

Effect of Growth Conditions on Post Harvest Rehydration Ability of Cut Chrysanthemum Flowers

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Abstract

Different batches of cut chrysanthemum flowers showed substantial variability in restoring their fresh weight after a moderate water loss. Cutting height strongly affected the rehydration ability of cut flowers, and the hydraulic conductance of the stem and its restoration after air aspiration. Within a batch of flowers, rehydration ability is negatively related with the hydraulic conductance. Rehydration ability of the flowering stems of all experimentst was highly correlated with the restoration of hydraulic conductance of stem segments after air aspiration. This was demonstrated for batches from different harvest dates and cutting heights above root-shoot junction as well as cultivars. Greenhouse temperature and irradiance level affected the ability to recover from air emboli only significantly when differences in treatments were rather extreme. Xylem hydraulic conductance as well as emboli removal (rehydration ability) of cut flowers was rather sensitive to root substrate moisture content during cultivation of the plants.

INTRODUCTION

The length of vase life of different batches of a given cut flower genotype can vary substantially, even under identical post harvest conditions. It was assumed for a long time, that this variability is caused by differences in the cultivation conditions during growth of the different batches. However, until now there is no clear knowledge about the processes underlying this variability in vase life and the pre-harvest environmental conditions that can affect these processes after harvest.

In general, a positive water balance (water uptake rate \geq transpiration rate) is a prerequisite for a good vase life. In many cases vase life is shortened because the water balance of the cut flowers becomes negative soon after placing them in water (Halevy and Mayak, 1981; van Doorn, 1997). Variability in vase life of cut chrysanthemum flowers is mainly caused by differences in their water balance, which can become negative within a few hours after placing the flowers in water (van Meeteren, 1989, 1992). In most cases, when this unbalance is present soon after harvest, it is due to a high hydraulic resistance in the lower part of the cut flower stem caused by air aspiration into the stem (air emboli) via its cut surface, due to harvest in air (van Meeteren, 1992; Nijssse et al., 2000; Nijssse et al., 2001a). The air in the xylem vessels (partly) disappears, restoring the hydraulic conductance of the stem, when cut flowers are placed in water (van Meeteren and van Gelder, 1999). Variations in rate and level of emboli removal are thought to contribute to the differences in water balance between different batches of the chrysanthemum cut flower. Using a model based on physical processes, van Ieperen et al. (2002) discussed that hydraulic conductance recovery of cut stems after aspiration of air is affected by the anatomical properties of the xylem. Therefore, it was investigated whether there is a correlation between the water balance during first days of vase life and hydraulic conductance recovery of stem segments for flowers from different batches. Research was started to investigate whether specific growth conditions can affect xylem hydraulic resistance as well as level of emboli removal and water balance during vase life of cut chrysanthemums.

MATERIAL AND METHODS

Plant Material

Chrysanthemum (*Dendranthema* × *grandiflorum* Tzvelev) plants were grown in a greenhouse at Wageningen University in 14-cm diameter plastic pots containing a commercial potting soil. In the experiment about root substrate water content, the plants were grown in wooden boxes (190cm × 90cm × 9cm) with drainage wholes in the bottom, filled with fine perlite (particle size 0.6-1.5 mm) above a 2-cm layer of gravel; 105 plants per box with a distance between the plants of 12cm. Using TDR-based water sensors coupled to a computer controlled water dripping system, we were able to have rather constant root substrate volumetric water contents in the perlite at different levels. The average temperature was 18°C and an 18 h photoperiod was maintained until the plants had formed 15-17 leaves longer than 0.5 cm (3-4 weeks). Thereafter, a 9 h photoperiod was maintained until harvest. When necessary, lengthening of the natural photoperiod was achieved by high-pressure sodium lamps (SON/T). Conversely, shortening of the natural photoperiod was achieved using black screens.

