

# Greenhouse Dehumidification Extends Postharvest Longevity of Cut Roses in Winter Season

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## Abstract

A strong inverse relationship between the preharvest relative air humidity (RH) and the postharvest longevity of cut roses has been observed previously. High RH levels common in greenhouses during winter reduce the vase life of cut roses, through the alteration of morphological and physiological characteristics. In this study, we investigated the use of a dehumidification system to reduce greenhouse RH levels and improve the postharvest longevity of cut roses. Longevity varied between seasons, with the longest vase life observed in spring (14.7 d), and shortest vase life in winter (9.1 d). Daily minimum RH ( $r = -0.80$ ,  $p < 0.01$ ) most strongly correlated with reduced vase life of cut flowers. Dehumidification effectively reduced greenhouse RH levels in winter and cut roses grown under the dehumidification environment showed a longer average vase life as well as higher fresh weight and thicker stem diameter compared to flowers grown under normal conditions (control). Stomata from cut roses grown in the dehumidification environment also had smaller, more responsive stomata, which likely contributed to longer vase life via effective regulation of transpiration. The current study demonstrates that dehumidification is an effective method for improving postharvest longevity and quality of cut roses in greenhouse production.

**Additional key words:** relative humidity, stomata, transpiration, vase life, VPD, *Rosa hybrida* L. ‘Lovely Lydia’

## Introduction

The vase life of cut roses is often shortened due to various postharvest disorders, including wilting of petals, bending of peduncles, and abscission of petals and leaves. This short vase life of cut roses is mainly attributable to the failure of tissue water relations, related to reduced water absorption due to vascular occlusion and water loss from leaves under postharvest conditions (van Doorn, 1989; van Meeteren, 1992; Doi et al., 2000). Water relations of cut roses are closely related to phenotypic characteristics such as leaf surface area, stomatal density and stomatal function, which in turn are determined by interaction between genotype (variety) and growth environment (Mortensen and Gislerod, 2000; Torre et al., 2003; Fanourakis et al., 2013).

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Previous studies have shown a strong relationship between the preharvest environment and the vase life of cut roses (Mortensen and Gislerød, 2000; Marissen and Benninga, 2001; Slootweg et al., 2001; Pompodakis et al., 2005). Roses grown in conditions with high relative air humidity (RH;  $\geq 85\%$ ) and low vapor pressure deficit (VPD) fail to regulate transpiration in postharvest conditions due to attenuated stomatal function, leading to excessive water loss and shortening of vase life (Torre et al., 2003; In et al., 2007; Fanourakis et al., 2012).

In commercial greenhouse environments for cut rose production, RH varies with seasons, weather conditions, and day-night cycles. Since the vents of greenhouses are kept closed to prevent heat loss in winter, environmental conditions during this season are characterized by a low temperature and a high RH, which result in a low VPD (Slootweg et al., 2001; Fanourakis et al., 2015; In et al., 2016). In this environment, air velocity is low, especially in dense rose canopies, and the lack of air movement increases the resistance to the diffusion of water vapor and CO<sub>2</sub> via a thickened air boundary layer around the plant surface (Mortensen and Gislerød, 1997; Wang et al., 2000; Raviv and Blom, 2001). Roses grown under these conditions experience no water stress during growth and consequently have attenuated stomatal function (Slootweg et al., 2001; In et al., 2007).

Previously, we demonstrated that improving local air circulation by air-blowing was an effective method for prolonging cut rose vase life (In et al., 2006a). Air-blowing treatments on both flowering and photosynthetic shoots reduce stomatal size and improve stomatal responsiveness, resulting in a longer vase life of cut roses grown in the winter. In this study, we assessed the dehumidification as an alternative method for improving vase life and postharvest quality of winter-grown cut roses. We determined the effect of dehumidification on greenhouse growing conditions, as well as postharvest morphological and physiological characteristics including vase life of cut roses.

