Europ.J.Hort.Sci., **69** (4). S. 159–166, 2004, ISSN 1611-4426. © Verlag Eugen Ulmer GmbH & Co. Stuttgart

Reduced Nutrient and Water Availability to *Hibiscus rosa-sinensis* 'Cairo Red' as a Method to Regulate Growth and Improve Post-production Quality

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Summary

The intensive use of water, fertiliser, and chemical growth retardants in horticulture reflects a need for developing new and more environmental suitable production methods to reduce the usage of water and fertiliser, and to reduce the use of pesticides for growth control. We have focused on drought as a single stress factor or combined with reduced phosphorus (P) or reduced nitrogen (N) availability to regulate the growth of *Hibiscus rosa-sinensis*. Drought stress was applied as cyclic drought, alternating between container capacity and drought to visible wilt (–650 to –800 hPa as measured with tensiometers placed in the growth substrate). We used a P buffer technique (Compalox®-P) to maintain a predetermined and stable P concentration in the growth substrate. Reduced N was either provided as a constant low N fertigation or as a dynamic supply where the N availability varied throughout production according to plant demand.

Drought as a single stress factor reduced plant height by 32 % and low P reduced plant height by 15 % as compared with the control. Combining drought and low P did not reduce the plant height much further. Continuous low N availability reduced plant height by 21 %, whereas there was no clear growth regulating effect of dynamic N availability.

Post-production evaluations showed that chemically growth regulated plants had by far the highest percentage of senescent flower buds throughout the post-production evaluation test compared with plants from all other treatments. Reduced P and N availability during production improved the post-production stress tolerance by significantly reducing the number of senescent flower buds and increasing the number of open flowers compared with chemically growth regulated plants. Several cycles of drought reduced post-production quality compared with control plants but improved it compared with chemically growth-regulated plants. The potential benefits of using combinations of reduced water and nutrient availability as methods to reduce the use of pesticides for growth regulation in horticulture, and how these production treatments influence the post-production stress tolerance are discussed.

Zusammenfassung

Reduzierte Nährstoff- und Wasserverfügbarkeit bei *Hibiscus rosa-sinensis* 'Cairo Red' als Methode zur Wachstumsregulierung und Verbesserung der Qualität beim Endverbraucher. Der intensive Gebrauch von Wasser, Düngemittel und chemischen Hemmstoffen im Gartenbau zeigt wie wichtig es ist, neue, umweltschonende Produktionsmethoden zu entwickeln, die diesen Verbrauch reduzieren. Deshalb haben wir Trockenheit als alleinigen Stressfaktor oder in Kombination mit geringer Phosphor- (P) oder Stickstoffverfügbarkeit (N) als Mittel zur Wachstumsregulation von *Hibiscus rosa-sinensis* untersucht. Trockenstress wurde in Form von zyklischer Trockenheit, alternierend zwischen Topfkapazität und Trockenheit bis zur sichtbaren Welke (–650 bis –800 hPa gemessen mittels Tensiometern im Substrat), eingesetzt. Zur Aufrechterhaltung der vorgegebenen und konstanten P-Konzentration im Substrat wurde eine P-Puffertechnik (Compalox®-P) angewendet. Geringe N-Mengen wurden entweder durch konstant geringe N-Düngung oder durch eine dynamische Versorgung in Abhängigkeit von den Pflanzenbedürfnissen während der Produktion verabreicht.

Im Vergleich zur Kontrolle reduzierte Trockenheit als alleiniger Stressfaktor die Pflanzenhöhe um 32 % und ein geringes P-Angebot um 15 %. Die Kombination von Trockenheit und geringem P-Angebot reduzierte die Pflanzenhöhe nicht erheblich stärker. Konstant geringe N-Verfügbarkeit reduzierte die Pflanzenhöhe um 21 %, wohingegen eine dynamische N-Versorgung keinen deutlichen Wuchsregulationeffekt zeigte.

Das Verhalten der Pflanzen beim Endverbraucher zeigte, dass Pflanzen, die mit chemischen Wachstumsregulatoren behandelt worden waren, in diesem Zeitraum im Vergleich mit allen anderen Behandlungsmethoden, den höchsten Prozentsatz an seneszenten Blütenknospen aufwiesen. Geringe P- und N-Verfügbarkeit während der Aufzucht verbesserte die Stresstoleranz der Pflanzen beim Endverbraucher, da im Vergleich zu wuchsstoffbehandelten Pflanzen, die Anzahl der seneszenten Blütenknospen deutlich verringert und die Anzahl offener Blüten erhöht war. Zahlreiche Trockenzyklen verringerten die Qualität beim Endverbraucher im Vergleich zur Kontrolle, erhöhten sie aber im Vergleich mit wuchsstoffbehandelten Pflanzen. Der potentielle

Key words. *Hibiscus* – growth regulation – low N – low P – drought stress – stress tolerance

Nutzen der methodischen Anwendung von Kombinationen aus geringer Wasser- und Nährstoffverfügbarkeit zur Reduktion des Pestizidverbrauchs im Gartenbau und ihr Einfluss auf die Qualität beim Endverbraucher ist Gegenstand der Diskussion.

