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Uniconazole Affects Vegetative Growth, Flowering, and Stem Anatomy of Hibiscus

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Abstract. **Eight-month-old 'Jane Cowl' hibiscus (*Hibiscus rosa-sinensis* L.) in 2.8-liter pots received 0, 0.1, 0.2, or 0.4 mg of uniconazole/pot as a soil drench. Plants were pruned 35 days after treatment and then grown for an additional 65 days. Plant height, number of leaves and flower buds per shoot, shoot length, stem diameter, and leaf size decreased with increasing rates of uniconazole. Flower number was greater at the two low rates; however, days to first bloom and leaf dark respiration rate were unaffected. Leaf chlorophyll concentration increased with increasing rates of uniconazole. Development of secondary xylem tissue, transverse diameter of vessels, and number and size of phloem fibers were suppressed by uniconazole, resulting in a cascading growth habit. Plants grown from cuttings taken from plants 35 days after treatment were shorter, with fewer lateral shoots and total leaves than cuttings from untreated plants. Uniconazole had no effect on growth of shoot tip cuttings taken from the new lateral shoots of treated plants 110 days after pruning. Soil drenches of uniconazole at 0.025 to 0.2 mg/pot to young plants in 1.5-liter pots resulted in shorter plants, delayed flowering, and fewer flowers with smaller diameter and shorter pedicels. Results from foliar application of uniconazole at 0.05 to 0.2 mg/plant (10 to 40 mg·liter^{-1}) were similar to the soil drench, except that the reduction in shoot growth was less at low rates than with drench application. Chemical name used: (E)-1-(*p*-chlorophenyl)-4,4-dimethyl-2-(1,2,4-triazol-1-yl)-1-penten-3-ol (uniconazole).**

Hibiscus recently has increased in popularity as a potted flowering plant (Miller, 1987) due to its profuse, large, and colorful flowers and dark green foliage. Research has been conducted to increase the marketability of hibiscus by developing techniques to reduce post-production abscission of flower buds and leaves (Gibbs et al., 1989; Kelley and Thaxton, 1987). When produced under greenhouse conditions of abundant nutrient supply and reduced light levels, plants can reach 90 cm in 4 months (Neumaier et al., 1987; Y.-T.W., unpublished data) with undesirably long internodes. Therefore, it is necessary to control internodal length to produce more-compact, attractive plants.

Plant growth retardants have been used on many floriculture crops to reduce vegetative growth and to increase their aesthetic value (Barrett et al., 1986; Larson and Kimmins, 1972; McDaniel, 1986; White and Holcomb, 1974). Chlormequat at 1000 to 3000 mg·liter^{-1} reduced growth of hibiscus that was used as a hedge (Criley, 1981). Butanedioic acid mono(2,2-dimethylhydrazide (daminozide), 2-chloro-*N,N,N*-trimethylethanaminium chloride (chlormequat), and α-cyclopropyl-α-(4-methoxyphenyl)-5-pyrimidinemethanol (ancymidol) induced shorter internodes, more blooms, and earlier flowering in several hibiscus cultivars (Shanks, 1972). Growth retardants appear to alter plant growth by changing the anatomy of cell and tissue development. *Chrysanthemum morifolium* treated with several retardants produced thick stems as a result of increased transverse cell division in the subapical tissues (Johnson, 1974; Sachs and Kofranek, 1963). This stem thickening may be necessary for producing strong plants in pots. Uniconazole (XE-1019, sumagic) is a new triazole growth retardant that effectively reduces shoot extension growth in several species (Barrett et al., 1986; Mansour and Poole, 1987; Sterett, 1988) and may be useful in the production of hibiscus as a potted flowering plant.

The objective of this study was to determine the effect of uniconazole on vegetative growth, flowering response, and stem anatomy of hibiscus and on the growth of successive cuttings obtained from treated plants.

Materials and Methods

'Jane Cowl' hibiscus were grown for 8 months in 2.6-liter plastic pots (≈15 cm i.d. and 17 cm deep) filled with a peatlite medium. They were placed on a greenhouse bench receiving a maximum photosynthetic photon flux (PPF) of 1260 μmol·s^{-1}·m^{-2}. On 10 May 1988, 0, 0.1, 0.2, or 0.4 mg of uniconazole was applied to each pot as a 250–ml soil drench. All plants were transferred with intact original medium to 5.2-liter pots (21 cm i.d. and 20 cm deep) after 7 days. Water containing 1.5 g 20N–8.6P–16.6K (5.6% NO_3-N, 4.0% NH_4-N, and 10.4% urea-N)/liter was used at all irrigations. There was one plant per pot as an experimental unit in a randomized complete block design (RCBD) replicated eight times.

