Research Article

Potted platycodon production in response to paclobutrazol[1]

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ABSTRACT

Platycodon grandiflorus is an ornamental species that can be marketed as a potted flower; however, it has fragile and bending floral stems. Plant growth regulators, such as paclobutrazol, are compounds that reduce stem elongation, enabling the production of plants with a more compact formation. This study aimed to evaluate the effects of paclobutrazol on platycodon growth, in a greenhouse. A completely randomized blocks experimental design was used in a 4 × 5 factorial scheme, with four replicates. The treatments consisted of four varieties of 'Astra Semi-Double' platycodon (Blue, Lavender, Pink and White) and five paclobutrazol doses (0, 1.25, 2.5, 3.75 and 5.0 mg pot^{-1}). The paclobutrazol application did not affect the stem diameter, number of leaves, days until anthesis, number of flowers or flower buds, and flower diameter. The shoot length, leaf area and shoot dry mass decreased with higher doses of the growth regulator. Lavender showed the highest values for shoot length, number of leaves, leaf area and shoot dry mass. Pink had the earliest anthesis, followed by Blue and White, whereas Lavender had the latest anthesis. The dose of 3.75 mg pot^{-1} of paclobutrazol efficiently controlled the growth and improved the visual quality of all the platycodon varieties.

KEYWORDS: *Platycodon grandiflorus* (Jacq.) A. DC., balloon flower, plant growth regulator.

RESUMO

Produção de platycodon em vaso
em resposta a paclobutrazol

Platycodon grandiflorus é uma espécie ornamental que pode ser comercializada como flor de vaso; porém, apresenta ramos florais frágeis e pendentes. Reguladores de crescimento, como o paclobutrazol, são compostos que reduzem o alongamento do caule, permitindo a produção de plantas com formação mais compacta. Objetivou-se avaliar os efeitos de paclobutrazol no crescimento de platycodon, em casa-de-vegetação. O delineamento experimental foi em blocos inteiramente casualizados, em esquema fatorial 4 × 5, com quatro repetições. Os tratamentos consistiram de quatro variedades de platycodon 'Astra Semi-Double' (Blue, Lavender, Pink e White) e cinco doses de paclobutrazol (0; 1,25; 2,5; 3,75; e 5,0 mg vaso^{-1}). A aplicação de paclobutrazol não afetou o diâmetro do caule, número de folhas, dias até a antese, número de flores ou botões florais e diâmetro da flor. O comprimento da parte aérea, área foliar e massa seca da parte aérea decresceram com o aumento da dose do regulador de crescimento. Lavender apresentou os maiores valores de comprimento da parte aérea, número de folhas, área foliar e massa seca da parte aérea. Pink teve a antese mais precoce, seguida de Blue e White, enquanto Lavender teve a antese mais tardia. A dose de 3,75 mg vaso^{-1} de paclobutrazol eficientemente controlou o crescimento e melhorou a qualidade visual de todas as variedades de platycodon.

PALAVRAS-CHAVE: *Platycodon grandiflorus* (Jacq.) A. DC., flor-balão, regulador de crescimento vegetal.

INTRODUCTION

The floriculture sector is constantly searching for new and differentiated products to satisfy the demands of producers and consumers (Junqueira & Peetz 2018). Platycodon, or balloon flower [*Platycodon grandiflorus* (Jacq.) A. DC., Campanulaceae], is one of those products that have been explored recently as a potted flower in the national market.

Originally from Asia, this species is widely used as a garden and bedding plant, but it may also be grown as a cut or potted flower (Halevy et al. 2002, Kim et al. 2017). It has several desirable ornamental characteristics, such as attractive flower buds, which resemble air balloons; stunning flowers, which keep

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their petals partially attached to each other, acquiring the configuration of a star; low susceptibility to post-harvest problems; long flowering period and pot life (Evensen & Beattie 1986, Starman et al. 1995, Song et al. 2012, Liu et al. 2014).

