Germination, Emergence, and Seedling Growth of Tomato and Impatiens in Response to Seed Treatment with Paclobutrazol

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Abstract. Seed treatments with paclobutrazol (PB), a triazole growth retardant, were examined for seedling growth suppression without exerting a deleterious effect on germination or emergence. Seeds of ‘Salmon Picotee’ impatiens (Impatiens wallerana Hook L.) and ‘Marglobe’ tomato (Lycopersicon esculentum Mill.) were soaked for 24 or 48 hours at 22 °C in 0, 50, 500, or 1000 mg·L–1 PB or were primed in polyethylene glycol 8000 or grade 5 exfoliated vermiculite (both at –1.0 MPa for 7 days at 22 °C) containing these PB solutions. Any PB seed treatment of impatiens (including a series of lower concentrations up to 50 mg·L–1 PB) that elicited seedling growth suppression also reduced germination and emergence. For tomato, soaking seeds for 24 hours in up to 1000 mg·L–1 PB had little or no effect on germination or emergence, and yet shoot height or dry weight was not decreased further by exceeding 50 mg·L–1 PB. At any PB concentration, soaking seeds for 48 hours or priming seeds resulted in lower percentage of germination or emergence than soaking seeds for 24 hours. Soaking tomato seeds in 50 mg·L–1 PB for 24 hours resulted in similar shoot growth suppression until at least 36 days after planting as a growth medium drench (1 mg·L–1 PB) or as a shoot spray (10 mg·L–1 PB), both applied at 14 days after planting. Beyond 31 days after planting, however, the latter two treatments gave greater seedling emergence suppression than the PB seed soak treatment, which had lost its growth suppressive effect. Chemical name used: (+)-H[2-(4-chlorophenyl)methyl]-[(1,1,2,4-triazole-3-yl)-dimethyl]-1H-1,2,4-triazole-1-ethanol (paclobutrazol).

Many bedding plants are being grown from plugs (Ball, 1998). Apart from plug tray filling machines and seed sowing machines, the plugs can be transplanted mechanically. It is imperative that uniform, healthy plants are produced for more mechanized production. Creating more compact plants with growth retardants renders them less prone to physical damage from rough handling or shipping, and reduces their water and fertilizer consumption. The triazole group of growth retardants, which includes paclobutrazol (PB) interferes with the biosynthesis of gibberellins and is active at very low application rates (Fletcher et al., 2000). Application method and rate of PB greatly influence bedding plant response. Spraying is the most common method of applying growth regulators, but spraying triazoles can cause inconsistent results due to poor spray coverage, poor absorption and translocation through the leaves and failure to reach the stem. Paclobutrazol is translocated through the xylem of roots and the stem making it more active when applied to the growth medium rather than to the foliage (Davis et al., 1988). The use of PB as a seed treatment would eliminate its application as a drench or spray, and reduce the amount of chemical needed. Pasian and Bennett (1999) reported that imibing marigold (Tagetes patula L.) and geranium (Pelargonium sp. L’Her) seeds in 500 and 1000 mg·L–1 PB solutions reduced height up to 36 d after sowing. Percentage laboratory germination of tomato seeds that were soaked in 500 or 1000 mg·L–1 PB for 6, 16, or 24 h was lower than that of water-soaked seeds, but percentage emergence in peat-lite was unaffected by duration or PB concentration of the seed soak (Pasian and Bennett, 2001). They further found that seedling height suppression at 36 d after planting was >30% for seeds that had been soaked for 16 h in 500 or 1000 mg·L–1 PB compared to those soaked in water. Pill and Gunter Jr. (2001) found that exposing Cosmos bipinnatus Cav. seeds to 1000 mg·L–1 PB during soaking or priming reduced shoot height, but also reduced seedling emergence with the responses being greater with longer exposure during priming than during soaking. Tagetes patula L. seed exposed to 1000 mg·L–1 PB during priming had no reduction in emergence percentage and had reduced shoot height at 32 d after planting (Pill and Gunter, 2001).

In this paper we examine the germination, emergence and seedling growth of impatiens and tomato in response to PB concentrations during seed soaking and priming.

