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

Jennifer R. Still and Wallace G. Pill

Department of Plant and Soil Sciences, University of Delaware, Newark, DE 19717-1303

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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 f.) 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 31 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 shoot growth suppression than the PB seed soak treatment, which had lost its growth suppressive effect. Chemical name used: (±)-(R*,R*)-[4-(4-chlorophenyl)methyl]- (1,1-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 imbibing 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 289 g·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 lid-ded 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 (G_{50} , 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 matrix 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-cm³ 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 hr (April through July).

Seedling 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 (E_{50} , an inverse measure

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, impatiens being slower growing. Shoot height and dry weights were measured 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.

At the time of the second harvest, four plants per treatment were transplanted into 15-cm-diameter standard pots (impatiens) or 3.78-L pots (tomato) to determine long-term growth effects of PB treatments. These plants, arranged in randomized blocks with four replications in the same greenhouse, received weekly fertilization (250 mg·L⁻¹ N from 21N–2P–17K). At the third harvest (72 DAP, 41 d after transplanting tomato and 78 DAP, 14 d after transplanting impatiens) shoot heights and dry weights were recorded. ANOVA was performed on all variables.

Results

Germination—impatiens. FGP and G_{50} were affected by PB concentration during seed soaking or priming (Table 1). Paclobutrazol, even at 50 mg·L⁻¹, decreased FGP and increased G_{50} . With increasing PB concentration, the decrease in FGP generally was linear while the increase in G_{50} 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 G_{50} . 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; G_{50} 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 G_{50} increased slightly. During matric priming, PB decreased FGP at the two highest concentrations (500 and 1000 mg·L⁻¹), and G_{50} increased linearly with increasing PB concentration.

Soaking for 24 h and matric priming, both using 0, 50, 500, 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 G_{50} 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 E_{50} (Table 2). For primed seeds, increasing PB concentration had no effect on FEP but caused a quadratic increase in E_{50} . 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 E_{50} 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 concentra-

tion 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 E_{50} , but at the highest PB concentration (1000 mg·L⁻¹ PB) E_{50} was not different from that of nontreated seeds. Priming with 50 mg·L⁻¹ PB increased emergence rate (E_{50} decreased by 1.3 d) while not lowering FEP. The E_{50} 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 (G_{50}) of 'Salmon Picotee' impatiens and 'Marglobe' tomato in response to seed treatments with paclobutrazol (PB).

Seed treatment ²	PB concn (mg·L ⁻¹)	Impatiens			Tomato		
		FGP (%)	G_{50} (deg.)	G_{50} (d)	FGP (%)	G_{50} (deg.)	G_{50} (d)
Nontreated	---	100.0 (90.0)		3.2	97.0 (81.5)		2.3
Soak 24 h	0	99.5 (88.0)		3.4	94.0 (76.4)		1.7
	50	93.5 (77.4)		6.5	97.0 (81.5)		1.9
	500	94.5 (76.9)		6.6	93.0 (74.9)		2.0
	1000	93.5 (75.7)		7.2	94.5 (77.3)		2.2
Soak 48 h	0	98.0 (84.4)		3.5	94.9 (79.3)		1.6
	50	93.4 (75.4)		8.1	93.9 (76.2)		2.0
	500	84.1 (66.7)		9.3	93.9 (76.1)		2.0
	1000	69.0 (56.3)		11.0	96.5 (82.3)		2.0
Osmotic priming	0	94.0 (76.4)		3.0	96.0 (80.3)		1.7
	50	62.7 (53.4)		5.7	95.5 (77.8)		1.6
	500	42.0 (40.3)		11.7	94.5 (76.6)		1.9
	1000	6.0 (13.4)		13.6	90.4 (72.3)		2.3
Matric priming	0	95.5 (79.8)		2.5	96.5 (80.9)		0.9
	50	76.7 (61.4)		4.8	96.5 (81.0)		1.2
	500	7.6 (15.8)		10.6	85.8 (68.2)		1.6
	1000	0 (—)		---	86.9 (69.0)		2.0
1-way LSD _{0.05}		(7.1)***		1.3***	(8.3)*		0.2***
Factorial treatments							
Seed treatment (ST)		***		***	NS		***
PB concentration (PB)		***		***	*		***
ST × PB		***		***	NS		***
Interaction LSD _{0.05}		(7.4)		1.3	(8.2)		0.2
PB concentration trends (highest order)							
Soak 24 h		L*		L***	NS		L***
Soak 48 h		Q***		Q**	NS		L*
Osmotic priming		L***		Q***	NS		L***
Matric priming		Q***		Q***	L***		L***

