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Compact *Campanula carpatica* 'Uniform' Without Chemical Growth Regulators

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Summary

Cyclic drought as a single stress factor or combined with low phosphorus (P) and/or low nitrogen (N) availability was tested on plant quality and post-production performance in *Campanula carpatica* 'Uniform'. Drought stressed plants were irrigated when the soil water potential ψ_s reached below –800 hPa and control plants were irrigated when ψ_s reached below –200 hPa. The growth substrate was a peat:perlite mixture. Plant height, leaf number, total leaf area, number of flower buds and total fresh and dry weight were reduced by continuous cyclic drought stress and by interrupted cyclic drought stress in combination with either low P alone or a combination of low P and low N. Low N combined with interrupted cyclic drought stress did not reduce plant height compared with cyclic drought as a single stress factor. Apparently, drought stress combined with low N availability favoured vegetative growth at the expense of reproductive growth, whereas dry matter in low P plants was distributed in favour of flower production. All plants produced with drought stress were more tolerant to a post-production drought stress treatment compared with control plants. Low P availability combined with interrupted drought stress during production improved the post-harvest stress tolerance to a larger extent than growing plants with drought stress and standard P levels.

Zusammenfassung

Kompakte *Campanula carpatica* 'Uniform' ohne Wachstumsregulatoren. An *Campanula carpatica* 'Uniform' wurden die Auswirkungen zyklischer Trockenheit als alleinigem Stressfaktor oder in Kombination mit geringer Phosphor- (P) und/oder Stickstoff-(N) Verfügbarkeit auf die Pflanzenqualität während der Kultur und beim Endverbraucher untersucht. Die trockengestressten Pflanzen wurden bewässert, wenn das Bodenwasserpotentials ψ_s unter –800 hPa und die Kontrollpflanzen, wenn ψ_s unter –200 hPa sank. Als Substrat diente eine Torf:Perlit Mischung. Anhaltender und unterbrochener zyklischer Trockenstress in Kombination mit geringem P oder einer Kombination von geringem P und N reduzierte die Pflanzenhöhe, die Blattzahl, die Gesamtblattfläche, die Anzahl Blütenknospen sowie das Frisch- und Trockengewicht. Die Kombination von geringem N und unterbrochenem zyklischen Trockenstress führte im Vergleich mit zyklischer Trockenheit als alleinigem Stressfaktor nicht zu geringerer Pflanzenhöhe. Anscheinend begünstigte Trockenstress in Kombination mit geringer N-Versorgung das vegetative Wachstum auf Kosten des generativen, wohingegen die Trockenmasse in Pflanzen mit wenig P zu Gunsten der Blütenbildung verteilt wurde. Alle während der Kultur trockengestressten Pflanzen waren beim Endverbraucher toleranter gegen Trockenheit als die Kontrollpflanzen. Geringe P-Verfügbarkeit kombiniert mit unterbrochenem Trockenstress verbesserte die Stresstoleranz der Pflanzen beim Endverbraucher in stärkerem Maße als eine Kultur mit Trockenstress und normaler P-Versorgung.

Key words. drought stress – growth regulator – nitrogen – phosphorus – stress tolerance

Introduction

During commercial production of greenhouse grown ornamentals, size, shape, and colour are important determinants of quality. Size and shape are traits determined by the genetic background of the plant but they can be modified by horticultural practice such as chemical growth regulation, irrigation practice, and environmental conditions. Due to legislation, the use of chemical growth retardants becomes more and more restricted and modified cultural practice should be implemented to give the desired plant height and quality. In this paper only drought stress and low nutrient availability will be discussed.

