Ornamental Cabbage and Kale Growth Responses to Daminozide, Paclobutrazol, and Uniconazole

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SUMMARY. **Ornamental cabbage and kale (*Brassica oleracea* var. *acephala*) plants of cultivars Osaka White and Nagoya Red were treated with paclobutrazol and uniconazole as foliar sprays or substrate drenches. These treatments were compared to the industry standard of daminozide foliar sprays. Applying drenches of paclobutrazol (a.i.) at 4 mg/pot or uniconazole (a.i.) at 1 mg/pot (28,350 mg = 1.0 oz) resulted in 6% or 17%, respectively, shorter 'Osaka White' plants while a 2 mg/pot paclobutrazol drench or a uniconazole drench at 0.25 mg/pot resulted in 25% shorter 'Nagoya Red' plants. Although effective, the expense of substrate drenches for both plant growth regulators (PGRs) would not be economically feasible for growers to use. Paclobutrazol foliar sprays at concentrations of up to 80 mg·L^{-1} (ppm) were ineffective in controlling plant height and diameter of either 'Osaka White' or 'Nagoya Red'. A uniconazole foliar spray of 16 mg·L^{-1} resulted in 17% shorter 'Nagoya Red' plants and 6% shorter 'Osaka White' plants. A daminozide foliar spray of 2500 mg·L^{-1}, sprayed twice, resulted in 21% shorter plants for both cultivars. Spraying daminozide would provide optimal height control for the retail grower. Although spraying daminozide twice controlled plant height and costs half the amount of an uniconazole spray at 16 mg·L^{-1}, plant diameter was not affected with daminozide, therefore a wholesale grower who would desire a smaller diameter plant should use a uniconazole spray of 16 mg·L^{-1}.**

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Ornamental cabbage and kale are attractive landscape plants for the fall and early winter garden. Commercial production of ornamental cabbage and kale in the southeastern U.S. occurs during the late summer when warm temperatures promote extensive plant growth. Growers face the challenge of maintaining a short, yet robust plant, which looks proportional to pot size.

Plant growth regulators (PGRs) are commonly applied to container-grown plants to inhibit stem elongation and produce a more compact plant (Tayama et al., 1992). Commercial PGR recommendations suggest using daminozide (2,2-dimethylhydrazide) (B-Nine, Uniroyal Chemical, Middlebury, Conn.) at 1,500 to 3,000 mg·L^{-1} to achieve desired height control (Luczai, 1992; McAvoy, 1994). A few PGR studies have been conducted on ornamental cabbage and kale, but all the previous work was conducted in geographical locations with milder production temperatures, or during seasons other than the typical fall production time of the southeastern U.S.

During the winter and spring production in California, paclobutrazol ((+)-(R*,R*)-β([4-chlorophenyl] methyl-α-(1,1-dimethylethyl)-1*H*-1,2,4-triazole-1-ethanol)(Bonzi, Uniroyal Chemical, Middlebury, Conn.) drenches (a.i.) of 1.25 to 2.5 mg/pot effectively inhibited excessive height of ornamental kale grown in 15.2-cm (6-inch) pots (Barcel, 1998). Foliar sprays of paclobutrazol at concentrations up to 200 mg·L^{-1} were ineffective in inhibiting ornamental kale growth, but the foliage became darker green and the center color intensified (Barcel, 1998).

Kuehny et al. (1998) applied foliar sprays of ancymidol (∝-cyclopropyl-∝-(p-methoxyphenyl)-5-pyrimidine methanol) (A-Rest, SePro Corp., Carmel, Ind.), paclobutrazol, or chlormequat (2-chloroethyltrimethylammonium ion) (Cycocel, Olympic Horticultural Products, Mainland, Pa.) plus daminozide to ornamental kale plants grown in 36-cell bedding plant trays. Ancymidol at 25 mg·L^{-1} and paclobutrazol at 15 mg·L^{-1} were effective in producing a 20% smaller plant. Tank mixes of chlormequat + daminozide produced plants that were 48% (1,000 + 800 mg·L^{-1}), 56% (1,250 + 1,250 mg·L^{-1}), or 80% (1,500 + 5,000 mg·L^{-1}) smaller when compared to the control, and a darker blue-green foliage color was observed.

