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Efficacy of Paclobutrazol and Gibberellin₄₊₇ on Growth and Flowering of Three Curcuma Species

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ADDITIONAL INDEX WORDS. *Curcuma alismatifolia*, *Curcuma gracillima*, *Curcuma thorelii*, gibberellic acid, paclobutrazol, postproduction elongation, postproduction longevity

SUMMARY. Rhizomes of *Curcuma alismatifolia* Roxb. 'Chiang Mai Pink', *C. gracillima* Roxb. 'Violet', and *C. thorelii* Roxb. were soaked in gibberellin (GA₄₊₇) at 0, 200, 400, or 600 mg·L⁻¹ (ppm) and planted into 15.2-cm-diameter (6 inches) containers. The plants were grown in a greenhouse at 30 °C day/23 °C night (86.0/73.4 °F) temperatures. When shoot height was 10 cm (3.9 inches), the plants were drenched with 118 mL (3.9 fl oz) of paclobutrazol at 0, 2, 3, or 4 mg a.i. per 15.2-cm-diameter container. Gibberellin₄₊₇ delayed shoot emergence and flowering but did not affect the flower number. Paclobutrazol rates were not effective in controlling height of *C. alismatifolia* 'Chiang Mai Pink' averaging 85 cm (33.5 inches), *C. gracillima* 'Violet' averaging 25 cm (9.8 inches), or *C. thorelii* averaging 17 cm (6.7 inches). *Curcuma alismatifolia* 'Chiang Mai Pink', *C. gracillima* 'Violet', and *C. thorelii* had postproduction longevity of 4.6, 2.6 and 3.8 weeks respectively, making these three species of curcuma excellent candidates for use as flowering pot plants.

The genus *Curcuma* Roxb. includes about 65 species that are native to southeast Asia. Commonly known as hidden or surprise ginger, these plants possess an

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attractive inflorescence with colorful bracts that enclose the flowers (Stefey, 1986; Chapman, 1995). Curcuma exhibit diversity in color, form and size (Lekawatana and Pituck, 1998), and have few disease and insect problems (Kuack, 1996; Lekawatana and Pituck, 1998). Cultural practices and optimal environmental conditions for curcuma vary according to species. These plants are commonly propagated from geophytic units that include a rhizome and several storage roots, termed t-roots (Hagiladi et al., 1997). Curcuma rhizomes are planted in early spring, flower from early spring to late fall, and retain vegetative growth until late fall or early winter when senescence begins and plants go dormant in response to short days (Lekawatana and Pituck, 1998).

The international market for curcuma is increasing yearly (E. Welch, personal communication). In 1995, Thailand exported 15 million rhizomes valued at \$3 million, compared to \$18,000 exported in 1990. Thailand exports curcuma rhizomes primarily to Japan and the Netherlands followed by the United States and New Zealand (Lekawatana and Pituck, 1998).

Curcuma alismatifolia, *C. gracillima* and *C. thorelii* have the most potential as flowering potted plants (Sarmiento, 2000). *Curcuma alismatifolia* has a terminal inflorescence with pink or white bracts, *C. gracillima* has a terminal inflorescence with red-white or red-violet bracts and *C. thorelii* has a white inflorescence (Chapman, 1995).

Marketable flowering potted plants are grown to a standard of 1.5 to 2 times the container height (Nelson, 1998). Some curcuma, *C. alismatifolia* 'Chiang Mai Pink' for example, produce excessively tall inflorescences that result in unmarketable plants. These curcuma, however, possess other redeeming qualities as mentioned earlier and growth retardants offer a potential aid in the production of marketable potted plants.

Gibberellic acid (GA₃) increased the number and size of flowers on rhizomatous plants such as liatris (*Liatris spicata* L.) and calla lily (*Zantedeschia elliottiana* W. Wats. and *Z. rehmannii* Engl.) (Corr and Widmer, 1991; Wan-jao and Waithaka, 1983). Gibberellic acid reduced flower and shoot number and in some cases inhibited flowering of edible ginger (*Zingiber officinale* Roscoe) 'Chinese' (Furutani and Nagao, 1986). In potatoes (*Solanum*

tuberosum L.), exogenous GA₃ reduced tuberization on whole plants, cuttings or *in vitro* plants (Ewing, 1997). GA₃ applied to seed pieces by dip or spray, however, promoted sprout growth breaking dormancy and stimulated sprout elongation (Mikitzel and Fuller, 1995). In fruit crops, GA₃ is used as a fruit setting agent in some species and a fruit thinner in other species.

