Abstract

POSSIEL, ERIN YORK. Effects of Preharvest Conditions and Postharvest Handling on Postharvest Characteristics of Cut Lilies, Roses, Sunflowers, and Zinnias. (Under the direction of Dr. John M. Dole.)

Studies were conducted to determine the effects of preharvest humidity and water stress levels during production on cut *Lilium* L. and *Helianthus* L. stems and various postharvest procedures on cut *Rosa hybrida* L., *Helianthus* L., and *Zinnia* Jacq. stems. Subjecting *Lilium* 'Dazzle' and 'Vermeer' stems to high humidity during production did not reduce cut flower vase life but increased stem length and production time. In *Helianthus*, vase life, water uptake, stem length, stem diameter, and head diameter of cut 'Sunbright' stems were positively correlated with production time in high humidity. Applying water stress to 'Dazzle', 'Vermeer', and 'Sunbright' during production did not affect vase life at the treatment level; however, water potential readings during the last five days before harvest were negatively correlated with vase life in 'Vermeer', and water potential readings from up to 36 days before harvest were positively correlated with vase life in 'Sunbright'. Bud number in 'Vermeer' was positively correlated with stem diameter, and stem diameter in 'Dazzle' and 'Vermeer' was smaller as soil moisture deficit increased. Quality of cut 'Sunbright' stems was less as soil moisture deficit increased. Vase life in cut 'Vermeer' and 'Sunbright' stems was negatively correlated with the change in fresh weight in both humidity and water stress preharvest experiments.

Postharvest studies determined that *R. hybrida* vase life was influenced by cultivar and vase solution, where commercial preservative solutions resulted in longer vase lives and smaller changes in fresh weight than the controls, but also less water uptake. Exogenous ethylene did not affect vase life but decreased water uptake. Application of the anti-ethylene

agent silver thiosulfate (STS) significantly improved vase life in a majority of the rose cultivars tested, but 1-methylcyclopropene (1-MCP) did not improve vase life over the control. Both vase life and water uptake were reduced when more than one stem was placed in a vase, where placing ten stems in a vase decreased vase life by 1.4 days and water uptake by up to 10.6 mL/stem/day. Leaving stems dry before placing in vases reduced vase life, but recutting immediately before placing in vases minimized the decline. Rose stems responded positively to increasing the amount of stem removed, where cutting from 1 to 15 cm off the end extended vase life.

Drying stems of *Helianthus* 'Sunbright' for up to 48 hours did not significantly reduce vase life when stems were recut after drying time; however, vase life was affected by storage temperature such that the longest vase life of 13.2 days occurred when stems were stored for 3 days at 5°C. Placing more sunflower stems in a vase did not statistically affect vase life.

Vase life of cut *Zinnia* 'Benary Giant Deep Red' stems was less when stems were recut compared to stems that were not recut. However, if stems were recut, a period of desiccation before placing in vases improved vase life. Vase life was improved by 2.1 days with the use of Floralife® Professional as a pulse solution versus tap water and by 2.2 days when stems were stored in a bleach solution versus tap water. Storage temperature affected vase life with 5 hours of storage at 5°C followed by 2 days of storage at 1°C resulting in the highest vase life of 13.0 days. Short vase lives occurred as storage temperature increased, with a low of 6.5 days after 2 days of storage at 20°C. Varying the number of stems per vase did not significantly affect vase life.

Effects of Preharvest Conditions and Postharvest Handling on Postharvest Characteristics of Cut Lilies, Roses, Sunflowers, and Zinnias

by
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Dedication

I would like to dedicate my thesis work to my late grandfather, Norman Charles Possiel, Sr., affectionately known as Poppop, who passed away in 2004. Poppop worked as a civil engineer for Edwards and Kelcey for 45 years and was known for his humility, his selfless attitude, and his ability to fix almost anything! Poppop always encouraged me to put forth my best effort and pursue my passions and I would like to offer this work in thanks for his support throughout my life.

Biography

Erin York Possiel was born on Dec. 23, 1982 in Raleigh, NC. She attended W.G. Enloe High School and then received a B.S. in Botany and a B.A. in Spanish Language and Literature with minors in Horticultural Science and French from North Carolina State University in 2006. After taking an introductory horticulture class taught by Bryce Lane, Erin discovered her interest in the subject and cultivated her newfound love of plants by pursuing her M.S. in Horticultural Science.

In her spare time, Erin enjoys traveling, spending time with her family and friends, and being outdoors. During her time at NC State, Erin participated in several organizations that have shaped her goals and interests. She was a member of Campus Crusade for Christ, which deepened her relationship with Jesus and introduced her to some of her closest friends. She was also a part of the Caldwell Fellows Program, which exposed her to a myriad of service opportunities and enabled her to study for a summer in Oxford, England. Through the Center for Student Leadership, Ethics, and Public Service, Erin participated in the Alternative Spring Break program where she worked for Habitat for Humanity in Ecuador and led a life changing trip to an orphanage in the Dominican Republic. Erin served as Co-Director for the Satellite Program, a five-day science camp that brings 10^{th} graders from rural schools to NC State to learn about opportunities in science and technology. She was also able to spend a summer in Costa Rica with the School for Field Studies, learning about sustainable development. During her undergraduate years, Erin worked as an assistant in the Service-Learning Program, which taught her the value of personal reflection and self discipline. Upon graduation, Erin hopes to work in the public gardens sector, specifically in educational programming.

Acknowledgements

I would like to acknowledge several people for their support and assistance over the past two years. I would like to thank my advisor and committee chair, Dr. John Dole, for his continuous advice and support and for never tiring of answering my many questions. I would also like to thank Dr. Brian Whipker and Dr. Sylvia Blankenship for offering their time and expertise to serve on my committee. I would like to gratefully acknowledge funding from the American Floral Endowment, the Association of Specialty Cut Flower Growers Research Fund, and Dole Fresh Flowers. I would also like to offer my immense gratitude to research technicians Diane Mays, Beth Harden, and especially Ingram McCall, as well as fellow floriculture graduate students Emma Locke and Erin Regan for their constant support and willingness to lend a helping hand whenever needed. I would also like to thank my family whose encouragement was invaluable. Finally, I would like to thank my fiancé Casey for his support, encouragement, silliness, sacrifice, and love, which has gotten me through many tough times and kept a smile on my face.

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Chapter 1

Introduction

The United States cut flower industry faces many challenges due to the difficulty in producing flowers with long postharvest performance. Customers may be more wary of purchasing cut flowers than any other flower commodity because the vase life is uncertain. To ensure a longer vase life, growers must carefully regulate the environmental factors, including both preharvest and postharvest conditions.

Preharvest humidity and water stress. Many preharvest factors affect the vase life in various species, such as *Bouvardia* Salisb. and *Rosa* L. (Torre et al., 2001; van Gorsel, 1993). Harvest season, light levels, temperature, humidity, and water stress in the preharvest environment influence how long the flowers last once they are cut, and conditions in the last two weeks prior to harvest appear to be the most critical (Slootweg, 2005). Relative humidity, in particular, is negatively correlated with the length of vase life and could have an even greater influence than nutrient status (Marissen, 2005; Slootweg, 2005; Torre et al., 2001, 2003; van Gorsel, 1993). Growing plants in high humidity during production encouraged the development of more stomata on the leaves (Torre et al., 2003). Once the flower was cut, the greater number of stomata resulted in less control over water loss. Flowers then exhibited wilting or bent neck because transpiration exceeded water uptake. Moderate humidity levels of 70 to 85 ± 5% produced the longest vase life (Slootweg, 2005; Torre et al., 2001). However, not all cultivars performed similarly; for example, *Rosa* 'Red Berlin' vase life was longer when plants were grown under high relative humidity (Marissen,

2005). In production situations, however, humidity will vary with the weather and consequently work is needed to determine if high humidity immediately prior to harvest will decrease vase life.

Water stress may also impact cut flower vase life. *Zinnia elegans* L. and *Dianthus caryophyllus* L. stems harvested from plants that received a water stress treatment took up more water and were less likely to wilt than stems harvested from well-watered plants (Mayak and Kofranek, 1976; Twumasi, et al., 2005). Cut *Dendranthema* × *grandiflorum* Tzvelev flowers grown at 20% substrate water content were able to rehydrate after experiencing dry storage, but flowers grown at 70% substrate water content could not (van Meeteren et al., 2005). Unfortunately, chronic water stress will decrease stem length (Lieth and Burger, 1989). Work is needed to determine if short-term water stress immediately prior to harvest increases water uptake and vase life.

Postharvest water uptake. Water uptake may be the most important factor in improving the length of vase life of cut flowers (Halevy and Mayak, 1979). As the leaves on the flowers transpire, water is drawn up through the xylem. If this process is impeded by a vascular blockage or accelerated by increased stomatal opening, then transpiration will exceed uptake and water deficiency will occur (van Doorn, 1997). Solutes, such as sucrose, 8-hydroxyquinoline citrate (8-HQC), or aluminum sulfate, which are frequently added to vase solutions, can decrease transpiration or increase water uptake (van Doorn, 1997).

Postharvest handling. Many postharvest processing procedures alter the water

relations in cut flowers, affecting their vase life. Because cut flowers are often transported or stored out of water for long periods of time, cutting procedures to remove or reduce air embolisms and other vascular occlusions must be studied. Vascular occlusions block water flow through the xylem, decreasing water uptake and subsequently decreasing vase life (Durkin and Kuc, 1966). Examination of xylem profiles in cut *Rosa* stems have shown that when kept in distilled water, bacterial contamination occludes the bottom 2.5 cm of the stem, while a carbohydrate substance occludes the stem about 10 cm higher than the level of solution (Lineberger and Steponkus, 1976). Work is needed to determine optimum recutting procedures and amounts to minimize the negative effects of vascular occlusions on vase life.

In addition, recommendations typically suggest recutting the stems while under water to prevent air embolisms. However, recent work indicates that recutting under water should be done only when the water is clean, otherwise bacterial contamination negates the benefits of recutting (Nell and Reid, 2004). Work is needed to determine if increasing the number of stems per vase will increase bacterial contamination and subsequently decrease vase life.

Temperature can also influence postharvest performance. Flowers typically spend one to several days in storage or transport where they might be subjected to high temperatures, increasing their transpiration and negatively affecting their vase life. High temperature stress has been shown to negatively impact the vase life of several *Rosa* cultivars, with other cultivars being unaffected (Nell and Leonard, 2005). Because of the variability among flowers to the tolerance of hot and cold temperatures, more work is needed to determine how temperature influences vase life.

Cultivars. Because of the variability among rose cultivars in response to postharvest processing procedures, more work is needed to examine how different cultivars perform under common postharvest practices. For example, adding a preservative to a postharvest vase solution is often recommended but the increase in vase life is dependent on the cultivar and on the concentration of sucrose used. In 'First Red', increasing the concentration of sucrose in a vase solution containing 0.03% aluminum sulfate up to 1.5% increased vase life; however, vase life declined with higher concentrations up to 3% (Singh et al., 2003). Bhattacharjee (1994) found that the use of a preservative solution containing 300 ppm 8-HQC and 10,000 ppm sucrose increased vase life versus using distilled water in a study on 10 rose cultivars; however, the extent of the increase varied by cultivar from 1.01 to 2.67 days. Ketsa et al. (1993) found that using a holding solution containing 5% sucrose and 20 mg silver nitrate significantly improved the vase life of rose cultivars 'Eiffel Tower', 'Swartmore', and 'Yankee' but did not improve vase life of 'King's Ransom' or 'Confidence'.

Adding sucrose to a vase solution will increase the presence of bacteria, so 8-HQC can be added to vase water to minimize occlusions from bacteria. The addition of this chemical to vase water containing *Rosa hybrida* 'Sonia' reduced bacteria levels from 8.4 x 10^5 cfu/g fresh weight found in the bottom 5 cm segment of the stem to $<1.2 \times 10^2$ cfu/g fresh weight (van Doorn, 1990). A low pH solution, produced by the addition of sodium hypochlorite and a pH 3.0 buffer, also reduced bacteria levels and increased water conductance in several *Rosa* cultivars (Marousky, 1971; van Doorn, 1990). Sucrose decreased water absorption in 'Better Times' roses; however, it extended vase life by

suppressing stomatal opening, thus decreasing transpiration (Marousky, 1969; 1971).

The effect of ethylene and anti-ethylene agents on cut *Rosa* flowers is varied and appears to be cultivar dependent. RueySong et al. (2001) noted that a 0.1 to 2 ppm exogenous application of ethylene significantly decreased vase life in 'Golden Medal' cut roses but had less of an effect on 'Grand Gala' vase life. Singh et al. (2004) found that silver thiosulfate (STS) improved the vase life in three of seven rose cultivars tested. Contrasting reports exist on the efficacy of 1-methylcyclopropene (1-MCP), with Philosoph-Hadas et al. (2005) finding that treating stems with 0.4 $\mu L \cdot L^{-1}$ 1-MCP for 4 h increased vase life for rose cultivars 'Pink Tango', 'Jazz', 'Frisco', and 'Golden Gate', whereas Chamani (2005) found that 1-MCP did not improve vase life in 'First Red'. Therefore, more work is needed to examine the effects of ethylene and anti-ethylene agents on commercially important or previously untested rose cultivars.

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Chapter 2

Effects of Preharvest Conditions on Postharvest Characteristics of Lilies and Sunflowers

(in the format appropriate for submission to HortScience)

Effects of Preharvest Conditions on Postharvest Characteristics of Lilies and Sunflowers

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Effects of Preharvest Conditions on Postharvest Characteristics of Lilies and Sunflowers

Abstract

Subjecting *Lilium* L. 'Dazzle' and 'Vermeer' stems to high humidity during production did not reduce cut flower vase life but increased stem length and production time. With *Helianthus annuus* L. 'Sunbright', vase life, water uptake, stem length, stem diameter, and head diameter of cut stems were positively correlated with production time in high humidity. Application of water stress to 'Dazzle', 'Vermeer', and 'Sunbright' during production did not affect vase life at the treatment level; however, in year one water potential readings during the last five days prior to harvest were negatively correlated with vase life in 'Vermeer' and water potential readings from up to 36 days prior to harvest were positively correlated with vase life in 'Sunbright'. Bud number in 'Vermeer' was positively correlated with stem diameter, and stem diameter in both 'Dazzle' and 'Vermeer' was smaller as soil moisture deficit increased. Quality of cut 'Sunbright' stems was less as the soil moisture deficit increased. Vase life in cut 'Vermeer' and 'Sunbright' stems was negatively correlated with the change in fresh weight in both humidity and water stress experiments.

Introduction

The United States cut flower industry faces many challenges due to the difficulty in producing flowers with long postharvest performances. Customers may be more wary of purchasing cut flowers than any other flower commodity because the vase life is uncertain.

To ensure a longer vase life, growers must carefully regulate the environmental factors, including both preharvest and postharvest conditions.

Many preharvest factors have been shown to affect the vase life in various species, such as *Bouvardia* Salisb. and *Rosa* L. (Torre et al., 2001; van Gorsel, 1993). Harvest season, light levels, temperature, humidity, and water stress in the preharvest environment can influence how long the flowers last once they are cut, and conditions in the last two weeks prior to harvest were the most critical (Slootweg, 2005). Relative humidity, in particular, is negatively correlated with the length of vase life and could have an even greater influence than nutrient status (Marissen, 2005; Slootweg, 2005; Torre et al., 2001, 2003; van Gorsel, 1993). Maintaining plants in high humidity during production encouraged the development of more stomata on the leaves (Torre et al., 2003). Once the flower was cut, the greater number of stomata resulted in less control over water loss. Flowers then exhibited wilting or bent neck because transpiration exceeded water uptake. Moderate humidity levels of 70 to 85 ± 5% produced the longest vase life (Slootweg, 2005; Torre et al., 2001). However, not all cultivars performed similarly; for example, *Rosa* 'Red Berlin' vase life was longer when plants were grown under high relative humidity (Marissen, 2005). In production situations, however, humidity will vary with the weather and consequently work is needed to determine if high humidity immediately prior to harvest will decrease vase life.

Water stress may also impact cut flower vase life. *Zinnia elegans* L. and *Dianthus caryophyllus* L. stems harvested from plants that received a water stress treatment took up more water and had longer vase lives than stems harvested from well-watered plants (Mayak and Kofranek, 1976; Twumasi, et al., 2005). Cut *Dendranthema* × *grandiflorum* Tzvelev

flowers grown at 20% substrate water content were able to rehydrate after experiencing dry storage, but flowers grown at 70% substrate water content could not (van Meeteren et al., 2005). Unfortunately, chronic water stress will decrease stem length (Lieth and Burger, 1989). Work is needed to determine if short-term water stress immediately prior to harvest increases water uptake and vase life.

Objectives

The objectives of this research were to:

1. Quantify the effect of preharvest humidity levels on postharvest performance.
2. Quantify the effect of preharvest plant and substrate water content on postharvest performance.

Materials and Methods

Plant production-2006. Bulb crates, measuring 56.5 cm x 36.5 cm x 20 cm for *Lilium* and 56.5 cm x 36.5 cm x 16 cm for *Helianthus*, were lined with newspaper and filled with a commercial peat-based substrate (Fafard 4P, Fafard, Agawam, MA). Twenty *Lilium* 'Vermeer' bulbs 14 to 16 cm in circumference per crate were planted in a 4x5 arrangement on 2 Nov. 2006 and held at 2.5°C for two weeks and 5.5°C for approximately one week for rooting until 27 Nov. 2006 when crates were transported to the greenhouse. On 20 Nov. 2006, *Helianthus* 'Sunbright' seeds were sown in crates in the greenhouse in a 4x6 arrangement, with two seeds per location, and thinned to 24 seedlings after the first true leaves were present. Plants were grown in a glass covered greenhouse set at 15ºC night and

25ºC day temperatures with ambient light (averaging 900 μmol·m^{-2}·s^{-1}) and ample substrate moisture, unless otherwise indicated. Plants were irrigated as needed with 250 ppm N from a commercial 20-10-20 fertilizer (20 N – 4.4 P – 16.6 K, Peters Professional® General Purpose™, Scotts Company LLC, Marysville, OH). Insect and disease control were accomplished as required. A split plot design was used with 5 repetitions (crates with 24 or 20 plants per rep) per treatment.

Plant production-2007. Twenty *Lilium* 'Dazzle' bulbs 12 to 14 cm in circumference per crate were planted in a 4x5 arrangement on 2 Nov. 2007 and held at 2.5°C for approximately two weeks and 5.8°C for approximately two weeks for rooting until 5 Dec. 2007 when crates were transported to the greenhouse. On 29 Nov. 2007, *Helianthus* 'Sunbright' seeds were sown in crates in the greenhouse in a 4x6 arrangement, with two seeds per location, and thinned to 24 seedlings. 'Sunbright' seedlings received supplemental lighting from 5 Dec. 2007 to 17 Dec. 2007, which was accomplished with 60 watt bulbs turned on from 10 PM until 2 AM. Plants were grown in a glass covered greenhouse set at 15ºC night and 25ºC day temperatures with ambient light (averaging 900 μmol·m^{-2}·s^{-1}) and ample substrate moisture, unless otherwise indicated. Plants were irrigated as needed with 250 ppm N from a commercial 20-10-20 fertilizer (20 N – 4.4 P – 16.6 K, Peters Professional® General Purpose™, Scotts Company LLC, Marysville, OH). Insect and disease control were accomplished as required. A split plot design was used with 7 repetitions (crates with 24 or 20 plants per rep) per treatment.

Humidity-2006. Plants were grown under one of six relative humidity (RH) treatments: 1) ambient RH (averaging 70%) during the entire crop cycle; 2) high RH

(averaging 87%) during the entire crop cycle; 3) ambient RH until the last 2 weeks prior to harvest when plants were grown under high RH; 4) high RH until the last 2 weeks prior to harvest when plants were grown under ambient RH; 5) ambient RH until the last 2 days prior to harvest when plants were grown under high RH; 6) high RH until the last 2 days prior to harvest when plants were grown under ambient RH. Data recorded included average temperature and percent relative humidity in five minute intervals.

Water stress-2006. Plants were subjected to one of six water stress treatments by being irrigated: 1) as needed (no water stress) for the entire crop cycle; 2) at the first sign of slight wilting (mild water stress) for the entire crop cycle; 3) as needed (no water stress) except for mild stress for the last 2 weeks prior to harvest; 4) as needed (no water stress) except for severe water stress (irrigated several hours after the first sign of wilting) for the last 2 weeks prior to harvest; 5) as needed (no water stress) except for mild stress for the last 2 days prior to harvest; 6) as needed (no water stress) except for severe water stress for the last 2 days prior to harvest. No water stress crates were irrigated when the water potentials reached from -9.33 to -14.67 kPa (tensiometer readings of 100 to 150), mild stress crates were irrigated when the water potentials reached from -30.66 to -41.33 kPa (tensiometer readings of 300 to 400) for *Lilium* and from -52 to -62.66 kPa (tensiometer readings of 500 to 600) for *Helianthus*, and severe stress crates were irrigated when the water potentials reached from -52 to -62.66 kPa (tensiometer readings of 500 to 600) for *Lilium* and from -84 to -89 kPa (tensiometer readings of 800 to 850) for *Helianthus*. Each crate was checked daily at approximately 10 AM. Data recorded included accumulated water potential deficit, which was attained by taking daily tensiometer readings.

Water stress-2007. Plants were subjected to one of four water stress treatments by being irrigated: 1) as needed (no water stress) for the entire crop cycle; 2) at the first sign of slight wilting (mild water stress) for the entire crop cycle; 3) as needed (no water stress) except for mild stress for the last 2 weeks prior to harvest; 4) as needed (no water stress) except for severe water stress (irrigated several hours after the first sign of wilting) for the last 2 weeks prior to harvest. Similar target water potential readings and procedures were used as in 2006.

Postharvest environment. Upon harvest, stems were taken to a postharvest evaluation room, where stem length from cut end to the base of the peduncle in *Helianthus* and from cut end to the top of the highest bud in *Lilium*, stem diameter, measured at 1 cm above the cut end, bud number in *Lilium*, and head diameter measured at the widest point in *Helianthus*, were recorded. *Lilium* stems were recut to 45 cm, *Helianthus* stems were recut to 30 cm (2006) or 35 cm (2007), lower foliage was removed, and fresh weight was recorded. Stems were placed in randomized vases containing 22°C deionized (DI) water at 22 °C under 20 $\mu mol \cdot m^{-2} \cdot s^{-1}$ for 12 h per day at 40% to 60% relative humidity. Upon termination in 2006, vase life, water uptake, and final fresh weight were recorded. In 2007, water uptake and *Lilium* stem quality ratings were recorded eight days after placement of stems in vases, and water uptake was recorded seven days after placement of *Helianthus* stems in vases. Dry weights of freshly cut stems of each species were also recorded. Recorded data were analyzed by analysis of variance using PROC GLM and correlation using PROC CORR (SAS Institute, Cary, NC) and means were separated using Tukey's Studentized range test at $P \leq 0.05$.

