

Postharvest Handling Techniques for Long-term Storage of Cut Tulip and Dutch Iris

Nathan J. Jahnke¹, Jennifer Kalinowski¹, and John M. Dole¹

ADDITIONAL INDEX WORDS. bulb, fresh weight, *Iris × hollandica*, preservative, pulsing treatment, temperature, *Tulipa* hybrids

SUMMARY. Postharvest handling is a multifaceted stage of the cut flower supply chain intended to maintain or improve the quality of perishable cut flower material. During this stage, cold storage is used to maintain quality and extend availability. Three experiments were conducted over the course of 2 years using cut tulip (*Tulipa* hybrids) and dutch iris (*Iris × hollandica*) cultivars to evaluate the impacts of dry storage with the bulb attached to the stem, sub-zero temperatures, and pre-storage and post-storage floral pulses on vase life. In the first experiment, six tulip and two dutch iris cultivars were stored for up to 6 or 8 weeks, respectively. The longest vase life at 6 weeks of storage was achieved for all tulip cultivars when stems were stored with the bulb still attached at -0.6°C . Storing cut stems at 0.7°C for 6 weeks resulted in the shortest vase life. The vase life of ‘Telstar’ and ‘River King’ dutch iris was longest at 4 and 2 weeks of storage, respectively, when stored at -0.6°C with the bulb attached. Additionally, 75% to 100% of flowers fully opened when stems were stored with the bulb still attached and 42% of flowers were able to at least partially open. In the second experiment, cut stored tulip stems maintained a vase life similar to that of nonstored, pulsed stems at 6 weeks of storage when pulsed with floral solutions containing benzyladenine and gibberellic acid phytohormones for 8 hours before storage. Similarly, dutch iris maintained significantly longer vase life and were able to fully expand flowers more often (60% to 80%) when prepulsed with the floral solutions compared with stems prepulsed with tap water after 6 weeks of storage at -0.6°C . Extending the length of pulsing time from 8 hours to 24 hours was not a significant factor in vase life and post-storage evaluations of flower opening. However, dutch iris flowers with an emerged secondary bud maintained an extended vase life up to 5 days post-storage. In the final experiment, the longest tulip vase life was achieved by combining a sub-zero storage temperature of -0.6°C , storing stems with the bulb attached, and pulsing stems with floral solutions after storage. Vase life did not significantly decrease over the course of the 6-week storage duration. Dutch iris stems pulsed with floral solutions after sub-zero storage with the bulb attached were able to more fully open after 8 weeks of storage compared to stems held dry or pulsed with tap water. These three experiments over the course of 2 growing years demonstrate various strategies for successfully storing cut tulips and dutch iris for an unprecedented duration while still maintaining vase life.

Many plant species grown for cut flowers and foliage have specific postharvest handling guidelines. Implementation of these

guidelines helps to maintain or improve quality throughout the supply chain. Keeping cut stems in cold storage is a reliable method of preserving quality and can range from a matter of hours, days, weeks, or even months. Long-term cold storage of perishable cut material is needed for inventory management and/or season extension or long shipping durations.

Tulip (*Tulipa* hybrids) and dutch iris (*Iris × hollandica*) are popular cut

flower species commonly produced during cool spring seasons. These species have a relatively short storage and vase life (Dole et al., 2017). Forcers can achieve a longer stem length on tulips by uprooting the bulb with the stem instead of cutting at ground level. Dutch iris has a more fibrous root systems, a naturally longer stem length, and is typically cut at ground level. For decades, multiple industry sources and published literature (De Hertogh, 1996) claimed that tulips can be stored for up to 2 to 3 weeks when the bulb is left attached to the stem compared with 5 to 7 d when cut stems are stored dry without water. However, there are little to no data to support these findings. Regarding dutch iris, Mayak and Halevy (1971) reported that stems stored dry as a cut stem had a longer vase life than those stored with only the bulb basal plate still attached.

Dry storage, without stem ends in water, is a common practice used to increase storage duration and decrease the storage volume of cut flowers. However, the vase life and quality of some species, such as ranunculus (*Ranunculus asiaticus*), dahlia (*Dahlia* hybrids), and iceland poppy (*Papaver nudicaule*) (Dole et al., 2009; Natarrella and Kays, 1979), decrease quickly when they are stored dry because of their inability to rehydrate. Successful dry storage is highly influenced by storage duration and temperature. The vase life of ‘Ambiance’ rose (*Rosa*), ‘King Alfred’ and ‘Paperwhite’ daffodil (*Narcissus*), ‘Imperial White’ carnation (*Dianthus caryophyllus*), ‘Telstar’ dutch iris, and tulip were no different when stored dry compared with those stored in water at 0°C for 6 d (Cevallos and Reid, 2001). Failure to rehydrate can be caused by the drying out of vascular tissue and air embolisms (Mayak and Halevy, 1971; van Meeteren et al., 2006), microbial growth in stem ends (van Doorn and Perik, 1990; Zagory and Reid, 1986), and whole plant

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¹Department of Horticultural Science, North Carolina State University, 2721 Founders Drive, Raleigh, NC 27695-7609

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J.M.D. is the corresponding author. E-mail: john_dole@ncsu.edu.

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Units

To convert U.S. to SI,
multiply by

29.5735

7.8125

3.7854

2.54

1

$(^{\circ}\text{F} - 32) \div 1.8$

U.S. unit

fl oz

fl oz/gal

gal

inch(es)

ppm

$^{\circ}\text{F}$

SI unit

mL

$\text{mL}\cdot\text{L}^{-1}$

L

cm

$\text{mg}\cdot\text{L}^{-1}$

$^{\circ}\text{C}$

To convert SI to U.S.,
multiply by

0.0338

0.1280

0.2642

0.3937

1

$(^{\circ}\text{C} \times 1.8) + 32$

desiccation. Recutting stem ends after storage or shipping is a common industry practice to improve water uptake. For example, if not recut, only 16% of dry-stored cut dutch iris buds opened compared with 100% when recut (Mayak and Halevy, 1971).

Cut flowers comprise three temperature classes when cold storage is considered (Goszczynska and Rudnicki, 1982; Halevy and Mayak, 1981). Tropical flowers, such as anthurium (*Anthurium*), orchids (Ochidaceae), and poinsettia (*Euphorbia pulcherrima*), are chilling-sensitive and should be stored between 12 and 18 °C. Sub-tropical flowers, such as protea (Proteaceae), are stored between 2 and 8 °C. Finally a majority of cut flowers, such as rose, carnation, chrysanthemum (*Chrysanthemum*), dutch iris, and tulip, are stored between 0 and 2 °C. A fourth class could be considered based on the results reported by Hardenburg et al., (1986), Nichols and Wallis (1972), and Post and Fischer (1952), who concluded that some species, such as tulip, lily of the valley (*Convallaria*), gardenia (*Gardenia*), sweet pea (*Lathyrus*), and chrysanthemum, are best stored at a sub-zero temperature of -0.5 °C. The industry has not adopted this storage temperature, likely because of the inability to precisely control air temperatures to avoid freezing, lack of knowledge on adaptable species, and the cost of the equipment. Freezing has been shown to occur in tulip petals and bulbs at -1.7 and -3.7 °C, respectively (Hardenburg et al., 1986). The presence of solute particles in the sap allows the plant tissue to avoid freezing at sub-zero temperatures just below 0 °C. Research of these near-freezing temperatures for fruit crop storage is gaining popularity. The storage life of cherries [*Prunus avium* (Zhao et al., 2019)], nectarines [*Prunus persica* (Zhao et al., 2018)], and apricots [*Prunus armeniaca* (Fan et al., 2018)] at temperatures between -1.2 and -3.0 °C exceeded that of fruit stored at temperatures above 0 °C. Lower respiration rates and ethylene production when stored at this “near-freezing” temperature have been reported.

Floral solutions are common products comprising one or a combination of the following: carbohydrates, acidifiers, antimicrobials, and plant growth regulators (Dole et al., 2017). These products can be incorporated in water, and many are used throughout

postharvest handling. Pulse treatments are versatile, short-duration treatments of floral solutions lasting less than 24 h that are used before cooling, storage, or shipping. The vase life of peonies [*Paeonia* (Sang et al., 1998)], statice [*Limonium* (Doi and Reid, 1995)], lisianthus [*Eustoma* (Huang and Chen, 2002)], and gladiolus [*Gladiolus* (Mayak et al., 1973)] have been improved with pulse treatments. Tulips are commonly treated with a pulse combination of gibberellic acid (GA) and benzyladenine (BA), as reported by van Doorn et al. (2011). Formulations combining BA and GA₄₊₇ have been commercialized and are readily available on the market and advertised for use for cut tulips (A. Ranwala, personal communication) and dutch iris (R. Timmerman, personal communication). These formulations have not been tested in conjunction with various storage methods or storage temperatures, however.