Lang (1998) in Texas, applied foliar sprays of daminozide between 2,500 and 7,500 mg·L^{-1}, paclobutrazol between 10 and 40 mg·L^{-1}, and multiple combinations of the two chemicals to an ornamental kale cultivar in 8.9-cm (3.5-inch) pots. Daminozide (2,500 mg·L^{-1}) plus paclobutrazol (20 mg·L^{-1}) resulted in 41% shorter plants when compared to the control. However, plants treated with paclobutrazol at 40 mg·L^{-1} were comparable to the tank mix with a 34% shorter height. Whipker et al. (1994) found foliar applications of uniconazole ((E)-1-(p-chlorphenyl)-4,4-dimethyl-2-(1,2,4-triazol-1-yl-1-penten-3-ol)) (Sumagic, Valent, USA, Marysville, Ohio) at 5 mg·L^{-1} or daminozide at 2,500 and 5,000 mg·L^{-1} resulted in the shortest plant height of two ornamental kale cultivars. This study was conducted in the midwestern U.S. and used only a limited number of concentrations.

Barcel (1998), Kuehny et al. (1998), and Lang (1998) evaluated several PGRs available to growers today. They did not determine optimal concentrations of paclobutrazol or uniconazole when applied as foliar sprays or drenches for plants grown in a container larger than 15.2 cm (6 inches). Kuehny et al. (1998) and Lang's (1998) PGR research focused on foliar concentrations for small containers used in bedding plant production, and only ornamental kale was evaluated. Recommended concentrations of PGRs used in these studies resulted in 20% to 35% shorter plants, when compared to untreated plants, and these percentages are common goals in plant growth regulator re-

search (J. Latimer, personal communication). Significant differences in plant vigor between ornamental cabbage and kale cultivars have been reported (Whipker et al., 1998). Past research directed the authors to investigate the effectiveness of PGRs as foliar sprays and substrate drenches for both ornamental cabbage and kale grown in the larger 20.8-cm (8-inch) pot commonly used by the industry.

Materials and methods

Ornamental cabbage and kale plugs (2.1 × 2.5 cm [0.8 × 0.95 inch] cells) of cultivars Osaka White and Nagoya Red were transplanted into 2.96-L (0.78-gal) (20.8-cm-diameter [8-inch]) round plastic containers on 20 Aug. 1998. The root substrate was Fafard 4-P (Fafard, Anderson, S.C.), which contained (v/v): 4 sphagnum peat : 2 pine bark : 2 vermiculite: 1 perlite. Plants were fertilized at each watering with 200 mg·L^{-1} N mixed from $Ca(NO_3)_2 \cdot 4H_2O$ (15.5N–0P–0K) and KNO_3 (13N–0P–36.5K) (Scotts, Marysville, Ohio). Once every 2 weeks, a supplemental application of magnesium sulfate ($MgSO_4 \cdot 7H_2O$) at 96 mg·L^{-1} Mg and Peters 20–10–20 (Scotts, Marysville, Ohio) (20N–4.4P–16.6K) at 200 mg·L^{-1} N were applied. The plants were grown under natural daylength. Thirteen PGR foliar sprays were applied 22 d after potting (using a volume of 204 mL·m^{-2} [0.5 gal/100 ft^2]): paclobutrazol at 5, 10, 20, 40, or 80 mg·L^{-1}; uniconazole at 2, 4, 8, 16 or 32 mg·L^{-1}; daminozide at 2500, 2500 (twice, with the second application occurring 14 d after the first), or 5000 mg·L^{-1}; and an untreated control. Ten PGR drench treatments were also applied 22 d after potting (using a volume of 300 mL [10 fl oz]) of solution per pot: paclobutrazol (a.i.) at 1, 2, 4, 8, or 16 mg/pot; uniconazole (a.i.) at 0.125, 0.25, 0.5, 1, or 2 mg/pot; or the untreated control. The experiment was a randomized complete-block design with five single-plant replications of the 24 treatments. On 1 Nov., total plant height (measured from the pot rim to the top of the foliage), plant diameter, and the diameter of the center color (all diameters measured at the widest dimension and turned 90°, and averaged) were recorded. The suitability of plants for the retail or wholesale markets was determined by grower evaluations of the PGR treatments.