Results

Humidity. For cut *Lilium* 'Vermeer' stems, average vase life across all treatments were not significant and ranged from 10.4 days to 11.1 days (Table 1). Plants in the 2-day treatments actually were subjected to either high or ambient humidity for 2 to 5 days, while stems in 2-week treatments experienced from 11 to 16 days in treatments. Bud number, stem diameter, vase life, water uptake, change in fresh weight, and dry weight were not significantly affected by humidity level at $P \leq 0.05$. The shortest stems were 97.0 cm, which were produced when plants were grown in ambient humidity and then moved to a high humidity environment for the last two days prior to harvest. Growing plants in a high humidity environment during the entire crop cycle resulted in the longest stems of 104.3 cm. Stem length was positively correlated with time in humidity (R^2=0.2815, P=0.0001) and time in humidity was positively correlated with production time (R^2=0.2456, P=0.0006). Vase life was not correlated with production time in high humidity but was positively correlated with stem length (R^2=0.2344, P=0.0062) and negatively correlated with change in cut stem fresh weight (R^2= -0.3669, P=0.0006). Bud number was positively correlated with stem diameter (R^2=0.4491, P=0.0001) and dry weight (R^2=0.7943, P=0.0001) and negatively correlated with change in cut stem fresh weight (R^2=-0.3486, P=0.0012).

For *Helianthus* 'Sunbright', longer and thicker stems were produced in high humidity than in ambient humidity (Table 2). Vase life was positively correlated with time in high humidity (R^2=0.1837, P=0.0062). Stems in 2-day treatments actually were subjected to either high or ambient humidity for 2 to 5 days, while stems in 2-week treatments experienced from 11 to 16 days in treatments. The longest vase life of 11.7 days occurred in the continuous

high humidity treatment and the shortest vase life of 9.7 days occurred in the ambient humidity treatment that was moved to high humidity for two days (Table 2). Time in high humidity was positively correlated with stem length (R^2=0.1739, *P*=0.0041), stem diameter (R^2=0.4023, *P*=0.0001), head diameter (R^2=0.1785, *P*=0.0032), water uptake (R^2=0.4315, *P*=0.0001), and production time (R^2=0.1794, *P*=0.0030). Not surprisingly, head diameter was positively correlated with stem length (R^2=0.5929, *P*=0.0001), stem diameter (R^2=0.1894, *P*=0.0017), and dry weight (R^2=0.6189, *P*=0.0001). Dry weight was also positively correlated with stem diameter (R^2=0.6628, *P*=0.0001) and stem length (R^2=0.6480, *P*=0.0001). Water uptake was positively correlated with stem diameter (R^2=0.6809, *P*=0.0001).

Water stress-2006. *Lilium* 'Vermeer' vase life ranged from 10.9 days to 11.4 days across all four treatments, but differences were not statistically significant (Table 3). Two days treatments were not included in the ANOVA analysis because stems did not experience sufficient water stress in the short time period; however, two day treatments were included in correlational analysis. Stem diameter varied by treatment where the thinnest stems occurred in the mild stress treatment. Production time varied by treatment, where stems experiencing two week mild stress had the longest production time and stems experiencing severe water stress during the two weeks prior to harvest had the shortest production time, but this difference of 0.8 days is not commercially significant. Vase life was positively correlated with water uptake (R^2=0.4394, *P*=0.0001) and negatively correlated with change in fresh weight (R^2=-0.3862, *P*=0.0002). Bud number was positively correlated with stem diameter (R^2=0.3781, *P*=0.0001) and dry weight (R^2=0.7147, *P*=0.0001) and negatively correlated

with change in cut stem fresh weight (R^2=-0.3842, *P*=0.0002). Water potential readings on individual days were correlated with vase life, water uptake, and change in fresh weight (Table 4). Tensiometer readings from the harvest day (Day 0) through five days prior to harvest (Day 5) were negatively correlated with vase life, readings from the harvest day though three days prior to harvest were negatively correlated with water uptake, and readings from the harvest day through four days prior to harvest were positively correlated with change in fresh weight.

Helianthus 'Sunbright' vase life varied from 12.0 days to 12.8 days, but differences among treatments were not statistically significant (Table 5). Two days treatments were not included in the ANOVA analysis because stems did not experience sufficient water stress in the short time period; however, two day treatments were included in correlational analysis. Stem length and head diameter were shortest in the mild water stress treatment, measuring 56.4 cm and 1.2 cm, respectively. Stem diameter was smallest in the mild and severe water stress treatments, measuring 0.56 cm and 0.54 cm, respectively. Water uptake varied by treatment, where no water stress and 2 weeks of mild stress produced the highest water uptake per day and continuous mild stress and 2 weeks of severe stress produced the lowest water uptake. Dry weight was also the lowest in the mild water stress treatment, weighing 1.34 g. Mild water stress resulted in the longest production time of 56.8 days, compared to 52.9 days in the no water stress treatment. Vase life was positively correlated with production time (R^2=0.4580, *P*=0.0001) and negatively correlated with change in fresh weight (R^2=-0.2212, *P*=0.0383). Significant positive correlations were found between average water potential readings from up to 36 days prior to harvest and vase life and

production time and negative correlations between average water potential readings from up to 39 days prior to harvest and stem diameter (data not presented).

Water stress-2007. *Lilium* 'Dazzle' vase life ranged from 12.2 days to 12.9 days across all four treatments, but differences were not statistically significant (Table 6). Plants in the 2-week treatments were actually subjected to either mild or severe water stress for 3 to 4 weeks. Bud number was affected by treatment, where two weeks of severe water stress resulted in fewer buds per stem, due to bud abortion, than any other treatment. Stem diameter varied by treatment where the thinnest stems occurred in the mild stress treatment. Dry weight and change in fresh weight were lowest in the two week severe stress treatment and highest with no water stress. Production time varied by treatment, where stems experiencing two weeks of severe stress had the longest production time.

Helianthus 'Sunbright' vase life varied from 16.0 days to 16.6 days, where differences among treatments were not statistically significant (Table 7). Plants in the 2-week treatments were actually subjected to either mild or severe water stress for 2.5 to 3.5 weeks. Stem length and stem diameter were shortest in the severe water stress treatment, measuring 64.2 cm and 0.54 cm, respectively. Head diameter and production time were affected by treatment, but varied by only 0.2 cm and 1.3 days, respectively, across treatments.

Discussion

Humidity. Vase life of cut lily stems was not affected by changes in relative humidity during the production cycle (Table 1). Though several studies reported that high humidity

decreased the vase life of cut flowers (ByungChun et al., 2006; Mortensen and Fjeld, 1998), Mortensen (2001) found that the effect of high relative humidity during rose production on vase life varied by cultivar, which suggests the effect is also likely to be species dependent. Mortensen and Fjeld (1995) reported that vase life was not significantly different among roses grown in either a 65% or 85% relative humidity environment; however, when the relative humidity was increased to 90%, vase life declined. Therefore, the high relative humidity level in this study may not have been high enough to elicit a change in vase life.

Of the variables measured, high relative humidity during the production cycle affected only lily stem length and production time, with a longer time in high humidity leading to longer stems and a longer production time. Several studies have shown that in roses, stem length was increased by maintaining plants at a high relative humidity during production (Blindeman, 2000; Mortensen and Fjeld, 1998; Mortensen and Gislerod, 2000). Lily vase life, in addition, was longest when the change in fresh weight was minimized, which is consistent with previous studies documenting the association between fresh weight, and vase life (Bhattacharjee, 1999).

Sunflowers grown in high humidity during the entire production cycle had a vase life of up to two days longer than those grown in an ambient humidity environment for the entire production cycle or for all but the final 2 days to 2 weeks of production (Table 2). This increase in vase life is inconsistent with several studies conducted on roses, which report that high humidity caused a decrease in vase life (ByungChun et al., 2006; Mortensen and Fjeld, 1998). However, these studies reported that vase life decline was due to an increase in bent neck which would not occur in sunflowers. In addition, Marissen (2005) found that while a

high relative humidity decreased vase life in *Rosa* 'Bianca', vase life increased in 'Red Berlin', again indicating that since the effect of high humidity on vase life is cultivar dependent, it is also likely to be species dependent.

Water uptake during postharvest was greatest when sunflower stems were grown with a longer amount of time in high humidity. Blindeman (2000) also found that when rose stems grown under high humidity were kept in a chamber of lower humidity, water uptake was greatly increased. Mortensen and Gislerod (2000) similarly reported that though cut rose stems grown in high relative humidity initially took up little water as compared to roses grown in low humidity, when these stems were transported to an environment of lower air humidity, water uptake was 20 to 30% greater than stems grown in low humidity. In our study, the high humidity preharvest environment caused sunflower stems to be longer and thicker with larger heads than those grown in an ambient humidity environment, which is consistent with previous studies documenting an increase in shoot length, leaf size, and fresh weight in roses grown in high relative humidity (Blindeman, 2000; Mortensen and Gislerod, 2000).

Water stress. Vase life of cut lily 'Vermeer' or 'Dazzle' was not significantly affected by changes in water stress levels during production at the treatment level (Tables 3 and 6). However, water stress levels during the last five days prior to harvest significantly influenced vase life in 'Vermeer', in that the more water stress a stem experienced in the few days before it was cut, the shorter the vase life (Table 4). A high water uptake and a low change in fresh weight contributed to a longer vase life in 'Vermeer', with increased levels of water stress during the last few days of production leading to decreased water uptake and

increased fresh weight lost.

Subjecting lilies to mild water stress throughout the entire production cycle resulted in stems with smaller diameters than those that were well watered for most of the crop cycle (Tables 3 and 6). Although allowing the stems to reach a severe water stress during the last two weeks prior to harvest produced the thickest stems, stem diameter in this treatment was not significantly different from all other treatments except the mild stress treatment. In 'Vermeer', stem diameter at harvest was negatively correlated with soil moisture deficit during the last two days prior to harvest, indicating that stem diameter is sensitive to changes in soil moisture close to the harvest date. In roses, stem diameter has been shown to decrease in as little as one day after a decrease in water is supplied (Urban et al. 1996). Thus, keeping lilies well-watered close to the harvest date is important in maintaining strong stems with thick diameters. Since stem diameter was positively correlated with bud number in 'Vermeer' for both the humidity and water stress experiments, maintaining growing conditions that favor larger diameter stems could lead to production of more buds per stem. Differences in production time among treatments, though significant, were not commercially important in that there was only a 2 day difference for 'Dazzle' (Table 6) and a 0.7 day difference in 'Vermeer' between the longest and shortest treatments (Table 3). Therefore, varying the amount of water stress that a lily crop receives will not greatly decrease or increase production time.

In 2006, higher tensiometer readings, or a greater soil deficit, throughout production was positively correlated with sunflower vase life, indicating that providing stems with water stress could increase vase life. Similarly, Twumasi et al. (2005) found that low soil water

content during production of three *Zinnia elegans* cultivars led to smaller xylem vessel diameters, which develop embolisms slower than large vessel diameters, thus enhancing water uptake and lengthening vase life.

As with previous experiments, extended sunflower vase lives were seen when the change in fresh weight was minimized. In addition, stems with longer production times had longer vase lives, suggesting that sunflowers that are slower to develop also live longer as cut flowers. Other than vase life, cut flower quality characteristics like stem length, stem diameter, and head diameter were reduced when stems experienced water stress during production (Tables 5 and 7). While production time only varied slightly in 2007 across treatments (Table 7), in 2006, providing a mild water stress increased production time by 3.9 days (Table 5), indicating that water stress could slow down flower development. These trends of an increase in production time and a decrease in quality were also found in rooted cuttings of 'Carl Red' roses, where an increase in soil moisture deficit increased days to harvest and decreased marketability of the cut roses (Terada et al., 1997).

Increasing the soil moisture deficit also led to a decrease in dry weight of sunflower stems, where dry weight was lowest in the continuous mild stress treatment in 2006 and in the severe two week treatment in 2007 (Table 5 and 7). This decrease in dry weight could be attributed to the smaller stem and head diameters in these treatments, as well as the decreased frequency of watering, and therefore nutrient levels, that these stems received. Similarly, Kittas et al. (2005) found that a lower irrigation frequency in roses led to a decrease in dry weight, while Lieth and Burger (1989) found that higher soil moisture tensions resulted in decreased dry weight in chrysanthemum.

Conclusion

Changes in humidity levels during production did not affect vase life in lilies; however, high humidity increased stem length and production time. In sunflowers, high humidity during production increased vase life, stem length and diameter, and water uptake. Thus, an increase in humidity levels from 70% to 87% was beneficial for sunflowers. Correlational analysis of 'Vermeer' lily showed that water stress during the last five days before harvest lowered both water uptake and vase life in cut stems. Constant mild water stress throughout the production cycle of lilies reduced stem diameter, with five days before harvest causing significant reductions. Interestingly, stem diameter was positively correlated with bud number in both the humidity and water stress experiments, so lily growers should avoid conditions that reduce stem thickness, such as water stress during the last week prior to harvest, to maintain high bud counts. Water stress during production reduced flower quality in sunflowers but was correlated with a longer vase life when stems experienced the stress up to 36 days before harvest. Therefore, applying water stress to sunflowers during production may result in cut flowers with longer vase lives but could reduce quality of the stems produced.

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Table 1. Effect of high (H) or ambient (A) relative humidity for the entire production cycle or until the last 14 days (H/A 2w, A/H 2w) or 2 days (H/A 2d, A/H 2d) prior to harvest of cut *Lilium* 'Vermeer' stems. Means are an average of 21 to 35 stems for stem length, bud number, and stem diameter; 14 to 25 stems for vase life; 9 to 15 stems for water uptake and change in fresh weight; and 7 to 10 stems for dry weight. Year one – 2006.

Treatment	Stem length (cm)	Buds (no.)	Stem diameter (cm)[y]	Vaselife (days)	Water uptake (mL/day)	Change in fresh weight (g)[x]	Dry weight (g)
A	101.6 ab[z]	3.5	0.77	11.1	17	-9.02	4.46
H	104.3 a	3.6	0.75	11.0	19	-11.07	4.40
H/A 2w	100.8 abc	4.0	0.78	10.7	16	-9.25	4.66
A/H 2w	99.0 bc	3.9	0.80	10.9	18	-9.66	4.73
H/A 2d	102.0 ab	3.5	0.75	10.4	16	-7.62	4.24
A/H 2d	97.0 c	3.7	0.77	11.0	17	-9.34	4.37
Significance	0.0001	NS	NS	NS	NS	NS	NS

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.

[y]Stem diameter measured 1 cm above cut at harvest.

[x]Final fresh weight recorded at termination of vaselife - initial fresh weight at harvest.

[NS]Nonsignificant at $P \leq 0.05$.

Table 2. Effect of high (H) or ambient (A) relative humidity for the entire production cycle or until the last 14 days (H/A 2w, A/H 2w) or 2 days (H/A 2d, A/H 2d) prior to harvest of cut *Helianthus* 'Sunbright' stems. Means are an average of 17 to 52 stems for stem length, stem diameter, and head diameter; 15 to 41 stems for vase life; 1 to 15 stems for water uptake; 2 to 15 for change in fresh weight; and 2 to 10 stems for dry weight. Year one – 2006.

Treatment	Stem length (cm)	Stem diameter (cm)[y]	Head diameter (cm)	Vaselife (days)	Water uptake (mL/day)	Change in fresh weight (g)[x]	Dry weight (g)
A	63.5 b[z]	0.56 c	1.4 b	10.7 ab	10 bc	-0.68	1.29
H	71.4 a	0.71 a	1.7 a	11.7 a	14 ab	-0.73	1.63
H/A 2w	66.2 ab	0.71 a	1.5 ab	11.3 a	15 a	-0.33	1.75
A/H 2w	71.2 a	0.66 ab	1.7 a	11.4 a	9 c	-2.00	1.95
H/A 2d	65.6 ab	0.73 a	1.6 ab	10.4 ab	15 a	-2.43	1.87
A/H 2d	65.8 ab	0.61 bc	1.6 ab	9.7 b	10 bc	-1.06	1.70
Significance	0.0004	0.0001	0.0063	0.0451	0.0002	NS	NS

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.

[y]Stem diameter measured 1 cm above cut at harvest.

[x]Final fresh weight recorded at termination of vaselife - initial fresh weight at harvest.

[NS]Nonsignificant at $P \leq 0.05$.

Table 3. Effect of no or mild water stress for the entire production cycle (no stress, mild stress) or 14 days of mild or severe water stress (M 2w, S 2w) prior to harvest of cut *Lilium* 'Vermeer' stems. Means are an average of 35 stems for stem length, bud number, and stem diameter; 24 to 25 stems for vase life; 14 to 15 stems for water uptake and change in fresh weight; 10 stems for dry weight; and 35 stems for production time. Year one – 2006.

Treatment	Stem length (cm)	Buds (no.)	Stem diameter (cm)[z]	Vaselife (days)	Water uptake (mL/day)	Change in fresh weight (g)[x]	Dry weight (g)	Production time (days)[w]
No stress	97.7	3.3	0.78 ab[y]	11.4	14	-9.95	4.25	55.4 ab
Mild stress	96.2	3.1	0.75 b	11.4	12	-8.09	3.64	55.8 ab
M 2w	98.0	3.3	0.78 ab	11.4	15	-8.47	3.79	56.1 a
S 2w	98.5	3.6	0.80 a	10.9	13	-7.69	4.13	55.3 b
Significance	NS	NS	0.0277	NS	NS	NS	NS	0.0328

[z]Stem diameter measured 1 cm above cut at harvest.

[y]Means followed by the same letter are not significantly different at $P \leq 0.05$.

[x]Final fresh weight recorded at termination of vaselife - initial fresh weight at harvest.

[w]Days from moving bulbs into the greenhouse.

[NS]Nonsignificant at $P \leq 0.05$.

Table 4. Correlational analysis of vase life, water uptake, and change in fresh weight for cut *Lilium* 'Vermeer' stems with water potential readings from 5 days prior to harvest (Day 5) up to day of harvest (Day 0). Year one – 2006.

Factor	Day 5	Day 4	Day 3	Day 2	Day 1	Day 0
Vase life (days)	-0.1901[z] *0.025*[y]	-0.2091 *0.0135*	-0.2529 *0.0027*	-0.258 *0.0022*	-0.2246 *0.0079*	-0.2158 *0.0107*
Water uptake (mL/day)	NS	NS	-0.2672 *0.0146*	-0.2374 *0.0307*	-0.2243 *0.0415*	-0.2261 *0.0399*
Change in fresh weight (g)	NS	0.2251 *0.0407*	0.2881 *0.0083*	0.3068 *0.0048*	0.3081 *0.0046*	0.2593 *0.0179*

[z]R^2 values.

[y]*P* values.

Table 5. Effect of no or mild water stress for the entire production cycle (no stress, mild stress) or 14 days of mild or severe water stress (M 2w, S 2w) prior to harvest of cut *Helianthus* 'Sunbright' stems. Means are an average of 49 to 57 stems for stem length, stems diameter, and head diameter; 39 to 46 stems for vase life; 14 to 15 stems for water uptake; 14 to 16 stems for change in fresh weight; 10 to 11 stems for dry weight; and 51 to 57 stems for production time. Year one – 2006.

Treatment	Stem length (cm)	Stem diameter (cm)[y]	Head diameter (cm)	Vaselife (days)	Water uptake (mL/day)	Change in fresh weight (g)[x]	Dry weight (g)	Production time (days)[w]
No stress	62.9 a[z]	0.63 a	1.7 a	12.0	15 a	-0.68	1.60 ab	52.9 b
Mild stress	56.4 b	0.56 b	1.2 b	12.8	11 bc	-0.14	1.34 b	56.8 a
M 2w	61.8 a	0.61 a	1.7 a	12.0	15 ab	-0.82	1.57 ab	53.2 b
S 2w	64.8 a	0.54 b	1.6 a	12.7	11 c	-0.25	1.61 a	54.3 b
Significance	0.0001	0.0001	0.0001	NS	0.0041	NS	0.0288	0.0001

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.

[y]Stem diameter measured 1 cm above cut at harvest.

[x]Final fresh weight recorded at termination of vaselife - initial fresh weight at harvest.

[w]Days from planting of seeds.

[NS]Nonsignificant at $P \leq 0.05$.

Table 6. Effect of no or mild water stress for the entire production cycle (no stress, mild stress) or 14 days of mild or severe water stress (M 2w, S 2w) prior to harvest of cut *Lilium* 'Dazzle' stems. Means are an average of 51 to 52 stems for stem length, bud number, stem diameter, and production time; 35 to 38 stems for vase life; 21 to 28 stems for water uptake and change in fresh weight; and 14 to 16 stems for dry weight. Year two – 2007.

Treatment	Stem length (cm)	Buds (no.)	Stem diameter (cm)[y]	Vaselife (days)	Water uptake on day 8 (mL/day)	Change in fresh weight (g)[x]	Dry weight (g)	Production time (days)[w]
No stress	108.2 a	3.7 a[z]	0.62 ab	12.7	17	-13.43 b	3.90 a	61.8 bc
Mild stress	108.2 a	3.5 a	0.60 b	12.2	16	-13.26 b	3.76 a	62.4 b
M 2w	104.3 b	3.5 a	0.62 a	12.5	15	-12.31 b	3.53 ab	61.6 c
S 2w	104.8 b	2.6 b	0.63 a	12.9	17	-10.15 a	2.97 b	63.6 a
Significance	0.0228	0.0001	0.0006	NS	NS	0.0001	0.0005	0.0001

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.

[y]Stem diameter measured 1 cm above cut at harvest.

[x]Final fresh weight recorded at termination of vaselife - initial fresh weight at harvest.

[w]Days from moving bulbs into the greenhouse.

[NS]Nonsignificant at $P \leq 0.05$.

Table 7. Effect of no or mild water stress for the entire production cycle (no stress, mild stress) or 14 days of mild or severe water stress (M 2w, S 2w) prior to harvest of cut *Helianthus* 'Sunbright' stems. Means are an average of 63 stems for stem length, stem diameter, head diameter, and production time; 49 stems for vase life; 21 stems for water uptake and change in fresh weight; and 14 stems for dry weight. Year two – 2007.

Treatment	Stem length (cm)	Stem diameter (cm)[y]	Head diameter (cm)	Vaselife (days)	Water uptake on day 7 (mL/day)	Change in fresh weight (g)[x]	Dry weight (g)	Production time (days)[w]
No stress	70.4 a[z]	0.63 a	1.6 ab	16.1	15	-1.79	1.63	62.0 a
Mild stress	67.3 ab	0.57 b	1.5 b	16.0	13	-1.29	1.70	61.6 ab
M 2w	70.7 a	0.57 bc	1.7 a	16.0	13	-1.22	1.75	61.0 b
S 2w	64.2 b	0.54 c	1.5 b	16.6	13	-0.68	1.59	62.3 a
Significance	0.0001	0.0001	0.0002	NS	NS	NS	NS	0.0002

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.

[y]Stem diameter measured 1 cm above cut at harvest.

[x]Final fresh weight recorded at termination of vaselife - initial fresh weight at harvest.

[w]Days from planting of seeds.

[NS]Nonsignificant at $P \leq 0.05$.

Chapter 3

Postharvest Handling of Cut Roses

(in the format appropriate for submission to HortScience)

Postharvest Handling of Cut Roses

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Postharvest Handling of Cut Roses

Abstract

Various postharvest procedures were conducted on several *Rosa hybrida* L. cultivars to determine the effects on vase life, water uptake, change in fresh weight, stage of opening, and termination criteria. Vase life was influenced by cultivar and vase solution, where commercial preservative solutions resulted in longer vase lives and smaller changes in fresh weight than the controls, but also smaller increases in water uptake. Exogenous ethylene did not affect vase life but lowered water uptake. Application of the anti-ethylene agent, silver thiosulfate (STS) significantly improved vase life in a majority of the cultivars tested, but 1-methylcyclopropene (1-MCP) did not improve vase life over the control. Both vase life and water uptake were reduced when more than one stem was placed in a vase, where placing 10 stems in a vase lowered vase life by 1.4 days and water uptake by up to 10.6 mL/stem/day. Leaving stems dry prior to placing in a vase reduced vase life, but recutting immediately prior to placing in a vase minimized the decline. Rose stems responded positively to increasing the amount of stem removed, where cutting from 1 cm to 15 cm off the stem end improved vase life.