## Materials and Methods

### Plant Material and Growth Condition

Cut spray roses (*Rosa hybrida* L. 'Lovely Lydia') were obtained from a commercial grower in Jangsu, Korea. The rose plants were grown in the greenhouse on rockwool slabs using the "arching" method (Ohkawa and Suematsu, 1999) and were drip-irrigated with a nutrient solution containing 0.78 g·L<sup>-1</sup> Ca(NO<sub>3</sub>)<sub>2</sub>·4H<sub>2</sub>O, 0.5 g·L<sup>-1</sup> NH<sub>4</sub>NO<sub>3</sub>, 0.17 g·L<sup>-1</sup> KH<sub>2</sub>PO<sub>4</sub>, 0.34 g·L<sup>-1</sup> KNO<sub>3</sub>, 0.28 g·L<sup>-1</sup> MgSO<sub>4</sub>·7H<sub>2</sub>O, and small amounts of other compounds. Temperature and RH inside the greenhouse were recorded at 30-min intervals by data loggers (WatchDog 1450, Spectrum Technologies, Aurora, IL, USA). VPD was calculated from the temperature and RH data. Solar irradiation was measured by a radiation sensor (SQ-100; Apogee Instruments, Inc., Logan, UT, USA) connected to the data logger.

For seasonal comparison, thirty rose flowers at an identical stage of maturity (onset of outer petal reflex) were randomly harvested on January 29, April 20, May 10, July 13, August 17, October 30, November 10, and December 8 in 2015. For the dehumidification treatment, nine dehumidifiers (SGD-11S, SG, Korea) were installed in an area (approximately 1,000 m<sup>2</sup>) separated by plastic screens in the glass greenhouse where 'Lovely Lydia' roses were grown. The dehumidifiers were turned on automatically when the level of RH was  $> 80\%$ , from October 2016 to April 2017. Thirty rose flowers each were harvested in January, February, and March in 2016 (control; no dehumidification) and in 2017 (dehumidification).

## Morphological and Physiological Characteristics

After harvest, cut flowers were immediately placed in a bucket of tap water and transported to the laboratory within 2 h. At the laboratory, initial fresh weight, stem length, and stem diameter of the individual cuttings were measured. Stem hardness at the cut end was measured with a digital hardness tester (TH200, Time Group, Beijing, China). Tissue samples (0.1 g) of the uppermost leaf were ground using a TissueLyser (TissueLyser II; Qiagen, Hilden, Germany) with 0.5 mL distilled water, and the brix (%) was measured with a portable refractometer (PR-104, Atago, Tokyo, Japan).

The day after harvest, sizes and densities of stomata were measured after 12 h of darkness and after 1 h of light exposure ( $30 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ ). Epidermal imprints were taken from the abaxial surface of the uppermost leaf, using Suzuki's Universal Micro-Printing (SUMP) method. Impressions of the leaf surfaces were photographed with a digital camera (PL-A662, PixeLink, Ontario, Canada) connected to an optical microscope (BX51; Olympus, Tokyo, Japan). The number, length and width of stomata (excluding guard cells) were measured from the images using Image J software (Version 1.49p, NIH, Bethesda, MD, USA).

## Vase Life Evaluation

Among the thirty cut spray roses, twelve were randomly chosen for evaluation of vase life. The stems were re-cut to a length of 50 cm; each stem contained five florets with three upper leaves on the main stems. Individual cut stems were placed through a hole (1 cm diameter) in the center of a cap on a glass jar containing 500 mL distilled water, which was subsequently held in a test room at 25°C, 50% RH, and a photoperiod of 12 h with light supplied by fluorescent tubes at  $20 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$  light intensity.

Postharvest quality of cut roses was determined by measuring changes in water uptake, fresh weight, and flower diameter daily. Flower diameter was determined by measuring the largest diameter of the flower and its perpendicular across the face of the flower. Transpiration was calculated as water absorption minus the increase in fresh weight, and water balance was calculated by deducting transpiration from daily water uptake.

Following placement of cut stems in the test room, vase life evaluation was performed daily in accordance with the evaluation card for Rosa (VBN, 2014) with modifications. Roses were considered to have reached the end of their vase life when one or more of the following senescence symptoms was detected in at least three of the five florets: bending of the pedicel (bent-neck; neck angle greater than  $45^\circ$ ), wilting ( $\geq 50\%$  petal turgor loss), bluing ( $\geq 50\%$  blue petals), petal abscission (drop of three or more petals), and leaf abscission and yellowing ( $\geq 50\%$  leaf drop and yellowing).