However, ornamental species grown both as a cut and potted flower need plant growth control to reach an adequate height and stem stiffness (Backes et al. 2005). Moreover, platycodon produces fragile and bending floral stems (Iversen & Weiler 1994), especially when grown under high night temperatures (Halevy et al. 2002). To avoid the need for staking and the loss of product quality in platycodon, techniques to reduce stem elongation are necessary, such as application of growth regulators, light management, temperature regulation, water and nutrients restriction, and selection of compact cultivars (Bergstrand 2017).

Growth regulators are employed in floriculture to control plant height and produce plants with a more appropriate architecture (Hawkins et al. 2015, Rezazadeh & Harkess 2015). Daminozide, ethephon, flurprimidol, paclobutrazol and uniconazole are some active ingredients used as growth regulators in flower production (Carver et al. 2014, Lee et al. 2015, Demir & Çelikele 2019). Paclobutrazol (PBZ), an inhibitor of gibberellin biosynthesis that belongs to the class of triazoles, is a growth regulator widely used in the flower market (Binotti et al. 2018). This triazole has high chemical activity in many ornamental plants and can reduce stem elongation with low concentrations (Grossi et al. 2009, Tinoco et al. 2011, Carvalho-Zanão et al. 2018).

Several studies have already indicated the effectiveness of PBZ application in reducing the growth of various species of potted flowers (Al-Khassawneh et al. 2006, Hwang et al. 2008, Wanderley et al. 2014, Lee et al. 2015, Bosch et al. 2016, Rezazadeh et al. 2016, Demir & Çelikele 2019). However, there are no reports in the literature on using this regulator to control the platycodon length. Therefore, this study aimed to evaluate the effects of drenched-applied PBZ doses on the growth of 'Astra Semi-Double' platycodon varieties.

MATERIAL AND METHODS

The experiment was conducted between October 28, 2019, and February 25, 2020, in a greenhouse (20º45'36.0"S, 42º51'47.4"W and 685 m of altitude), under natural photoperiod. The maximum and minimum temperature values (Figure 1) were daily recorded with a digital thermo-hygrometer (J. Prolab™) installed inside the greenhouse (1.80 m above the ground level). The average air relative humidity was 62.75 %, with minimum of 37.53 % (1.06 %) and maximum of 87.98 % (10.94 %).

Commercial seeds of 'Astra Semi-Double' *Platycodon grandiflorus* (Sakata™) were sown in expanded polystyrene trays (28 mL $cell^{-1}$) with commercial substrate [Tropstrato™: pine bark; peat; vermiculite; single superphosphate; potassium nitrate; pH = 5.8; water holding capacity = 130 %; electroconductivity (1.5:1 water/substrate) = 2.1 mS cm^{-1}]. One seed for each cell was sown at 0.5 cm deep. The seedlings started to emerge at 10-12 days after sowing (DAS) and, at 38 DAS, two seedlings (with two pairs of true leaves) were transplanted to plastic pots (nº 14; 9.8 cm high; 13.0 cm wide at the top; 1.0 L capacity). The pots were filled with 350 g of the substrate and 2.0 g of a homogeneous mixture of single superphosphate and potassium chloride (4:1) (Iversen & Weiler 1994). After that, all pots were arranged on a bench, with 10.0 × 8.0 cm spacing among them.

Water was supplied in alternate days with 150 mL pot^{-1} (substrate saturation point), and fertilization was provided via fertigation, distributed with the water supply, providing a solution of NPK 20:20:20 (Peters™: 20 % of N; 20 % of P; 20 % of K; 0.05 % of Mg; 0.05 % of Fe; 0.03 % of Mn; 0.01 % of B; 0.013 % of Cu; 0.025 % of Zn) (Kwon et al. 2019a).