Introduction

The United States cut flower industry faces many challenges due to the difficulty in producing flowers with a long postharvest vase life. Customers may be more wary of purchasing cut flowers than any other flower commodity because the vase life is uncertain.

To ensure a longer vase life, growers must carefully regulate the environmental factors, including postharvest conditions, and postharvest handling methods that influence postharvest performance.

Water uptake. Water uptake may be the most important factor in improving the length of vase life of cut flowers (Halevy, 1979). As the leaves on the flowers transpire, water is drawn up through the xylem. If this process is impeded by a vascular blockage or accelerated by increased stomatal opening, then transpiration will exceed uptake and water deficiency will occur (van Doorn, 1997). Solutes, such as sucrose, 8-hydroxyquinoline citrate (8-HQC), or aluminum sulfate, which are frequently added to vase solutions, can decrease transpiration or increase water uptake (van Doorn, 1997).

Cultivars. The effect of additives or preservatives in vase solutions on rose vase life must also be considered. Adding sucrose to a vase solution will increase the presence of bacteria, so 8-HQC can be added to vase water to minimize occlusions from bacteria. The addition of this chemical to vase water containing *Rosa hybrida* 'Sonia' reduced bacteria levels from 8.4×10^5 cfu/g fresh weight found in the bottom 5 cm segment of the stem to $<1.2 \times 10^2$ cfu/g fresh weight (van Doorn, 1990). A low pH solution, produced by the addition of sodium hypochlorite and a pH 3.0 buffer, also reduced bacteria levels and increased water conductance in several *Rosa* cultivars (Marousky, 1971; van Doorn, 1990). Sucrose decreased water absorption in 'Better Times' roses; however, it extended vase life by suppressing stomatal opening, thus decreasing transpiration (Marousky, 1969; 1971). The

increase in vase life due to sucrose and commercial preservatives containing sucrose on cut roses is dependent on the cultivar and on the concentration of sucrose used. In 'First Red', increasing the concentration of sucrose in a vase solution containing 0.03% aluminum sulfate up to 1.5% increased vase life; however, vase life declined with higher concentrations up to 3% (Singh et al., 2003). Bhattacharjee (1994) found that the use of a preservative solution containing 300 ppm 8-HQC and 10,000 ppm sucrose increased vase life versus using distilled water in a study on 10 rose cultivars; however, the extent of the increase varied by cultivar from 1.01 to 2.67 days. Ketsa et al. (1993) found that using a holding solution containing 5% sucrose and 20 mg silver nitrate significantly improved the vase life of rose cultivars 'Eiffel Tower', 'Swartmore', and 'Yankee' but did not improve vase life of 'King's Ransom' or 'Confidence'.

The effect of ethylene and anti-ethylene agents on cut *Rosa* flowers is varied and appears to be cultivar dependent. RueySong et al. (2001) noted that a 0.1 to 2 ppm exogenous application of ethylene significantly decreased vase life in 'Golden Medal' cut roses but had less of an effect on 'Grand Gala' vase life. Singh et al. (2004) found that silver thiosulfate (STS) improved the vase life in three of seven rose cultivars tested. Contrasting reports exist on the efficacy of 1-methylcyclopropene (1-MCP), with Philosoph-Hadas et al. (2005) finding that treating stems with 0.4 $\mu L \cdot L^{-1}$ 1-MCP for 4 h increased vase life for cut rose cultivars 'Pink Tango', 'Jazz', 'Frisco', and 'Golden Gate', whereas Chamani (2005) found that 1-MCP did not improve vase life in 'First Red'.

Postharvest. Many postharvest handling procedures alter the water relations in cut

flowers, affecting the length of their vase life. Because cut flowers are often transported or stored out of water for long periods of time, cutting procedures to remove or reduce air embolisms and other vascular occlusions must be studied. Vascular occlusions block water flow through the xylem, decreasing water uptake and subsequently decreasing vase life (Durkin and Kuc, 1966). Examination of xylem profiles in cut *Rosa* stems have shown that when kept in distilled water, bacterial contamination occludes the bottom 2.5 cm of the stem, while a carbohydrate substance occludes the stem about 10 cm higher than the level of solution (Lineberger and Steponkus, 1976). Work is needed to determine optimum recutting procedures and amounts to minimize the negative effects of vascular occlusions on vase life.

Objectives

The objectives of this research were to:

1. Determine the variation among *Rosa* cultivars in terms of response to various vase solutions.
2. Quantify the effect of exogenous ethylene and anti-ethylene compounds on postharvest characteristics of several *Rosa* cultivars.
3. Quantify the effect of placing multiple stems in a vase on bacteria counts in vase water and its effect on vase life.
4. Quantify the effect of postharvest dry storage on postharvest performance of cut *Rosa* stems.

Materials and Methods

Postharvest environment. Unless otherwise indicated, treatments and vase life determinations were conducted at 20ºC under 20 to 40 $\mu mol \cdot m^{-2} \cdot s^{-1}$ light for 12 h/day at 40% to 60% relative humidity. Vase life was recorded for every experiment, with vase life termination determined by one or more of the following criteria: the presence of bent neck (Fig. 1), wilted petals (Fig. 2), or the occurrence of black tips (Fig. 3) or petal discoloration (Fig. 4) on at least three petals. Reasons for termination and stage of flower opening were also recorded, where stage of flower opening was ranked on a scale from 0 (tight) to 3 (very open). The experiment was arranged in a completely randomized design with five replications of three stems (subsamples) each. Data were analyzed using analysis of variance (SAS Institute, Cary, NC) and means were separated using Tukey's Studentized range test at $P \leq 0.05$. Trend analysis was also conducted, where appropriate.

Postharvest.

Cultivar evaluations. Colombian-grown *Rosa* stems used in this study were of nine cultivars: 'Black Baccara', 'Black Magic', 'Charlotte', 'Classy', 'First Red', 'Forever Young', 'Freedom', 'Queen 2000', and 'Rouge Baiser'. Within 4 h of receipt, stems of each cultivar were sorted into six uniform groups, based on stem caliper, recut to 45 cm with the lower third of the foliage removed, and placed in quart mason jars (Ball, Muncie, IN) filled with 300 mL of one of six solutions with three stems of the same cultivar per vase: 1) calcium hypochlorite (0.1 g/L) and aluminum sulfate (0.74 g/L) mixed in tap water resulting in a solution pH of 3.7 and EC of 0.73; 2) Chrysal Professional #3 (Pokon and Chrysal, Miami,

FL) (10 g/L) in tap water resulting in a solution pH of 2.8 and EC of 0.49; 3) Floralife® Crystal Clear packets (Floralife, Inc., Walterboro, SC) (10 g/L) in tap water resulting in a solution pH of 3.1 and EC of 0.50; 4) Florissant 600 (Roosendaal, the Netherlands) (1.25 mL/L) in tap water resulting in a solution pH of 3.5 and EC of 0.71; 5) deionized water (pH 3.8, EC 0.00); or 6) tap water (pH 6.6, EC 0.25). Additional solution was added as needed to maintain at least 100 mL. Data included initial wet weight, termination wet weight, and water uptake measured at termination.

Anti-ethylene agents – North Carolina. Colombian-grown *Rosa* stems used in this study were of six cultivars: 'Charlotte', 'Classy', 'First Red', 'Forever Young', 'Freedom', and 'Rouge Baiser'. Upon receipt, stems of each cultivar were sorted into nine uniform groups, based on stem caliper, recut to 35 cm, and the lower third of the foliage removed. Stems were placed in quart mason jars (Ball, Muncie, IN) filled with 400 mL of tap water (pH 6.6, EC 0.25) and three stems per jar. Jars were placed in sealed metal barrels for 4 h containing 1) 1-methylcyclopropene [740 $nL \cdot L^{-1}$, from Ethylbloc™ (Floralife, Inc., Walterboro, SC)]; 2) STS [0.2 mM, 1.0 $mL \cdot L^{-1}$ AVB (Pokon and Chrysal, Miami, FL) in tap water]; or 3) ambient air. After this pre-treatment, jars were resealed in barrels and exposed to 4.0, 0.42, or 0 $\mu L \cdot L^{-1}$ ethylene for 24 h. Additional tap water was added as needed to maintain at least 100 mL.

Anti-ethylene agents – Colombia. Colombian-grown *Rosa* stems used in this study were of four cultivars: 'Anna', 'Charlotte', 'Freedom', and 'Konfetti'. Three 25-stem bunches of each cultivar were treated on the farm in Colombia with either STS or water for 4 h, after which time bunches were packed, stored, and shipped to Raleigh, NC. Bunches were

received nine days after treatment, at which point bunches were transferred to tap water and stems of each cultivar were sorted into four uniform groups, based on stem caliper, recut to 45 cm, and the lower third of the foliage removed. Stems were placed three per quart mason jars (Ball, Muncie, IN) filled with 300 mL of 1) Chrysal Professional #3 (Pokon and Chrysal, Miami, FL) (10g/L) in tap water resulting in a solution pH of 2.8 and EC of 0.49; 2) Floralife® Crystal Clear packets (Floralife, Inc., Walterboro, SC) (10 g/L) in tap water resulting in a solution pH of 3.1 and EC of 0.50; or 3) deionized water (pH 3.8, EC 0.00). Half of the stems in deionized water were exposed to 1.0 $\mu L \cdot L^{-1}$ ethylene in a sealed barrel for 24 h. Additional solution was added as needed to maintain at least 100 mL. Data collected included initial wet weight, wet weight measured four days after placement of stems in vases, and water uptake measured four days after placement of stems in vases.

Stems per vase. Colombian-grown *Rosa* stems used in this study were of three cultivars: 'Charlotte', 'Classy', and 'Freedom'. Upon receipt, stems of each cultivar were sorted into four uniform groups, based on stem caliper, recut to 45 cm, and the lower third of the foliage removed. Stems were placed in quart mason jars (Ball, Muncie, IN) filled with 500 mL of tap water (pH 6.6, EC 0.25), where each jar contained a total of one, three, five, or ten stems of the same cultivar. Additional tap water was added as needed to maintain at least 100 mL. Data collected included water uptake at termination, but not reasons for termination or stage of opening.

Drying time after recutting. Colombian-grown *Rosa* stems used in this study were of three cultivars: 'Charlotte', 'Classy', and 'Freedom'. Unless otherwise noted, upon receipt, stems of each cultivar were sorted into eight uniform groups, based on stem caliper, recut to

48 cm, stripped of the lower third of the foliage, and placed in buckets at 20ºC containing 5 L of tap water to rehydrate overnight. Subsequently, in this experiment, stems were recut to 45 cm and placed dry at 20ºC for 0, 10, 20, 60, or 120 min, or 4, 24, or 48 h prior to being placed in quart mason jars (Ball, Chicago, IL) filled with 500 mL of tap water and three stems per jar. Additional tap water was added as needed to maintain at least 100 mL. Reasons for termination and stage of opening were not recorded.

Drying time before recutting. After rehydration, stems were placed dry at 20ºC for 0, 10, 20, 60, or 120 min, or 4, 24, or 48 h prior to being recut (with a removal of 2.5 cm off the stem base) and placed in quart mason jars (Ball, Muncie, IN) filled with 500 mL of tap water and three stems per jar. Additional tap water was added as needed to maintain at least 100 mL. Reasons for termination and stage of opening were not recorded.

Recutting amount. Upon receipt, stems were sorted for uniformity, recut to 45 cm, stripped of the lower one to two leaves, and placed at 20ºC in buckets containing 5 L of tap water to rehydrate overnight. After rehydration, stems were placed dry at 20ºC for 24 h prior to being recut with a removal of 0, 1, 2, 3, 4, 5, 10, or 15 cm off the stem base and placed in quart mason jars (Ball, Muncie, IN) filled with 500 mL of tap water and three stems per jar. Additional tap water was added as needed to maintain at least 100 mL.

Results

Cultivar evaluations. Of the nine cultivars tested, average rose vase life was between 8.4 days and 13.3 days, where ‘Queen 2000’ had the shortest average vase life and ‘Forever Young’ had the longest average vase life across all treatments (Table 1).

Of the six vase solutions tested, Floralife® Crystal Clear (Floralife) and Chrysal Professional #3 (Chrysal) resulted in the longest average vase life across all cultivars of 12.4 days and 11.7 days, respectively (Table 1). Florissant 600 solution (Florissant) resulted in the shortest average vase life among all cultivars of 5.7 days and produced the shortest vase life in each cultivar. The short vase life resulting from Florissant prevented flowers from opening (Table 2), and in a majority of the cultivars, stems in the Florissant treatment were terminated because of bent neck (Table 3). The two controls, deionized water (DI) and tap water, both produced an intermediate vase life of 10.1 days (Table 1). Most stems in these control treatments were terminated due to wilted petals (Table 4).

Cultivar and vase solution interacted such that the three effective preservative solutions, calcium hypochlorite and aluminum sulfate solution (Ca+Al), Chrysal, and Floralife, produced a similar vase life for all of the nine cultivars tested (Table 1). For 'Black Magic' and 'Forever Young', DI water produced a similar vase life to the preservative solutions, where Floralife produced a significantly longer vase life for 'Black Magic' than either Florissant or tap water and Ca+Al and Chrysal produced significantly longer vase lives for 'Forever Young' than either Florissant or tap water (Table 1). Tap water produced a similar vase life as the preservative solutions for 'Charlotte', where Floralife and tap water resulted in a significantly longer vase life than produced by Florissant or DI water. Floralife produced a significantly longer vase life than Florissant, DI water, and tap water for 'First Red' and 'Queen 2000'. For 'Black Baccara', 'Classy', 'Freedom', and 'Rouge Baiser', Florissant was the only vase solution that produced a significantly different (in this case, shorter) vase life.

Stage of opening varied by cultivar with ‘Charlotte’ remaining most tight when terminated, while ‘Queen 2000’ opened the most (Table 2). Cultivar and vase solution interacted such that for ‘Black Baccara’ and ‘Forever Young’, stage of opening was greatest in Ca+Al, Chrysal, Floralife, and tap water vase solutions. For ‘Black Magic’, ‘Charlotte’, ‘Classy’, and ‘Freedom’ all treatments, but Florissant, resulted in similar stages of opening. For ‘First Red’ and ‘Queen 2000’ only Ca+Al, Chrysal, and Floralife resulted in the greatest flower opening. Stage of opening was not affected by vase solution for ‘Rouge Baiser’.

Across all cultivars, average water uptake was greatest in DI water with an uptake of 8.7 mL/stem/day (data not presented). Average water uptake of ‘Charlotte’ across all solutions was 8.4 mL/stem/day, the greatest of any cultivar (Table 5). Average water uptake of the other eight cultivars ranged from 8.1 mL/stem/day for ‘Black Baccara’ down to 5.7 mL/stem/day for ‘Rouge Baiser’ (data not presented). Cultivar interacted with treatment such that in ‘Black Baccara’, DI water resulted in a significantly greater uptake than both the Ca+Al and Florissant treatments. DI water had significantly greater uptake than Ca+Al, Chrysal, and Floralife for ‘First Red’ and had significantly greater uptake than all other treatments in ‘Queen 2000’. Tap water had greater uptake than Ca+Al and Chrysal for ‘Freedom’. Water uptake was not affected by vase solution for ‘Black Magic’, ‘Charlotte’, ‘Classy’, ‘Forever Young’, and ‘Rouge Baiser’.

Change in wet weight was cultivar dependent, where Floralife and Chrysal, the two commercial consumer solutions, produced the smallest change in wet weight in ‘Black Baccara’, ‘Charlotte’, ‘Forever Young’, and ‘Freedom’, but DI water produced the smallest change in wet weight in ‘Queen 2000’, and ‘Rouge Baiser’ (Table 6). Cultivar and treatment

interacted such that all solutions resulted in similar losses in wet weight except Ca+Al which resulted in a greater wet weight loss in 'Black Baccara', 'Charlotte', and 'Queen 2000'. Change in wet weight was not affected by vase solution for 'Black Magic', 'Classy', and 'First Red'.

Reasons for flower termination varied and were cultivar dependent. 'Black Baccara' and 'Charlotte' developed bent neck more than the other cultivars (Table 3), while 'First Red', 'Queen 2000', and 'Rouge Baiser' were more likely to develop wilted petals (Table 4). 'Black Baccara', 'Black Magic', 'Charlotte', and 'Freedom' developed black tips more often than the other cultivars (Table 7). Cultivar interacted with vase solution in every reason for termination such that the occurrence of bent neck for 'Classy' and 'Freedom' was greatest in Florissant and DI water (Table 3). For 'Charlotte' and 'Rouge Baiser', bent neck occurred most frequently in the Ca+Al and Florissant treatments, as well as DI water for 'Charlotte' and tap water for 'Rouge Baiser'. No differences in the occurrence of bent neck were seen among treatments in 'Black Magic', 'First Red', and 'Queen 2000' and for 'Black Baccara' and 'Forever Young' the only difference in bent neck occurred with the Florissant treatment. Of the nine cultivars tested, only 'Charlotte', 'Classy', and 'Forever Young' exhibited interaction effects between cultivar and vase solution for the occurrence of wilted petals (Table 4). Interactions between cultivar and vase solution for the occurrence of black tip were significant for 'Black Baccara', 'Charlotte', 'Forever Young', 'Freedom', and 'Queen 2000' (Table 7). For 'Queen 2000', Chrysal and Floralife resulted in the greatest occurrence of black tips, while in 'Forever Young' black tips most often occurred in these two treatments as well as the Ca+Al solution. For 'Black Baccara' and 'Charlotte', all solutions

but Florissant resulted in a large percentage of stems that developed black tips.

Anti-ethylene agents – North Carolina. Treating roses with STS significantly improved vase life for 'Charlotte', 'First Red', and 'Freedom' (Table 8). 'Classy', 'Forever Young' and 'Rouge Baiser' were not affected by treatment of stems with anti-ethylene agents. On average, vase life for all cultivars was extended from 7.3 days in the air to 8.6 days in the STS treatment. 'First Red' had the greatest response to STS with an increase in vase life from 5.2 days to 7.6 days. Average vase life was not significantly affected by 1-MCP.

The effect of ethylene concentration was not statistically significant (data not presented). No significant interactions between anti-ethylene agent and ethylene concentration occurred. Average vase life of the cultivars across all treatments ranged from 6.2 days and 6.3 days for 'Rouge Baiser' and 'First Red', respectively, to 9.5 days for 'Freedom' (Table 8).

Reasons for termination varied by cultivar, where 'Classy' and 'Rouge Baiser' had the greatest occurrence of bent neck, 'Freedom' had the greatest occurrence of black tips, 'Forever Young' had the greatest occurrence of petal discoloration, and 'Charlotte', 'First Red', and 'Rouge Baiser' had the greatest occurrence of wilted petals (Table 9).

Anti-ethylene agents – Colombia. Pre-treating roses with an STS application increased vase life by 1.2 days over the control with no significant interactions (Table 10). Cultivar affected vase life, with 'Konfetti' and 'Freedom' having the longest vase lives of 15.4 days and 14.6 days, respectively. STS did not significantly affect water uptake or change in wet weight (data not presented).

Treating the roses with 1 ppm ethylene resulted in the shortest vase life for 'Charlotte' and 'Freedom' but vase life for this treatment was not significantly different than the control in the other two cultivars (Table 11). Vase life varied with the cultivar across all treatments from 8.1 days in 'Anna' to 15.4 days in 'Konfetti' (Table 11). The two previously studied cultivars 'Charlotte' and 'Freedom' had average vase lives of 13.5 days and 14.7 days, respectively.

For all cultivars, water uptake was the lowest for flowers treated with 1 ppm ethylene but varied from a low of 15.3 mL/stem in 'Konfetti' to a high of 23.8 mL/stem in 'Anna' (Table 12). Only 'Freedom' showed a significant improvement in vase life when treated with the preservative solutions, Chrysal and Floralife, over the control, DI water (Table 12).

Stems per vase. Across all cultivars, placing 10 stems in a vase resulted in the shortest vase life of 9.5 days and placing one to five stems in a vase resulted in the longest vase life (Table 13). Average vase life resulting from placing one, three, and five stems in a vase were not significantly different, although one and three stems per vase resulted in a significantly longer vase life than placing 10 stems in a vase. Water uptake across all cultivars increased as fewer stems were placed in a vase, from 6.1 mL/stem/day with 10 stems per vase to 14.1 mL/stem/day with one stem per vase (Table 14). The greatest water uptake, 16.9 mL/stem/day, occurred with one 'Charlotte' stem per vase, while the lowest water uptake, 5.8 mL/stem/day, occurred with 10 'Freedom' stems per vase. Placing one stem per vase resulted in significantly greater water uptake than any of the other treatments in 'Charlotte' and 'Freedom'.

Drying time after recutting. 'Charlotte' and 'Freedom' experienced a decreasing

trend in vase life the longer stems were left dry. However, for 'Charlotte' the only significant difference in vase life occurred from 10.4 days with 0 min drying time to 3.4 days with 240 min drying time after being recut (Fig. 5). For 'Freedom', a vase life of 9.7 days with 0 min. drying time was significantly greater than a vase life of 6.3 days and 6.2 days when stems were left dry for 60 and 240 min., respectively, after being recut. Recutting and allowing 'Classy' stems to dry for 0 to 240 min. did not significantly decrease vase life. 'Charlotte' did not rehydrate at all and 'Freedom' and 'Classy' only had vase lives of 1.7 and 1.5 days respectively when left dry for 24 h after being recut (data not presented). None of the three cultivars tested rehydrated when left dry for 48 h.

Drying time before recutting. Recutting stems immediately (0 min. dry) resulted in the highest vase life for both 'Charlotte' and 'Classy' of 10.2 days and 9.3 days (Fig. 6). Vase life was only significantly reduced when stems were allowed to dry for 24 h for 'Freedom' and 48 h for 'Charlotte' and 'Classy'.

Recutting amount. No significant interactions occurred between cultivar and treatment. Treatment affected vase life such that recutting any amount off the stem significantly improved vase life (Fig. 7). Recutting 10 cm off the stems resulted in the maximum vase life of 8.4 days and recutting 0 cm off the stems resulted in the minimum vase life of 5.3 days.

Discussion

Cultivar evaluations. The cultivars differed in vase life and in stage of opening at termination, which is consistent with previous cultivar studies (Table 1). Nell and Leonard

(2004) reported a difference of up to 10 days among vase lives of 16 rose varieties and a range in stage of opening from 1.3 to 3.9 on a 1 to 4 scale. In the study, 'Classy' lasted 0.6 days longer than 'Charlotte', the same difference in average vase life for these two cultivars in the current study (Table 1). 'First Red' also had a longer vase life than 'Black Magic', which is consistent with this study (Table 1). Durkin and Kuc (1966) found a 6 day difference among four rose varieties, while in this study, vase life varied by 4.9 days among the nine cultivars.