## Petal Color and Leaf Chlorophyll

Petal color of cut roses was determined daily using randomly selected outermost petals. The petal color was measured with a chromameter (CR-400, Konica Minolta Sensing, Inc., Osaka, Japan) using CIE-L\*a\*b\* coordinates, hue ( $h^*ab$ ), and the chroma ( $C^*ab$ ) notation system, which are related to visual perception (Mcguire, 1992). Chlorophyll status of the leaves was measured using a chlorophyll meter (SPAD-502Plus; Konica Minolta Sensing, Inc., Osaka, Japan). The SPAD measurements were performed on the terminal leaflets of the uppermost leaves three times every other day.

## Experimental Design and Data Analysis

The vase life experiment followed a completely randomized block design with twelve replicates for each experiment. To determine seasonal variations in vase life, the data were separated into four seasons as follows: winter, December–January;

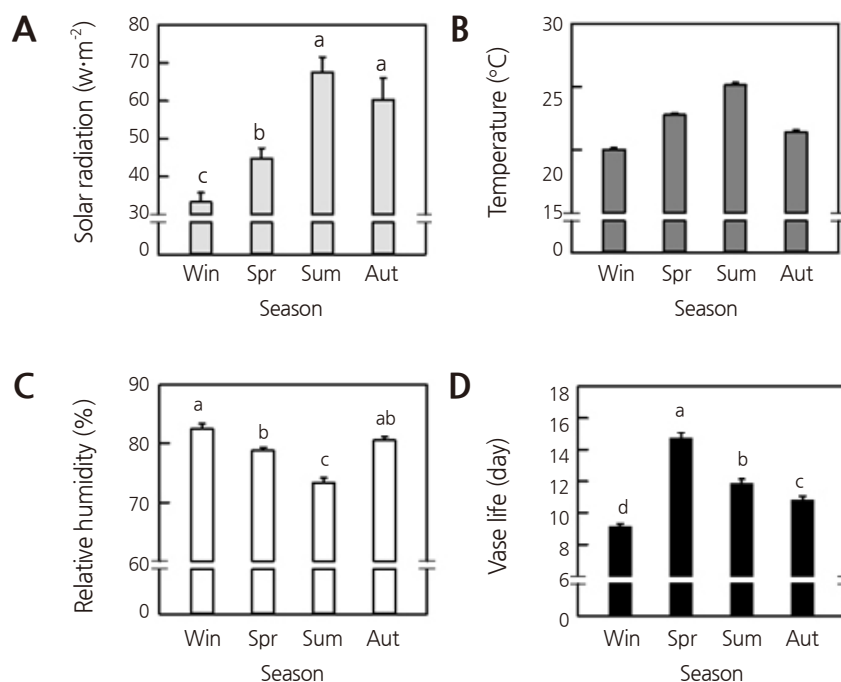
spring, April–May; summer, July–August; and autumn, October–November. One-way analyses of variance (ANOVA) were conducted for the seasonal comparison. When significant effects were detected, post-hoc pairwise comparisons of group means were executed with Duncan's multiple range tests, with a significance level of  $p=0.05$ . To clarify the correlations between vase life and environmental factors, Pearson correlation analysis was performed. Average vase life values from each season were compared with their corresponding average environmental conditions throughout the year. Paired t-tests were conducted for vase life, morphological and physiological data between control and dehumidification treatment cuttings. Statistical analyses were performed using SPSS version 18.0 (IBM, Somers, NY, USA).

## Results

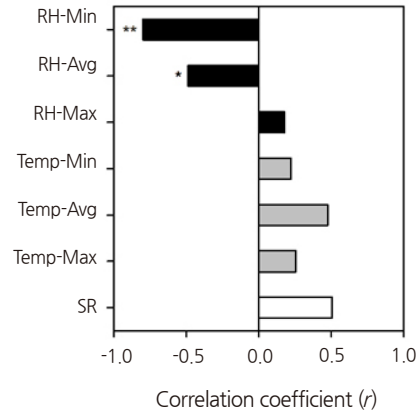
### Seasonal Variation in Environmental Conditions and Vase Life of Cut Roses

Preharvest environmental conditions in the greenhouse and vase life cut roses varied greatly between seasons. The average solar radiation and temperature increased in the summer and decreased in the winter, whereas the average RH increased during the winter and dropped in summer (Fig. 1A, B and C). Cut roses showed the longest vase life in spring (14.7 d), followed by summer (11.8 d), autumn (10.8 d), and winter (9.1 d). The vase life of winter flowers was reduced by 5.6 d compared to that of spring flowers on average (Fig. 1D).