Reducing the water supply to pot plants affects turgor and many physiological processes such as photosynthesis and respiration thereby altering plant growth and development. Typical effects of drought stress on the outer appearance are reductions in: plant height, total leaf area, area of individual leaves, total fresh and dry weight of above ground parts, plant diameter, and number of flowers (EAKES et al. 1991; HASENBUSCH 1994; RÖBER and HAAS 1997; WILLIAMS et al. 1999). To which degree these parameters are reduced depends on

the type and severity of drought stress, plant species and cultivar, and other growing conditions such as temperature, light, relative humidity, nutrient supply etc. On the other hand, root length, fresh and dry weight of the root system, and dry matter content may increase during drought stress. Root dry weight and root to shoot ratio was increased after drought stress in *Hibiscus rosa-sinensis* 'Leprechaun' (EGILLA et al. 2001). The effects of drought stress on plant quality and post-production performance depend on how and when it is applied and on the severity of the drought stress treatment given to the plant. Most used in scientific studies are cyclic or constant drought stresses. When cyclic drought stress is applied the water content of the growing medium alternates between container capacity and a very low soil water potential (ψ_s), often to a level where the plants show visible signs of wilting. When constant drought stress is applied, the water content of the growing medium is kept continuously low without much fluctuation. Constant drought stress can be applied in different ways. Plants can be irrigated each day but are only given a certain percentage of control irrigated plants (RÖBER et al. 1995; RÖBER and HAAS 1997), they are weighed and given the amount of water needed to reach a certain weight percentage of fully irrigated (WILLIAMS et al. 1999), or a specific tension may be kept by ceramic plugs (RÖBER and HAFEZ 1981; RÖBER et al. 1986).

The availability of single nutrients can also change processes involved in plant growth and development. It has been shown that continuous low levels of phosphorus can reduce plant height substantially. In *Pentas lanceolata* plant height was reduced by 16 % when grown at low P (0.05 mM) compared to control (1.0 mM P) and in potted miniature roses the reduction in plant height was 25 % (HANSEN and NIELSEN 2001). In some species, low P as a single factor can substitute chemical growth regulation, whereas in other species it must be combined with other growth regulating methods. Also low nitrogen availability can reduce plant height, but probably not to the same extent as low P and drought stress. In poinsettia the plant height was reduced by approx. 10 % when the nitrogen concentration was reduced from 17 to 2.1 mM, even though the dry matter content increased (STARKEY and ANDERSSON 2000). The objective of this investigation was to study plant growth, flowering, and post-production performance when cyclic drought as a single stress factor or combined with low phosphorus or low nitrogen availability was given to *Campanula carpatica* 'Uniform' during forcing. It was also evaluated if post-production drought tolerance was improved by the different production treatments.

Materials and Methods

Plant material

Campanula carpatica 'Uniform' is a hardy perennial grown out-door on container areas during spring and summer. Plants are over-wintered out-doors, moved to greenhouse conditions and forced to flowering in early spring. This experiment only included the forcing period followed by a post-production evaluation.

Over-wintered plugs of *Campanula carpatica* 'Uniform' were potted in a peat:perlite based growing substrate in 10 cm pots according to standard practice in the commercial nursery who delivered the plants. The peat:perlite mixture was either fully amended with nutrients, or phosphorus was omitted. For the low P treatment a P-buffer technique as described by HANSEN and NIELSEN (2001) was used to maintain a stable P concentration of 0.05 mM in the soil solution throughout the forcing period. This is a 20-fold reduction in P availability compared with modern horticultural practice. One week after potting, plants were randomly placed into two blocks on closed 1.25 m^2 trays spaced with 40 plants per m^2.

During forcing, plants were treated twice with 0.6 ‰ Amistar against *Phytophthora* and once with 1 ‰ Acrobat against *Fusarium*.

