

Prohexadione calcium on the growth and quality of eggplant seedlings

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Abstract – The objective of this work was to evaluate the effects of prohexadione calcium concentrations on the growth and quality of eggplant (*Solanum melongena*) seedlings. The effects of prohexadione calcium concentrations of 0, 50, 100, or 150 mg L⁻¹ on seedling growth parameters were evaluated in a greenhouse experiment. After the greenhouse experiment, the seedlings were transplanted to the field. During the field experiment, the number of days to flowering, plant height, number of fruits per plant, average fruit weight and yield were evaluated. Both experiments were carried out in a completely randomized design with four replicates. All prohexadione calcium concentrations significantly reduced shoot height and internode length, when compared to the control. The concentrations of 50, 100, and 150 mg L⁻¹ prohexadione calcium reduced shoot height by 27, 32, and 38%, respectively. Prohexadione calcium treatments (except the one with 50 mg L⁻¹) enhanced relative chlorophyll content of leaves in comparison to the control. There were no delays in flowering and no significant differences in number of fruits per plant among treatments with prohexadione calcium. The concentrations of 100 and 150 mg L⁻¹ prohexadione calcium significantly reduced yield per plant and total fruit yield, whereas the concentration of 50 mg L⁻¹ did not cause any change in yield compared to the control. The lowest prohexadione calcium concentration can be used to control excessive elongation of eggplant seedlings without yield loss.

Index terms: *Solanum melongena*, growth retardant, seedling height control.

Prohexadiona de cálcio sobre o crescimento e a qualidade de mudas de berinjela

Resumo – O objetivo deste trabalho foi avaliar os efeitos da aplicação de prohexadiona de cálcio no crescimento e na qualidade de mudas de berinjela (*Solanum melongena*). Os efeitos das concentrações de 0, 50, 100 ou 150 mg L⁻¹ de prohexadiona de cálcio nos parâmetros de crescimento de mudas foram avaliados em experimento em casa de vegetação. Após a avaliação em casa de vegetação, as plântulas foram transplantadas para o campo. No experimento em campo, foram avaliados número de dias para o florescimento, altura de plantas, número de frutos por planta, peso médio e produtividade dos frutos. Ambos os experimentos foram realizados em delineamento inteiramente casualizado, com quatro repetições. Todas as concentrações de prohexadiona de cálcio reduziram significativamente a altura da parte aérea e o comprimento dos entrenós, em comparação ao controle. As concentrações de 50, 100 e 150 mg L⁻¹ de prohexadiona de cálcio reduziram a altura da parte aérea em 27, 32 e 38%, respectivamente. Os tratamentos com prohexadiona de cálcio (exceto o de 50 mg L⁻¹) aumentaram o teor de clorofila na folha, em relação ao controle. Não foram observados atrasos na floração nem diferenças significativas no número de frutos por planta entre os tratamentos com prohexadiona de cálcio. As concentrações de 100 e 150 mg L⁻¹ de prohexadiona de cálcio reduziram a produção por planta e o rendimento total de frutos, enquanto a aplicação de 50 mg L⁻¹ não causou qualquer alteração no rendimento quando comparado ao controle. A concentração mais baixa de prohexadiona de cálcio pode ser usada para controlar o alongamento excessivo de mudas de berinjela sem perda de rendimento.

Termos para indexação: *Solanum melongena*, inibidor de crescimento, controle de altura de mudas.

Introduction

Eggplant (*Solanum melongena* L.) is initially grown in tunnels or greenhouses and then transplanted as seedlings to the field. These transplants are commonly grown in plug trays at high plant densities due to

production costs. However, high plant density results in morphological changes collectively referred to as shade-avoidance response. Plants that shade each other develop longer stems and produce less dry matter to compete for the limited amount of light in the plant canopy. The resulting tall, weak-stemmed seedlings

are difficult to transplant and are easily damaged (Garner & Björkman, 1996). Tall seedlings are also less compatible with transplanting machines than more moderately-sized plants, since mechanical transplanters are designed to accommodate plants of a specific size (Bozokalfa, 2008). Besides that, unfavorable weather conditions can delay field preparation for transplanting. In this case, seedlings should be kept in a hotbed or greenhouse. This causes the seedlings to grow taller unless adequate measures are taken to control plant height. For these reasons, controlling seedling height is vital for vegetable transplant production in both greenhouse and field conditions.

