Effects of Light Intensity and Paclobutrazol on Growth and Interior Performance of Pachira aquatica Aubl.

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Abstract. Pachira aquatica Aubl. has recently been introduced as an ornamental foliage plant and is widely used for interiorscaping. Its growth and use under low light conditions, however, have two problems: leaf abscission and accelerated internode elongation. This study was undertaken to determine if production light intensity and foliar application of paclobutrazol [β-(4-chlorophenyl)methyl-α-(1,1-dimethyl-1H-1,2,4-triazole-1-ethanol)] improved plant growth and subsequent interior performance. Two-year-old P. aquatica trunks were planted in 15-cm diameter plastic pots using a peat-based medium and were grown in a shaded greenhouse under three daily maximum photosynthetic photon flux densities (PPFD) of 285, 350, and 550 μmol m⁻² s⁻¹. Plant canopy heights, average widths, and internode lengths were recorded monthly over a 1-year production period. Two months after planting, the plant canopy was sprayed once with paclobutrazol solutions at concentrations of 0, 50, and 150 mg L⁻¹ and foliar spraying of paclobutrazol once at a concentration of 5 mL per plant. Before the plants were placed indoors under a PPFD of 18 μmol m⁻² s⁻¹ for 6 months, net photosynthetic rates, quantum yield, and light saturation and compensation points were determined. Results showed that lowering production light levels did not significantly affect canopy height, width, or internode length but affected the photosynthetic light response curve and reduced the light compensation point. Foliar application of paclobutrazol reduced internode length, thereby resulting in plants with reduced canopy height and width and more compact growth form. Paclobutrazol application also reduced the light compensation point of plants grown under 550 μmol m⁻² s⁻¹. Plants with the compact growth form did not grow substantially, dropped fewer leaflets, and thus maintained their aesthetic appearance after placement indoors for 6 months. These results indicated that the ornamental value and interior performance of P. aquatica plants can be significantly improved by producing them under a PPFD range between 285 and 350 μmol m⁻² s⁻¹ and foliar spraying of paclobutrazol once at a concentration between 50 and 150 mg L⁻¹.

Additional index words. light acclimatization, light compensation point, money tree, ornamental foliage plants

Pachira aquatica Aubl., a member of the family Bombacaceae, is a tropical wetland tree indigenous to Central and South America from southern Mexico to Guyana and north-eastern Brazil (Robyns, 1964). It has shiny green palmate leaves with five to nine lanceolate leaflets and a smooth green stem with a distinctive swollen base. Flowers are showy and have long, narrow petals and hair-like yellowish orange stamens. In its native habitat, P. aquatica grows under full sun or partial shade and can reach 18 m in height. Seeds are consumed raw (tastes like peanuts) or as roasted beans with a flavor of chestnuts. Thus, P. aquatica is also known as Malabar chestnut or Guyana chestnut. Young leaves and flowers are also edible as a vegetable (Oliveira et al., 2000). Propagation of P. aquatica is by means of seeds or stem cuttings.

In addition to being a specialty food crop, P. aquatica has recently been introduced as a tropical ornamental foliage plant. Large trunks are planted singly in containers or small trees (four to six) are grown together and braided as potted foliage plants used for interiorscaping. Because of its swollen stem base and flexibility of the branch and stem, P. aquatica is also grown as bonsai or pseudo bonsai. In East Asia, P. aquatica is known as the money tree and is believed to bring financial fortune in business. As an indoor plant, P. aquatica has been shown to reduce volatile organic compounds (Song et al., 2007). The money tree is also becoming popular in the United States as a potted house plant or bonsai. However, there are two common problems associated with its growth and use under low light conditions, leaf abscission and accelerated internode elongation, which are similar to the responses of Ficus benjamina L. to low light levels (Chen et al., 2001; Fonteno and McWilliams, 1978). Thus far, there is no information available regarding cultural practices to control the two problems in P. aquatica.

Leaf abscission is a major factor influencing interior performance of many ornamental plants (Embry and Northnagel, 1994). To have a plant that is used to growing under full sun or partial shade to better adapt to interior low light environments, light acclimatization is required (Chen et al., 2005a; Conover and Poole, 1984). There are two methods of light acclimatization (Chen et al., 2005a). One is to grow plants under relatively high light conditions to near-finished sizes and then provide plants with a reduced light level for 4 to 5 weeks or longer before shipping to market for interiorscaping. The other is to grow plants initially under reduced light levels until marketable sizes are reached. Light acclimatization improves the plant interior performance by lowering the light compensation point, thus reducing leaf abscission and maintaining the aesthetic values during interiorscape (Chen et al., 2005a; Fonteno and McWilliams, 1978; Reyes et al., 1996; Yeh and Wang, 2000).