Materials and Methods

Lots of 200 nontreated seeds of ‘Marglobe’ tomato and ‘Salmon Picotee’ impatiens (Park Seed Co., Greenwood, S.C.) were soaked for 24 or 48 h at 22 °C in 50 mL of continuously aerated solutions of 0, 50, 500, or 1000 mg·L–1 PB contained in 100-mL beakers covered with Parafilm (American National Can, Greenwich, Conn.) to reduce evaporative loss.

Seeds were osmotically primed using the same technique as for soaking except that the PB was added to polyethylene glycol 8000 (PEG), –1.0 MPa at 22 °C requiring 298 mg·kg–1 H2O (Michel, 1983), and priming continued for 7 d. Seeds were primed matrically in grade 5 exfoliated vermiculite (W.R. Grace, Cambridge, Mass.) at –1.0 MPa for 7 d at 22 °C. Seeds were mixed at a dry weight ratio of 1 seed : 5 vermiculite. The –1.0 MPa was achieved by adding the PB solution at 60% (w/w) of the vermiculite dry weight, according to the moisture release curve developed by Khan et al. (1992). The mixture of seeds, liquid, and vermiculite was stirred thoroughly in 33-mL plastic soufflé cups (Solo Cup Co., Urbana, Ill.) and covered with Parafilm to minimize evaporative loss. Cups were placed in a dark incubator kept at 22 °C.

Germination. Fifty seeds per treatment were placed in transparent polystyrene boxes (12.5 × 8 × 2 cm) containing two layers of germination paper (Seed Germination Blotters No. 385; Seedburo Co., Chicago) moistened to saturation (15 mL) with 0.5 X Hoagland solution (Hoagland and Arnon, 1950). The lidged germination boxes were placed in a dark incubator set at 25 °C. Germinated seeds were counted daily and removed from the boxes. From these data, the angular transformation of the final germination percentage (FGP) and days to 50% of FGP (t50, an inverse measure of germination rate) were calculated and subjected to analysis of variance (ANOVA).

Emergence and seedling growth. The two seed treatment techniques, solid matric priming and 24-h soak, were repeated using methods described above. While 0, 50, 500, and 1000 mg·L–1 PB were used for tomato, lower PB concentrations (0, 12.5, 25, and 50 mg·L–1) were used for impatiens due to low germination at the higher concentrations.

Treated and nontreated seeds were planted in Scotts Redi-earth Plug and Seedling Mix (Marysville, Ohio) in 45-cm2 cell market packs (nine cells per pack, eight packs per flat) with one seed per cell. Tomato seeds were covered with 3 mm of growth medium while impatiens seeds were not covered. Additional flats were sown for PB applications to shoots and growth medium. Treatments (flats) were arranged as randomized blocks in a greenhouse with average 23.5 °C day/19.5 °C night and natural light supplemented with irradiation from 1000-W high-pressure sodium lamps 1.5 m above the bench from 0600 to 2000 h (April through July).

Seeding emergence was counted on a daily basis when the hypocotyl was first visible. From these data, final emergence percentage (FEP) and days to 50% FEP (t50, an inverse measure of...
of emergence rate) were calculated. After the majority of the seedlings had emerged, all flats were fertilized weekly with 250 mg·L−1 N from 21N–2P–17K. Paclobutrazol was applied as spray and drench at 10 and 18 d after planting (DAP) for tomato and impatiens, respectively. The spray was applied at 10 mg·L−1 PB until incipient runoff, while the 1 mg·L−1 PB growth medium drench was applied at 18 mL per cell, rates recommended by the manufacturer (Uniroyal Chemical Co., Middlebury, Conn.). Flats were evenly watered to saturation several hours before these drench and spray applications.

The first harvest for tomatoes was 17 DAP and 38 DAP for impatiens, seedlings being slower growing. Shoot height and dry weights were recorded on 12 plants randomly selected from the center of each flat. Height was measured from the growth medium surface to the shoot tip. Shoots then were cut at the growth medium surface and dried (65 °C for 1 week) before recording their dry weights. Measurements for the second harvest (31 DAP for tomato and 63 DAP for impatiens) were the same as those for the first harvest, but from 20 plants per treatment, again avoiding border plants. By the second harvest, all DAP, 3 weeks after transplanting from plug cells to 15 cm pots, the majority of the seedlings had emerged, all shoots of plants that had been drenched with PB were smaller (22% shorter, 40% lighter) than those of nontreated plants.