Introduction

Environmental considerations have necessitated an increasing restriction in the use of chemical growth regulation. Therefore other methods to control plant height and shape are investigated. In this report we focus on drought stress and reduced nutrient availability as alternative methods to chemical growth regulation.

There are at least two ways to inflict drought stress or water deficit on plants in order to reduce plant height in ornamentals. Either a constant low level of available water can be maintained in the growing medium or water availability can alternate between container capacity and a very low water content in the growth substrate, called cyclic drought stress (RÖBER and HAFEZ 1981; WILLIAMS et al. 1999; EGILLA et al. 2001). The soil water potential (ψ_s) necessary to reduce plant height is often less severe for steady-state drought treatment than for cyclic drought. In Chrysanthemum a steady-state soil tension of –120 hPa reduced plant height from 94 cm to 80 cm whereas cyclic drought to –120 hPa did not alter the height significantly (RÖBER and HAFEZ 1981). In *Campanula carpatica* and *Aster novi-belgii* plant height was reduced by 18 % (PETERSEN and HANSEN 2003) and 9 % (unpublished data) by cyclic drought to –800 hPa and –600 hPa, respectively. Reducing the amount of water supplied per day to *Chrysanthemum* x *hortorum* grown as cut flower reduced the plant height by 15 – 21 % depending on clay amendment to the growing medium (RÖBER and HAFEZ 1981) and in *Hydrangia* x *hybrida* the reduction was 23 % (RÖBER and HAAS 1997). In some plant species drought stress should be combined with other methods to obtain a sufficient growth regulating effect. Combined with negative DIF (higher night than day temperature) a plant height similar to chemical growth regulated plants was obtained in *Dendranthema* x *grandiflorum* (RÖBER et al. 1995) and in *Begonia* x *elatior* (HASENBUSCH 1994). Growing plants at reduced water availability is often followed by an improved post-production stress tolerance (RÖBER and HAFEZ 1981; HASENBUSCH 1994; WILLIAMS et al. 2000).

It is well documented that low P availability increases the allocation of dry matter to roots while suppressing shoot growth, resulting in increased root to shoot ratios (eg. GUTSCHICK and KAY 1995; HANSEN and LYNCH 1998). Growing plants with a predetermined low and stable P availability has been reported to be an efficient, non-chemical method for growth regulation of a number of ornamental plant species (e.g. HANSEN and NIELSEN 2001; HANSEN 2002). BORCH et al. (1998) reported that there was no effect of low P availability on plant height and compactness of *Tagetes patula*, however, they found that plants grown at low P were more tolerant to subsequent post-production drought conditions. No information is available on how reduced P or combined low P and drought influence growth and post-production stress tolerance of *Hibiscus rosa-sinensis*.

Also the availability of other nutrients than P may influence plant height and post-production quality. Reduced N availability is, like low P, known to increase the root:shoot ratio on a dry weight basis and was found to reduce plant height in *Euphorbia pulcherrima* (STARKEY and ANDERSSON 2000). Low N to *E. pulcherrima* also reduced the number of damaged brackets, thereby improving the post-production quality (STARKEY and NIELSEN 2001).

The aim of this study was to determine the possibility of using drought stress, low P availability, or low N availability during production to reduce the use of pesticide for chemical growth regulation of *Hibiscus rosa-sinensis* 'Cairo Red'; and to determine how these production treatments influence the post-production stress tolerance.