To determine the effect of uniconazole on the growth of subsequent cuttings, terminal cuttings (first generation) with stem sections ≈7 cm long were taken from shoots of the above plants 35 days after treatment and placed in a mist propagation bed for rooting. Rooted cuttings were transferred on 3 Aug. into 1.5-liter pots (15 cm i.d. and 11 cm deep) filled with a peatlite mix (Sunshine Mix No. 1, Fisons, Vancouver, B.C., Canada) and cultured as above. Plants were pinched on 17 Aug., allowed to grow, and evaluated on 21 Sept. for overall height (from pot rim to the highest node), number of lateral shoots, and total leaf number per plant. Leaf number for the uppermost shoot was also recorded. There were four pots, each with one plant, as an experimental unit replicated five times in a RCBD.

The original plants were pruned to ≈30 cm tall after cuttings were taken for the previous experiment, allowed to grow for 65 days, and evaluated on 18 Aug. Four terminal lateral shoots that developed from separate stems were selected at random from each plant. Shoot length, number of leaves >2 cm long, number

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of flowers, and number of flower buds >1 cm long were recorded. Stem diameter at 2 cm above the juncture was measured using an electronic digital caliper (Fred V. Fowler Co., Newton, Mass.). Overall plant height and date of first bloom for each plant were recorded. Leaf area was measured and a single leaf disk (0.33 cm^2) taken between the mid-rib and leaf edge from each of the four youngest expanded leaves. The four leaf disks from each plant were placed in a glass vial and chlorophyll was extracted, measured, and calculated as described by Moran and Porath (1980) and Moran (1982). Plants were placed in a dark laboratory for 4 hr before respiration rates were measured on an uppermost expanded leaf of each plant at 25C with a LI-COR 6200 photosynthesis unit. A 2-mm-thick stem section was taken at the midpoint between the first and second nodes from several shoots of each treatment, fixed in FAA, dehydrated in ethanol, and embedded in paraffin. Transverse sections 15 μm thick were made and stained with safranin-fast green.

Twenty-cuttings (second generation) then were taken for each treatment from the above plants, rooted for 6 weeks, and transplanted into 1.5-liter pots. Plants were allowed to grow for 90 days in a completely randomized design and evaluated for total height, number of shoots bearing flowers and/or buds, and length and number of leaves on the longest shoot.

Newly rooted cuttings in 1.5-liter pots were pinched twice to promote lateral shoot growth. Uniconazole was applied to plants 10 days after the second pinch as a 100-ml soil drench at 0, 0.025, 0.05, 0.10, 0.15, or 0.20 mg/pot. Foliar treatments were applied at 5 ml/plant with 0, 10, 20, 30 or 40 mg uniconazole/liter (the equivalents of 0, 0.05, 0.10, 0.15, and 0.20 mg/plant, respectively) in water solutions. Medium surface was covered with polyethylene during treatment to prevent the solution from contaminating the medium. Irrigation was stopped 2 days before and resumed 1 day after treatment. Air temperature was 29C at the time of treatment. Date on which each flower bloomed and the flower diameter and pedicel length were recorded. Overall plant height and width (the average of two measurements made at perpendicular angles parallel to the bench), leaf number (>3 cm), length and diameter (at 2 cm above the juncture) of the uppermost shoot, and total number of blooms were recorded 86 days after the second pinch. Only diameter and pedicel length of the latest bloom were used in calculating the means of these variables. Stem sections were taken from soil-drench-treated plants, prepared as above, and examined.

All uniconazole solutions used in this study had 0.1% Tween 20 as a wetting agent. Since uniconazole resulted in plants of various sizes that consumed water at different rates, irrigation was applied as needed. Maximum (day) and minimum (night) air temperatures in the greenhouse during this study were 35 and 13C, respectively. Data were subjected to linear and quadratic regression analyses.

