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Full Length Research Paper

Effects of chlormequat chloride and different rates of prohexadione-calcium on seedling growth, flowering, fruit development and yield of tomato

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The aim of the study was to determine the effects of chlormequat chloride and different rates of prohexadione-calcium on seedling growth, flowering and fruit development and yield characteristics of tomato under conventionally poor growing conditions in an unheated greenhouse in Tekirdag, Turkey (40°59' N, 27°29' E). The effects of medium drench and spray applications of chlormequat chloride (2000 mg l^{-1}) and different rates of prohexadione-calcium [(Regalis®)(50, 100, 200, 250, 300, 100 × 2, 125 × 2 and 150 × 2 mg l^{-1})] were evaluated. Chlormequat chloride and prohexadione-calcium effected seedling height, seedling diameter, number of leaves, chlorophyll, total and early yields, fruit diameter, percentage of fruits falling into the weight classes and flowering, and fruit development of tomato. In exception of 4 of 16 treatments, prohexadione-calcium, as well as chlormequat chloride, reduced seedling height related to control. The highest total yield was observed with chlormequat chloride and medium drench and spray applications of 100 and 300 mg l^{-1} and spray application of 100 × 2 mg l^{-1} prohexadione-calcium (pro-Ca). The lowest average fruit weight was from 150 × 2 mg l^{-1} and control plots. Fruit diameters were larger with the most of the pro-Ca rates in comparison to the control plants. In some pro-Ca treatments, flowers in the first florescences remained either at anthesis or fruit set stage throughout the growing period. Nevertheless, flower and fruit developments were normal in the 2nd, 3rd and 4th trusses in these treatments.

Key words: Prohexadione-calcium, chlormequat chloride, seedling height, flowering, yield, tomato.

INTRODUCTION

The uniform seedling growth is important in the cultivation of tomato. Environmental conditions such as low or high temperature or low light intensity of production area and high density of plant in mass production resulted in seedling with longer internodes and weaker stems. Seedling sturdiness determines the growth of transplants in the field, thus early and total yields is important in vegetable growing. This leads to the control of the growth of seedlings by means of different practices. The parameters involved in the control of the growth process are nutrients, salts, temperature, photoselective films and phytohormones (Pasian and Bennett, 2001; Schnelle et al., 1993; Rajapakse and Li, 2004; Rideout, 2004; Rideout and Overstreet, 2003; Duman and Duzyaman, 2003; Latimer et al., 1991).

Plant growth regulators have been used in agricultural industry for decades. Many of these compounds however have a disadvantage of being persistent, for example chlormequat chloride, one of the most used growth retardant, can persist in the tree in an unmetabolized form for up to six months (Smit et al., 2005). Prohexadione-calcium, on the other hand, is a gibberellin biosynthesis inhibitor likewise chlormequat chloride with short-term effect and persistency. It has been registered in the U.S.A (trade name Apogee®) and in Europe (trade name Regalis®) for use on reducing shoot growth on apple (Rademacher, 2000; Ilias and Rajapakse, 2005; Smit et al., 2005; Kang et al., 2010).

It has gained attention as a bioregulator, not only for its specific inhibitory effect on seedling height and shoot length without not being persistent in plant and in soil but also for increasing effect on yield, fruit quality and

Table 1. Chemical characteristics of the soil (0 to 20 cm).

Parameter	Value	Unit	Method
pH	7.51	%	Saturated extract
EC	0.1	%	Saturated extract
$CaCO_3$	2.2	%	Calsimetric
Organic matter	3.95	%	Saturated extract
Total N	0.19	%	Walkey-Black
Available Ca	0.63	%	Olsen-ICP
Available P	146	ppm	Kjeldahl
Available K	499	ppm	A.Asetat-ICP
Available Mg	539	ppm	A.Asetat-ICP
Available Mn	15.5	ppm	A.Asetat-ICP
Available Cu	1.28	ppm	DTPA-ICP
Available Fe	5.17	ppm	DTPA-ICP
Available Zn	3.48	ppm	DTPA-ICP