Materials and Methods

Production

Cuttings of *Hibiscus rosa-sinensis* 'Cairo Red' were planted with three cuttings per 12 cm pot either in peat:perlite fully amended with all nutrients according to standard practice at commercial nurseries, or in peat:perlite with reduced phosphorus availability. A continuous low level of P, 1.5 ppm, was obtained by mixing 2 % (v/v) Compalox®-P buffer into the growth substrate. The cuttings were rooted under greenhouse conditions at 22 °C during the first week of propagation and thereafter at 25 °C. After six weeks of propagation the plants were pinched. During production the temperature was kept at 21 °C day and night with venting at 25 °C. Supplementary light by high pressure sodium lamps (60 μmol m^{-2} s^{-1}) was switched on below 4000 lux (approx. 72 μmol m^{-2} s^{-1}) and turned off at 5000 lux (approx. 90 μmol m^{-2} s^{-1}) to extend the photoperiod to an 18 h day. Insulating curtains were drawn at night to save energy, and when the global radiation was ≥600 W m^{-2} (approx. 1380 μmol m^{-2} s^{-1}) for shading. Carbon dioxide was supplied to 800 ppm during the light period when windows were closed. Ten treatments were applied during production; they are listed in Table 1. The standard fertilisation regime added with the irrigation water was (in ppm): 161 N (14 % NH_4), 32 P, 160 K, 26 Mg, 119 Ca, 26 Cl and 25 SO_4. EC was 1.45 mS cm^{-1} and pH was 5.8. All plots were ebb and flood fertigated separately from 40–liter tanks with re–circulation. The low P treatment started immediately after the cuttings were planted. Low N and Dynamic N treatments started after propagation, and the first drought cycle started three weeks later, when also the first treatments with Chlormequat–chlorid (CCC)

Table 1. Treatments.

Treatment	Irrigation	Phosphorus (ppm)	Nitrogen (ppm)	Cycocel (CCC) applications
Control	Standard	32	161	0
Dynamic N	Standard	32	54 – 161	0
Low P	Standard	1.5	161	0
Low N	Standard	32	54	0
Drought	Drought	32	161	0
Low P + drought	Drought	1.5	161	0
Low P + low N + drought	Drought	1.5	54	0
Low P + CCC	Standard	1.5	161	7, first one with reduced conc. (98 %)
Drought + CCC	Drought	32	161	3, all with reduced conc. (17 %)
CCC	Standard	32	161	7 (100 %)

for chemical growth regulation was given. The CCC and low P + CCC treatments were sprayed with CCC after the following scheme after pinching: 0.2 ‰ (0.1 ‰ to low P + CCC) week two, 0.25 ‰ week three, 0.5 ‰ week four, 0.75 ‰ week five, and 1.0 ‰ week six, seven, and eight. The drought + CCC treated plants were sprayed with: 0.1 ‰ week two, 0.25 ‰ week four, and 0.5 ‰ week five after pinching. Drought stress was applied as cyclic drought, alternating between container capacity and drought to visible wilt (–650 to –800 hPa as measured with tensiometers placed in the growth substrate). At the end of production drought stressed plants were on average fertigated every second day whereas plants fertigated after a standard regime were supplied with water and nutrients once or twice a day. In order to obtain container capacity in the drought treatments, the nutrient solution was supplied on the trays three times at each fertigation compared with one time when standard fertigated. The strategy for dynamic N supply, that is addition of N according to plant demand throughout the production period, was: $^1/_3$ N compared with standard until two weeks before the first visible flower bud or until visible symptoms of N deficiency, $^1/_2$ N until two weeks before flowering and then $^1/_3$ N until end of production (flowering). The actual course was 54 ppm N until four weeks after pinching when the plants showed signs of N deficiency. After one week, where 80 ppm N was supplied, plants were still yellow and the supplied concentration was increased to 161 ppm N. Two weeks before the expected end of production, 7 WAP, the concentration was reduced to 80 ppm. End of production was 9 WAP when at least one flower bud per plant showed colour. The experimental design was a randomised complete block with two replicates and 32 plants per treatment and replicate. On four plants from each replicate within a treatment the following was determined: Height from table to upper most shoot apex; number of open flowers; number of flower buds; leaf area of the third leaf from the shoot apex of the three longest shoots; number of nodes on the longest shoot. A destructive harvest was carried out and fresh weight was determined before drying at 70 ºC for 24 h to determine dry weight of flowers, flower buds, stems and leaves. Also, all above ground material from the four plants within a treatment and replicate was pooled and a sample taken for analysis of total–N, P, K, Ca, Na, Mg, SO_4–S, Cl, Fe, Mn, B, Cu and Zn by a commercial laboratory.

Data was analysed using the SAS MIXED procedure (SAS Institute, Cary, NC). When necessary, to ensure variance homogenity, data was transformed: specific fresh weight expressed as fresh weight per cm stem ($1/\sqrt{x}$); leaf area (log); number of buds (log); dry weight leaves + stems (log); dry weight leaves (log).