Production of plants under reduced light levels, however, may modify some morphological traits such as increasing internode length, which may affect the plant’s aesthetic appearance, especially of some woody ornamental plants like Ficus and Schefflera (Kubatsch et al., 2006). To reduce rapid internode elongation under a low light level, plant growth retardants have been used as a foliar spray or soil drench (Davis, 1987). Paclobutrazol [β-(4-chlorophenyl)methyl-α-(1,1-dimethyl-1H-1,2,4-triazole-1-ethanol)] has been shown to control the height of Caladium chordatum Bird., Codiaeum variegatum (L.) Blume, Schefflera actinophylla Endl., Euphorbia pulcherrima Wind., and Impatiens walleriana (L.) Hook. f. (Barrett et al., 1994) as well as F. benjamina (Barrett and Nell, 1983). Application of flurprimidol [a-(methylthio)-a-[4-(trifluoromethoxy)-phenyl]-5-pyrimidinemethanol] or ancymidol, [a-cyclopropyl-a-[4-(methoxyphenyl)-5-pyrimidinemethanol] controlled the height of Geogenanthus undatus C. Koch & Linden (Burton et al., 2007). In a preliminary study using different growth retardants, we found that a foliar spray of paclobutrazol reduced the internode elongation, thus controlling the height of P. aquatica.

This study was undertaken to evaluate the effects of light intensity and paclobutrazol application on growth and subsequent interior performance of P. aquatica. The objective was to determine if the combination of production light level and paclobutrazol application could reduce the internode elongation and leaf drop and improve P. aquatica’s ornamental value as an indoor foliage plant.

Materials and Methods

Two-year-old P. aquatica rooted trunks (trunk diameter 3 to 4 cm and height 25 cm

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Results and Discussion

Effects on plant canopy. All plants initially had similar canopy heights (36.8 to 40.8 cm), average widths (48.2 cm to 52.9 cm), and five to six palmate leaves before the foliar spray of paclobutrazol. Canopy heights and widths, internode lengths, and the percentage of canopy height and width increases at the end of production were not significantly different among plants grown under the three light regimes without paclobutrazol treatment (Table 1), although the net photosynthetic rate of plants grown under 550 μmol·m⁻²·s⁻¹ was higher with A_max of 4.7 compared with 4.2 and 3.3 at 285 and 285 μmol·m⁻²·s⁻¹, respectively (Table 2). The discrepancy between the higher net photosynthetic rate and nonsignificant increase in the measured growth parameters could be attributed to the higher photosynthesis-enhancing plant dry matter accumulation such as increased leaf thickness and mechanical strength but not affecting plant form such as canopy heights and widths. As shown in Figure 1, the leaves of plants grown under PPFD of 550 μmol·m⁻²·s⁻¹ were thicker than those grown under 285 μmol·m⁻²·s⁻¹.

Canopy height, internode length, and percentage of canopy height increase were significantly reduced 10 months after the plants

Table 1. Effects of different light intensities and concentrations of paclobutrazol as a one-time foliar spray on Pachira aquatica plant growth in a shaded greenhouse for 1 year.

| Light intensity (μmol·m⁻²·s⁻¹) | Paclobutrazol concn (mg·L⁻¹) | 10 months after paclobutrazol application | Mean internode length (cm) | Percentage of increase* |
|---------------------------------|-------------------------------|------------------------------------------|---------------------------|--------------------------|
|                                 |                              | Canopy ht (cm)                          | Canopy width (cm)         |                          |
| 285                             | 0                             | 81.4 a                                  | 92.7 a                    | 10.7 a                   | 93.7 a                    | 78.3 ab                   |
| 285                             | 50                            | 60.4 b                                  | 86.1 ab                   | 1.2 b                     | 50.2 b                    | 62.8 abc                  |
| 285                             | 150                           | 45.5 b                                  | 60.5 d                    | 0.9 b                     | 14.3 b                    | 10.0 d                    |
| 350                             | 0                             | 81.4 a                                  | 90.8 a                    | 10.3 a                   | 99.5 a                    | 82.3 a                    |
| 350                             | 50                            | 55.6 b                                  | 77.8 abc                  | 0.9 b                     | 36.9 b                    | 44.9 abc                  |
| 350                             | 150                           | 45.4 b                                  | 66.4 cd                   | 0.8 b                     | 15.8 b                    | 26.5 d                    |
| 550                             | 0                             | 82.8 a                                  | 87.4 ab                   | 11.1 a                    | 106.0 a                   | 81.3 a                    |
| 550                             | 150                           | 59.4 b                                  | 82.8 ab                   | 1.1 b                     | 50.8 b                    | 71.8 abc                  |
| 550                             | 250                           | 45.4 b                                  | 57.7 d                    | 0.9 b                     | 23.4 b                    | 40.0 bcd                  |
| Significance**                  | Light                         | NS                                       | NS                        | NS                       | NS                       | NS                        |
|                                | Paclobutrazol                 | **                                       | **                        | **                       | **                       | **                        |
|                                | Interaction                   | NS                                       | NS                        | NS                       | NS                       | NS                        |

