2.3	28.4	8.1	33.2	14.5	79.8	23.7	47.2	20.5
Debonair	Control	5.2	21.9	3.0	28.8	14.1	20.1	22.3	70.8	39.4	33.1	97.8
	0	1.4	14.8	0.4	29.8	11.8	45.6	13.6	90.2	20.3	17.0	14.6
	3	1.7	13.4	0.0	30.9	10.7	40.5	12.4	84.5	22.3	19.1	24.0
Emily	Control	6.0	21.9	5.3	23.2	10.3	13.1	21.6	58.2	23.0	26.1	69.4
	0	0.2	6.8	0.0	8.8	4.4	18.2	4.6	33.8	23.7	21.7	2.2
	3	0.6	5.5	0.0	5.6	4.3	13.3	4.9	24.4	26.5	27.8	4.5
Naomi	Control	6.2	22.4	2.8	26.0	14.0	20.1	23.0	68.5	31.2	42.0	76.8
	0	1.5	8.2	0.1	13.0	5.0	26.1	6.6	47.3	28.3	34.5	23.2
	3	0.6	5.3	0.0	7.2	4.6	19.7	5.2	32.2	26.7	43.8	11.5
ANOVA												
Cultivar (C)		*	*	***	***	***	*	**	**	**	***	*
Temperature (T)		NS	NS	NS	*	NS	NS	NS	*	NS	NS	NS
T × C		NS	NS	*	*	*	NS	*	*	**	NS	NS
Contrasts[x]: Control vs. (0,3)												
Anna		*	**	***	*	**	*	***	*	NS	NS	***
Debonair		**	**	***	NS	***	*	***	NS	NS	*	***
Emily		***	***	***	**	***	NS	***	*	NS	NS	**
Naomi		***	***	***	**	***	NS	***	*	NS	NS	**

[z]Control represents cuttings before storage and numbers for control are the average of 10 cuttings. Numbers for 0 or 3 °C represents average means for 4, 5, and 6 week analysis. Means were pooled because there were no significant changes among 4-, 5-, or 6-week analysis.
[y]TSS = sucrose + glucose + fructose.
[x]Single degree of freedom contrasts.
[NS,*,**,***]Nonsignificant or significant at $P = 0.05$, 0.01, or 0.001, respectively.

No significant changes in sucrose, glucose, and fructose were found among 4-, 5-, or 6-week storage duration within a temperature (data not shown). Therefore, the data presented in Table 3 are the pooled means for 4-, 5-, and 6-week analysis within a temperature. Before storage (control), stems of 'Anna' cuttings had significantly higher total soluble sugars (TSS = sucrose + glucose + fructose) than 'Debonair', 'Emily' or 'Naomi' stems (Table 3). Initial stem TSS of 'Debonair' and 'Naomi' were not significantly different, but, were higher than that of 'Emily' which had the lowest stem TSS among the cultivars. The initial TSS in leaves did not significantly differ among cultivars (Table 3). Storage at 0 °C significantly increased stem TSS of 'Anna' and 'Debonair' cuttings due to fructose accumulation. Stem TSS of 'Anna' cuttings stored at 3 °C remained relatively unchanged, but that of 'Debonair' increased at 3 °C compared to the control. In 'Emily' and 'Naomi', however, stem TSS decreased during dark storage at 0 or 3 °C, but the decrease was greater at 3 than 0 °C. Leaf TSS of all cultivars decreased during storage regardless of temperature, but the percentage reduction of leaf TSS was greater in 'Naomi' and 'Emily' cuttings than in 'Anna' and 'Debonair' cuttings.

The change of individual sugars during storage was significantly affected by cultivar, but not by storage temperature (Table 3). Leaf sucrose of 'Anna' and 'Debonair' decreased by 36% and 70%, respectively, while in 'Naomi' and 'Emily' leaf sucrose decreased 83% to 93%. Stem sucrose of 'Anna' and 'Debonair' decreased 30% to 36%, while in 'Naomi' and 'Emily' stem sucrose decreased 70% to 72%. During storage, leaf glucose concentration showed the greatest reduction in all cultivars. In 'Emily' and 'Naomi', leaf glucose decreased 100%, while in 'Anna' and 'Debonair' leaf glucose decreased 74% and 93%, respectively. Stem glucose of 'Anna' was significantly reduced by storage at 3 °C but not at 0 °C, while in 'Debonair', stem glucose remained unchanged during storage at 0 or 3 °C. Regardless of the temperature, stem glucose of 'Emily' decreased 69%. In 'Naomi', stem glucose was reduced during storage at 3 or 0 °C, but the reduction was greater at 3 °C than at 0 °C. Leaf fructose decreased 33%, 20%, 58%, and 66%, in 'Anna', 'Debonair', Emily', and 'Naomi', respectively. Stem fructose increased in all cultivars during storage but the increase varied with the temperature. In 'Anna' and 'Debonair' cuttings, stem fructose increased during storage at 0 or 3 °C. In 'Emily' and 'Naomi', storage at 0 °C increased stem fructose by 39% and 30%, while stem fructose levels remained unchanged in cuttings stored at 3 °C. Before storage, 'Debonair' leaves had significantly more starch than other cultivars. Leaf or stem starch was not affected by dark storage except in 'Debonair' cuttings (Table 3).