Several chemical growth promoters or retardants have been used to treat plants in order to control the growth and development of vegetative or reproductive parts. Sumagic (uniconazole) is the only growth regulator labeled as a foliar spray for use on eggplant seedlings. A single Sumagic spray application between 5.0 and 10 mg L⁻¹ on eggplants is suggested as a starting rate. Runkle & Blanchard (2012) reported that there was little or no effect of Sumagic on eggplant height at the rates of 1.25, 2.5, and 5.0 mg L⁻¹, although plants treated with Sumagic had smaller leaves. Therefore, rates greater than 5.0 mg L⁻¹ are likely required to suppress stem elongation (Runkle & Blanchard, 2012). Plant growth regulators (PGRs) that inhibit gibberellin biosynthesis have been effectively used to control transplant height. One of the PGRs used to control plant height in recent years is prohexadione calcium, which inhibits the production of growth-active gibberellins, retarding shoot elongation.

Prohexadione calcium has shown excellent vegetative growth-control properties in a number of plant species, such as rice, apple, petunia, and various vegetable crops, including cucumber and tomato (Ilias & Rajapakse, 2005; Ergun et al., 2007; Kim et al., 2007; Altintas, 2011). Soaking of faba bean seeds in solutions of prohexadione calcium caused significant reduction in shoot height and shoot fresh weight, with increasing prohexadione calcium concentrations (Bekheta et al., 2009). Currently, prohexadione calcium has been classified as a reduced-risk compound, since it exhibits negligible toxicological effects on mammals and has been reported to degrade in higher plants with a half-life of a few weeks and in soil with a half-life of less than a week. Therefore, prohexadione calcium is not persistent in the environment and has a low potential for bioaccumulation (Ilias & Rajapakse, 2005).

However, there are no known works on the response of the growth retardant prohexadione calcium in controlling the growth and development of the vegetative or reproductive parts of vegetable crop species, like eggplant.

The objective of this work was to evaluate the effects of prohexadione calcium concentrations on the growth and quality of eggplant (*Solanum melongena*) seedlings.

Materials and Methods

Greenhouse and field experiments were conducted from April 2009 to October 2011 at the Horticultural Sciences Research Unit of Kahramanmaraş Sutcu Imam University, in Kahramanmaraş, Turkey (37°35'N, 36°49'E, at 502 m altitude).

'Faselis F1' eggplant seeds from De Ruyter Seeds (Bergschenhoek, Holland), which are commonly grown in Turkey, were used in the study.

The effects of prohexadione calcium concentrations on seedling growth parameters were evaluated in greenhouse conditions. The greenhouse experiment was carried out in a completely randomized design with four replicates. Seedlings were grown in an unheated greenhouse with average day/night temperature of 30.5/20.3°C and relative humidity of 55%. Untreated eggplant seeds were sown in 35-cell plastic trays (100 cm³ cell volume), which were filled with a media consisting of peat and perlite in the ratio of 4:1 and placed on a greenhouse bench. Seedlings were watered daily and fertilized with 20-20-20 N-P-K soluble fertilizer at a rate of 200 mg L⁻¹ N (20 mL per plant) once a week. At the emergence of the third true leaf (20 days after sowing), eggplant seedlings were sprayed one time with 0, 50, 100, or 150 mg L⁻¹ prohexadione calcium solutions containing 0.1% Tween 20 (Sigma-Aldrich, St. Louis, MO, USA) as a wetting agent. A solution containing 0.1% Tween 20 was applied to the control plants. The eggplant seedlings were sprayed to run-off. At the time of spraying, the surface of the growing medium was covered with aluminum foil to minimize the contact of the growth regulator solutions with the substrate. At 35 days after sowing, the greenhouse experiment was discontinued and final seedling growth measurements were taken. Ten plants per treatment were randomly chosen from each

replicate to determine seedling height, internode length, stem diameter, number of true leaves, relative leaf chlorophyll content with a chlorophyll meter SPAD-502 (Konica Minolta Sensing, Inc., Sakai, Osaka, Japan), leaf area with a leaf area meter LI-3100C (LI-COR Biosciences, Lincoln, Nebraska, USA), shoot fresh and dry weights, and root fresh and dry weights, after samples were dried in the oven at 80°C until constant weight.

The seedlings from the greenhouse experiment were transplanted to the field in order to investigate the effects of prohexadione calcium on growth and yield parameters. The experimental plots consisted of two rows of 10 plants each, with 20 plants per treatment, with a drip irrigation tube in the middle. The beds were 120 cm apart, with plant rows spaced at 50 cm and plants within each row also at 50 cm (120x50x50 cm). During the field experiment, the effects of prohexadione calcium were observed on number of days to flowering, plant heights measured at 35 and 70 days after the treatments (DAT), number of fruits per plant, average fruit weight, and fruit yield.