Water Balance during Vase Life

For vase life experiments flowering stems were harvested in the greenhouse at commercial maturity by cutting the stalks at soil level. Flowers were brought to the laboratory as fast as possible. Lower leaves were removed up to 40 cm from the cut stem base. Thereafter, cut stem ends were trimmed by 1 cm in air (to get clean stem ends without soil particles), and the stalks were placed for 3h in a bucket with a mixture of ice and water (3:2 by volume) in darkness at 4°C. During this treatment, flowers achieved full turgidity (van Meeteren, 1992). The stems were cut at the desired cutting heights after this hydration treatment. Thereafter, the fresh weight of the flowers was determined as the initial weight, and flowers were moderately desiccated by placing the individual stems horizontally on two wires in the vase life evaluation room until they had lost about 5% of their fresh weight (≈ 1 h). Afterwards 2 cm from the cut-ends was recut in air to obtain fresh cut surfaces (this 2-cm was included in the cutting height). The flowers were placed in Erlenmeyer flasks containing a solution of 0.7 mM CaCl_2 , 1.5 mM NaHCO_3 and 50 μM CuSO_4 (van Meeteren et al., 2000) at 20 ± 1 °C, $60 \pm 5\%$ RH and a light intensity of $14 \mu\text{mol m}^{-2} \text{s}^{-1}$ (Philips, TLD 50W/84HF) with a light period of 12 h.

Hydraulic Conductance and Restoration after Air Aspiration

For measurements of hydraulic conductivity intact plants were transported to the laboratory. Stems were cut under water to prevent the entrance of air into the vessels at their cut ends. Stem segments for hydraulic conductance measurements were prepared under water according to van Ieperen et al. (2001). The hydraulic conductance of 30 cm long stem segments (K_h) was measured by pulling water through a stem segment at a known pressure difference (40.0 ± 0.01 kPa) using the apparatus described by van Ieperen et al. (2000). Initial K_h was measured until a constant value was obtained (about 15 min). Then air entrance at the basal part of the stem segment was allowed for 3 min by removing the water supply from the basal cut surface while maintaining the pressure. Afterwards water was reapplied to the stem segment and the restoration of K_h was measured over approximately 1.5 h. The before mentioned solution of CaCl_2 , NaHCO_3 and CuSO_4 (van Meeteren et al., 2000) was used. In the trials with different cutting heights, stem segments were taken at these cutting heights. A typical time curve of K_h during a rehydration experiment is given in Fig.1. As indicator of restoration of K_h after aspiration of air into the xylem conduits of stem segments, the K_h -values at 5400 s (1.5 h) after reapplying water to the stem segments were used.

Statistics

For each cutting height, 12 flowers were used for determination of fresh weight of flowers (one per Erlenmeyer flask) and 4 stem segments for hydraulic conductance

measurements. Effects of root substrate water content were analysed by two-way analysis of variance, followed by Bonferroni post-test using GraphPad Prism version 4.02 for Windows, GraphPad Software, San Diego California USA, www.graphpad.com. The same package was used for calculating the significance of correlations.

RESULTS

Chrysanthemum plants 'Cassa' were grown in a greenhouse at intervals of 4-6 weeks. Fresh weight of cut flowers was measured during 2 days of vase life, following a rapid water loss of about 5%. Although there were no special treatments applied and we tried to grow plants as standardized as possible, the changes in fresh weight during the first 2 days of vase life varied largely between the dates of harvest, without a clear seasonal effect (Fig. 2). Leaf wilting was visible when fresh weight was <90-95% of the initial weight. Because the earlier reported effect of cutting position (distance above the root-shoot junction) (van Meeteren and van Gelder, 1999), in four of the trials flowers were cut at four different heights above the root-shoot junction (Fig. 2). The effect of cutting height above soil level (root-shoot junction) on the water balance of the cut flowering stems was clear in all trials. However, the relative effects varied between the trials at different harvest dates. Cutting 25 cm above soil level resulted always in a better rehydration of the stems after a short period of water loss than cutting 10 or 15 cm above soil level, but was no assurance that the fresh weight recovered fully to the initial weight.

The hydraulic conductance (K_h) of stem segments taken from fresh flowers of the same batches showed also large differences between the batches (Fig. 3). Different K_h -values within a batch were mainly the result of different cutting heights. There was no correlation between K_h -restoration after air aspiration and K_h before air uptake when all batches were taken together. However, these parameters were strongly correlated for different cutting heights within one batch of flowers from the same date of harvest (Fig. 3).

