J Plant Growth Regul (1998) 17:75–79

Journal of Plant Growth Regulation

Effect of Pot Size and Timing of Plant Growth Regulator Treatments on Growth and Tuber Yield in Greenhouse-Grown Norland and Russet Burbank Potatoes

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Received May 30, 1997; accepted February 3, 1998

Abstract. The effects of pot size, timing of the application of paclobutrazol (PTZ) and gibberellic acid (GA_3), and the counteractive effect of these two compounds on growth and tuber yield of greenhouse-grown Norland and Russet Burbank potatoes were investigated. Plants were grown either in 1.5-liter pots (15 cm deep) or 3.0-liter pots (18 cm deep) and received a foliar application of either 1.5 mM PTZ or 9×10^{-3} mM GA_3 at early or late stolon initiation. Some plants that had been foliar treated with 1.5 mM PTZ at early stolon initiation were foliar treated with 9×10^{-3} mM GA_3 at late stolon initiation. PTZ reduced haulm length in both cultivars significantly, particularly when the treatment was applied at early stolon initiation, but the late treatment reduced haulm length only when growing in 3.0-liter pots. Irrespective of the timing of treatment, GA_3 increased haulm length in Norland growing in both pot sizes, but the treatment increased haulm length in Russet Burbank only when applied at late stolon initiation. GA_3 applied after PTZ did not overcome the growth-inhibiting effect of the PTZ treatment. The PTZ treatment effectively increased usable tuber number/plant (UTN) in Norland, but PTZ had no effect on UTN in Russet Burbank. PTZ reduced usable tuber weight/plant (UTW) only in Norland growing in 1.5-liter pots. By contrast, GA_3 increased UTN only when treated at late stolon initiation of 1.5-liter pot-grown Norland, whereas the same treatment was effective when applied only at early stolon initiation for Russet Burbank. For Norland, the increase in UTN by early applied PTZ was reduced by the subsequent application of GA_3. The use of 3.0-liter pots for minituber production in both Norland and Russet Burbank appears to have no advantage over growing in 1.5-liter pots, particularly when PTZ or GA_3 is used to enhance tuberization.

Key Words. Gibberellic acid—Minituber production—Paclobutrazol—*Solanum tuberosum* L.

The North American seed potato industry is based on production of early generations of disease-free potatoes (minitubers) under greenhouse conditions. Efforts to improve the cost efficiency of this greenhouse production hinge on increasing the number of usable tubers produced by each plant per unit of time. The promotive effect of gibberelin inhibitors such as chlorocholine chloride (CCC) on tuberization can be overcome by gibberellic acid (GA_3) treatment (Abdala et al. 1995, Dyson 1965). These findings have led to the hypothesis that roots synthesize a factor with GA-like properties which is responsible for delaying tuberization in potatoes (Abdala et al. 1995, Pont-Lezica 1970). Hammes and Nel (1975) suggested that tuberization in potatoes is controlled by a balance between endogenous GAs and a tuber-forming stimulus. Among the plant growth regulators (PGRs) that have been used to study the potato tuberization phenomenon, GA_3 has been reported to have a consistent delaying or inhibiting effect on potato tuberization (Abdala et al. 1995, Koda and Okazawa 1983).

Paclobutrazol [PTZ, (2*R*,3*R*+2*S*,3*S*)-1-(4-chlorophenyl 4,4-dimethyl-2-(1,2,4-triazol-1-yl)-pentan-3-ol] is a triazole compound that blocks GA biosynthesis in plants (Davis et al. 1988). It has also been shown to inhibit shoot growth in a wide range of plant species (Barrett and Bartuska 1982, Child et al. 1993) including potatoes (Balamani and Poovaiah 1985, Pelacho et al.

Abbreviations: ANOVA, analysis of variance; CCC, chlorocholine chloride; GAs, gibberellins; GA_3, gibberellic acid; LSD, least significant difference; PGRs, plant growth regulators; PTZ, paclobutrazol; UTN, usable tuber number/plant; UTW, usable tuber weight/plant.

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1994). Treatments with PTZ promoted tuberization in potatoes in vitro (Harvey et al. 1991, Simco 1991) and under greenhouse conditions (Balamani and Poovaiah 1985, Bandara and Tanino 1995) with cultivar-specific response to timing of the treatment (Bandara, unpublished data).