flowering, and fruit set of some species such as Chinese cabbage (Kang et al., 2010), okra (Ilias et al., 2007), petunia and impatent (Ilias and Rajapakse, 2005), strawberry (Duval, 2002), pear (Smit et al., 2005) and avocado (Mandemaker et al., 2005) and also reducing effect on shoot length for apple (Ratiba and Blanco, 2004) and pear (Smit et al., 2005), and on height for cucumber (Ergun et al., 2007), cabbage (Hamano et al., 2002), okra (Ilias et al., 2007), petunia and impatients (Ilias and Rajapakse, 2005). On the other hand, there are reports stating that this compound have no effect on yield, fruit quality, fruit set and flower initiation (Zandstra et al., 2006; Smit et al., 2005; Ratiba Medjdoub and Blanco, 2004), or that it does not have any significant negative effect on either return bloom or yield (Asín et al., 2007). Delayed initiation of flowering or delayed fruit set has been reported related to rates and application time by several studies (Ilias et al., 2007; Ilias and Rajapakse, 2005; Giudice et al., 2004).

Because of researches conducted on effect of pro-Ca on vegetative and generative performance of plant mainly concentrated on orchard plants, grains and pot flowers, there is limited work related to vegetable crops. This experiment was therefore conducted to determine the effects of chlormequat chloride and different rates of prohexadione-Calcium on the seedling growth, flowering and fruit development, and yield characteristics of tomato under conventionally poor growing conditions in an unheated greenhouse in Turkey.

MATERIALS AND METHODS

Plant material, location and cultivation method

The research was carried out at the Department of Horticulture, Faculty of Agriculture, Namik Kemal University, Tekirdag, Turkey (40°59' N, 27°29' E). Seeds of the tomato F_1 cultivar of Maya (May Seed Co., Turkey) were sown in multicelled trays (50 ml each cell) filled with peat (Klasmann Potgrond H, Germany) on 5th May 2009. Soil transplantation was carried out at the seven to eight true-leaf stage on the 25th June 2009 into an unheated glasshouse at a density of 2.0 plant m^{-2} (21 plants for each application). Chemical content of the soil is presented in Table 1 and environmental condition of glasshouse during the period of experiment is presented in Figure 1. Plants were pruned regularly once a week. In order to maintain one main shoot, every side shoot was removed. The number of clusters on each plant was limited to four and each cluster was left with four fruits to control the growth and development of both the plants and the fruits. Fruit pruning was performed when fruits were 2.0 to 2.5 cm in diameter. Top removing was performed above the 4th truss leaving five leaves before the top.

Plants were divided into 19 groups containing 27 seedlings in each group. Applications evaluated included one chlormequat chloride [(CCC) (% 40, W/V)] rate (2000 mg l^{-1}) and 8 prohexadione-Calcium (pro-Ca) [(Regalis®) (BAS 125 10W, BASF Corp)] rates (50, 100, 200, 250, 300, 100 × 2, 125 × 2 and 150 × 2 mg l^{-1}) and two application methods (medium drench=D and foliar and stem spray=S). Untreated (control) plots were also included in the experiment. Suspensions of pro-Ca and CCC in water were prepared and either drenched into the medium or sprayed to leaves and stems. First applications of chemical in all groups were performed at the two true leaf stage (fully expanded) and second applications of double rates groups were performed one week after first treatment.

Fertilization

Seedlings were fed using liquid fertilizer from the three true-leaf stage onwards. The content of the fertilizer applied every watering, was N, 110 mg l^{-1}; P_2O_5, 40 mg l^{-1} and K_2O, 275 mg l^{-1}. Prior to planting, N, 10 kg da^{-1}; P_2O_5, 4.3 kg da^{-1}; K_2O, 10 kg da^{-1}; CaO, 10 kg da^{-1} and MgO, 2.3 kg da^{-1} were applied and additional fertilization was provided at the flowering stage as N, 10 kg da^{-1} and K_2O, 10 kg da^{-1}.

