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GROWTH RETARDANT INFLUENCE ON TRANSPIRATION AND MORPHOLOGICAL TRAITS OF *Pelargonium* × *hortorum* L.H. Bailey

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Abstract. Growth retardants may affect some morphological and physiological traits of plants. The aim of the research was to evaluate the influence of a single, flurprimidol spray on transpiration, growth and flowering of geranium. Flurprimidol (Topflor 015 SL) was applied once, as a foliar spray at 7.5, 15.0 or 22.5 mg dm^{-3}. The desirable heights of 'Classic Noblesse' and 'Classic Diabolo' geraniums were obtained with flurprimidol at concentrations of 22.5 and 15.0 mg dm^{-3}, respectively. Flurprimidol had no influence on stomatal conductance, transpiration rate, the number of days to flower, diminished plant diameter, leaf area, plant fresh and dry mass, inflorescence area index, inflorescence number and increased the inflorescence area to plant height ratio. Chemical name used: α-(1-methylethyl)-α-[4-(trifluromethoxy)phenyl]-5-pyrimidinemethanol (flurprimidol).

Key words: stomatal conductance, geranium, flurprimidol, growth inhibition

INTRODUCTION

Pelargoniums, commonly known as geraniums, are one of the most popular bedding and container plants, grown in almost every region of the country. Pelargoniums cultivated in containers should be short, well compact, densely foliated and have height proportional to the container. There are some geranium cultivars reaching the desired height but most of them are too high to be grown in pots. The cheapest and the fastest way to obtain short, with a good habit and of high quality ornamental plants is application of growth retardants. These chemicals can also reduce leaf area [Pobudkiewicz 2006], intensify green leaf pigmentation [Pobudkiewicz 2000a, Pobudkiewicz 2014], influence flowering [Pobudkiewicz 2008] and may reduce the number of insects on plants [Pobudkiewicz et al. 2013]. Growth retardants of old generation were applied at very high doses and with multiple applications [Tayama and Carver 1990] which was

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costly and time consuming. Development of new generation growth retardants (e.g., flurprimidol) has enabled the use of only one application of these chemicals, at very low doses in order to obtain well compact and short plants. Flurprimidol (a pyrimidine) belongs to the ent-kaurene oxidase inhibitors which cause inhibition of gibberellin biosynthesis [Reed et al. 1989], thereby inhibiting the process of plant cell elongation. As a consequence thereof flurprimidol treated plants have shorter internodes. Flurprimidol has a long duration of effectiveness in the plant tissues and a relatively high growth retarding activity in a broad spectrum of ornamental plants [Pobudkiewicz and Nowak 1994, Pobudkiewicz 2000a, Pobudkiewicz 2006, Pobudkiewicz and Treder 2006, Barnes et al. 2013, Bąbolewski and Pancerz 2014, Pobudkiewicz 2014, Smith et al. 2014].

A quantity of water transpired by plants might depend on the number and size of their leaves. Geraniums with small leaves require smaller quantities of water and they transpire less intensively relative to plants with large, densely spaced leaves. There are also studies indicating that growth retarding chemicals can influence the transpiration of water in plants [Schuch 1994, Jaleel et al. 2007] however there is no research on the influence of flurprimidol on transpiration in geranium. Due to the lack of such information we decided to investigate the effect of flurprimidol on geranium transpiration. The purpose of this study was to determine the impact of flurprimidol applied as a single spray on transpiration rate per unit leaf area and morphological traits of 'Classic Noblesse' and 'Classic Diabolo' geraniums.

MATERIALS AND METHODS

The experiment was conducted during two growing seasons. Rooted, vegetative cuttings of 'Classic Noblese' and 'Classic Diabolo' geraniums (*Pelargonium* × *hortorum* L.H. Bailey) were potted individually into 12 cm plastic pots containing the commercial substrate TS2 based on blend of white sphagnum peat (Klasmann Deilmann GmbH, Geeste, Germany) and amended with Osmocote Exact (4 g dm^{-3} of substrate). Plants were grown in a glasshouse under natural daylength with minimum night and day temperatures of 16 and 20°C, respectively. Inflorescences were regularly removed until the date of the flurprimidol treatment. The plants were selected for uniformity prior to growth retardant application. Flurprimidol (Topflor 015 SL) was applied as a single, foliar spray, at concentrations of 7.5, 15.0 and 22.5 mg dm^{-3} when the plants had developed three to five expanded true leaves. Control plants were treated with tap water. Geraniums were sprayed until the foliage and stems were thoroughly covered but the spray solution was not allowed to drop off from the plants into the medium. Flurprimidol applications were performed early in the morning and the environmental conditions were as follows, relative humidity: 51%, air temperature: 18°C and sky cloudy.