*The percentage of canopy height or width increase was calculated as follows: (height or width at the end of production – height or width before paclobutrazol application)/height or width before paclobutrazol application.

**The mean internode length was the stem height divided by the number of nodes.

Means within column followed by different letters are significantly different by Duncan’s new multiple range test at P = 0.05.

NS indicates nonsignificant; **significant at P = 0.01 (n = 9).
were treated with paclobutrazol regardless of the production light levels, but these parameters did not significantly differ between plants treated with the two paclobutrazol concentrations (Table 1). The average internode lengths of plants treated with paclobutrazol ranged from 0.8 to 1.2 cm compared with 10.3 to 11.1 cm of the control plants. As a result, canopy heights increased only 14.3% to 50.8% for plants treated with paclobutrazol but 95.7% to 106.0% for control plants. Canopy widths and percentages of canopy width increase were significantly reduced by paclobutrazol treatment at 150 mg/L but not at 50 mg/L. Paclobutrazol application in reduction of internode length was also reported in *Plectranthus australis* R. Br., *Zebrina pendula* Schnizl., and *F. benjamina* (Davis, 1987) as well as *Gynura aurantiaca* (Blume) DC (Chen et al., 2002) and other floriculture crops (Barrett et al., 1994). Paclobutrazol is an effective inhibitor that blocks gibberellin biosynthesis by inhibiting kaur- ene oxidase, an enzyme-converting kauren to kaurenoic acid (Wang et al., 1986). When gibberellin biosynthesis is blocked, cell division still occurs, but the new cells do not elongate, which results in shoots with the same numbers of leaves but compressed internodes (Chaney, 2003). As a consequence, *P. aquatica* treated with paclobutrazol showed a compact appearance, thereby increasing its ornamental value.

**Effects on photosynthesis.** The net photosynthetic rates ($A$) of *P. aquatica* increased rapidly as PPFD increased from 0 to 150 mol m$^{-2}$s$^{-1}$ and reached their saturation at a PPFD range of 213 to 259 mol m$^{-2}$s$^{-1}$ (Fig. 2). In general, plants grown under higher PPFD have high light saturation points because of the higher level of enzymes for carboxylation and electron transport (Callan and Kennedy, 1995). In the present study, light saturation points of plants grown under the three PPFD regardless of paclobutrazol treatments did not significantly differ except for plants grown under 285 mol m$^{-2}$s$^{-1}$ and treated by paclobutrazol at 150 mg L$^{-1}$ that were significantly lower than plants grown under 550 mol m$^{-2}$s$^{-1}$ without paclobutrazol treatment (Table 2). These results generally concurred with those reported by Seemann (1989) in which light saturation points of soybean (*Glycine max* L.) grown under 250 to 500 mol m$^{-2}$s$^{-1}$ and 1000 to 1500 mol m$^{-2}$s$^{-1}$ were not significantly different. The explanation was that plants grown under 1000 to 1500 mol m$^{-2}$s$^{-1}$ had higher Rubisco than those grown under 250 to 500 mol m$^{-2}$s$^{-1}$. As a result, photosynthesis per unit of Rubisco for plants grown under the two light regimes were almost equal and thus similar light saturation points (Seemann, 1989).