Treatments

Forcing. The experiment included three irrigation treatments: control irrigation when the soil water potential (ψ_s) in the growing medium reached below –200 hPa and two cyclic drought stress treatments. In the drought stress treatments plants were irrigated when ψ_s reached below –800 hPa either throughout the entire forcing period (continuous drought stress; CDS) or the drought stress treatment was interrupted by two weeks of control irrigation in the middle of the forcing period (interrupted drought stress; IDS). IDS was also combined with low phosphorus availability, 0.05 mM P, or low nitrogen availability, 5.35 mM N, hereafter referred to as low N and low P, respectively. Finally, IDS, low P and low N was combined (low P + N). The control nutrient solution contained in mM: 12.92 N, 0.84 P, 6.40 K, 3.62 Ca and 1.77 Mg, EC 1.8–2.0 mS cm^{-1} and pH 6.0. Plants were fertigated using an ebb/flood system partly controlled by tensiometers (Tensio Technick E-sensors CV2 0–1000 hPa). In treatments where ψ_s should fall below –800 hPa it was visually judged when to irrigate, because the contact between the tensiometer cup and the soil-mixture was partly broken resulting in increasing values of low reliability. Plants were irrigated when they started loosing turgidity and were visually drought stressed. During forcing the temperature was 17 °C day and night with venting at 20 °C. Day length was 18 hours and supplementary light, 40 W m^{-2} installed, from high-pressure sodium lamps (SON-T) was given when irradiation was below 36 μmol m^{-2} s^{-1} outdoors.

At flowering the following was recorded on three plants per tray (6 per treatment): height from soil surface to the ovary of the top flower, number of open flowers, number of flower buds. Also fresh- and dry weight of flowers and flower buds, stems, and leaves were recorded. On approximately 25 % (by weight) of each plant the number of leaves and leaf area were determined. Data were analysed by the GLM procedure of SAS/STAT Software version 8 (SAS Institute, Cary, NC) and are presented as LS-means.

Post-production evaluation. At flowering, as defined by 5–7 open flowers per plant, 12 plants from each treatment were transferred to a keepability room at 20±0.2 °C, 60 % RH and 14 μmol m^{-2} s^{-1} at plant

level provided by fluorescent lamps (Pope type FTD 36/33) for 12 hours per day. Six plants per treatment were sub-irrigated when necessary and the other six plants remained unwatered until the wilting point. Hereafter all plants were irrigated when necessary. The treatments were placed in two randomised blocks with three plants per block per production treatment and post-production treatment.

On day 0, 10, 14, 18 and 21 in the keepability test the number of open and senescent flowers were recorded. All post-production data were analysed at the individual observation day using the GLM procedure of SAS.

Results

Plant height

IDS alone did not reduce plant height significantly compared with control irrigation, whereas CDS reduced plant height by 14.3 % (Fig. 1a). Combining IDS with low N did not influence plant height further, but an additive effect of combining IDS and low P was found. The strongest growth retarding effect was obtained in treatments including low P; where the plant height was reduced by 17.8 %. Subjecting the plants to a triple stress combination, IDS and low P + N, resulted in a plant height similar to the combination of IDS and low P.

Number of leaves and leaf area per plant

CDS or IDS combined with either low P or low P + N reduced the number of leaves significantly by 28–34 % (Fig. 1b), whereas IDS alone or in combination with low N did not reduce the number of leaves significantly compared with control irrigation. The total leaf area was significantly reduced in all drought stress treatments compared with control irrigation (Fig. 1d); least (14–19 %) when IDS was applied either alone or in combination with low N, and most (45 %) where IDS was combined with low P + N (Fig. 1d). The size of individual leaves (total leaf area divided by number of leaves) was not significantly influenced by the different treatments and ranged between 1.97 cm^2 when plants were control irrigated or continuously drought stressed and 1.69 cm^2 when a combination of IDS and low P was given.

Number of flowers and flower buds per plant

The number of flowers and flower buds was reduced by all drought stress treatments. CDS affected the number of flowers and flower buds more than IDS and reduced the number from 124 when control irrigated to 73 and 88, respectively (Fig. 1c). Low P availability did not reduce the number of flower buds further (79), whereas low N (76) and low P + N combined with IDS (62) resulted in fewer flowers and flower buds than IDS alone. Despite the reduced number of flowers and flower buds, a sufficiently high number was obtained in all treatments to give a satisfying plant quality. At sale, first grade plants should have 10 open flowers and at least 30–50 buds.

