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EFFECT OF GROWTH RETARDANT ON SOME MORPHOLOGICAL AND PHYSIOLOGICAL TRAITS OF CHRYSANTHEMUM

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Key words: pot chrysanthemum, flurprimidol, growth retardation, transpiration, stomatal conductance.

Abstract

The aim of this work was to evaluate the effectiveness of a single flurprimidol foliar spray on growth, flowering, transpiration rate and stomatal conductance of medium height chrysanthemums "Kodiak" and "Jewel Time", grown in pots. Flurprimidol applied once, as a foliar spray, at concentrations of 7.5, 15 or 22.5 mg dm^{-3} was effective in reducing stem extension without adverse side-effects. The degree of growth inhibition varied by cultivar and flurprimidol concentration. The desirable heights of "Jewel Time" and "Kodiak" chrysanthemums were obtained with flurprimidol at 7.5 or 22.5 mg dm^{-3}, respectively. Growth retardant slightly delayed anthesis, reduced the canopy width, the leaf area, plant dry weight and the number of inflorescences but had no effect on inflorescence diameter. There was no significant effect of flurprimidol on leaf stomatal conductance to water vapor and transpiration rate per unit leaf area of both chrysanthemum cultivars. Chemical name used: α-(1-methylethyl)-α-[4-(trifluromethoxy)phenyl]-5-pyrimidinemethanol (flurprimidol).

WPŁYW FLUROPRIMIDOLU NA NIEKTÓRE MORFOLOGICZNE I FIZJOLOGICZNE CECHY CHRYZANTEM

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Słowa kluczowe: chryzantema doniczkowa, fluroprimidol, retardant wzrostu, transpiracja, przewodność szparkowa.

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Abstrakt

Celem pracy była ocena skuteczności fluroprimidolu, stosowanego dolistnie, jednokrotnie, na wzrost, kwitnienie, transpirację i przewodność szparkową średnio silnie rosnących chryzantem "Kodiak" i "Jewel Time;, uprawianych w doniczkach. Fluroprimidol stosowany jednokrotnie, dolistnie, w stężeniach 7.5, 15 lub 22.5 mg dm^{-3} skutecznie hamował wydłużanie się pędów, nie powodując niepożądanych skutków ubocznych. Stopień zahamowania wzrostu zależał od odmiany i stężenia fluroprimidolu. Pożądane wysokości chryzantem "Jewel Time" i "Kodiak" uzyskano stosując fluroprimidol, odpowiednio w stężeniach 7.5 lub 22.5 mg dm^{-3}. Retardant wzrostu nieznacznie opóźnił kwitnienie, zmniejszył średnicę roślin, powierzchnię liścia, suchą masę roślin i liczbę kwiatostanów ale nie miał wpływu na średnicę kwiatostanu. Nie stwierdzono istotnego wpływu fluroprimidolu na przewodność szparkową liści i transpirację na jednostkę powierzchni liścia obu odmian chryzantem. Nazwa chemiczna: α-(1-metyloetylo)-α-[4-(trifluorometoksyfenylo]-5-pirymidynometanol (fluroprimidol).

Introduction

Flurprimidol (a pyrimidine) belongs to a group of growth retardants which inhibit the *ent*-kaurene oxidase in the biosynthetic pathway of gibberellins. The elongation of cells mainly depends on the level of gibberellins in the plant tissues (GRAEBE 1987). The *ent*-kaurene oxidase inhibitors cause inhibition of gibberellin biosynthesis (REED et al. 1989), thereby inhibiting the elongation of plant cells. Thanks to shorter cells, growth retardant treated plants also have shorter internodes, but the number of internodes and leaves on the plant remains unchanged. These compounds can also influence leaf size, flower size, pedicel length, number of flowers, flower longevity, number of days to anthesis and the aging process of plants. Flurprimidol has a long duration of effectiveness in the plant tissues and can be used once, at very low doses, in order to receive short and well compact plants. Flurprimidol applied as a single application, at very low doses, has proved very effective in restricting extension growth of *Globba winitii* Siam (POBUDKIEWICZ and PODWYSZYŃSKA 1999), *Pelargonium* x *hortorum* L.H. Bailey (POBUDKIEWICZ 2000a), *Cuphea ignea* (POBUDKIEWICZ 2000b), *Streptocarpus hybridus* (POBUDKIEWICZ 2000c), dwarf alstroemeria (POBUDKIEWICZ et al. 2000), *Helianthus annuus* (WHIPKER et al. 2004), oriental hybrid lily (POBUDKIEWICZ and TREDER 2006), *Euphorbia pulcherrima* (CURREY and LOPEZ 2011) and many other flowering plants cultivated in pots.

Chrysanthemum, one of the most important ornamental crops worldwide can be produced both as pot plant or cut flower. A major problem with chrysanthemums grown as pot plants is plant height greater than desired and an irregular plant habit. The fastest and the cheapest way to improve compactness and to reduce the height of chrysanthemums is application of growth retardants. Many researchers have shown that there is a great variation in sensitivity of chrysanthemum cultivars to application of growth

retardants. For example, TAYAMA and CARVER (1992) have demonstrated that uniconazole at 20 mg dm^{-3} applied as a foliar spray to *Dendranthema grandiflora* Tzvelev reduced the height of "Bright Golden Anne" plants by 27% as compared to the control plants. On the other hand, STARMAN (1990) applying uniconazole at this same concentration (20 mg dm^{-3}) to *Dendranthema grandiflora* Tzvelev, "Puritan" and "Favor" obtained very little growth inhibition (8%). Due to different responses of chrysanthemums to growth retardant treatments, doses of these compounds, required to inhibit stem elongation, should be determined individually for each variety or a group of varieties. For retardation of chrysanthemum growth, have been used various growth retardants, including daminozide (PAPAFOTIOU and VAGENA 2012), chlormequat chloride (HAGUE et al. 2007), paclobutrazol (PASIAN 1999) but there is very little information on the influence of flurprimidol on height suppression and flowering of chrysanthemums. Flurprimidol, applied as a foliar spray, has been reported to suppress stem elongation of tall-growing *Dendranthema grandiflora* Tzvelev "Altis" and "Surf" POBUDKIEWICZ and NOWAK 1997) but it has not been used to control the plant growth of medium height chrysanthemums "Kodiak" and "Jewel Time".