Data analysis. Data for plant height, plant diameter, and center color diameter were tested by analysis of variance by general linear model (SAS Inst., Cary, N.C.). Means for the cultivars and treatment were separated by least significant differences (LSD) at $P \leq 0.05$.

Plant height and diameter values were regressed using the PROC REG procedure (SAS Inst.) to determine the best fit linear or quadratic model for each PGR (paclobutrazol or uniconazole) and application method (foliar spray or substrate drench). Variables in the model were plant growth regulator concentration (Con) and indicator variables for cultivar (Cult) ('Nagoya Red' or 'Osaka White'), with the full model being $\text{concentration}_i = \beta_0 + \beta_1 Cult_2 + \beta_2 Con + \beta_3 Con \times Cult_2 + \beta_4 Con^2 + \beta_5 Con^2 \times Cult_2$, where concentration_i = PGR concentration, i = variable being regressed (plant height or plant diameter), $Cult_2$ = 1 if cultivar = 'Osaka White', 0 if otherwise (for 'Nagoya Red'), and β_k = estimated coefficients (k = 0 to 5).

Terms of the model were judged to be significant or nonsignificant and included in the final model based on a comparison of F values at $\alpha = 0.05$. The NLIN procedure in SAS (SAS Institute, 1982), as modified by Cox (1992), was used to calculate linear-plateau functions (model IV) relating plant height and diameter to paclobutrazol and uniconazole substrate drench concentrations. The quadratic and the linear-plateau models were compared to determine the best fit based on r^2 values.

Results and discussion

Daminozide sprays

Plant height. Plant height of both cultivars responded similarly to daminozide, therefore the data for both cultivars were pooled. Daminozide treatments of 2,500 or 2,500 mg·L^{-1} sprayed twice significantly affected plant height, when compared to the untreated control (Table 1). Plants were 12% shorter when treated with 2,500 mg·L^{-1} daminozide as a single application, and when sprayed twice, were 21% shorter, when compared to the untreated plants. Applying daminozide at 2,500 mg·L^{-1} twice gave better control of height (21% smaller plants) than the single application at 5,000 mg·L^{-1} (12% smaller plants).

Plant diameter. Plant diameter was not controlled by daminozide for either cultivar and averaged 40.3 cm (15.9 inches) (data not shown). Commercial recommendations for daminozide at 1,500 to 3,000 mg·L^{-1} (Luczai, 1992; McAvoy, 1994) may be appropriate for more northern climates. Southeastern U.S. growers may need to monitor the height of the ornamental cabbage and kale crop on a regular basis when applying daminozide. Although daminozide may have no effect on plant diameter, it may be a tool for growth control by retail and wholesale growers because of its economic advantage of costing $0.01 to $0.02 per pot, based on a daminozide cost of $154/kg ($70/lb). Internode elongation and undesirable expansive plant diameters may be avoided with higher concentrations than used in this study or multiple applications of daminozide.

Paclobutrazol drenches

Plant height. 'Osaka White' plant height responded linearly to increasing paclobutrazol substrate drench concentrations (Fig. 1A). The response of 'Nagoya Red' plants was best described by a linear-plateau model with the smallest plants being 12.7 cm (5 inches) tall at concentrations of 2.7 mg (the joinpoint) or greater (Fig. 1A). No further increases in control occurred at concentrations of 2.7 mg or greater, the plateau portion of the

Table 1. Effect of daminozide on growth of ornamental cabbage and kale.

