Gibberellic Acid Shows Promise for Promoting Flower Stem Length in Four Field-grown Cut Flowers

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ADDITIONAL INDEX WORDS. production time, harvest date

SUMMARY. Increasing cut stem length and reducing crop production time are producers' goals for numerous cut flower species. One or both of these aims was met in several field-grown cultivars through foliar application of gibberellic acid (GA₃), but effectiveness varied by cultivar, application rate, and timing. Of the 13 cultivars tested, stem length was increased in nine cultivars [Toreador Red celosia (*Celosia argentea*), Camelot White foxglove (*Digitalis purpurea*), Imperial Giants Pink Perfection larkspur (*Larkspur* hybrids), Compliment mix lobelia (*Lobelia* hybrids), Nippon Taka ornamental pepper (*Capsicum annuum*), Amazon Neon Duo and Bouquet Purple sweet william (*Dianthus* hybrids), Summer Pastels yarrow (*Achillea millefolium*), and Benary's Giant Scarlet zinnia (*Zinnia elegans*)], and time to harvest was decreased in four cultivars [High Tide White ageratum (*Ageratum houstonianum*), lobelia, ornamental pepper, and zinnia], when GA₃ was applied as a foliar spray. Concentrations of 400, 800, and 1600 mg·L⁻¹ GA₃ were most effective. Application of GA₃ resulted in malformed or smaller flowers or lighter green foliage in foxglove, lobelia, sweet william, and zinnia. In most cases, only one application was tested, and greatest response to GA₃ was observed during 3–6 weeks post application. Gibberellic acid did not influence stem length in three cultivars [High Tide White ageratum, Aurora Deep Purple delphinium (*Delphinium* hybrids), and Column Lilac Lavender stock (*Matthiola incana*)], and decreased flower stem length in one cultivar (High Tide Blue ageratum). Four cultivars were identified as good candidates for further research given their promising responses to GA₃ treatments.

Successful cut flower production depends on the ability to produce crops economically in a short, predictable amount of time. Profitability of a cut flower cultivar relies on market price, yield of long, strong, and easy-to-harvest stems, manageable insect and disease pressures, short crop cycle, and long postharvest life (Armitage and Laushman, 2003; Bridgen, 1992). Few cultivars have all these characteristics. Common problems include unacceptably short stems, long production times, or lengthy flower-initiation procedures. Growers may be able to alleviate some of these issues by applying gibberellic acid to their crops.

Gibberellic acid can be used to break dormancy, promote stem elongation, and replace photoperiodic requirements (Kende and Zeevaart, 1997; Pharis and King, 1985; Sharma and Kumar, 2005; Wittwer and Bukovac,

1957). Examples of cut flowers that are treated with GA₃ during production include lisianthus (*Eustoma grandiflorum*) to prevent rosetting and shorten production time (Jie et al., 2003; JongWon et al., 2000), calla lily (*Zantedeschia albomaculata*) to increase the number of flowers and shorten production time (Ball, 1991), and species in which GA₃ can be used to break dormancy such as liatris (*Liatris spicata*), monkshood (*Aconitum napellus*), and peony (*Paeonia suffruticosa*) as reported by Wanjab and Waithaka (1983), Lurie et al. (1992), and GuoSheng et al. (2009), respectively. With other species, such as cut poinsettia (*Euphorbia pulcherrima*), tall stems can be produced without GA₃, but using the growth regulator can produce the desired height in a shorter time period

(Hartrath, 1987). Three benefits were achieved by treating perennial aster (*Aster ericoides*) with GA₃: breaking dormancy, increasing stem length, and reducing production time (Naranja and Balladares, 2008).

Because GA₃ effects can vary greatly among different taxa, the objective of these trials was to quantify the effects of GA₃ on cut stem production in 13 field-grown, cut flower cultivars: ageratum (two cultivars), celosia, delphinium, foxglove, larkspur, lobelia, ornamental pepper, stock, sweet william, dianthus (two cultivars), yarrow, and zinnia.