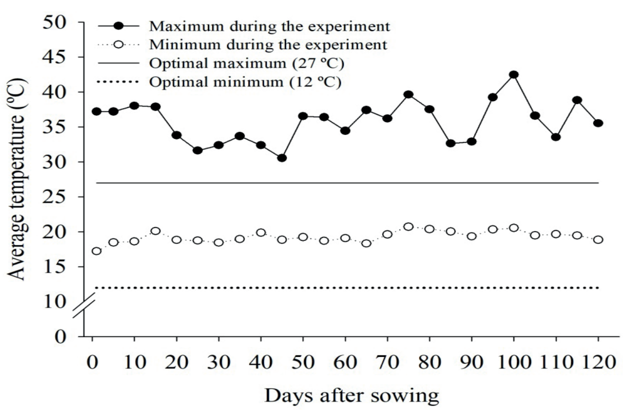


Figure 1. Maximum and minimum average temperatures inside the greenhouse, during the experiment, compared to the optimal maximum and minimum temperatures of platycodon cultivation proposed by Halevy et al. (2002).

A solution with 1.0 g L^{-1} of this soluble fertilizer was applied until 30 days after transplanting (DAT). After this period, the nutrient solution concentration was doubled. Only the pinching (removal of shoot tip) was performed at 12 DAT, as a cultivation practice.

A completely randomized blocks experimental design was used, in a 4 × 5 factorial scheme, with four replicates, totaling 80 pots and 160 plants. The treatments consisted of four varieties of 'Astra Semi-Double' platycodon (Blue, Lavender, Pink and White) and five PBZ doses (0, 1.25, 2.5, 3.75 and 5.0 mg pot^{-1}). Each experimental unit was composed of a specific pot.

The active ingredient paclobutrazol was used in the commercial formulation Cultar 250 SC (250 g L^{-1}). Five PBZ solutions (0, 25, 50, 75 and 100 mg L^{-1}) were prepared, from which 50 mL samples were taken to constitute the respective treatments (0, 1.25, 2.5, 3.75 and 5.0 mg pot^{-1}). Each sample was evenly distributed on the substrate of each replicate. This procedure was performed two more times, totaling three drench applications (37, 47 and 57 DAT), based on stem elongation, before flowering. All applications occurred between 8:00 a.m. and 9:30 a.m., with the substrate previously moistened to maximize the absorption by the plant and reduce losses by immobilization.

The growth evaluation occurred at 82 DAT, when each replicate had at least one open flower. The shoot length, stem diameter, number of leaves, anthesis (number of days between transplanting and opening of the first flower), number of flowers or flower buds, flower diameter, leaf area and shoot dry mass (leaves, stem and total) were evaluated. The leaf area was determined with the aid of a bench-top area meter (LI-COR™). For the dry masses, the plant parts were individually packed and placed in a drying oven with forced air circulation at 70 ºC, for 72 hours, and weighed in a semi-analytical scale (0.001 g) (Benincasa 2003).

The F test estimated the effect significance of the treatments through analysis of variance. The Tukey test compared the means at 5 % of probability, for the variety factor. The data were fitted to regression equations, to verify the effect of the PBZ doses. The significance of these regression models was estimated by the Student's t-test, at 0.1 % or 5 % of probability. The data from the number of leaves and leaf area were transformed into their square roots to attend the normality premise (Shapiro-Wilk's test). All analyses were performed using the 'ExpDes.pt' package (Ferreira et al. 2018), in the R 3.6.3 statistical software (R Core Team 2020).

RESULTS AND DISCUSSION

There was no interaction between the factors (varieties and PBZ concentrations) (Table 1). This result indicates that the varieties have similar vegetative and reproductive growth responses to the increasing PBZ doses applied to the substrate. Therefore, the commercial production of 'Astra Semi-Double' platycodon as a potted flower may become viable, since the producer will be able to adopt the same concentration of this regulator for the four varieties.