The objectives of this study were to evaluate the effects of long-term storage on the vase life durations of tulip and dutch iris cultivars using stems with or without bulbs still attached, sub-zero storage temperatures, and premixed commercial floral pulses before and after storage. Using these data, we demonstrate multiple postharvest handling procedures for both cut tulip and dutch iris to achieve optimized storage and vase life.

Materials and methods

PLANT MATERIAL. Noncooled bulbs of tulip were planted in bulbs crates filled with a peat-based substrate mix (Old Castle Fafard 4P Mix; Sun Gro Horticulture, Agawam, MA). Bulbs were rooted and vernalized through a temperature regime of 8.9 ± 0.5 °C for 8 weeks, 5.0 ± 0.5 °C for 7 weeks, and 0.6 °C for ≈4 weeks. The total duration ranged from 16 to 19 weeks and was dependent on cultivar. Plants were forced under natural daylength from mid-March to early April, and in the next season from late March to late April. Greenhouse temperatures were maintained at 18/15 °C (day/night). Plants were watered daily with nonamended water and with once-weekly 15N-0P-12.5K water-soluble fertilizer (Jack's Professional Calcium Nitrate; JR Peters, Allentown, PA) at 150 ppm. In year 1, tulips were harvested by uprooting the stem with the bulb attached when tepals were 25% to 50% colored.

Dutch iris stems were harvested with the bulb attached in late April by a local grower at the bud stage, when little to no color was showing. The stems were transported within 3 h of harvest to North Carolina State University, Raleigh, in ice water. In year 2, ‘Telstar’ was obtained from the same local grower in mid-March at the same stage of development as that in year 1 without the bulb attached. Stems obtained with the bulb attached were slightly premature in bud emergence, with no visible color showing. Stems were transported within 3 h of harvest to North Carolina State University, Raleigh, while held dry in 5-gal buckets. Additional cut ‘Telstar’ stems were obtained from a wholesale florist in early May of the same year for the pre-storage pulses experiment. In both years, stems were stored at 4 °C for 12 h before processing for each experiment.

STEMS STORED WITH BULB-ATTACHED VS. REMOVED. Treatments consisted of two storage temperatures, two storage methods, and two storage durations, resulting in a 2 × 2 × 2 factorial arrangement. A total of nine groups of 5 to 10 stems of each cultivar were made: Black Parrot, Foxy Foxtrot, Golden Oxford, Lingerie, Menton, Renown, Telstar, and River King. One group was used as a nonstored control (duration = 0) and directly taken to postharvest evaluation. Half of the remaining eight groups were left with the bulb attached and half were cut to remove the bulb. Tulips were cut 30 to 40 cm depending on the cultivar, and all dutch iris were cut to 45 cm when measuring from the petal or sheath tip to the stem end. Groups were wrapped in newspaper and placed in cardboard boxes lined with polyvinyl wrap. One box of each cultivar with the bulb attached and one box of each cultivar with cut stems were held dry at -0.6 °C, and one box of each cultivar with the bulb attached and one box of each cultivar with cut stems were held dry at 0.7 °C. Relative humidity (RH) was maintained between 80% and 90%. One bulb-attached group and one cut group per cultivar were removed from each temperature after 3 and 6 weeks of storage.

In year 2, treatments consisted of two storage temperatures, two storage methods, and three storage durations, resulting in a 2 × 2 × 3 factorial arrangement. A total of 13 groups of 10 stems

comprised ‘Telstar’. One group was used as a nonstored control (duration = 0) and directly taken to undergo postharvest evaluation. Half of the remaining 12 groups had the bulb attached and half were cut. Dutch iris were cut to 22.5 cm when measuring from the petal or sheath tip to the stem end. Groups were wrapped in newspaper and placed in cardboard boxes lined with polyvinyl wrap to reduce water loss. One box of each bulb-attached group and one box of each cut stems group were held dry at -0.6°C , and one box of each bulb-attached group and one box of each cut stems group were held dry at 0.7°C . RH was maintained between 80% and 90%. One bulb-attached group and one cut group were removed from each temperature after 2, 4, and 8 weeks of storage.

PRE-STORAGE PULSES. Stems of ‘Golden Oxford’, ‘Menton’, ‘Piste’, and ‘River King’ were used to determine the effect of pre-storage pulses on stored cut stems. Stems of each cultivar were cut to a set length of either 35 or 45 cm before sorting stems into nine groups of up to 10 stems. Groups were placed into treatments arranged in a 3×3 factorial consisting of three pre-storage pulses and three storage durations. Groups were pulsed by placing stem ends into one of three pulse solutions: tap water, $2 \text{ mL}\cdot\text{L}^{-1}$ Bulb 100 (Floralife, Walterboro, SC), or $2 \text{ mL}\cdot\text{L}^{-1}$ BVB (Chrysal Americas, Doral, FL) for 8 h at 4°C . Groups were wrapped in newspaper and held at -0.6°C in cardboard boxes lined with polyvinyl wrap. RH was maintained at 80% to 90%. One group of each cultivar and one box of each pulse treatment were removed from storage at 3 and 6 weeks. Nonstored groups of each pulse treatment were moved directly into postharvest evaluation area (duration = 0).

In year 2, stems of ‘Telstar’ were used to determine the effect of pre-storage pulses on stored cut stems. Stems of each cultivar were cut to a set length of 31.5 cm before sorting stems into 24 groups of 10 stems. Groups were placed into treatments arranged in a $2 \times 3 \times 4$ factorial consisting of two pulsing times, three pre-storage pulses, and four storage durations. Groups were pulsed for either 8 or 24 h and then stored in the same manner as that in year 1. One group

from each pulse time and pulse treatment was removed from storage at 2, 4, and 8 weeks. A nonstored group of each pulse treatment were moved directly into postharvest evaluation (duration = 0).

POST-STORAGE PULSES. Stems of ‘Menton’ with the bulb still attached were sorted into 16 groups of 10 stems and assigned to treatments. Treatments consisted of four storage durations and four post-storage pulses arranged as a 4×4 factorial. Groups of bulb-attached stems were wrapped in newspaper and each cultivar was held at -0.6°C in separate cardboard boxes. Four groups of each cultivar were removed from storage at 3, 6, and 9 weeks. After storage, stems were cut to 35 cm. One group was held dry and the other three groups were pulsed with tap water, $2 \text{ mL}\cdot\text{L}^{-1}$ BVB, or $2 \text{ mL}\cdot\text{L}^{-1}$ Bulb 100 for 8 h at 4°C . A nonstored group of each pulse treatment including the dry control were moved directly into postharvest evaluation area (duration = 0).

In year 2, stems of ‘Telstar’ with the bulb still attached were sorted into 32 groups of 10 stems and assigned to treatments. Treatments consisted of two pulsing times, four post-storage pulses, and four storage durations and arranged as a $2 \times 4 \times 4$ factorial. Groups of bulb-attached stems were wrapped in newspaper and held at -0.6°C in separate cardboard boxes. Four groups of each cultivar were removed from storage at 2, 4, and 8 weeks. After storage, stems were cut to 22.5 cm. One group was held dry and the other three groups were pulsed with tap water, $2 \text{ mL}\cdot\text{L}^{-1}$ BVB, or $2 \text{ mL}\cdot\text{L}^{-1}$ Bulb 100 for either 8 or 24 h at 4°C . A nonstored group of each pulse treatment were moved directly into postharvest evaluation area (duration = 0).

PULSE CHEMICALS. Both commercial products contain GA_{4+7} and BA. Products were mixed according to the manufacturer’s instructions at a rate of $2 \text{ mL}\cdot\text{L}^{-1}$ in 2.5-gal containers. Each container had 1 L of solution per 25 stems. Stems were pulsed for 8 h in year 1 and for 8 or 24 h in year 2 at 4°C with an average RH of 86%.