As indicator of the water balance during vase life of cut flowers we used two different parameters: i) the rehydration rate during the first 24 hours after transferring the dry stored flowers to vases with water, ii) fresh weight after 2 days of vase life, expressed as percentage of the full hydrated fresh weight (FW_{Day2}). Both indicators showed a very highly significant correlation ($p=0.0009$ and $p=0.0005$, respectively) with K_h -restoration of stem segments for all batches and cutting heights. The correlation between FW_{Day2} and K_h -restoration is shown in Fig. 4A. As for K_h -restoration, FW_{Day2} showed a strong correlation with K_h (before air uptake) at different cutting heights within one batch of flowers, but not when all batches were taken together (data not shown).

To further investigate the correlation between K_h -restoration of stem segments and the water balance during vase life of cut flowers, three other cultivars were included in two trials; all flowers were cut 15 cm above the root-shoot junction. There was a highly significant correlation ($p=0.0031$) between FW_{Day2} and K_h -restoration (Fig. 4B).

A possible cause of the large variability between trials with the same cultivar could be the effect of growth conditions on xylem anatomy. Therefore experiments with different light intensities (different levels of shading) and temperatures during cultivation were conducted. Greenhouse temperature and irradiance level affected the ability to recover from air emboli. However, the effects were small and only significant when the differences between treatments were rather extreme (data not shown).

Besides irradiance level and temperature, moisture content of the potting compost will have varied between the trials. By growing plants in fine perlite and using TDR-based water sensors coupled to a computer controlled water dripping system, we were able to have rather constant root substrate water contents at different levels. The water content of the perlite (WC) had a clear effect on the stem hydraulic conductance of the plants (Fig. 5A). K_h is high in plants grown at WC of 70% (v/v) compared to plants grown at WC 20%. Because the large effect of the root substrate water content on total stem length (WC 70%: 120 cm; WC 20%: 92 cm) and the effect of cutting height on the water balance and K_h -restoration, stem segments were taken at two different cutting heights.

Cutting height showed an interaction with WC; there was only a significant effect of cutting height at the high WC. As shown in Fig. 5B, also the recovery of K_h by reapplying water after air aspiration was significantly ($p=0.016$) affected by the root substrate water content. There was no significant interaction between cutting height and WC for the recovery of K_h .

Cut flowers grown at a perlite water content of 20% showed a recovery of their fresh weight during vase life following a short dry period (Fig. 6). Flowers grown at a water content of 70% did not. There was no significant effect of cutting height on the fresh weight of the flowers during vase life.

DISCUSSION

Although Halevy and Mayak mentioned already in their extensive review in 1979 the importance of growth conditions for post-harvest behaviour of cut flowers, the knowledge about pre-harvest environmental conditions that can be used for controlling vase life is still very limited. As mentioned elsewhere in this Acta (Marissen), knowledge of physiological backgrounds of the processes involved in pre-harvest influence on post-harvest quality will be needed to aim for further improvement of quality. Because in many cases vase life is shortened by a negative water balance of the cut flowers, understanding the role of environmental growth conditions on the post-harvest water balance of cut flowers can be an important step to increase the knowledge to control post-harvest vase life by pre-harvest environmental conditions.

In cut flowers air emboli are initially present in the basal part of the stems due to harvest in air. Removal of these air emboli is essential for restoration of the water uptake during vase life and strongly depends on xylem anatomy near the cut surface. In intact plants, xylem anatomy (diameter of the xylem conduits) determines the vulnerability for cavitations (Tyree and Sperry, 1989). In a cut flower, air uptake in the vessels via the cut surface happens easier in larger diameter conduits than in smaller ones (van Ieperen et al., 2001) and repair of hydraulic conductivity is much slower (van Ieperen et al., 2002). The restoration of hydraulic conductivity in stem segments correlated strongly with the water balance of cut flowers and could explain about 50% of the variability between different batches of flowers (Fig. 4A). Note that the determination of fresh weight during vase life was necessarily performed on other stems (though of the same batch) than the stems used in the analysis of hydraulic conductivity. Because of the variability also within a batch of flowers (as can be seen by the large SD's) this will have had a negative effect on the r^2 .

Differences in hydraulic conductivity will be the result of differences in number, length, and diameter of xylem conduits. Emboli removal is mostly affected by the diameter of the conduits (van Ieperen et al., 2002). Within a stem, average conduit diameter decreases from root to top; the average cross-sectional conduit area is exponential related to height up the stem (Nijse et al., 2001b). The strong relation between K_h at different cutting heights to K_h -restoration within a batch of the same harvest date (Fig.3) suggests that within a stem, xylem conduit diameter is the most important changing xylem characteristic. The absence of an overall relation between K_h and K_h -restoration or FW_{Day2} of batches from different harvest dates suggest that the different batches differed also in number and/or length of xylem conduits.