Materials and methods

Experiments with 13 cut flower cultivars were conducted at the North Carolina State University Horticultural Field Laboratory in Raleigh, NC. Separate experiments were conducted in three different years with four, five, and four cultivars used in years 1, 2, and 3, respectively.

Trial plants were started in a greenhouse from seed early each spring or obtained as plugs from commercial suppliers ≈2 weeks before field planting. Standard greenhouse management included growing plants in bedding plant flats with 2.25 × 1.50 × 2.13-inch individual cells containing soil-less substrate (Fafard 4P; Conrad Fafard, Agawam, MA), fertilizing at each overhead irrigation with 150 mg·L⁻¹ nitrogen (N) from 20N-4.4P-16.6K liquid fertilizer [20-10-20 (Everris, Dublin, OH)], and setting temperatures to 24/18 °C (day/night). Trial plants were transplanted to the field at 12 × 12-inch spacing before imposition of GA₃ treatments. Raised beds had been amended with ammonium nitrate applied at 100 lb/acre N before transplanting, and drip irrigation was used as necessary during the experiments.

Experiments were established as randomized complete block designs with four beds serving as the four blocks and each cultivar × treatment combination serving as an experimental

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
2.54	inch(es)	cm	0.3937
1.1209	lb/acre	kg·ha ⁻¹	0.8922
1	ppm	mg·L ⁻¹	1
(°F - 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

unit within each block. Individual plants per treatment in each block served as subsamples—the number of which was consistent within each cultivar but differed among cultivars. Data were analyzed using analysis of variance (SAS version 9.2; SAS Institute, Cary, NC), and means were separated using least significant difference test at $P \leq 0.05$.

YEAR 1. ‘Aurora Deep Purple’ delphinium, ‘Imperial Giants Pink Perfection’ larkspur, ‘Column Lilac Lavender’ stock, and ‘Amazon Neon Duo’ sweet william seeds were sown on 9 Jan. Plants were transplanted to the field on 3 Mar. Plants were sprayed to point of runoff from leaves and stems on 17 Mar. with 0, 50, 100, 200, or 400 mg·L⁻¹ GA₃ (ProGibb; Valent BioSciences, Walnut Creek, CA). Two weeks later, a second application of equal concentration was applied to half of the plants that had received 50, 100, or 200 mg·L⁻¹ GA₃. Subsample number for each treatment by block combination was 16, 8, and 6 for larkspur and sweet william, stock, and delphinium, respectively.

Delphinium, larkspur, and stock stems were harvested when 1/4 to 1/3 of the flowers on the inflorescence were fully open. Sweet william stems were harvested when three to five florets were open on the inflorescence. Recorded data included date of harvest and stem length at harvest.

YEAR 2. ‘Toreador Red’ celosia, ‘Camelot White’ foxglove, and ‘Benary’s Giant Scarlet’ zinnia seeds were sown on 30 Jan., and plugs of ‘Bouquet Purple’ sweet william and ‘Summer Pastels’ yarrow were received from a commercial grower on 1 May. Plugs and seedlings were transplanted to the field on 29 Mar. (foxglove), 14 May (sweet william and zinnia), or 19 May (celosia and yarrow). Plants were sprayed to point of runoff from leaves and stems on 30 June with 0, 200, 400, 800, or 1600 mg·L⁻¹ GA₃ (ProGibb). Plants were well established and a few (sweet william and yarrow) or all (celosia, foxglove, and zinnia) had just begun to produce flower stalks when treatments were imposed. Subsample number for each treatment by block combination was 16, 12, 8, and 4 for celosia, zinnia, sweet william and yarrow, and foxglove, respectively.