POST-STORAGE EVALUATION. Stems were recut, thus removing 2.5 cm from the stem end before evaluation. The stem length after recutting

ranged from 32.5 to 38.5 cm for tulip and 20 to 42.5 cm for dutch iris, depending on the length of available stems each year. Stems were individually placed in separate vases filled with 400 mL of tap water. The evaluation environment was maintained at $20 \pm 2^{\circ}\text{C}$ with 40% to 60% RH and a 12-h photoperiod at $15 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$.

Tulip vase life, the number of days a flower remained presentable in tap water, was calculated as the number of days until tepals senesced. Tepal senescence was characterized when more than 50% of tepals were slightly wilted or translucent or when any tepals abscised. Dutch iris vase life was calculated as the number of days until banners or tepals abscised, when more than 50% in-rolled, or when more than 50% were discolored. The dutch iris flower opening (Fig. 1) was rated as failed to open, partially open, or fully open. The tulip stem length gained during evaluation was calculated as the length at termination minus the initial length measured from the cut end to the tepal tip. The percent fresh weight (FW) loss after storage and recovered pulsing was determined using at least five stems of each cultivar. Experiments performed in year 2 also evaluated the contribution of a secondary bud (Fig. 1) to extended the vase life of dutch iris. An extended vase life was only considered if the secondary bud emerged before initial flower termination. The extended vase life was considered separately from all other vase life calculations, and only secondary buds that were able to fully expand were evaluated.

EXPERIMENTAL DESIGN AND STATISTICS. A completely randomized design was used for each experiment in year 1 and for the pre-storage pulses experiment in year 2. Alternatively, bulb-attached and post-storage pulse experiments in year 2 were arranged as a randomized block design. Data from each cultivar and year were analyzed and subjected to an analysis of variance separately using the Generalized Linear Models procedure and statistical software (SAS version 9.4; SAS Institute, Cary, NC). Post hoc tests were implemented using Tukey’s honestly significant difference test with $P \leq 0.05$ for significant interactions and main effects. The reported values are the least squared means to account for missing samples, such as flowers that failed to rehydrate after

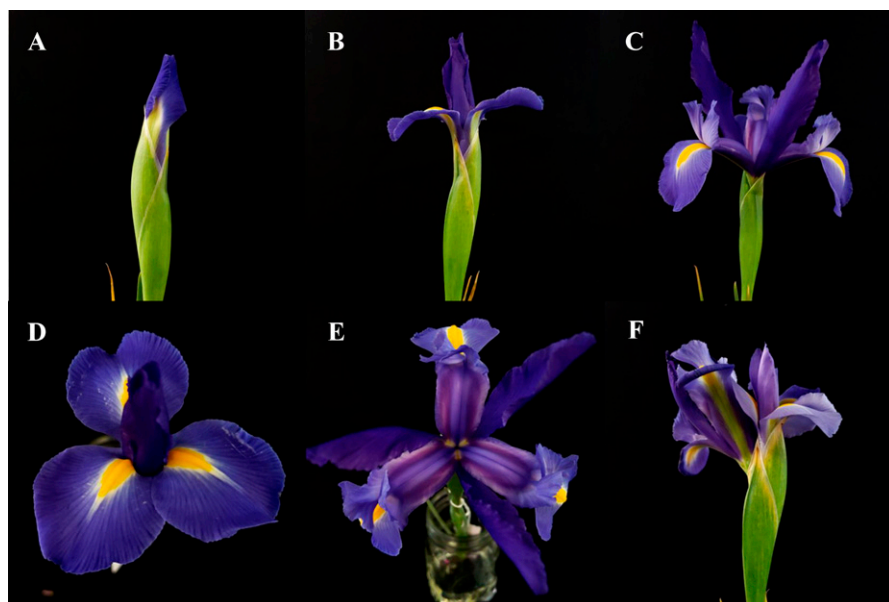


Fig. 1. Image reference for dutch iris stages of flowering opening: bud emergence (A); partially open flower (B); fully expanded flower (C); aerial view of partially open flower (D); aerial view of fully expanded flower (E); and secondary bud emergence adjacent to the primary expanded flower (F).

storage or flowers that failed to open, which were not used for vase life calculations.

Results

BULB-ATTACHED VS. REMOVED: TULIP. Vase life durations of nonstored ‘Black Parrot’, ‘Foxy Foxtrot’, ‘Golden Oxford’, ‘Lingerie’, ‘Menton’, and ‘Renown’ tulip were 7.6, 8.1, 5.9, 7.9,

7.5, and 6.4 d, respectively. The vase life of all stored stems, independent of the storage method and temperature, was significantly shorter than that of the nonstored stems, with the exception of ‘Black Parrot’, after 3 weeks of storage (data not shown). Among stored stems, the main effects were significant for most cultivars, and the significant three-way interaction was ignored for Foxy Foxtrot and Golden

Oxford to simplify interpretation of the results. Vase life was significantly shorter for stems stored for 6 weeks compared to those stored for 3 weeks and for those stored at 0.7°C compared with those stored at –0.6°C; all but two cultivars had a significantly longer vase life when stored with the bulb attached compared with being stored as a cut stem (Fig. 2). On average, the vase life was 1.4 d longer at 3 weeks and 0.6 d longer when stored with the bulb or at –0.6°C.

The percent FW lost during storage was between 9% and 25% for all tulip cultivars. Weight lost was significantly higher when stems were stored for 6 weeks compared with 3 weeks, and when stored with the bulb attached compared with without the bulb (cut) (Table 1), with the exception of ‘Menton’.

Cut tulip stems continue elongation after harvest, specifically in the last internode between the flower and uppermost leaf (Table 2). The stem length gained was significantly ($P \leq 0.017$) influenced by the storage duration for cultivars Foxy Foxtrot, Golden Oxford, and Menton; stems stored for longer exhibited less stem elongation. The storage method was only significant ($P = 0.04$) for ‘Lingerie’; cut stored stems experienced more stem length gain (15.7 cm) than stems stored with the bulb attached (14.5 cm). Storage at –0.6°C significantly

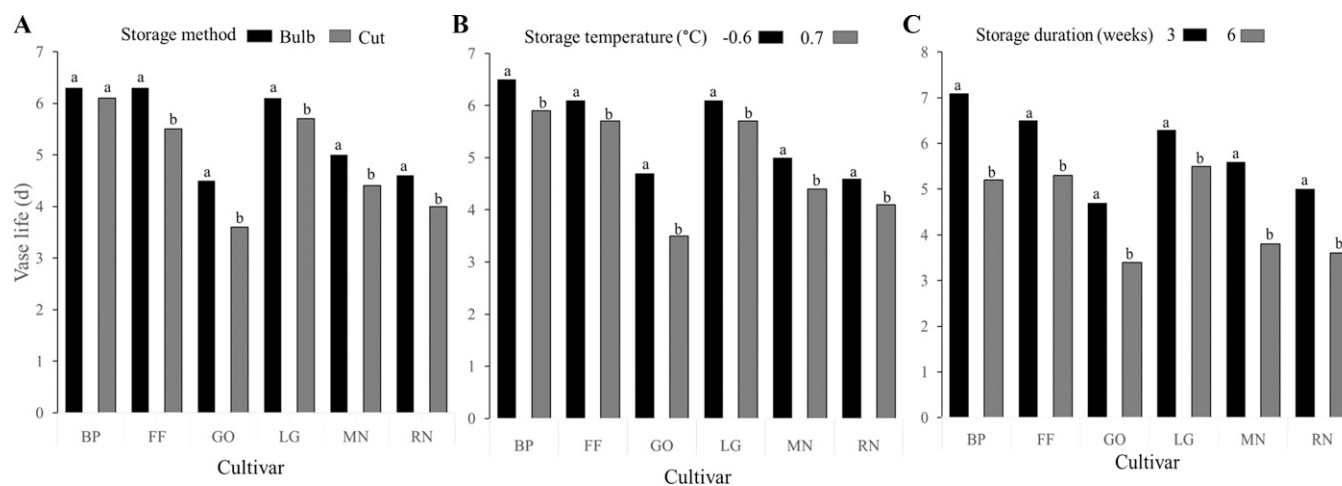


Fig. 2. Vase life of ‘Black Parrot’ (BP), ‘Foxy Foxtrot’ (FF), ‘Golden Oxford’ (GO), ‘Lingerie’ (LG), ‘Menton’ (MN), and ‘Renown’ (RN) tulip flowers as affected by significant main effects of the storage method (A), storage temperature (B), and storage duration (3 or 6 weeks) (C). Treatment analyses were separated by cultivar because of the significant differences among cultivars. The same lowercase letters within each cultivar are not significantly different according to Tukey’s honestly significant difference test at $P \leq 0.05$. Vase life was determined by the number of days from placing stems in vases containing 400 mL (13.53 fl oz) of tap water in the evaluation room until termination. Storage methods consisted of stems with the bulb attached (Bulb) or with the bulb removed (Cut). The storage temperature was held at 0.7°C (33.26 °F) or –0.6°C (30.92 °F). Stored stems were held dry, wrapped in newspaper, and placed in cardboard boxes lined with polyvinyl wrap.