Postproduction longevity is important to the development and introduction of new crops in the floriculture industry (Nell and Barrett, 1989). Flower quality must be maintained in spite of low light conditions provided by the retailer and final consumer (Armitage, 1986; Plummer et al., 1990). Evaluation of the interior performance of flowering pot plants contributes to a successful market strategy and assures consumer acceptance (Nell and Barret, 1989).

The objectives of this research were to determine 1) the effects of GA₄₊₇ on rhizome emergence of *C. alismatifolia* 'Chiang Mai Pink', *C. thorelii*, and *C. gracillima* 'Violet' and 2) the effects of GA₄₊₇ and paclobutrazol on days to bloom, inflorescence height and number, postproduction longevity and elongation.

Materials and methods

Rhizomes [1 cm (0.4 inch)] of *Curcuma alismatifolia* 'Chiang Mai Pink', *C. gracillima* 'Violet', and *C. thorelii* were soaked for 10 min in a

solution containing GA₄₊₇ (Provide; Abbot Labs, North Chicago, Ill.) at 0, 200, 400, or 600 mg·L⁻¹; 100,000 mg·L⁻¹ Physan 20 (a.i. dimethyl benzyl ammonium chloride and dimethyl ethyl ammonium chloride; Maril Products, Tustin, Calif.) and distilled water. Rhizomes were dried and planted one per 15.2-cm-diameter container filled with a medium consisting of 50% peatmoss, 30% pine bark, and 20% perlite (v/v), amended with 5.1 kg·m⁻³ (0.32 lb/yd³) dolomite limestone and superphosphate 2.7 kg·m⁻³ (0.17 lb/yd³) 0N-18P-0K on 17 Apr. 1999.

Plants were placed in a greenhouse on 20.3 × 20.3-cm (8-inch) centers and drenched with a tank mix of metalaxyl (Subdue 2E; Novartis, Greensboro, N.C.) and PCNB quintozone (Terraclor 75% WP; Uniroyal Chemical Co., Middlebury, Conn.). Plants were fertilized with 150 mg·L⁻¹ nitrogen (N) using 24N-3.5P-13.3K (Peters 24-8-16 Tropical Foliage; Scotts Co., Marysville, Ohio). When shoots were 10.2 cm (4 inches) tall, substrates were drenched with 118 mL paclobutrazol (Bonzi; Uniroyal Chemical Co.) at 0, 2, 3, or 4 mg a.i. per 15.2-cm-diameter container. All plants received ambient light levels in the greenhouse.

When the last bract and one flower opened (marketable stage), days to emergence and days to bloom were determined from date of planting. Number of flowers and height of the inflores-

cence stalk were recorded for all plants. Once measured, plants were moved to a postproduction room maintained at 20 °C (68.0 °F) with 12 h of light at 14 μmol·m⁻²·s⁻¹. Flower height and quality were measured on a weekly basis until senescence of the final flower. Flower height was determined by measuring the length of the petiole from the pot rim to the tip of the inflorescence. Postproduction elongation was determined by the difference in height of the inflorescence spike at the marketable stage and the last week that the plants maintained an acceptable quality. Visual quality was measured on a scale from 1 to 5. The scale was defined as follows: 1) a plant with perfect quality received 5, 2) a rating between 4 and 5 was assigned to plants with no necrosis and bright and intense pink bracts, 3) ratings between 3 and 4 were assigned to plants without necrosis and with pink bracts in which the color begins to fade, 4) plants that received a rating between 2.5 and 3 had no necrosis but presented significant color loss of the pink bracts, 5) plants with necrotic bracts and with poor coloration were not considered acceptable and received a rating below 2.5, 6) flowers that had completed senescence received a rating of 1. Data for each curcuma species were subjected to analysis of variance separately using a completely randomized design with ten replicates (plants) per treatment. Tukey's studentized range test was used for mean separation.