Although most of the environmental factors were not significantly correlated with vase life, daily minimum RH (RH-Min) was negatively correlated ( $r=-0.80$ ;  $p<0.01$ ; Fig. 2), consistent with the seasonal variation in the vase life and RH (Fig. 1C, D).



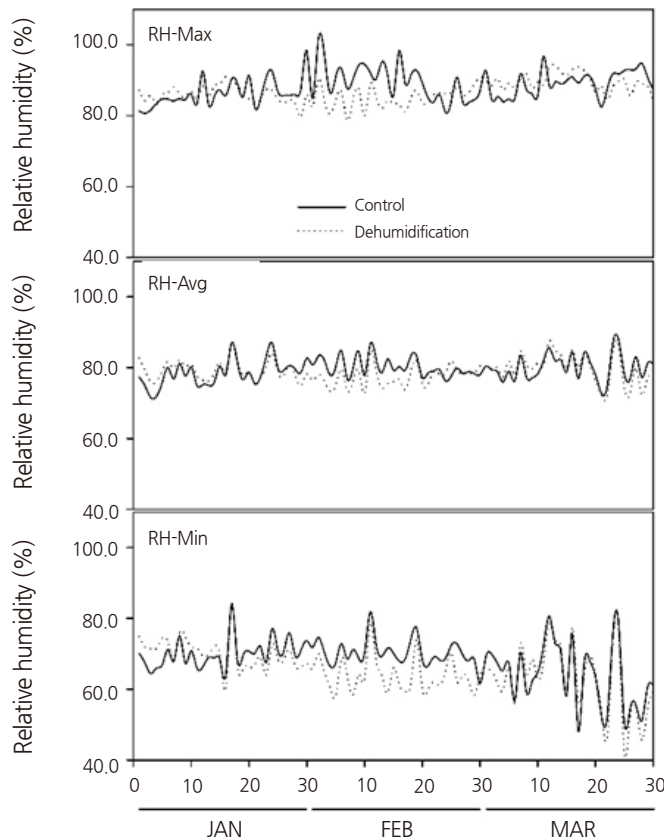
**Fig. 1.** Seasonal variation in greenhouse environmental conditions and vase life. Changes in (A) solar radiation, (B) temperature, and (C) relative humidity in the greenhouse, and (D) vase life of cut 'Lovely Lydia' roses grown year-round in the greenhouse. Win, winter (Dec.-Jan.); Spr, spring (Apr.-May); Sum, summer (Jul.-Aug.); Aut, autumn (Oct.-Nov.). Vertical bars represent standard errors of the means ( $n = 62$  for A-C and 24 for D). One-way analysis of variance (ANOVA) was conducted separately for each factor. Different letters (a-d) between seasons indicate statistically significant differences at  $p < 0.05$  based on Duncan's multiple range test.



**Fig. 2.** Correlation coefficient values for the relationships of preharvest environmental factors with vase life of cut 'Lovely Lydia' flowers. SR, solar radiation; Temp, temperature; RH, relative humidity; -Max, maximum; -Avg, average; -Min, Minimum. Data were subjected to Pearson correlation analysis ( $n = 11$ ). Horizontal bars represent correlation coefficient ( $r$ ) values. Asterisks (\*, \*\*) represent significant differences at  $p < 0.05$  and  $p < 0.01$ , respectively.