Dry weight

All drought stress treatments reduced the total dry weight (DW) of above ground parts (Table 1) compared with control irrigation. CDS reduced the total

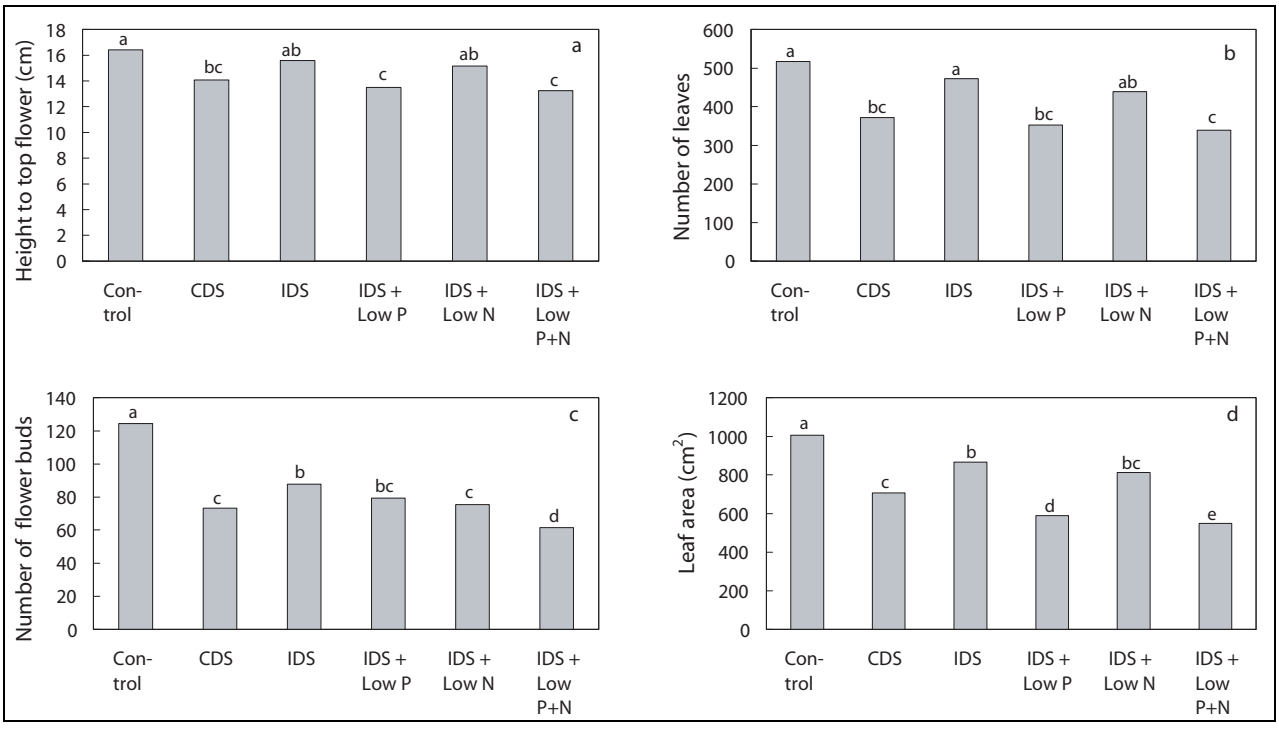


Fig. 1. Plant height, number of leaves per plant, number of flowers and flower buds per plant, and total leaf area per plant in *C. carpatica* 'Uniform' produced at continuous drought stress (CDS) or interrupted drought (IDS) as a single stress factor or in combination with low P, low N, or low P+N.

Table 1. Dry weight of leaves, stems and flowers and flower buds in *C. carpatica* 'Uniform' produced at continuous drought stress (CDS) or interrupted drought (IDS) as a single stress factor or in combination with low P, low N and low P + N.