²Soaked in 22 °C aerated PB solutions; Osmotic priming in PEG 8000 or matric priming in exfoliated grade five vermiculite (both -1.0 MPa for 7 d at 22 °C).

NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively; L = linear, Q = quadratic.

Table 2. Final emergence percentage (FEP) and its angular transformation, days to 50% of FEP (E_{50}), 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 ^z	PB concn (mg·L ⁻¹)	FEP		E_{50} (d)	Shoot height (mm)			Shoot dry wt (g/shoot)		
		(%)	(deg.)		DAP: 38	63	78	DAP: 38	63	78
Nontreated	---	93.1	(74.9)	9.3	62	248	251	0.20	0.78	12.64
Seed soak	0	92.2	(74.7)	9.1	60	258	257	0.20	0.80	13.20
	12.5	87.5	(69.4)	10.5	50	248	242	0.17	0.94	13.19
	25.0	82.3	(65.3)	9.9	46	250	251	0.19	1.06	13.30
	50.0	84.0	(66.5)	9.8	43	261	240	0.16	0.73	13.03
Seed matric priming	0	92.0	(73.8)	8.8	62	258	263	0.19	0.94	12.95
	12.5	83.3	(66.2)	13.7	49	218	241	0.15	0.92	13.27
	25.0	88.5	(70.5)	13.1	51	256	257	0.18	0.80	13.00
	50.0	87.0	(70.0)	15.3	39	229	272	0.12	0.78	12.52
Shoot spray	10.0	---	---	---	41	254	245	0.16	0.72	12.77
Growth medium drench	1.0	---	---	---	29	87	196	0.17	0.46	7.53
1-way LSD _{0.05}			(5.5)***	1.2***	1***	30***	27**	0.03*	0.17***	1.48***
<i>Factorial treatments</i>										
Seed treatment (ST)			(NS)	***	NS	NS	NS	NS	NS	NS
PB concentration (PB)			(**)	***	**	NS	NS	**	*	NS
ST × PB			(NS)	***	NS	NS	NS	NS	*	NS
Interaction LSD _{0.05}			(4.9)	1.4	1	3	28	0.05	0.16	1.24
<i>PB concentration trends (highest order)</i>										
Seed soak			(L**)	NS	Q*	NS	NS	NS	L**	NS
Seed matric priming			(NS)	Q**	Q**	NS	NS	Q*	Q*	NS

^zSeed 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 $P \leq 0.05$, 0.01, or 0.001, respectively. L = linear; Q = quadratic.

Table 3. Final emergence percentage (FEP) and its angular transformation, days to 50% of FEP (E_{50}), and shoot height and shootdry 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 ^z	PB concn (mg·L ⁻¹)	FEP		E_{50} (d)	Shoot height (mm)			Shoot dry wt (g/shoot)		
		(%)	(deg.)		DAP: 38	63	72	DAP: 38	63	72
Nontreated	---	94.4	(76.8)	4.6	91	276	1037	0.15	0.76	38.19
Seed soak	0	93.8	(75.8)	4.5	81	258	1014	0.14	0.57	38.16
	50	94.8	(77.0)	4.7	40	99	1003	0.10	0.39	34.44
	500	95.8	(78.4)	4.8	36	107	1045	0.08	0.39	31.58
	1000	94.8	(77.0)	4.7	36	100	1006	0.08	0.35	32.35
Seed matric priming	0	94.1	(76.5)	2.6	103	268	1022	0.20	0.72	36.84
	50	89.2	(71.5)	3.3	78	254	1032	0.14	0.59	36.08
	500	81.9	(65.2)	4.3	45	156	978	0.10	0.47	36.49
	1000	69.8	(56.8)	4.7	40	144	1041	0.10	0.55	33.88
Shoot spray	10.0	---	---	---	46	88	862	0.10	0.37	24.16
Growth medium drench	1.0	---	---	---	44	85	463	0.10	0.39	12.68
1-way LSD _{0.05}			(5.7)***	0.3***	9***	21***	83***	0.03***	0.10***	4.10***
<i>Factorial treatments</i>										
Seed treatment (ST)			(***)	***	***	***	NS	***	***	NS
PB concentration (PB)			(**)	***	***	***	NS	***	***	NS
ST × PB			(***)	***	***	***	NS	NS	NS	NS
Interaction LSD _{0.05}			(6.4)	0.3	8	23	81	0.03	0.12	4.00
<i>PB concentration trends (highest order)</i>										
Seed soak			(NS)	NS	Q***	Q***	NS	Q*	Q**	L**
Seed matric priming			L***	Q***	Q***	Q***	NS	Q*	L**	NS