Table 1. Effect of gibberellin₄₊₇ (GA₄₊₇) and paclobutrazol on days to emergence, days to bloom, flower height (measured from pot rim to top of plant), postproduction longevity, and postproduction elongation of *Curcuma alismatifolia* 'Chiang Mai Pink'.

Chemical	Days to emergence	Days to bloom	Flower ht (cm) ^z	Postproduction longevity (weeks)	Postproduction elongation (cm)
GA ₄₊₇ [(mg·L ⁻¹ (ppm))]					
0	44 a ^y	113 a	92 b	4.8 a	1.8 a
200	53 b	115 ab	89 ab	4.2 a	2.0 a
400	57 b	128 b	88 ab	4.4 a	2.2 a
600	55 b	126 ab	86 a	5.0 a	3.0 a
Paclobutrazol (mg a.i.)					
0		118 a	88 ab	4.5 a	1.7 a
2		117 a	91 b	4.8 a	2.3 a
3		125 a	85 a	4.6 a	2.8 a
4		122 a	90 ab	4.5 a	2.3 a
Pooled means	52	120	88	4.6	2.2
GA ₄₊₇	***	*	*	NS	NS
Paclobutrazol	--- ^x	NS	*	NS	NS
GA ₄₊₇ × paclobutrazol	---	NS	NS	NS	*

^z1 cm = 2.54 inches.

^yMeans within a column followed by different letters are significantly different from each other by Tukey's studentized range test, *P* = 0.05. Means are an average of 10 replications.

^xPaclobutrazol was applied after emergence.

NS, *, ***Nonsignificant or significant at *P* ≤ 0.05 or 0.001, respectively.

Results

Gibberellin₄₊₇ at 200, 400 and 600 mg·L⁻¹ significantly delayed shoot emergence of *C. alismatifolia* 'Chiang Mai Pink' (Table 1). Gibberellin₄₊₇ at 400 mg·L⁻¹, delayed flowering by approximately 1 week and did not increase the number of inflorescences. All plants had one inflorescence per container. Paclobutrazol did not affect number of days to bloom. Application of GA₄₊₇ at 600 mg·L⁻¹ resulted in a flower height 6 cm (2.4 inches) shorter than the control, while paclobutrazol applied at 3 mg a.i.

per pot produced flowers 6 cm shorter than the 2 mg a.i. per pot. None of the rates of paclobutrazol however, reduced flower height compared to the control.

Paclobutrazol and GA₄₊₇ did not affect postproduction longevity or elongation of *C. alismatifolia* 'Chiang Mai Pink'. The combination of 0 mg·L⁻¹ GA₄₊₇ and 4 mg a.i. paclobutrazol, however, significantly reduced postproduction elongation [0.51 cm (0.2 inch)] more than the combination of 600 mg·L⁻¹ GA₄₊₇

and 4 mg a.i. paclobutrazol [5.1 cm (2 inches)] (data not presented). Acceptable postproduction longevity was determined to be 4.6 weeks (Table 4). This was indicated by a postproduction quality rating ≥ 4 for 2.4 weeks and ≥ 2.5 for 4.6 weeks. Senescence (rating of 1) occurred after 6.3 weeks. Neither GA₄₊₇ nor paclobutrazol affected quality ratings throughout the postproduction study (data not shown).

Gibberellin₄₊₇ concentrations of 600 mg·L⁻¹ delayed shoot emergence of *C. gracillima* 'Violet' and *C. thorelii*

Table 2. Effect of gibberellin₄₊₇ (GA₄₊₇) and paclobutrazol on days to emergence, days to bloom, flower height (measured from pot rim to top of plant), postproduction longevity, and postproduction elongation of *Curcuma gracillima* 'Violet'.