Post-production evaluation

At flowering, as defined by 1 flower bud per plant showing colour, five plants from each replicate within a treatment were transferred to a post-production evaluation room. Interior room conditions were simulated, by keeping the temperature at 20 °C, and a low photosynthetic photon flux density (12 μM m^{-2} s^{-1} PPFD) was supplied by fluorescent lamps (Pope type FTD 36/33) for 12 h per day. Plants from all production treatments were irrigated adequately according to the largest plants need. Keeping quality was evaluated on an individual pot basis at days 0 (day of transfer to evaluation room), 7, 14, 21 and 28. The number of open flowers and fresh flower buds, the number of senescent flowers and flower buds were recorded. All post-production data were analysed at the individual observation day using the SAS MIXED procedure (SAS Institute, Cary, NC).

Results

Plant quality at the end of production

Chemical growth regulation with CCC reduced the plant height in *Hibiscus rosa-sinensis* 'Cairo Red' with more than 50 % compared with control plants (Fig. 1a). Drought stress in combination with a reduced application of CCC (17 %), and low P in combination with reduced application of CCC (98 %) resulted in plants of the same height as the CCC treatment (Fig. 1a).

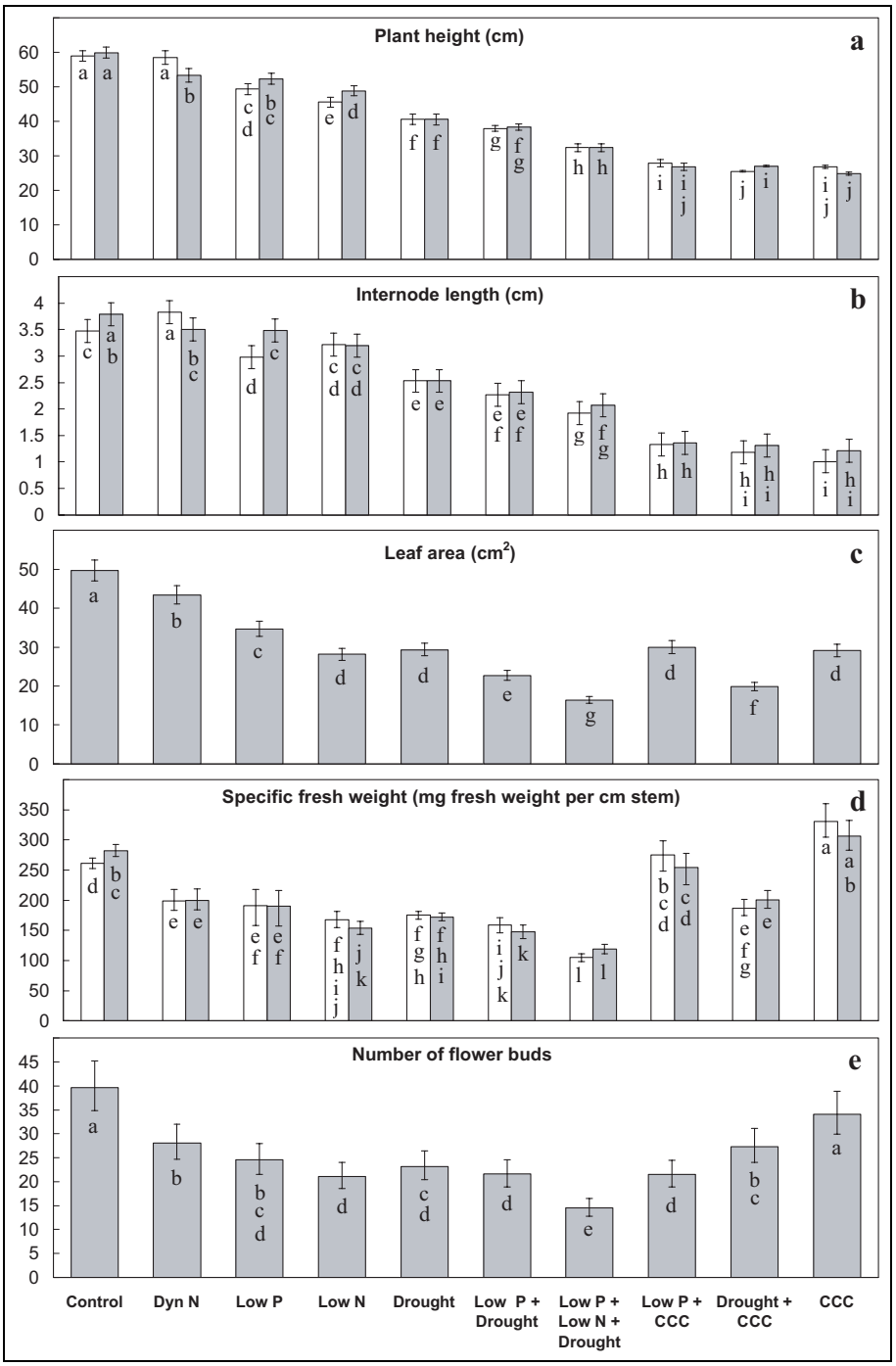


Fig. 1. Plant height, internode length, area of young fully developed leaf, specific fresh weight, and number of flower buds in *H. rosa-sinensis* 'Cairo Red' produced at dynamic N availability, continuously low N availability, low P availability as a single stress factor or in combination with drought, drought + low N or chemical growth regulation, cyclic drought as a single stress factor or in combination with chemical growth regulation and compared with plants grown with or without (control) chemical growth regulation (CCC). Data are presented as means with standard deviations (n=4 when second order interaction between treatment and replicate was significant otherwise n=8). Two columns per treatment indicate significant difference between replicates within at least one of the treatments.

Drought as a single stress factor could reduce plant height by 32 % from 59.5 cm to 40.6 cm (Fig. 1a). Growing plants at low P availability resulted in a 15 % reduction in plant height compared with control plants, and combining low P with drought did not reduce plant height much further than drought as a single stress factor (Fig. 1a). However, combining low P, low N and drought reduced plant height by 45 % (Fig. 1a) showing that there was an additive growth regulating effect by this triple combination. Continuously low N availability as a single factor reduced plant height by 21 % whereas the growth regulating effect of dynamic N was less clear; in one greenhouse compartment plants grown at dynamic N availability were of the same height as control plants and in the other compartment they were 10 % lower (Fig. 1a). Differences in plant height were mainly due to differences in internode length (Fig. 1b).

The area of the youngest fully developed leaf, showed the following ranking of leaf size: control > dynamic N (13 % reduction) > low P (30 % reduction) > low N (43 % reduction) = drought = low P + CCC = CCC > low P + drought (54 % reduction) > drought + CCC (60 % reduction) > low P + low N + drought (67 % reduction), Fig. 1c.