Although the chemical activity of this triazole can be affected by genetic parameters of different varieties (Francescangeli & Zagabria 2008), some reports indicate that the effects, in vegetative and reproductive growth parameters, of this regulator do not depend on the genotype of different potted flowers varieties (Lenzi et al. 2015, Carvalho-Zanão et al. 2018). Thus, it is essential to study the performance of different varieties within the same cultivar to confirm whether or not there are different responses to the PBZ application. For platycodon, the same PBZ doses can be used for potted production of the four varieties, since the PBZ doses acted independently of the variety on the evaluated variables.

Lavender had the highest shoot length, number of leaves, leaf area, stem dry matter, leaf dry matter and total dry matter, showing that it invested more in vegetative growth than the others (Table 1). As a result of this investment, it took more time to open the first flower (approximately 76 days), while Pink blossomed earlier, with 64 days (Table 1). Both differed statistically and from the other two varieties for this variable (anthesis). Since Lavender delayed more its anthesis, it produced a higher number of flowers or flower buds, as well as bigger flowers, being statistically similar only to the White variety for number of flowers or flower buds, and to the Blue variety for flower diameter.

Pink had the highest value for stem diameter and was statistically similar to the White variety. In general, Lavender was the most susceptible to stem bending, due to its high shoot length, thin stem diameter and larger flowers. These results show that the growth and flowering of platycodon are

Table 1. Shoot length (SL), stem diameter (SD), number of leaves (NL), anthesis (A), number of flowers or flower buds (NF), flower diameter (FD), leaf area (LA), stem dry mass (SDM), leaf dry mass (LDM) and total dry mass (TDM) of four varieties (VAR) of 'Astra Semi-Double' platycodon treated with paclobutrazol (PBZ; mg pot^{-1}) doses.

Sources of variation	SL (cm)	SD (mm)	NL[(1)]	A (days)	NF	FD (cm)	LA[(1)] (cm^2)	SDM (g)	LDM (g)	TDM[(2)] (g)
VAR (F_c)	36.90**	6.30**	33.38**	81.94**	3.94*	9.77**	20.96**	14.76**	23.06**	7.26**
Blue	17.92 b	6.05 b	9.53 b	70.65 b	20.95 b	7.00 a	21.36 b	0.81 b	1.71 b	3.94 b
Lavender	21.11 a	5.98 b	12.21 a	75.90 a	26.05 a	7.07 a	24.69 a	1.13 a	2.20 a	4.63 a
Pink	16.75 b	6.90 a	9.59 b	63.85 c	21.70 b	6.43 b	20.09 b	0.83 b	1.52 b	3.86 b
White	17.17 b	6.61 ab	9.48 b	69.05 b	23.05 ab	6.10 b	20.02 b	0.81 b	1.50 b	3.75 b
PBZ										
0	20.07	6.03	10.26	68.18	23.00	6.67	23.82	1.01	1.95	4.46
1.25	18.91	6.38	10.39	70.00	23.25	6.68	21.56	0.94	1.78	4.25
2.50	18.35	6.62	10.24	70.50	23.75	6.83	21.59	0.92	1.77	4.15
3.75	16.84	6.43	10.14	70.12	23.31	6.40	20.06	0.79	1.57	3.68
5.00	17.02	6.46	9.97	70.50	21.37	6.66	20.71	0.85	1.61	3.72
VAR × PBZ (F_c)	0.71^{ns}	1.21^{ns}	0.76^{ns}	1.64^{ns}	1.11^{ns}	0.90^{ns}	1.23^{ns}	0.67^{ns}	0.88^{ns}	1.15^{ns}
CV (%)	7.98	12.31	10.14	3.51	22.08	10.02	9.91	20.53	17.55	16.38

F_c: F calculated value (^{ns} p-value > 0.05; * p-value < 0.05; ** p-value < 0.001). Means followed by the same letter in the column do not differ by the Tukey test, at 5 % of probability. [(1)] Data transformed into their square roots ($y = \sqrt{x}$) to attend the normality premise of the analysis of variance. [(2)] Includes the dry mass of stem, leaves, flowers and flower buds.

significantly influenced by genetic and environmental factors associated with each variety (Kwon et al. 2019b).