Data collection and measurements

In the conclusion of seedling growing period, the characteristics studied were seedling height (cm), stem diameter (mm, below the first true leaf), number of leaves, leaf stem, root fresh, dry weight (g) (ventilated oven, 105°C), specific leaf area (m^2 g^{-1}), specific leaf dry

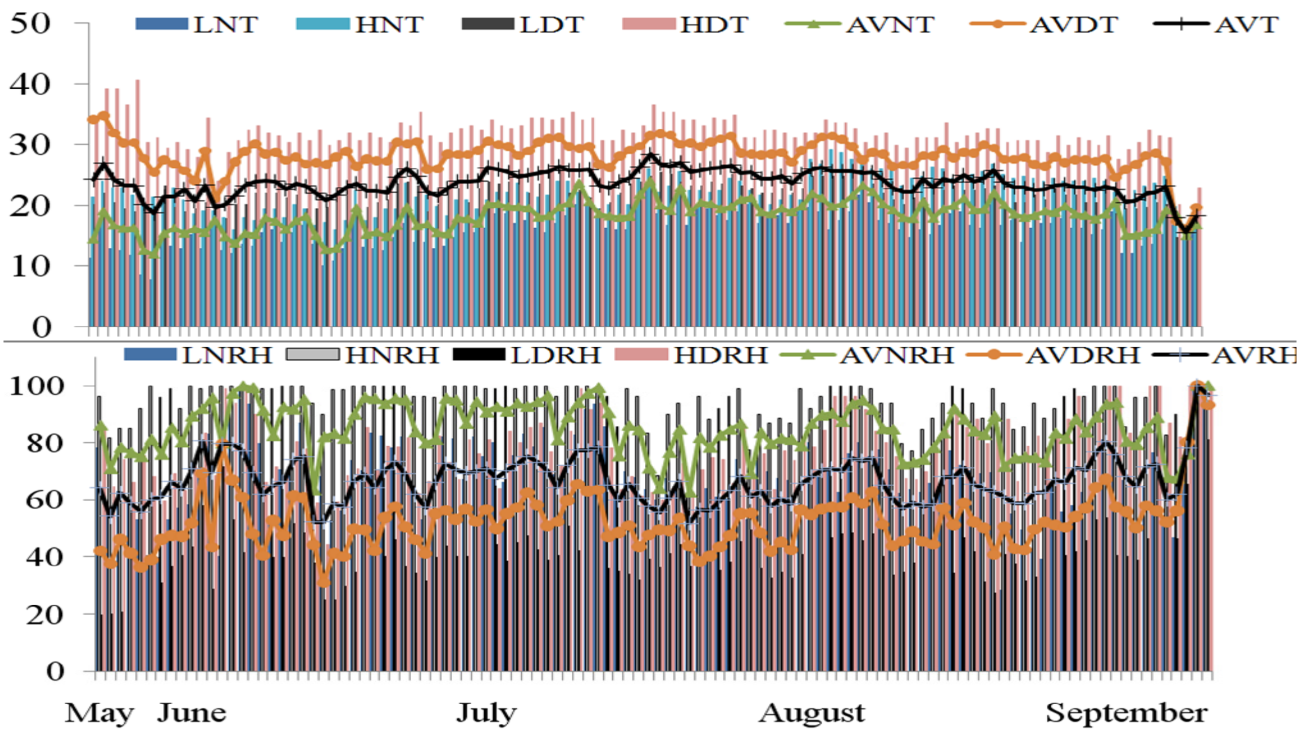

Figure 1. Environmental condition of glasshouse during the period of experiment. LNT, the lowest night temperature; HNT, the highest night temperature; LDT, the lowest day temperature; HDT, the highest day temperature; AVNT, average night temperature; AVDT, average day temperature; AVT, average temperature; LNRH, the lowest night relative humidity; HNRH, the highest night reletive humidity; AVNRH, average night relative humidity; AVDRH, average day relative humidity; AVRH, average relative humidity.

weight (mg) and chlorophyll (SPAD unit, Minolta Chlorophyll Meter SPAD 502).