Specific fresh weight or compactness within the plant was expressed by calculating top fresh weight per

stem length. The most compact plants were obtain when growth was regulated with CCC followed by slightly less compact plants from the control and low P + CCC treatments (Fig. 1d). The triple combination resulted in plants with a very low specific fresh weight that was only between one half and one third of CCC plants (Fig 1d). Drought as a single stress factor also resulted in plants with significantly less fresh weight per stem length and therefore a less compact appearance than chemically growth regulated plants (Fig. 1d). Plants exposed to drought + 17 % CCC were slightly more compact than plants grown at drought as a single stress factor, but still the specific fresh weight was much lower than for plants from the CCC treatment.

The highest number of flower buds was recorded on control plants (39.6) and on plants from the CCC treatment (33.5), Fig. 1e, and the lowest number of flower buds was recorded on plants grown at the low P + low N + drought (14.5). In the other treatments the number of flower buds was between 28.4 (dynamic N) and 21.1 (low N) (Fig. 1e).

Plants from all treatments had the same production time (108 days) except plants grown at reduced N availability and plants from the triple combination, which were delayed by 4 and 7 days, respectively.

Plants grown under control conditions had the highest top dry weight (leaves + stems) and plants from the triple combination low P + low N + drought were the least efficient plants in dry-matter production (Table 2). Treatments involving drought stress resulted in plants with a low top dry weight compared with all other treatments (Table 2). The distribution of dry matter between leaves and stems was the same for plants exposed to drought as a single stress factor, dynamic N and control conditions, and low P + drought did not differ significantly from control plants. In all treatments, where plants were given CCC, a high percentage of the dry matter was distributed to the leaves and less was found in the short stems. Plants grown at low N, low P, and low P + low N + drought fell into an intermediate group concerning dry matter distribution.

The nutrient content of above ground plant parts is shown in Table 2. The concentrations of Na, SO_4-S, Fe and B only varied slightly between treatments and are not shown. It is obvious that low P and N availability in the soil solution resulted in low concentrations of these nutrients in the aboveground plant tissue compared with control plants. At the end of production all plants grown at constant low N availability showed severe N deficiency symptoms. Since the visual plant quality was poor and far from a saleable product, plants from the low N treatment and from the triple combination of low P + low N + drought were not included in the subsequent post-production evaluation).

Table 2. Dry weight of leaves + stems, percentage dry weight of leaves and the content (%) of N, P, K, Mg, Ca and Cl in the dry matter of leaves + stems at the end of production. When a significant difference between replicates was found within a treatment, both values are shown, otherwise the mean value. Values followed by the same letter are not significant different at the 5 % level.