Data taken included total plant height [during the experiment, there was measured the length of each flowering stem on the plant (stem length was the distance from the pot rim to the top of the inflorescence)], leaf canopy height (measured from the pot rim to the top of the foliage – the measurements were performed seven times, once every two weeks from the date of flurprimidol application), plant diameter, leaf area (determined for fully expanded leaves, developed after flurprimidol application (stationary planimeter, Delta-T Devices, LTD., Cambridge, UK), inflorescence area index [of each of the flowering stem was determined by using the formula for an ellipse (widest inflorescence diameter × shortest inflorescence diameter × π)/4] and petal size (the average of the widest petal diameter and the petal diameter 90° across). The inflorescence area to plant height ratio was calculated by dividing inflorescence area index by final plant height as a measure of the aesthetic ratio of "color" to height. Days to flower (the number of days from plant potting until the first flower within an inflorescence opened). The measurements of stomatal conductance to water vapor and transpiration rate per unit leaf area (LI-1600 Steady Porometer from Li-COR) were performed at midday on attached, expanded leaves that developed after flurprimidol application. The fresh mass of each whole plant and dry mass (the plants were dried in a 70°C oven until they reached a constant mass) were recorded at the end of the experimental period.

The experiment was arranged as a randomized complete block design with three replications per treatment. Data were analyzed using the two-way ANOVA method as a synthesis of two years. Means were separated with the Duncan's multiple range test at the 0.05 significance level. Approximation of the leaf canopy height changes across vegetation time at different flurprimidol concentrations was performed using logistic function:

$$y = \frac{A}{1 + b \cdot e^{-kt}}$$

where:
A – asymptotic value of final height;
b, k – parameters,
t – time of growth.

Significance of applied model and parameters were verified statistically basing on the correlation coefficient R and t test, respectively. All calculations were done with the statistical software STATISTICA 10.0 [Statsoft, Inc. 2011].

RESULTS AND DISCUSSION

Effects of growth retardant on transpiration, leaf stomatal conductance and morphological traits of both geranium cultivars were similar in two growing seasons. Flurprimidol at concentrations of 7.5–22.5 mg dm^{-3} had no significant influence on leaf stomatal conductance to water vapor of 'Classic Noblesse' and 'Classic Diabolo' geraniums relative to the control (tab. 1). Single growth retardant applications at all concentrations also had no effect on transpiration rate per unit leaf area of both geranium cultivars (tab. 1). 'Classic Noblesse' geraniums carried out the transpiration per unit leaf area at a similar level compared to 'Classic Diabolo'. The results obtained in this study are in accordance with some earlier reports which showed that flurprimidol had no effect on transpiration in *Euphorbia pulcherrima* Wild. [Pobudkiewicz 2014], *Forsythia spectabilis* [Vaigro-Wolf and Warmund 1987], *Acer rubrum*, *Juglans nigra* and *Quer-*

cus palustris [Sterrett et al. 1989] but other reports indicate that other growth retardants may influence transpiration. For example, transpiration was reduced by paclobutrazol or uniconazole in *Catharanthus roseus* (L.) G. Don. [Jaleel et al. 2007] and *Dendranthema grandiflora* Tzvelev 'Dalvina' [Schuch 1994], respectively. In the present study, no effect of flurprimidol on geranium transpiration may be due to the fact that the measurements of transpiration were carried out in a relatively long time (10 weeks) after the application of growth retardant. Some studies indicate that transpiration can be reduced in a short time after retardant application. For example, flurprimidol decreased stomatal conductance and transpiration rate of pruned *Euonymus fortunei* three days after treatment but had no impact if measurements were performed eighteen days following growth retardant application [Norcini 1991]. In this study no effect of flurprimidol on geranium transpiration may also be connected with the level of abscisic acid (ABA) in plants. ABA is the hormone that triggers closing of the stomata when soil water is insufficient to keep up with transpiration. Flurprimidol was reported to reduce the ABA contents in plants [Graham et al. 1994] while other growth retardants, which resulted in stomata closure, increased the ABA content in plants [Ulger et al. 2010]. Perhaps in 'Classic Noblesse' and 'Classic Diabolo' geraniums flurprimidol has not influenced the endogenous abscisic acid content, which is responsible for closing of stomata and thus the growth retardant could not affect the transpiration.