Our previous studies indicated that Norland potatoes growing in large pots (15 cm in diameter and 15 cm deep) produced larger haulms and a higher number of tubers/plant than those produced in small pots (12.5 cm in diameter and 12 cm deep), although the mean tuber weight was not affected by the pot size (Bandara and Tanino 1995). Nowak et al. (1996) reported that the depth of the growing medium correlated positively with shoot dry weight, stolon weight, tuber number, and tuber weight in Shepody and Kennebec potatoes. Most greenhouse growers, however, use containers that are 15 cm deep to produce minitubers (Nowak et al. 1996). Information on the influence of the timing of PGR treatments on tuberization in potatoes growing in different pot sizes is limited. We hypothesized that larger pots (>15 cm deep) may facilitate both above and below ground biomass production in potatoes, resulting in larger plants that in turn enhance PGR effects on tuberization. These effects may manifest themselves through improved uptake of foliar applied compounds and consequently produce a higher usable tuber number/plant (UTN) than those produced in smaller pots. The present study examined the optimum timing (crop growth stage) for foliar application of PTZ and GA_3 and the counteractive effect of these two PGRs on tuberization to increase the number of UTN growing in pots that are 15 cm deep (1.5 liters) or 18 cm deep (3.0 liters) under greenhouse conditions in Norland and Russet Burbank potato cultivars.

Materials and Methods

Seed tubers (Elite III) of potato (*Solanum tuberosum* L.) cultivars Norland and Russet Burbank were used for this study. Pieces (15–20 g) cut from the apical ends of the seed tubers were planted in plastic pots (15 cm deep and 1.5 liters, standard pot size; and 18 cm deep and 3.0 liters) filled with a peat/vermiculite based medium (Redi Earth, Grace Horticultural Products of Canada Ltd., Ajax, ON, Canada). The plants were grown in a greenhouse at 23 ± 2°C/18 ± 2°C (day/night), and a 16-h day length with 600–700 μmol m^{-2} s^{-1} light intensity maintained using Sylvania Cool White and Sylvania Grow-Lux fluorescent lamps (Sylvania Canada Ltd., Mississauga, ON, Canada). Plants were watered every other day to maintain adequate moisture levels. The crop was fertilized once weekly with a 250-ppm solution of 20:20:20 (N:P:K) commencing the 2nd week of planting.

Timing and concentration of treatments were based upon results of preliminary studies (Bandara, unpublished data) and as reported elsewhere (Bandara and Tanino 1995). The potatoes were treated with 1.5 mM PTZ (25% paclobutrazol, Zeneca Agro, Stoney Creek, ON, Canada) or 9×10^{-3} mM GA_3 (90% GA_3, Sigma Chemical Co., St. Louis, MO, USA) at early stolon initiation (for Norland, 21 days after planting; for Russet Burbank, 28 days after planting) or late stolon initiation (for Norland, 28 days after planting; and for Russet Burbank, 38 days after planting). Each solution was made using distilled water containing the surfactant Cittowett Plus (octylphenoxy-polyethoxy ethanol 50%, BASF Canada Inc., Rexdale, ON, Canada) at 0.12% (v/v). All treatments were applied to foliar runoff, using an atomizer. Treatment with 1.5 mM PTZ at early stolon initiation followed by 9×10^{-3} mM GA_3 at late stolon initiation was also included to examine the counteractive effects of these two PGRs on tuberization. Control plants were treated with water and the surfactant. Each treatment of Norland grown in 1.5-liter pots was repeated 11 times and 4 times for Russet Burbank, whereas all treatments of both cultivars grown in 3.0-liter pots were repeated 12 times. Each replicate consisted of five plants in all cases. Tubers weighing >1 g were considered as usable tubers, and only those tubers were used in determining total tuber number and total tuber fresh weight/plant. Haulm length, total UTN and total usable tuber weight/plant (UTW) were determined at 75 days after planting for Norland and 90 days after planting for Russet Burbank. Analysis of variance (ANOVA) was executed separately for each cultivar and each pot size in a randomized complete block design. Treatment means were compared using a least significant difference (LSD) test, whenever the F-tests for treatments were significant at $p < 0.05$.