Stem diameter, number of leaves, days until anthesis, number of flowers or flower buds, and flower diameter were not affected by the PBZ doses (Table 1). The other variables, except for leaf area, fitted to the polynomial regression with the linear model, decreasing with increasing PBZ doses (Figure 2). The polynomial regression with the quadratic model was significant for leaf area, with a minimum point (4.08 mg pot^{-1}; 20.45 cm^2) (Figure 2B).

The platycodon shoot length, leaf area and dry masses were reduced with the increasing PBZ doses. However, the number of leaves was not affected. Larcher et al. (2011) obtained similar results with PBZ application in camellia cultivars. These authors observed that the application of this regulator reduced the length and dry mass of stem and leaves, with no effect on the number of leaves in potted camellia. Nevertheless, Carver et al. (2014) reported a decrease not only in the shoot length and shoot dry mass, but also in the number of leaves, with an increasing PBZ concentration in sea marigold.

This triazole reduces plant height due to the inhibition of the enzymatic activity of *ent*-kaurene oxidase, which catalyzes the conversion of *ent*-Kaurene to GA_{12} on the gibberellin biosynthesis pathway (Bishop et al. 2015). Therefore, the PBZ application interrupts the gibberellin synthesis and promotes a reduction in plant height, given that the stem elongation process is regulated by this hormone (Taiz et al. 2017).

Bosch et al. (2016) also reported a decrease in dry masses and attributed it to the stem internode reduction caused by PBZ. More compact plants have an architecture that does not favor the lower leaves' light absorption, and, consequently, these plants will produce and assimilate a smaller amount of photoassimilates.

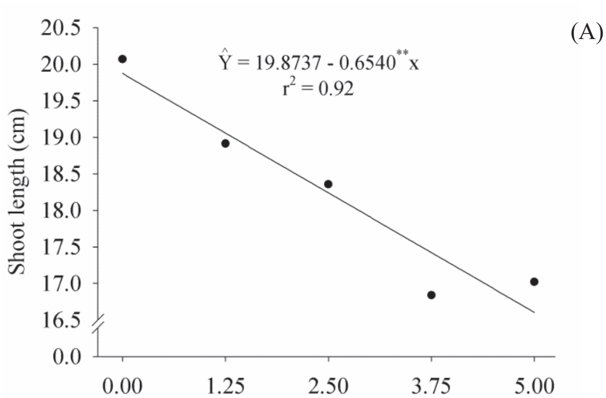
Similar results were also obtained by Takane et al. (2019), with a decrease in the shoot length and leaf and shoot dry mass of desert rose (*Adenium obesum*) in response to increasing PBZ concentrations. However, no statistical differences were observed for leaf area. Matsoukis et al. (2014) and Carvalho-Zanão et al. (2017) also observed a decrease in leaf area in response to increasing PBZ doses in lantana and rose, respectively. According to Leyser & Day (2015), this reduction in leaf area is due to a decrease in leaf expansion caused by the inhibition of gibberellin synthesis by this triazole.

Although the increasing PBZ doses caused reductions in shoot length, leaf area and dry masses, this regulator did not affect the flower diameter, number of flowers and flower buds, and anthesis of the varieties. In potted narcissus (Demir & Çelikel 2019) and zinnia (Ahmad et al. 2015) production, the PBZ application also reduced the shoot length.

This regulator also decreased the number of narcissus flowers and the diameter of zinnia flowers and delayed the anthesis of both species, differently from what was observed in platycodon. Furthermore, the PBZ application in potted red fire spike reduced not only the plant height, leaf area and total dry mass, but also the number and length of the inflorescences, and more days were required for anthesis (Rezazadeh et al. 2016).