Table 1. Stem fresh weight (FW) loss after storage with the significant main effects of storage duration and storage method for ‘Black Parrot’ (BP), ‘Foxy Foxtrot’ (FF), ‘Golden Oxford’ (GO), ‘Lingerie’ (LG), Menton’ (MN), and ‘Renown’ (RN) tulip.

Storage treatment	Stem FW loss (%) ^z					
	BP	FF	GO	LG	MN	RN
Duration (weeks)						
3	13	8	11	19	14	10
6	20	12	16	13	25	16
<i>P</i> value ^y	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Storage method ^x						
Bulb	18	11	13	13	20	15
Cut	14	19	13	19	18	11
<i>P</i> value	<0.007	<0.001	NS	<0.001	NS	<0.001

^zFW loss = [(pre-storage FW – post-storage FW)/pre-storage FW] × 100%.

^y*P* ≤ 0.05 indicates a significant difference between the least squared means using mean separation adjusted with Tukey’s honestly significant difference test within each cultivar and treatment; NS = not significant.

^xStorage method included stems stored with the bulb still attached (bulb) and stems without the bulb (cut).

(*P* ≤ 0.043) increased the stem length gained for both ‘Golden Oxford’ and ‘Menton’ when compared with storage at 0.7 °C.

BULB VS. CUT STORAGE: DUTCH IRIS. Nonstored stems of ‘River King’ and ‘Telstar’ dutch iris had vase life durations of 6.8 d and 6.7 d, respectively, in year 1. Vase life did not significantly decline as storage duration increased and was unaffected by storage temperature (data not presented). On average, ‘River King’ had a significantly longer vase life (*P* < 0.05) when stored with the bulb attached (6.0 d) compared with storage as a cut stem (5.4 d).

If buds were able to partially open, then flowers of both cultivars

were fully open for approximately half of their vase life. Nonstored stems fully opened more than 90% of time. On average, ‘River King’ stored with the bulb attached fully opened 81% of the time compared with 25% of the time for cut stems. No trend was seen for ‘Telstar’, with 50% to 60% of buds fully opening when stored. The percent FW change of ‘Telstar’ dutch iris significantly increased from 9% to 15% when stored for 6 weeks compared with 3 weeks.

In year 2, nonstored stems of ‘Telstar’ dutch iris had an average vase life of 3.4 d. Vase life did not significantly decrease until after 8 weeks of storage (0.9 d) and was unaffected by storage temperature (Fig. 3). Stems

stored with the bulb attached in above-freezing temperatures (0.7 °C) maintained a vase life after 8 weeks of storage similar to that of nonstored controls (Fig. 3B). Stems stored in below-freezing temperatures (–0.6 °C) had significantly fewer flowers fail to partially open (32%) compared with stems stored at temperatures just above freezing (45%). No significant difference in the ability of flowers to partially open based on the storage method was observed. However, of the flowers able to partially open, 15% more flowers were able to fully expand when stored as a cut stem than when they were stored with the bulb attached. Conversely, the average vase life was significantly longer (*P* ≤ 0.001) by 0.4 d for

Table 2. Significant main effects of storage duration, method, and temperature on stem length gained post-storage for ‘Black Parrot’ (BP), ‘Foxy Foxtrot’ (FF), ‘Golden Oxford’ (GO), ‘Lingerie’ (LG), Menton’ (MN), and ‘Renown’ (RN) tulip.

Storage treatment	Stem length gained (cm) ^z					
	BP	FF	GO	LG	MN	RN
Duration (weeks)						
3	8.8	7.8	11.8	15.5	8.3	8.0
6	8.5	6.8	9.9	14.7	6.7	8.1
<i>P</i> value ^y	NS	0.017	<0.001	NS	0.012	NS
Storage method ^x						
Bulb	9.0	7.4	11.1	14.5	8.0	7.8
Cut	8.4	7.1	10.6	15.7	7.0	8.3
<i>P</i> value	NS	NS	NS	0.036	NS	NS
Temperature						
0.7 °C (33.26 °F)	8.2	6.9	9.7	14.6	6.9	8.2
–0.6 °C (30.92 °F)	9.2	7.6	12.0	15.5	8.2	7.9
<i>P</i> value	NS	NS	<0.001	NS	0.043	NS

^zStem length gained was calculated as the length at termination minus the initial length measured from the cut end to the tepal tip; 1 cm = 0.3937 inch.

^y*P* ≤ 0.05 indicates a significant difference between the least squared means using mean separation adjusted with Tukey’s honestly significant difference test within each cultivar and treatment; NS = not significant.

^xStorage method included stems stored with the bulb still attached (bulb) and stems without the bulb (cut).

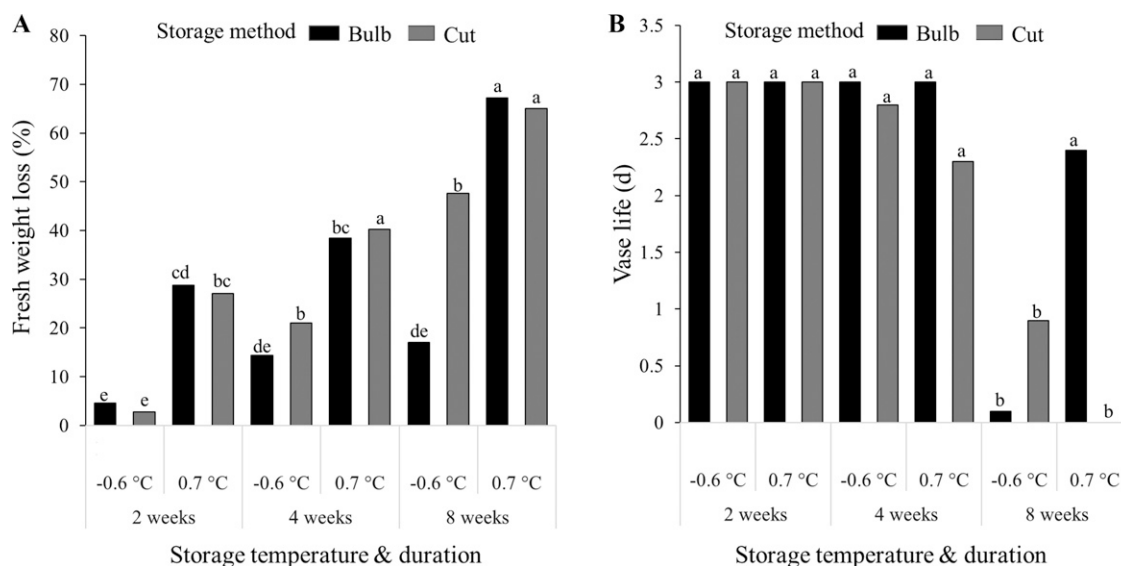


Fig. 3. Fresh weight (FW) loss of ‘Telstar’ dutch iris stems as affected by the significant interaction of the storage method, storage temperature, and storage duration (2, 4, or 8 weeks) (A). Vase life of ‘Telstar’ dutch iris as affected by the significant interaction of the storage method, storage temperature, and storage duration (B). Treatment analyses were separated by storage method. Means with the same lowercase letters are not significantly different according to Tukey’s honestly significant difference test at $P \leq 0.05$. FW loss = [(pre-storage FW – post-storage FW)/pre-storage FW] \times 100%. Vase life was determined by the number of days from placing stems in vases containing 400 mL (13.53 fl oz) of tap water in the evaluation room until termination. Storage methods consisted of stems with the bulb attached (Bulb) or bulb removed (Cut). The storage temperature was held at 0.7 °C (33.26 °F) or –0.6 °C (30.92 °F). Stored stems were held dry, wrapped in newspaper, and placed in cardboard boxes lined with polyvinyl wrap.

stems stored with the bulb attached than for stems stored cut.