Results

Norland

The plant growing in large pots (3.0 liters) produced longer haulms than those growing in small pots (1.5 liters) (Table 1). Irrespective of pot size, PTZ applied at early stolon initiation reduced haulm length significantly. However, PTZ treatment applied at late stolon initiation reduced the haulm length of plants growing only in larger pots. Irrespective of timing of application and pot size, GA_3 increased haulm growth significantly compared with the control (Table 1). The PTZ followed by GA_3 treatment reduced haulm length of the crop (Table 1). PTZ applied at early stolon initiation increased UTN by 330 and 67% compared with controls in the small and large pots, respectively (Table 1). PTZ applied at late stolon initiation increased UTN by 230% compared with the control in the small pots (Table 1). Regardless of pot size, GA_3 applied at early stolon initiation had no significant effect on UTN (Table 1). However, plants treated with GA_3 at late stolon initiation increased UTN by 63% over the control, only when growing in large pots. By contrast, the PTZ followed by GA_3 treatment increased UTN significantly when growing only in small pots. Irrespective of timing of application, PTZ reduced UTW in small pots only (Table 1). Conversely, GA_3 significantly increased UTW, irrespective of timing of application and pot size (Table 1). The effect of PTZ followed by GA_3 treatment on UTW was dependent upon the pot size. Treated plants growing in small pots produced significantly lower UTW than the controls, whereas the same treatment applied to the plants growing in large pots increased UTW more than their respective controls (Table 1).

Table 1. Effect of pot size and timing of application of PTZ and GA_3 on haulm growth and tuber yield of Norland potatoes.

Treatment	1.5-liter pot (15 cm deep) Haulm length (cm)	Tuber[a] number/ plant	Tuber[a] weight (g)/plant	3.0-liter pot (18 cm deep) Haulm length (cm)	Tuber[a] number/ plant	Tuber[a] weight (g)/plant
Control (H_2O)	23.5	1.6	85.7	81.3	2.8	70.6
1.5 mM PTZ						
21 DAP[b]	14.3	7.0	48.3	54.1	4.7	69.8
28 DAP	25.0	5.3	21.9	58.8	3.8	73.2
9×10^{-3} mM GA_3						
21 DAP	34.3	2.3	102.1	91.4	2.9	99.7
28 DAP	32.0	2.6	108.1	85.4	2.8	86.8
PTZ 21 DAP and						
GA_3 28 DAP	16.2	3.9	61.5	58.4	3.8	86.9
Statistical significance						
	**[c]	**	**	**	*	**
LSD	4.4	0.8	11.3	3.2	1.3	15.9
CV%	21.1	25.2	18.2	5.5	44.3	24.0

[a] Usable tubers (>1 g in weight).
[b] DAP, days after planting.
[c] * and ** are significant at $p < 0.01$ and $p < 0.05$, respectively.

Russet Burbank

In Russet Burbank, the growth-inhibiting effect of the PTZ treatment was influenced by the timing of the application and the size of the pots. Regardless of pot size, PTZ applied at early stolon initiation reduced haulm length significantly, but the late treatment was effective only on those plants growing in large pots (Table 2). Irrespective of timing of treatment, GA_3 increased the haulm length of the crop growing in large pots. The PTZ followed by GA_3 treatment reduced haulm length, indicating that the inhibiting effect on haulm growth produced by PTZ was not completely counteracted by GA_3. PTZ had no significant effect on UTN (Table 2). GA_3 applied at early stolon initiation increased UTN by 45 and 37% over controls growing in small and large pots, respectively. The same treatment applied at late stolon initiation had no significant effect on UTN. PTZ followed by GA_3 increased UTN by 36% over the control when the crop was growing in small pots but had no effect when growing in large pots. None of the treatments had a significant effect on UTW.