Influence of irradiance on storage quality. Light provided during low-temperature storage greatly improved overall visual quality and delayed the development of leaf necrosis in 'Naomi' cuttings (Table 4). Only slight leaf necrosis (<10%) was observed in 'Naomi' cuttings stored under low irradiance for 4 weeks. 'Anna' and 'Naomi' cuttings stored in the dark had a pale green appearance compared to control cuttings (data not shown). Chlorophyll a of dark-stored cuttings decreased compared to control, but chlorophyll b increased during dark storage, thus reducing the chlorophyll a:b ratio. Total chlorophyll of control or dark-stored cuttings was not significantly different due to the shift in the chlorophyll a:b ratio during low-temperature storage (Table 4). Regardless of light treatment, stored cuttings had a reduced chlorophyll a:b ratio. Cuttings stored in light had higher chlorophyll than dark-stored cuttings. 'Anna' cuttings stored under high irradiance were pale green compared to low or medium irradiance

Table 4. Influence of irradiance during low temperature storage on visual quality and leaf chlorophyll of 'Anna' and 'Naomi' chrysanthemum cuttings after 4 weeks of storage.

Cultivar	Irradiance[z]	Quality[y]	Necrosis (%)	Chlorophyll concn (μg·cm^{-2}) a	b	a : b
Anna	Control (C)	5	0	24.9	7.5	3.3
	Dark (D)	4	0	23.3	8.9	2.6
	Low (L)	5	0	28.5	10.0	2.9
	Medium (M)	5	0	27.6	9.9	2.8
	High (H)	5	0	24.9	9.4	2.6
Naomi	C	5	0	24.1	6.7	3.6
	D	1	100	21.9	9.9	2.2
	L	4	<10	29.9	11.7	2.6
	M	5	0	29.2	10.9	2.7
	H	5	0	29.1	11.0	2.6
Anna						
C vs. D				NS	*	***
Irradiance						
Linear				**	***	***
Quadratic				***	NS	***
Naomi						
C vs. D				*	***	***
Irradiance						
Linear				***	NS	***
Quadratic				**	NS	***

[z]Control, dark, low, medium, and high represents cuttings before storage or stored 4 weeks in dark, 11, 23, or 34 μmol·m^{-2}·s^{-1}, respectively.
[y]Plant quality scale: 0 (severely damaged, not acceptable); 1 (very poor quality, not acceptable); 2 (poor quality, not acceptable); 3 (fair quality, marginally acceptable); 4 (good quality, acceptable); 5 (excellent quality, acceptable).
NS,*,**,***Nonsignificant or significant at P = 0.05, 0.01, or 0.001, respectively.

plants and contained lower chlorophyll a than low or medium irradiance stored plants.

Dark storage significantly decreased leaf dry weight of 'Naomi' but not of 'Anna' (Table 5). Medium and high irradiance in storage increased leaf and stem dry matter accumulation compared to dark- or low-irradiated cuttings in both cultivars. Low irradiance did not significantly increase dry matter accumulation in 'Anna' or 'Naomi' cuttings.

Headspace CO_2 concentration of 'Anna' and 'Naomi' plug trays covered with polybag and stored in dark increased to 42 ± 2 and 96 ± 7 μmol·L^{-1}, respectively. When polybag covered plug trays were stored in light, head space CO_2 levels were significantly reduced. Head space carbon dioxide concentration of covered 'Anna' plug trays was reduced to 12 ± 1, 2 ± 0.2, and 1.4 ± 0.2 μmol·L^{-1}, respectively under low, medium, and high irradiance levels while that in covered 'Naomi' plug trays reduced to 13 ± 3, 2.5 ± 0.4, and 3 ± 0.8 μmol·L^{-1} under the respective irradiance levels.

Discussion

Our results indicated that the storage of rooted chrysanthemum cuttings below 0 °C was not feasible due to freezing damage. In contrast, Rudnicki et al. (1991) reported that rooted chrysanthemum cuttings could be stored for 3 to 6 weeks at temperatures ranging from –0.5 to –1.6 °C. Cuttings from plants which have developed a greater frost hardiness are more suitable for low-temperature storage (Rudnicki et al., 1991). The contrasting observations may be due to the degree of frost hardiness attained by stock plants when the cuttings were obtained for the present study. Since cuttings for our study were obtained from actively growing stock plants in Florida, they probably had not developed frost hardiness.