Chrysanthemums have very high demand for water and they transpire a lot of water. A quantity of water transpired by plants might depend on the number and size of their leaves. Chrysanthemums with small leaves require smaller quantities of water and they transpire less intensively compared to cultivars with large, densely spaced leaves. There are reports which indicate that growth retardants might also reduce transpiration rate in some plants (JALEEL et al. 2007) but there is no information concerning the influence of flurprimidol on transpiration not only in chrysanthemums but also in other flowering pot plants. Due to the lack of such information an attempt was made to examine the effect of flurprimidol on chrysanthemum transpiration. This study was undertaken to evaluate the effectiveness of a single flurprimidol application on growth, flowering and transpiration of medium height chrysanthemums (*Dendranthema grandiflora* Tzvelev) "Kodiak" and "Jewel Time;, grown in pots.

Materials and Methods

The experiment was repeated twice, in growing seasons 2010 and 2011, from August till November. Medium height "Kodiak" and "Jewel Time" chrysanthemums (both cultivars: 7-week photoperiodic response) were used in this study. The chrysanthemums were obtained as rooted cuttings from a commercial source and planted into 12 cm pots (3 cuttings per pot). The pots

were filled with commercial substrate TS2 (Klasmann Deilmann GmbH, Geeste, Germany) based on blend white sphagnum peat. Plants were grown in a greenhouse with temperature ranging from 17°C to 25°C during the day and 14°C to 18°C during the night. After the cuttings were established, the upper nodes were removed leaving 4 leaves on the remaining plant. The plants were grown in the greenhouse, in conditions of controlled short photoperiod (black-out from 5 p.m. until 7 a.m.) since the day of potting. Composition of nutrient for chrysanthemum fertilisation was different for vegetative phase: (mg dm^{-3}) N-217, P-62, K-285, Ca-160, Mg-24, S-SO_4 <50, Fe-0.84, Mn-0.27, Zn-0.20, B-0.11, Cu-0.032 and Mo-0.048 and generative phase: (mg dm^{-3}) N-140, P-46, K-254, Ca-100, Mg-18, S-SO4 <50, Fe-0.84, Mn-0.27, Zn-0.20, B-0.11, Cu-0.032 and Mo-0.048. Electrical conductivities (EC) for vegetative phase and generative one were 2.2 and 1.6 mS cm^{-1}, respectively.

The plants were selected for uniformity prior to growth retardant application. Chrysanthemums were treated with flurprimidol (Topflor 015 SL) following pinching, when lateral shots were 3–5 cm in length. Flurprimidol was applied as a single foliar spray, at concentrations of 7.5, 15 and 22.5 mg dm^{-3}. The control plants were treated with a tap water at the same time. Chrysanthemums were sprayed with a hand sprayer (1 liter) until whole plants were thoroughly covered with spray solution but the solution was not allowed to drop off. No surfactants were added to the flurprimidol spray solutions. Environmental conditions on the day of growth retardant application were as follows: air temperature – 18°C, relative humidity – 75%, sky cloudy, time of application – early in the morning.

Data recorded at the beginning of flowering included the following measurements: shoot length (was the distance from substrate surface to the top of the inflorescence), canopy width (width was determined from the average of two canopy diameter measurements), number of inflorescences (including all visible buds) and leaf area (determined for fully expanded leaves, developed after flurprimidol application). Leaf area was measured using stationary planimeter (Delta-T Devices, LTD., Cambridge, UK). When plants were fully flowering, the inflorescence diameter was measured. Time to anthesis was evaluated on the day when the ray florets of the first inflorescence per plant were completely unfolded. Fully expanded leaves that developed after flurprimidol application were used for measurements of stomatal conductance to water vapor and transpiration rate (per unit leaf area). The measurements of transpiration rate and stomatal conductance were performed at midday on attached leaves using the LI-1600 Steady Porometer from Li-COR. At the end of the experimental period, the whole plants were cut off at the base (just above the soil surface). Then, the fresh weight of each plant was recorded. After that the plants were dried at 70°C until they reached a constant mass to determine dry weights.

The experiment was arranged as a randomized complete block design with three replications (each one included 5 plants per treatment). The data were averaged over two growing seasons. The experimental data were subjected to an analysis of variance. The Duncan's multiple range test at 5% was used for mean separation. Values of $p = 0.05$ were considered to be statistically significant. All statistical analyses were performed with Statistica package, version 10 (2011).

Results

The influence of growth retardant concentration on "Kodiak" and "Jewel Time" chrysanthemums was similar in two growing seasons. Flurprimidol appeared to be very effective for controlling plant height of tested cultivars and a single application was sufficient to achieve short and good quality plants (Figure 1a). The degree of growth inhibition varied by cultivar and retardant concentration. In both cultivars, shoots were shorter when plants received higher flurprimidol applications. Compared to the control, retardant at concentration of 7.5 mg dm^{-3}, applied to "Jewel Time" and "Kodiak" resulted in 41% and 25% shorter shoots, respectively. Higher flurprimidol doses resulted in further inhibition of stem elongation of both cultivars. The shoots of "Jewel Time" and "Kodiak" plants sprayed with the highest retardant concentration were 54% and 42% shorter, respectively relative to the untreated plants. The desirable plant height (16–18 cm) for "Jewel Time" was obtained with the lowest flurprimidol concentration (7.5 mg dm^{-3}) but for "Kodiak" the highest growth retardant concentration (22.5 mg dm^{-3}) was needed in order to achieve the proper height. There were also differences in shoot length between tested cultivars. Shoots of flurprimidol treated "Jewel Time" were about 25% shorter than shoots of similar plants of "Kodiak".