Tinoco et al. (2011) obtained no statistical differences for anthesis, number and diameter of geranium inflorescences in response to PBZ doses. The application of this triazole can negatively affect the number and size of reproductive organs and extend the number of days to flower maturation. These effects were not observed in the platycodon varieties under study. The drench PBZ applications enabled a reduction in the vegetative growth of platycodon varieties without causing adverse effects on reproductive development.

Hwang et al. (2008) observed a reduction in stem diameter with the PBZ application in kalanchoe, whereas the application of this same regulator promoted an increment for this variable in lupine (Karaguzel et al. 2004). However, the stem diameter was not significantly affected by the PBZ application



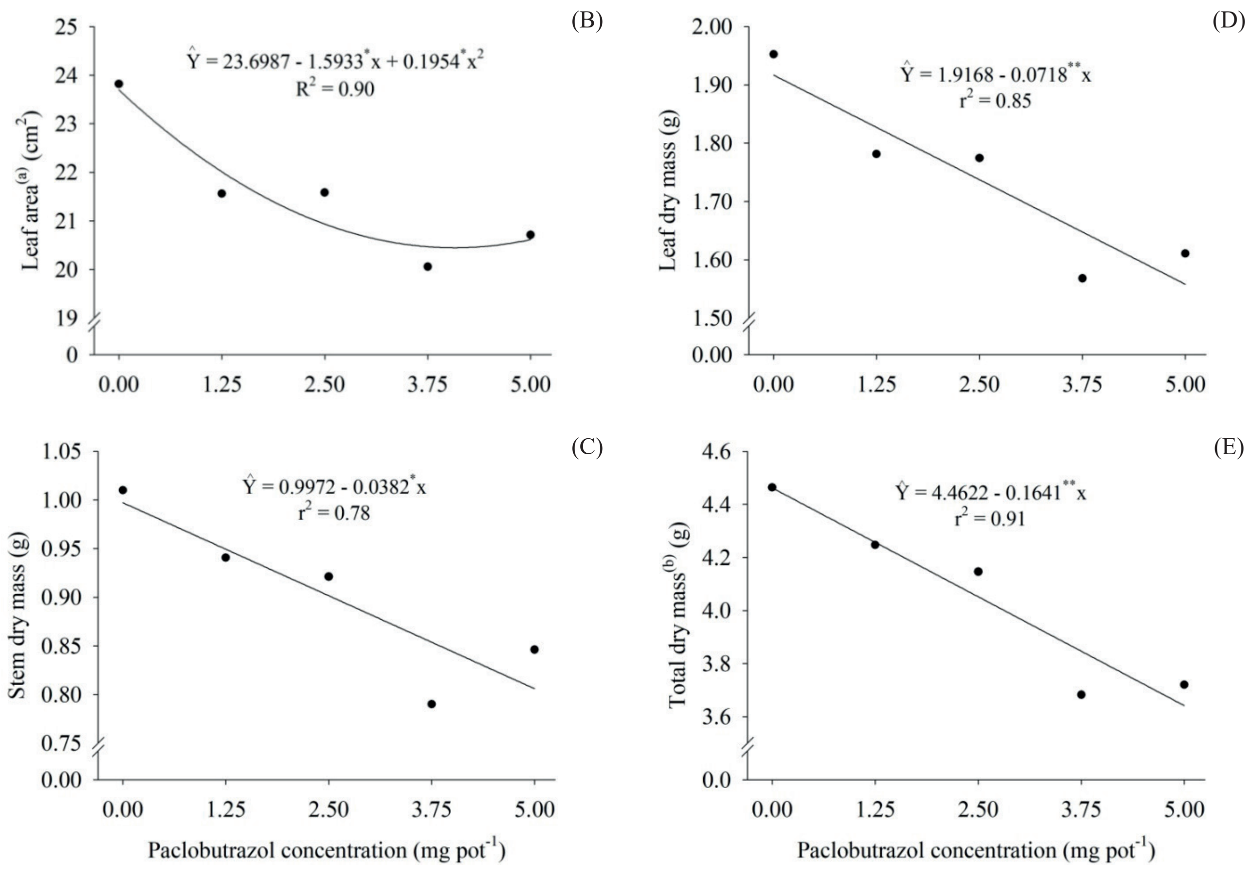


Figure 2. Shoot length (A), leaf area (B), stem dry mass (C), leaf dry mass (D) and total dry mass (E) of 'Astra Semi-Double' platycodon varieties treated with paclobutrazol doses. * p-value < 0.05; ** p-value < 0.001. (a) Data transformed into their square roots ($y = \sqrt{x}$) to attend the normality premise of the analysis of variance. (b) Includes dry mass of stem, leaves, flowers and flower buds.

in platycodon and, in other studies, sunflower (Koutroubas & Damalas 2015) and Thai tulip (Pinto et al. 2006). All previous comparisons confirm the efficiency of this triazole in controlling the vegetative growth of several flowers, including platycodon, and the different responses of other species to PBZ.

The control (0 mg pot^{-1}) was the only treatment in which the plants reached a height outside the range (20.07 cm) recommended by Barbosa et al. (2019) for the marketing of potted flowers, which is 1.5 to 2.0 times the pot height (Figure 2A). Although the other doses resulted in plants with appropriate heights for the pot size used, only the doses of 3.75 and 5.0 mg pot^{-1} provided, by visual analysis, more rigid and erect flowering stems, which are considered of better quality. These doses reduced, respectively, in 16.1 and 15.2 % the plant height, if compared to the control, with no phytotoxicity symptoms in the plants. Also, no deficiency symptoms were observed during the experiment.