Plant part	Control	CDS	IDS	IDS + Low P	IDS + Low N	IDS + Low P+N
Leaves	2.89 a	2.34 b	2.65 a	1.95 c	2.30 b	1.71 d
Stems	1.83 a	1.12 cd	1.51 b	1.13 cd	1.26 c	0.96 d
Flowers + buds	1.37 a	0.87 c	1.03 bc	1.16 b	0.91 c	0.91 c
Total	6.07 a	4.33 c	5.20 b	4.23 c	4.47 c	3.57 d

DW more than IDS, and low P or low N combined with IDS reduced it to the same level as CDS (Table 1). Plants grown at the triple combination had their total FW reduced by 50 % (data not shown) and their DW reduced by 41 % compared with control plants. CDS reduced the DW of all plant parts (leaves, stems, and flowers and flower buds) compared with control irrigation (Table 1). IDS also resulted in a reduced DW of stems and flowers and flower buds, whereas the DW of leaves was not significantly reduced. Low N availability reduced the DW of leaves less than low P availability, whereas the opposite was true for the weight of flowers and flower buds. In low P treatments a significantly higher percentage of the total DW was found in flowers and flower buds due to a higher weight per bud/flower (data not shown).

Post-production quality. Plants exposed to drought stress during the forcing period and irrigated sufficiently during the following post-production test, had less open flowers at day 10, 14 and 18 than control irrigated plants (Fig. 2). When plants were exposed to a wilting treatment at the beginning of the post-production evaluation, all plants irrespective of the previous treatment during forcing had the same number of open flowers at day 10 and 14. After 18 and 21 days in the keepability room none of the forcing treatments including drought stress were significantly different from control-irrigated plants concerning number of open flowers. The number of senescent flowers at day 21 only varied between 15.2 for plants from the triple combination (low P + N, and IDS) to 11.25 for low N plants (data not shown; $p<0.0086$). A drought cycle at the beginning of the post-production evaluation only increased the number of senescent flowers from 12 to 14 at day 21 ($p<0.0075$; data not shown), but the number of open flowers was reduced from 32.8 to 21.1 ($p<0.0001$) regardless of forcing treatment (Fig. 2). The actual number of flowers in relation to the potential number of open flowers showed that when irrigated sufficiently during post-production, control plants and low P plants performed best at day 10 (61–67 % open flow-