The percent FW change of ‘Telstar’ dutch iris significantly increased as the storage duration increased from 2 weeks (15%) to 4 weeks (29%) to 8 weeks (49%). There were no significant differences among storage methods at above-freezing temperatures or among durations at below-freezing temperatures. Conversely, there were significant interactions among storage duration, storage method, and storage temperature (Fig. 3A). Stems stored at above-freezing temperatures experienced greater FW loss across all storage durations than stems maintained at below-freezing temperatures for the same duration. There were substantial increases in FW loss after 8 weeks of storage at above-freezing temperatures for both bulb-attached stems (67%) and cut stems (65%) compared with those after 4 weeks of storage (38% and 40%, respectively). Cut stems stored for 8 weeks incurred the highest FW loss when stored at temperatures just below freezing (48%); this loss was significantly higher than that of bulb-attached stems stored under similar conditions (17%).

PRE-STORAGE PULSES: TULIP AND DUTCH IRIS. The main effects (storage duration and pre-storage pulses) significantly impacted the vase life

durations of stored cut stems of ‘Menton’ and ‘Piste’ tulip and ‘River King’ dutch iris independent of each other. Vase life significantly decreased for ‘Menton’ ($P \leq 0.0001$) from 7.0 d for nonstored stems to 5.6 d when stems were stored for 3 weeks at –0.6 °C, but not when stems were stored for 6 weeks (4.9 d). ‘Piste’ vase life significantly ($P \leq 0.0001$) decreased at each storage duration from 6.3 to 5.1 d and finally to 4.4 d at 6 weeks of storage. Stems pulsed with floral solutions had a significantly longer vase life than tap water-pulsed stems. Vase life was, on average, 1.4 and 2.0 d longer for ‘Menton’ ($P \leq 0.001$) and ‘Piste’ ($P \leq 0.001$), respectively. Similarly, vase life was significantly shorter at 2 weeks of storage (7.0 d) compared with nonstored stems (7.5 d) of ‘River King’ dutch iris, and vase life was significantly longer (+1.1 d) when pulsed with floral solutions compared with tap water-pulsed stems (6.5 d). Although a significant interaction was found for treatment effects on the vase life of ‘Golden Oxford’ (Table 3), the vase life was longer for floral solution-pulsed stems when stored for 3 or 6 weeks at –0.6 °C.

Stem length gained was not generally impacted by storage duration among

cultivars; however, it was significantly higher for both Golden Oxford ($P < 0.003$) and Piste ($P = 0.001$) when pulsed with either floral solution compared with tap water (10.1 and 8.0 cm, respectively). ‘Golden Oxford’ pulsed with either floral solution gained, on average, 1.5 to 2.2 cm in length and ‘Piste’ gained 0.9 to 1.5 cm in length compared with water-pulsed stems. No treatment significantly affected stem length gained by ‘Menton’, with an average stem elongation of 11.5 cm throughout the post-storage evaluation.

In year 2, for dutch iris, there was no significant difference in the pulsing time of 8 h compared to that of 24 h. The interaction of main effects (storage duration and pulsing type) significantly impacted the vase life of stored cut stems of ‘Telstar’ dutch iris (Fig. 4). BVB-pulsed stems had a significantly longer ($P < 0.038$) vase life than tap water-pulsed stems after 2 weeks storage (4.7 d compared to 3.9 d, respectively). Vase life was significantly longer for Bulb 100-pulsed stems (4.5 d) than tap water-pulsed stems (3.6 d) after 4 weeks of storage ($P \leq 0.007$). There was no significant difference among treatments after 8 weeks of storage.

There was no significant effect of duration on the ability of flowers to

Table 3. Vase life of ‘Golden Oxford’ tulip as affected by significant ($P < 0.05$) two-way interaction between pre-storage pulse treatment and storage duration at -0.6°C (30.92°F) when stored as cut stems and held dry.^z

Pre-storage pulse ^y	Storage duration (weeks)		
	0	3	6
Tap water	6.2	4.6	3.9
Bulb 100 ^w	6.6	5.5*	5.6*
BVB ^v	6.6	5.3	5.6*

^zHeld dry indicates that stems were wrapped in newspaper in groups of 10 stems and held in cardboard boxes lined with polyvinyl wrap during the designated storage duration.

^yPre-storage pulses were applied by placing cut ends of stems in pulse solutions of tap water or commercial floral solutions containing benzyladenine and gibberellic acid mixed according to the manufacturer’s instructions with tap water at a rate of $2\text{ mL}\cdot\text{L}^{-1}$ (0.26 fl oz/gal) for 8 h at 4°C (39.2°F) before storage duration.

^xDays from placing stems in vases containing 400 mL (13.53 fl oz) of tap water in the evaluation room until termination.

^wBulb 100 (Floralife, Walterboro, SC) commercial floral solution.

^vBVB (Chrysal Americas, Doral, FL) commercial floral solution.

*Least squared means are significantly different from the tap water control within each column when adjusted with Tukey’s honestly significant difference test with $P \leq 0.05$.

fully open after 2 and 4 weeks of storage. Conversely, the pulsing type significantly ($P < 0.001$) effected the ability of flowers to fully expand (data not presented). Stems pretreated with BVB before a storage duration of 2 weeks were able to fully expand 90% of the time as opposed to stems pulsed with tap water, which were only able to fully expand at a rate of 32%. Stems pulsed

with floral solution were able to fully expand flowers significantly more often (60% to 80% of the time); however, no flowers were able to fully open when stems were treated with tap water after 4 weeks of storage.

A secondary bud analysis showed an increase in vase life for all stems with a fully emerged secondary flower up to an additional 5 d (Table 4).

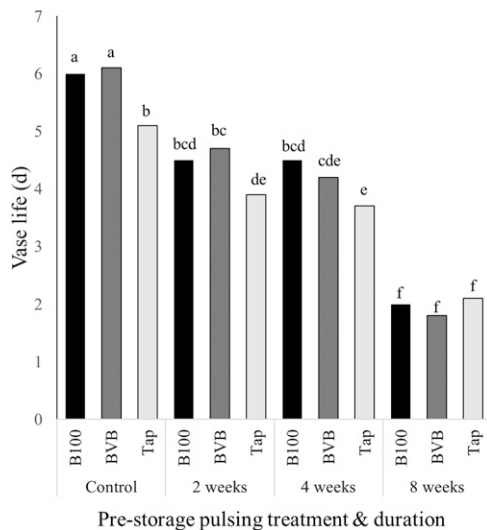


Fig. 4. Vase life of ‘Telstar’ dutch iris as affected by the significant interaction of the pre-storage pulsing treatment and storage duration. Treatment analyses were separated by pulsing type. Means with the same lowercase letters are not significantly different according to Tukey’s honestly significant difference test at $P \leq 0.05$. Vase life was determined by the number of days from placing stems in vases containing 400 mL (13.53 fl oz) of tap water in the evaluation room until termination. Pre-storage pulses were applied by placing cut ends of stems into pulse solutions of tap water (Tap) or commercial floral solutions B100 (Bulb 100; Floralife, Walterboro, SC) or BVB (Chrysal Americas, Doral, FL) containing benzyladenine and gibberellic acid mixed according to the manufacturer’s instructions with tap water at a rate of $2\text{ mL}\cdot\text{L}^{-1}$ (0.26 fl oz/gal) for 8 h at 4°C (39.2°F). Stored stems were held dry, wrapped in newspaper, and placed in cardboard boxes lined with polyvinyl wrap.

After a 2-week storage period, the increase in vase life was significantly higher for stems pulsed with BVB (2.2 d) compared with the increase in the vase life of stems pulsed with tap water (1.3 d). Similarly, a significant difference in the added vase life was observed after 4 weeks of storage for Bulb 100-pulsed stems (2.1 d) and tap water-pulsed stems (1.3 d).

POST-STORAGE PULSES: TULIP. The vase life of ‘Menton’ tulip was significantly higher when pulsed with commercial floral solutions compared with the nontreated control and stems pulsed with tap water until 9 weeks of storage, when the vase life of BVB-pulsed stems (5.9 d) was no different from that of tap water-pulsed stems (4.2 d) (Table 5). There was no significant decrease in the vase life of Bulb 100-pulsed stems, but the vase life of BVB-pulsed stems was significantly lower at 9 weeks. However, this value was similar for stems stored for 9 weeks and pulsed with Bulb 100. The vase life of tap water-pulsed stems was statistically similar to that of the nontreated control throughout the storage duration. Over the course of 9 weeks of storage, nontreated stems lost 4.8 d of vase life compared with 1.7 d of vase life when Bulb 100 was used after storage.