Table 1. Effect of flurprimidol on stomatal conductance to water vapor (g_s) and transpiration rate (T) per unit leaf area of geranium

Flurprimidol concentrations (mg dm^{-3})	g_s (mmol m^{-2} s^{-1})		T (mmol m^{-2} s^{-1})	
	'Classic Noblesse'	'Classic Diabolo'	'Classic Noblesse'	'Classic Diabolo'
Control	149.7 b	141.6 ab	2.81a	2.68 a
7.5	145.7 ab	136.9 ab	2.73a	2.61a
15.0	146.9 ab	128.6 a	2.76 a	2.46a
22.5	148.0 ab	131.5ab	2.88 a	2.52a

Data averaged over two growing seasons. Means followed by the same letter do not differ significantly at p = 0.05, according to Duncan's Multiple Range Test

In the study reported here flurprimidol appeared to be very effective growth retardant for controlling plant height of tested geranium cultivars. A single flurprimidol treatment was sufficient to achieve short and of good quality plants (fig. 1a). Growth retardant application of 7.5 mg dm^{-3}, resulted in 'Classic Noblesse' and 'Classic Diabolo' shoots that were 18 and 28% shorter, respectively, than the control plants. Higher flurprimidol doses resulted in further inhibition of stem elongation in both cultivars. Plant height response to flurprimidol treatment varied with cultivar. The desirable geranium height (17–20 cm) was obtained with flurprimidol at 15.0 mg dm^{-3} for 'Classic Diabolo' and 22.5 mg dm^{-3} for 'Classic Noblesse'. This study indicates that growth retardant doses should be differentiated depending on geranium cultivar. This concurs with results obtained by Pobudkiewicz [2000b] who showed differences among seed propagated geranium cultivars regarding the need for height control, e.g., 'Ringo 2000 Light Salmon' and 'Pinto Salmon' geraniums required higher flurprimidol concentration, relative to 'Ringo 2000 Violet' and 'Ringo 2000 Deep Rose'. It seems that vegetatively propagated 'Classic Noblesse' and 'Classic Diabolo' geraniums, used in this study, were very sensitive to flurprimidol application because a single flurprimidol treatment at 15.0 mg dm^{-3} resulted in 34.5% (on average) shorter plants while seed propagated geraniums, treated with this same dose, were on average 23.5% shorter as compared to the control [Pobudkiewicz 2000b]. Other seed propagated geranium cultivars, treated even with 2-fold higher dose of flurprimidol were on average only 23.8% shorter, relative to the untreated plants [Zawadzińska 2013]. The results presented in this study show that the efficacy of flurprimidol is superior to growth retardants of old generation e.g., chlormequat. Flurprimidol applied only once, at very low concentrations (15.0–22.5 mg dm^{-3}) was sufficient for proper height suppression of 'Classic Diabolo' and 'Classic Noblesse' geraniums while chlormequat had to be applied three times at 1500 mg dm^{-3} in order to achieve short 'Grand Prix', 'Atlantis' and 'Rocky Mountain' geraniums [Tinoco et al. 2011]. In geranium cultivation, single flurprimidol treatment, at very low concentrations (relative to e.g., triple chlormequat application, at very high concentrations) has also some environmental benefits and the economic advantage to producers due to reduced labor costs. Good regulating activity of a single flurprimidol treatment, at very low doses, was also observed in other plant species, e.g., *Euphorbia pulcherrima* [Pobudkiewicz 2014], oriental hybrid lily [Pobudkiewicz and Treder 2006] and many other plant species grown in pots [Pobudkiewicz 2006].