The quantum yield ($A_{qe}$) ranged from 0.033 to 0.058 mol CO$_2$/mol quantum, which was similar to the range from 0.037 to 0.069 mol CO$_2$/mol quantum estimated in *Begonia semperflorens-cultorum* Hort. (Nemali and van Iersel, 2004). Plants grown under PPFD of 285 and 350 mol m$^{-2}$s$^{-1}$ and treated by paclobutrazol at 150 mg L$^{-1}$ had lower quantum yields than those grown under the PPFD of 350 mol m$^{-2}$s$^{-1}$ without paclobutrazol treatment or those grown under 550 mol m$^{-2}$s$^{-1}$ irrespective of paclobutrazol treatment (Table 2). Correspondingly, $A_{max}$ of
those plants with the reduced quantum yield significantly decreased. However, conflicting results exist regarding paclobutrazol effects on photosynthesis. Vu and Yelenosky (1992) reported that net photosynthesis of *Citrus sinensis* (L.) Osbeck was reduced by paclobutrazol application, whereas Jaleel et al. (2007) reported that photosynthesis of *Catharanthus roseus* (L.) G. Don. was enhanced by paclobutrazol. The results from the present study were in agreement with those reported by Vu and Yelenosky (1992). The reduced net photosynthetic rate in *P. aquatica* was correlated with the reduction in the quantum yield (Table 2). The quantum yield of CO₂ assimilation has been widely used for evaluating the efficiency of photosynthesis at low PPFD (Ehleringer and Bjorkman, 1977).

Light compensation points of *P. aquatica* grown under PPFD of 285 µmol m⁻² s⁻¹ ranged from 8.0 to 9.0 µmol m⁻² s⁻¹, which was not significantly affected by paclobutrazol application (Table 2). However, light compensation points of plants grown under 350 and 550 µmol m⁻² s⁻¹ decreased from 11.0 to 8.0 and from 16.0 to 10.0 µmol m⁻² s⁻¹, respectively. The light compensation point reduction appeared to relate to the reduction of quantum yield and maximum net photosynthetic rate (Table 2).

**Leaf anatomical differences.** Microscopic observations showed more elongated palisade mesophyll cells in leaves of *P. aquatica* grown under PPFD of 550 µmol m⁻² s⁻¹ (Fig. 1B) compared with the leaves produced under 285 µmol m⁻² s⁻¹ (Fig. 1A) or under 350 µmol m⁻² s⁻¹ regardless of paclobutrazol application. The elongation of palisade cells resulted in slightly thicker leaves when plants were grown under 550 µmol m⁻² s⁻¹. The palisade cells in the leaves of plants grown under 550 µmol m⁻² s⁻¹ were vertically and more tightly aligned compared with the loosely arrayed palisade cells in the leaves of plants grown under 285 µmol m⁻² s⁻¹. The tight alignment resulted in the reduction of intercellular spaces with a larger number of palisade cells per unit area (Fig. 1). Thus, net photosynthetic rates of plants grown under PPFD of 550 µmol m⁻² s⁻¹ were higher than those grown under the low PPFD. The palisade cell orientation was similar to that observed in *F. benjamina* (Fails et al., 1982) in which palisade cells were tightly aligned along radial walls in leaves of plants grown under high PPFD compared with a loose alignment in leaves of plants grown under low PPFD. However, unlike *F. benjamina* in which there were multiple layers of palisade cells, leaves of *P. aquatica* had only one layer of palisade cells.

**Effects on interior performance.** Plant growth after placement indoors for 6 months depended on treatment. Canopy height increase ranged from 0.2% to 6.5% for plants treated with paclobutrazol and 8.0% to 11.1% for those without paclobutrazol treatment (Table 3). Canopy width increase varied from 0.1% to 6.8% regardless of treatment, but such an increase was not significant. The results showed that residual effects of paclobutrazol remained in plants for 16 months. Karaguzel and Ortaçems (2002) reported that internode lengths of *Bougainvillea glabra* Choisy ‘Sanderiana’ treated with a foliar spray of paclobutrazol could reach the internode lengths of control plants in only 120 d. The prolonged effect may indicate that *P. aquatica* is more sensitive to paclobutrazol than *B. glabra* because plant species differences in paclobutrazol sensitivity have been widely documented (Barrett et al., 1994; Wang and Blessington, 1990).