Storage potential and optimum storage duration are greatly influenced by the cultivar. Storage at 0 or 3 °C may be used to retard growth and maintain visual quality without adversely affecting regrowth of chrysanthemum cultivars with greater storage life. Three to 4 week storage in the dark at 0 to 3 °C did not significantly affect visual quality or the greenhouse establishment of cultivars with greater storage life but, extended storage up to 5 to 6 weeks could significantly reduce visual quality and regrowth upon removal from storage. Results suggest that storage potential and optimum storage duration should be evaluated for each cultivar before deciding on low-temperature storage.

Carbohydrates are a major source of energy used for life sustaining processes, and therefore, storage potential and poststorage performance of harvested produce are closely related to carbohydrate content of the plant at the time of harvest (McConchie and Lang, 1993; Nell et al., 1990). Initial soluble sugar content and the loss of those compounds during storage showed a clear relationship to storage quality of the cultivars evaluated in this study. Two cultivars with long storage life ('Anna' and 'Debonair') had significantly higher soluble sugars than two cultivars with short storage life ('Emily' and 'Naomi'). The loss of sucrose, glucose, and fructose in leaves and sucrose and glucose in stems during dark storage was greater in cultivars with short storage life than in cultivars with long storage life. Stem fructose increased during storage at 0 °C, but the magnitude of increase was greater in the cultivars with long storage life than the cultivars with short storage life. It is possible that the increase in stem fructose could be due to the breakdown of fructans. Fructans are fructose polymers that are the principal carbohydrate reserve in the stems and leaves of numerous species, many in the Asteraceae. Trusty and Miller (1991) reported that fructans accounted for about 50% of the stem total soluble carbohydrates in 'Favor' chrysanthemum and that fructan concentration decreased consid-

Table 5. Influence of light in low temperature storage on leaf and stem dry weight of 'Anna' and 'Naomi' chrysanthemum cuttings after 4 weeks of storage.

Cultivar	Light level[z]	Dry wt (g) Leaf	Stem
Anna	Control (C)	0.16	0.05
	Dark (D)	0.16	0.05
	Low (L)	0.17	0.06
	Medium (M)	0.20	0.11
	High (H)	0.26	0.09
Naomi	Control (C)	0.24	0.05
	D	0.18	0.04
	L	0.19	0.04
	M	0.21	0.06
	H	0.26	0.07
Anna			
C vs. D		NS	NS
Irradiance			
Linear		***	NS
Quadratic		NS	NS
Naomi			
C vs. D		**	NS
Irradiance			
Linear		**	***
Quadratic		NS	NS

[z]Control, dark, low, medium, and high represents plant before storage or stored 4 weeks in dark, 11, 23, or 34 $\mu mol \cdot m^{-2} \cdot s^{-1}$, respectively.
NS,*,**,***Nonsignificant or significant at $P = 0.05$, 0.01, or 0.001, respectively.

erably during postproduction. They also reported that stem fructose content increased during the early postproduction stages and then remained relatively unchanged.

Accumulation of high levels of CO_2 inside trays covered with polybag and stored in dark indicates that a high respiration rate is a characteristic of cultivars with short storage life. Rapid depletion of soluble sugars during dark storage of 'Naomi' and 'Emily' cuttings also support the contention that these cultivars may have a higher respiration rate than 'Anna' and 'Debonair' cuttings. When stored in the dark, carbohydrates are depleted due to respiration and therefore, could adversely affect survival during storage and regrowth of cuttings upon removal from storage due to lack of energy for life sustaining process.

If loss of carbohydrates during storage results in leaf discoloration and poor quality, provision of light in storage should overcome the reduction of visual quality. Providing light was beneficial for maintaining visual quality and delaying the development of leaf necrosis during low-temperature storage. However, benefits of providing light in storage were far greater for the cultivar with short storage life. Low light during storage maintained chlorophyll. Therefore, plants stored under light had a better appearance than those stored in the dark. Medium to high irradiance during storage maintained photosynthesis, and therefore resulted in increased dry matter accumulation. Paton and Schwabe (1987) reported that pretreatment of *Pelargonium* cuttings with ≤5% sucrose before dark storage resulted in a significant increase in total soluble sugar, and that sucrose pretreatment was beneficial for rooting of dark-stored cuttings. They also reported that rooting potential of sucrose-treated cuttings was comparable to that of cuttings stored under light, suggesting that additional carbohydrates compensated for beneficial effects by light.

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