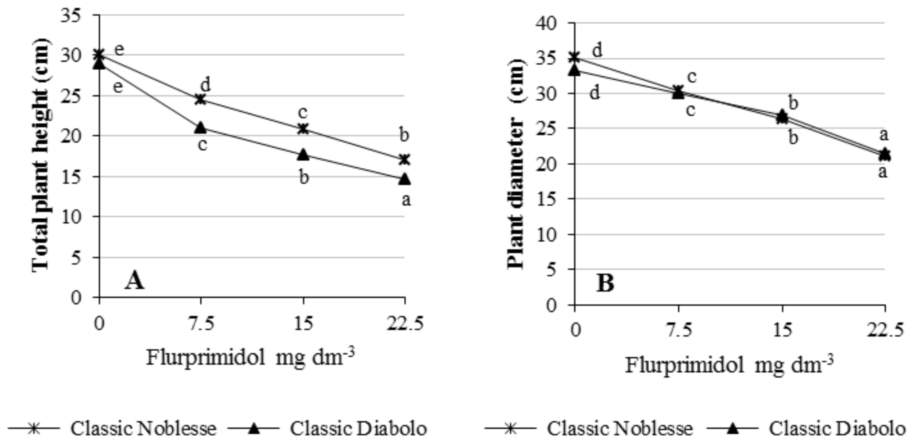

Fig. 1. Total plant height (A) and plant diameter (B) of geranium as affected by flurprimidol applied as single, foliar spray. Data averaged over two growing seasons. Means followed by different letters differ significantly at p = 0.05, according to Duncan's multiple range test

The diameters of flurprimidol sprayed ‘Classic Noblesse’ and ‘Classic Diabolo’ were also smaller as compared to the control plants and geraniums were narrower with increasing growth retardant concentrations (fig. 1b). Flurprimidol at 7.5, 15.0 and 22.5 mg dm^{-3} reduced the plant diameters up to 14, 25 and 40%, respectively. More compact ‘Classic Noblesse’ and ‘Classic Diabolo’ geraniums might be an economic advantage to commercial growers due to increased plant density on greenhouse benches and higher quality of plants. Improved shape of flurprimidol treated pot plants was also observed in seed propagated geranium [Pobudkiewicz 2000b] and other plant species, e.g., *Dianthus caryophyllus* [Pobudkiewicz and Nowak 1994], *Cuphea ignea* [Pobudkiewicz 2000a] or *Euphorbia pulcherrima* [Pobudkiewicz 2014].

Among many mathematical growth functions, the logistic function has a relatively large application for description of finished growth processes, mainly due to the ease of physiological interpretation of its parameters. Significant and high values (from 0.642 to 0.991) of the correlation coefficients indicated good approximation of the canopy height by logistic model (fig. 2). Time course of the growth for both cultivars was almost the same, except for flurprimidol at 15.0 mg dm^{-3}. This concentration inhibited the elongation of ‘Classic Diabolo’ shoots faster and more intensively than ‘Classic Noblese’ (almost twice lower value of “*b*” equation parameter). This effected final leaf canopy height of ‘Classic Diabolo’, which was stabilized on 84 day at the height of 11.4 cm.

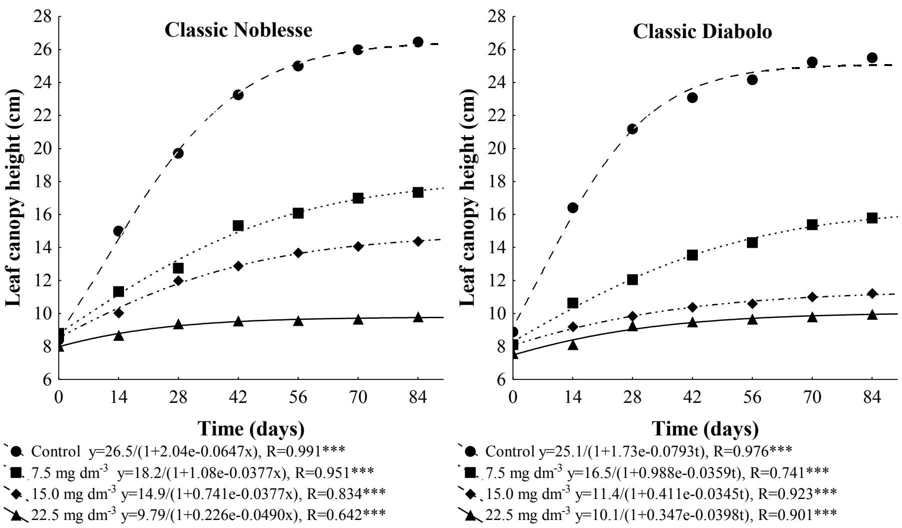

Fig. 2. Time dynamic of leaf canopy height (means) of geranium estimated by means of logistic functions at different flurprimidol concentrations (n = 21 for each flurprimidol concentration, *** – $p \leq 0.001$)