The field experiment was also carried out in a completely randomized design with four replicates. Both the greenhouse and the field experiments were repeated twice and resulted in similar data. After conducting Levene's test to confirm the possibility of grouping, the data from the two experiments were combined and subjected to analysis of variance using the SAS software, version 9.1. (SAS Institute Inc., Cary, NC, USA), and mean separation was performed by Fisher's least significant difference (LSD) test when the F test was significant at 5% probability.

Results and Discussion

The application of prohexadione calcium reduced vegetative growth, most clearly shown by a reduction in plant height and internode length, in comparison to the control treatment (Table 1). With the concentrations of 50, 100, and 150 mg L⁻¹ prohexadione calcium, shoot height was suppressed by 27, 32, and 38%, respectively, when compared to the control. All prohexadione calcium concentrations significantly reduced internode length in comparison to the control. These results are in agreement with previous studies conducted with other vegetable and fruit crops (Rayirath et al., 2009; Kim et al., 2010; Guak, 2013). Soaking of faba bean (*Vicia faba* L.) seeds in solutions of prohexadione calcium caused significant reduction in shoot height and fresh weight, with increasing prohexadione calcium concentrations (Bekheta et al., 2009). Similarly, Ouzounidou et al. (2011) reported significant inhibition of shoot height in onion (*Allium cepa* L.) and garlic (*Allium sativum* L.) with the application of prohexadione calcium. The inhibitory effect of prohexadione calcium on seedling height is further supported by other researches on cabbage (*Brassica oleracea* var. *capitata*) by Hamano et al. (2002), petunia (*Petunia x hybrida* Vilm.-Andr.) and impatiens (*Impatiens walleriana* Hook.f.) by Ilias & Rajapakse (2005), tomato (*Lycopersicon esculentum* Mill.) by Giannakoula & Ilias (2007), and okra [*Abelmoschus esculentus* (L.) Moench] by Ilias et al. (2007).

There were no significant differences in stem diameter and number of true leaves between the prohexadione calcium treatments and the control plants (Table 1). These results can be interpreted as an advantage

Table 1. Effects of prohexadione calcium treatments on shoot height, internode length, stem diameter, number of true leaves, and leaf area of 5-week-old eggplant (*Solanum melongena*) seedlings⁽¹⁾.

Prohexadione calcium (mg L ⁻¹)	Shoot height (cm)	Internode length (cm)	Stem diameter (mm)	Number of true leaves (leaves per plant)	Leaf area (cm ² per plant)
0	6.75a	1.84a	2.68	4.73	79.83a
50	4.95b	0.99b	2.68	4.57	75.91b
100	4.63b	0.83b	2.71	4.60	72.36b
150	4.08b	0.80b	2.67	4.63	68.19b
LSD _{0.05}	0.93	0.38	0.31	0.35	8.20
Significance	***	***	ns	ns	*

⁽¹⁾Means followed by equal letters do not differ significantly by Fisher's LSD test, at 5% probability. nsNonsignificant. * and ***Significant at 5% and 1% probability, respectively.

of using prohexadione calcium because it reduced eggplant seedling height without negatively affecting stem diameter and number of true leaves. There are no known previous studies on the use of prohexadione calcium on eggplant supporting or contradicting the obtained results. In a previous study conducted on tomato seedlings, the application of prohexadione calcium decreased both stem diameter and number of true leaves (Altintas, 2011). In contrast, Kofidis et al. (2008) found that stems of coriander (*Coriandrum sativum* L.) plants treated with prohexadione calcium had greater diameter than those of the controls, and were more compact and stronger due to the increased volume of the collenchyma tissue and the greater number of vessels in the vascular bundles.

The highest concentration of prohexadione calcium (150 mg L⁻¹) reduced leaf area of eggplant seedlings by 15%, when compared to the control plants, but there were no significant differences among the control and the other prohexadione calcium treatments (50 and 100 mg L⁻¹). It is important to highlight that reduced leaf area can lower photosynthesis. Davis et al. (1988) observed that the photosynthetic rate decreased as a result of leaf expansion inhibition. However, it has been reported that prohexadione calcium had a positive effect on photosynthesis on some crops, such as strawberries (*Fragaria x ananassa* Duchesne) (Reekie et al., 2005). The mechanistic basis for the positive effect of prohexadione calcium on photosynthesis may be related to its effect on leaf area. In the present study, in comparison to the control, treated leaves had lower leaf area and higher chlorophyll content on a leaf area basis (Table 2).