Treatment	Replicate	Dry weight of leaves + stems	Leaves[1)]	N (%)	P (%)	K (%)	Mg (%)	Ca (%)	Cl (%)
Control	1	28.95 b	63.06 ef	2.82	0.53	2.43	0.34	1.96	0.48
	2	31.49 a							
Dynamic N		21.01 cd/de	62.94 f	1.78	0.60	2.57	0.32	1.90	0.67
Low P		22.23 cd	67.50 c	2.20	0.10	2.10	0.23	1.30	0.34
Low N		17.28 ef/fg	66.07 cd	1.17	0.71	2.11	0.28	1.87	0.69
Drought	1	15.08 gh	63.08 f	2.62	0.50	2.48	0.36	1.85	0.48
	2	14.09 I							
Low P + drought	1	13.62 hi	65.05 de	1.92	0.12	2.46	0.26	1.59	0.46
	2	11.84 j							
Low P + low N + drought		9.14 m/lm	65.87 cd	1.24	0.13	2.08	0.22	1.24	0.43
Low P + CCC		16.32 ef/fg	77.28 a	2.75	0.16	2.54	0.32	1.95	0.31
Drought + CCC		10.71 kl/jk	69.95 b	2.98	0.56	2.05	0.31	1.55	0.45
CCC	1	17.42 f	76.37 a	3.00	0.62	2.63	0.39	2.53	0.36
	2	14.46 hi							

[1)] Dry weight percentage of leaves + stems

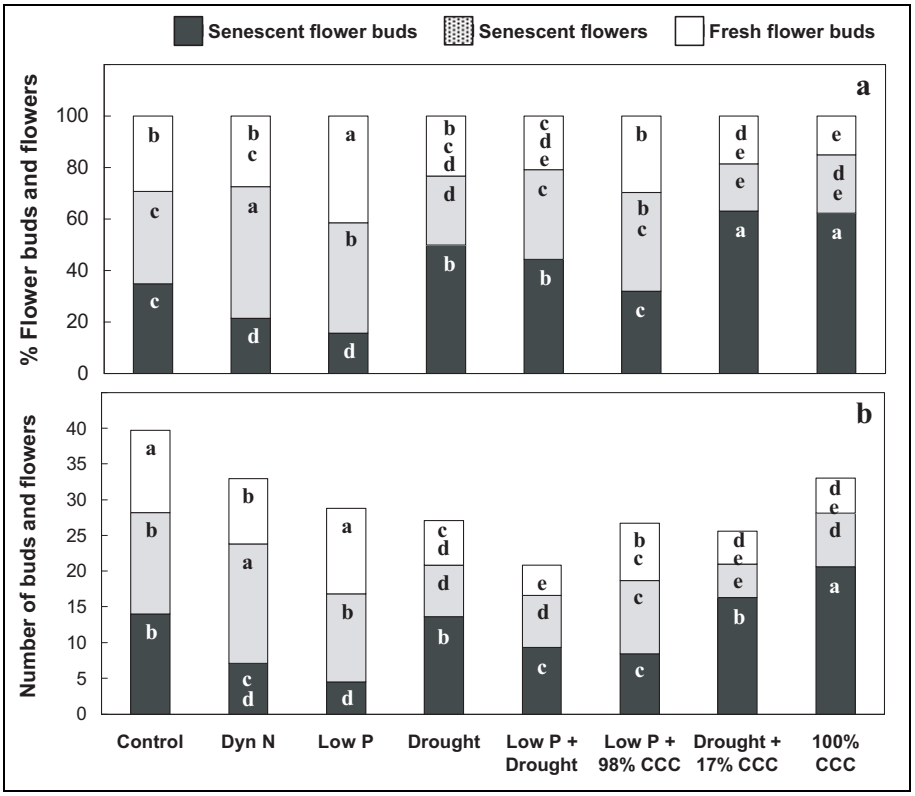


Fig. 2. The percentage distribution (a) and actual number (b) of senescent flower buds, senescent flowers and fresh flower buds at the end of the post-production evaluation (day 28). Within each category of flowers/buds, treatments with the same letter are not significantly different at the 5 % level.