Specific leaf area (SLA) was calculated according to the following equation (Hunt et al., 2002):

$$SLA\ (m^2\ g^{-1}) = \frac{LA}{LW} \qquad (1)$$

Where, LW is total leaf dry weight per plant, LA is total leaf area per plant. Specific leaf dry weight were calculated according to the following equation:

$$SLDW\ (mg) = \frac{LDW}{LA} \qquad (2)$$

Where, LDW is leaf dry weight.

Following transplanting, flower and fruit development were observed and recorded three times a week. All measurements were performed separately for four plants per replication for all treatments. During the main growing period, the following characteristics were studied: total and early yield, (g plant^{-1}); total and early number of fruits per plant; average fruit weight (g fruit^{-1}) and fruit diameter (mm). Early yield was considered to be the yield obtained from the first three of six harvest. The equatorial diameter of each fruits obtained from each harvest were measured and classified according to fruit diameters of small, medium, large and extra large fruits measured at < 50, 50 to 60, 61 to 70, > 70 mm, respectively. Average fruit weight was calculated by dividing total fruit weight by total fruit number of plant. Harvest was performed when fruits were in pink-red stage.

Statistical analysis

The experiment was laid out in a completely randomized block design with each treatment (∑19) comprising three replications. Effects of treatments were compared by Duncan's multiple range test. Statistical analysis was performed with the aid of the SPSS statistical package (18.0 for Windows).

RESULTS

Seedling growth

Significant differences among treatments were observed with seedling height, leaf number, stem diameter and chlorophyll content of leaves (Table 2). Among all treatments, including control, seedling height from the 50 and 250 mg l-1 pro-Ca D (medium drench) treatments were the highest. Following this, 50 pro-Ca mg l^{-1} S (spray), 100 mg l^{-1} pro-Ca D and control, having higher seedlings than all other treatments, were in the same statistical group. The shortest seedlings were observed with 125 × 2 mg l^{-1} pro-Ca S. Reducing effects of CCC on seedling height, as on the leaf number, was significant,

Table 2. Effects of CCC and pro-Ca[1] on seedling characteristics of tomato.

Rates ($mg\ l^{-1}$)	AP	Seedling height (cm)	Leaf number	Stem diameter (mm)	Specific leaf area ($m^2\ g^{-1}$)	Specific leaf dry weight (mg)	Chlorophyll (SPAD unit)
50 Pro-Ca	D	27.00[a]	6.67[ce]	4.40[bg]	0.0069	14.5	42.70[ac]
	S	21.67[b]	7.67[ac]	4.77[ac]	0.0049	20.2	35.80[ce]
100 Pro-Ca	D	22.00[b]	8.33[a]	4.90[a]	0.0068	14.6	39.70[ad]
	S	11.00[fg]	6.33[de]	4.60[ae]	0.0064	15.6	36.87[be]
200 Pro-Ca	D	15.00[ce]	8.00[ab]	4.25[dg]	0.0085	11.7	37.77[be]
	S	9.67[fh]	5.67[e]	4.33[cg]	0.0068	14.7	31.50[e]
250 Pro-Ca	D	25.33[a]	7.33[ad]	4.57[af]	0.0095	10.5	43.77[ac]
	S	17.67[c]	7.67[ac]	4.80[ab]	0.0068	14.6	36.97[be]
300 Pro-Ca	D	14.33[de]	7.33[ad]	4.67[ad]	0.0065	15.3	35.97[ce]
	S	10.00[fh]	7.00[bd]	4.48[af]	0.0060	16.7	36.10[ce]
100 x 2 Pro-Ca	D	14.67[de]	7.00[bd]	4.87[b]	0.0054	18.3	38.7[be]
	S	17.00[cd]	7.67[ac]	3.98[g]	0.0063	15.9	39.23[ae]
125 x 2 Pro-Ca	D	8.67[gh]	7.00[bd]	4.12[fg]	0.0062	16.1	36.03[ce]
	S	7.67[h]	6.33[de]	4.38[bg]	0.0065	15.3	40.10[ad]
150 x 2 Pro-Ca	D	10.67[fh]	7.00[bd]	4.70[ad]	0.0064	15.5	33.83[de]
	S	12.67[ef]	7.67[ac]	4.14[ag]	0.0067	14.9	40.87[ad]
2000 CCC	D	15.00[ce]	6.33[de]	4.46[af]	0.0052	23.4	44.93[ab]
	S	16.70[cd]	6.33[de]	4.69[ad]	0.0043	19.3	43.53[ac]
Control		21.67[b]	7.00[bd]	4.53[af]	0.0063	15.8	47.20[a]
Level of significance		$P < 0.01$	$P < 0.01$	$P < 0.01$	ns	ns	$P < 0.05$