During vase life, hydraulic conductance of cut flowers is decreasing due to several factors like plugging by micro-organisms and a physiological reaction to the wounding of the stem (van Doorn, 1997). Also for chrysanthemum a wound-induced xylem occlusion is reported (van Doorn and Cruz, 2000). Emboli due to air aspiration via the cut surface are present from the moment of cutting. To get rid of these emboli is the first prerequisite to ensure sufficient water uptake. It is suggested that presence of air hastens the physiological wound reaction (van Doorn and Cruz, 2000).

Xylem anatomy can vary with environmental factors during growth. Lovisolo and Schubert (1998) reported of reduced development of xylem vessels among grape plants grown at moderate water-stressed conditions. Water balance of cut flowers, as reflected in fresh weight changes, was strongly affected by the water content of the root substrate

during pre-harvest cultivation (Fig. 6). Flowers grown at high water content showed a negative water balance, while flowers grown in a dry substrate showed a positive balance. This agreed with the differences in stem hydraulic conductivity and emboli removal (Fig. 5). Water balance is the result of water uptake rate and transpiration rate. Environmental conditions during growth of plants will also affect plant characteristics that are important in transpiration rate, like number and size of stomata, and closing behaviour of stomata. Besides the variability between plants, this could be another reason that hydraulic conductance restoration of stem segments explains 50% of the differences in the water balance of cut flowers. Understanding the effects of environmental conditions on emboli removal as well as on transpiration rate will be an important step to understand the influence of growth conditions on post-harvest water balance of cut flowers. Breeding for genotypes or growing plants in such a way that most of the conduits in their xylem have a relative small diameter will lower the risk for hampered water uptake due to emboli.