Chemical	Days to emergence	Days to bloom	Flower ht (cm ²)	Postproduction longevity (weeks)	Postproduction elongation (cm)
GA ₄₊₇ [(mg·L ⁻¹ (ppm))]					
0	40.5 a ^y	108 a	23.8 a	2.3 a	1.2 a
200	44.6 ab	114 a	26.1 a	2.0 a	0.9 a
400	44.6 ab	109 a	25.2 a	2.3 a	1.5 a
600	47.9 b	121 a	26.8 a	3.2 a	1.3 a
Paclobutrazol (mg a.i.)					
0		114 a	28.6 a	2.2 a	1.0 a
2		111 a	26.8 a	2.1 a	0.9 a
3		114 a	24.0 a	2.6 a	1.5 a
4		112 a	22.5 a	2.9 a	1.3 a
Pooled means	44	113	25.3	2.6	1.3
GA ₄₊₇	*	NS	NS	NS	NS
Paclobutrazol	--- ^x	NS	NS	NS	NS
GA ₄₊₇ × paclobutrazol	---	NS	NS	NS	NS

²1 cm = 2.54 inches.

^yMeans within a column followed by different letters are significantly different from each other by Tukey's studentized range test, $P = 0.05$. Means are an average of 10 replications.

^xPaclobutrazol was applied after emergence.

NS,*,***Nonsignificant or significant at $P \leq 0.05$ or 0.001, respectively.

Table 3. Effect of gibberellin₄₊₇ (GA₄₊₇) and paclobutrazol on days to emergence, days to bloom, flower height (measured from pot rim to top of plant), postproduction longevity, and postproduction elongation of *Curcuma thorelii*.

Chemical	Days to emergence	Days to bloom	Flower ht (cm ²)	Postproduction longevity (weeks)	Postproduction elongation (cm)
GA ₄₊₇ [(mg·L ⁻¹ (ppm))]					
0	40.2 a ^y	113 a	16.0 a	4.3 a	0.9 a
200	43.7 ab	115 a	17.7 a	4.1 a	1.2 a
400	45.0 ab	113 a	17.5 a	3.6 a	0.5 a
600	51.2 b	131 a	17.1 a	3.8 a	0.5 a
Paclobutrazol (mg a.i.)					
0		121 a	17.8 a	4.5 a	0.4 a
2		125 a	17.4 a	3.2 a	0.7 a
3		109 a	17.3 a	3.9 a	1.3 a
4		116 a	15.8 a	4.3 a	0.9 a
Pooled means	44	117	17.3	3.8	0.8
GA ₄₊₇	*	NS	NS	NS	NS
paclobutrazol	--- ^x	NS	NS	NS	NS
GA ₄₊₇ × paclobutrazol	---	NS	NS	NS	NS

²1 cm = 2.54 inches.

^yMeans within a column followed by different letters are significantly different from each other by Tukey's studentized range test, $P = 0.05$. Means are an average of 10 replications.

^xPaclobutrazol was applied after emergence.

NS,*,***Nonsignificant or significant at $P \leq 0.05$ or 0.001, respectively.

Table 4. Postproduction longevity (weeks) at 4, 3, 2.5, 2, and 1 quality ratings and standard errors following production of *Curcuma alismatifolia* 'Chiang Mai Pink', *C. gracillima* 'Violet' and *C. thorelii*.

Quality rating ^a	<i>C. alismatifolia</i> 'Chiang Mai Pink'	<i>C. gracillima</i> 'Violet'	<i>C. thorelii</i>
≥4	2.4 ± 0.1	2.2 ± 0.3	3.4 ± 0.2
≥3	4.1 ± 0.1	2.6 ± 0.3	3.6 ± 0.3
≥2.5	4.6 ± 0.2	2.7 ± 0.2	3.9 ± 0.3
≥2	5.3 ± 0.2	3.0 ± 0.3	4.5 ± 0.3
≥1	6.3 ± 0.2	3.9 ± 0.3	5.5 ± 0.3

^aVisual quality was measured on a scale from 1 to 5. The scale was defined as follows: 1) a plant with perfect quality received 5, 2) a rating between 4 and 5 was assigned to plants with no necrosis and bright and intense pink bracts, 3) ratings between 3 and 4 were assigned to plants without necrosis and with pink bracts in which the color begins to fade, 4) plants that received a rating between 2.5 and 3 had no necrosis but presented significant color loss of the pink bracts, 5) plants with necrotic bracts and with poor coloration were not considered acceptable and received a rating below 2.5, 6) flowers that had completed senescence received a rating of 1.