Treatment	Mean plant ht (cm)[z]
Untreated control	20.1
2,500 mg·L^{-1} daminozide	17.6
2,500 mg·L^{-1} daminozide (twice)[y]	15.8
5,000 mg·L^{-1} daminozide	17.7
Significance	***
LSD ($\alpha \leq 0.05$)	1.6

[z]2.54 cm = 1.0 inch.
[y]The second daminozide foliar spray applied 14 d after the first.
***Significant at $P \leq 0.001$. Daminozide was significant only by treatment, n = 10.

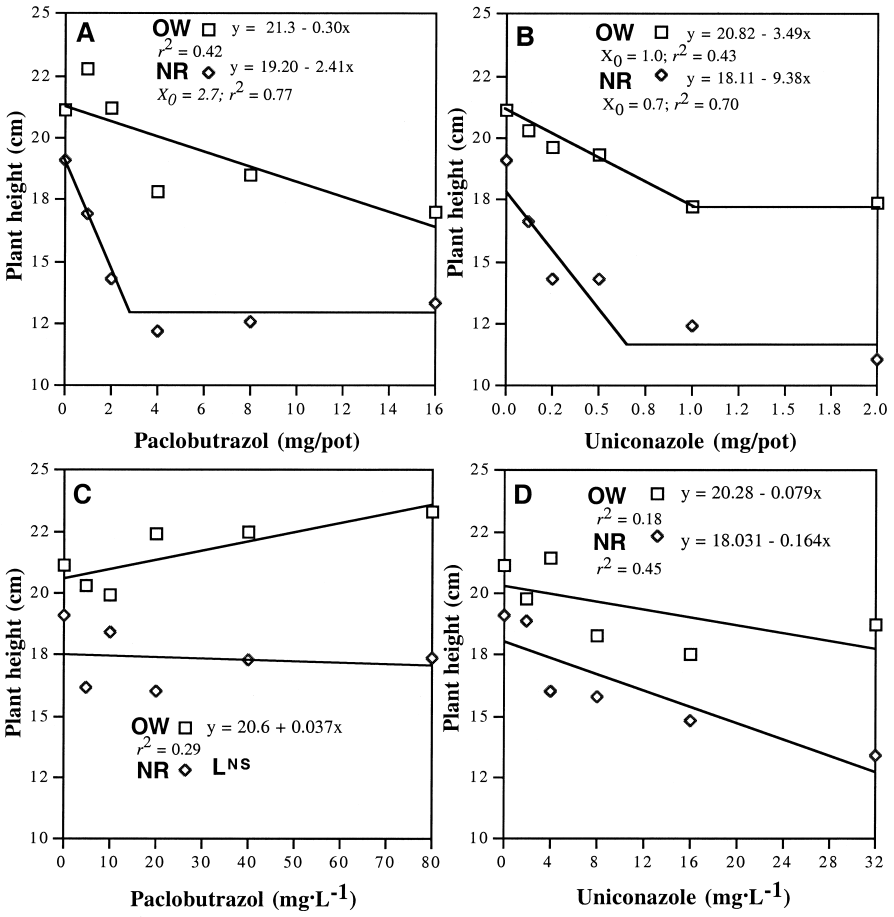

Fig. 1. Plant growth regulator effects on plant height of 'Osaka White' (OW) and 'Nagoya Red' (NR) ornamental cabbage and kale. Regression lines were generated from the best-fit model, and points are means for each treatment (n = 5). ^{ns,**,***}Nonsignificant or significant at $P \leq 0.01, 0.001$, respectively; L = linear, Q = quadratic, and LP = linear-plateau, X_0 = joinpoint; (A) paclobutrazol substrate drench for OW: L^{***}, NR: $L^{***}Q^{***}LP^{***}$; (B) uniconazole substrate drench adjusted for OW: $Q^{**}LP^{***}$, NR: $Q^{***}LP^{***}$; (C) paclobutrazol foliar spray for OW: L^{**}, NR: L^{NS}; (D) uniconazole foliar spray for OW: L^{***}, NR: L^{***}. Substrate drench rates are expressed as mg of active ingredient. 2.54 cm = 1.0 inch.

line. 'Osaka White' plants were 6% shorter when treated with 4 mg and 11% shorter when treated with 8 mg of paclobutrazol, and the 'Nagoya Red' kale plants were 34% shorter when treated with 2.7 mg, when compared to the untreated control plants.