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Figures

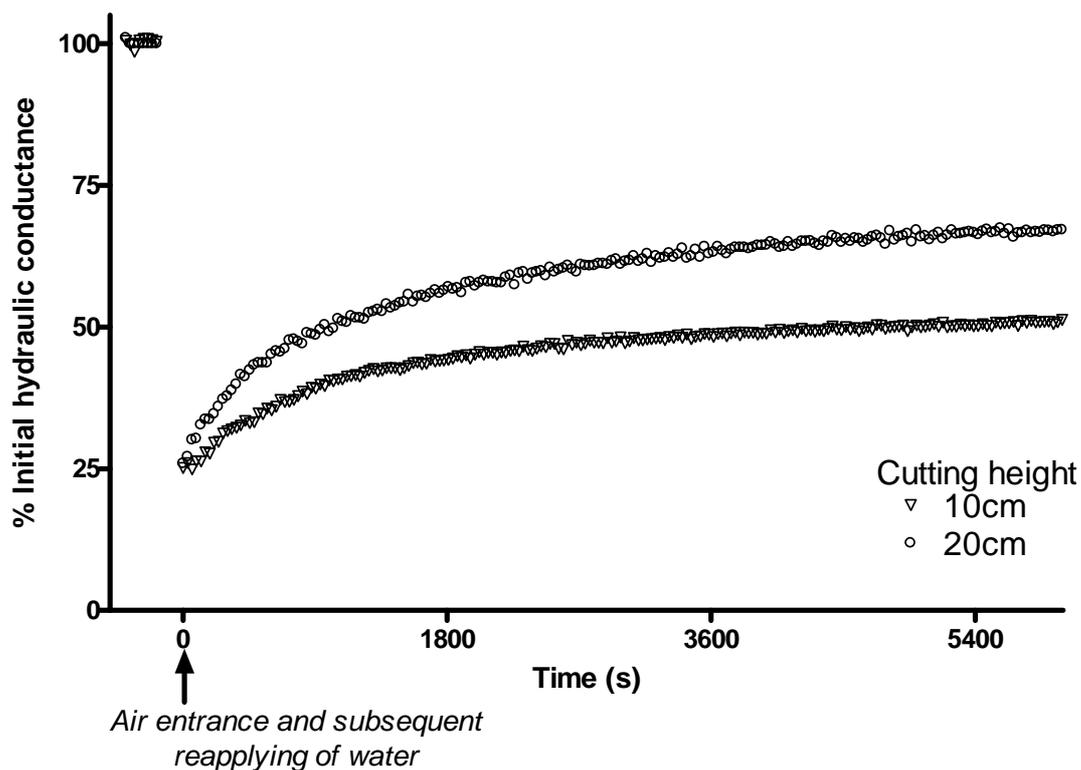


Fig. 1. Time course of hydraulic conductance of a 30-cm long stem segment cut 10 or 20 cm above the root-shoot junction. After measuring the initial hydraulic conductance without air in the xylem conduits, air was aspirated at the basal cut-surface for 3 min. Thereafter water was reapplied. Time 0 is the time of reapplying water.

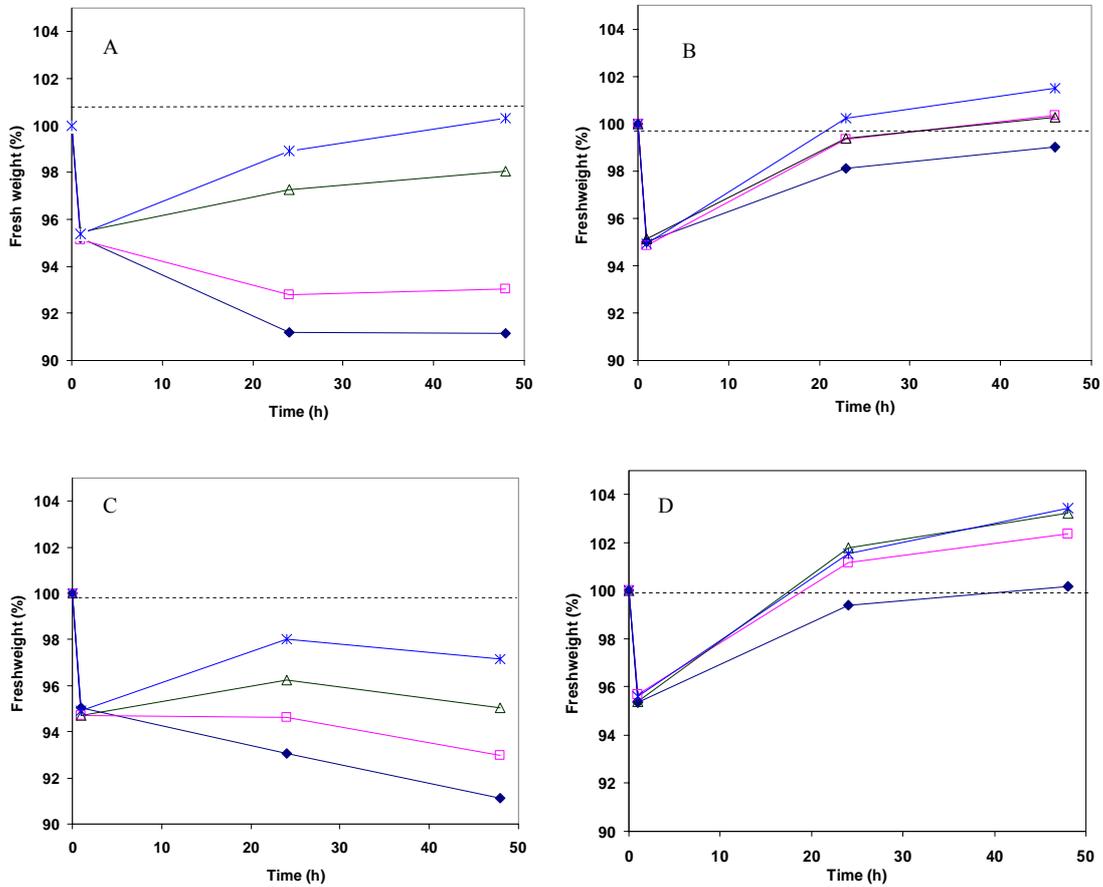


Fig. 2. Changes in fresh weight of cut chrysanthemum flowers during first 2 days of vase life in four identical experiments; flowers harvested at May 28 (A), July 4 (B), October 6 (C) and November 5 (D). Flowers were cut 10cm (◆), 15cm (□), 20cm (△) or 25cm (*) above root-shoot junction. Total flower stem length from root-shoot junction after harvest was 88.6 ± 1.2 cm, 95.1 ± 2.6 cm, 90.4 ± 3.9 cm and 87.3 ± 1.9 cm respectively for A, B, C and D. Fresh weight expressed as percentage of the fully hydrated weight. N=12