(Tables 2 and 3). Neither paclobutrazol nor GA₄₊₇ affected flower height or days to bloom of *C. gracillima* 'Violet' nor *C. thorelii*. Similar results were indicated for number of inflorescences. Plants developed no more than one flowering stem.

Postproduction longevity or elongation of *C. gracillima* 'Violet' or *C. thorelii* was not affected by GA₄₊₇ or paclobutrazol (data not presented). The postproduction life of *C. gracillima* 'Violet' was 2.6 weeks and elongation was 1.3 cm (0.51 inches) (Table 2). During the postproduction period, plants maintained a quality rating ≥4 for 2.2 weeks, ≥2.5 for 2.7 weeks and reached senescence (rating 1) after 3.9 weeks (Table 4). Postproduction longevity of *C. thorelii* was 3.8 weeks and elongation was 0.8 cm (0.32 inches) (Table 3), while plants maintained a quality rating ≥4 for 3.4 weeks, ≥2.5 for 3.9 weeks and reached senescence after 5.5 weeks (Table 4).

Discussion

Gibberellin₄₊₇ did not increase inflorescence number of the three *Curcuma* species grown in this study. Gibberellin₄₊₇ at 600 mg·L⁻¹, however, delayed shoot emergence as much as 11 d but did not inhibit it. Foliar application of GA₃ applied at concentrations of 1.44 and 2.88 mM suppressed shoot emergence of field grown edible ginger (Furutani and Nagao, 1986). Okwuowulu and Nnodu (1988) applied GA₃ at 150 mg·L⁻¹ as a 24-h dip to determine the effect of a pre-storage chemical treatment on the storability of edible ginger. This treatment rate was not observed to be effective in controlling sprouting and higher rates were suggested. Gibberellic acid has been recommended for extending dormancy, thereby inhibiting sprouting in storage

of yams (*Dioscorea cayenensis rotundata* Lam. and *D. alata* L.), an edible tuber (Girardin et al., 1998). These studies and the GA₄₊₇ research conducted in this study suggests that gibberellin might be used to prolong storage of ornamental ginger rhizomes prior to planting. Gibberellin should not be used to promote or increase flowering as indicated for calla lily (Corr and Widmer, 1991).

Gibberellic acid stimulated stem elongation (Nelson, 1998). Gibberellin₄₊₇ at 600 mg·L⁻¹ significantly reduced flower height of *C. alismatifolia* 'Chiang Mai Pink' by 6.5%. Similar results were found in yams (*D. cayenensis rotundata*), where GA₃ at 150 mg·L⁻¹ as a tuber soak reduced stem length by 63% (Girardin et al., 1998; Igwilo, 1988).

The most effective rate of paclobutrazol on *C. alismatifolia* 'Chiang Mai Pink' was 3 mg a.i., which produced plants 85.3 cm (33.58 inches) tall. The standard height of a flowering pot plant grown in a 15.2-cm-diameter container should be 22 to 30 cm (8.7 to 11.8 inches). Thus, higher rates of paclobutrazol or the use of other growth retardants must be evaluated in order to determine efficacy on plant height. *Curcuma gracillima* 'Violet' and *C. thorelii*, propagated by 1-cm rhizomes, are naturally low growing plants. Average height for all treatments was 25.3 cm (9.96 inches) for *C. gracillima* 'Violet' and 17.3 cm (6.69 inches) for *C. thorelii*. Thus, the use of a PGR does not appear to be necessary.

Curcuma alismatifolia 'Chiang Mai Pink' had an excellent postproduction life of 4.6 weeks and little postproduction elongation [2.3 cm (0.91 inch)]. Postproduction elongation was not significant for *C. thorelii* or *C. gracillima* 'Violet' while postproduction longevity was also very good at 3.8 weeks and shorter at 2.6 weeks, respectively.

These attributes along with those previously discussed, indicate that these three *curcuma* species are excellent candidates for flowering pot plants and should be considered as an alternative crop.

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