**Results**

Germination—impatiens. FGP and G50 were affected by PB concentration during seed soaking or priming (Table 1). Paclobutrazol, even at 50 mg·L−1, decreased FGP and increased G50. With increasing PB concentration, the decrease in FGP generally was linear while the increase in G50 had significant quadratic components. Soaking seeds in 500 or 1000 mg·L−1 PB for 48 h rather than 24 h further decreased FGP and increased G50. In response to increasing PB concentration, FGP decreased linearly during osmotic priming and decreased quadratically during matric priming. A second germination study using 0, 12.5, 25, or 50 mg·L−1 PB and only the 24-h-soak and matric priming, but otherwise identical materials and methods, showed that with increasing PB concentration, FGP decreased quadratically after matric priming but was unaffected after the 24-h-soak; G50 increasing in both treatments (data not shown). These treatments were repeated for a seedling emergence and growth study.

Germination—tomato. Soaking tomato seeds for 48 h rather than 24 h conferred no germination benefit (Table 1). Germination responses of osmotically and matrically primed seed were similar. Increasing PB from 0 to 1000 mg·L−1 during the 24-h soak had no effect on FGP, although G50 increased slightly. During matric priming, PB decreased FGP at the two highest concentrations (500 and 1000 mg·L−1), and G50 increased linearly with increasing PB concentration.

Soaking for 24 h and matric priming, both using 0, 50, 300, and 1000 mg·L−1 PB, were selected as seed treatments for a seedling emergence and growth study. Relative to responses from the nontreated seeds, these treatments did not increase G50 but decreased FGP with matric priming at 500 and 1000 mg·L−1 PB.

**Emergence and seedling growth—impatiens.** For soaked seeds, increasing PB concentration (12.5, 25, 50 mg·L−1) caused a linear decrease in FEP and had no effect on E50 (Table 2). For primed seeds, increasing PB concentration had no effect on FEP but caused a quadratic increase in E50. Compared to responses of nontreated seeds, 12.5 mg·L−1 PB during soaking or priming, respectively, decreased FEP by 6 and 10 percentage points and increased E50 by 1.3 and 4.5 d.

By 38 DAP, increasing PB concentrations during seed soaking or priming resulted in a quadratic decrease in shoot height, although 12.5 mg·L−1 PB failed to reduce height relative to that achieved with nontreated seeds (Table 2). With only an 18-d response, PB spray and drench had decreased shoot height by 33% and 53%, respectively, below that of nontreated plants. Plants from PB seed treatments appeared more green as PB concentration increased, but these responses were not as dramatic as those resulting from the drench and spray treatments which caused leaf margins to curve downward slightly.

Shoot dry weights by 38 DAP were affected little by seed treatments, with only matrically primed seeds (12.5 and 50 mg·L−1 PB) resulting in lower shoot dry weights than those of nontreated plants (Table 2). Shoot dry weights of plants sprayed or drenched with PB were not different from those of nontreated plants by 38 DAP.

By the second harvest (63 DAP), only plants that received PB drench had lower shoot height (29%) and lower shoot dry weight (42%) than those of nontreated plants (Table 2). By 78 DAP, 3 weeks after transplanting from plug cells to 15 cm pots, only the shoots of plants that had been drenched with PB were smaller (22% shorter, 40% lighter) than those of nontreated plants.

**Emergence and seedling growth—tomato.** Increasing PB concentration during the 24-h soak had no effect on FEP, but during 7-d matric priming resulted in a linear decrease in FEP (Table 3). Increasing PB during priming increased E50 but at the highest PB concentration (1000 mg·L−1 PB) E50 was not different from that of nontreated seeds. Priming with 50 mg·L−1 PB increased emergence rate (E50; decreased by 1.3 d) while not lowering FEP. The E50 of soaked seeds was not different from that of the nontreated seeds, irrespective of PB concentration.