Florissant proved to be the least effective vase solution, producing shorter vase lives than all other solutions (Table 1). When mixed, Florissant left a cloudy residue at the bottom of the vase, indicating that perhaps the product was improperly stored during shipping and thus was not effective. Not surprisingly, Floralife and Chrysal, the other two commercial floral preservatives tested in this study, produced the highest vase lives of all treatments (Table 1). These two preservatives contain a sucrose component, which has been shown to increase vase life (Marousky, 1969, 1971; Mor et al., 1989).

Average water uptake was greatest in both the tap water and DI water control treatments for all cultivars but 'Rouge Baiser' (Table 5). Though water uptake has been shown to be positively correlated with vase life (Hettiarachchi and Balas, 2005), uptake can be inhibited by the addition of sucrose to a vase solution (Marousky, 1971). This reduction in uptake is thought to be due to the high osmotic potential of concentrated sucrose solutions and the ability of sucrose to induce closure of stomates (Marousky, 1969; 1971). In the cultivar evaluations study, treatments containing sucrose, Floralife and Chrysal, had lower water uptake than the controls (Table 5), but also longer vase lives (Table 1). These

treatments also reduced losses in wet weight (Table 6). Marousky (1969) found similar results with cut 'Better Times' roses and concluded that because floral preservatives helped maintain fresh weight, while still causing less water uptake, measuring remaining solution in a vase to determine transpiration did not yield accurate results. Variability among cultivars as to the effect of solution treatment of water uptake may be due to differences in xylem anatomy, which has been shown to greatly influence hydraulic conductivity (Nijsse et al., 2001). Van Doorn and Reid (1995) did not find significant differences in xylem anatomy among rose cultivars 'Frisco', 'Sonia', 'Madelon', and 'Cara Mia'; however, Twumasi (2005) found that water availability during preharvest environment can affect xylem vessel diameter. Since all cultivars were not tested at the same time or produced in the same greenhouses, it is possible that some cultivars experienced more water stress than others due to environmental conditions during their growth, which might have affected the xylem properties within the cultivars.

Average wet weight loss was lowest in the two preservative treatments (Table 6), which is consistent with the findings of Ichimura (1999) and Marousky (1969; 1971) that sucrose increases fresh weight due to its ability to increase carbohydrate levels in petals and induce stomatal closure. Average change in wet weight was variable among cultivars, with treatments causing no significant differences in change in wet weight in 'Black Magic', 'Classy', and 'First Red'.

Termination criteria proved to be cultivar dependent with several cultivars, such as 'Black Baccara' and 'Charlotte', being more susceptible to postharvest problems than others (Tables 3, 4, and 7); however, in general cultivars were terminated because the stems had

developed multiple problems throughout its vase life. Physiological processes occurring in cut rose stems are complex and often interrelated such that determining the specific causes of problems developed in the stem is difficult (Zieslin, 1989). A common cause of rose termination is bent neck, which has been attributed to the presence of embolisms in the stem that restrict water flow (Burdett, 1970). These embolisms are thought to be mostly bacterial in nature (Burdett, 1970; Reid et al., 1996), such that the addition of compounds with bactericidal effects greatly reduces the occurrence of bent neck (Ohkawa, 1999). However, water flow restriction has also been attributed to blockage caused by particulates clogging the xylem (Burdett, 1970; Reid et al., 1996). These physical blockages have been shown to occur about 10 cm above the level of the vase solution (Lineberger and Steponkus, 1976). In the current study, Florissant produced the highest occurrence of bent neck in every cultivar, except 'Rouge Baiser' which did not exhibit bent neck (Table 3). The observed cloudiness in the vase solution could have been due to precipitation of particulates that occluded the stems and led to the development of bent neck. Blackening of petal tips was another commonly observed problem in several cultivars in the current study (Table 7). Similar tip blackening has also been shown to appear in other red rose cultivars such as 'Mercedes' and 'Jaguar', where black tip development was attributed to both an exposure to ultraviolet radiation and low temperatures during growth (Jaffrin, 2002, Mor and Zieslin, 1990; Raviv, 1988). Barendse (1981) also observed petal tip blackening in *Gerbera* 'Roeland' due to the use of Rosal, a vase life preservative, which is consistent with the results of the current study where black tip was most prevalent in the commercial preservative treatments (Table 7). Stems were also terminated due to wilted petals which was the most common reason for termination

in all cultivars (Table 4). This wilting is most likely due to high transpiration losses that exceed water uptake at some point during vase life and trigger wilting when insufficient water is available to the petals (Carpenter and Rasmussen, 1973).

Anti-ethylene agents. STS significantly increased vase life in three of the six cultivars treated in North Carolina, with 'First Red' and 'Freedom' having at least a two day increase in vase life when treated with STS as compared to the control (Table 8). Pre-treating stems with STS in Colombia prior to shipping significantly increased vase life by 1.2 days across all cultivars (Table 10). Similarly, Singh et al. (2004) reported an increase in vase life due to STS in rose cultivars 'Grand Gala', 'Sangria', and 'Kiss' but not in four other cultivars tested. Mor et al. (1989) reported a 2.7 day increase in vase life in 'Gabriella' roses that were treated with STS. Chamani et al. (2005) found that a 0.5 mM STS application increased vase life in 'First Red', but 1-MCP did not, which is consistent with the results for 'First Red' and the other five cultivars tested in this study where 1-MCP did not significantly improve vase life (Table 8). Philosoph-Hadas et al. (2005) observed that 1-MCP is more effective in improving vase life when applied at low temperatures, which may be why 1-MCP was ineffective in this study.

Treating the rose cultivars with exogenous ethylene did not affect vase life (Table 11). This is consistent with previous studies which have found that sensitivity to ethylene can vary within rose cultivars (Mor et al., 1989, RueySong et al., 2001), where some cultivars, such as 'Cara Mia', 'Sonia', and 'Gold Rush' do not exhibit as many deleterious effects to ethylene as other cultivars (Reid et al., 1989). Lukaszewska et al. (1990) reported that a 7 day exposure to ethylene was needed for an increase in petal drop to be observed.

Though an exogenous ethylene application did not affect vase life, it did decrease water uptake (Table 12). Similarly, Mayak et al. (1977) found that applying ethylene to carnation stems drastically decreased water uptake after 4 h by altering cell membrane permeability, thus increasing ion efflux and lowering turgor pressure.

The increases in vase life due to STS, while exogenous ethylene had no effect, reveals that STS must be playing another role in the stem other than acting solely as an anti-ethylene agent. Similarly, STS improved vase life regardless of exogenous ethylene application for cut 'First Red' and 'Sonia' roses (Chamani et al., 2005; Lukaszewska et al., 1990). Even though the primary use of STS is ethylene inhibition, STS has also been shown to exhibit antimicrobial characteristics (Al-Humaid, 2004), which could be why vase life was improved in stems treated with STS even when exogenous ethylene had no effect.

Vase solution did not affect vase life (Table 11) and only affected water uptake for 'Freedom' (Table 12). DI water resulted in lower water uptake than the preservative treatments in this case, which is inconsistent with the findings in the cultivar evaluations study for the effects of preservative solutions on water uptake (Table 5). However, for the current experiment, uptake was recorded four days after the start of vase life instead of at termination, which could account for the difference observed.

Stems per vase. Increasing the number of stems per vase decreased vase life by up to 1.4 days (Table 13). Water uptake also decreased by up to 10.6 mL/stem/day with an increase in stem number from one stem per vase to ten stems per vase. This decrease in both vase life and water uptake could be due to greater amounts of bacteria and cellular contents in the vase water from the increased number of stems per vase, which clog the stem xylem

and increase water flow resistance (Burdett, 1970). Decreased water uptake has been shown to decrease vase life when there are no carbohydrates in the vase water (Burdett, 1970).

Drying time and recutting. Letting cut rose stems dry for any amount of time prior to placement in solution caused a decrease in vase life; however, the extent of that decrease was dependent on cultivar and at what point in time the stems were recut. The vase lives of 'Charlotte' and 'Freedom' both declined the longer the stems were left dry after being recut (Fig. 5), but vase life could be improved if the stems were recut after being left dry (Fig. 6). 'Classy' was more durable, keeping a fairly constant average vase life of 5.6 days when left dry for up to 240 min after being recut. Recutting stems of 'Classy' and 'Charlotte' immediately prior to placing in vases did not significantly reduce vase life for up to 24 h. Leaving stems dry for 48 hours with any cultivar is not recommended because this resulted in either the inability of the stems to rehydrate when recut prior to experiencing water stress or a decreased vase life when recut after experiencing water stress. Certainly, rose stems are regularly shipped and stored dry for 48 h or more. However, in those cases temperatures are typically much cooler than the 20°C used in this study. Nell and Leonard (2005) found that warm temperatures even as low as 10°C decreased vase life by up to 8 days in 13 of the 14 cultivars tested. Recutting any amount off the stem ends improved vase life, with a 10 cm removal resulted in the highest average vase life (Fig. 7).

Conclusion

Although vase life varied by cultivar, commercial preservatives should be used in vase solutions to maximize the vase life of cut roses. Preservative solutions produced a

lower water uptake per day than control solutions but also minimized losses in fresh weight. Ethylene effects on vase life were not pronounced, though use of the anti-ethylene agent silver thiosulfate (STS) significantly improved vase life in several cultivars, possibly due to its anti-microbial properties. Placing more than one stem per vase reduced water uptake but vase life was only significantly reduced by placing 10 stems in a vase. Recutting stem ends before placing in water was effective in minimizing losses in vase life due to long exposure of stems to air, where recutting 10 cm off stem ends resulted in roses with the longest vase life.

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Table 1. Effect of vase solutions [calcium hypochlorite and aluminum sulfate (Ca+Al), Chrysal Professional #3 (Chrysal), Floralife Crystal Clear (Floralife), Florissant 600 (Florissant), deionized (DI) water, and tap water] on vase life (days) of nine *Rosa* cultivars. Means are an average of five replications of three stems each.

Treatment	Black Baccara	Black Magic	Charlotte	Classy	First Red	Forever Young	Freedom	Queen 2000	Rouge Baiser	Average[y]
Ca+Al	10.1 a[z]	9.3 ab	9.3 ab	10.2 a	11.3 abc	16.1 a	12.7 a	9.0 ab	12.9 a	11.2
Chrysal	11.3 a	8.8 ab	10.7 ab	11.3 a	11.9 ab	16.2 a	13.9 a	9.7 ab	11.6 a	11.7
Floralife	10.7 a	11.1 a	11.1 a	10.9 a	12.3 a	15.2 ab	13.6 a	11.5 a	15.1 a	12.4
Florissant	3.4 b	6.8 b	4.1 c	6.0 b	6.5 d	5.5 c	7.9 b	5.7 c	5.8 b	5.7
DI water	8.6 a	8.4 ab	8.4 b	9.8 a	9.7 c	15.3 ab	11.9 a	7.1 bc	11.9 a	10.1
Tap water	9.3 a	7.5 b	10.9 a	9.9 a	10.0 bc	11.7 b	13.1 a	7.1 bc	11.8 a	10.1
Significance	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	
Average[x]	8.9	8.7	9.1	9.7	10.3	13.3	12.2	8.4	11.5	
Overall significance										
Cultivar		0.0001								
Treatment		0.0001								
Cultivar*treatment		0.0001								

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.

[y]Across all cultivars.

[x]Across all treatments.

Table 2. Effect of vase solutions [calcium hypochlorite and aluminum sulfate (Ca+Al), Chrysal Professional #3 (Chrysal), Floralife Crystal Clear (Floralife), Florissant 600 (Florissant), deionized (DI) water, and tap water] on stage of opening (0=tight to 3=very open) of nine *Rosa* cultivars. Means are an average of five replicates of three stems each.

Treatment	Black Baccara	Black Magic	Charlotte	Classy	First Red	Forever Young	Freedom	Queen 2000	Rouge Baiser
Ca+Al	1.8 a[z]	2.2 ab	1.6 a	2.1 a	1.9 ab	1.9 ab	1.6 a	2.9 a	2.1
Chrysal	1.7 ab	2.5 a	1.5 a	1.8 a	2.2 a	2.0 a	1.7 a	2.7 ab	2.3
Floralife	1.7 ab	2.4 ab	1.5 a	1.7 a	2.3 a	1.7 ab	1.9 a	3.0 a	2.3
Florissant	0.1 c	1.8 b	0.1 b	0.3 b	1.3 b	1.1 c	0.8 b	2.1 c	2.1
DI water	1.1 b	2.1 ab	0.9 ab	1.9 a	1.2 b	1.4 bc	1.7 a	2.4 bc	2.3
Tap water	1.3 ab	2.1 ab	1.5 a	1.8 a	1.3 b	1.6 abc	1.9 a	2.1 c	2.3
Significance	0.0001	0.0202	0.0001	0.0001	0.0007	0.0012	0.0007	0.0001	NS
Overall significance									
Cultivar		0.0001							
Treatment		0.0001							
Cultivar*treatment		0.0001							

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.

[NS]Nonsignificant at $P \leq 0.05$.

Table 3. Effect of vase solutions [calcium hypochlorite and aluminum sulfate (Ca+Al), Chrysal Professional #3 (Chrysal), Floralife Crystal Clear (Floralife), Florissant 600 (Florissant), deionized (DI) water, and tap water] on occurrence of bent neck (% of stems) of nine *Rosa* cultivars. Means are an average of five replicates of three stems each.

Treatment	Black Baccara	Black Magic	Charlotte	Classy	First Red	Forever Young	Freedom	Queen 2000	Rouge Baiser
Ca+Al	0 b[z]	0	33 ab	7 c	0	0 b	20 bc	0	7 ab
Chrysal	13 b	0	13 b	0 c	0	0 b	0 c	0	0 b
Floralife	27 b	0	7 b	7 c	0	13 b	0 c	0	0 b
Florissant	100 a	7	73 a	73 a	13	73 a	73 a	0	47 a
DI water	40 b	0	37 ab	53 ab	0	20 b	47 ab	0	0 b
Tap water	13 b	0	13 b	20 bc	0	0 b	7 c	0	27 ab
Significance	0.0001	NS	0.0006	0.0001	NS	0.0001	0.0001	NS	0.0122
Overall significance									
Cultivar		0.0001							
Treatment		0.0001							
Cultivar*treatment		0.0001							

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.

[NS]Nonsignificant at $P \leq 0.05$.

Table 4. Effect of vase solutions [calcium hypochlorite and aluminum sulfate (Ca+Al), Chrysal Professional #3 (Chrysal), Floralife Crystal Clear (Floralife), Florissant 600 (Florissant), deionized (DI) water, and tap water] on occurrence of wilted petals (% of stems) of nine *Rosa* cultivars. Means are an average of five replicates of three stems each.

Treatment	Black Baccara	Black Magic	Charlotte	Classy	First Red	Forever Young	Freedom	Queen 2000	Rouge Baiser
Ca+Al	93	53	27 b[z]	87 a	87	93 a	47	100	93
Chrysal	67	53	33 ab	87 a	87	33 cd	73	93	87
Floralife	73	67	80 a	80 a	93	73 abc	47	93	100
Florissant	80	87	20 b	33 b	93	40 bcd	53	100	87
DI water	93	73	47 ab	87 a	100	87 ab	40	100	80
Tap water	93	73	53 ab	80 a	100	20 d	53	100	100
Significance	NS	NS	0.021	0.0011	NS	0.0002	NS	NS	NS

Overall significance	
Cultivar	0.0001
Treatment	0.0162
Cultivar*treatment	0.0001

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.

[NS]Nonsignificant at $P \leq 0.05$.

Table 5. Effect of vase solutions [calcium hypochlorite and aluminum sulfate (Ca+Al), Chrysal Professional #3 (Chrysal), Floralife Crystal Clear (Floralife), Florissant 600 (Florissant), deionized (DI) water, and tap water] on water uptake (mL/stem/day) of nine *Rosa* cultivars. Means are an average of five replicates of three stems each.

Treatment	Black Baccara	Black Magic	Charlotte	Classy	First Red	Forever Young	Freedom	Queen 2000	Rouge Baiser
Ca+Al	6.9 b[z]	6.9	7.6	6.1	5.4 bcd	5.3	4.3 c	6.0 cd	5.0
Chrysal	8.5 ab	7.5	8.0	6.9	4.9 d	7.1	6.1 bc	7.8 bc	7.3
Floralife	8.2 ab	7.2	8.5	7.8	5.2 cd	7.0	8.1 ab	7.1 bcd	5.6
Florissant	5.7 b	8.7	8.4	7.3	7.6 ab	5.7	7.3 abc	5.1 d	5.7
DI water	10.7 a	9.3	8.1	9.4	8.1 a	7.2	9.1 ab	11.2 a	5.1
Tap water	8.3 ab	7.8	9.7	7.8	7.2 abc	6.7	9.6 a	8.7 b	5.5
Significance	0.0036	NS	NS	NS	0.0003	NS	0.0009	0.0001	NS

Overall significance	
Cultivar	0.0001
Treatment	0.0001
Cultivar*treatment	0.0001

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.

[NS]Nonsignificant at $P \leq 0.05$.

Table 6. Effect of vase solutions [calcium hypochlorite and aluminum sulfate (Ca+Al), Chrysal Professional #3 (Chrysal), Floralife Crystal Clear (Floralife), Florissant 600 (Florissant), deionized (DI) water, and tap water] on change in wet weight (g) of nine *Rosa* cultivars. Means are an average of five stems.

Treatment	Black Baccara	Black Magic	Charlotte	Classy	First Red	Forever Young	Freedom	Queen 2000	Rouge Baiser
Ca+Al	-4.60 b[z]	-5.82	-2.96 b	-5.52	-3.40	-5.72 c	-8.50 c	-7.14 b	-3.78 b
Chrysal	-1.96 ab	-1.68	0.04 a	-2.24	-3.40	0.50 a	-2.16 ab	-2.42 ab	-1.70 ab
Floralife	0.08 a	-1.98	-0.64 a	-0.20	-4.20	-2.18 ab	-1.78 a	-3.16 ab	-2.16 ab
Florissant	-0.82 a	-3.25	-1.30 ab	-3.62	-4.82	-3.12 bc	-7.64 c	-2.52 ab	-2.40 ab
DI water	-0.88 a	-3.00	-1.76 ab	-1.30	-3.14	-3.92 bc	-5.36 bc	-2.04 a	-0.70 a
Tap water	-2.58 ab	-3.38	-1.68 ab	-2.24	-4.06	-2.70 b	-3.46 ab	-3.02 ab	-3.66 b
Significance	0.0004	NS	0.0019	NS	NS	0.0001	0.0001	0.0434	0.0173
Overall significance									
Cultivar		0.0001							
Treatment		0.0001							
Cultivar*treatment		0.0053							

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.

[NS]Nonsignificant at $P \leq 0.05$.

Table 7. Effect of vase solutions [calcium hypochlorite and aluminum sulfate (Ca+Al), Chrysal Professional #3 (Chrysal), Floralife Crystal Clear (Floralife), Florissant 600 (Florissant), deionized (DI) water, and tap water] on occurrence of black tip (% of stems) of nine *Rosa* cultivars. Means are an average of five replicates of three stems each.

Treatment	Black Baccara	Black Magic	Charlotte	Classy	First Red	Forever Young	Freedom	Queen 2000	Rouge Baiser
Ca+Al	67 a[z]	20	33 ab	7	27	13 ab	47 b	0 b	0
Chrysal	67 a	27	67 a	27	33	47 a	93 a	27 ab	7
Floralife	60 a	33	73 a	20	33	27 ab	93 a	47 a	0
Florissant	7 b	53	7 b	0	7	0 b	47 b	0 b	0
DI water	47 ab	20	40 ab	0	7	7 b	53 b	0 b	0
Tap water	47 ab	40	73 a	7	20	7 b	67 ab	0 b	0
Significance	0.0096	NS	0.0004	NS	NS	0.0134	0.0181	0.0003	NS
Overall significance									
Cultivar		0.0001							
Treatment		0.0001							
Cultivar*treatment		0.0060							

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.

[NS]Nonsignificant at $P \leq 0.05$.

Table 8. Effect of 1-MCP, STS, or air (control) on vase life (days) of six *Rosa* cultivars. Stems were treated in North Carolina. Means are an average of 13 to 15 replicates of three stems each.

Treatment	Charlotte	Classy	First Red	Forever Young	Freedom	Rouge Baiser
1-MCP	8.6 ab[z]	8.1	6.0 b	9.0	9.2 b	6.0
STS	9.2 a	8.5	7.6 a	9.4	10.6 a	6.5
Air	7.4 b	7.2	5.2 b	9.3	8.6 b	6.1
Significance	0.0113	NS	0.0001	NS	0.0001	NS
Overall significance						
Cultivar		0.0001				
Treatment		0.0001				
Cultivar*treatment		0.0129				

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.
[NS]Nonsignificant at $P \leq 0.05$.

Table 9. Effect of cultivar ('Charlotte', 'Classy', 'First Red', 'Forever Young', 'Freedom', and 'Rouge Baiser') on occurrence of termination criteria (%). Means are an average of 43 to 45 stems.

Treatment	Bent neck	Black tips	Petal discoloration	Wilted petals
Charlotte	11.9 bc[z]	33.3 b	4.4 d	93.3 ab
Classy	25.4 a	3.0 c	51.5 b	81.8 b
First Red	0.7 c	6.7 c	26.7 c	94.8 ab
Forever Young	0.7 c	4.4 c	85.2 a	54.1 c
Freedom	5.2 bc	77.0 a	10.4 d	57.0 c
Rouge Baiser	16.7 ab	1.2 c	16.3 cd	98.8 a
Significance	0.0001	0.0001	0.0001	0.0001

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.

Table 10. Effect of cultivar ('Anna', 'Charlotte', 'Freedom', and 'Konfetti') and pretreatment [STS and water (control)] on vase life (days) of four *Rosa* cultivars. Means are an average of 40 replicates of three stems each for cultivar and 80 replicates of three stems each for pretreatment.

	Vase life
Cultivar	
Anna	8.1 c[z]
Charlotte	13.5 b
Freedom	14.6 a
Konfetti	15.4 a
Significance	0.0001
Pretreatment	
STS	13.5 a[z]
Water	12.3 b
Significance	0.0001

[z]Means within cultivar or pretreatment followed by the same letter are not significantly difference at $P \leq 0.05$

Table 11. Effect of Chrysal Professional #3 (Chrysal), Floralife Crystal Clear (Floralife), deionized (DI) water, and 1.0 ppm ethylene plus deionized water (Ethylene+DI) on vase life (days) of four *Rosa* cultivars. Means are an average of ten replicates of three stems each.

Treatment	Anna	Charlotte	Freedom	Konfetti
Chrysal	7.9	14.9 a[z]	15.2 a	15.3
Floralife	7.6	14.4 a	15.5 a	14.9
DI	8.2	13.0 ab	14.6 ab	15.5
Ethylene+DI	8.5	11.8 b	13.3 b	15.9
Significance	NS	0.0037	0.0108	NS
Overall significance				
Cultivar	0.0001			
Treatment	NS			
Cultivar*treatment	0.0014			

[z]Means followed by the same letter are not significantly difference at $P \leq 0.05$

[NS]Nonsignificant at $P \leq 0.05$.

Table 12. Effect of Chrysal Professional #3 (Chrysal), Floralife Crystal Clear (Floralife), deionized (DI) water, and 1.0 ppm ethylene plus deionized water (Ethylene+DI) on water uptake (mL/stem) measured four days after placement of stems in vase on four *Rosa* cultivars. Means are an average of ten replicates of three stems each.