These findings agree with previous studies on the application of prohexadione calcium and of some

regulators of the triazole group on apples (*Malus sylvestris* var. *domesticus*) (Glenn & Miller, 2005; Medjdoub et al., 2007). It has been reported that the application of prohexadione calcium decreased leaf area of tomato plants when compared to the control (Altintas, 2011). Reduced leaf area with increasing concentrations is most likely due to the inhibition of gibberellin biosynthesis (Rademacher, 2000). Kang et al. (2010) found that the endogenous bioactive GA₁ and GA₄ contents of Chinese cabbage (*Brassica rapa* L.) drastically decreased with elevated prohexadione calcium.

The highest concentration of prohexadione calcium (150 mg L⁻¹) resulted in a reduction of 14 and 15%, respectively, in shoot fresh and dry weights of eggplant seedlings (Table 2). These results are in alignment with Grossmann et al. (1994), who observed that the treatment of wheat (*Triticum aestivum* L.) seedlings with increasing prohexadione calcium concentrations in hydroponics reduced shoot fresh weight up to 40%. In the present study, the concentration of 150 mg L⁻¹ prohexadione calcium resulted in some reduction in root fresh weight of eggplant seedlings; however, no significant differences in root dry weight among prohexadione calcium treatments were found (Table 2).

Prohexadione calcium treatments (except the one with 50 mg L⁻¹) enhanced relative leaf chlorophyll content, in comparison to the control (Table 2). Sabatini et al. (2003) found that prohexadione calcium positively affected the leaf chlorophyll content of apple and pear (*Pyrus communis* L.) trees. These authors observed that prohexadione calcium increased net photosynthesis and concluded it had a positive influence on fruit weight and yield. Kofidis et al. (2008) reported no significant differences in chlorophyll content

Table 2. Effects of prohexadione calcium treatments on shoot fresh weight, shoot dry weight, root fresh weight, root dry weight, and relative leaf chlorophyll content (SPAD units) of 5-week-old eggplant (*Solanum melongena*) seedlings⁽¹⁾.

Prohexadione calcium (mg L ⁻¹)	Shoot fresh weight (g)	Shoot dry weight (mg)	Root fresh weight (g)	Root dry weight (mg)	SPAD
0	2.23a	233a	1.18a	65.33	33.74b
50	2.09ab	230ab	1.10ab	64.00	36.23ab
100	1.97b	223ab	1.07ab	61.67	37.63a
150	1.91b	197b	1.03b	60.00	38.00a
LSD _{0.05}	0.18	15.75	0.14	15.80	2.69
Significance	**	**	*	ns	*

⁽¹⁾Means followed by equal letters do not differ significantly by Fisher's LSD test, at 5% probability. ^{ns}Nonsignificant. *and **Significant at 5 and 1% probability, respectively.

between leaves treated with prohexadione calcium and control leaves of coriander plants. In contrast, Meagy (2009) stated that high concentrations of prohexadione calcium significantly reduced chlorophyll in spearmint (*Mentha spicata* L.) plants when compared to the control. Similarly, prohexadione calcium treatments (100–300 mg L⁻¹) resulted in a significant decline in the leaf chlorophyll content of tomato plants (Giannakoula & Ilias, 2007).

Significant reductions in plant height were observed with higher prohexadione calcium concentrations (100 and 150 mg L⁻¹) in the field experiment at 35 DAT (Figure 1). Prohexadione calcium treatments resulted in a reduction of 11% in plant height at 35 DAT, but in no significant reduction at 70 DAT. These results show that prohexadione calcium lost its growth inhibitory effectiveness over time, indicating prohexadione

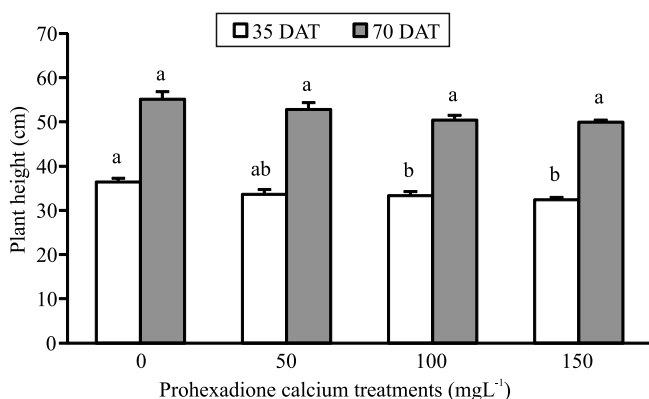


Figure 1. Effect of prohexadione calcium treatments on the height of eggplant (*Solanum melongena*) plants measured 35 and 70 days after the treatment (DAT). Bars with equal letters do not differ significantly by Fisher's LSD test, at 5% probability.

calcium has low toxicity and persistence in the plant (Ilias & Rajapakse, 2005). This is important to control plant height in vegetable crops, such as eggplants. According to Greene & Schloemann (2010), inhibitory effects of an application of prohexadione calcium lasted for about 28 days.