Flurprimidol also had an apparent effect on canopy width of both cultivars at both growing seasons. At the time of flowering, the canopies of "Jewel Time" and "Kodiak" plants treated with flurprimidol at all tested doses were much narrower compared to the control and those differences were statistically significant (Figure 1b). Relative to the untreated plants, flurprimidol at 7.5 mg dm^{-3} reduced canopy widths of "Jewel Time" and "Kodiak" by 20% and 12%, respectively. Higher growth retardant doses resulted in further reduction of canopy widths of both cultivars. Compared to the control the canopies of "Jewel Time" and "Kodiak" plants treated with the highest flurprimidol concentration were 26% and 19% narrower, respectively. Growth retardant treated chrysanthemums were smaller in size and more compact. Shoots of flurprimidol treated chrysanthemums were not only shorter, more rigid but

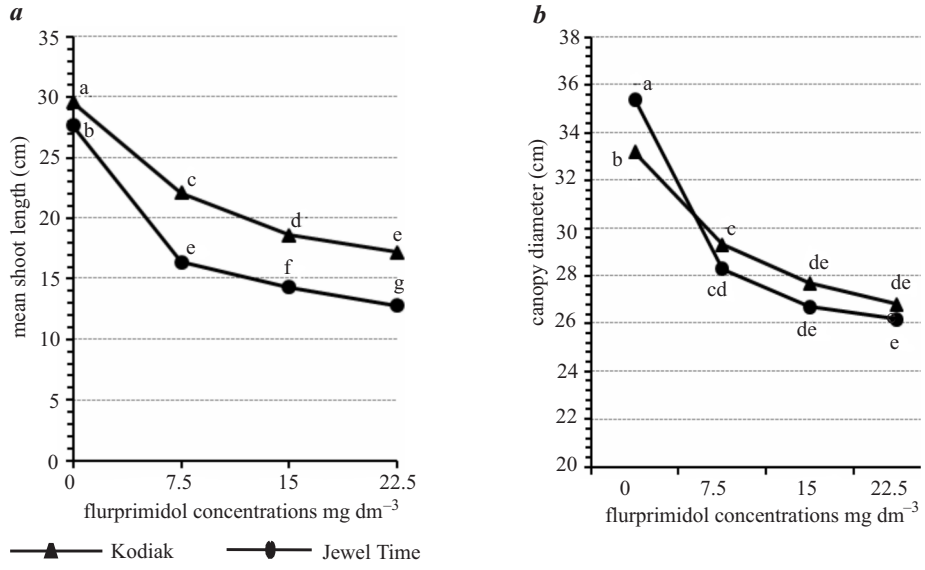

Fig. 1. Mean shoot length (*a*) and canopy diameter (*b*) of "Kodiak" and "Jewel Time" chrysanthemums as affected by flurprimidol applied as single, foliar spray. Data averaged over two growing seasons. The means indicated by the same letter do not differ significantly at $p = 0.05$, according to Duncan's multiple range test

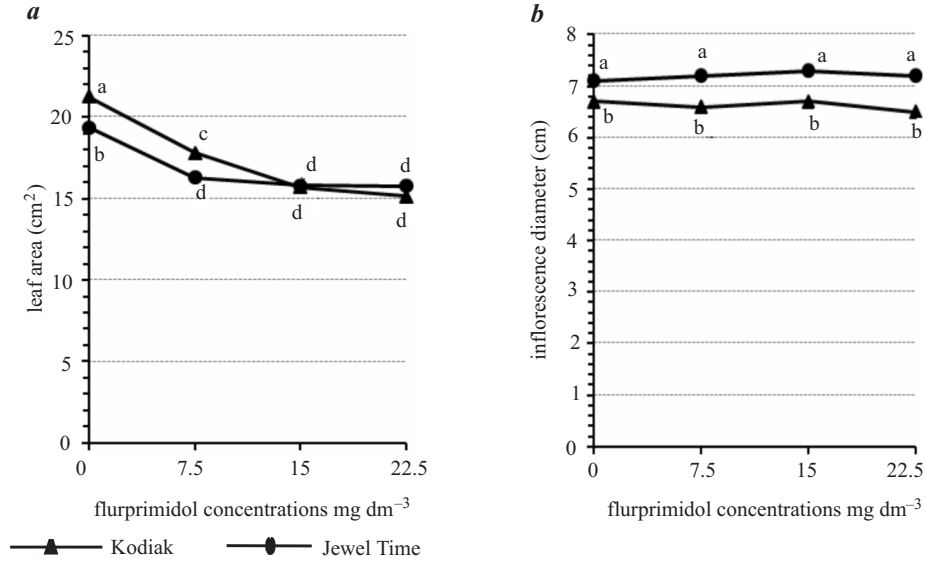

Fig. 2. Effect of flurprimidol applied as single, foliar spray on leaf area (*a*) and inflorescence diameter (*b*) of "Kodiak" and "Jewel Time" chrysanthemums. Data averaged over two growing seasons. The means indicated by the same letter do not differ significantly at $p = 0.05$, according to Duncan's multiple range test

also aligned relative to each other thus the inflorescences on the plant were placed on the same level, which greatly increased the plant quality. Plants exposed to flurprimidol also had intensified green leaf pigmentation. There was almost no abscission of the oldest leaves in low portions of growth retardant treated plants, relative to the control. No phytotoxicity was observed on flurprimidol treated chrysanthemums.