Treatment	Anna	Charlotte	Freedom	Konfetti
Chrysal	33.2 a[z]	33.7 a	32.3 a	23.3 a
Floralife	30.7 a	30.3 a	29.5 a	20.7 a
DI	31.5 a	27.8 a	23.0 b	19.3 ab
Ethylene+DI	23.8 b	19.0 b	18.7 b	15.3 b
Significance	0.0001	0.0001	0.0001	0.0001
Overall significance				
Cultivar	0.0001			
Treatment	0.0001			
Cultivar*treatment	0.0176			

[z]Means followed by the same letter are not significantly difference at $P \leq 0.05$

Table 13. Effect of stem number per vase on vase life (days) of 'Charlotte', 'Classy', and 'Freedom' *Rosa* cultivars. Means are an average of 30 vases where each vase contains one, three, five, or ten stems.

Number of stems/vase	Vase life (days)
1	10.9 a[z]
3	10.5 a
5	10.2 ab
10	9.5 b
Significance	0.0022

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.

Table 14. Effect of stem number per vase on water uptake (mL/stem/day) of 'Charlotte', 'Classy', and 'Freedom' *Rosa* cultivars. Means are an average of ten vases where each vase contains one, three, five, or ten stems.

Number of stems/vase	Charlotte	Classy	Freedom	Average[y]
1	16.9 a[z]	12.2 a	13.3 a	14.1
3	8.5 b	9.0 b	7.7 b	8.4
5	8.5 b	7.2 bc	6.8 b	7.5
10	6.3 b	6.2 c	5.8 b	6.1
Significance	0.0001	0.0001	0.0001	
Overall significance				
Cultivar	0.0013			
Stems/vase	0.0001			
Cultivar*stems/vase	0.0067			

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.
[y]Across all treatments.

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stems. Interactions between cultivar and treatment were not significant at the $P \leq 0.05$ level. Treatment means were significantly different ($P=0.0001$). Data was significant at the quadratic level ($P=0.0001$).

Fig. 1. Termination criteria - bent neck exhibited on ‘Black Baccara’.

Fig. 2. Termination criteria – wilted petals exhibited on ‘Rouge Baiser’.

Fig. 3. Termination criteria – black tips exhibited on ‘Charlotte’.

Fig. 4. Termination criteria – petal discoloration exhibited on ‘Classy’.

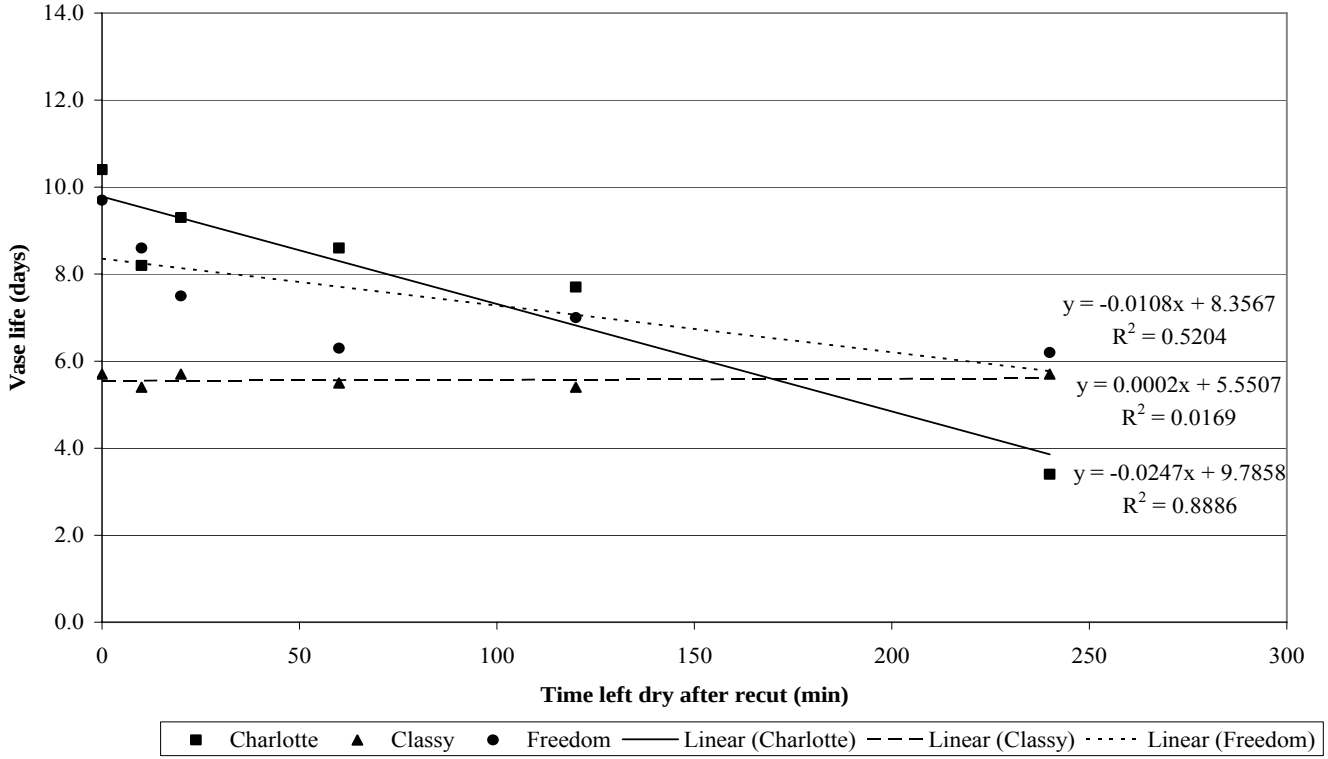

Fig. 5. Effect of drying time after recutting on vase life of *Rosa* 'Charlotte', 'Classy', and 'Freedom' stems. Treatment means were significantly different for 'Charlotte' and 'Freedom' (P=0.0001; P=0.0137). Data was linearly significant ($P \leq 0.0001$). Treatment means were not significantly different at $P \leq 0.05$ for 'Classy'. Interactions between cultivar and treatment were significant (P=0.0001).

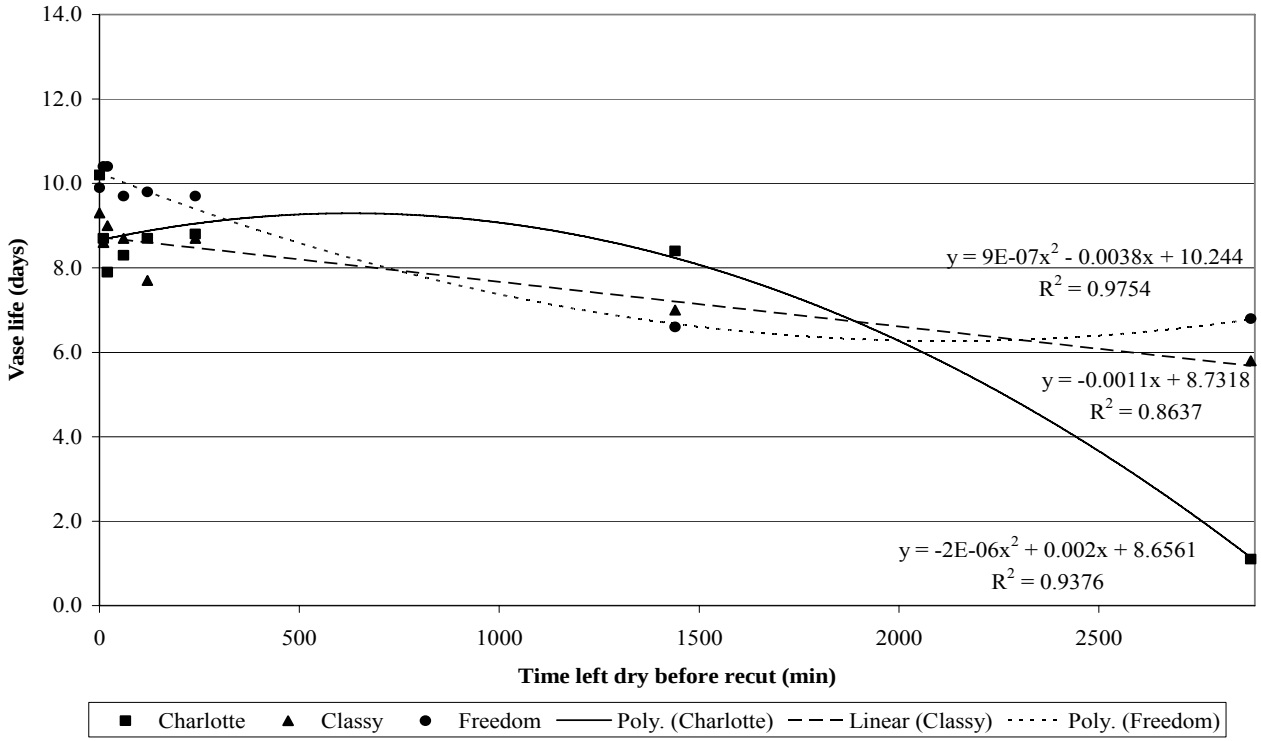

Fig. 6. Effect of drying time before recutting on vase life of *Rosa* 'Charlotte', 'Classy', and 'Freedom' stems. Treatment means were significantly different for 'Charlotte', 'Classy', and 'Freedom' (P=0.0001; P=0.0016; P=0.0001). Data was significant at the quadratic level for 'Charlotte' and 'Freedom' (P=0.0036; P=0.0033). Data was linearly significant for 'Classy' (P=0.0001). Interactions between cultivar and treatment were significant (P=0.0005).

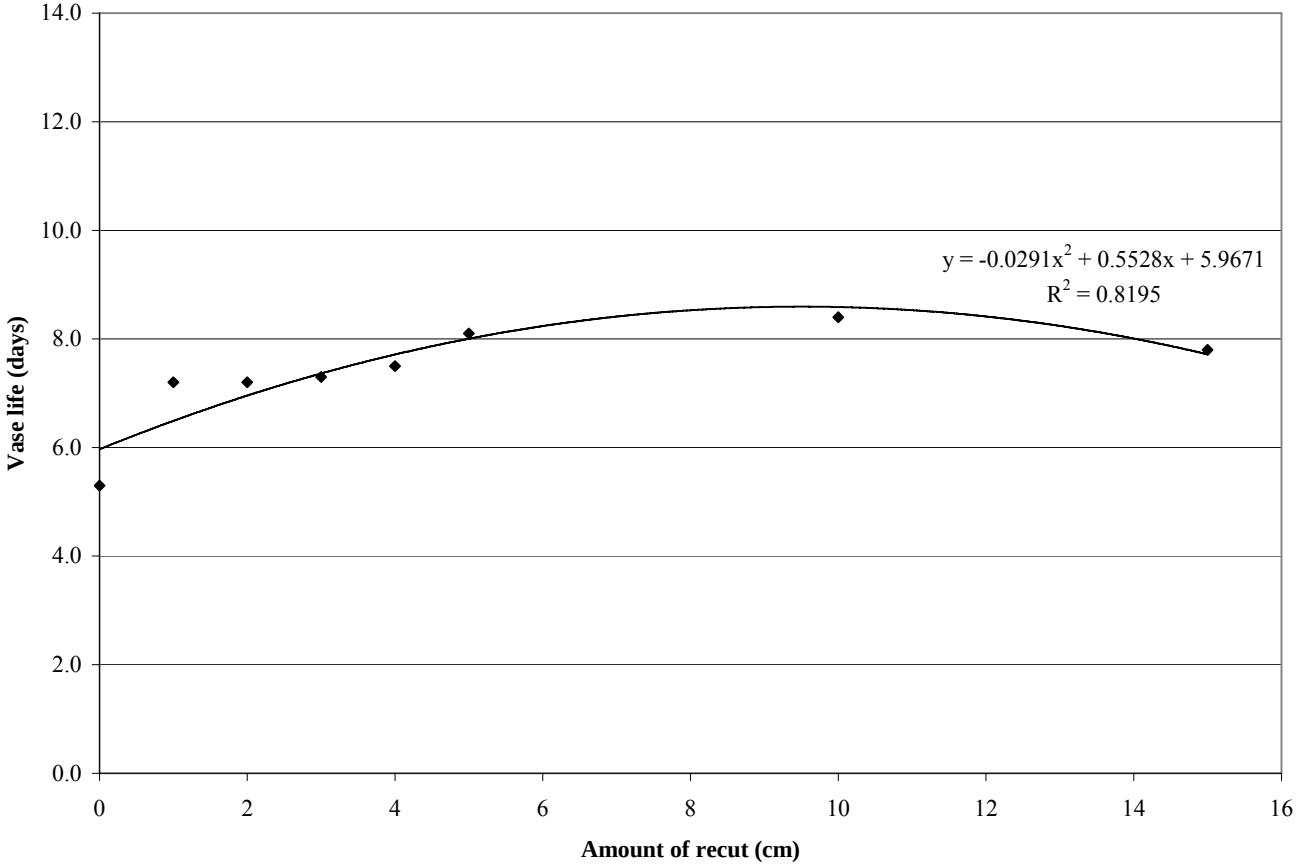

Fig. 7. Effect of recutting amount on vase life of *Rosa* 'Charlotte', 'Classy', and 'Freedom' stems. Interactions between cultivar and treatment were not significant at the $P \leq 0.05$ level. Treatment means were significantly different ($P=0.0001$). Data was significant at the quadratic level ($P=0.0001$).

Chapter 4

Postharvest Handling of Cut Sunflowers

(in the format appropriate for submission to HortScience)

Postharvest Handling of Cut Sunflowers

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Postharvest Handling of Cut Sunflowers

Abstract

Helianthus annuus L. is a commercially important species in the cut flower industry, but more work is needed to determine optimal postharvest handling procedures necessary for maximizing vase life. Drying stems of *Helianthus* 'Sunbright' for up to 48 h did not significantly reduce vase life when stems were recut after drying time. Vase life was affected by storage temperature such that the longest vase life of 13.2 days occurred when stems were stored for 3 days at 5° C then placed in the postharvest evaluation room at 20°C. Placing more sunflower stems in a vase did not statistically affect vase life.

Introduction

The United States cut flower industry faces many challenges due to the difficulty in producing flowers with a long postharvest vase life. Customers may be more wary of purchasing cut flowers than any other flower commodity because the vase life is uncertain. To ensure a longer vase life, growers must carefully regulate the environmental factors, including postharvest conditions, and postharvest handling methods that influence postharvest performance.

Water uptake. Water uptake may be the most important factor in improving the length of vase life of cut flowers (Halevy, 1979). As the leaves on the flowers transpire, water is drawn up through the xylem. If this process is impeded by a vascular blockage or accelerated by increased stomatal opening, then transpiration will exceed uptake and water

deficiency will occur (van Doorn, 1997). Solutes, such as sucrose, 8-hydroxyquinoline citrate (8-HQC), or aluminum sulfate, which are frequently added to vase solutions, can decrease transpiration or increase water uptake (van Doorn, 1997).

Postharvest. Many postharvest handling procedures alter the water relations in cut flowers, affecting the length of their vase life. Because cut flowers are often transported or stored out of water for long periods of time, cutting procedures to remove or reduce air embolisms and other vascular occlusions must be studied. Vascular occlusions block water flow through the xylem, decreasing water uptake and subsequently decreasing vase life (Durkin and Kuc, 1966). Examination of xylem profiles in cut *Rosa* stems have shown that when kept in distilled water, bacterial contamination occludes the bottom 2.5 cm of the stem, while a carbohydrate substance occludes the stem about 10 cm higher than the level of solution (Lineberger and Steponkus, 1976). Work is needed to determine optimum recutting procedures and amounts to minimize the negative effects of vascular occlusions on vase life.

In addition, recommendations typically call for recutting the stems while under water to prevent air embolisms. However, recent work indicates that recutting under water should be done only when the water is clean, otherwise bacterial contamination negates the benefits of recutting (Nell and Reid, 2004). Work is needed to determine if increasing the number of stems per vase will increase bacterial contamination and subsequently decrease vase life.

Temperature can also influence postharvest performance. Flowers typically spend several days in storage or transport where they might be subjected to high temperatures, increasing their transpiration and negatively affecting their vase life. High temperature stress has been shown to negatively impact the vase life of several *Rosa* cultivars, with other

cultivars being unaffected (Nell and Leonard, 2005). Because of the variability among flowers to the tolerance of hot and cold temperatures, more work is needed to determine how temperature influences vase life in *Helianthus*.

Objectives

The objectives of this research were to:

1. Quantify the effect of postharvest dry storage on postharvest performance of cut *Helianthus* stems.
2. Determine the optimum postharvest recutting procedures for cut *Helianthus* stems.
3. Quantify the effect of placing multiple stems in a vase on bacteria counts in vase water and its effect on vase life.
4. Determine the optimum postharvest storage temperatures for cut *Helianthus* stems.

Materials and Methods

Postharvest environment. Unless otherwise indicated, treatments and vase life determinations were conducted at 20ºC under 20 to 40 $\mu mol \cdot m^{-2} \cdot s^{-1}$ light for 12 h/day at 40% to 60% relative humidity. Vase life was recorded for every experiment, with vase life termination determined by one or more of the following criteria: stem collapse, brown petals, wilted petals, and loss of petals. Reasons for termination were also recorded. The experiment was arranged in a completely randomized design with 5 replications of three stems (subsamples) each. Data were analyzed using analysis of variance (SAS Institute, Cary, NC) and means were separated using Tukey's Studentized range test at $P \leq 0.05$. Trend

analysis was also conducted, where appropriate.

Postharvest.

Drying time after recutting. Field-grown *Helianthus* 'Sunbright' stems were cut 9 Sept. 2006 in the field, sorted into eight uniform groups, based on stem caliper, flower head size, and opening of flower, of 15 stems each, recut to 48 cm, lower third of the foliage was removed, and stems were placed at 20ºC in buckets containing 5 L of tap water (pH 6.6, EC 0.25), to rehydrate overnight. Subsequently, stems were recut to 45 cm and placed dry at 20ºC for 0, 10, 20, 60, or 120 min, or 4, 24, or 48 h prior to being placed in quart mason jars (Ball, Muncie, IN) filled with 500 mL of tap water. Additional tap water was added as needed to maintain at least 300 mL.

This experiment was repeated 30 July 2007 in which stems were cut, sorted, and rehydrated as above, and then recut to 45 cm and placed dry at 20ºC for 0, 10, 60, or 120 min, or 4, or 6 h prior to being placed in quart mason jars (Ball, Muncie, IN) filled with 600 mL of tap water. Additional tap water was added as needed to maintain at least 300 mL. Four days after stems were placed in jars, water uptake, stem quality, and microbial counts of vase water using commercial test kits (Petrifilm, Minneapolis, MN) as directed, were recorded. Water potential of five detached leaves per treatment was recorded using a pressure bomb (PMS Instrument Co., Corvallis, OR).

Drying time before recutting. Field-grown *Helianthus* 'Sunbright' stems were cut 3 Oct. 2006 in the field. As in the previous experiment, stems were sorted into eight uniform groups of 15 stems each, recut to 48 cm, lower third of the foliage was removed, and stems were placed at 20ºC in buckets containing 5 L of tap water (pH 6.6, EC 0.25), to rehydrate

overnight. After rehydration, stems were placed dry at 20ºC for 0, 10, 20, 60, or 120 min, or 4, 24, or 48 h prior to being recut to 45 cm and placed in quart mason jars (Ball, Muncie, IN) filled with 500 mL of tap water. Additional tap water was added as needed to maintain at least 300 mL.

This experiment was repeated 30 July 2007 in which stems were cut, sorted, and rehydrated as above, and then were placed dry at 20ºC for 0, 10, 60, or 120 min, or 4, or 6 h prior to being recut to 45 cm and placed in quart mason jars (Ball, Muncie, IN) filled with 600 mL of tap water. Additional tap water was added as needed to maintain at least 300 mL. Four days after stems were placed in jars, water uptake, stem quality, and microbial counts of vase water using commercial test kits (Petrifilm, Minneapolis, Minn.) as directed, were recorded.

Harvesting procedures and postharvest storage temperatures. Field-grown *Helianthus* 'Sunbright' stems were harvested either directly into buckets of tap water or harvested dry, and lower third of the foliage removed. Within each of these two initial treatments, stems were sorted into eight uniform groups, based on stem caliper, flower head size, and opening of flower, of 15 stems each. After sorting, stems experienced one of the following treatments: 1) brought immediately to the postharvest monitoring area and placed in quart mason jars (Ball, Muncie, IN); 2) brought immediately to the postharvest monitoring area, recut removing the basal 2.5 cm, and placed in jars; 3) brought immediately to a 20ºC cooler, held for 2 h, then placed in jars; 4) brought immediately to a 20ºC cooler, held for 2 h, then recut removing the basal 2.5 cm, and immediately placed in jars; 5) held for 2 days at 5ºC then placed in jars; 6) held for 2 days, recut removing the basal 2.5 cm, and immediately placed in jars; 7) recut into tap water removing the basal 2.5 cm, held for 3 days at 5ºC, then

placed in jars; 8) recut into tap water with removing the basal 2.5 cm, held for 3 days at 5ºC, recut removing the basal 2.5 cm, then immediately placed in jars. Jars were filled with 500 mL deionized (DI) water with one stem per jar. Additional DI water was added as needed to maintain at least 300 mL.

Stems per vase. Field-grown *Helianthus* 'Sunbright' stems were cut either 7, 9, or 11 Aug. 2006, with equal replications cut per treatment per each day. Stems were harvested directly into buckets of tap water, sorted into four groups of 10, 30, 50, or 100 uniform stems, cut to 45 cm, and stripped of the lower third of the foliage. Stems were placed in quart mason jars (Ball, Muncie, IN) filled with 500 mL of tap water, where each jar contained a total of one, three, five, or ten stems. Additional tap water was added as needed to maintain at least 300 mL. Data collected included water uptake at termination and microbial counts of vase water taken 4 and 7 days after harvest using commercial test kits (Petrifilm, Minneapolis, MN) as directed. The experiment was repeated 31 July 2007 as stated above.

Cooling rate. Field-grown *Helianthus* 'Sunbright' stems were harvested directly into buckets of tap water, sorted into five uniform groups, based on stem caliper, flower head size, and opening of flower, of 15 stems each, cut to 45 cm, and stripped of the lower third of the foliage. Stems were placed in buckets containing 5 L of tap water in the following environments before removing the basal 2.5 cm: 1) stems were stored in a dark 5ºC cooler immediately after cutting and held for 3 days; 2) stems were stored in a lighted 20ºC cooler with 8 $\mu mol \cdot m^{-2} \cdot s^{-1}$ light for 24 h after cutting and then held in a dark 5ºC cooler for 2 days; 3) stems were stored in a lighted 20ºC cooler with 8 $\mu mol \cdot m^{-2} \cdot s^{-1}$ light for 3 days; 4) stems were stored at 32ºC in a shaded area outdoors (30 $\mu mol \cdot m^{-2} \cdot s^{-1}$ light) for 24 h after cutting,

then held in a dark 5ºC cooler for 2 days; 5) stems were stored at 32ºC in a shaded area outdoors (30 $\mu mol \cdot m^{-2} \cdot s^{-1}$ light) for 3 days. Stems were then placed in quart mason jars (Ball, Muncie, IN) filled with 500 mL of tap water and three stems per jar. Additional tap water was added as needed to maintain at least 300 mL.