The percent FW lost after storage increased significantly as the storage duration increased, but the percent FW gained after 8-h pulses also significantly increased as the storage duration increased (Fig. 5). The 8-h pulse treatments did not replace all of the FW lost after storage, leaving stems with deficits of 3%, 4%, and 8% after 3, 6, and 9 weeks of storage, respectively. There was no difference in the percent FW lost or gained among tap water and commercial floral solutions.

Compared with nonstored stems (11.6 cm), the stem length gained was significantly ($P = 0.014$) less after 6 and 9 weeks of storage (9.8 and 9.1 cm, respectively). Compared with the control and tap water stems, floral solution-pulsed stems were significantly ($P \leq 0.001$) longer by 3.4 cm. Independent of the storage duration, stems pulsed with floral solutions gained significantly more length ($P \leq 0.001$) compared with tap water-pulsed stems or the nontreated control. On average, the length gained was 2.8 cm more for floral solution-pulsed stems.

Table 4. Extended vase life of ‘Telstar’ dutch iris when considered by a fully emerged secondary bud with significant ($P < 0.05$) two-way interaction between pre-storage pulse treatment and storage duration at -0.6°C (30.9°F) when stored as cut stems and held dry.^z

Pre-storage pulse ^y	Storage duration (weeks)		
	0	2	4
	Secondary bud vase life (d) ^x		
Tap water	6.1	4.8	3.9
Bulb 100 ^w	7.3	6.1	5.8*
BVB ^v	7.0	6.9*	6.3*

^zHeld dry indicates that stems were wrapped in newspaper in groups of 10 stems and held in cardboard boxes lined with polyvinyl wrap during the designated storage duration.

^yPre-storage pulses were applied by placing cut ends of stems into pulse solutions of tap water or commercial floral solutions containing benzyladenine and gibberellic acid mixed according to the manufacturer’s instructions with tap water at a rate of $2\text{ mL}\cdot\text{L}^{-1}$ (0.26 fl oz/gal) for 8 h at 4°C (39.2°F) before storage duration.

^zDays from placing stems in vases containing 400 mL (13.53 fl oz) of tap water in the evaluation room until termination of the secondary bud/flower.

^wBulb 100 (Floralife, Walterboro, SC) commercial floral solution.

^vBVB (Chrysal Americas, Doral, FL) commercial floral solution.

*Least squared means are significantly different from the tap water control within each column when adjusted with Tukey’s honestly significant difference test with $P \leq 0.05$.

POST-STORAGE PULSES: DUTCH IRIS. The post-storage pulsing duration did not have a significant effect on any variables. The inability of flowers to fully expand was 100% after 8 weeks of storage for all pulsing treatments. Stems pulsed with floral solution had a significantly ($P < 0.001$) better ability to fully expand (35%), whereas non-pulsed dry stems were only able to fully expand flowers 18% of the time. Dry controls and tap water-pulsed stems were not able to partially open 85% to 100% of the time after 8 weeks of storage (Fig. 6).

Vase life was significantly higher when pulsed with BVB (3.6 d) or Bulb 100 (3.5 d) compared with control

stems (3.1 d) held dry post-storage. Stems pulsed with tap water showed no significant difference in vase life among the different treatments. Stems stored for 4 weeks had a similar vase life (3.5 d) as the nonstored controls (3.6 d); however, stems stored for 2 weeks displayed a significantly ($P < 0.001$) shorter vase life of 3.1 d. Stems pulsed with Bulb 100 had a significantly higher vase life after 4 weeks of storage (3.5 d) than stems pulsed with BVB or dry controls (3.1 d) after 2 weeks of storage (Fig. 6). However, this value was not significantly different among treatment groups stored for 4 weeks and pulsed with either BVB or tap water or held dry. The vase life of tap water-pulsed stems

was statistically similar to that of the nontreated dry control throughout all storage durations.

Discussion

VASE LIFE: TULIP. Storing tulip with the bulb attached resulted in the longest vase life at the longest storage duration without the use of a commercial floral solution. These results validate decades of use and claims by the industry and in the literature (De Hertogh, 1996), which lacked supporting data. Retaining bulbs may allow for the translocation of carbohydrates, water, and nutrients, which would have been used to complete flowering and daughter bulb formation (De Hertogh, 1996; Miller and Langhans, 1990). Bulb scales likely reduce vascular desiccation by providing water, thereby preserving vascular tissue for future water uptake when cut and placed in a vase.

In conjunction with a sub-zero storage temperature of -0.6°C , the storage life of stems stored with the bulb attached was extended to 6 weeks, with all cultivars having a vase life of more than 4 to 6 d in bulb-attached experiments, with the exception of Golden Oxford (3.6 d). The vase life of cut tulips at 6 weeks using this combination was similar to that of tulips stored for 6 d at 0°C (Cevallos and Reid, 2001). The vase life most similar to the results of the bulb-attached experiments in this study was 6.7 d after 31 d of storage when held in modified atmospheric packaging at 0°C (Aros et al., 2017). However, the combination of sub-zero storage and bulb-attached stems is likely a more cost-effective method. Modified atmospheric packaging can be expensive and requires technical skills to achieve accurate atmosphere concentrations, whereas cooling systems currently used by cut flower growers may already have the ability to maintain sub-zero temperatures between 0 and -1°C .

Commercial floral solutions improved the vase life of stored cut stems when used before storage on cut stems and when applied after the storage of bulb-attached stems. Both commercial floral solutions contain BA and GA₄₊₇ phytohormones; the positive impacts of these phytohormones align with those previously reported for cut tulip vase life and quality (Kim and Miller, 2008;

Table 5. Vase life of ‘Menton’ tulip as affected by a significant ($P < 0.05$) two-way interaction between pre-storage pulses and storage duration -0.6°C (30.9°F) when stored with the bulb attached.

Pre-storage pulse ^z	Storage duration (weeks)			
	0	3	6	9
	Vase life (d) ^y			
Nontreated, control	7.6	6.8	5.2	2.8
Tap water	7.5	7.1	5.0	4.2
Bulb 100 ^x	8.8*	8.5*	7.8*	7.1*
BVB ^w	8.9*	8.5*	7.9*	5.9

^zPre-storage pulses were applied by placing cut ends of stems into pulse solutions of tap water or commercial floral solutions containing benzyladenine and gibberellic acid mixed according to the manufacturer’s instructions with tap water at a rate of $2\text{ mL}\cdot\text{L}^{-1}$ (0.26 fl oz/gal) for 8 h at 4°C (39.2°F). Nontreated controls were held dry for 8 h at 4°C .

^yDays from placing stems in vases containing 400 mL (13.53 fl oz) of tap water in the evaluation room until termination.

^xBulb 100 (Floralife, Walterboro, SC) commercial floral solution.

^wBVB (Chrysal Americas, Doral, FL) commercial floral solution.

*Least squared means are significantly different from stems pulsed in tap water and nontreated control stems within each column when adjusted with Tukey’s honestly significant difference test with $P \leq 0.05$.

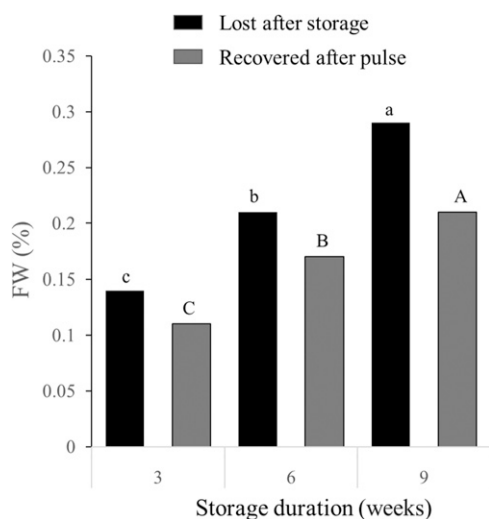


Fig. 5. Percent fresh weight (FW) change for 'Menton' tulip as affected by storage duration. The same lowercase letters are not significantly different according to Tukey's honestly significant difference test at $P \leq 0.05$ for the percent FW lost after storage ($P \leq 0.001$). The same uppercase letters are not significantly different according to Tukey's honestly significant difference test at $P \leq 0.05$ for the percent FW recovered after pulsing ($P \leq 0.001$) stems for 8 h at 4°C (39.2°F) with either tap water or commercial solutions Bulb 100 (Floralife, Walterboro, SC) or BVB (Chrysal Americas, Doral, FL) containing benzyladenine and gibberellic acid mixed according to the manufacturer's instructions with tap water at a rate of $2\text{ mL}\cdot\text{L}^{-1}$ (0.26 fl oz/gal). FW loss = $[(\text{pre-storage FW} - \text{post-storage FW})/\text{pre-storage FW}] \times 100\%$. FW gain = $[(\text{FW after pulsing} - \text{post-storage FW})/\text{FW after pulsing}] \times 100\%$. Stored stems were held dry, wrapped in newspaper, and placed in cardboard boxes lined with polyvinyl wrap.

van Doorn et al., 2011). The vase life improvement was less than that reported by van Doorn et al. (2011);

however, the results of both the current study and that by van Doorn et al. (2011) indicate cultivars differ in their

responses to pulses, and that the concentrations of BA and GA may differ between the commercial products and that used by van Doorn et al. (2011). Flower qualities such as color retention, petal enlargement, and delay of abscission were also observed to be better when floral solution was used (Fig. 7). The BA component likely alleviated petal discoloration (van Doorn et al., 2011).