Results and Discussion

Growth of the first-generation cuttings was affected by uniconazole applied to the growing medium of stock plants, indicating that the compound had been effectively translocated to snoot terminals of both the stock plants and new lateral shoots. Although cuttings taken from treated plants had shorter internodes and more nodes as the rate of uniconazole increased, production of lateral shoots was reduced progressively (Table 1). Uniconazole induced short plants with fewer total leaves, but had no effect on rate of leaf production by individual shoots. There was no noticeable difference in leaf color and size among

Table 1. Growth of 'Jane Cowl' hibiscus cuttings taken from plants 35 days following treatment with uniconazole. Means are averages of 20 replicates.

Rate of uniconazole (mg/plant)	Plant height (cm)	Mean no. leaves/ plant	Mean shoot no.	Tallest shoot	
				Length (cm)	No. leaves
0	18.1	22.9	6.0	16.0	4.9
0.1	14.8	18.3	5.0	12.8	4.5
0.2	16.3	19.5	4.9	14.4	4.8
0.4	15.9	18.2	4.6	13.5	4.8
Significance					
Linear	NS	**	**	NS	NS
Quadratic	*	NS	NS	NS	NS

NS,*,**Nonsignificant or significant at $P = 0.05$ or 0.01, respectively.

treatments, suggesting that existing uniconazole in the cuttings may have been diluted in the plant tissues as they grew.

Applying uniconazole to the medium before pruning effectively suppressed the extension growth of the new lateral shoots and overall plant height (Table 2). The rate of leaf production decreased only slightly, but leaf area was reduced by nearly 50% by the 0.4-mg rate. Chlorophyll concentration increased linearly with higher rates of uniconazole, whereas leaf dark respiration per unit leaf area was unaffected (Table 2). Reduction in leaf size and increased chlorophyll have been observed in other plant species after the application of growth retardants (Halfacre et al., 1968; :LeCain et al., 1986; Mansour and Poole, 1987). However, it is not known whether this was due to the increased number of chloroplasts or greater chlorophyll concentrations in chloroplasts. Gao et al. (1988) reported that uniconazole (S-3307) increased the size of chloroplasts in wheat leaves, which could be the result of enhanced endogenous cytokinin levels (Fletcher and Arnold, 1985). Leaf cupping, possibly due to uneven cell division or growth, occurred at the 0.4-mg rate, but this was not observed on shoots before pruning. Flower number increased at the two moderate rates without any delay in blooming (Table 2). In a previous study, uniconazole applied to a bark medium at a high rate of 0.7 mg per 11.5-cm pot increased flower number of unpinched hibiscus by 125% (Maus, 1987). The shiny leaves we observed on treated plants may have resulted from increased deposition of epicuticular wax (Gao et al., 1988).

Most new shoots that were produced on plants following pruning and that had been treated with uniconazole at 0.1 or 0.2 mg/pot showed a cascading characteristic (Fig. 1). Shoots on plants receiving 0.4 mg remained upright because of much shorter internodes; however, these shoots became trailing several months after data were taken and remained short 14 months after treatment. Measurements of stem size indicated that uniconazole resulted in smaller stem diameters (Table 2). Since plants used in this experiment were cultured similarly and all the lateral shoots arose from inactive axillary buds at the time of pruning, all the differences in shoot growth were likely due to the direct effect of uniconazole. Diameter of existing stems of a young apple tree and the first few internodes developed after the application of daminozide were thinner than the control, but terminal internodes were substantially thicker 10 weeks after treatment (Halfacre et al., 1968). Ancymidol induced larger and stronger stems in chrysanthemum (Larson and Kimmins, 1972; Johnson, 1974).

Histological examinations showed the production of xylem tissue and diameter of individual vessel elements progressively

Table 2. Growth and flowering of 'Jane Cowl' hibiscus 65 days after pruning. Uniconazole was applied to the growth medium 35 days before plants were pruned. Means are averages of 32 replicates.