Results

Drying time after recutting. In both years, increasing the amount of time cut *Helianthus* 'Sunbright' stems remained dry before placing in water decreased vase life (Fig. 1). Increasing the amount of time that stems were allowed to remain dry before recutting decreased the water potential of the leaves (Table 1). Water uptake increased as the drying time after recutting lengthened (Table 2).

Drying time before recutting. In 2006, increasing the amount of time stems were left dry before recutting slightly reduced vase life (Fig. 2). In 2007, placing stems of *Helianthus* 'Sunbright' directly in tap water resulted in a vase life of 15.5 days, with no significant difference in vase life due to drying time before recutting (Fig. 2). Water uptake was unaffected by drying time before recutting (Table 2).

Harvesting procedures and postharvest storage temperatures. No significant differences in vase life or termination criteria occurred due to cutting into water or carrying stems to the processing area dry (Table 4) or to recutting or not recutting (Table 4). Storage temperature did not affect termination criteria, but did affect vase life, with the highest vase life including storage time of 11.9 days occurring when stems were stored for 3 days at 5°C (Table 5). The shortest vase life occurred when stems were placed directly at 20°C without

storage. No significant interactions occurred among harvesting procedures and storage temperatures.

Stems per vase. In 2006, vase life, water uptake, termination criteria, and bacteria counts taken on day 7 after harvest were unaffected by the number of 'Sunbright' stems placed in a vase (Table 6). For bacteria counts taken on day 4, the most colony forming units appeared in vases with three stems per vase. In 2007, vase life was again unaffected by the number of stems per vase (Table 7). Water uptake decreased as the number of stems per vase increased, with the highest uptake achieved with one stem per vase and the lowest uptake achieved with ten stems per vase. Bacteria counts taken on day 4 after harvest were not significantly affected by treatment.

Cooling rate. Subjecting stems of 'Sunbright' to different cooling rates resulted in a difference in vase life, where a 3 day storage in 5°C resulted in the longest vase life of 13.2 days and a 3 day storage in 32°C resulted in the shortest vase life of 8.6 days (Table 8). Vase life declined as time spent in higher temperatures increased. Cooling rate had no significant effect of termination criteria.

Discussion

Recutting and drying time. Helianthus 'Sunbright' proved to be relatively tolerant of desiccation regardless of when the stems were recut. Though vase life slightly decreased with longer drying times, significant differences in vase life were only found in 2007 when stems were allowed to dry for 0 to 360 min after recutting. In both drying time experiments conducted in 2006, even drying stems for up to 2880 min did not significantly reduce vase life, indicating that *Helianthus* is a durable cut flower and can withstand long periods of time

dry before being placed in water without sacrificing vase life.

Trends in vase life appeared similar between 2006 and 2007 due to drying time; however, vase life significantly increased from 11.0 days in 2006 to 14.4 days in 2007 across both recutting experiments ($P \leq 0.0001$). This difference in average vase life could be due to environmental differences during production between the years, such as soil moisture or average daily temperatures (Marissen, 2005; Twumasi et al., 2005).

Water uptake increased as drying time increased after recutting (Table 2). Since vase life decreased as drying time increased, water uptake did not positively influence vase life in *Helianthus* 'Sunbright' in these experiments and therefore cannot be used as a valid indicator of vase life in all circumstances. A similar debate about the feasibility of using water uptake rates as an indicator for vase life has occurred in *Rosa*, since different studies have shown that water uptake may or may not correlate to vase life (De et al., 1999; Suzuki et al., 2001)

Harvesting procedures and postharvest storage temperatures. Harvesting procedures, including placing stems wet or dry after harvest and recutting stems or not recutting after harvest, produced no difference in vase life in *Helianthus* 'Sunbright', indicating again the durability of this cultivar and its adaptability to cut flower harvesting procedures (Tables 3 and 4). Vase life of *Helianthus* 'Sunbright' was affected by storage temperature, where vase life increased with longer storage in cool (5°C) temperatures (Tables 5 and 8), which is consistent with the general recommendation of a 2 to 5°C storage to hold *Helianthus* stems (Stevens et al., 1993). Similarly, Çelikel and Reid (2002) found that vase life for *Helianthus* increased linearly as storage temperature decreased from 15°C to 0°C for six days of storage. Storage temperature, as well as respiration rate, was negatively correlated with vase life, with respiration rates increasing as temperature rose. Therefore,

high respiration rates caused by high storage temperatures could be the cause of decreased vase life in warm stored stems. Limitations on the length of cold storage that *Helianthus* stems can tolerate could exist, since Redman et al. (2002) found that a 7 day storage of *H. maximilianii* stems at 4°C decreased vase life by 0.9 days as compared to the control.

Stems per vase. Although no significant differences were found in vase life for placing different numbers of stems per vase, a slight downward trend in vase life suggests that 'Sunbright' is mildly negatively affected by the addition of more stems in a vase (Tables 6 and 7). This decline in vase life could be caused in part by a suppressed ability of stems to take up water as more stems are placed in a vase, since water uptake declined as stem number per vase increased in 2007 (Table 7). It was hypothesized that an increase in the number of stems placed in a vase would result in an increase in bacterial counts in the vase water, but the results show no clear trend. In addition, Mensuali-Sodi and Ferrante (2005) found that adding 8-HQS, a typical biocide, to vase solutions did not increase vase life, indicating that bacterial growth leading to stem plugging may not be the cause of a decrease in water uptake of *Helianthus* stems throughout vase life.

Conclusion

Vase life of *Helianthus* 'Sunbright' was unaffected by whether stems were harvested wet or dry in the field, whether or not stems were recut, how many stems were placed in a vase, and amount of time that stems were left dry, indicating the durability of this cultivar. Sunflower stems lasted longer when stored for up to 3 days at 5°C; therefore, cut sunflower stems should be stored cold to maximize vase life.

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Table 1. Effect of drying time after recutting stems of *Helianthus 'Sunbright'* on water potential of leaf petioles. Means are an average of data from four to five leaves from different stems.

Drying time	Stem water potential (kPa)
0 min	-550
10	-650
20	-620
60	-763
4 h	-713
6	-1100
24	-1160
48	-1340
Significance	
Linear	0.0001
Quadratic	0.0007
Cubic	0.0014
Residual	NS

[NS]Nonsignificant at $P \leq 0.05$.

Table 2. Effect of drying time after recutting and drying time before recutting on water uptake recorded four days after start of treatments (mL/stem/day) of *Helianthus* 'Sunbright'. Means are an average of five replicates of three stems each.

	Drying time after recutting	Drying time before recutting
Time (min)	Water uptake (mL/stem/day)	
0	27.7	27.8
10	26.3	27.5
60	30.5	28.3
120	28.2	29.3
240	31.4	30.8
360	33.2	32.0
Significance		
Linear	0.0001	0.0165
Quadratic	NS	NS
Cubic	NS	NS
Residual	NS	NS

[NS]Nonsignificant at $P \leq 0.05$.

Table 3. Effect of harvesting procedure (wet, dry) on vase life and termination criteria of *Helianthus* 'Sunbright'. Means are an average of 39 to 40 stems.

Treatment	Vase life (days)	Loss of petals (%)	Wilted petals (%)
Wet	10.1	10.0	100.0
Dry	10.4	5.1	100.0
Significance	NS	NS	NS

[NS]Nonsignificant at $P \leq 0.05$.

Table 4. Effect of harvesting procedure (recut, not recut) on vase life and termination criteria of *Helianthus* 'Sunbright'. Means are an average of 39 to 40 stems.

Treatment	Vase life (days)	Loss of petals (%)	Wilted petals (%)
Recut	10.1	10.0	100.0
Not recut	10.4	5.1	100.0
Significance	NS	NS	NS

[NS]Nonsignificant at $P \leq 0.05$.

Table 5. Effect of postharvest storage procedure (20°C, no storage; 20°C, 2 h; 5°C, 2 days; 5°C, 3 days) on vase life and termination criteria of *Helianthus* 'Sunbright'. Means are an average of 19 to 20 stems.

Treatment	Vase life (days)	Loss of petals (%)	Wilted petals (%)
20°C, no storage	9.1 b[z]	15.0	100.0
20°C, 2 h	9.6 ab	10.0	100.0
5°C, 2 days	10.6 ab	5.3	100.0
5°C, 3 days	11.9 a	0.0	100.0
Significance	0.0432	NS	NS

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.
[NS]Nonsignificant at $P \leq 0.05$.

Table 6. Effect of number of stems per vase on vase life, water uptake, occurrence of wilted petals, stem collapse, and brown petals (%), and bacterial counts taken four and seven days after harvest of *Helianthus* 'Sunbright'. Means are an average of ten vases where each vase contains one, three, five, or ten stems.

Stems/vase (no.)	Vase life (days)	Water uptake (mL/stem/day)	Brown petals (%)	Stem collapse (%)	Wilted petals (%)	Bacterial count day 4 (cfu/cm^2)	Bacterial count day 7 (cfu/cm^2)
1	14.8	22.6	0.0	0.0	100.0	137402	4556000
3	12.8	22.5	10.0	3.3	93.3	485168	272333
5	13.4	22.9	13.3	0.0	90.0	800	90161
10	12.9	18.6	6.7	1.7	98.3	1172	145800
Significance	NS	NS	NS	NS	NS	0.0421	NS

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.

[NS]Nonsignificant at $P \leq 0.05$.

Table 7. Effect of number of stems per vase on vase life, water uptake taken four days after harvest, and bacterial counts taken four days after harvest of *Helianthus* 'Sunbright'. Means are an average of ten vases where each vase contains one, three, five, or ten stems.

Stems/vase (no.)	Vase life (days)	Water uptake (mL/stem/day)	Bacterial count day 4 (cfu/cm^2)
1	16.4	34.6 a[z]	2282
3	16.0	25.8 b	60381
5	16.1	24.3 b	38145
10	15.9	18.7 c	68707
Significance	NS	0.0001	NS

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.
[NS]Nonsignificant at $P \leq 0.05$.

Table 8. Effect of cooling rate (days after harvest) on the vase life (days after harvest) and termination criteria of *Helianthus* 'Sunbright'. Means are an average of five replicates of three stems each.

Treatment (°C)				Brown	Stem	Wilted
Day 1	Day 2	Day 3	Vase life	petals (%)	collapse (%)	petals (%)
5	5	5	13.2 a	13.3	0.0	100.0
20	5	5	13.1 a	20.0	6.7	93.3
20	20	20	10.3 bc	33.3	0.0	100.0
32	5	5	11.3 ab	13.3	0.0	100.0
32	32	32	8.6 c	6.7	6.7	93.3
Significance			0.0001	NS	NS	NS

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.
[NS]Nonsignificant at $P \leq 0.05$.

List of Figures

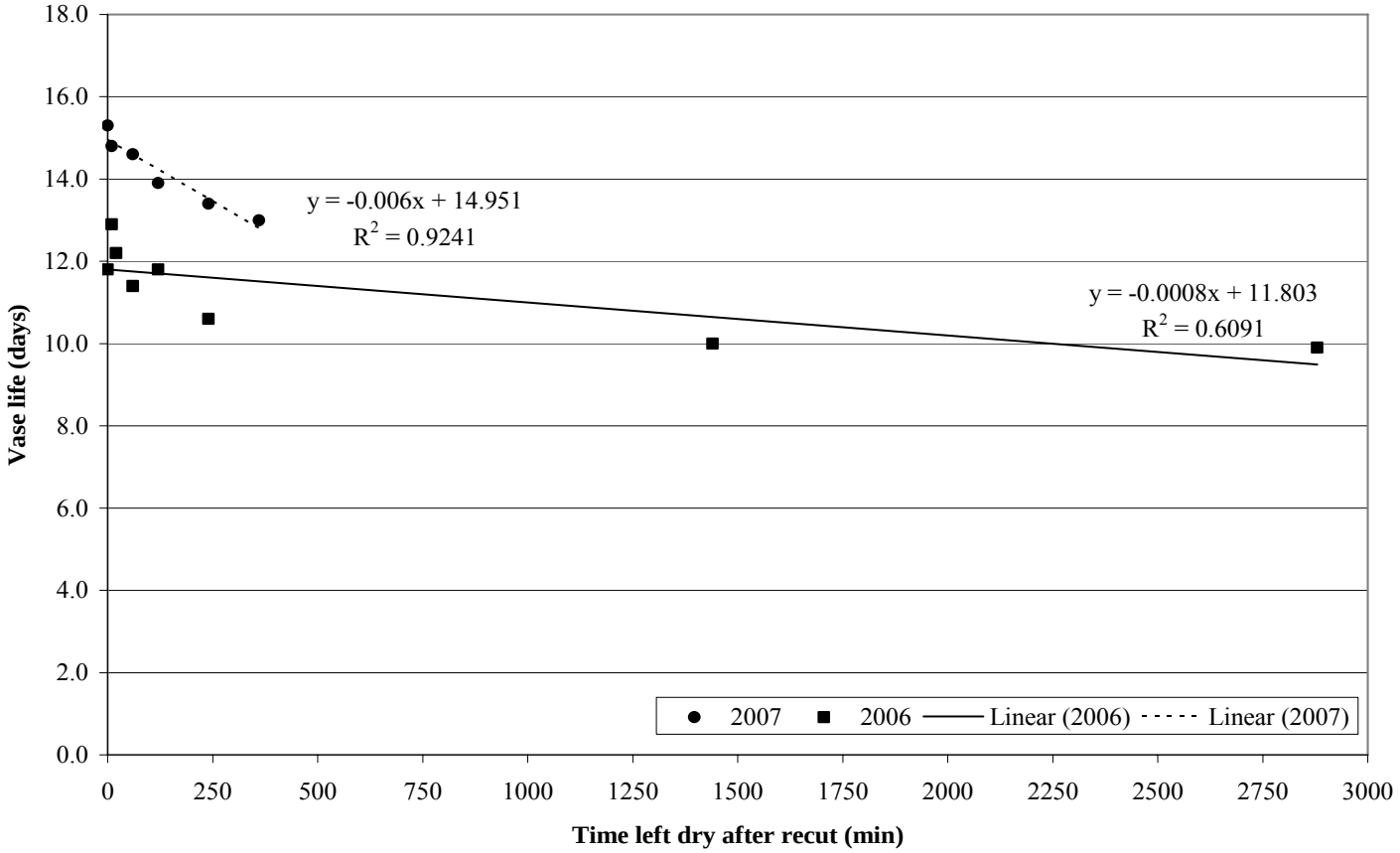

Fig. 1. Effect of drying time after recutting on vase life of *Helianthus* 'Sunbright' stems in 2006 and in 2007. Data had a linear trend in 2006 (P=0.0016) and in 2007 (P=0.0003).

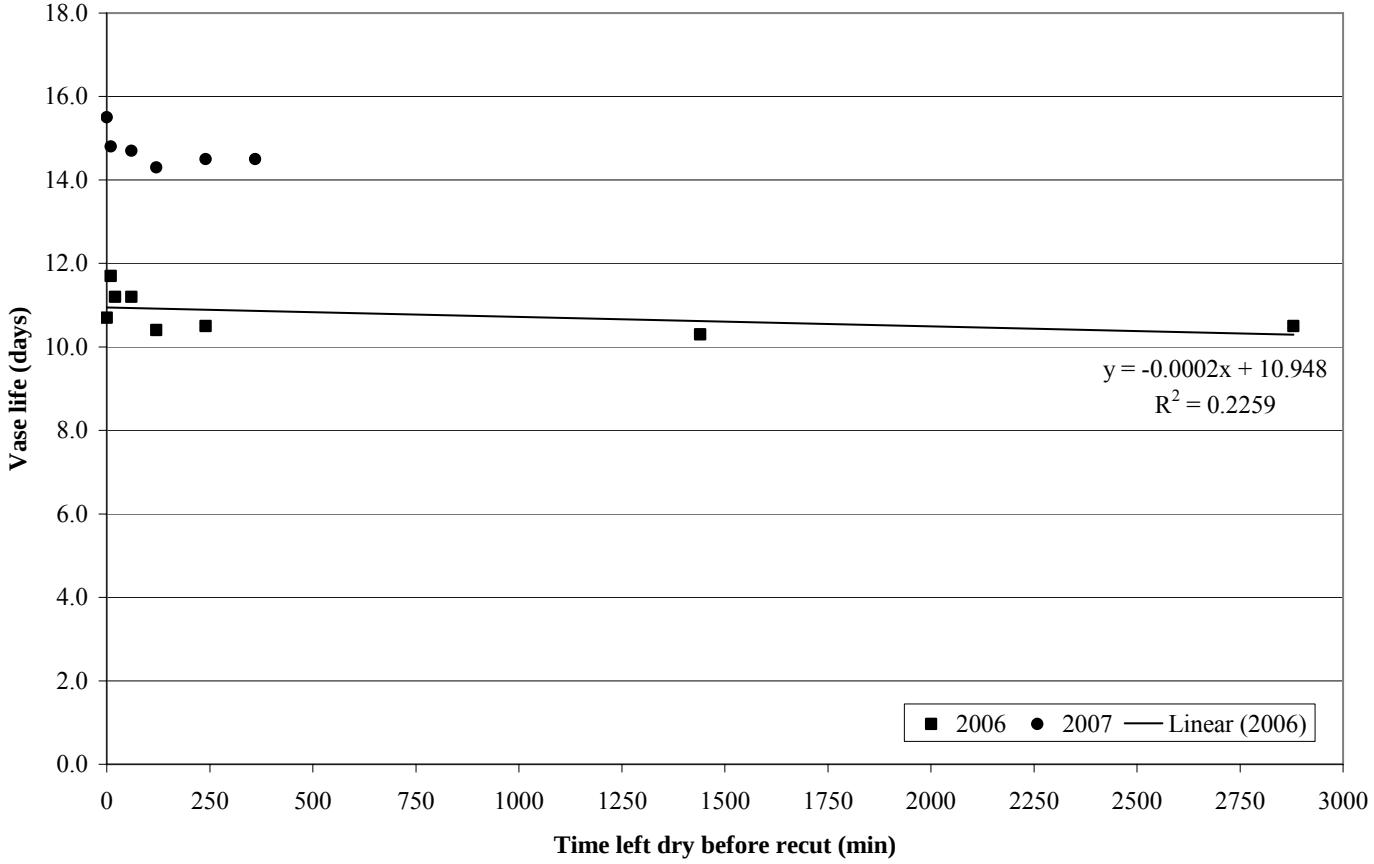

Fig. 2. Effect of drying time before recutting on vase life of *Helianthus* 'Sunbright' stems in 2006 and in 2007. Data had a linear trend in 2006 (P=0.041). Data are not significantly different at the $P \leq 0.05$ level in 2007.

Chapter 5

Postharvest Handling of Cut Zinnias

(in the format appropriate for submission to HortScience)

Postharvest Handling of Cut Zinnias

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Postharvest Handling of Cut Zinnias

Abstract

Zinnia elegans Jacq. is a commercially important species in the cut flower industry, but little work has been done to determine the postharvest handling procedures necessary for maximizing vase life. Vase life of cut 'Benary Giant Deep Red' stems was reduced when stems were recut as compared to stems that were not recut. However, if stems were recut, a period of dessication before placing in vases improved vase life. Vase life was improved by 2.1 days with the use of Floralife® Professional as a pulse solution instead of tap water and by 2.2 days when stems were stored in a bleach solution versus tap water. Storage temperature affected vase life with 5 hours of storage at 5°C followed by 2 day storage at 1°C resulting in the highest vase life of 13.0 days. Short vase lives occurred as storage temperature increased, with a low of 6.5 days when stems were stored for 2 days at 20°C. Varying the number of stems per vase did not significantly affect vase life.

Introduction

The United States cut flower industry faces many challenges due to the difficulty in producing flowers with a long postharvest vase life. Customers may be more wary of purchasing cut flowers than any other flower commodity because the vase life is uncertain. To ensure a longer vase life, growers must carefully regulate postharvest conditions and postharvest handling methods.

Water uptake. Water uptake may be the most important factor in improving the length of vase life of cut flowers (Halevy and Mayak, 1979). As the leaves on the flowers transpire, water is drawn up through the xylem. If this process is impeded by a vascular blockage or accelerated by increased stomatal opening, then transpiration will exceed uptake and water deficiency will occur (van Doorn, 1997). Solutes, such as sucrose, 8-hydroxyquinoline citrate (8-HQC), or aluminum sulfate, which are frequently added to vase solutions, can decrease transpiration or increase water uptake (van Doorn, 1997).

Postharvest. Many postharvest handling procedures alter the water relations in cut flowers, affecting the length of their vase life. Because cut flowers are often transported or stored out of water for long periods of time, cutting procedures to remove or reduce air embolisms and other vascular occlusions must be studied. Vascular occlusions block water flow through the xylem, decreasing water uptake and subsequently decreasing vase life (Durkin and Kuc, 1966). Examination of xylem profiles in cut *Rosa* stems have shown that when kept in distilled water, bacterial contamination occludes the bottom 2.5 cm of the stem, while a carbohydrate substance occludes the stem about 10 cm higher than the level of solution (Lineberger and Steponkus, 1976). Work is needed to determine optimum recutting procedures and amounts to minimize the negative effects of vascular occlusions on vase life.

In addition, recommendations typically call for recutting the stems while under water to prevent air embolisms. However, recent work indicates that recutting under water should be done only when the water is clean, otherwise bacterial contamination negates the benefits of recutting (Nell and Reid, 2004). Work is needed to determine if increasing the number of

stems per vase will increase bacterial contamination and subsequently decrease vase life.

Temperature can also influence postharvest performance. Flowers typically spend one to several days in storage or transport where they might be subjected to high temperatures, increasing their transpiration and negatively affecting their vase life. High temperature stress has been shown to negatively impact the vase life of several *Rosa* cultivars, with other cultivars being unaffected (Nell and Leonard, 2005b). Little work has been done on determining the tolerance of zinnias to both hot and cold temperatures; therefore, more work is needed to determine how temperature influences vase life.

Objectives

The objectives of this research were to:

1. Quantify the effect of postharvest dry storage on postharvest performance of cut *Zinnia* stems.
2. Determine the optimum postharvest recutting procedures for cut *Zinnia* stems.
3. Quantify the effect of placing multiple stems in a vase on bacteria counts in vase water and its effect on vase life.
4. Determine the optimum postharvest storage temperatures for cut *Zinnia* stems.

Materials and Methods

Postharvest environment. Unless otherwise indicated, treatments and vase life determinations were conducted at 20ºC under 20 to 40 $\mu mol \cdot m^{-2} \cdot s^{-1}$ light for 12 h/day at 40% to 60% relative humidity. Vase life was recorded for every experiment, with vase life

termination determined by one or more of the following criteria: brown petals, stem collapse, and wilted petals. Reasons for termination were also recorded. The experiment was arranged in a completely randomized design with 5 replications of three stems (subsamples) each. Data were analyzed using analysis of variance (SAS Institute, Cary, NC) and means were separated using Tukey's Studentized range test at $P \leq 0.05$.

Postharvest.

Drying time after recutting-2006. Field-grown *Zinna elegans* 'Benary Giant Deep Red' stems were cut 5 July in the field, sorted into eight uniform groups, based on stem caliper, flower size, and opening of flower, of 15 stems each, lower third of the foliage was removed, and stems were placed at 20ºC in buckets containing 5 L of tap water (pH 6.6, EC 0.25), to rehydrate overnight. Subsequently, stems were recut to 40 cm and placed dry at 20ºC for 0, 10, 20, 60, or 120 min, or 4, 24, or 48 h prior to being placed in quart mason jars (Ball, Muncie, IN) filled with 500 mL of tap water.