Post-production quality

In *Hibiscus rosa-sinensis* 'Cairo Red' an open flower only lasts for one day. Therefore, one can use the percentage of senescent flowers as a measure of open flowers or ornamental value during the test period. At day 0 there was no significant effect of production treatments on the number of flowers due to the fact that plants were selected with 1–3 flowers. However, during the post-harvest period plants grown at low P or dynamic N during production had significantly less senescent flower buds and a higher percentage of senescent flowers (Fig 2a) which indicate that plants from these treatments succeeded in unfolding the highest percentage of their flowers, thereby resulting in a higher ornamental value. In the dynamic N treatment the actual number of open flowers during the keeping quality test was higher than for control plants and low P plants unfolded the same number of flowers as control plants (Fig. 2b). The poorest post-harvest performance was seen in chemically growth-regulated plants, but also drought stressed plants opened a much lower percentage of their flower buds than control plants (Fig. 2a). Reduced P availability could to some extend compensate for this as seen in Fig. 2a. The percentage of senescent flower buds was reduced from 62 % to 32 % at the end of the keeping quality test, day 28, when CCC and low P was combined during production compared with CCC or CCC + drought. The percentage of senescent flower buds on low P plants was only 16 % and in the dynamic N treatment 21 %. Already after 21 days in the post-harvest evaluation room there was a high percentage of senescent flower buds on plants growth regulated with CCC (37 %), grown at drought (32 %), and plants grown at the combination of drought + CCC treatments (45 %) (data not shown). Plants grown at low P availability had the highest percentage of fresh flower buds at day 28 (41 %) and therefore the highest ornamental value at the end of the post-production period, whereas CCC plants only had 15 % fresh flower buds left.

Discussion

Growth regulation

Reduced water and nutrient availability is a potential method to cut down significantly on chemical growth regulation in *H. rosa-sinensis* 'Cairo Red'. Plant height was reduced by 30 % in drought stressed plants as compared with non-growth regulated control plants. The use of drought stress to regulate growth has also been reported in *Rosa* x *hybrida* (WILLIAMS et al. 1999) and *Dendranthema* x *grandiflorum* (RÖBER et al. 1995) showing that drought stress is a potential method for non-chemical growth regulation in ornamental plants. In the present study drought stress was also combined with chemical growth regulation in reduced concentrations and reduced number of applications. In this way it was possible to produce plants quite similar to the saleable standard with 83 % less CCC. Plants from the low P + CCC treatment were also of the same height as CCC plants, but the amount of CCC could not be markedly reduced by this combination.

Reduced P availability was reported to have a strong growth regulating effect in *Pentas* when the P availability was approx. 20 times reduced compared with a traditionally high P level (~30 ppm), whereas miniature roses were efficiently growth regulated at a 10-fold reduction

in P availability (HANSEN and NIELSEN 2001). This is consistent with the P response of other ornamental plant species (HANSEN 2002), and shows that also reduced P availability is a potential method for growth regulation.

In our study plant height was reduced by 15 % in *Hibiscus rosa-sinensis* 'Cairo Red' when grown at a 20-fold reduction in P availability. The success of using reduced P as a method to control plant height and to what extent chemical growth regulation can be reduced or substituted by low P availability varies with species probably due to genetic adaptation to different P availability in their original habitat. However, in order to achieve efficient growth regulation the P availability must be very low. In fact so low, that it may be impossible to maintain a stable low P level without using a buffering technique (HANSEN and NIELSEN 2001).

The use of constant low N reduced plant height by 20 %, but resulted in severe N deficiency symptoms. Growing plants at dynamic N availability overcame the N deficiency problem during the production period. However, this treatment did not reduce plant height much. Combining the three stress factors low P, low N and drought resulted in a height similar to CCC plants, but the plants were less compact due to a much lower leaf area and specific fresh weight.

The aim of combining different stress factors was to obtain an additive effect on plant height. RÖBER et al. (1995) combined drought stress with negative DIF to *Dendranthema* x *grandiflorum*, but it did not result in an additive effect, whereas in *Hydrangea* x *hybrida* and *Euphorbia pulcherrima* an additive effect of drought stress and cool mornings was found (HAAS and RÖBER 1997; RÖBER and HAAS 1997). In *Aster novi-belgii* 'Fanny', plant height was not reduced significantly by cyclic drought stress to ψ_s = –400 hPa, but in combination with a constant low P level (1.5 ppm) plants became 16 % lower than the control irrigated plants (unpublished data). Similar effects were found in *Campanula carpatica* 'Uniform' where interrupted drought stress did not have a growth regulating effect unless combined with low P (PETERSEN and HANSEN 2003). In the present investigation no significant additive effect of drought and low P on plant height was found, but adding a third stress factor, low N, reduced plant height by 13 % compared with drought as a single stress factor.