### Vase Life and Morphological and Physiological Factors

RH was reduced by the dehumidification treatment in the winter. The daily minimum RH (RH-Min) during February was approximately 10% lower in the dehumidification environment compared to that of the control (Fig. 3). The vase life of



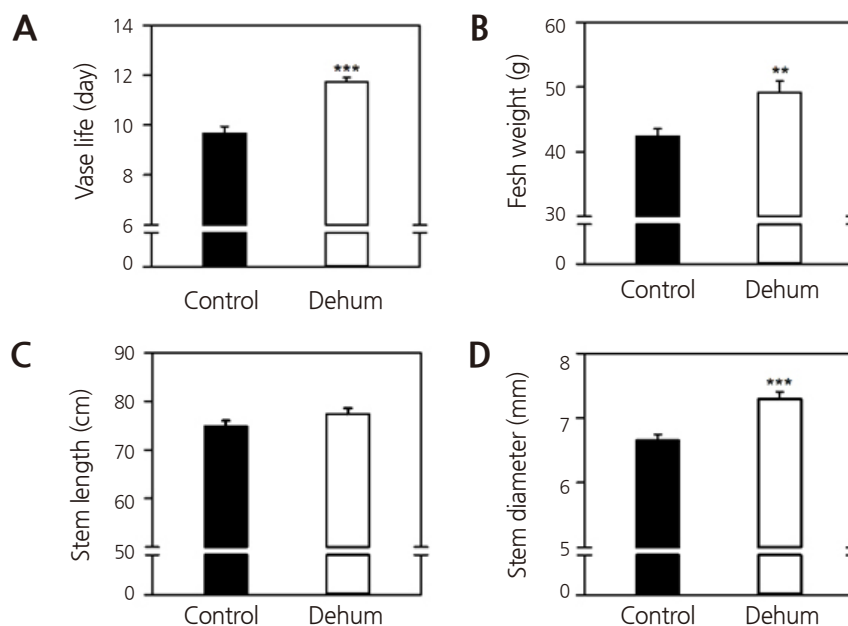
**Fig. 3.** Changes in relative humidity (RH) in the greenhouse during the winter. RH-Max, daily maximum RH; RH-Avg, daily average RH; RH-Min, daily minimum RH. Control, normal environment; Dehumidification, dehumidification environment.

dehumidification flowers grown in winter was significantly prolonged by 2 d on average, compared to non-treated control flowers (Fig. 4A). The primary senescence symptom that terminated vase life in control flowers was wilting (70%) and bluing (20%), whereas it was equally wilting (40%) and petal abscission (40%) in dehumidification-treated flowers (data not shown). The initial fresh weight and stem diameter were greater in dehumidification-treated cuttings (Fig. 4B and D), but stem length showed no significant difference between the treatments (Fig. 4C). Although there was no significant difference in the stem hardness and chlorophyll content of the leaves, the brix of leaves was higher in dehumidification flowers by 30% compared to control (Fig. 5B). The color parameter  $a^*$ , which is associated with red coloration, was significantly reduced in dehumidification-treated flowers (Fig. 5D).

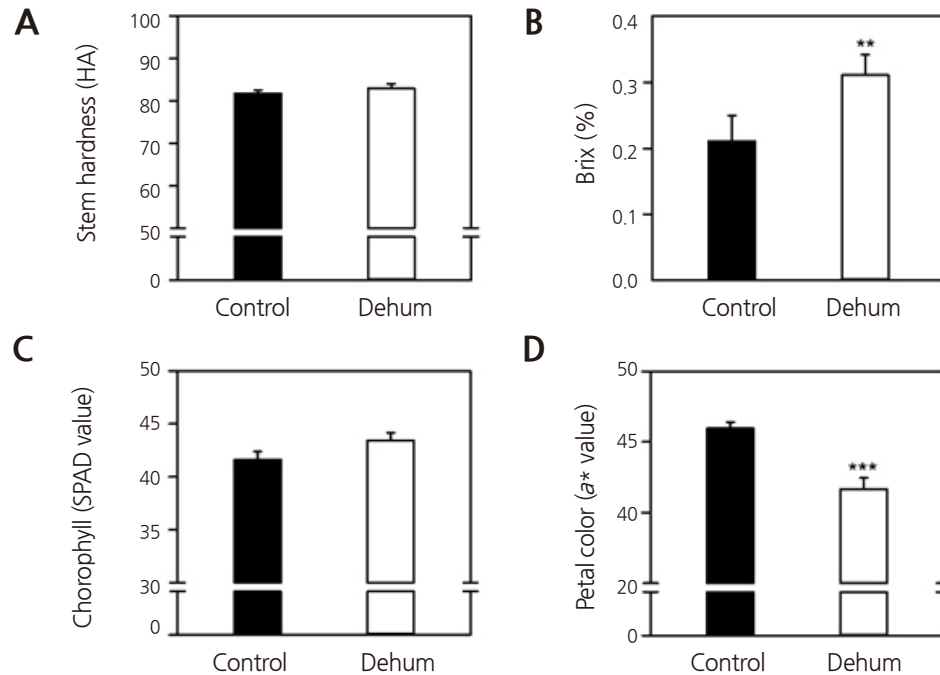
Fresh weight (percentage of initial) of cut flowers reached a maximum at day 3 and subsequently decreased thereafter (Fig. 6A). Dehumidification-treated flowers maintained their initial fresh weight 2 days longer than control flowers. Despite higher water uptake during vase life for control flowers, the number of days that flowers retained a positive water balance was shorter than treated flowers (Fig. 6C and D), probably due to higher water loss in these flowers (Fig. 7F). Changes in flower diameters (percentage of initial) of cut flowers mirrored the changes in fresh weight (Fig. 6B). The increase in radial expansion of the flowers was higher for the flowers in dehumidification treatment compared to those in control.