Flowers were harvested when one to three florets (foxglove), three to four florets (sweet william), or at least half of the florets (yarrow) on the

inflorescence was fully open. Celosia flowers were harvested when the heads reached full size and florets at the base of the head were fully open. Zinnia flowers were harvested when the petals on the outer rows had unfurled. Flowers were cut over three (celosia and zinnia) or five (foxglove, sweet william, and yarrow) 10-d harvest periods. Recorded data were the number of flowers per harvest period, flower stem length, and zinnia flower diameters.

YEAR 3. ‘High Tide Blue’ and ‘High Tide White’ ageratum and ‘Nippon Taka’ ornamental pepper seeds were sown and plugs of ‘Compliment’ mix lobelia were received from a commercial grower on 1 Apr. Plants were transplanted to the field on 13 Apr. (lobelia), 25 Apr. (ageratum), or 4 May (ornamental pepper). In addition to the pretransplant nitrogen incorporated into the raised beds as in previous years, beds were fertilized with 200 mg·L⁻¹ N from 20N-4.4P-16.6K through drip irrigation on 12 June and 12 July. Plants were sprayed to point of runoff from leaves and stems on 19 June with 0, 200, 400, 800, or 1600 mg·L⁻¹ GA₃ (ProGibb). Plants were well established and had begun producing flowers (ageratum and ornamental pepper) or flower stalks (lobelia) at the time treatments were imposed. Subsample number for each treatment by block combination was 12, 6, and 4 for ornamental pepper, lobelia, and ageratum, respectively.

Ageratum flowers were harvested when the center florets were open and the lateral florets were well colored. Ornamental pepper was harvested when most of the fruit were well colored. Lobelia flowers were harvested when three to four florets on the inflorescence were fully open. Recorded data included date of harvest and stem length at harvest.

Results

YEAR 1. Gibberellic acid increased flower stem length in larkspur and sweet william but not in delphinium and stock. Compared with water-treated controls, stem length of ‘Imperial Giants Pink Perfection’ larkspur was increased by 6.6 or 17.3 cm with one application of 200 or 400 mg·L⁻¹ GA₃, respectively (Table 1). Flower stem length of ‘Amazon Neon Duo’ sweet william was increased by 7.2 cm over the control

with two applications of 200 mg·L⁻¹ GA₃ (Table 1).

Gibberellic acid applications did not affect the number of flowers harvested, the average number of days to flower harvest, or flower appearance of the four first-year cultivars (data not shown). We observed that foliage of sweet william plants was lighter green for 7–10 d after treatment.

YEAR 2. Flower stem length caused by GA₃ was greater in the five cultivars tested (Table 2). Considering all flowers cut overall harvest periods, average stem length increase was greatest when GA₃ was applied at 800 or 1600 mg·L⁻¹ in celosia (3.1–4.1 cm increase), at 800 mg·L⁻¹ in foxglove (8.6 cm increase), and at 400 to 1600 mg·L⁻¹ in ‘Bouquet Purple’ sweet william (2.3–4.5 cm increase), yarrow (3.0–4.5 cm increase), and zinnia (1.5–2.3 cm increase). The greatest disparity in flower stem length between the water control and GA₃-treated plants was much larger during certain harvest periods. For example, sweet william treated with 1600 mg·L⁻¹ GA₃ produced flower stem lengths that were 9.3 cm longer than those from control plants during the second harvest period (Fig. 1). Yarrow treated with 400 mg·L⁻¹ GA₃ produced flower stem lengths that were 5.4 cm longer than those from control plants during the first harvest period (Fig. 1).

Treatment with 800 mg·L⁻¹ GA₃ resulted in the longest foxglove flower stems, the only cultivar for which stems produced on plants treated with the highest GA₃ concentration were significantly shorter than for the next lower concentration (Table 2). Likewise, foxglove was the only cultivar in which flower malformations were common, occurring after all GA₃ treatments and becoming more prevalent as concentration increased. An insufficient number of cut stems were produced to draw conclusions beyond the basic stem length observations.