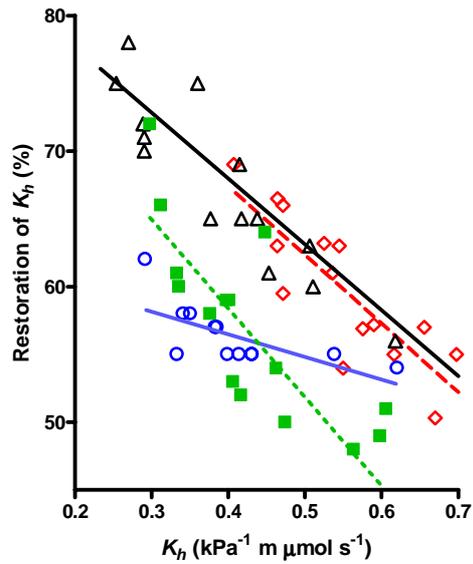


Fig. 3. Correlation between K_h -restoration 1.5 h after reapplying water following air aspiration and initial hydraulic conductance (before air entrance) (K_h) of 30-cm stem segments. Stem segments of cultivar Cassa from various cutting heights and harvesting dates: \triangle = May 28, \diamond = July 4, \circ = October 6, \blacksquare = November 5.

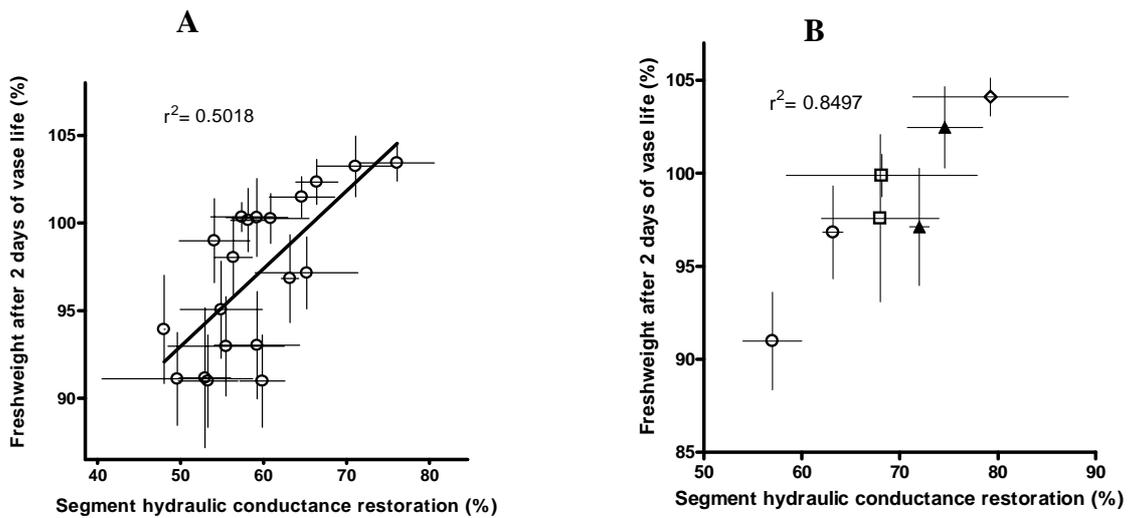


Fig. 4. Correlation between fresh weight of cut flowers after 2 days of vase life (FW_{Day2}) ($N=12$) and hydraulic conductance (K_h) recovery 1.5 h after reapplying water following air aspiration of 30-cm stem segments ($N=4$). A: Flowers of cultivar Cassa from various harvesting dates and cutting heights. B: Flowers of 4 cultivars: \circ = 'Cassa', \square = 'Vyking', \blacktriangle = 'Reagan', \blacklozenge = 'Super Yellow'. Before flowers were placed in vases they were kept dry to loose about 5% of their fully hydrated fresh weight. Fresh weight during vase live is expressed as percentage of their fully hydrated fresh weight. Horizontal and vertical lines show SD.