Plant diameter. Both 'Osaka White' and 'Nagoya Red' plant diameters were best described by linear-plateau models with no additional response in plant diameter being observed at concentrations of 4.3 mg or greater (Fig. 2A). 'Osaka White' and 'Nagoya Red' plants were 33% and 30% smaller in diameter, respectively, for these concentrations. Smaller diameter plants would be an advantageous trait to wholesale growers because a greater number of pots could fit on shipping carts and trucks.

Center color diameter. Center color diameter was 49% smaller for 'Nagoya Red' plants treated with paclobutrazol drenches of 8 mg (data not shown, $P \leq 0.05$). No other PGR treatment had an effect on center color diameter.

Although greater height control was observed at 8 mg for 'Osaka White' with plants being 11% shorter, when compared to the untreated control, the plant diameter was detrimentally affected (60% smaller). Paclobutrazol drenches of 4 mg or greater were excessive and resulted in a stunted appearance for 'Nagoya Red'. Plant diameter was 31% smaller when treated with 4 mg for 'Osaka White' and 14% smaller for 'Nagoya Red' when treated at 2 mg. Optimal concentrations of paclobutrazol substrate drenches would be 4 mg for vigorous cultivars like 'Osaka White' or 1 to 2 mg for less vigorous cultivars like 'Nagoya Red'. Although paclobutrazol drenches effectively inhibited plant growth, the time involved in drenching a crop and the economic impact needs to be considered. Paclobutrazol substrate drenches of 2 mg would cost the grower $0.06 per pot, while a 4 mg drench would cost $0.12, based on the cost of $116/L ($110/qt).

Uniconazole drenches

Plant height. The effects of uniconazole drenches were best described by a linear-plateau model (Fig. 1B). Uniconazole substrate drenches resulted in a significantly shorter plant height of 'Nagoya Red', with no further control above 0.7 mg. At this concentration, 'Nagoya Red' plants were 35% shorter, compared to the untreated control. 'Nagoya Red' plants had a stunted appearance, but when treated with 0.5 mg, the plants were 26% shorter than the untreated plants and in proportion to pot size. Concentrations of 1 mg or greater were similar in inhibiting plant height of 'Osaka White' with plants being 17% shorter than the untreated plants.

Plant diameter. The effects of uniconazole substrate drenches on plant diameter were best described by a linear-plateau model (Fig. 2B). No further control of diameter was observed for 'Osaka White' at concentrations above 0.7 mg or with 0.5 mg for 'Nagoya Red'. Plant diameter was 20% smaller for 'Osaka White' at 0.7 mg and 29% smaller for 'Nagoya Red' at 0.5 mg, when compared to the untreated control plants.

Marketable wholesale shipping plants of 'Osaka White' were produced with drench concentrations of 0.7 to 1 mg, while 0.5 mg produced marketable 'Nagoya Red' plants. Economically, a 0.5 to 1 mg drench of uniconazole would cost $0.12 to $0.23, respectively, per pot. These expenses are based on the cost of $116/L for uniconazole.