The difference in the vase life of pulsed stems compared with that of nonpulsed stems was greater when pulses were used before storage on cut stems than when pulses were used after storage on stems stored with the bulb attached. However, the vase life of bulb-attached stems pulsed after storage was longer than that of cut stems pulsed before storage. Specifically, the vase life of 'Menton' with pre-storage pulsing before 6 weeks of storage was between 6.1 and 6.4 d; it was between 8.0 and 8.1 d with post-storage pulsing. The results of this comparison match the results of the bulb-attached experiment, which indicated that bulb-attached stems had a longer vase life than cut-stored stems. Although there was no statistical comparison between experiments, the post-storage pulsing experiment resulted in the longest vase life at 6

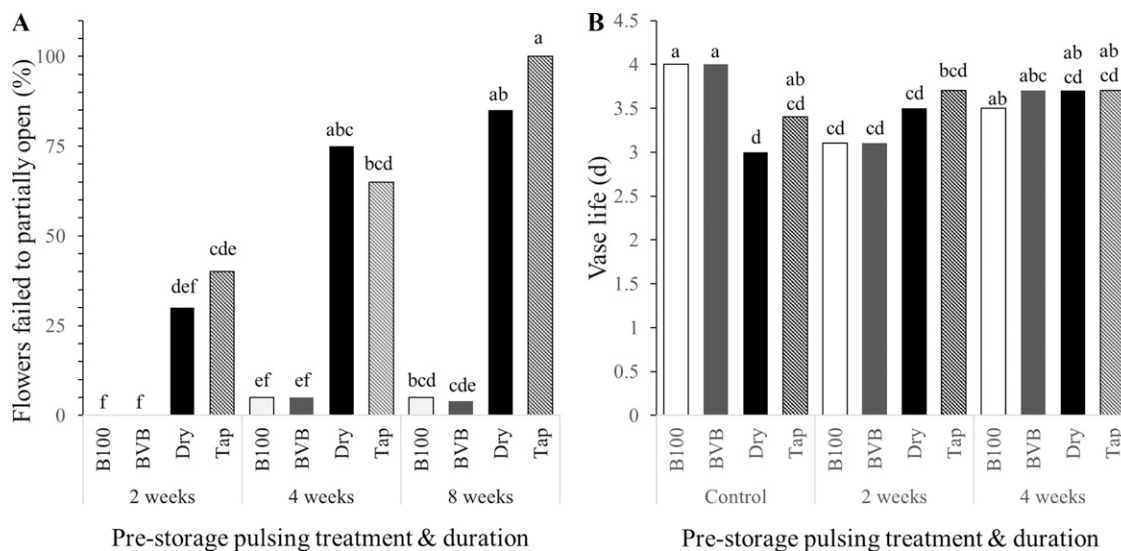


Fig. 6. The percentage of flowers of 'Telstar' dutch iris that failed to partially open as affected by post-storage pulsing solution (A). Vase life of 'Telstar' dutch iris as affected by post-storage pulsing solution (B). Treatment analyses were separated by pulsing type and storage duration when affected. Means with the same lowercase letters are not significantly different according to Tukey's honestly significant difference test at $P \leq 0.05$. Failure to partially open was designated by the inability to expand the first primary petals. Post-storage bulbs were removed by cutting and stems were pulsed for 8 or 24 h at 4°C (39.2°F) with either tap water (tap) or commercial solutions B100 (Bulb 100; Floralife, Walterboro, SC) or BVB (Chrysal Americas, Doral, FL) containing benzyladenine and gibberellic acid mixed according to the manufacturer's instructions with tap water at a rate of $2\text{ mL}\cdot\text{L}^{-1}$ (0.26 fl oz/gal), or they were held dry (dry). Vase life was determined by the number of days from placing stems in vases containing 400 mL (13.53 fl oz) of tap water in the evaluation room until termination.

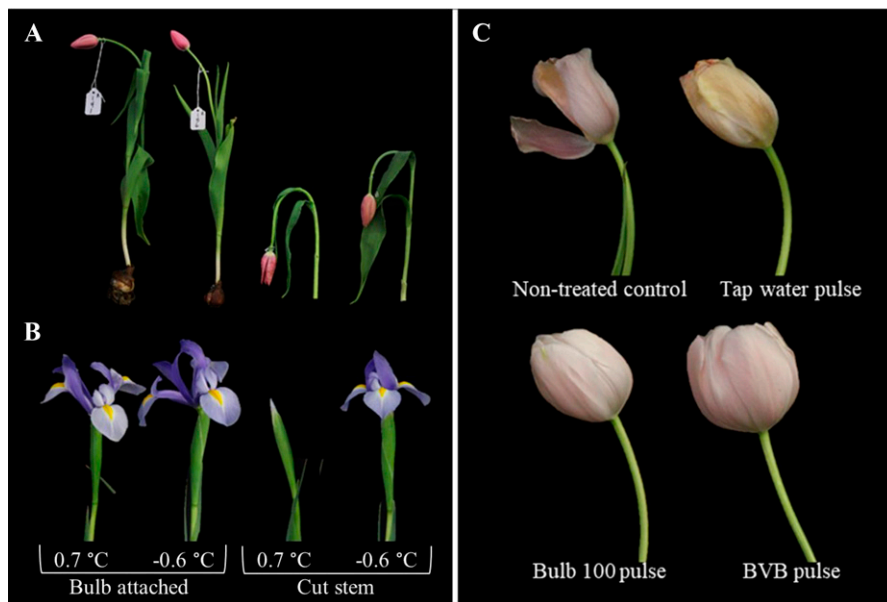


Fig. 7. Visual wilting symptoms of ‘Renown’ tulip immediately after being removed from 6-week storage treatments with the bulb still attached to stems or as cut stems at 0.7 °C (33.26 °F) or –0.6 °C (30.92 °F) (A). ‘River King’ dutch iris extent of flower opening after 2-week storage treatments with the bulb still attached to stems or as cut stems at 0.7 or –0.6 °C (B). Flower quality of ‘Menton’ tulip 6 d after being removed from the 6-week storage treatment with the bulb still attached at –0.6 °C and pulsing post-storage for 8 h at 4 °C (39.2 °F) in either tap water or commercial solutions Bulb 100 (Floralife, Walterboro, SC) or BVB (Chrysal Americas, Doral, FL) containing benzyladenine and gibberellic acid mixed according to the manufacturer’s instructions with tap water at a rate of 2 mL·L⁻¹ (0.26 fl oz/gal) (C). Stored stems were held dry, wrapped in newspaper, and placed in cardboard boxes lined with polyvinyl wrap.

weeks of storage. Sub-zero storage of cut tulips was first reported by Post and Fischer (1952), who claimed cut tulips could be stored dry for 8 weeks at –0.5 °C. The post-storage pulsing experiment results support the first use of sub-zero temperatures for cut tulip storage by Post and Fischer (1952) and provide evidence extending storage to 9 weeks when storing stems with the bulb attached and pulsing stems with a floral solution containing BA and GA.