Gibberellic acid treatments increased average flower stem length at harvest beyond more than 30 d after application for celosia, sweet william, yarrow, and zinnia (Fig. 1). Longer flower stems from GA₃-treated plants were the norm during the last harvest period for celosia and zinnia, which had three 10-d harvest periods, but the influence of GA₃ appeared to have waned by the last harvest period in

Table 1. Effect of gibberellic acid (GA₃) on flower stem length of field-grown ‘Imperial Giants Pink Perfection’ larkspur and ‘Amazon Neon Duo’ sweet william. Plants were sprayed with GA₃ 2 weeks after transplant to the field and again 2 weeks later in all cases but the 400 mg·L⁻¹ treatment, which was not repeated. Means are an average of 16–33 stems.

GA ₃ (mg·L ⁻¹) ^z	Applications (no.)	Stem length (cm) ^y	
		Larkspur	Sweet william
0	1	52.3 c ^y	47.2 c
50	1	50.5 c	48.8 bc
50	2	53.8 bc	49.3 b
100	1	54.6 bc	49.5 b
100	2	50.8 c	49.5 b
200	1	58.9 b	48.8 bc
200	2	55.6 bc	54.4 a
400	1	69.6 a	48.3 bc
ANOVA significance		0.0001	0.0001

ANOVA = analysis of variance.

^z1 mg·L⁻¹ = 1 ppm, 1 cm = 0.3937 inch.

^yAverages within a column followed by the same letter are not significantly different at $P \leq 0.05$ using least significant difference test.

Table 2. Effect of gibberellic acid (GA₃) on flower stem length of field-grown ‘Toreador Red’ celosia, ‘Camelot White’ foxglove, ‘Bouquet Purple’ sweet william, ‘Summer Pastels’ yarrow, and ‘Benary’s Giant Scarlet’ zinnia. Plants were sprayed one time with GA₃ 42 d (celosia and yarrow), 50 d (sweet william and zinnia), or 62 d (foxglove) after transplant to the field. Means are an average of 218–267 stems (celosia), 24–45 stems (foxglove), 318–391 stems (sweet william), 74–133 stems (yarrow), or 262–319 stems (zinnia).

GA ₃ (mg·L ⁻¹) ^z	Stem length (cm) ^y				
	Celosia	Foxglove	Sweet william	Yarrow	Zinnia
0	28.7 d ^y	38.6 c	24.1 c	35.1 c	46.5 c
200	30.0 c	42.7 b	26.4 b	36.3 bc	47.0 bc
400	31.0 bc	40.9 bc	28.4 a	38.4 a	48.0 ab
800	31.8 ab	47.2 a	27.9 a	39.6 a	48.8 a
1,600	32.8 a	43.2 b	27.9 a	38.1 ab	48.5 ab
ANOVA significance	0.0001	0.0001	0.0001	0.0003	0.0220

ANOVA = analysis of variance.

^z1 mg·L⁻¹ = 1 ppm, 1 cm = 0.3937 inch.

^yAverages within a column followed by the same letter are not significantly different at $P \leq 0.05$ using least significant difference test.

sweet william and yarrow, which had five 10-d harvest periods (Fig. 1).

Application of GA₃ in zinnias had two statistically significant effects apart from flower stem length. All GA₃ treatments resulted in reduced flower diameter (Table 3), though number and appearance, apart from diameter, of zinnia flowers was unaffected by GA₃ treatments. A slightly reduced time to harvest was observed at the higher GA₃ concentrations (Table 3).

Gibberellic acid treatments did not influence number of stems produced or time to harvest in celosia, sweet william, or yarrow (data not shown).

YEAR 3. Influence of GA₃ treatments on flower/fruit stem length ranged from reduced length to no

effect to increased length. Except for the highest concentration, the effect of GA₃ treatments on ‘High Tide Blue’ ageratum was to suppress flower stem elongation as compared with control plants (Table 4). Flower stem length in ‘High Tide White’ ageratum did not differ among treatments (data not shown). Lobelia flower stems were 9.4 cm longer than stems from control plants when treated with 800 mg·L⁻¹ GA₃, and stem lengths were greatest in ornamental pepper when treated with 400 to 1600 mg·L⁻¹ GA₃ (Table 4).