Rate of uniconazole (mg/plant)	Plant height (cm)	Shoot length (cm)	Mean no. leaves/ shoot	Leaf[z] area (cm^2)	Chlorophyll concn ($\mu g \cdot cm^{-2}$)	Dark respiration (mg CO_2/dm^2 per sec)	Days[y] to bloom	Mean no. of flowers/ shoot	No. flower buds >1 cm	Stem diam. (mm)
0	70.6	37.4	11.6	56.5	43.2	0.58	57.3	1.5	3.8	5.2
0.1	56.0	30.3	11.7	40.9	47.6	0.70	53.0	3.8	3.8	4.3
0.2	40.4	24.1	10.8	31.2	53.0	0.61	54.1	2.3	3.3	3.6
0.4	38.1	11.2	10.2	29.9	60.7	0.69	56.1	1.9	3.4	3.5
Significance										
Linear	**	**	**	**	**	NS	NS	*	**	**
Quadratic	**	NS	NS	**	NS	NS	NS	**	NS	**

[z]Area of the uppermost fully expanded leaf.
[y]Days from pruning.
NS,*,**Nonsignificant or significant at $P = 0.05$ or 0.01, respectively.

Fig. 1. 'Jane Cowl' hibiscus treated with uniconazole at 0 (control, **left**) and 0.2 mg (**right**) per pot. Note the trailing characteristic of the shoots on the treated plant.

decreased with increasing rate of uniconazole (Fig. 2). The cambial layer appeared wider in treated plants, while the number and size of phloem fibers decreased. Stems from treated plants had fewer bands of fibers than the control. Phloem fiber cells in the control plants had thick walls, with little or no open space in the center, whereas the lumen in fibers of treated plants increased in size with higher rates of uniconazole (Fig 2). *Tagetes erecta* treated with daminozide produced phloem fibers with larger lumen and thinner walls (McConnell and Struckmeyer, 1971). The rate of cell division and degree of cell differentiation in hibiscus shoots appeared to have been suppressed by uniconazole. Halfacre and Barden reported (1968) that daminozide induced thick cell walls and affected cell division more than cell expansion in apple stems. Stem collapse in poinsettia receiving paclobutrazol (Wilfret, 1981) may have also been the result of changes in internal stem structure. We do not know whether the biosynthesis or the deposition of lignin and cell wall carbohydrates were affected by uniconazole.

Growth retardants have been shown to interfere with gibberellic acid (GA), DNA, and RNA synthesis in the apical and subapical regions of the shoots and root tips (Mahmond and Steponkus, 1970; Wylie et al., 1970), resulting in reduced cell division and internodal elongation. Uniconazole, which supresses biosynthesis of GA, may have induced an imbalance between endogenous auxin and GA levels, resulting in slow secondary growth of the stem (Morey and Cronshaw, 1968; Wareing et al., 1964).

Transverse diameter of pith cells in hibiscus was unaffected by the retardant (not shown), contrary to narrow and short pith cells observed in apple trees (Halfacre and Barden, 1968) and chrysanthemum (Larson and Kimmins, 1972; Johnson, 1974) after the application of daminozide and ancymidol, respectively. Parenchyma cells in the stem cortex became more round and less organized in treated plants. We also observed that suberization of the stem surface was delayed substantially in plants receiving uniconazole. The stem surface of plants receiving 0.4 mg remained smooth and was heavily pigmented. Many of the lower leaves on shoots of untreated plants had abscised at the time data were taken. Number of abscised leaves decreased with increasing rates of uniconazole. Little or no leaf abscission was observed on plants receiving the highest rate.