Growth parameters other than shoot length and canopy width were also affected by flurprimidol. The reactions of tested cultivars to increasing retardant concentrations were similar at both growing seasons. There were significant differences in leaf area between control plants and chrysanthemums treated with flurprimidol at 7.5–22.5 mg dm^{-3} (Figure 2a). The leaves of "Kodiak" and "Jewel Time" chrysanthemums treated with the lowest flurprimidol concentration (7.5 mg dm^{-3}) were 16% smaller as compared to the control. In "Jewel Time", higher retardant doses did not result in further leaf area reduction. In "Kodiak" leaf area was retarded with increasing flurprimidol concentrations up to 15 dm^{-3} but the higher concentration (22.5 mg dm^{-3}) caused no additional, statistically significant retarding effect, compared to flurprimidol at 15 mg dm^{-3}.

There was no effect of flurprimidol on inflorescence diameter of both cultivars but inflorescences of "Kodiak" were slightly smaller compared to those of "Jewel Time" (Figure 2b). Inflorescences of "Kodiak" plants treated with the highest retardant concentration (22.5 mg dm^{-3}) were 10% smaller than those of similar plants of the "Jewel Time".

Each chrysanthemum cultivar responded differently to growth retardant application, but the trend of reaction was the same at two growing seasons. On the day of taking data, there were significant differences between the number of inflorescences on the control plants and those of plants treated with flurprimidol at all tested doses (Figure 3a). Compared to the control, flurprimidol at 7.5 mg dm^{-3} reduced the number of inflorescences of "Kodiak" by 13% but the higher concentrations (15–22.5 mg dm^{-3}) caused no additional reduction. Relative to the control, "Jewel Time" plants sprayed with flurprimidol at 7.5 mg dm^{-3} and 15 mg dm^{-3} had 18% and 29% less inflorescences, respectively, but the higher concentration (22.5 mg dm^{-3}) resulted in plants of approximately the same number of inflorescences as those treated with retardant at 15 mg dm^{-3}.

Compared to the control flurprimidol slightly delayed anthesis of both tested cultivars when applied at concentration of 7.5 mg dm^{-3} and above (Figure 3b). Anthesis occurred within a few days in all growth retardant treated "Jewel Time" and "Kodiak" plants. There were differences in the number of days to anthesis between cultivars. "Kodiak" reached anthesis four days earlier than "Jewel Time".

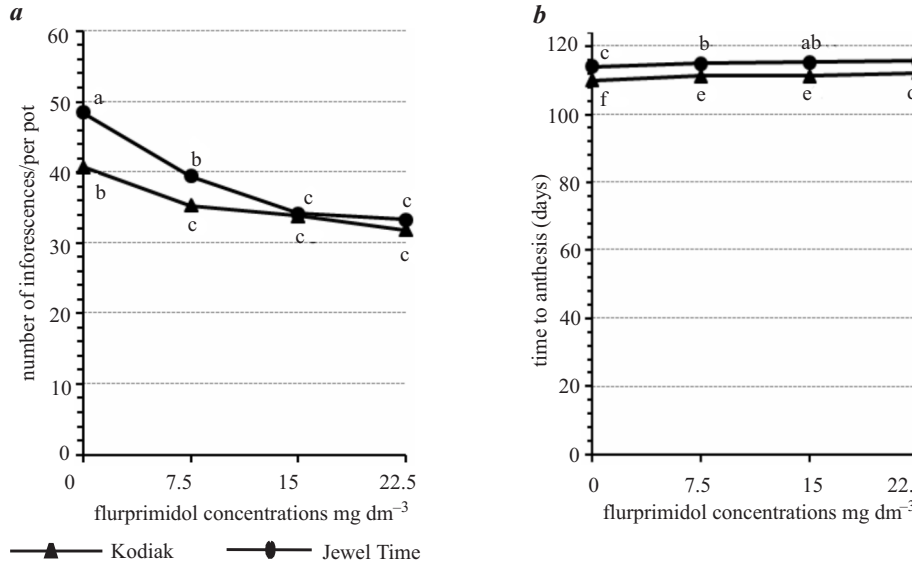

Fig. 3. Number of inflorescences per pot (*a*) and number of days to anthesis (*b*) of "Kodiak" and "Jewel Time" chrysanthemums as affected by flurprimidol applied as single, foliar spray. Data averaged over two growing seasons. The means indicated by the same letter do not differ significantly at $p = 0.05$, according to Duncan's multiple range test

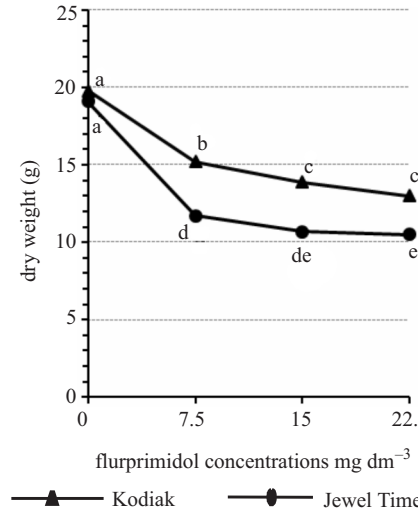

Fig. 4. Dry weights of "Kodiak" and "Jewel Time" chrysanthemums as affected by flurprimidol applied as single, foliar spray. Data averaged over two growing seasons. The means indicated by the same letter do not differ significantly at $p = 0.05$, according to Duncan's multiple range test

Growth retardant influenced the dry and fresh weights of both cultivars similarly at two growing seasons. The dry weight (Figure 4) and fresh weight (data not shown) of "Kodiak" and "Jewel Time" treated with flurprimidol at 7.5–22.5 mg dm^{-3} were significantly reduced compared to the control. The dry weights were smaller with higher flurprimidol doses. Relative to the untreated plants, retardant at the highest concentration reduced dry weights of "Kodiak" and "Jewel Time" up to 34% and 47%, respectively. There were also differences in dry matter between tested cultivars. The dry weights of "Jewel Time" treated with flurprimidol at 7.5, 15 and 22.5 mg dm^{-3} were 23%, 23.5% and 20% smaller, respectively than those of "Kodiak".