We observed different responses to GA₃ treatments among ‘High Tide Blue’ and ‘High Tide White’ ageratum, ‘Nippon Taka’ ornamental pepper, and ‘Compliment’ mix lobelia in terms of time to harvest. Lobelia exhibited a

trend for higher concentrations of GA₃ to reduce the number of days to harvest, with 1600 mg·L⁻¹ GA₃ shortening time to harvest by 9 d compared with control plants (Table 4). The lower concentrations of GA₃ significantly influenced time to harvest by shortening the time by as much as 9 d in ‘High Tide White’ ageratum and 3 d in ornamental pepper when treated with 800 and 200 mg·L⁻¹ GA₃, respectively. Of the GA₃ treatments, only 800 mg·L⁻¹ differed from control plants in ‘High Tide Blue’ ageratum, with the GA₃-treated plants taking 2 d longer than controls to yield harvestable flowers (Table 4).

Gibberellic acid did not influence the number of flower/fruit stems in any cultivar (data not shown). Ageratum cultivars and ornamental pepper appeared consistently normal in flower/fruit appearance, but lobelia exhibited occasional flower abnormalities when plants were treated with 1600 mg·L⁻¹ GA₃.

Discussion

Applications of GA₃ were used on 13 field-grown cut flower cultivars with the aim of increasing flower stem length and/or shortening time to harvest. To show promise for commercial implementation, the benefit(s) of GA₃ treatments would have to be great enough to have practical importance without significant deleterious effects. With this thought in mind, our work allowed us to divide the tested cultivars into groups according to the likelihood that GA₃ treatment would have practical benefit in developing new field-grown, cut flower protocols (Table 5). Additional research is required to refine treatments and demonstrate that GA₃ treatments are an economically viable option for improving field-grown, cut flower production in the four cultivars for which we found that GA₃ application holds promise: Bouquet Purple sweet william, Imperial Giants Pink Perfection larkspur, Summer Pastels yarrow, and Toreador Red celosia.

We found that GA₃ increased flower stem length in nine of the 13 cultivars tested, with 400 mg·L⁻¹ GA₃ or higher resulting in the longest stems for most cultivars. One application was tested in most cases, and the most pronounced influence of GA₃ was typically observed 3–6 weeks after application. One cultivar (High

Fig. 1. Effect of gibberellic acid (GA_3) and number of days between GA_3 application and flower harvests on flower stem length of field-grown ‘Toreador Red’ celosia, ‘Camelot White’ foxglove, ‘Bouquet Purple’ sweet william, ‘Summer Pastels’ yarrow, and ‘Benary’s Giant Scarlet’ zinnia. Plants were sprayed one time with GA_3 42 d (celosia and yarrow), 50 d (sweet william and zinnia), or 62 d (foxglove) after transplant to the field. Concentrations in legend are in $\text{mg}\cdot\text{L}^{-1}$. Stem lengths were recorded during three (celosia and zinnia) or five (sweet william and yarrow) 10-d harvest periods. Statistical separation of averages within cultivar and across harvest period are shown in Table 2; $1\text{ mg}\cdot\text{L}^{-1} = 1\text{ ppm}$, $1\text{ cm} = 0.3937\text{ inch}$.

Table 3. Effect of gibberellic acid (GA_3) on ‘Benary’s Giant Scarlet’ zinnia flower diameter and days to flower harvest. Averages are calculated using 40 stems (diameter) and 262–319 stems (harvest).

GA_3 ($\text{mg}\cdot\text{L}^{-1}$) ^z	Flower diam (cm) ^z	Time to harvest (d)
0	5.8 a ^y	90 a
200	4.8 b	89 ab
400	4.8 b	88 b
800	4.3 b	89 ab
1,600	4.3 b	87 b
ANOVA significance	0.0001	0.0255

ANOVA = analysis of variance.