VASE LIFE: DUTCH IRIS. The response of dutch iris was similar to that of cut tulip cultivars; however, dutch iris did not benefit as much from being stored with the bulb attached. The vase life was slightly longer when stems were stored for 2 weeks at –0.6 °C. In year 1, there were no negative effects of storing stems with the bulb attached or when storing stems at –0.6 °C, and there was a positive impact on the number of flowers that fully opened, specifically for ‘Telstar’. In year 2, the vase life was significantly higher for stems stored with the bulb attached; however, 100%

of flowers failed to fully expand. Water conductivity and flower opening were lower for ‘Wedgwood’ and ‘Professor Blaauw’ dutch iris when stored for 4 d at 4 °C with the basal plate still attached (Mayak and Halevy, 1971). Potentially removing more stem from bulb-attached stems may have further reduced vascular blockage, which may explain the ability of flowers to open more in year 1. However, a preliminary test examining stem length removal above the attached bulb indicated that there was no difference in the flower opening of ‘Telstar’ when 2.5 cm was removed above the attached bulb compared with removing 15 cm after storage (data not presented).

van Doorn et al. (2014) also reported that ‘Blue Magic’ was chilling-sensitive when stored at 0.5 °C; however, no injury was observed on either dutch iris cultivar tested. Many of the differences between the results of the current studies compared with those in the literature could have been attributable to the cultivar. For example, ‘Telstar’ and ‘River King’ dutch iris were used for these experiments and are grown by North

Carolina growers because of their reliability to fully expand compared to other cultivars (M. Hommes, personal communication). As stated, the combination of storing stems with the bulb attached and at –0.6 °C may have minimized the development of a vascular occlusion, which improved flower opening and vase life. However, the ability of flowers to fully open varied slightly by growing year likely because of environmental differences.

Pulsing treatments were not as effective on ‘River King’ dutch iris as they were on tulip. However, a positive benefit was still measurable and may be applicable to other cultivars such as Telstar. A 24-h pre-storage pulse combination of thidiazuron and GA₃ improved the vase life of ‘Discovery’ dutch iris after 2 weeks of storage at 0 °C (Macnish et al., 2010). In year 2, significantly fewer flowers failed to fully expand after 8 weeks of storage when pulsed with floral solution post-storage, but the vase life was maintained after 4 weeks of storage when stored with the bulb attached. Additionally, if stems had a second bud emerge before termination of the primary flower, then the vase life was extended up to 5 d when stems had been pulsed with either floral solution before storage. It should be noted that only flowers obtained from the wholesale florist in year 2 for the pre-storage pulsing experiment had secondary buds emerge for this analysis.

PERCENT FW CHANGE AND FLOWER OPENING. Preservation of FW and maintaining turgidity are key points of cut flower postharvest handling. Stored tulips in the bulb-attached experiment lost a maximum of 25% FW by 6 weeks of dry storage. Differences were statistically and visually observable, primarily between stems stored with the bulb attached and those stored as cut stems (Fig. 7A). Stems with the bulb attached were visually less wilted than stored cut stems (personal observation), thus contradicting the higher amount of FW lost after storage compared with the FW lost by cut stems. Considering that bulbs were not measured before and after storage, we cannot pinpoint which tissue, the stem or the bulb, lost more FW. However, it is likely that the FW was lost primarily from the bulb tissue by water moving into stem, leaf, and floral tissue, where it was transpired. This would explain

the less severe wilting and higher percent FW lost after storage experienced by bulb-attached stored stems.

The ability of bulb-attached tulip stems to recover FW after storage was measured after placing cut stem ends in 8-h pulsing treatments. The percent FW recovered increased as stems became more dehydrated with increasing storage duration. However, tulip stems likely have a limited ability to rehydrate based on the amount of dehydration because the difference between the percent FW lost after storage and the percent FW recovered after pulsing was larger at 9 weeks compared with that at 6 weeks. In year 1, no stems were lost because of an inability to rehydrate. Turgidity, meaning stiff stems and leaves, was observed 30 to 60 min after placement in tap water or commercial floral solutions after storage.

Dutch iris reacted similarly to tulips; cut stored stems lost less FW and were visually more wilted compared with stems stored with the bulb still attached. Dutch iris flowers were visually less wilted than tulip flowers. Siberian iris (*Iris siberica*), a related species, has lignified hydrocytes, which likely increased stem strength (Tikhomirova et al., 2018) and masked dehydration. The difference in the ability of dutch iris and tulip to rehydrate and develop floral structures could be explained by differences in cell composition and vascular structure. Some tulips (*Tulipa gumusanica* ‘Terzioglu’ and *Tulipa armena* var. *armena*) were reported to have a large amount of succulent parenchyma in and around the vascular bundles (Coskuncelebi et al., 2008), which could explain the propensity to rehydrate quickly.

In year 1 of the bulb-attached experiment, 0% to 50% of ‘Telstar’ dutch iris failed to open after 2 weeks of storage, regardless of the storage temperature. In year 2, 95% of flowers failed to fully expand after 2 weeks of storage, but 92% partially opened. Dutch iris have been difficult to rehydrate compared with tulip after dry storage (van Doorn et al., 2014), even with a portion of the basal plate still attached (Mayak and Halevy, 1971). Water movement (van Meeteren et al., 2006) and elongation of the pedicel and ovary are responsible for petal

expansion and dutch iris flower opening (van Doorn et al., 2014).

In most cases, in year 1, a higher percentage of ‘River King’ and ‘Telstar’ flowers fully and partially opened when stored with the bulb attached compared with cut stems, for which a higher percentage failed to open when stored for 2 weeks (data not presented). By retaining the bulb scales, the vascular system may have avoided desiccation, which could have improved water uptake after recutting. Both BVB (A. Ranwala, personal communication) and Bulb 100 (R. Timmerman, personal communication) contain GA₄₊₇, which improved the flower opening of dutch iris ‘Discovery’ (Macnish et al., 2010). The pulse treatment duration was 16 h longer in the study by Macnish et al. (2010), which may explain why there was no improvement in flower opening when stems were treated with either floral solution compared with tap water. In year 2, there were no discernable differences in stems pulsed for 8 or 24 h in the pulsing experiments. However, 35% more stems stored with the bulb attached were able to fully open when pulsed with a floral solution after storage.

TULIP STEM LENGTH GAIN. In-vase stem elongation can be an undesirable characteristic of tulip. Increasing the storage duration decreased the stem length gained during postharvest evaluation, as did storage at 0.7°C compared with storage at -0.6°C. Cold temperatures are often used to increase the tulip stem length during the forcing phase of production (De Hertogh, 1996; De Hertogh and Le Nard, 1993). It is suggested that cold temperatures induce invertase and water-channel proteins for increased water potential, thus causing internodal stretching (Balk and Douwe de Boer, 1999). Floral solution pulses increased the length gained during the pre-storage and post-storage pulsing experiments. van Doorn et al. (2011) reported increased stem elongation and bending of stems treated with GA₃, but no effect was observed when treated with BA. van Doorn et al. (2011) also found that the addition of ethephon, a precursor to ethylene, reduced stem elongation; it is now included with BA and GA in commercial floral solutions. Therefore, the use of this type of floral solution may yield positive results if used as a post-storage pulse.

Conclusions

The cut flower industry is constantly looking for ways to improve postharvest handling practices to maintain or enhance their products. The longest vase life durations of tulip and dutch iris were achieved when storing stems with the bulb attached at -0.6°C. Leaving the bulb attached is also a simple and effective method of preserving vase life when sub-zero temperatures are not available. Pre-storage pulses were not as beneficial as the combination of post-storage pulses on bulb-attached stored stems; however, this may be an effective method when keeping the bulb is undesirable or cut stems need to be held for an extended period. Finally, the best method of long-term storage of cut tulips and ‘Telstar’ dutch iris was storing stems with the bulb attached at -0.6°C, followed by at least an 8-h pulse of either floral solution to increase the ability of flowers to fully expand and maintain vase life.

The methods studied for tulip and dutch iris, such as keeping stems with a storage organ or using sub-zero temperatures, could be extended to other cut flower species. Sub-zero storage temperatures are not currently used in the industry, and the adoption of -0.6°C would increase if more species were tolerant of this temperature. Although not all species require long-term storage capabilities, having the option to store multiple crops at the same temperature for long periods of time gives growers and suppliers flexibility by allowing them to store more product for periods of high demand when warm production temperatures result in early harvest or when other issues may arise. The rehydration ability of tulip after storage is uncharacteristic of cut flowers. A better understanding of the vascular structure and water transport may provide insight that could improve hydration of many other cut flower species.

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