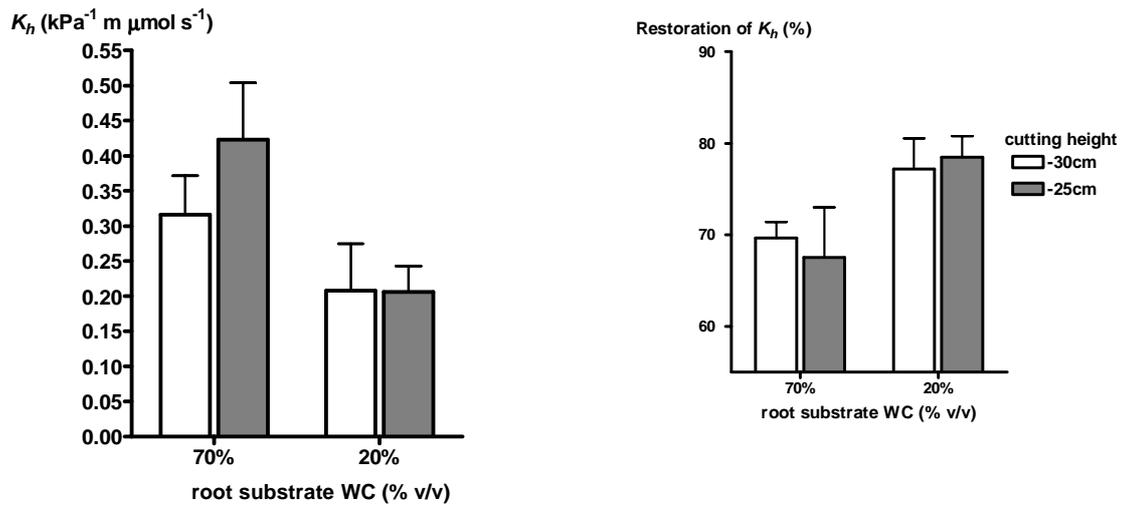


Fig. 5. Effect of root substrate water content (WC) and cutting height above soil level (root-shoot junction) on hydraulic conductance (K_h) (A) and on restoration of K_h after air aspiration (B) of stem segments. Different letters indicate significant difference (5%); bars indicate SEM.

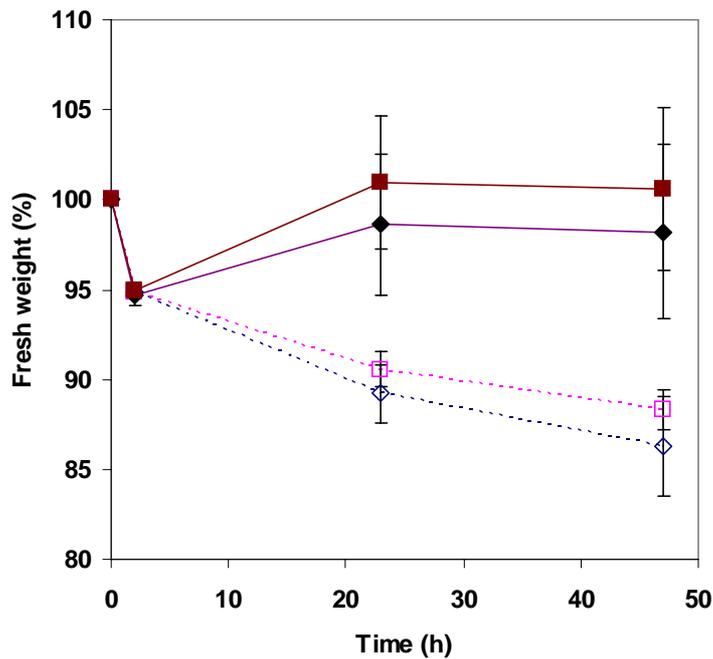


Fig. 6. Changes in fresh weight of cut chrysanthemum flowers during first 48h of vase life. Plants were grown in perlite with a water content of 20% (v/v) (full lines) or 70% (dotted lines). Flowers were cut 25cm (\blacklozenge, \diamond) or 30cm (\blacksquare, \square) above root-shoot junction. Fresh weight expressed as percentage of the fully hydrated weight. N=12. Bars indicate SD.