In this study, the fresh (fig. 3a) and dry (fig. 3b) mass of both geranium cultivars decreased as flurprimidol doses increased. As compared to the control, flurprimidol at 7.5, 15.0 and 22.5 mg dm^{-3} reduced the fresh mass of geranium cultivars up to 24, 43 and

65%, respectively (fig. 3a). Plant fresh mass response to flurprimidol treatment varied between cultivars and the fresh weight of 'Classic Diabolo' was smaller relative to 'Classic Noblesse'. A similar trend was observed for the dry mass of both geranium cultivars (fig. 3b). Decreased plant dry mass in response to growth retardant sprays corresponded with reduced plant height and resulted in plants with improved growth habit. Similar reductions in dry weight of plants treated with growth retardants have been widely reported [Schuch 1994, Pobudkiewicz 2014].

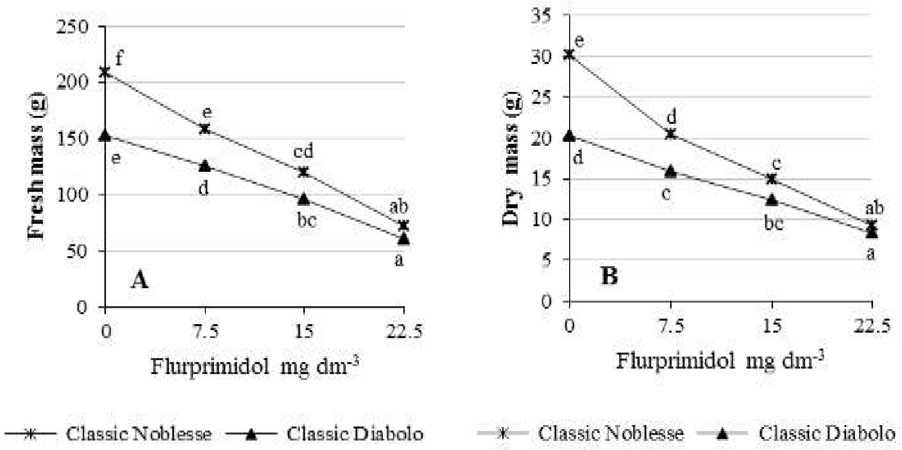

Fig. 3. Fresh (A) and dry (B) mass of geranium as affected by flurprimidol applied as a single, foliar spray. For further explanations see figure1

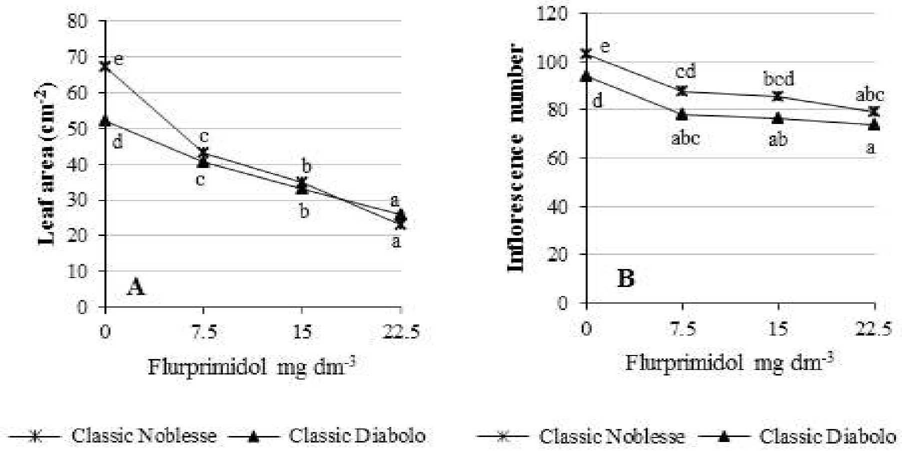

Fig. 4. Leaf area (A) and the inflorescence number (B) of geranium as affected by flurprimidol applied as a single, foliar spray. For further explanations see figure 1