Compared to the control, flurprimidol at 7.5, 15 and 22.5 mg dm^{-3} did not influence leaf stomatal conductance to water vapor of "Kodiak" and "Jewel Time" chrysanthemums (Figure 5a). Single growth retardant applications at all concentrations also had no effect on transpiration rate per unit leaf area of both cultivars although there was a trend of increasing transpiration rate for plants treated with increasing concentrations of flurprimidol (Figure 5b). "Jewel Time" chrysanthemums carried out the transpiration per unit leaf area at a similar level compared to "Kodiak".

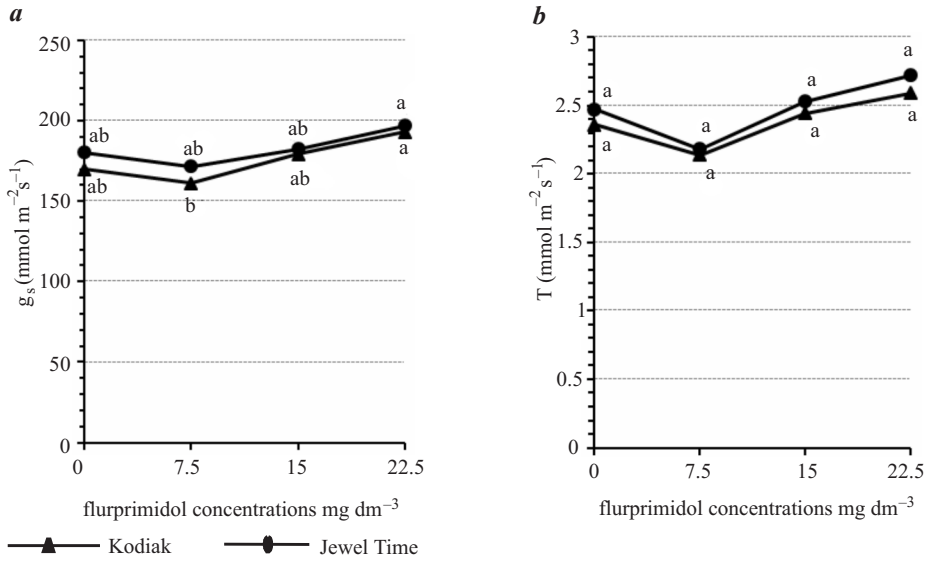

Fig. 5. Effect of flurprimidol applied as single, foliar spray on stomatal conductance to water vapor (g_s) (*a*) and transpiration rate (T) per unit leaf area (*b*) of "Kodiak" and "Jewel Time" chrysanthemums. Data averaged over two growing seasons. The means indicated by the same letter do not differ significantly at $p = 0.05$, according to Duncan's multiple range test

Discussion

In the present experiment a single flurprimidol treatment was sufficient to inhibit stem elongation of medium height "Kodiak" and "Jewel Time" chrysanthemums. This study shows that flurprimidol doses should be differentiated depending on chrysanthemum variety. "Jewel Time" plants were very sensitive to applied chemical and required the lowest flurprimidol concentration (7.5 mg dm^{-3}) in contrast to "Kodiak" which needed the highest growth retardant concentration (22.5 mg dm^{-3}) in order to achieve the desirable shoot length (16–18 cm). This concurs with our previous results, which showed that tall-growing chrysanthemums "Altis" required higher doses of flurprimidol for height suppression compared to "Surf" (POBUDKIEWICZ and NOWAK 1997). Much higher flurprimidol concentration (75 mg dm^{-3}) was used to suppress stem elongation of *Dendranthema grandiflora* Tzvelev "Nob Hill" grown in different climate conditions (BARRETT et al. 1987). HICKLENTON (1990), using another growth retardant,uniconazole, reported that the magnitude of *Dendranthema grandiflora* Tzvelev response to that growth retardant treatment was cultivar dependent. Uniconazole applied as a post-plant spray, at 10 mg dm^{-3} reduced plant heights of "Deep Luv", "Tip" and "Tara" by 19%, 39% and 35%, respectively relative to the control. Other authors also reported that chemical doses should be varied according to chrysanthemum cultivars (GARDNER and METZGER 2005, PASIAN 1999). The data obtained in this experiment demonstrate, that the efficacy of flurprimidol is superior to daminozide which is commonly used in commercial chrysanthemum production. Flurprimidol applied just once, at very low concentrations (7.5–22.5 mg dm^{-3}) was sufficient for proper height suppression of "Jewel Time" and "Kodiak" while daminozide had to be applied several times at very high concentrations (2000–3500 mg dm^{-3}) in order to achieve short chrysanthemums (PAPAFOTIOU and VAGENA 2012). Single flurprimidol application (compared to multiple daminozide treatment) in chrysanthemum cultivation has the economic advantage to producers due to reduced labor costs. The use of flurprimidol at very low concentrations (compared to very high daminozide doses) might also have environmental benefits. We have also observed good regulating activity of flurprimidol, applied once, at very small doses, in a variety of other plant species, including dwarf carnation (POBUDKIEWICZ and NOWAK 1994), seed propagated geranium (POBUDKIEWICZ 2000a), dwarf alstroemeria (POBUDKIEWICZ et al. 2000), oriental hybrid lily (POBUDKIEWICZ and TREDER 2006) and a variety of other plant species cultivated in pots.

In the study reported here chrysanthemums were sprayed with flurprimidol when lateral shoots were very short, so from the very beginning those shoots were developing under the influence of retardant. Thanks to it the first

internodes on such plants were kept very short. In pot chrysanthemums the length of the first internode plays very important role. Plant having short first internodes, develops leaves very low and this is why there is no empty space between the pot rim and the first leaves on the growth retardant treated plant. These leaves, in the low part of plants, also do not fall off until the end of the production cycle. In contrast, the oldest leaves of the untreated plants often turn yellow and fall off in the low parts of chrysanthemums. This results in an empty space between the pot rim and the first leaves on the plant which greatly diminish the plant quality. In the present study, abscission of the oldest leaves was only observed at the low parts of the control plants but it was not noted in flurprimidol treated ones. No leaf abscission in growth retardant treated plants might be associated with higher cytokinins (GROSSMANN 1990) and polyamines (GROSSMANN et al. 1987) contents. Cytokinins and polyamines such as spermine and spermidine delay aging of plants and this might be the reason why leaves in growth retardant treated plants do not fall off and remain green for a longer time compared to the untreated plants.