Table 1. Final germination percentage (FGP) and its angular transformation and days to 50% of FGP (G50) of ‘Salmon Picotee’ impatiens and ‘Marglobe’ tomato in response to seed treatments with paclobutrazol (PB).

| Seed treatment                  | FGP (%) | G50 (d) | Tomato | G50 (d) |
|--------------------------------|---------|---------|--------|---------|
| PB concentration              |         |         |        |         |
| 0 mg·L−1                       | 97.0    | 2.3     |        |         |
| 50 mg·L−1                      | 94.0    | 1.9     |        |         |
| 1000 mg·L−1                    | 93.0    | 2.0     |        |         |
| Impatients                     |         |         |        |         |
| Non-treated                    | 100.0   | 3.2     | 97.0   | 2.3     |
| Soak 24 h                      | 99.5    | 3.4     | 94.0   | 1.7     |
| 50 mg·L−1                      | 93.5    | 6.5     | 97.0   | 1.9     |
| 500 mg·L−1                     | 94.5    | 6.6     | 93.0   | 2.0     |
| 1000 mg·L−1                    | 93.5    | 7.2     | 94.5   | 2.2     |
| Osmotic priming                |         |         |        |         |
| Non-treated                    | 98.0    | 3.5     | 93.9   | 1.6     |
| Soak 24 h                      | 93.4    | 8.1     | 93.9   | 2.0     |
| 50 mg·L−1                      | 84.1    | 9.3     | 93.9   | 2.0     |
| 500 mg·L−1                     | 69.0    | 11.0    | 95.6   | 2.0     |
| 1000 mg·L−1                    | 94.0    | 3.0     | 96.5   | 1.7     |
| Matric priming                 |         |         |        |         |
| Non-treated                    | 95.5    | 2.5     | 96.5   | 0.9     |
| Soak 24 h                      | 76.7    | 4.8     | 96.5   | 1.2     |
| 50 mg·L−1                      | 62.7    | 5.7     | 85.8   | 1.6     |
| 500 mg·L−1                     | 42.0    | 11.7    | 85.8   | 1.6     |
| 1000 mg·L−1                    | 6.0     | 13.6    | 86.9   | 2.0     |

*Ways LSD of**: 0.05, 0.01, or 0.001, respectively; L = linear, Q = quadratic.
Increasing PB during either soaking or priming quadratically decreased shoot height and shoot dry weight at 17 DAP (Table 3). Soaking seeds with 50 mg·L–1 PB resulted in shoot heights and dry weights not different from those of plants from nontreated seeds. Leaves of plants treated with 1000 mg·L–1 PB appeared to be more green and smaller than those of control plants. Shoot height and weight of plants with growth medium drench applications were about one-half those of sprayed plants. Soaking seeds for 24 h in 50 mg·L–1 PB thus decreased shoot growth at 17 and 31 DAP, but the PB effect on growth was not apparent by 72 DAP.

Results from the germination studies showed a marked species sensitivity to PB. Higher concentrations of PB (50 to 1000 mg·L–1), especially with the priming treatments, dramatically reduced the FGP of impatiens in response to seed, shoot spray, or growth medium drench treatments with paclobutrazol (PB).

### Table 2. Final emergence percentage (FEP) and its angular transformation, days to 50% of FEP (E50), and shoot height and shoot dry weight at 38, 63, and 78 d after planting (DAP) of ‘Salmon Picotee’ impatiens in response to seed, shoot spray, or growth medium drench treatments with paclobutrazol (PB).

| Treatment | PB concn (mg·L–1) | FEP (%) | E50 (d) | Shoot height (mm) | Shoot dry wt (g/shoot) |
|-----------|-------------------|---------|---------|-------------------|------------------------|
| Nontreated | ---               | 93.1    | 9.3     | 62                | 248                    |
| Seed soak | 10.0              | 93.8    | 4.3     | 40                | 144                    |
| Seed matric priming | 0.0            | 92.0    | 8.8     | 62                | 258                    |
| Shoot spray | 10.0             | 92.2    | 4.5     | 45                | 156                    |
| Growth medium drench | 1.0              | 87.5    | 13.7    | 49                | 218                    |
| 1-way LSD0.05 | (5.5)**         | 1.2***  | 1***    | 29                | 87                     |