Other growth parameters were also affected by growth retardant treatment. Compared to the control, the leaf areas of 'Classic Noblesse' and 'Classic Diabolo' geraniums treated with flurprimidol at 7.5 mg dm^{-3} were 36 and 23% smaller, respectively (fig. 4a). In both geranium cultivars higher flurprimidol concentrations resulted in further significant leaf area reduction. In this research project, the leaves of flurprimidol treated plants were smaller but they were proportional to the whole plant due to reduced size of the entire geranium. In this study, in flurprimidol treated geranium, the abscission of the oldest leaves in low portions of plants was not observed at the end of the production cycle in contrast to the untreated plants. In the control plants, in low portions of geranium, the leaves were turning yellow and then the leaves were falling. That resulted in an empty space between the pot rim and the first leaves on the plant which greatly diminished the plant quality. No leaf abscission in growth retardant treated plants might be associated with higher polyamine [Grossmann et al. 1987] and cytokinin [Grossmann 1990] contents, which delay aging of plants. That might be the reason why leaves in growth retardant treated plants remain green for longer duration and do not fall. 'Classic Noblesse' and 'Classic Diabolo' plants exposed to flurprimidol also had intensified green leaf pigmentation. In this experiment, were not collected data concerning the chlorophyll content but research conducted in other plant species has shown that intensified green leaf pigmentation in growth retardant treated plants might be associated with higher chlorophyll level [Kucharska and Orlikowska 2008, Lodeta et al. 2010].

Table 2. Effect of flurprimidol on geranium flowering

Flurprimidol concentrations (mg dm^{-3})	Petal size (cm)		Days to flower	
	'Classic Noblesse'	'Classic Diabolo'	'Classic Noblesse'	'Classic Diabolo'
Control	2.26 cd	2.33 d	48.4 b	46.8 ab
7.5	2.10 ab	2.26 cd	46.2 ab	44.3 a
15.0	2.08 ab	2.27 cd	45.5 a	46.8 ab
22.5	1.99 a	2.18 bc	46.3 ab	45.5 a

For further explanations see table 1

The results presented in this paper demonstrate that flurprimidol influenced geranium flowering. Relative to the untreated plants, growth retardant at 7.5 mg dm^{-3} slightly reduced the number of inflorescences but the higher concentrations (15.0–22.5 mg dm^{-3}) caused no additional, statistically significant retarding effect, compared to flurprimidol at 7.5 mg dm^{-3} (fig. 4b). Reduced number of flowers was also observed in other plant species treated with growth retardants [Schuch 1994, Pobudkiewicz 2008]. Flurprimidol when used at concentrations optimum for height suppression may not influence the flower size [Pobudkiewicz and Nowak 1994] but also can diminish flower diameter [Pobudkiewicz 2014]. The results reported here indicate that flurprimidol only slightly affected the petal size of both geranium cultivars (tab. 2). The petals of plants, sprayed with growth retardant, at the optimum for height control concentrations, were only 13% ('Classic Noblesse') and 4% ('Classic Diabolo') smaller than those of the control plants. The inflorescence area index of both geranium cultivars was also affected by tested chemical and inflorescences were smaller with increasing growth retardant concentrations (fig. 5a). Relative to the controls retardant, at the optimum for height control concentrations, resulted in 'Classic Noblesse' and 'Classic Diabolo' plants with smaller inflorescence area indices up to 23%. The inflorescence area index response to flurprimidol varied with cultivar. This is consistent with results obtained by Pobudkiewicz [2000b] in seed propagated geranium. The author has shown that depending on flurprimidol concentration the inflorescence diameters were up to 15% smaller relative to the control. Zawadzińska [2013] reported that the inflorescence diameters of flurprimidol treated seed propagated geraniums depended on the type of substrate. The growth retardant slightly diminished the inflorescence diameter in plants grown in coconut substrate but did not affect the inflorescence diameters in plants cultivated in peat substrate.

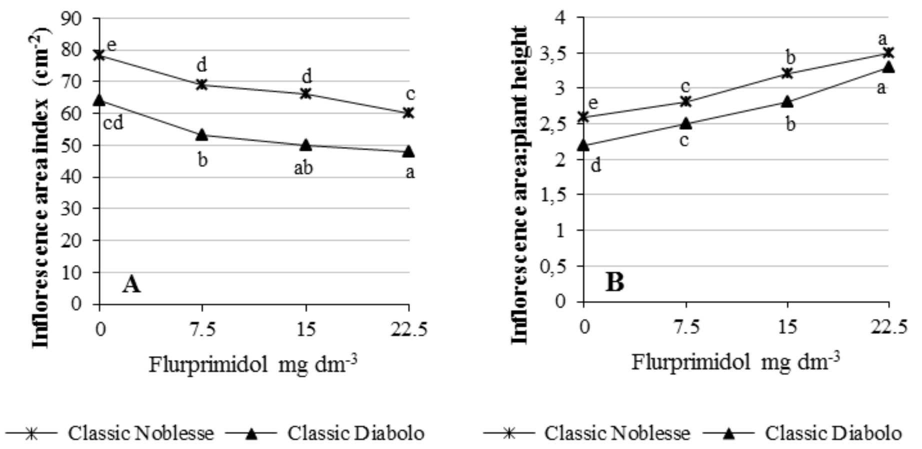

Fig. 5. Inflorescence area index (A) and inflorescence area/plant height ratio (B) of geranium as affected by flurprimidol applied as a single, foliar spray. Explanations: see figure 1