[1] Mean separation by Duncan's multiple range test ($P < 0.05$); ns, non-significant; AP, application method; D, medium drench application ; S, spray application. Spray applications were performed under shading cloth in order to maximize chemical uptake, due to uniform Pro-Ca drench; is critical for uniform height control, root applications limited to 15 ml for each pot (Ø 3.5 cm). Means within the same column with different letters are significantly different.

Table 3. Effects of CCC and pro-Ca[1] on yield parameters of tomato.

Rates (mg l^{-1})	AP	Total yield (g $plant^{-1}$)	Early yield (g $plant^{-1}$)	Average fruit weight (g $plant^{-1}$)	Total fruit number	Early fruit number
50 Pro-Ca	D	1347^{ac}	742^{be}	$127,33^{ac}$	10.66^{ab}	5.33^{ce}
	S	846^{ce}	474^{cf}	93.31^{bc}	9.00^{ad}	5.16^{ce}
100 Pro-Ca	D	1738^{ab}	1228^{b}	127.96^{ac}	13.83^{a}	9.66^{b}
	S	1460^{ac}	594^{cf}	158.46^{a}	9.91^{ab}	3.25^{cf}
200 Pro-Ca	D	1125^{be}	628^{cf}	132.33^{ac}	8.66^{ad}	4.16^{cf}
	S	715^{ce}	133^{ef}	142.08^{ac}	5.58^{bd}	1.33^{ef}
250 Pro-Ca	D	950^{be}	525^{cf}	104.75^{ac}	9.25^{ad}	5.00^{ce}
	S	1076^{be}	505^{cf}	107.65^{ac}	10.67^{ab}	5.00^{ce}
300 Pro-Ca	D	1370^{ac}	742^{be}	127.18^{ac}	11.00^{ab}	5.75^{cd}
	S	1310^{ad}	862^{bc}	143.43^{ac}	9.5^{ad}	6.50^{bc}
100 x 2 Pro-Ca	D	998^{be}	523^{cf}	124.81^{ac}	8.33^{ad}	4.66^{ce}
	S	1471^{ac}	623^{cf}	154.61^{a}	9.75^{ac}	4.50^{cf}
125x 2 Pro-Ca	D	463^{de}	43^{f}	137.83^{ac}	4.17^{cd}	0.50^{f}
	S	750^{ce}	240^{def}	150.00^{ab}	5.50^{bd}	1.50^{ef}
150 x 2 Pro-Ca	D	710^{ce}	392^{cf}	161.00^{a}	5.75^{bd}	3.25^{cf}
	S	317^{e}	142^{ef}	88.12^{c}	4.00^{d}	1.75^{df}
2000 CCC	D	2037^{a}	2037^{a}	144.89^{ac}	14.00^{a}	14.00^{a}
	S	1516^{abc}	806^{bd}	124.39^{ac}	12.25^{a}	6.75^{bc}
Control		1091^{be}	544^{cf}	85.95^{c}	10.75^{ab}	5.00^{ce}
Level of significance		$P < 0.05$	$P < 0.01$	$P < 0.05$	$P < 0.01$	$P < 0.01$