Although the second-generation cuttings taken from the new

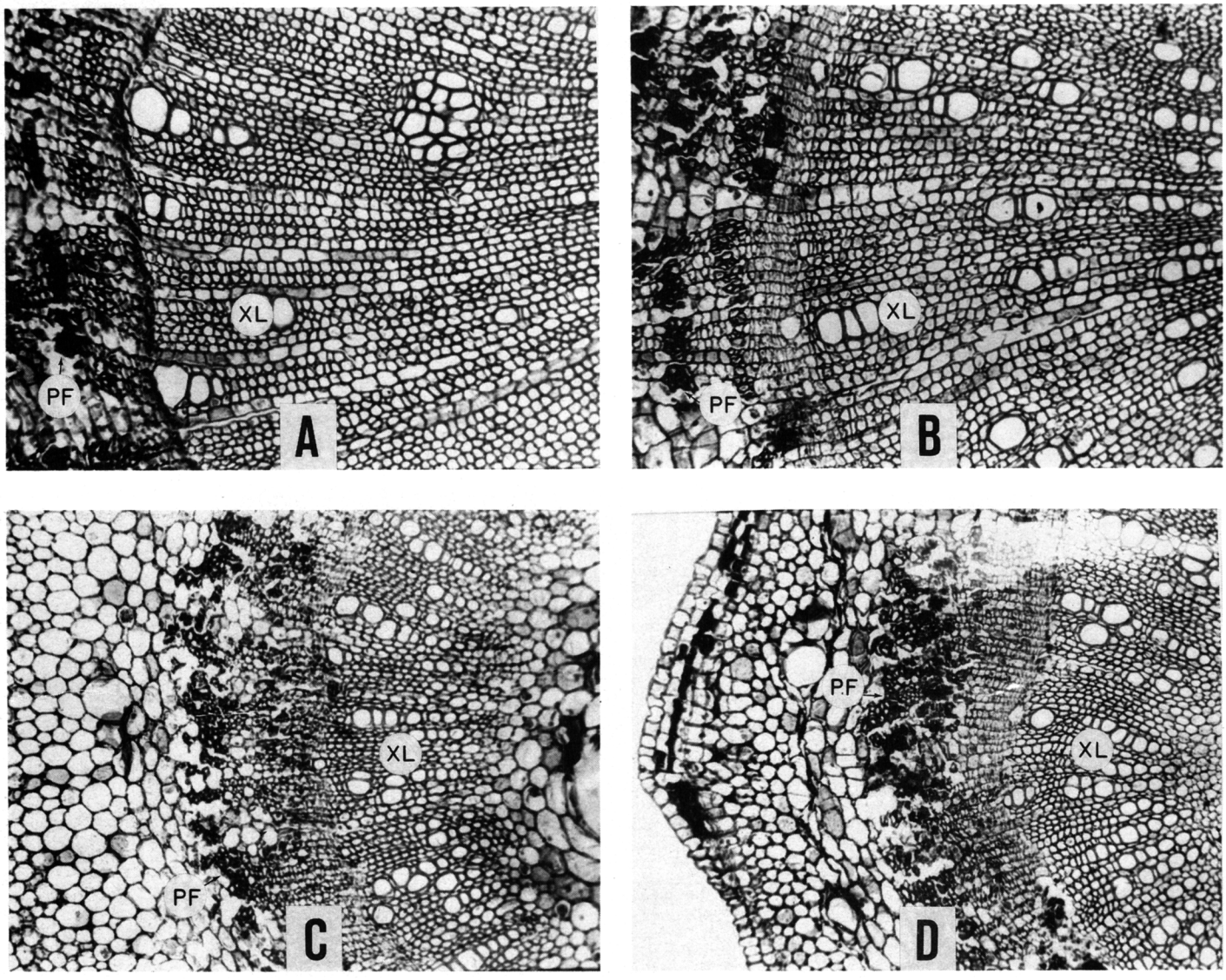

Fig. 2. 'Jane Cowl' hibiscus plants previously treated with uniconazole as a soil drench at 0 (**A**), 0.1 (**B**), 0.2 (**C**), or 0.4 (**D**) mg/pot showing the xylem (XL) and phloem fiber cells (PF), ×80. Note the thickness of xylem tissues and number and size of phloem fibers among treatments.

lateral shoots had shorter internodes than those from the controls, new lateral shoots arising from these cuttings did not exhibit any growth retardation (data not presented). Uniconazole was found to move very slowly up the xylem after its injection into grafted young apple plants (Sterrett, 1988). It is possible that uniconazole was so diluted in the tissues of treated hibiscus at time the second-generation cuttings were taken that it had limited effect on GA biosynthesis in shoot tips. Uniconazole is physiologically similar to its structural analog paclobutrazol (Richardson and Quinlan, 1986; Wang et al., 1986), having limited or no basipetal movement in the stem (Sterett, 1988) or out of the leaves; its effect on plant growth may also depend on site of application (Barrett and Bartuska, 1982). Paclobutrazol was shown to break down rapidly in shoots of young peach seedlings, particularly in leaves (Early and Martin, 1988). Therefore, the small amount of uniconazole in the shoots may have little or no effect on GA biosynthesis in the new roots. It was unlikely that uniconazole had been completely leached out from the medium when the second-generation cuttings were collected (Seely, 1982). It was possible that reduced absorption of uniconazole by the roots, breakdown of the molecules in the shoots, and lack of translocation out of the leaves had contributed to the normal growth of the second-generation cuttings.