Drying time after recutting-2007. Field-grown 'Benary Giant Deep Red' stems were cut 15 August in the field. As in 2006, stems were sorted into eight uniform groups of 15 stems each, except that after sorting, stems were recut to 42.5 cm prior to the removal of lower third of the foliage and placed at 20ºC in buckets containing 5 L of tap water (pH 7.2, EC 0.26), to rehydrate overnight. Subsequently, stems were recut to 40 cm and placed dry at 20ºC for 0, 10, 60, or 120 min, or 4, or 6 h prior to being placed in quart mason jars (Ball, Muncie, IN) filled with 300 mL of tap water. Additional tap water was added as needed to maintain at least 100 mL. Four days after stems were placed in jars, water uptake, stem

quality, and microbial counts of vase water using commercial test kits (Petrifilm, Minneapolis, MN) as directed, were recorded. Water potential of five detached leaves per treatment was recorded using a pressure bomb (PMS Instrument Co., Corvallis, OR).

Drying time before recutting-2006. Field-grown 'Benary Giant Deep Red' stems were cut 11 July in the field. As in the previous experiment, stems were sorted into eight uniform groups of 15 stems each, recut to 42.5 cm, lower third of the foliage was removed, and stems were placed at 20ºC in buckets containing 5 L of tap water (pH 6.6, EC 0.25), to rehydrate overnight. After rehydration, stems were placed dry at 20ºC for 0, 10, 20, 60, or 120 min, or 4, 24, or 48 h prior to being recut to 40 cm and placed in quart mason jars (Ball, Muncie, IN) filled with 500 mL of tap water.

Drying time before recutting-2007. Field-grown 'Benary Giant Deep Red' stems were cut 15 August in the field. Methods were the same as in 2006, except that after rehydration, stems were placed dry at 20ºC for 0, 10, 60, or 120 min, or 4, or 6 h prior to being recut to 40 cm and placed in quart mason jars (Ball, Muncie, IN) filled with 300 mL of tap water. Additional tap water was added as needed to maintain at least 100 mL. Four days after stems were placed in jars, water uptake, stem quality, and microbial counts of vase water using commercial test kits (Petrifilm, Minneapolis, MN) as directed, were recorded.

Recutting amount. Immediately after harvest, field-grown 'Benary Giant Deep Red' stems were sorted into eight uniform groups, based on stem caliper, flower size, and opening of flower, of 15 stems each, recut to 45 cm, lower third of the foliage removed, and stems were placed in buckets containing 5 L of tap water to rehydrate overnight at 20ºC. After rehydration, stems were placed dry at 20ºC for 4 h prior to removal of 0, 1, 2, 3, 4, 5, 10, or

15 cm from the stem base and placed in quart mason jars (Ball, Muncie, IN) filled with 500 mL of tap water.

Harvesting procedures and postharvest storage temperatures. Field-grown 'Benary Giant Deep Red' stems were harvested either directly into buckets of tap water or harvested dry, with lower third of the foliage removed. Within each of these two initial treatments, stems were sorted into eight uniform groups, based on stem caliper, flower size, and opening of flower, of 15 stems each, where initial treatments contained uniform groups. After sorting, stems experienced one of the following treatments: 1) brought immediately to the postharvest monitoring area and placed in quart mason jars (Ball, Muncie, IN); 2) brought immediately to the postharvest monitoring area, recut removing the basal 2.5 cm, and placed in jars; 3) brought immediately to a 20ºC cooler, held for 2h, then placed in jars; 4) brought immediately to a 20ºC cooler, held for 2 h, then recut removing the basal 2.5 cm, and immediately placed in jars; 5) held for 2 days at 5ºC then placed in jars; 6) held for 2 days, recut removing the basal 2.5 cm, and immediately placed in jars; 7) recut into tap water removing the basal 2.5 cm, held for 3 days at 5ºC, then placed in jars; 8) recut into tap water removing the basal 2.5 cm, held for 3 days at 5ºC, recut removing the basal 2.5 cm, then immediately placed in jars. Jars were filled with 500 mL deionized (DI) water with one stem per jar.

Recutting, hydration, and holding procedures. Field-grown 'Benary Giant Deep Red' stems were cut in the field into tap water, sorted into 16 uniform groups, based on stem caliper, flower size, and opening of flower, of 10 stems each, and lower third of the foliage was removed. After harvest, stems experienced the following treatments: 1) either recut to

38 cm or not recut; 2) placed in either Hydraflor 100 (Floralife, Inc., Walterboro, SC) (8 mL/L of DI water) (pH 2.4,EC 0.56) or tap water (pH 6.6, EC 0.25) for 2 h; 3) placed in either Floralife® Professional (Floralife, Inc., Walterboro, SC) (10mL/L of DI water) (pH 3.0, EC 0.37) or tap water for 20 h; 4) placed in quart mason jars (Ball, Muncie, IN) containing 300 mL of either a chlorine bleach solution, 1.23 mL bleach (James Austin Company, Mars, PA) per 4 L of tap water (pH 6.3, EC 0.32), or tap water with one stem per jar. Additional solution was added as needed to maintain at least 100 mL.

Stems per vase. Field-grown 'Benary Giant Deep Red' stems were harvested directly into buckets of tap water, sorted into four groups of 10, 30, 50, or 100 uniform stems, cut to 40 cm, and lower third of the foliage was removed. Stems were placed in quart mason jars (Ball, Muncie, IN) filled with 500 mL of tap water, where each jar contained a total of one, three, five, or ten stems. Data collected included water uptake at termination and microbial counts of vase water taken 4 and 7 days after harvest using commercial test kits (Petrifilm, Minneapolis, MN) as directed.

Chilling sensitivity and harvest time. Field-grown 'Benary Giant Deep Red' stems were cut in the field at either 8:00 AM, 1:00 PM, or 6:00 PM into tap water, sorted by stem caliper, flower size, and opening of flower, with each treatment containing 15 uniform stems, cut to 40 cm, and lower third of the foliage was removed. Stems were stored in buckets containing 5 L of tap water for 2 days in a dark 1.9ºC cooler. Stems were then placed in quart mason jars (Ball, Muncie, IN) filled with 300 mL of DI water and three stems per jar. Additional DI water as added as needed to maintain at least 100 mL. Data collected included stem quality and percentage of each flower showing cold damage.

Chilling sensitivity to storage temperatures. Field-grown 'Benary Giant Deep Red' and 'Uproar Rose' stems were cut in the field at 8:00 AM into tap water, sorted into three uniform groups, based on stem caliper, flower size, and opening of flower, of 15 stems each, cut to 40 cm, and lower third of the foliage was removed. Stems were stored in buckets containing 5 L of tap water for 2 days in either a dark 1ºC cooler, a dark 5ºC, or a lighted 20ºC cooler at 0, 0, and 8 $\mu mol \cdot m^{-2} \cdot s^{-1}$ light, respectively. Stems were then placed in quart mason jars (Ball, Muncie, IN) filled with 300 mL of DI water and three stems per jar. Additional DI water was added as needed to maintain at least 100 mL. Data collected included percentage of each flower showing cold damage.

Holding temperatures. Field-grown 'Benary Giant Deep Red' stems were cut in the field at 9:00 AM into tap water, sorted into four uniform groups, based on stem caliper, flower size, and opening of flower, of 15 stems each, cut to 40 cm, and lower third of the foliage was removed. Stems were stored in buckets containing 5 L of tap water for 6 h at 5, 14, 20, or 31ºC at 0, 0, 8, and 27 $\mu mol \cdot m^{-2} \cdot s^{-1}$ light, respectively. Stems were then placed in quart mason jars (Ball, Chicago, IL) filled with 300 mL of DI water. Jars were stored at 5ºC for 25 h and were then placed in the postharvest evaluation room. Additional DI water was added as needed to maintain at least 100 mL. Data collected included stem quality and percentage of each flower showing cold damage.

Cooling rate. Field-grown 'Benary Giant Deep Red' stems were harvested directly into buckets of tap water, sorted into 5 uniform groups, based on stem caliper, flower size, and opening of flower, of 15 stems each, cut to 45 cm, and lower third of the foliage was removed. Stems were placed in buckets containing 5 L of tap water in the following

environments before removing the basal 2.5 cm: 1) stems were stored in a dark 5ºC cooler immediately after cutting and held for 3 days; 2) stems were stored in a lighted 20ºC cooler (8 $\mu mol \cdot m^{-2} \cdot s^{-1}$) for 24 h after cutting and then held in a dark 5ºC cooler for 2 days; 3) stems were stored in a lighted 20ºC cooler (8 $\mu mol \cdot m^{-2} \cdot s^{-1}$) for 3 days; 4) stems were stored at 26ºC in a shaded area outdoors (30 $\mu mol \cdot m^{-2} \cdot s^{-1}$ light) for 24 h after cutting, then held in a dark 5ºC cooler for 2 days; 5) stems were stored at 26ºC in a shaded area outdoors (30 $\mu mol \cdot m^{-2} \cdot s^{-1}$ light) for 3 days. Stems were then placed in quart mason jars (Ball, Muncie, IN) filled with 300 mL of tap water and three stems per jar. Additional tap water was added as needed to maintain at least 100 mL.

Results

Drying time after recutting-2006. Vase life decreased with an increase in drying time when a curve was fitted to the data; however, no significant differences in vase life were observed until after 240 min drying time (Fig. 1). Stems did not rehydrate when left dry for 48 h (data not presented).

Drying time after recutting-2007. When a curve was fitted to the data, vase life was estimated at a maximum of 16.1 days at 0 min drying time (Fig. 2). Vase life decreased with an increase in drying time; however, a significant decline in vase life was not observed until 240 min drying time. Water uptake taken four days after start of treatments was significantly lower for the 240 min and 360 min drying time treatments than average uptake of the 0 min drying time treatment (Table 1). Water potential measured in leaf pedicels decreased as drying time increased, from -500 kPa at 0 min drying time down to -1810 kPa after 24 h

(Table 2). No sap was expressed when stems were recut and left dry for 48 h.

Drying time before recutting-2006. When a curve was fitted to the data, vase life remained fairly constant; however the R^2 value was low, indicating that the data do not follow a clear mathematical model (Fig. 3). No significant differences in vase life occurred after 20 min of drying time. Stems did not rehydrate when left dry for 24 h or 48 h.

Drying time before recutting-2007. No significant differences in vase life of cut 'Benary Giant Deep Red' stems occurred with an increase in drying time (Fig. 3). Water uptake taken four days after start of treatments was unaffected by drying time (Table 1).

Recutting amount. No significant differences in vase life of cut 'Benary Giant Deep Red' stems occurred with an increase in the amount of stem removed (Fig. 4). When a line was fitted to the data, vase life remained constant.

Harvesting procedures and postharvest storage temperatures. Vase life of cut 'Benary Giant Deep Red' stems was unaffected by the harvesting procedure, recutting procedure, and storage temperature treatments and no significant interactions (Table 3).

Recutting, hydration, and holding procedures. Vase life of cut 'Benary Giant Deep Red' stems was only 6.9 days when stems were recut versus 10.5 days when stems were not recut before being placed in vases after harvest (Table 4). Recutting stems also increased the percentage of stems collapsing from 37.2% when not recut to 58.4% when recut. The hydrating solution, Hydraflor 100, had no significant effect on vase life or termination criteria (Table 5). Floralife® Professional pulse solution increased vase life from 7.7 days in tap water to 9.8 days (Table 6). Pulse solution did not affect termination criteria. Adding bleach to tap water in the holding solution also increased vase life from 7.6 days to 9.8 days

but did not affect termination criteria (Table 7). No significant interactions were found.

Stems per vase. Vase life of cut 'Benary Giant Deep Red' stems was not affected by the number of stems placed in a vase (Table 8). However, one stem per vase resulted in the highest uptake of 12.3 mL/stem/day, while three, five, or ten stems resulted in a similar amount of water taken up (Table 8). Neither the occurrence of wilted or brown petals was significantly affected by the number of stems in a vase. Stem collapse occurred in 24% to 29.9% in the treatments with three, five, or ten stems per vase but did not occur in the one stem per vase treatment. Bacteria counts taken both four and seven days after stems were placed in the vases resulted in no significant difference among treatments.

Chilling sensitivity and harvest time. Cut 'Benary Giant Deep Red' stems did not exhibit any symptoms of cold damage on either 4 or 12 days after being placed in vases in any treatment (Table 9). Harvest time had no significant effect on vase life, stem quality, or termination criteria.

Chilling sensitivity to storage temperatures. Neither 'Benary Giant Deep Red' nor 'Uproar Rose' exhibited differences in symptoms of cold damage due to storage temperature (Table 10). Vase life of both cultivars was affected by storage temperature, where a two day storage at 1 or 5°C produced higher vase lives of 9.0 days and 8.2 days, respectively, than a two day storage in 20°C. However, the two cultivars had similar vase lives and the data were combined. Stems of 'Uproar Rose' were 35.6% more susceptible to being terminated because of collapsed stems than stems of 'Benary Giant Deep Red'(Table 11), but stem collapse was unaffected by storage temperature (data not presented). Neither the occurrence of brown petals or wilted petals as termination criteria was significantly affected by treatment or cultivar (Table 10).

Holding temperatures. Holding stems at 5, 14, 20, or 31°C for 5 h prior to a 2 day storage at 5°C did not result in cold damage symptoms on any stems of 'Benary Giant Deep Red' (Table 12). Holding temperature also did not significantly affect vase life, stem quality, or termination criteria.

Cooling rate. Subjecting stems of 'Benary Giant Deep Red' to different cooling rates did not significantly affect vase life or the percentage of stems that were terminated due to wilted petals (Table 13). One day storage at 26°C followed by two days of storage at 5°C resulted in the highest percentage of stems that collapsed (60%) and three days of storage at 20°C resulting in the smallest percentage of stems that collapsed (20%).

Discussion

Recutting and drying time. Vase life of cut *Zinnia* 'Benary Giant Deep Red' stems to different amounts of drying time was not consistent across years or across both recutting experiments. Previous studies have found that exposing cut stems to air introduces air emboli into the stems, thus blocking xylem elements and restricting water flow (Durkin, 1979; van Doorn, 1990). Since a decrease in water movement through the stem is thought to decrease vase life (Halevy and Mayak, 1981), recutting the stem to remove the segment containing the embolus and immediately placing in water has been suggested to improve vase life. However, in 2006, vase life exhibited a less drastic decline after 10 min of drying time as well as an overall longer vase life when stems were recut before experiencing desiccation (Fig. 1) rather than when stems were recut after experiencing desiccation and then placed immediately in a vase (Fig. 3) suggesting that unlike many cut flowers, *Zinnia*

stems do not respond as well to recutting immediately prior to placing in vases.

Vase life decreased as drying time increased whether stems were recut prior to hydration (Fig. 2) or not (Fig. 1). In both cases, however, vase life did not drop drastically until at least 2 h, indicating that *Zinnia* stems can tolerate drying for up to 2 h after being recut without a significant decrease in vase life. There also appear to be limitations on the length of time that stems can remain dry before they can no longer rehydrate, whether they are recut before or after drying time, since rehydration was inhibited after 24 h (data not presented). Similarly, van Meeteren and van Gelder (1999) found that after only 4 h of dry storage, chrysanthemum stems would not rehydrate when recut in air. When differences were found among treatments, water uptake seemed to follow the trend in vase life with higher water uptake occurring when vase life was high and significantly lower uptake when vase life was short (Table 1). Similar results, where water uptake was positively correlated with vase life, have been shown to occur in cut *Rosa* stems (De, 1999). This could indicate that higher water uptake could contribute to longer vase lives in *Zinnia*.

Vase life response to drying time and recutting treatments differed significantly across years, with higher vase lives achieved in 2007 as compared to 2006. This higher average vase life can be attributed to the time of year that the experiments were conducted (early July in 2006 and early August in 2007) because *Zinnia* has been shown to exhibit differences in vase life due to time of year in which harvesting occurred (Dole, unpublished data).

Recutting different amounts off stem ends before placing in vases did not have a significant effect on vase life of *Zinnia* ‘Benary Giant Deep Red’ (Fig. 5), indicating that the

standard recommendation of 4 cm is adequate or even excessive (Dole and Wilkins, 2005). However, in *Helianthus*, longer stem lengths have been shown to be positively correlated with vase life (Mensuali-Sodi and Ferrante, 2005). Since zinnias appear to be more sensitive to recutting than sunflowers, perhaps the advantage of longer stems was negated when *Zinnia* stems were recut to achieve different stem lengths.

Harvest and postharvest procedures. Neither harvesting procedure nor postharvest storage temperature had any significant effect on vase life of cut *Zinnia* 'Benary Giant Deep Red' stems indicating that this cultivar is relatively tolerant of various harvest and postharvest conditions (Table 3). Of all the postharvest procedures tested, recutting stems of *Zinnia* 'Benary Giant Deep Red' had the most detrimental effect on vase life (Table 4). On the other hand, a study conducted by Carneiro et al. (2002) found that recutting *Zinnia elegans* stem bases every 48 h increased both water uptake and vase life. However, stems in this study were placed in treatments containing sucrose and since sucrose has been shown to decrease water uptake (Marousky, 1971), it is possible that the improved water uptake caused by recutting the stems contributed to the longer vase life, rather than the act of recutting. Recutting stem ends had no significant effect in the 'Harvesting procedures and postharvest storage temperatures' experiment; however, recutting in that experiment mainly occurred after stems had been hydrated and immediately before they were put in vases, in contrast to the 'Recutting, hydration, and holding procedures' experiment where stems were either recut or not recut before being rehydrated. In the former experiment, the two treatments that compare the difference between recutting and not recutting before stem hydration resulted in a vaselife of 10.0 and 12.4 days, respectively, prior to being stored for three days (data not

presented). Therefore, the timing of the recut may also be important.

Using a floral preservative instead of tap water as a pulse (Table 6) and a bleach solution instead of tap water as a holding solution (Table 7) both improved vase life, while hydrating solution did not affect vase life (Table 5). Many studies have shown the beneficial effects of floral preservatives in increasing vase life, however optimum concentrations and preservative components differ for species such as *Gerbera* (Meman and Dabhi, 2007), *Gladiolus* (Sharma and Singh, 2006), *Lilium* (Sharma et al., 2005) and others (Ichimura, 1998). Stimart and Brown (1982) found that the effect on vase life of *Zinnia elegans* depended on the concentration of sucrose in the vase solution, and Dole et al. (2005) found that several cultivars of *Zinnia* respond negatively to either hydrator solutions or holding solutions.

Stems per vase. Although the number of stems placed in a vase did not result in significant differences in vase life, there was a decreasing trend as the number of stems per vase increased (Table 8). Placing one stem per vase not only resulted in the longest vase life, but it took up the greatest amount of water. Bhattacharjee (1999) has shown that in hybrid tea roses, water uptake is positively correlated with vase life, as may be the case in *Zinnia*. The high vase life resulting from placing only one stem per vase could also partially be explained by the fact that there was no incidence of stem collapse in this treatment. The smaller number of stems in each replication could be a possible cause. It was hypothesized that bacterial counts would negatively correlate with vase life such that bacteria in the vase water could be attributed to a possible cause of vase life decline; however, this hypothesis was not validated, as bacterial counts were not significantly different among treatments.

Chilling sensitivity and temperature effects. These experiments found that cut *Zinnia* 'Benary Giant Deep Red' stems, as well as 'Uproar Rose' stems, were not sensitive to storage at cold temperatures (Tables 9, 10, 12, and 13). Contrary to growers comments (Arnosky, 2003; E. Hitt, personal communication) vase life did not show a significant decline due to low storage temperatures, and in some cases vase life increased with decreasing temperatures, even as low as 1°C (Table 10). However, long term cold storage of cut *Zinnia* stems may reduce vase life since a three day storage at 5°C reduced vase life by 2.3 days as compared to a one day 20°C storage followed by two days at 5°C (Table 13). A narrow window of cold storage may prove to be beneficial for the vase life of *Zinnia* 'Benary Giant Deep Red' as has been found in other species (Nell and Leonard, 2005a).

Neither 'Benary Giant Deep Red' nor 'Uproar Rose' stems exhibited significant differences in cold damage due to storage temperature treatments (Table 10). Differences in vase life due to time of day when stems were harvested were also not significant, with lowest average vase life occurring when stems were harvested in the morning (Table 9). Similarly, harvesting in the afternoon also resulted in longer vase lives for roses (GwiYeon and JoongChoon, 1996) and gladiolus (Seemann and Huber, 1995) than when cut in the morning. Termination criteria in all of the chilling sensitivity experiments were unaffected by differences in storage temperature (Tables 10, 12, 13); however, stem collapse, one of the main reasons for short vase lives in zinnias, was most reduced when stems were stored for three days at 20°C (Table 13). The occurrence of stem collapse may also be cultivar dependent since 'Uproar Rose' was more prone to this problem than 'Benary Giant Deep Red' (Table 11).

Conclusion

Zinnia 'Benary Giant Deep Red' stems exhibited shorter vase lives when recut after being harvested in the field than stems that were not recut, thus recutting procedures should be minimized to extend vase life. Storing flowers in a commercial holding solution (Floralife® Professional) improved vase life. However, hydrating stems with a commercial hydrating solution had no significant effect on vase life. Zinnia stems tolerated a period of desiccation for up to 2 h without exhibiting a significant decrease in vase life regardless of whether stems were recut before or after being left dry. Vase life was unaffected by the amount of stem recut off the stem base, by placing multiple stems in a vase, and by time of day at which stems were harvested. Storage temperature can be used to maximize vase life of cut zinnias since flowers stored at cold temperatures (1°C and 5°C) up to 2 days lasted longer than flowers stored at 20°C and exhibited no apparent chilling injury.

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Table 1. Effect of drying time after recutting and before recutting on water uptake recorded four days after start of treatments (mL/stem/day) on cut *Zinnia* 'Benary Giant Deep Red' stems in 2007. Means are an average of five replicates of three stems each. Year two – 2007.

Drying time (min)	After recutting	Before recutting
0	15.1 ab[z]	15.7
10	16.4 a	15.9
60	15.0 ab	16.3
120	13.3 ab	13.4
240	10.9 b	14.0
360	10.6 b	13.9
Significance	0.0125	NS

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.
[NS]Nonsignificant at $P \leq 0.05$.

Table 2. Effect of drying time after recutting stems of *Zinnia* 'Benary Giant Deep Red' on water potential of leaf petioles. Means are an average of data from five leaves from different stems. Year two – 2007.

Drying time	Stem water potential (kPa)
0 min	-500
10	-860
20	-890
60	-940
240	-1220
360	-1390
24 h	-1810
48	no sap expressed
Significance	
Linear	0.0052
Quadratic	0.0420
Cubic	NS
Residual	NS

[NS]Nonsignificant at $P \leq 0.05$.

Table 3. Effect of harvesting procedure (wet, dry), recutting procedure (recut, not recut), and postharvest storage procedure (20°C, no storage; 20°C, 2 h; 5°C, 2 days; 5°C, 3 days) on vase life (days) and termination criteria of *Zinnia* 'Benary Giant Deep Red'. Means are an average of 39 to 40 stems for harvesting and recutting procedures and 19 to 20 stems for postharvest storage procedure.