Discussion

Triazole compounds and GAs usually have opposite and mutually antagonistic effects on plant growth and development (Balamani and Poovaiah 1985, Biddington et al. 1992). Although Bandara and Tanino (1995) found previously that PTZ had no effect on haulm growth in greenhouse-grown Norland potatoes, in the present study PTZ inhibited haulm growth in both potato cultivars depending upon the timing of treatment and the size of the pot. The inhibitory effect of PTZ on vegetative growth in potatoes was also reported by Simco (1991) in vitro and by Balamani and Poovaiah (1985) under greenhouse conditions. GA_3 generally increased the haulm lengths in both cultivars used in this study. This corresponds with the findings of Balamani and Pooviah (1985) and Langille and Hepler (1992). The plants treated with GA_3 after PTZ produced shorter haulms than the controls, indicating that the concentration of GA_3 used in the study was not sufficient to counteract the growth-inhibitory effect caused by the PTZ treatment. Balamani and Pooviah (1985) found that the inhibiting effect on haulm growth of 340 mM PTZ applied as a soil drench was reversed by multiple foliar applications of GA_3 at 2 mM.

In the present study, depending upon the pot size and timing of treatment, both PTZ and GA_3 treatments increased UTN in both cultivars (Tables 1 and 2). For the fast maturing determinant cultivar Norland, PTZ produced the most pronounced effect on UTN when applied at early stolon initiation to plants growing in 1.5-liter pots. This suggests that the plants should be treated with PTZ at a relatively early stage. The slow maturing indeterminant cultivar Russet Burbank responded profoundly to GA_3 treatment applied at early stolon initiation when growing in 1.5-liter pots. The responses to the GA_3 treatment are contrary to evidence reported by many workers (Hammes and Nel 1975, Pont-Lezica 1970, Tizio 1971),

Table 2. Effect of pot size and timing of application of PTZ and GA_3 on haulm growth and tuber yield of Russet Burbank potatoes.

Treatment	1.5-liter pot (15 cm deep)			3.0-liter pot (18 cm deep)		
	Haulm lenght (cm)	Tuber[a] number/plant	Tuber[a] weight (g)/plant	Haulm length (cm)	Tuber[a] number/plant	Tuber[a] weight (g)/plant
Control (H_2O)	52.0	3.3	99.2	74.4	3.0	84.5
1.5 mM PTZ						
28 DAP[b]	21.5	3.3	55.4	53.3	3.2	72.5
38 DAP	42.5	4.0	123.7	61.0	3.7	83.5
9×10^{-3} mM GA_3						
28 DAP	52.3	4.8	130.1	78.3	4.1	87.2
38 DAP	61.5	3.8	89.4	81.4	2.8	80.6
PTZ 28 DAP &						
GA_3 38 DAP	25.3	4.5	81.5	56.2	3.2	70.7
Statistical significance						
	**[c]	*	ns	**	*	ns
LSD	10.0	1.1		3.8	0.8	
CV%	15.6	18.4	34.6	6.9	28.9	21.2

[a] Usable tubers (>1 g in weight).
[b] DAP, days after planting.
[c] **, *, and ns are significant at $p < 0.01$ and $p < 0.05$, and nonsignificant at $p < 0.05$.

who found that GAs are responsible for inhibiting or delaying tuberization in potatoes. This apparent contradiction may be reconciled, if GA(s) other than GA_3 control haulm growth and tuberization in potatoes. Jackson and Prat (1996) reported that although *S. tuberosum* ssp. *andigena* responded to the GA_3 treatment with the expected increase in haulm length, the treatment had no inhibiting effect on tuberization. This observation led them to suggest that inhibition of tuberization may be controlled by a GA other than GA_3. Moreover, GA_3 has been reported to have dose-dependent induced prolongation or shortening of dormancy in tubers or rhizomes of East Asian *Dioscorea* (Okagami and Tanno 1993) and in potatoes (van Ittersum and Scholte 1993). Further investigations are required to elucidate the GA involvement in tuberization of different potato cultivars.

Bandara and Tanino (1995) reported that PTZ increased the tuber number by twofold in Norland potatoes when growing in 1.5-liter pots, but the positive response was reduced by 35% when the crop was grown in 1.0-liter pots. In the present study, however, the treatment effect on tuber number was more pronounced when the crops were grown in 1.5-liter pots than when grown in 3.0-liter pots. This suggests that using larger pots has no advantage over 1.5-liter pots for minituber production.

Acknowledgments. We acknowledge, with thanks, the financial support by Saskatchewan Agriculture Development Fund through Grant ADF-R-0856 and the supply of paclobutrazol by Zeneca Agro, Stoney Creek, ON, Canada. We are grateful to Dr. L. V. Gusta of the Crop Development Center, University of Saskatchewan, for useful comments.

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