Low levels of soil-applied uniconazole provided greater height control on young plants than foliar spray at similar low rates (Table 3). This difference could have been the result of lack of inhibition of biosynthesis of GA in roots of foliarly treated plants due to lack of uniconazole translocation out of the treated leaves or down the stem (Sterrett, 1988); also, uniconazole does not interfere with the biological function of exogenously applied GA. Soil application at 0.025 mg was effective in curtailing growth, but the retardant had no effect on number of lateral shoots because they had already elongated at the time of treatment. Flowering was delayed and flower number was reduced by uniconazole, particularly at the higher rates. Flower size and pedicel length decreased with increasing rates, and the reductions were less for the foliar treatment than for the drench (Table 3). Cascading shoots occurred on plants receiving the two low rates as a soil drench, but this growth characteristic was not so obvious on those receiving foliar application at the time data

Table 3. Growth and flowering of 'Jane Cowl' hibiscus as affected by soil or foliar application of uniconazole. Treatments were applied 2 weeks after the second pinch and data were taken 70 days after treatment. Means are averages of four replicates.

Uniconazole application	Plant height (cm)	Plant width (cm)	Shoot			Flowers			Pedicel length (cm)
			Length (cm)	Diameter (mm)	No. leaves	Days to bloom	No. flowers	Diameter (cm)	
Soil drench (mg/pot)									
0	44.4	52.5	33.3	5.2	10.3	62.3	20.8	13.1	9.1
0.025	15.0	34.8	14.0	3.2	8.5	64.8	18.0	10.9	4.6
0.050	14.3	27.0	12.4	3.3	8.5	63.5	14.5	11.2	2.4
0.100	15.0	21.2	6.6	3.5	7.0	65.5	9.5	10.4	2.2
0.150	12.3	21.0	4.8	3.5	5.8	67.5	6.6	9.7	1.5
0.200	13.0	18.0	5.0	3.2	6.3	71.0	5.0	9.3	1.6
Significance									
Linear	**	**	**	*	**	**	**	**	**
Quadratic	**	**	**	*	**	NS	*	NS	**
Foliar spray (mg/pot)[z]									
0	42.5	50.0	32.9	---	10.5	61.3	17.8	13.5	9.7
0.05 (10)	23.5	38.3	17.7	---	8.0	68.0	13.0	12.9	7.3
0.10 (20)	18.0	28.5	13.2	---	7.8	70.8	9.8	11.4	5.7
0.15 (30)	15.0	21.8	6.3	---	6.8	71.0	9.5	10.8	3.2
0.20 (40)	13.0	20.0	4.7	---	7.5	72.3	6.5	10.6	2.6
Significance									
Linear	**	**	**		*	**	**	**	**
Quadratic	**	**	**		NS	NS	NS	NS	NS
SD vs. FS	**	**	**		*	*	NS	*	**

[z]In parentheses, each plant received an average of 5-ml solution of the indicated concentration (mg·liter^{-1}).
NS,*,**Nonsignificant or significant at $P = 0.05$ or 0.01, respectively.

were recorded. Shoots on plants with drench rates ≥0.1 mg were much shorter than lower rates and remained upright. Microscopic examination of shoot cross-sections indicated that the thickness of xylem in treated plants was reduced by 70%, with little or no dose effect (data not presented). Stems of treated plants had larger cortical cells with greater diameters and shorter pith cells than the control. Since xylem production was suppressed in plants treated with uniconazole, restricted water and nutrient supply might have been partially responsible for their slow growth.

Uniconazole was shown in this study to be effective in controlling stem length of hibiscus. It was present in the stem and/or continuously taken up by the roots or by both mechanisms to provide good height control after plants were treated and pruned. The mechanical strength of shoots on treated plants at moderate rates may have been reduced due to changes in shoot anatomy, resulting in bending of the lateral shoots. However, this change may offer an opportunity for the upright hibiscus cultivars to be grown for hanging baskets. Studies are being conducted to determine the possible interaction of uniconazole with other plant growth regulators, such as auxin and gibberellic acid, on the growth and development of hibiscus.

Literature Cited

Barrett, J.E. and C.A. Bartuska. 1982. PP333 effects on stem elongation dependent on site of application. HortScience 17:737–738.