Treatment	Vase life (days)	Brown petals (%)	Stem collapse (%)	Wilted petals (%)
Wet	9.6	2.6	2.6	97.4
Dry	8.6	2.6	12.8	94.9
Significance	NS	NS	NS	NS
Recut	8.9	2.6	7.7	94.9
Not recut	9.4	2.6	7.9	97.4
Significance	NS	NS	NS	NS
20°C, no storage	8.9	5.0	0.0	100.0
20°C, 2 h	8.2	5.3	10.5	94.7
5°C, 2 days	9.7	0.0	16.7	94.4
5°C, 3 days	9.7	0.0	5.0	95.0
Significance	NS	NS	NS	NS

[NS]Nonsignificant at $P \leq 0.05$.

Table 4. Effect of recutting procedure (cut, not cut) on the vase life and termination criteria of cut *Zinnia* 'Benary Giant Deep Red' stems. Means are an average of 77 to 78 stems. Recutting, hydration, and holding procedures experiment.

Treatment	Vase life (days)	Brown petals (%)	Stem collapse (%)	Wilted petals (%)
Cut	6.9 b[z]	16.9	58.4 a	84.4
Not Cut	10.5 a	10.3	37.2 b	80.8
Significance	0.0001	NS	0.004	NS

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.
[NS]Nonsignificant at $P \leq 0.05$.

Table 5. Effect of hydrating solution (Hydroflor, tap water) on the vase life and termination criteria of cut *Zinnia* 'Benary Giant Deep Red' stems. Means are an average of 77 to 78 stems. Recutting, hydration, and holding procedures experiment.

Treatment	Vase life (days)	Brown petals (%)	Stem collapse (%)	Wilted petals (%)
Hydraflor	8.5	18.1	42.9	83.1
Tap water	9.0	9.0	52.6	82.1
Significance	NS	NS	NS	NS

[NS]Nonsignificant at $P \leq 0.05$.

Table 6. Effect of pulse solution (Floralife Professional, tap water) on the vase life and termination criteria of cut *Zinnia* 'Benary Giant Deep Red' stems. Means are an average of 76 to 79 stems. Recutting, hydration, and holding procedures experiment.

Treatment	Vase life (days)	Brown petals (%)	Stem collapse (%)	Wilted petals (%)
Floralife Professional	9.8 a[z]	13.9	41.8	83.6
Tap water	7.7 b	13.2	53.9	81.6
Significance	0.0105	NS	NS	NS

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.
[NS]Nonsignificant at $P \leq 0.05$.

Table 7. Effect of holding solution (bleach solution, tap water) on the vase life and termination criteria of cut *Zinnia* 'Benary Giant Deep Red' stems. Means are an average of 76 to 79 stems. Recutting, hydration, and holding procedures experiment.

Treatment	Vase life (days)	Brown petals (%)	Stem collapse (%)	Wilted petals (%)
Bleach solution	9.8 a[z]	15.2	44.3	83.5
Tap water	7.6 b	11.8	51.3	81.6
Significance	0.0078	NS	NS	NS

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.
[NS]Nonsignificant at $P \leq 0.05$.

Table 8. Effect of number of stems per vase on vase life, water uptake, occurrence of wilted petals, stem collapse, and brown petals, and bacterial counts taken four and seven days after harvest of cut *Zinnia* 'Benary Giant Deep Red' stems. Means are an average of ten vases where each vase contains one, three, five, or ten stems.

Stems/vase (no.)	Vase life (days)	Water uptake (mL/stem/day)	Brown petals (%)	Stem collapse (%)	Wilted petals (%)	Bacterial count day 4 (cfu/cm^2)	Bacterial count day 7 (cfu/cm^2)
1	14.7	12.3 a[z]	20.0	0.0 b	90.0	905823	77119
3	13.6	8.7 b	16.6	29.9 a	83.4	226000	86620
5	12.0	7.1 b	6.0	24.0 ab	90.0	292667	180333
10	11.2	7.5 b	7.0	28.0 ab	88.0	220000	92667
Significance	NS	0.0001	NS	0.0298	NS	NS	NS

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.

[NS]Nonsignificant at $P \leq 0.05$.

Table 9. Effect of harvest time (8:00 AM, 1:00 PM, 6:00 PM) on the vase life, cold damage 4 and 12 days after stems placed in vases (% of affected petals), stem quality 12 days after stems placed in vases (% of flower with dead petals) and termination criteria of cut *Zinnia* 'Benary Giant Deep Red' stems. Means are an average of five replicates of three stems each.

Treatment	Vase life (days)	Cold damage on day 4	Cold damage on day 12	Stem quality on day 12	Brown petals (%)	Wilted petals (%)
8:00 AM	17.3	0.0	0.0	20.1	93.3	6.7
1:00 PM	18.1	0.0	0.0	5.5	93.3	13.3
6:00 PM	18.1	0.0	0.0	3.9	100.0	0.0
Significance	NS	NS	NS	NS	NS	NS

[NS]Nonsignificant at $P \leq 0.05$.

Table 10. Effect of two day storage temperature (1, 5, or 20°C) on the vase life, cold damage 12 days after stems placed in vases (% of stems showing cold damage on 1 to 10 petals) and termination criteria of cut *Zinnia* 'Benary Giant Deep Red' and 'Uproar Rose' stems. Means are an average of ten replicates of three stems each and pooled for both cultivars.

Treatment	Vase life (days)	Cold damage on day 12	Brown petals (%)	Wilted petals (%)
1°C	9.0 a[z]	38.3	21.7	90.0
5°C	8.2 a	36.7	33.3	90.0
20°C	6.5 b	20.0	20.0	80.0
Significance	0.0001	NS	NS	NS

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.
[NS]Nonsignificant at $P \leq 0.05$.

Table 11. Effect of *Zinnia* cultivar ('Benary Giant Deep Red' and 'Uproar Rose') on the occurrence of stem collapse. Means are an average of 15 replicates of three stems each.

Cultivar	Stem collapse (%)
'Benary Giant Deep Red'	33.3 b[z]
'Uproar Rose'	68.9 a
Significance	0.0066

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.

Table 12. Effect of 5 h holding temperature (5, 14, 20, or 31°C) on the vase life, cold damage 6 days after stems placed in vases (% of affected petals), stem quality 6 days after stems placed in vases (% of flower with dead petals) and termination criteria of cut *Zinnia* 'Benary Giant Deep Red' stems. Means are an average of five replicates of three stems each.

Treatment	Vase life (days)	Cold damage on day 6	Stem quality on day 6	Brown petals (%)	Stem collapse (%)	Wilted petals (%)
5°C	12.7	0.0	0.7	93.3	6.7	0.0
14°C	13.0	0.0	2.7	100.0	0.0	0.0
20°C	12.0	0.0	1.5	93.3	0.0	6.7
31°C	10.4	0.0	6.4	86.7	0.0	20.0
Significance	NS	NS	NS	NS	NS	NS

[NS]Nonsignificant at $P \leq 0.05$.

Table 13. Effect of cooling rate (days after harvest) on the vase life and termination criteria of cut *Zinnia* 'Benary Giant Deep Red' stems. Means are an average of five replicates of three stems each.

Treatment (°C)			Vase life	Stem collapse	Wilted petals
Day 1	Day 2	Day 3	(days)	(%)	(%)
5	5	5	8.3	46.7 ab[z]	100.0
20	5	5	10.6	23.3 ab	83.3
20	20	20	9.7	20.0 b	93.3
26	5	5	8.7	60.0 a	93.3
26	26	26	8.5	26.7 ab	86.7
Significance			NS	0.0271	NS

[z]Means followed by the same letter are not significantly different at $P \leq 0.05$.
[NS]Nonsignificant at $P \leq 0.05$.

List of Figures

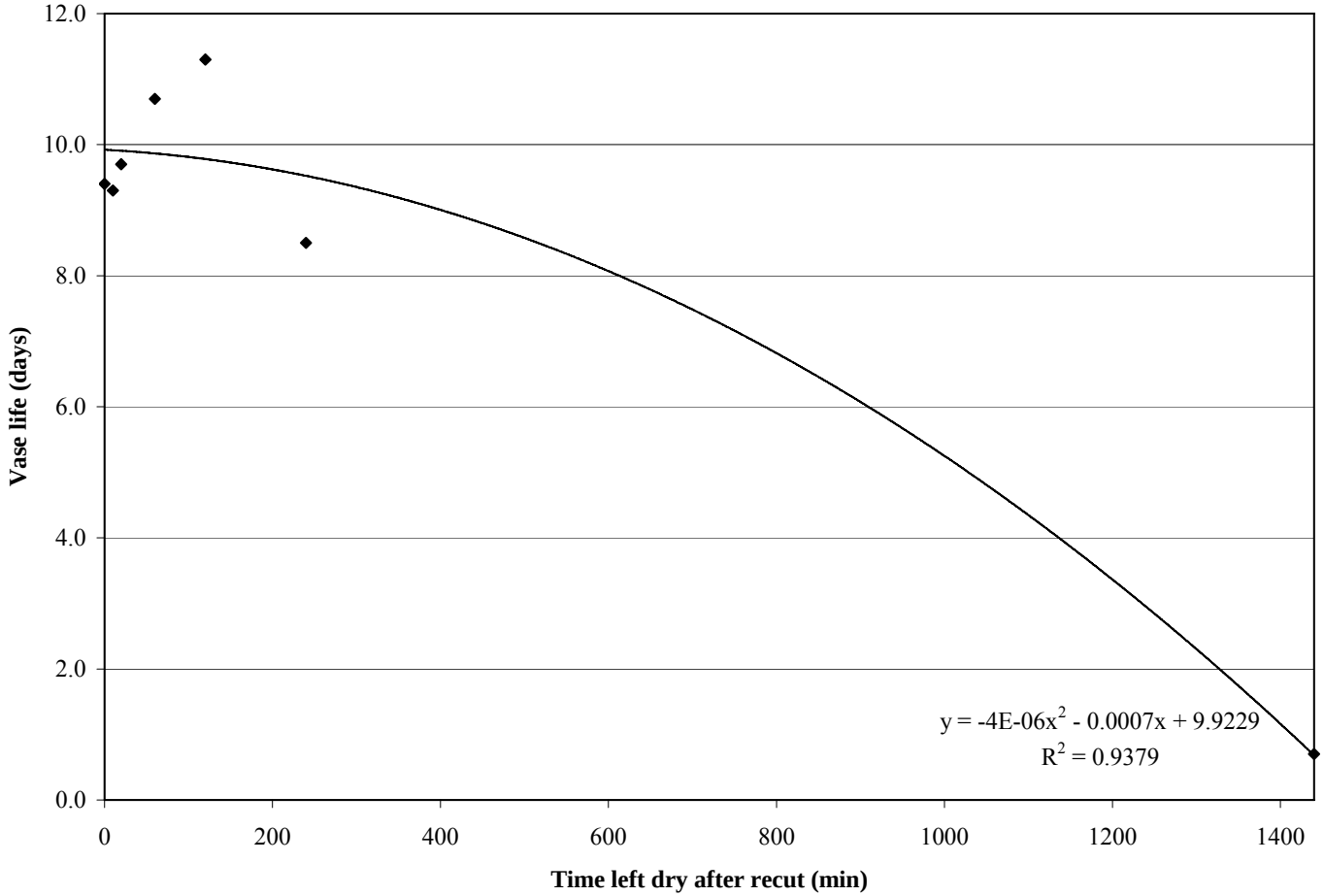

Fig. 1. Effect of drying time after recutting on vase life of *Zinna elegans* 'Benary Giant Deep Red' stems in 2006. Treatment means were significantly different at P =0.0001.

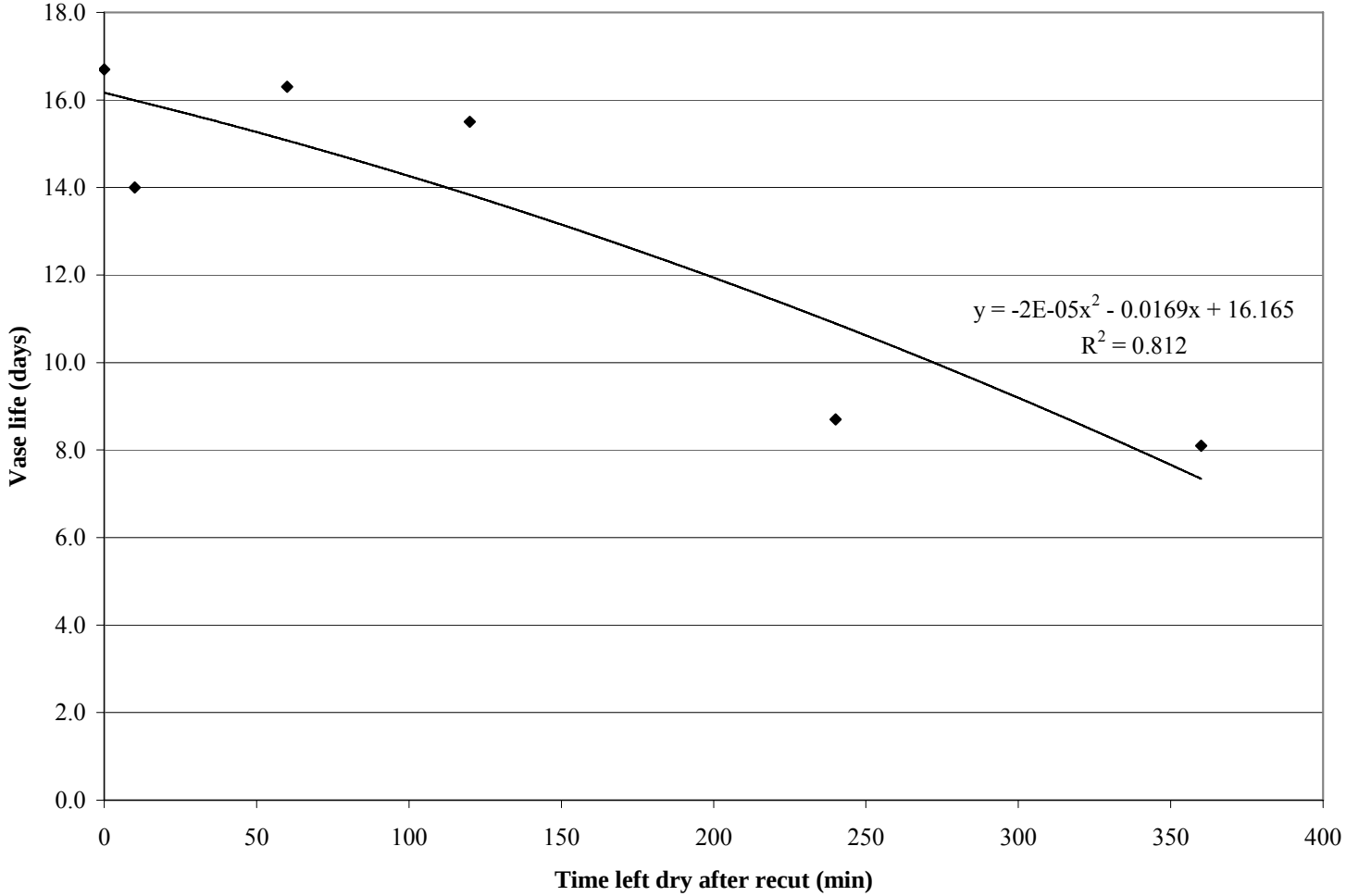

Fig. 2. Effect of drying time after recutting on vase life of *Zinna elegans* 'Benary Giant Deep Red' stems in 2007. Treatment means were significantly different at P=0.0128.

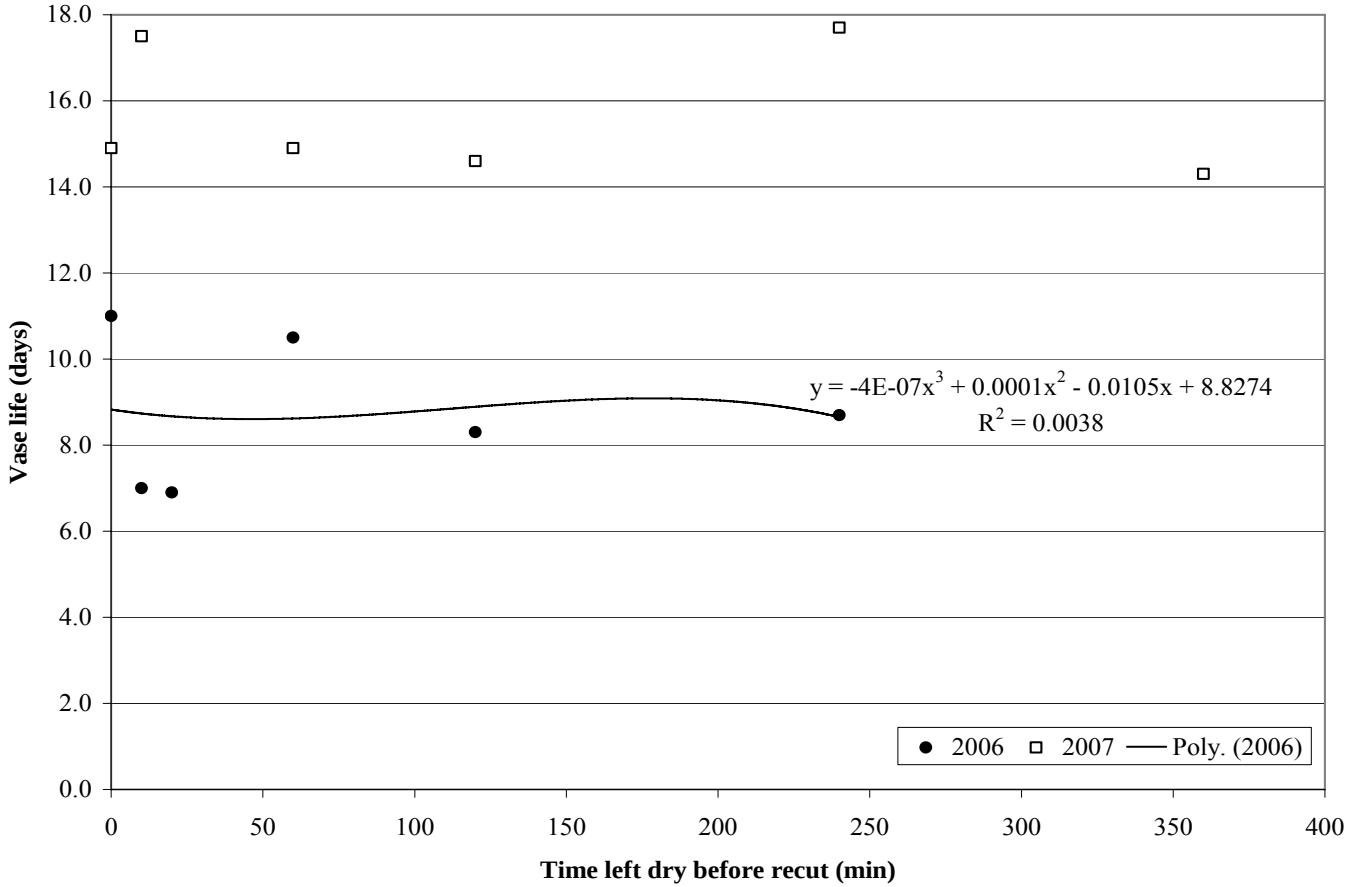

Fig. 3. Effect of drying time before recutting on vase life of *Zinna elegans* 'Benary Giant Deep Red' stems in 2006 and 2007. Treatment means for 2006 were significantly different at P=0.0122. Treatment means for 2006 were not significantly different at $P \leq 0.05$.

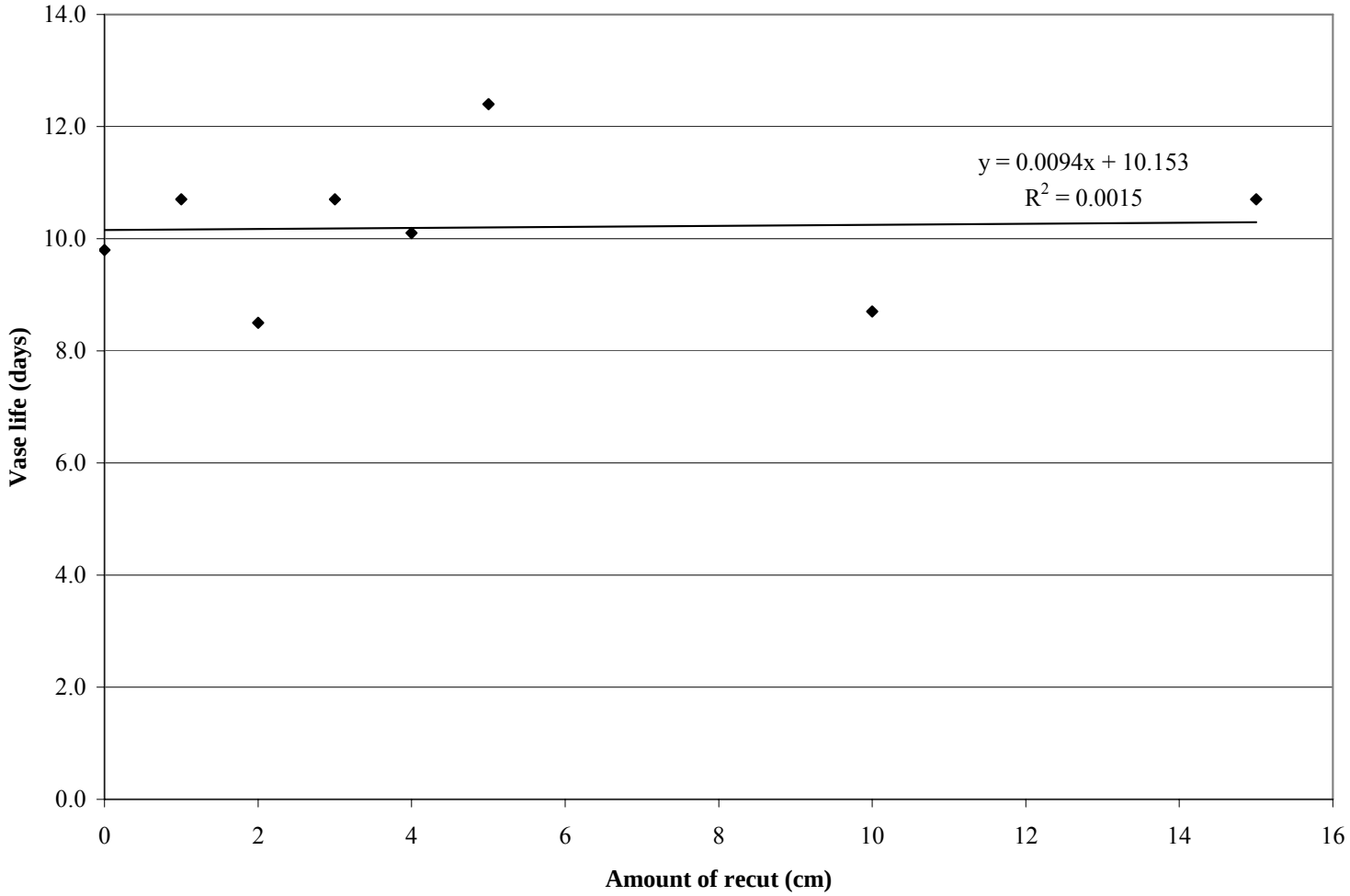

Fig. 4. Effect of recutting amount on vase life of *Zinna elegans* 'Benary Giant Deep Red' stems in 2007. Treatment means were not significantly different at $P \leq 0.05$.