Not only plant height is influenced by drought stress. Other common effects are: reduced dry weight, smaller plant diameter, reduced total leaf area and single leaf area, reduced number of flowers and a better keeping quality (EAKES et al. 1991; HASENBUSCH 1994; RÖBER and HAAS 1997; WILLIAMS et al. 1999), which were also seen in *Hibiscus rosa-sinensis* 'Cairo Red'. Except for the better keeping quality these effects are mostly undesirable, although a somewhat reduced leaf area is beneficial in some plant species when the height is reduced, to give a well-proportioned product. Chemical growth regulation also reduces total dry weight and leaf area, but to a lesser extend than reduced water availability. Therefore chemically growth regulated plants are more compact. Whether the side effects of drought stress are acceptable depends on plant species and may be overcome by adjustments such as an extra cutting planted per pot or other cultural practices.

Reduced P and N availability obviously resulted in low tissue content of these nutrients. Only treatments with low P affected tissue P content as compared with control plants. Control plants had less content of all the nutrients except Cl in the aboveground plant parts as compared with CCC as compared with CCC treated plants. Significantly higher leaf area in control plants suggest that this decline in nutrient content may be explained by the nutrient content being diluted in more tissue. Although CCC contains chloride, tissue Cl content was not affected by the CCC treatments.

The treatments that reduced plant height most in *Hibiscus rosa-sinensis* 'Cairo Red' also reduced the area of single leaves and the number of flower buds the most, except when plant height was regulated with CCC as a single factor. Combining drought stress with low P, CCC or low P + low N resulted in an additive effect. A reduction in total leaf area was also seen in *H. rosa-sinensis* 'Leprechaun' as a result of drought stress (EGILLA et al. 2001).

The production time was slightly prolonged by the dynamic N and drought treatments by up to four days. In other plant species production time was not influenced by drought stress (EAKES et al. 1991; RÖBER and HAAS 1997; WILLIAMS et al. 1999).

In an attempt to further reduce the use of pesticides in horticulture, using a combination of reduced water and P availability as a potential alternative method to chemical growth regulation in *Hibiscus rosa-sinensis* 'Cairo Red' is being further investigated.

Post-production

In *Rosa* x *hybrida* the percentage of senescent flowers and flower buds was either lower or not influenced by reduced production water availability if the plants were watered well during a keeping quality test (WILLIAMS et al. 2000). And, if one drought cycle was applied at the beginning of the keeping quality test, plants produced under cyclic drought had less damaged and wilted flowers (WILLIAMS et al. 2000). In our study repeated cycles of drought treatment during production did not influence the post-production stress tolerance in *Hibiscus rosa-sinensis* 'Cairo Red'. However, we did not subject the plants to drought during the 28 days post-production period, where all plants were irrigated as the controls. The best keeping quality at day 21 and 28 was seen in plants grown at low P or dynamic N availability due to a high percentage of fresh flower buds and a low percentage of senescent flower buds. Also the ornamental value during the test was high because of many open flowers. Chemical growth regulation negatively influenced the post-production stress tolerance, which has also been found in other plant species (HANSEN 2002). We showed that reduced P and N availability during production significantly improved plant tolerance to post-production stress such as low light conditions. Reduced P also improved post-production tolerance when combined with drought or chemical growth regulation.

Conclusion

The growth of *Hibiscus rosa-sinensis* 'Cairo Red' was efficiently controlled by drought stress combined with 83 % less CCC than grower practice resulting in a plant height similar to a saleable product.

Growing *Hibiscus rosa-sinensis* 'Cairo Red' at reduced P or dynamic N availability during production efficiently preconditioned the plants to cope better with adverse post-production conditions. This positive influence by reduced P on the post-production quality was maintained in treatments where low P was combined with chemical growth regulation or drought.

These findings have considerable importance for the horticultural industry and for the consumer, and offer the possibility of reduced water and fertiliser use and of reduced use of chemical growth regulators while improving the keeping quality of *Hibiscus rosa-sinensis* 'Cairo Red' plants. Further investigations on the effect of reduced P and water availability and combinations of these production treatments on growth and post-production stress tolerance of *Hibiscus rosa-sinensis* 'Cairo Red' will be carried out and will include evaluations of the ability of plants to cope with post-production drought.

Acknowledgement

The authors want to thank Kaj Ole Dideriksen and Connie Krogh Damgaard for excellent technical assistance. This research was funded by The Danish Institute of Agricultural Sciences, The Directorate for Food, Fisheries and Agricultural Business, The Danish Ministry of Food, Agriculture and Fisheries, and The Danish Ornamental Plant Producers Association (PFP).

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Received August 7, 2003 / Accepted April 28, 2004

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