### Stomatal Characteristics

The stomata on the abaxial surface of the leaves was observed under light and dark conditions. There were significantly larger stomata in control flowers (Fig. 7A left) compared to flowers grown in the dehumidification environment (Fig. 7A right) during winter. The stomatal size of control flowers was significantly larger than that of dehumidification-treated flowers by 20% and



**Fig. 4.** Vase life and physical characteristics of cut 'Lovely Lydia' roses grown in the greenhouse with and without dehumidification treatment. (A) Vase life, (B) fresh weight, (C) stem length, and (D) stem diameter after harvest. Cut roses were grown in the greenhouse with normal environment (Control) or with dehumidification environment (Dehum) in the winter. Vertical bars represent standard errors of the means ( $n = 36$  for A and 90 for B-D). Asterisks (\*\*, \*\*\*) represent a significant difference between control and dehumidification at  $p < 0.01$  and  $p < 0.001$ , as determined by a t-test.



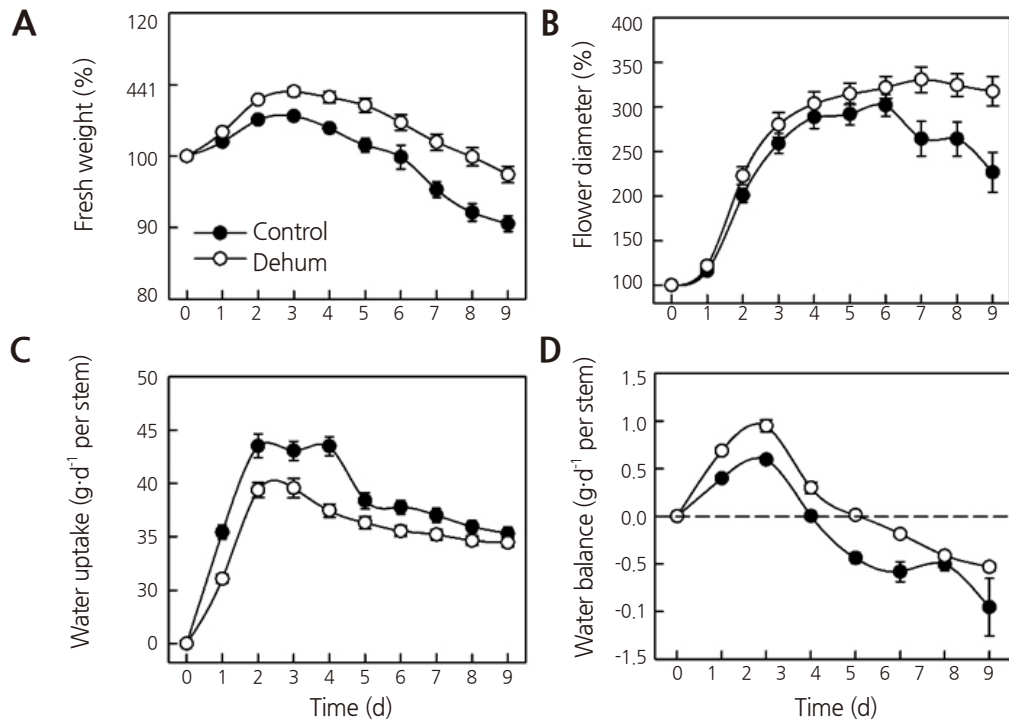
**Fig. 5.** Physiological characteristics of cut 'Lovely Lydia' roses grown in the greenhouse with dehumidification treatment. (A) Stem hardness, (B) Brix, (C) chlorophyll, and (D) petal color after harvest. Cut roses were grown in the greenhouse in a normal environment (Control) or with dehumidification (Dehum) in winter. Vertical bars represent standard errors of the means ( $n = 90$  for A and 36 for B-D). Asterisks (\*\*, \*\*\*) represent a significant difference between control and dehumidification at  $p < 0.01$  and  $p < 0.001$ , as determined by a t-test.