[1]Mean separation by Duncan's multiple range test ($P < 0.05$). Means within the same column with different letters are significantly different. AP,application method; D, medium drench application and S, spray application. Spray applications were performed under shading cloth in order to maximize chemical uptake, due to uniform Pro-Ca drench; is critical for uniform height control, root applications limited to 15 ml for each pot (Ø 3.5 cm).

however seedlings from CCC applications had the higher height related to half of the pro-Ca applications. Additionally, from CCC applications, leaf numbers were lower than most pro-Ca applications. Highest and lowest leaf numbers were from 100 mg l^{-1} pro-Ca D and 200 mg l^{-1} pro-Ca S, respectively (Table 2). In 12 of 16 pro-Ca treatments, leaf numbers were either higher or same compared to the control. Although not significant, similar results were obtained from pro-Ca and CCC on SLA (Table 2). CCC appli-cations reduced SLA and seedlings from CCC applications had smaller SLA even than pro-Ca applications that had similar leaf number. The highest SLDW (23.4) was found in plants from the CCC D, the groups ranking second consisted of, in descending order, 50 mg l-1 pro-Ca S, CCC S and 100 x 2 mg l-1 pro-Ca D, with weights of 20.2, 19.3 and 18.3 respectively. In exception of the applications which gave the highest (50 mg l-1 pro-Ca S and 100 x 2 mg l-1 pro-Ca D) and lowest (200 and 250 mg l-1 pro-Ca D) values, SLDWs were similar with those from control (Table 2).

Stem diameter of control plants were smaller than several pro-Ca applications (Table 2). The smallest stem diameter was observed with 100 × 2 mg l^{-1} pro-Ca S while the largest was with 100 mg l^{-1} pro-Ca D.

Yield

Both pro-Ca and CCC chemicals affected total and early yields, total and early fruit numbers, and average fruit weight significantly (Table 3). Regarding all combinations for total and early yields and early fruit number, the highest values were observed with CCC D application, while for total fruit number, the highest values were observed with CCC D and 100 mg l^{-1} pro-Ca S and CCC S treatments, respectively. For average fruit weight, on the other hand, the highest values were observed with 150 × 2 mg l^{-1} D, 100 mg l^{-1} S and 100 × 2 mg l^{-1} S pro-Ca applications. In CCC D application, total and early yields, early fruit number and average fruit weight were higher than those with spray applications, while total fruit number of plants in both CCC applications were in the same statistical group. But in drench application of CCC, total fruit number was slightly higher than its spray application. In pro-Ca applications, however, effect varied by application method, and it did not show a specific pattern. For both total and early yields, 100 mg l^{-1} pro-Ca D application was statistically the second best group. 150 × 2 mg l^{-1} pro-Ca S produced the lowest total yield and total fruit number as 125 × 2 mg l^{-1} pro-Ca D produced the lowest early yield and early fruit number. 150 × 2 mg l^{-1} pro-Ca S and the control plots produced the lowest average fruit weight. Control plants with the 544 g plant $^{-1}$, produced lower early yield compared to some pro-Ca treatments. With regards to all yield parameters subjected here, it was found that control plants had either lower or similar results compared to several pro-Ca applications.

Total and early yields, and total and early fruit numbers and average fruit weight were significantly reduced by 47, 73, 23, 64 and 40%, respectively, with the control plants in comparison to CCC D and significantly reduced by 37, 55, 22, 48 and 33%, respectively, in comparison with the 100 mg l^{-1} pro-Ca D.