Paclobutrazol sprays

Plant height. Paclobutrazol foliar sprays at concentrations of up to 80 mg·L^{-1} were ineffective in inhibiting plant height of 'Nagoya Red' (Fig. 1C). 'Osaka White' exhibited a posi-

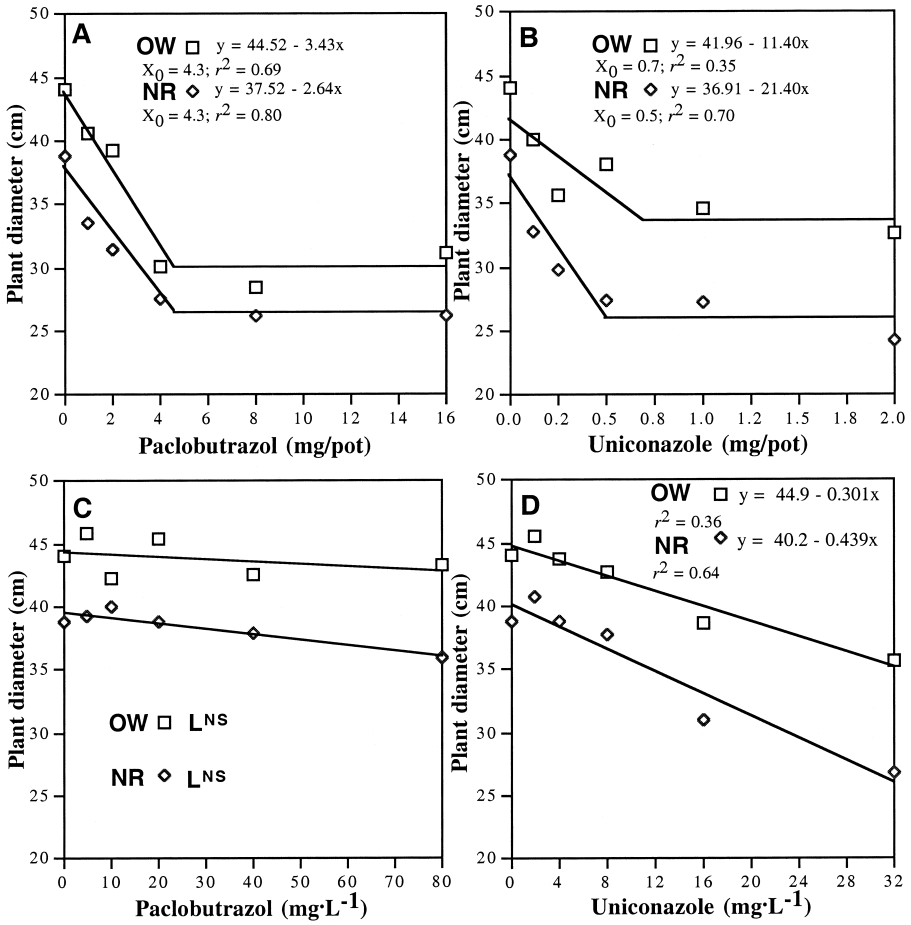

Fig. 2. Plant growth regulator effects on plant diameter of 'Osaka White' (OW) and 'Nagoya Red' (NR) ornamental cabbage and kale. Regression lines were generated from the best-fit model, and points are means for each treatment (n = 5). ^{ns,**,***}Nonsignificant or significant at $P \leq 0.01$, 0.001, respectively; L = linear, Q = quadratic, and LP = linear-plateau, X_0 = joinpoint; (A) paclobutrazol substrate drench for OW and NR: $L^{***}Q^{***}LP^{***}$; (B) uniconazole substrate drench for OW: $Q^{**}LP^{***}$, NR: $Q^{***}LP^{***}$; (C) paclobutrazol foliar sprays were not significant; (D) uniconazole foliar spray for OW: $L^{***}Q^{**}$, NR: L^{**}. Substrate drench rates are expressed as mg of active ingredient. 2.54 cm = 1.0 inch.

tive response of greater plant height as the paclobutrazol foliar spray concentration increased. The ineffectiveness of paclobutrazol foliar sprays in controlling height was in agreement with Barcel (1998) who found 200 mg·L^{-1} was only slightly effective on ornamental kale. These findings are in contrast to those of Kuehny et al. (1998) and Lang (1998) where paclobutrazol foliar sprays of 10 to 40 mg·L^{-1} inhibited plant growth of ornamental kale. Greater control of plant height with paclobutrazol foliar sprays of 10 to 40 mg·L^{-1} by Kuehny et al. (1998) and Lang (1998) may be a direct result of restricting growth through the use of smaller containers or due to regional climate differences. This highlights the need to conduct PGR trials in multiple locations to account for differences in climate and timing of the crop.