^z $1\text{ mg}\cdot\text{L}^{-1} = 1\text{ ppm}$, $1\text{ cm} = 0.3937\text{ inch}$.

^yAverages followed by the same letter are not significantly different at $P \leq 0.05$ using least significant difference test.

Tide Blue ageratum) had shorter flower stems in some of the GA_3 treatments as compared with controls, and three cultivars appeared to be insensitive to foliar applications of GA_3 , similar to findings in Brilliant Barbara stock (Grzesik, 1995). Because the GA_3 concentrations we used were based primarily on published literature for greenhouse-grown crops, concentrations and number of applications used in these studies may have been too low to affect growth of the cultivars that appeared GA_3 insensitive, especially as field-grown plants may have lower

GA_3 absorption given their thicker cuticle compared with greenhouse-grown plants (Bleckmann et al., 1980; Sandoval et al., 1994; Stover and Greene, 2005; Templeton and Hurtt, 1972).

As has been shown in gladiolus (*Gladiolus*) by Dua et al. (1984) and chrysanthemum (*Chrysanthemum morifolium*) by Gupta and Datta (2000), we observed shorter harvest times in four of the tested cultivars. Our work showed a reduced time to harvest in response to GA_3 application ranging from 3 d in ornamental pepper and

zinnia to 9 d in ‘High Tide White’ ageratum and lobelia. Our finding with zinnia contrasts with earlier research showing that application of $200\text{ mg}\cdot\text{L}^{-1}$ GA_3 delayed bud initiation by 1.6 d (Sharma et al., 2008). None of the four cultivars exhibiting reduced time to harvest were among the cultivars we believe showed promising benefit from GA_3 treatment, but the limited benefit of GA_3 in three of them may warrant further investigation (Table 5).

The negative effects of GA_3 applications that we observed in some cultivars, such as reduced flower diameter in zinnia, lighter green foliage in sweet william, and flower malformations in foxglove and lobelia, were not surprising given previous research with these and other cut flowers. Keever (1999) documented that flower malformations and lighter green foliage occurred along with longer flower stems in foxglove treated with GA_3 . Temporarily lighter green foliage following GA_3 applications was noted by Marth et al. (1956) in many of the dozens of plant taxa tested in their seminal work. Other negative side effects on horticultural production characteristics caused by GA_3 include reduced flower diameter and malformation in cosmos (*Cosmos bipinnatus*), later and fewer florets in gladiolus, flower deformities in billy buttons (*Craspedia globosa*), decreased fruit production in chili pepper (*Capsicum baccatum*), and reduced spadix width and flower abnormalities in calla lily as reported by Molder and Owens (1974), Dua et al. (1984), Annis et al. (1992), Tofanelli et al. (2003), and Choi et al. (2005), respectively.

For the 13 cultivars tested in this work, increased flower stem length was necessary but not sufficient for us to consider a cultivar as having an overall benefit from GA_3 treatment. Of the nine cultivars that responded to GA_3 treatments by producing stems that were statistically significantly longer, five had stem length increases that were insufficiently great and/or had the greater stem length accompanied by other negative response(s). For example, zinnia produced flower stems up to 4.0 cm longer than control plants, but the 8% increase in stem length was accompanied by an only slightly reduced harvest time (3%) and a very large reduction in flower diameter (26%). Increasing flower stem length by up to 8.6 cm in foxglove was

Table 4. Effect of gibberellic acid (GA₃) on flower stem length and time to harvest from transplanting in ‘High Tide Blue’ ageratum, ‘High Tide White’ ageratum, ‘Compliment’ mix lobelia, and ‘Nippon Taka’ ornamental pepper. Plants were sprayed one time with 0, 200, 400, 800, or 1600 mg·L⁻¹ GA₃. Averages are from 197–289 stems (‘High Tide Blue’ ageratum), 21–85 stems (‘High Tide White’ ageratum), 21–97 stems (lobelia), or 201–231 stems (ornamental pepper).