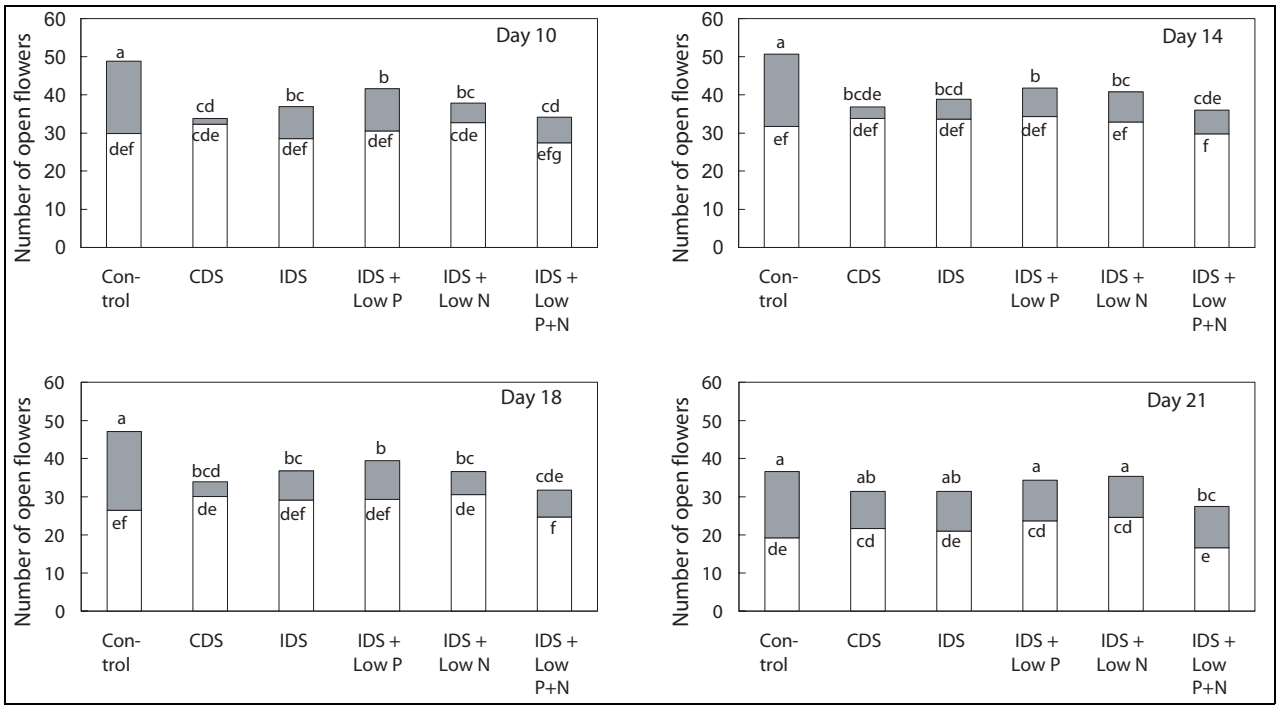


Fig. 2. Number of open flowers in *C. carpatica* 'Uniform' after 10, 14, 18 and 21 days in a post-production evaluation. Plants were produced at continuous drought stress (CDS) or interrupted drought (IDS) as a single stress factor or in combination with low P, low N, or low P+N and either irrigated when necessary (total height of columns) or subjected to one drought cycle at the start of the test (open part of columns).

ers), 14 (63–67 % open flowers), and 18 (59–63 % open flowers) and low P plants also at day 21 (55 % open flowers). Plants subjected to CDS during forcing had the lowest percentage of open flowers at day 10 (50 %), 14 (54 %) and 18 (50 %). If subjected to post-production drought stress plants produced at CDS and low P plants opened the highest percentage of their flower buds (54–56 % on day 14 and 33–39 % on day 21); control irrigated plants opened the lowest percentage of flowers (41 % on day 14 and 25 % on day 21).

Discussion

By using CDS or combinations of IDS and low P or low P + N it was possible to growth regulate plants to a similar height as traditionally obtained with chemical growth regulation in the horticultural industry, but the plants appeared thinner due to a reduced leaf area, probably a reduced plant diameter and a more uneven height of the foliage, and the plants had less flower buds. Plants from the CDS treatment were slightly less uniform and combinations with IDS were just as uniform as the control. Chemical growth regulation, which was not included in the present experiment, tends to give a very high degree of uniformity.

Reduced plant height is a common effect of drought stress, whether a cyclic or constant low ψ_s is maintained in the growing medium. In *Begonia* x *elatior* (HASENBUSCH 1994) and poinsettia (HAAS and RÖBER 1997) the plant height was reduced by drought stress, in combination with negative DIF or cool mornings, compared with non-growth-regulated plants, and the stronger the drought stress the lower the plants. In these two species plant height and quality were the same as for chemically growth-regulated plants.

It has been found in many investigations that the total leaf area is reduced by drought stress, but whether this is due to a reduced size of individual leaves or a reduced number of leaves is not always stated (EAKES et al. 1991; RÖBER and HAAS 1997; RÖBER et al. 1995). In *C. carpatica* the total leaf area was also reduced in proportion to the level of stress experienced by the plants. Both drought stress and reduced nutrient availability reduced the total leaf area by reducing the number of leaves rather than individual leaf size in *C. carpatica*. Whether the leaf size is influenced or not by drought stress may depend on many factors such as plant species, severity of the stress, type of stress and the developmental stage of the plant. In *Rosa hybrida* mild drought stress did not influence leaf number, but the size of individual leaves was decreased, whereas in more severely drought stressed plants the leaf number was reduced, but not the individual leaf size (WILLIAMS et al. 1999). *Helianthus annuus* responds to drought stress by reducing individual leaf size and not the number of leaves (MARC and PALMER 1976; YEGAPPAN et al. 1980; TAKAMI et al. 1981), but in *Begonia* x *elatior* the number of leaves was reduced and the more severe the drought stress the fewer the leaves (HASENBUSCH 1994).