There was little change in mean internode length and canopy height of plants treated by paclobutrazol at 150 µg L⁻¹ irrespective of production light levels. Canopy heights, mean internode lengths, and the percentage of canopy height increases were also significantly decreased by paclobutrazol treatment at 50 µg L⁻¹. Leaflet drop occurred 3 weeks after placement indoors. Production PPFD played a more important role in preventing leaflet drop than paclobutrazol treatment. Regardless of paclobutrazol treatment, the number of leaflets dropped ranged from 10 to 23 for plants produced under 550 µmol m⁻² s⁻¹ compared with one to five and six to 12 for those produced under 285 and 350 µmol m⁻² s⁻¹, respectively. The reduced leaflet drop is probably because the plants grown under low PPFD had low light compensation points, thus allowing them to better and more quickly adapt to interior light conditions. Similar results were also reported in *Chamaedorea elegans* Mart. (Reyes et al., 1996), *F. benjamina* (Chen et al., 2005b; Fonteno and McWilliams, 1978; Pass and Hartley, 1979), *Hedera helix* L. (Yeh and Hsu, 2004), and *Leea coccina* L. and *Leea rubra* L. (Sarracino et al., 1992).

Paclobutrazol treatment also reduced leaflet drop; such reduction was more pronounced for plants produced under PPFD of 550 µmol m⁻² s⁻¹ than those produced under 285 µmol m⁻² s⁻¹. Reduced leaf drop was reported in *F. benjamina* during a simulated shipping and interiorscape when plants were treated with amcydin (Peterson and Blessington, 1982). The interior performance of *F. benjamina*, *Radermachera sincica* (Hance) Hemsl., and *Epipremnum aureum* (Linden & Andre) Bunt. was improved by paclobutrazol application (Barrett et al., 1983; Poole and Conover, 1992). However, there has been no report on paclobutrazol application in the reduction of leaf drop. The leaf drop reduction in *P. aquatica* could also be attributed to the fact that paclobutrazol treatment decreased the light compensation points of plants grown under 550 µmol m⁻² s⁻¹ (Table 2).

In conclusion, *P. aquatica* responded to decreasing production PPFD and paclobutrazol application rates by reducing net photosynthetic rates, lowering light compensation points, and reducing internode lengths and canopy heights and widths. Plants with the

| Light intensity (µmol m⁻² s⁻¹) | Paclobutrazol concn (mg L⁻¹) | Six months after placement indoors | Mean internode length cm | Percentage of increase | Leaflet drop (no.) |
|-------------------------------|-----------------------------|----------------------------------|--------------------------|-----------------------|-------------------|
| 285                           | 0                           | 90.5 a                           | 92.8 a                   | 11.0 a                | 11.1 a            |
| 285                           | 50                          | 63.7 b                           | 88.8 ab                  | 1.3 b                 | 5.5 b             |
| 350                           | 0                           | 45.5 c                           | 61.9 c                   | 0.9 b                 | 0.0 d             |
| 350                           | 50                          | 88.4 a                           | 90.7 ab                  | 11.3 a                | 8.4 a             |
| 350                           | 150                         | 59.2 b                           | 82.0 abc                 | 0.9 b                 | 6.5 b             |
| 550                           | 0                           | 45.4 c                           | 70.9 c                   | 0.9 b                 | 0.0 d             |
| 550                           | 50                          | 89.4 a                           | 91.1 ab                  | 12.1a                 | 8.0 a             |
| 550                           | 150                         | 62.4 b                           | 86.8 ab                  | 1.2 b                 | 5.1 b             |
| 550                           | 150                         | 46.8 c                           | 58.4 bc                  | 0.9 b                 | 3.1 c             |

*Significance*:
- Light: NS
- Paclobutrazol: **
- Interaction: NS

*Plants were placed indoors for 6 months under a photosynthetic photon flux density (PPFD) of 18 µmol m⁻² s⁻¹. The plants were produced in a shaded greenhouse under three PPFD for 1 year and treated by a one-time foliar application of three rates of paclobutrazol 2 months after potting. The light compensation point was the stem height divided by the number of nodes. The mean internode length was the stem height divided by the number of nodes. The mean internode length was the stem height divided by the number of nodes.

*Means within column followed by different letters are significantly different by Duncan’s new multiple range test at P = 0.05.

*NS indicates nonsignificant; **significant at P = 0.01 and *significant at P = 0.05 (n = 5).
compact growth form grew slowly and dropped few leaflets, thus maintaining their aesthetic appearance after placement indoors for 6 months. Based on the results presented in this study, it is suggested that production of P. aquatica under a PPFD range between 285 and 350 μmol·m⁻²·s⁻¹ with one-time foliar spraying of paclobutrazol at a concentration between 50 and 150 mg·L⁻¹ after canopy establishment can result in plants with a compact appearance and prolonged interior performance.

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