In the present study, due to reduced lengths of all internodes, the shoots were not only shorter but also aligned relative to each other. As a result all the inflorescences on the plant were placed on this same level, which greatly increased the plant quality. In the study reported here, flurprimidol sprayed "Jewel Time" and "Kodiak" plants, were more densely foliated and more compact resulting in higher quality appearance. These chrysanthemums narrower in width might also be an economic advantage to commercial growers due to increased plant density on greenhouse benches. Improved shape of flurprimidol treated pot plants was observed in our previous studies with tall-growing "Altis" and "Surf" chrysanthemums (NOWAK 1997) and other plant species, including *Pelargonium x hortorum* L.H. Bailey (POBUDKIEWICZ 2000a), *Cuphea ignea* (POBUDKIEWICZ 2000b) and *Streptocarpus hybridus* (POBUDKIEWICZ 2000c).

In this research project the leaf area was diminished in flurprimidol treated "Kodiak" and "Jewel Time" but due to reduced size of the whole plant, the leaves were proportionate to the entire smaller chrysanthemum. The reduced leaf area of flurprimidol sprayed plants was also observed in other plants species, including *Globba vinniti* (Siam) (POBUDKIEWICZ and PODWYSZYŃSKA 1999), *Cuphea ignea* (POBUDKIEWICZ 2000b) and oriental hybrid lily (POBUDKIEWICZ and TREDER 2006). Intensified green leaf pigmentation was observed in the present study with medium height chrysanthemums and in the previous experiment with tall-growing chrysanthemums (POBUDKIEWICZ and NOWAK 1997), which might be associated with higher chlorophyll content. There is no information about the flurprimidol influence on the chlorophyll level in chrysanthemum leaves but there are reports which indicate that the chloro-

phyll content per unit leaf area was increased by: daminozide in *Chrysanthemum indicum* (MAHALLE et al. 2001), uniconazole in *Chrysanthemum zawadskii* ssp. *Naktongense* (YOO and KANG 1999) or by paclobutrazol in *Dendranthema grandiflora* (KUCHARSKA and ORLIKOWSKA 2008).

In ornamental plants, growth retardants may not affect the number of flowers (POBUDKIEWICZ and GOLDSBERRY 1989), can reduce (POBUDKIEWICZ 2000a, POBUDKIEWICZ et al. 2000) or sometimes even increase the number of flowers (JUNG et al. 2000, YOO and KANG 1999). In the work reported here flurprimidol reduced the number of inflorescences and buds in both cultivars. This may be due to the fact that the assessment of the number of inflorescences per plant was done once, at the beginning of flowering. Our observations carried out over many years, in different experiments, have shown that on the day of taking data (at the beginning of flowering) very often flurprimidol treated plants had less flowers than the control ones. We have also noted that flowering period of flurprimidol sprayed plants was much longer compared to the untreated ones and during that time, the number of flowers per plant was increasing. Very often at the end of the flowering period, the number of flowers on growth retardant treated plants was similar to that on the control plants. In this experiment fewer inflorescences and buds in flurprimidol treated chrysanthemums at the beginning of flowering, may be due to the fact that growth retardants indirectly delay the aging process of plants by increasing the cytokinin (GROSSMAN 1990) and polyamines (GROSSMAN et al. 1987) contents with the result that plants are aging slower and have longer period of time to produce the yield. At the beginning of flowering smaller number of inflorescences in flurprimidol treated plants was also observed in our previous study with tall-growing chrysanthemums (POBUDKIEWICZ and NOWAK 1997). Reduced number of inflorescences, in chrysanthemums treated with other growth retardants, have also been reported by other workers (SCHUCH 1994).

The influence of flurprimidol on flower size of ornamental plants may depend on plant cultivar (POBUDKIEWICZET al. 2000), method of flurprimidol application (POBUDKIEWICZ and TREDER 2006) and the dose of this growth retardant (POBUDKIEWICZ 2000c). Flurprimidol may not influence the flower size, when used at concentrations optimum for height suppression (POBUDKIEWICZ and NOWAK 1994) but used at too high doses it often slightly diminish flower diameter (POBUDKIEWICZ 2000b). In this study even the highest flurprimidol concentration has not affected inflorescence size of medium height chrysanthemums which is consistent with our previous observations in tall-growing chrysanthemums (POBUDKIEWICZ and NOWAK 1997). In contrast other growth retardants e.g. uniconazole (STARMAN 1990) and daminozide (HICKLENTON 1990) influenced inflorescence size depending on chrysanthemum cultivar.

Variable effects of flurprimidol treatments on time to anthesis of ornamental plants have been reported. Flurprimidol induced early flowering in geranium (POBUDKIEWICZ 2000a), delayed anthesis of oriental hybrid lily (POBUDKIEWICZ and TREDER 2006) or had no effect on number of days to flowering of *Cuphea* (POBUDKIEWICZ 2000b) or *Streptocarpus* (POBUDKIEWICZ 2000c). Delayed anthesis is usually observed when flurprimidol is applied at very high doses (POBUDKIEWICZET al. 2000). Chrysanthemum appears to be very sensitive to flurprimidol application as compared to other species. Flurprimidol at a very low concentration (7.5 mg dm^{-3}) applied to "Kodiak" and "Jewel Time" in the present study delayed anthesis, but in dwarf carnations "Snowmass" anthesis was unaffected even by double flurprimidol treatment, at very high concentration, 45 mg dm^{-3} (POBUDKIEWICZ and NOWAK 1994). Other growth retardants, applied at very low doses, have also been reported to increase the number of days to flowering of chrysanthemums (STARMAN 1990, TAYAMA and CARVER 1992).