24% in the light and in the dark, respectively (Fig. 7C and D). However, there were fewer stomata observed in control flowers compared to dehumidification flowers (Fig. 7E).

Initial transpiration rate mirrored the stomatal size. The transpiration rate per cut stem was twice as high in control flowers as for dehumidification flowers (Fig. 7F). Together, these data indicate reduced functionality for the stomata of cut roses grown in normal greenhouse conditions during in the winter. By contrast, cut flowers grown in the dehumidification environment have functional stomata, and consequently lose less water from leaves after harvest.

## Discussion

The inherent longevity of cut flowers, as determined by varietal genotype, is greatly modified by morphological and physiological changes resulting from environmental conditions during growth (Mortensen and Gislerød, 1999; Ichimura et al., 2002; Fanourakis et al., 2013). The present study revealed that environmental conditions in the greenhouse and the vase life of cut roses covaried between seasons. The environmental conditions in the winter were characterized by a low solar radiation, a low temperature, and a high RH. Cut roses grown under these conditions had shorter vase life after harvest. Correlation analysis demonstrated that among the environmental conditions measured, daily minimum RH showed the strongest (negative) correlation with the vase life of cut roses. These results are consistent with previous studies which showed that cut roses grown under winter greenhouse conditions with high RH and low VPD have attenuated stomatal function, and excessive postharvest water loss (Mortensen and Gislerød, 1999; Slootweg et al., 2001; Fanourakis et al., 2012; In et al., 2016).



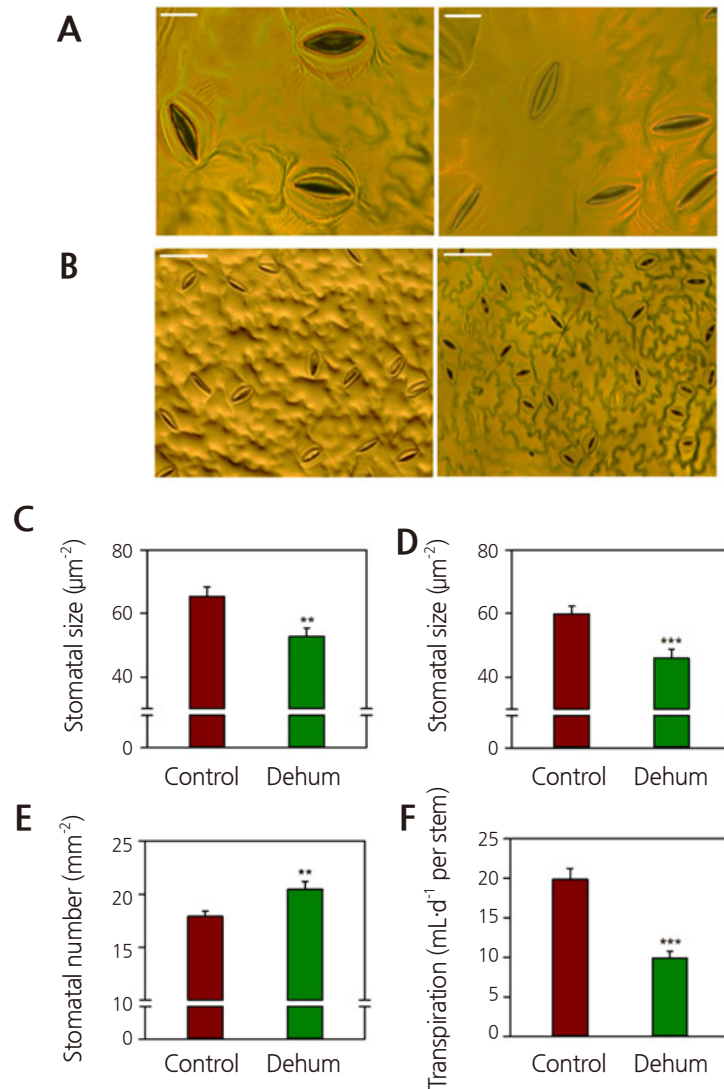
**Fig. 6.** Effects of greenhouse dehumidification on physical characteristics after harvest. Average fresh weight (A), flower diameter (B), water uptake (C), and water balance (D) of cut 'Lovely Lydia' roses after harvest. Cut roses were grown in the greenhouse in a normal environment (Control) or with dehumidification (Dehum) in winter. Vertical bars represent standard errors of the means ( $n = 36$ ).