In this study we observed positive effect of flurprimidol sprays on the ratio of inflorescence area to plant height for both cultivars. The inflorescence area to plant height ratio increased with increasing flurprimidol concentrations from 7.5 to 22.5 mg dm^{-3} (fig. 5b). That ratio in geraniums, treated with flurprimidol at concentrations optimum for height control, has increased by 35 and 27% in 'Classic Noblesse' and 'Classic Diabolo', respectively. Although inflorescence area is smaller when plants are sprayed with flurprimidol, the smaller inflorescence area and suppressed plant height are proportional to each other. Therefore, the smaller inflorescence area does not negatively impact the aesthetic quality of finished plants treated with flurprimidol.

In this experiment, regardless of concentration, flurprimidol did not affect the time to flower of ‘Classic Noblesse’ and ‘Classic Diabolo’ geraniums (tab. 2). There were also no significant differences in the number of days to flower between cultivars. This is consistent with results obtained by Tayama and Carver [1990] using uniconazole and paclobutrazol sprays but Chung et al. [1998] reported that flowering of growth retardant treated geranium was significantly delayed. In contrast, in seed propagated geranium the effect of flurprimidol on the number of days to flowering varied with geranium cultivar and growth retardant dose [Pobudkiewicz 2000b]. The author reported that flurprimidol hastened flowering of some geranium cultivars by 5–8 days. In this study, no phytotoxicity or malformations were observed in growth retardant treated ‘Classic Noblesse’ and ‘Classic Diabolo’ geraniums.

CONCLUSIONS

1. Flurprimidol treatments at 7.5–22.5 mg dm^{-3} do not affect the stomatal conductance and transpiration rate per unit leaf area of both geranium cultivars.
2. Single flurprimidol sprays at 15.0 mg dm^{-3} and 22.5 mg dm^{-3} effectively inhibit stem elongation of ‘Classic Diabolo’ and ‘Classic Noblesse’ geraniums, respectively.
3. Flurprimidol sprays, at concentrations optimum for height control, increase the inflorescence area to plant height ratio by 27–35% depending on geranium cultivar.
4. Flurprimidol sprays at 7.5–22.5 mg dm^{-3} have no impact on the number of days to flower of both geranium cultivars.
5. Flurprimidol sprays intensify green leaf pigmentation and produce small, compact and decorative plants.

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WPŁYW RETARDANTU WZROSTU NA TRANSPIRACJĘ I CECHY MORFOLOGICZNE *Pelargonium × hortorum* L.H. Bailey

Streszczenie. Retardanty wzrostu mogą wpływać na pewne cechy morfologiczne i fizjologiczne roślin. Celem badań była ocena wpływu fluroprimidolu stosowanego dolistnie i jednokrotnie na transpirację, wzrost i kwitnienie pelargonii. Fluroprimidol (Topflor 015 SL) stosowano dolistnie, jednokrotnie, w stężeniach 7,5, 15,0 lub 22,5 mg dm^{-3}. Żądaną wysokość pelargonii ‘Classic Noblesse’ i ‘Classic Diabolo’ uzyskano, stosując fluroprimidol w stężeniach, odpowiednio, 22,5 i 15,0 mg dm^{-3}. Fluroprimidol nie miał wpływu na przewodność szparkową, transpirację, liczbę dni do kwitnienia, zmniejszył średnicę rośliny, powierzchnię liścia, świeżą i suchą masę rośliny, powierzchnię i liczbę kwiatostanów oraz zwiększył stosunek powierzchni kwiatostanów do wysokości rośliny. Nazwa chemiczna: α-(1-metyloetylo)-α-[4-(trifluorometoksyfenylo]-5-pirymidynometanol fluroprimidol).

Słowa kluczowe: przewodność szparkowa, pelargonia, fluroprimidol, zahamowanie wzrostu

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