In the study reported here flurprimidol has not affected stomatal conductance to water vapor and transpiration rate per unit leaf area of "Kodiak" and "Jewel Time" chrysanthemums. The present findings on the influence of flurprimidol on transpiration are in accordance with some earlier findings with flurprimidol treatments. There was no effect of flurprimidol on transpiration rates in *Forsythia spectabilis* (VAIGRO-WOLF and WARMUND 1987), *Acer rubrum*, *Juglans nigra* and *Quercus palustris* (STERRETT et al. 1989). There are reports which indicate that other growth retardants usually decrease transpiration. Uniconazole was reported to reduce transpiration on a per leaf area basis of *Dendranthema grandiflora* Tzvelev "Dalvina" (SCHUCH 1994) and paclobutrazol to decrease transpiration rate in *Catharanthus roseus* (L.) G. Don. (JALEEL et al. 2007). In the present study no effect of flurprimidol on the chrysanthemum transpiration rate might be due to the fact that measurements of transpiration and stomatal conductance were carried out in a relatively long time (5 weeks) following retardant application. Some workers have shown that transpiration was reduced if measurements were performed in a short time following retardant treatment. For example, 24 hours after daminozide application to tomato plants, transpiration was reduced up to 34%, but after 5 days transpiration was only reduced 19% (MISHRA and PRADHAN 1971). NORCINI (1991) has shown that flurprimidol reduced transpiration rate and stomatal conductance of pruned *Euonymus fortunei* 3 days after treatment. Eighteen days following treatment transpiration rate and stomatal conductance were not lower in growth retardant treated plants compared to control ones. The author has also demonstrated that values of transpiration and stomatal conductance of flurprimidol treated plants were even slightly higher compared to values of the untreated plants if those measurements were made 18 and 21 days after flurprimidol application to *Euonymus* and pruned *Ligustrum x vicaryi*, respectively. This is consistent with results obtained in

the present study. Flurprimidol applied to "Kodiak" and "Jewel Time" chrysanthemums at higher concentrations caused even slight increase in transpiration rate and stomatal conductance relative to the control. In the experiment reported here no effect of flurprimidol on chrysanthemum transpiration might also be connected with abscisic acid (ABA) level 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 *Foeniculum* sp. (HOFMAN et al. 1992) and *Pseudotsuga menziesii* (GRAHAM et al. 1994) while other growth retardants, which resulted in stomata closure, increased the levels of abscisic acid in apple seedlings (Sutthiwal Setha Kondo 2009) and olive trees (ULGER et al. 2010). Perhaps in "Kodiak" and „Jewel Time" chrysanthemums flurprimidol has not influenced the endogenous abscisic acid content, which is responsible for closing of stomata and thus that growth retardant could not affect the transpiration.

Conclusions

Flurprimidol was highly effective for height control of "Kodiak" and "Jewel Time" chrysanthemums and a single treatment was sufficient to achieve short and very high quality plants. Flurprimidol doses should be varied according to chrysanthemum cultivar. Growth retardant at concentration of 7.5 mg dm^{-3} is recommended for "Jewel Time" but much higher concentration – 22.5 mg dm^{-3} is required for "Kodiak" in order to produce short and well compact chrysanthemums. Flurprimidol reduced the leaf area and had minimum effect on the time to anthesis. Growth retardant applications had no influence on inflorescence diameter, stomatal conductance and transpiration rate per unit leaf area of medium height chrysanthemums. Narrower in width plants treated with retardant might also be an economic advantage to commercial growers due to increased plant density on greenhouse benches. Thanks to intensified green leaf pigmentation, inflorescences placed on this same level, no leaf abscission and improved compactness, the flurprimidol treated chrysanthemums were more decorative and of much higher quality.

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References

BARRETT J.E., BARTUSKA C.A., NELL T.A. 1987. *Efficacy of ancymidol, daminozide, flurprimidol, paclobutrazol and XE-1019 when followed by irrigation*. Hort. Science, 22: 1287–1289.

CURREY C.J, LOPEZ R.G. 2011. *Early flurprimidol drench applications suppress final height of four poinsettia cultivars*. Hort. Technology, 21: 35–40.

GARDNER D.S., METZGER J.D. 2005. *Use of Trinexepac-ethyl for growth regulation of chrysanthemum* (*Dendranthema x grandiflora*). Hort. Science, 40: 670–674.

GRAEBE J. 1987. *Gibberellin biosynthesis and control*. Ann. Rev. Plant Physiol. 38, 419–465.

GRAHAM J.S., HOBBS S.D., ZAERR J.B. 1994. *The effect of flurprimidol on bud flush, shoot growth and on endogenous gibberellins and abscisic acid of Douglas-fir seedlings*. J. Plant Growth Regul., 13: 131–136.

GROSSMANN K. 1990. *Plant growth retardants as a tool in physiological research*. Physiol. Plant., 78: 640–648.

GROSSMANN K., KWIATKOWSKI J., SIEBECKER H., JUNG J. 1987. *Regulation of plant morphology by growth retardants. Effect of phytohormone levels in soybean seedlings determined by immunoassay*. Plant Physiol., 84: 1018–1021.

HAGUE S., FAROOQI A.H.A., GUPTA M.M., SANGWAN R.S., KHAN A. 2007. *Effect of ethrel, chlormequat chloride and paclobutrazol on growth and pyrethrins accumulation in Chrysanthemum cinerariaefolium* Vis. Plant Growth Regul., 51: 263–269.

HICKLENTON P.R. 1990. *Height control of pot chrysanthemums with pre- and post plant treatments of daminozide and uniconazole*. Can. J. Plant Sci., 70: 925–930.

HOFMAN P.J., MENARY R.C., CLARK R.J. 1992. *Effect of the growth retardant EL 500 on growth and plant growth substances in fennel* (*Foeniculum* sp.). J. Essential Oil Res., 4: 401–409.