Factorial treatments

| Seed treatment (ST) | (NS) | *** | NS | NS | NS | NS | NS |
|---------------------|------|-----|----|----|----|----|----|
| PB concentration (PB) | (**) | *** | *** | NS | NS | NS | NS |
| ST × PB | (NS) | *** | NS | NS | NS | NS | * NS |
| Interaction LSD0.05 | (4.9) | 1.4 | 1 | 3 | 28 | 0.05 | 0.16 |

### Table 3. Final emergence percentage (FEP) and its angular transformation, days to 50% of FEP (E50), and shoot height and shoot dry weight at 17, 31, and 72 d after planting (DAP) of ‘Marglobe’ tomato in response to seed, shoot spray or growth medium drench treatments with paclobutrazol (PB).

| Treatment | PB concn (mg·L–1) | FEP (%) | E50 (d) | Shoot height (mm) | Shoot dry wt (g/shoot) |
|-----------|-------------------|---------|---------|-------------------|------------------------|
| Nontreated | ---               | 94.4    | 4.6     | 91                | 276                    |
| Seed soak | 1000              | 93.8    | 4.5     | 81                | 258                    |
| Seed matric priming | 50             | 98.4    | 4.7     | 40                | 99                     |
| Shoot spray | 500              | 95.8    | 4.8     | 36                | 107                    |
| Growth medium drench | 1000          | 94.1    | 4.7     | 36                | 100                    |
| 1-way LSD0.05 | (5.7)**        | 0.3***  | 9***    | 21***             | 83***                  |

Factorial treatments

| Seed treatment (ST) | (NS) | NS | Q** | NS | NS | NS | NS |
|---------------------|------|----|-----|----|----|----|----|
| PB concentration (PB) | (**) | *** | *** | NS | NS | NS | NS |
| ST × PB | (NS) | *** | NS | NS | NS | NS | NS |
| Interaction LSD0.05 | (6.4) | 0.3 | 8 | 23 | 81 | 0.03 | 0.12 |

PB concentration trends (highest order)

Seed soak | (L**) | NS | Q** | NS | NS | NS | L** |
Seed matric priming | (NS) | NS | Q** | NS | NS | NS | NS |

Seed soaked in 22 °C aerated PB solutions; matric priming in exfoliated grade five vermiculite (–1.0 MPa for 7 d at 22 °C); shoot spray until incipient runoff at 10 DAP; growth medium drench at 18 mL per 33 cm3 cell at 10 DAP.

NS, *, **, ***: Nonsignificant or significant at P ≤ 0.05, 0.01, or 0.001, respectively. L = linear; Q = quadratic.

### Discussion

Results from the germination studies showed a marked species sensitivity to PB. Higher concentrations of PB (50 to 1000 mg·L–1), especially with the priming treatments, dramatically reduced the FGP of impatiens, whereas they only slightly reduced the FGP of tomatoes (Table 1). Even lower
PB concentrations (12.5 to 50 mg·L⁻¹) during matric priming reduced impatients FGP by 22%, while during soaking FGP was similar to that of nontreated seeds. Priming tomato seeds in hypertonic salt solutions for 6 d with 0.1 and 10 mg·L⁻¹ uniconazole (a growth retardant related to PB) resulted in 1.6 d lower $G_{50}$ than that of control seeds, but no difference in FGP (Davis et al., 1990). Pill and Gunter (2001) found that FGP of primed or soaked Cosmos bipinnatus seeds decreased as PB increased from 0 to 1000 mg·L⁻¹, with the response being more pronounced in primed seeds. The FGP of marigold seeds, however, treated with the same methods and PB concentrations was not different from that of nontreated seed. Pasian and Bennett (2001) noted that 500 or 1000 mg·L⁻¹ PB reduced and delayed germination of tomato, geranium, and marigold seeds. Germination percentages were decreased with >16-h soak in marigold, but little affected by soaking tomato and geranium seeds for 24 h.