Preharvest RH level was effectively reduced by the dehumidification treatment in the greenhouse (Fig. 3). Cut roses grown in the reduced RH conditions by dehumidification on average had a longer vase life as well as a higher fresh weight and a thicker stem diameter. Our data suggest that the shorter vase life of control flowers was caused by deterioration in water relations related to increased stomatal size and reduced stomatal function. Postharvest water loss for cut roses is mainly caused by transpiration through stomata in the leaves, which is physically correlated with VPD (Doi et al., 2000; Fanourakis et al., 2012). The rose plants grown in the winter greenhouse conditions, with high RH (70–90%) and low VPD, could not close their stomata sufficiently, and consequently transpired excessively after harvest. The high postharvest water loss in control flowers led to early wilting of flowers, resulting in a reduced vase life, consistent with previous studies (De Stigter, 1980; Blomzandstra et al., 1995; van Doorn, 1997; Doi et al., 2000). By contrast, rose plants grown in the dehumidification-treated environment with lower RH (60–80%) likely experienced water stress, and consequently possessed the ability to regulate their stomata after harvest. Our interpretation is consistent with a previous works showing that stomatal function is improved by low RH ( $\leq 75\%$ ) during growth, resulting in prolonged vase life of cut roses (Mortensen and Gislerod, 2000; Torre et al., 2003; In et al., 2006b; Fanourakis et al., 2013).

Notably, the dehumidification-treated flowers had more endogenous sucrose than the control flowers. This result supports the idea that congenital sucrose contents may also be important for extending the vase life of cut flowers by providing a source of energy for maintaining tissue function post-harvest, since carbohydrate accumulation by photosynthesis is generally very low in cut rose flowers (Ichimura et al., 2005; In et al., 2010; Nabigol et al., 2010).

In conclusion, the current study examined the utility of a dehumidification system for reducing winter greenhouse RH





**Fig. 7.** Stomatal characteristics and transpiration of cut 'Lovely Lydia' roses. Cut roses were grown in the greenhouse in a normal environment (Control) or with dehumidification (Dehum) in winter. (A and B) Epidermal imprints of the abaxial leaf surface of cut roses in the dark. Left, Control; right, Dehum. Scale bars in (A) and (B) represent 10 and 100  $\mu\text{m}$ , respectively. Stomatal size (C) in the light and (D) in the dark; (E) stomatal density; (F) transpiration per cut stem. Transpiration was calculated as water absorption minus the increase in fresh weight measured on d 1. Vertical bars represent standard errors of the means ( $n = 18$  for C-E and 36 for F). Asterisks (\*\*, \*\*\*) represent a significant difference between control and dehumidification at  $p < 0.01$  and  $p < 0.001$ , as determined by a t-test.

conditions and thus extending the vase life of cut roses. Our results clearly demonstrate that dehumidification is an effective method for reducing RH level during growth. The RH during winter often remains high because greenhouse vents are kept closed to prevent heat loss. Dehumidification in winter prolongs the potential vase life of cut roses by improving postharvest water relations.

Because the dehumidification examined in this study was performed in a large commercial setting, it was difficult to precisely control humidity throughout the greenhouse. Further studies are needed to accurately identify the effect of RH reduction on the vase life of cut roses using dehumidification in smaller greenhouses and to investigate other practical techniques that can alleviate the constant high humidity such as air blowing or heating pipes.

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