GA ₃ (mg·L ⁻¹) ^z	Stem length (cm) ^z			Time to harvest (d)			
	‘High Tide Blue’ ageratum	Ornamental pepper	Lobelia	‘High Tide Blue’ ageratum	‘High Tide White’ ageratum	Ornamental pepper	Lobelia
0	25.1 a ^y	32.5 c	68.1 bc	103 bc	110 a	149 a	108 a
200	19.6 c	34.0 b	68.8 bc	104 ab	103 b	146 b	108 a
400	23.4 b	34.8 ab	67.8 c	103 bc	104 b	147 b	105 ab
800	23.4 b	34.5 ab	77.5 a	105 a	101 b	149 a	101 bc
1,600	25.7 a	35.8 a	74.9 ab	102 c	105 ab	150 a	99 c
ANOVA	0.0001	0.0001	0.0255	0.0001	0.0009	0.0001	0.0004
significance							

ANOVA = analysis of variance.

^z1 mg·L⁻¹ = 1 ppm, 1 cm = 0.3937 inch.

^yAverages within a column followed by the same letter are not significantly different at $P \leq 0.05$ using least significant difference test.

Table 5. Thirteen cultivars grouped according to whether gibberellic acid (GA₃) treatments were found to be neutral/detrimental, of limited benefit, or potentially beneficial in the production of field-grown cut flowers.

Cultivars in which GA ₃ treatments were neutral or detrimental	Observations of GA ₃ treated plants compared with control plants ^z
Aurora Deep Blue delphinium	Same flower stem length, flower number, timing of flowering, and flower appearance
Benary’s Giant Scarlet zinnia	Increased flower stem length by up to 4.0 cm (8%), reduced time to harvest by up to 3 d (3%), reduced flower diameter by up to 1.5 cm (26%)
Camelot White foxglove	Increased flower stem length by up to 8.6 cm (22%), high flower malformation frequency
Column Lilac Lavender stock	Same flower stem length, flower number, timing of flowering, and flower appearance
High Tide Blue ageratum	Reduced flower stem length by up to 5.5 cm (22%), increased time to harvest by up to 2 d (2%)
Cultivars in which GA ₃ treatments were of limited benefit	Observations of GA ₃ treated plants compared with control plants
Amazon Neon Duo sweet william	Increased flower stem length by up to 7.2 cm (15%), same flower number, timing of flowering, and flower appearance
Compliment mix lobelia	Increased flower stem length by up to 9.4 cm (14%), reduced time to harvest by up to 9 d (9%), flower malformation seen on occasion at highest GA ₃ concentration
High Tide White ageratum	Same flower stem length, reduced time to harvest by up to 9 d (9%)
Nippon Taka ornamental pepper	Increased fruit stem length by up to 3.3 cm (10%), reduced time to harvest by up to 3 d (2%)
Cultivars in which GA ₃ treatments were beneficial	Observations of GA ₃ treated plants compared with control plants
Bouquet Purple sweet william	Increased flower stem length by up to 9.3 cm (38%), same flower number, timing of flowering, and flower appearance
Imperial Giants Pink Perfection larkspur	Increased flower stem length by up to 17.3 cm (33%), same flower number, timing of flowering, and flower appearance
Summer Pastels yarrow	Increased flower stem length by up to 6.4 cm (21%), same flower number, timing of flowering, and flower appearance
Toreador Red celosia	Increased flower stem length by up to 5.6 cm (21%), same flower number, timing of flowering, and flower appearance

^z1 cm = 0.3937 inch.

accompanied by an unacceptably high frequency of flower malformations. All four of the cultivars that showed clear benefit from GA₃ treatment did so by having a greatly increased flower stem length while having unchanged flower number, timing of flowering, and flower appearance (Table 5).

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