The dose of 3.75 mg pot^{-1} is recommended, given that it was the lowest PBZ dose that provided the best results for growth control and quality of the final product. In addition, it must be applied three times during the plant cycle, in 10 days intervals, for platycodon, since it allows obtaining flowering stems that support the weight of their flowers, excluding the need for staking.

According to Grossi et al. (2009), plants grow faster under temperatures above their ideal range of cultivation. Therefore, they require higher concentrations or more frequent applications of the growth regulator. Considering that the platycodon cultivation occurred under temperatures above the ideal (Figure 1), it was necessary to apply one of these management strategies to use plant growth regulators for potted production.

Several applications with a low growth regulator concentration provide better results and a lower chance of phytotoxicity than a single application with a high concentration (Grossi et al. 2009). For that reason, three PBZ applications in lower doses were provided during the period of greatest elongation of the platycodon stem, characterized as the pre-flowering period. In ornamental peppers, a single drench application of 10 or 15 mg pot^{-1} of PBZ promoted a stunted growth with wrinkled and brittle leaves in the 'Biquinho Vermelha' variety and accession 2334PB, what makes this management inappropriate for both genotypes in potted production (França et al. 2018). Although a single application with a high growth regulator concentration is more advantageous for ornamental growers to reduce labor costs, the risk of phytotoxicity is much greater, significantly compromising the final visual quality of the product.

CONCLUSIONS

1. Drench paclobutrazol applications with the dose of 3.75 mg pot^{-1}, at 37, 47 and 57 days after transplanting, are recommended for the potted production of 'Astra Semi-Double' platycodon, in pots of 1.0 L capacity;
2. The effect of paclobutrazol doses is not dependent on the 'Astra Semi-Double' platycodon varieties (Blue, Lavender, Pink and White);
3. Regardless of the paclobutrazol application, Lavender has a more vigorous vegetative growth than the other varieties. Pink is characterized as an early-flowering variety, while Lavender is a late-flowering one;
4. The Lavender variety is the most susceptible to stem bending, and might not be indicated for commercial production as a potted flower.

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