Barrett, J.E., M.E. Peacock, and T.A. Nell. 1986. Height control of *Exacum* and *Chrysanthemum* with paclobutrazol, XE-1019, and RSW-0411. Proc. Fla. State Hort. Soc. 99:254–255.

Criley, R.A. 1981. Vegetative growth control of *Hibiscus rosa-sinensis* hedges with chlormequat. HortScience 16:343–344.

Fletcher, R.A. and V. Arnold. 1986. Stimulation of cytokinin and chlorophyll synthesis in cucumber cotyledons by triadimefon. Physiol. Plant. 66:197–210.

Gao, J., G. Hofstra, and R.A. Fletcher. 1988. Anatomical changes induced by trizoles in wheat seedlings. Can. J. Bot. 66:1178–1185.

Gibbs, M.M., T.M. Blessington, J.A. Price, and Y.T. Wang. 1989. Effect of dark storage temperature and duration on flowering and quality retention of hibiscus. HortScience 24(4):646–647.

Halfacre, R.G. and J.A. Barden. 1968. Anatomical response of apple leaf and stem tissues to succinic acid 2,2-dimethylhydrazide (Alar). Proc. Amer. Soc. Hort. Sci. 93:25–32.

Halfacre, R.G., J.A. Barden, and H.A. Rollins, Jr. 1968. Effect of Alar on morphology, chlorophyll content, and net CO_2 assimilation rate of young apple trees. Proc. Amer. Soc. Hort. Sci. 93:40–52.

Johnson. C.R. 1974. Response of chrysanthemum grown in clay and plastic pots to soil applications of ancymidol. HortScience 9:58.

Kelly, J.W. and D.R. Thaxton. 1987. Reduce bud abscission of hibiscus. Greenhouse Grower 5(3):88.

LaCain, D.R., K.A. Schekel, and R.L. Wample. 1986. Growth-retarding effects of paclobutrazol on weeping fig. HortScience 21:1150–1152.

Larson, R.A. and R.J. Kimmins. 1972. Response of *Chrysanthemum morifolium* Ramat to foliar and soil applications of ancymidol. HortScience 7:192–193.

Mahmond, T.A. and P.T. Steponkus. 1970. Effect of phosfon on shoot histogenesis of *Chrysanthemum morifolium*. J. Amer. Soc. Hort. Sci. 95:295–299.

Mansour, H.A. and R.T. Poole. 1987. Trials with growth retardants on ornamental plants. Proc. Fla. State Hort. Soc. 100:375–378.

Maus, W.L. 1987. Effect of paclobutrazol and uniconazole-P on *Hibiscus rosa-sinensis*. Proc. Fla. State. Hort. Soc. 100:373–375.

McConnell, D.B. and B.E. Struckmeyer. 1971. The effect of succinic acid 2,2-dimethyl hydrazide on the anatomy of *Tagetes erecta L.* J. Amer. Soc. Hort. Sci. 96:70–73.

McDaniel, G.L. 1986. Comparison of paclobutrazol, flurprimidol, and tetcyclacis for controlling poinsettia height. HortScience 21:1161–1163.

Miller, R.O. 1987. Take a look at hibiscus. Grower Talks 51(4):136–138.