JALEEL C.A., MANIVANNAN P., SANKAR B., KISHOREKUMAR A., SANKARI S., PANNERSELVAM R. 2007. *Paclobutrazol enhances photosynthesis and ajmalicine production in Catharathus roseus*. Process Biochem., 42: 1566–1570.

JUNG S.S., JEONG H.H., KIM K.S. 2000. *Effects of uniconazole treatment on the growth and flowering of potted Chrysanthemum indicum* L. Korean J. Hortic. Sci. Techn., 18: 28–32.

KUCHARSKA D., ORLIKOWSKA T. 2008. *The influence of paclobutrazol in the rooting medium on the quality of chrysanthemum vitroplants*. J. Fruit Ornam. Plant Res., 16: 417–424.

MAHALLE B.F., TIDKE S.S., KHOBRAGADE H.M., BELORKAR P.V. 2001. *Effect of foliar spray of B-9 on growth parameters and chlorophyll content of chrysanthemum*. J. Soil Crops 11: 120–124.

MISHRA D., PRADHAN G.C. 1971. *Effect of transpiration-reducing chemicals on growth, flowering, and stomatal opening of tomato plants*. Plant Physiol., 50: 271–274.

NORCINI J.G. 1991. Growth and water status of pruned and unpruned woody landscape plants treated with Sumagic (uniconazole), Cutless (flurprimidol) or Artimmec (dikegulac). J. Environ. Hort., 9: 231–235.

PAPAFOTIOU M., VAGENA A. 2012. *Cotton gin trash compost in the substrate reduces the daminozide spray dose needed to produce compact potted chrysanthemum*. Sci. Hortic., 143: 102–108.

PASIAN C.C. 1999. *Response of Dendranthema grandiflora (Ramat) to three plant growth regulators in container paint mix application*. Sci. Hortic., 80: 277–287.

POBUDKIEWICZ A. 2000a. *Response of seed-propagated geranium (Pelargonium x hortorum L.H. Bailey) to application of flurprimidol*. Acta Agrobot., 53: 31–38.

POBUDKIEWICZ A. 2000b. *The response of Cuphea ignea A.DC. to flurprimidol application*. Folia Hortic., 12: 99–106.

POBUDKIEWICZ A. 2000c. *Controlling the growth habit of Streptocarpus hybridus with flurprimidol*. J. Fruit Ornam. Plant Res., 8: 7–18.

POBUDKIEWICZ A., GOLDSBERRY K.L. 1989. *Dwarf carnation response to soil application of Sumagic. Colo*. Green. Grow. Res. Bul., 474: 1–2.

POBUDKIEWICZ A., NOWAK J. 1994. *The influence of flurprimidol and uniconazole on growth of the CMM dwarf Dianthus caryophyllus L. "Snowmass"*. J. Fruit Ornam. Plant Res., 2: 135–142.

POBUDKIEWICZ A., NOWAK J. 1997. *Response of chrysanthemum (Dendranthema grandiflora Tzvelev) cvs Altis and Surf to flurprimidol application*. J. Fruit Ornam. Plant Res., 5: 43–52.

POBUDKIEWICZ A., NOWAK J., PODWYSZYŃSKA M., PRZYBYŁA A. 2000. *The effect of growth retardants on growth and flowering of dwarf alstroemeria*. Acta Agrobot., 53, 77–84.

POBUDKIEWICZ A., PODWYSZYŃSKA M. 1999. *The response of Globba winitii (Siam) to application of flurprimidol*. Folia Hortic., 11: 37–44.

POBUDKIEWICZ A., TREDER J. 2006. *Effects of flurprimidol and daminozide on growth and flowering of oriental hybrid lily "Mona Lisa"*. Sci. Hortic., 110: 328–333.

REED A.N., CURRY E.A., WILLIAMS M.W. 1989. *Translocation of triazole growth retardants in plant tissues*. J. Amer. Soc. Hortic. Sci., 114: 893–898.

SCHUCH U.K. 1994. *Response of chrysanthemum to uniconazole and daminozide applied as dip to cuttings or as foliar spray*. J. Plant Growth Regul., 13: 115–121.

STARMAN T. W. 1990. *Whole-plant response of chrysanthemum to uniconazole foliar sprays or medium drenches*. Hort. Science, 25: 935–937.

StatSoft, Inc. 2011. *STATISTICA (data analysis software system), version 10*. www.statsoft.com.

STERRETT J.P., TWORKOSKI T.J., KUJAWSKI P.T. 1989. *Physiological responses of deciduous tree root collar drenched with flurprimidol*. J. Arboric., 15: 120–124.

Sutthiwal Setha Kondo S. 2009. *Abscisic acid levels and anti-oxidant activity are affected by an inhibitor of cytochrome P450 in apple seedlings*. J. Hortic. Sci. Biotech., 84: 340–344.

TAYAMA H.K., CARVER S.A. 1992. *Concentration response of zonal geranium and potted chrysanthemum to uniconazole*. HortScience, 27: 126–128.

ULGER S., AKDESIR O., DEMIRAL S., ATMACA A. 2010. *Investigation of the effects of external daminozide application on endogenous hormone levels in "Memecik" olive trees*. Acta Hortic., 884: 153–156.

VAIGRO-WOLF A.L., WARMUND M.R. 1987. *Suppression of growth and plant moisture stress of forsythia with flurprimidol and XE-1019*. Hort. Science, 22: 884–885.

WHIPKER B.E., MCCALL I., GIBSON J.L., CAVINS T.J. 2004. *Flurprimidol foliar sprays and substrate drenches control growth of "Pacino" pot sunflowers*. Hort. Technology, 3: 411–414.

YOO Y.K., KANG S.W. 1999. *Effects of uniconazole treatment on the growth and flowering of Chrysanthemum zawadskii ssp. naktongense*. J. Korean Soc. Hortic. Sci., 40: 515–519.