Plant diameter. Paclobutrazol foliar sprays at concentrations of up to 80 mg·L^{-1} were also ineffective in controlling plant diameter of either 'Osaka White' or 'Nagoya Red' (Fig. 2C).

Paclobutrazol applied as a foliar spray does not appear to be useful to wholesale growers in the southeastern U.S. for controlling growth of ornamental cabbage and kale grown in larger 20.8-cm containers. Similar results were reported by Barcel (1998) with foliage color being darker on plants treated at concentrations of 20 mg·L^{-1} or greater.

Uniconazole sprays

Plant height. There was a linear relationship between increasing concentrations of uniconazole foliar sprays and plant height for both 'Osaka White' and 'Nagoya Red' (Fig. 1D). An 8 mg·L^{-1} application of uniconazole resulted in a 3% shorter plant height for 'Osaka White' and 7% for 'Nagoya Red'. This concentration for both cultivars may be appropriate for retail growers who do not need to control height for shipping purposes. A concentration of 16 mg·L^{-1} significantly decreased plant height by 6% and 15%, when compared to the untreated control for 'Osaka White' and 'Nagoya Red', respectively. Wholesale growers may desire concentrations as high as 32 mg·L^{-1} to control height of vigorous ornamental cabbage cultivars like 'Osaka White'.

Plant diameter. There was a linear relationship between increasing concentrations of uniconazole foliar sprays and plant diameter for both 'Osaka White' and 'Nagoya Red' (Fig. 2D). The plant diameters for 'Osaka White' and 'Nagoya Red' were 11% and 17% smaller, respectively, than the untreated control plants when sprayed with 16 mg·L^{-1} uniconazole.

An optimal concentration of uniconazole to produce marketable plants in retail settings would be 8 mg·L^{-1} for 'Nagoya Red'. A concentration of 16 mg·L^{-1} limited stem elongation and lateral expansion of both cultivars. Although uniconazole at 16 mg·L^{-1} did not result in plants between the threshold of being 20 to 30% shorter for 'Osaka White', the treatment did result in significantly smaller plant diameters. Our recommended concentrations of 8 to 16 mg·L^{-1} for southeastern U.S. growers is slightly higher than the concentration of 5 mg·L^{-1} recommended for northern U.S. growers (Whipker et al., 1994). Based on the cost of $116/L, the 16 mg·L^{-1} uniconazole spray would cost $0.04 per 2.96-L pot, which was 3 times less expensive than the uniconazole drench at 0.5 mg or the paclobutrazol drench at 4 mg.

Conclusion

Although substrate drenches of paclobutrazol at 2 to 4 mg and uniconazole at 0.5 to 1 mg produced compact plants for the retail and wholesale grower, the economic aspect in growing ornamental cabbage and kale needs to be considered. Method of application is an important consideration in determining the most cost-effective way of inhibiting plant growth. Daminozide sprayed at 2,500 mg·L^{-1}

was effective in limiting stem elongation of ornamental kale cultivars, and cost $0.004 per pot as a single application or $0.01 when sprayed twice. Two applications of 2,500 $mg \cdot L^{-1}$ daminozide may be applicable to wholesale southeastern U.S. growers who desire an economical ($0.01) and effective measure for inhibiting height of ornamental cabbage and kale. A uniconazole foliar spray of 16 $mg \cdot L^{-1}$ was effective in inhibiting plant growth, but would cost the grower $0.04 per pot. Although more expensive, a uniconazole foliar spray of 16 $mg \cdot L^{-1}$ resulted in both a smaller plant height and smaller plant diameter, when compared to daminozide applied twice at 2,500 $mg \cdot L^{-1}$.

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