Moran, R. 1982. Formulae for determination of chlorophyllous pig-

ments extracted with *N,N*-dimethylformamide. Plant Physiol. 69:1376–1381.
Moran, R. and D. Porath. 1980. Chlorophyll determination in intact tissues using N,N-dimethylformamide. Plant Physiol. 65:478–479.
Morey, P.R. and J. Cronshaw. 1968. Developmental changes in the secondary xylem of *Acer rubrum* induced by gibberellic acid, various auxins and 2,3,5-tri-iodobenzoic acid. Protoplasma 65:315–326.
Neumaier, E.E., T.M. Blessington, and J.A. Price. Effect of light and fertilizer rate and source on flowering, growth and quality of hibiscus. HortScience 22:902–904.
Richardson, P.J. and J.D. Quinlan. 1986. Uptake and translocation of paclobutrazol by shoots of M.26 apple rootstock. Plant Growth Regulat. 4:347–356.
Sachs, R.M. and A.M. Kofranek. 1963. Comparative cytohistological studies on inhibition and promotion of stem growth in *Chrysanthemum morifolium*. Amer. J. Bot. 50:772–779.
Seely, J.G. 1982. Retention of ancymidol in a soil medium and in clay pots. HortScience 17:198–199.
Shanks, J.B. 1972. Chemical control of growth and flowering in hibiscus. HortScience 7:574.
Sterrett, J.P. 1988. XE-1019: plant response, translocation, and metabolism. J. Plant Growth Regulat. 7:19–26.
Wang, S.Y., T. Sun, and M. Faust. 1986. Translocation of paclobutrazol, a gibberellin biosynthesis inhibitor, in apple seedlings. Plant Physiol. 82:11–14.
Wareing, P.E., C. Hanney, and J. Digby. 1964. The formation of wood in forest trees. Academic, New York. p. 323–344.
Warly, J.D. and G.C. Martin. 1988. Translocation and breakdown of ^{14}C-labeled paclobutrazol in 'Nemaguard' peach seedlings. HortScience 22:196–200.
White, J.W. and E.J. Holcomb. 1974. Height control methods for poinsettia. HortScience 9:146–147.
Wilfret, G.J. 1981. Height retardation of poinsettia with ICI-PP-333. HortScience 16:443. (Abstr.)
Wylie, A.W., K. Ryugo, and R.M. Sachs. 1970. Effect of growth retardants on biosynthesis of gibberellin precursors in root tips of peas, *Pisum sativum* L. J. Amer. Soc. Hort. Sci. 95:627–630.

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Postharvest Calcium Chloride Infiltration Affects Textural Attributes of Apples

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Abstract. **'Golden Delicious' apples (*Malus domestica* Borkh.) were pressure-infiltrated (68.9 kPa) at two harvest dates with 0%, 1%, 2%, or 4% (w/v) solutions of $CaCl_2$ and stored at 0C for 2, 4, or 6 months followed by 1 week at 20C. Calcium concentrations, axial compression profiles, and Magness–Taylor firmness were measured. Calcium chloride infiltration increased all measures of tissue strength immediately and relative increases persisted during storage. A 1-week difference in harvest date markedly affected Ca uptake and textural responses; however, for both dates, 2% $CaCl_2$ was effective in firming the apples. Apples from the second harvest, which were treated with 2% $CaCl_2$ and stored for 6 months, had textural measurement values equal to or greater than those of comparable apples infiltrated only with water and measured before storage. Calcium chloride at 4% had a greater firming effect, but caused severe surface damage. Differential reponses to $CaCl_2$ levels and storage durations by various textural measurements indicate that supplemental Ca not only increased firmness retention during storage, but also induced patterns of textural change different from those that occurred under the influence of the endogenous Ca alone.**

Postharvest infiltration of Ca into apples has been shown to increase firmness immediately and to maintain firmness during storage (Bangerth et al., 1972; Mason et al., 1974, 1975, 1976; Riley and Kolattukudy, 1976; Scott and Wills, 1977; Conway and Sams, 1983; Sams and Conway, 1984). Pressure infiltration is more effective for getting Ca into the tissues than dips or vacuum infiltration (Scott and Wills, 1977, 1979; Conway and Sams, 1983).

Some researchers have observed that the texture of apples treated with Ca was "different" from that of nontreated apples, the implication being that they were not just firmer as indicated by Magness–Taylor fruit firmness tester (MT) values, but that various textural properties had been affected differentially (R.E. Hardenburg, W.S. Conway, and C.E. Sams, personal communications).

The increase in firmness due to Ca treatments previously has been quantified using a Magness-Taylor or the similar Effegi fruit firmness tester. These fruit firmness testers measure only the maximum force required to cause a probe to penetrate the apple flesh a defined distance. The depth of penetration at which that force occurs is not measured, but may be characteristic of textural differences (Bourne, 1965).

Because several mechanisms may be involved in normal softening and Ca-related firming of apples, we selected a modified texture profile approach, in which force and deformation are recorded during uniaxial compression of an excised sample of flesh, to determine whether Ca infiltration affected various textural attributes of apples differentially. We also document further the effects of Ca on firmness of apples after storage.

Materials and Methods

'Golden Delicious' apples were harvested from a small block of trees in southcentral Pennsylvania 1 week before and at commercial harvest for that orchard (harvests 1 and 2). The apples

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