^zSeed 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 $P \leq 0.05$, 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 or priming with 500 mg·L⁻¹ PB resulted in shoot heights and weights not different from those of plants that had been sprayed or drenched with PB at 14 DAP (Table 3). By 31 DAP, treatment-induced trends in shoot growth were similar to those observed at 17 DAP. Spray and drench applications gave similar growth suppression, ≈69% lower shoot height and 43% lower shoot dry weight than those of nontreated plants. At any PB concentration, seed soaking resulted in lower shoot height and dry weight than seed priming, so that shoot heights and dry weights

resulting from 50 mg·L⁻¹ PB during seed soaking were similar to those achieved with PB drench or spray. Shoot height and dry weight from soaked seeds (50 mg·L⁻¹ PB) were 36% and 59%, respectively, those of plants from nontreated seeds. Leaves of plants treated with PB appeared to be more green and smaller than those of nontreated plants.

By 72 DAP (41 d after transplanting) shoot height was unaffected by any PB seed treatment, although shoot height and shoot dry weight from the spray and drench treatments were lower than those from the nontreated plants (Table 3). Shoot dry weights from seeds primed with 1000 mg·L⁻¹ PB were slightly 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.

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 $50\text{ mg}\cdot\text{L}^{-1}$) during matric priming reduced impatiens 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 $10\text{ mg}\cdot\text{L}^{-1}$ 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 $1000\text{ mg}\cdot\text{L}^{-1}$, 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 $1000\text{ mg}\cdot\text{L}^{-1}$ 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 $1000\text{ mg}\cdot\text{L}^{-1}$ 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 (Beresniewicz 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 concur with results of other research involving growth effects of triazoles. Gilley and Fletcher (1997) found that wheat seedling shoots at 10 DAP from seeds treated with PB ($50\text{ mg}\cdot\text{L}^{-1}$, soaked for 18 h) were 40% shorter, and shoot dry weights were 23% lighter than those from nontreated seeds. Tomato plants from seeds primed in solutions containing 1 or $10\text{ mg}\cdot\text{L}^{-1}$ of uniconazole for 6 d at $24\text{ }^{\circ}\text{C}$, 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 $1000\text{ mg}\cdot\text{L}^{-1}$ PB failed to reduce shoot height or shoot dry weight at 32 DAP compared to nontreated plants, though priming with $1000\text{ mg}\cdot\text{L}^{-1}$ PB reduced height and shoot dry weight by 13% and 22%, respectively. While Pasian and Bennett (2001) noted $\approx 30\%$ reduction in tomato shoot height at 36 DAP following 6- to 16-h seed soak in $1000\text{ mg}\cdot\text{L}^{-1}$ 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 $50\text{ mg}\cdot\text{L}^{-1}$ 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 $50\text{ mg}\cdot\text{L}^{-1}$ PB were 42% shorter than those from nontreated seeds 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 $1000\text{ mg}\cdot\text{L}^{-1}$ PB for 24 h had little or no effect on germination or emergence, and yet exceeding $50\text{ mg}\cdot\text{L}^{-1}$ PB

failed to decrease shoot height or dry weight further. Soaking tomato seeds in $50\text{ mg}\cdot\text{L}^{-1}$ 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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