Whether the number of flower buds and open flowers is influenced by drought stress depends on plant species and the severity of the stress. In the present study the number of flowers and flower buds was reduced by 41 % when plants were irrigated at a ψ_s below –800hPa or when visible signs of wilt was attained. Similar in miniature roses irrigated at a ψ_s below –650 hPa the number of buds was reduced by 40 % (WILLIAMS et al. 1999) and in *Begonia* x *elatior* bud number was reduced by 16 % (HASENBUSCH 1994). In *Dendranthema* drought stress did not influence the number of flowers (RÖBER et al. 1995).

In *Campanula*, the distribution of available resources from photosynthesis apparently followed different strategies depending on stress type. The two types of drought stress and low N availability combined with IDS favoured vegetative growth at the expense of reproductive growth, estimated by number of flowers per unit leaf area, or number of flowers per gram dry weight in vegetative parts (leaves and stems). Low P availability on the other hand favoured flower production over vegetative growth compared with control irrigated plants. In the low P treatment one should expect only 60 flower buds from the present leaf area, but the actual number was 79. Similar in the triple treatment (low P + N and IDS), the expected number of flowers was 51 and the actual number was 61.5. Similar to drought stress, the effect of low P on reproductive growth varies with species and the severity of the stress. In *Chrysanthemum*, *Pentas lanceolata* and miniature roses, a reduced number of flower buds at anthesis when grown at low P availability was reported (HANSEN and LYNCH 1998; HANSEN and NIELSEN 2001), but the number of inflorescences and the number of open flowers at the end of production was not significantly affected by low P availability (HANSEN and NIELSEN 2001).

Improved post-production quality of potted plants after production at reduced water availability has been found in a number of investigations (WILLIAMS et al. 2000; HASENBUSCH 1994). Despite a lower number of flowers and buds showing colour in drought stressed *Begonia* x *elatior* at the end of production, the same number of flowers were open at the end of a keeping quality test (HASENBUSCH 1994). In the same experiment, plants growth-regulated with Basacel (chlormequat) developed 16 % less flowers and buds showing colour, and lost 3 to 4 more leaves, during the keeping quality test than drought stressed plants (HASENBUSCH 1994). In the present experiment, drought stressed plants of *C. carpatica* had an improved stress tolerance, but it was only expressed when the plants were also subjected to a post-production drought stress treatment. Then plants from all production-treatments opened the same number of flowers during the keepability test, despite a much higher number of flower buds on control plants. Likewise, it was found in miniature roses, that cyclic drought stress preconditioned the plants to tolerate subsequent drought stress (WILLIAMS et al. 2000). It was also shown that cyclic drought stress improved post-production stress tolerance more than constant drought stress, irrespective of the severity of this stress (WILLIAMS et al. 2000).

Both low P (HANSEN and LYNCH 1998) and low N (STARKEY and ANDERSSON 2000) may be considered ways to optimise root activity. Maintaining a high root activity during the production and post-production phases could be a way to improve post-production

stress tolerance, ensuring adequate water and nutrient uptake under less favourable growth conditions such as low light intensity. In miniature roses and *Pentas lanceolata*, post-production stress tolerance was improved by delayed floral senescence and reduced root dieback when plants were grown at low P (HANSEN and NIELSEN 2001). This is consistent with our findings that plants grown at low P availability resulted in a very high percentage of open flowers during all 21 days in the keepability room whether subjected to post-production stress or not. STARKEY and ANDERSSON (2000) showed that low N improved the post-production stress tolerance of poinsettia, but *C. carpatica* grown at low N combined with IDS during forcing did not perform better than plants that were only drought stressed.

Conclusion

By a combination of IDS and low P availability it was possible to produce *C. carpatica* 'Uniform' of the same height as commercially produced plants. However, the product appeared thinner and the number of flower buds was reduced, although the flower bud production was considered to be sufficient for a commercial saleable product. When subjected to one post-production drought stress treatment the same number of flowers opened in plants produced under drought stress as in control plants. All plants produced with drought stress during production were more tolerant to post-production drought stress. Plants grown with a combination of IDS and low P opened the highest percentage of their flower buds whether subjected to post-production drought or not showing an additive effect of combining different stress treatments during production.

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