For impatiens, we noted a slightly lower percentage of emergence (Table 2) than germination (Table 1) for seeds soaked in PB, but a higher percentage emergence than germination for PB-primed seeds. For tomato, however, percentage germination (Table 1) was similar to percentage emergence (Table 3) for soaked or primed seed at any PB concentration. Pasian and Bennett (2001) noted that while germination was decreased by soaking tomato, geranium and marigold seeds in 500 or 1000 mg·L⁻¹ PB for 6, 16, or 24 h, no such reduction occurred in emergence percentage. They hypothesized that PB diffusing from the seed could accumulate to deleterious concentrations near the seed in the germination blotter, whereas PB could more readily move away from the seed in irrigated peat-lite so that emergence would be less affected.

The differential responses of impatiens and tomato to PB and methods may be explained by the differences in their seedcoat structure or permeability/sorbency. Pasian and Bennett (1999) hypothesized that the PB adheres to the seedcoat of treated seeds and then diffuses into the growth medium where it can be taken up by the seedling roots. However, PB may penetrate the seedcoat and exert a direct toxic effect on the embryo. This may be the case with impatiens since increasing exposure time (48 vs 24-h soak, or 24-h soak vs. 7-d prime) reduced FGP and increased $G_{50}$ (Table 1). The seedcoats of tomato have a semipermeable layer (Beresniecicz, et al., 1995) that may prevent the PB from entering the endosperm and embryo thereby lessening negative effects of PB on germination.

Shoot height and dry weight reductions in impatiens (Table 2) and tomato (Table 3) with PB treatments concurred with results of other research involving growth effects of triazole. Gilley and Fletcher (1997) found that wheat seedling shoots at 10 DAP from seeds treated with PB (50 mg·L⁻¹, soaked for 18 h) were 40% shorter, and shoot dry weights were 25% lighter than those from nontreated seeds. Tomato plants from seeds primed in solutions containing 1 or 10 mg·L⁻¹ of uniconazole for 6 d at 24 °C, had 20% shorter shoots than those of the control plants by 14 DAP (Davis et al., 1990). However, Pill and Gunter (2001) reported that soaking marigold seeds in 500 or 1000 mg·L⁻¹ PB failed to reduce shoot height or shoot dry weight at 32 DAP compared to nontreated plants, though priming with 1000 mg·L⁻¹ PB reduced height and shoot dry weight by 13% and 22%, respectively. While Pasian and Bennett (2001) noted ≥30% reduction in tomato shoot height at 36 DAP following 6- to 16-h seed soak in 1000 mg·L⁻¹ PB compared to the water control, we observed a 62% decrease in shoot height at 31 DAP with a 24-h seed soak in only 50 mg·L⁻¹ PB. Such differential responses reflected variable cultivar sensitivity to PB.

The observed greater reductions in shoot height of impatiens (Table 2) and tomato (Table 3) by the third harvest when PB was applied as a drench relative to that from the PB seed treatments reflected the increased longevity of PB when applied to the growth medium as reported by Sanderson et al. (1988). Although PB is fairly immobile in plants, some of the spray may have contacted the plant stems where it elicits the growth suppressive effect (Fletcher et al., 2000). Growth responses of both species to seed treatment with PB were not significant by the third harvest (Tables 2 and 3). Souza-Machado et al. (1998) noted tomato plants from seeds primed in salt solutions containing 50 mg·L⁻¹ PBwere 42% shorter than those from nontreated by 2 weeks after planting. By 4 weeks after transplanting to the field (6 weeks after planting), however, shoot heights of the PB-treated plants and the controls were similar.

Results of this study revealed a marked differential response to seed treatment with PB between tomato and impatiens. Any reduction in shoot growth from PB treatment of impatiens seeds occurred after a loss of emergence percentage, and so we recommend not treating impatiens seeds with PB. For tomato, soaking seeds in up to 1000 mg·L⁻¹ PB for 24 h had little or no effect on germination or emergence, and yet exceeding 50 mg·L⁻¹ PB failed to decrease shoot height or dry weight further. Soaking tomato seeds in 50 mg·L⁻¹ PB for 24 h gave similar shoot growth suppression as the shoot spray or growth medium drench. Since matric priming of tomato seeds with increasing PB resulted in a linear decrease in emergence percentage and concomitant reduction in emergence rate, we recommend avoiding this treatment.

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