No delays in flowering were observed in eggplant plants due to prohexadione calcium treatments (Table 3). This is an advantage of using prohexadione calcium instead of some other growth retardant, including abscisic acid and chlorocholine chloride. Growth retardants may delay flowering in vegetable crops, including eggplants, and cause yield and income losses. These findings on eggplant flowering are in line with Ilias et al. (2007), who reported that control and prohexadione-calcium-treated okra plants took the same time to bloom. In contrast, the application of 200 mg L⁻¹ prohexadione calcium, 45 days after planting, delayed anthesis up to 11 days (Cerny-Koenig et al., 2005). This may be explained by the late application of the retardant. In the present study, no significant differences in number of fruits per plant among prohexadione calcium treatments were found (Table 3). These results confirm those obtained by Mandemaker et al. (2005), who observed no differences in fruit number or size between untreated and treated avocado (*Persea americana* Mill.) plants with prohexadione calcium.

The highest concentration of prohexadione calcium (150 mg L⁻¹) reduced mean fruit weight by 7% in comparison to the control plants (Table 3), and there were no significant differences among the control and the other prohexadione calcium treatments (50 and 100 mg L⁻¹). These findings are consistent with those of Sugar et al. (2004), who reported that mean fruit weight in pear was reduced by prohexadione

Table 3. Effects of prohexadione calcium treatments on days to flowering, number of fruits, mean fruit weight, yield per plant, early and total marketable yield of eggplant (*Solanum melongena*)⁽¹⁾.

Prohexadione calcium (mg L ⁻¹)	Days to flowering (days)	Number of fruits (fruits per plant)	Mean fruit weight (g)	Yield per plant (kg)	Early marketable yield (Mg ha ⁻¹) ⁽²⁾	Total marketable yield (Mg ha ⁻¹)
0	53	14.25	173.68a	2.44a	9.58a	65.03a
50	54	13.83	168.82ab	2.33a	9.34a	62.23a
100	54	13.08	165.13ab	2.20b	8.28b	58.58b
150	55	12.84	162.18b	2.11b	7.29c	56.24b
LSD _{0.05}	2.82	2.36	9.55	0.13	0.37	3.41
Significance	ns	ns	*	**	***	**

⁽¹⁾Means followed by equal letters do not differ significantly by Fisher's LSD test, at 5% probability. ⁽²⁾Yield at the first two harvests. nsNonsignificant. *, **, and ***Significant at 5%, 1%, and 1% probability, respectively.

calcium treatments. Prohexadione calcium may be reducing fruit size primarily by slowing down cell division development in fruits (Greene, 2008). An alternative or contributing factor to reducing fruit size could be reduced leaf area (Greene, 2008), which is true in the case of the present study. A reduction in leaf area, which may reduce carbohydrate supply to the developing fruit, could also reduce fruit size. The present study showed that the mean fruit weight was reduced by the application of 150 mg L⁻¹, whereas fruit number per plant was not affected. Linearity was also observed between mean fruit weight and yield per plant (Table 3).

The highest prohexadione calcium concentrations (100 and 150 mg L⁻¹) significantly reduced yield per plant, as well as early and total marketable yield of eggplant, whereas 50 mg L⁻¹ did not cause any change in yield when compared to the control (Table 3). These results are similar to those reported for coriander plants by Kofidis et al. (2008). These authors found that 100 and 200 mg L⁻¹ prohexadione calcium led to significant decreases in fruit yield when in comparison to the control. However, the results obtained in the present study are contrary to those of other works. Greene & Schloemann (2010) observed that prohexadione calcium increased total marketable yield without affecting mean fruit size. Asin et al. (2007) concluded that prohexadione calcium did not have any significant negative effect on pear yield. Therefore, the improving or negative effect of prohexadione calcium depends on application time, doses, environmental conditions, species, cultivar, and even on the individual plant (Altintas, 2011).

Conclusions

1. Prohexadione calcium is effective in reducing shoot height in eggplant (*Solanum melongena*), and the response varies with the applied concentration.

2. The lowest prohexadione calcium concentration (50 mg L⁻¹) can be used to control excessive elongation of eggplant seedlings without any major yield loss.

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Received on February 24, 2015 and accepted on August 20, 2015