The effect of pro-Ca, as well as CCC, was significant on fruit diameter and percentage of extra large fruit, whereas the effect of these chemicals on percentages of small, medium and large fruit were not significant (Table 4). The percentage of fruits falling into the weight classes varied depending on the pro-Ca rates applied. The largest and smallest diameters, same as the highest and lowest percentages of extra large fruits, were from CCC D, and 150 × 2 mg l^{-1} pro-Ca S applications, respectively. The control plants produced a comparatively smaller percentage of extra large fruits with 5.5%. Despite the fact that the pro-Ca rates applied did not have any significant effect on the other weight classes and percentages of fruits, noticeable results in quality were determined. 100, 200, 100 × 2 and 300 mg l^{-1} pro-Ca treatments produced higher percentages of large fruit related to control and CCC treatments. Majority of fruits of the control plots, same as of 50 mg l^{-1} pro-Ca S and 250 mg l^{-1} pro-Ca D and S, were in the small and medium class. CCC D treatment produced no small class of fruit. The highest percentage of small fruit was obtained from 150 × 2 mg l^{-1} pro-Ca S. Regarding the percentages of large + extra large fruits, the highest percentages were from 100 × 2 mg l^{-1} S (78%), 125 × 2 mg l^{-1} S (78%), 100 mg l^{-1} D (80%), 200 mg l^{-1} D (76%) and S (73%), 50 mg l^{-1} D (74%), and 150 × 2 mg l^{-1} D (73%) pro-Ca applications and CCC D (78%), as opposed to the lowest number from the 150 × 2 mg l^{-1} S (5%) plants. Control plants had 40% large + extra large fruits.

Flower and fruit development

In both CCC treatments, flowers were at the anthesis stage at the transplanting, while in the pro-Ca applications and control, flowers in the first florescences were not developed. Three weeks after transplanting flowers in the first florescence, they were either at the anthesis or at fruit set in pro-Ca treatments whereas they were in hazelnut-size in the control and in CCC treatments (Table 5). Interestingly though, flowers in the second florescence were at anthesis stage in both CCC treatments, while in control and in some pro-Ca treatments, that is, 50 mg l-1 pro-Ca S, 200 mg l-1 pro-Ca D and 150 x 2 mg l-1 pro-Ca S, they were at fruit set.

DISCUSSION

According to results of seedling period, pro-Ca reduced seedling height with the exception of four treatments. Two times spray applications of pro-Ca (seven days apart), generally gave higher seedlings related to drench applications of same pro-Ca rates. Additionally with one time application, seedling heights were taller when pro-Ca was applied as a drench. It may be due to the pro-Ca degraded in the medium faster than it did in plants with one time applications (Ilias and Rajapakse, 2005). With the exception of 250 mg l^{-1}, height reducing effect of pro-Ca as a drench application generally increased with increasing rates, while spray applications did not show similar respond (Table 2).

The height reducing effect by pro-Ca in tomato, presented here, supports the work of Ergun et al. (2007) who found that pro-Ca treated cucumber plants produced significantly smaller seedlings. In accordance with the results of this experiment, Ergun et al. (2007) also pointed out that reducing effect of spray applications of pro-Ca on seedling height was more strong than drench applications. In contrast with the results of this experiment, however, authors did not find important differences between pro-Ca rates by spray applications. This could be due to the relatively high rates of pro-Ca evaluated in this work.

In contrast with another study carried out by this present author (not published), seedling height with 100 mg l^{-1} pro-Ca D application was similar with the control. In the mentioned study, author pointed out that both drench and spray application of 100 mg l^{-1} pro-Ca gave the same seedling height and produced shorter seedlings related to the control. According to the results obtained from the present and other works, it may be argued that drench

Table 4. Effects of CCC and pro-Ca[1] on some quality parameters of tomato.

Rates (mg l^{-1})	AP	Fruit diameter (mm)	% of Small fruit	% of Medium fruit	% of Large fruit	% of Extra large fruit
50 Pro-Ca	D	65.78^{ab}	3.13	22.16	45.19	29.51^{ac}
	S	57.49^{bd}	15.83	45.84	33.75	4.58^{cd}
100 Pro-Ca	D	63.52^{ac}	1.28	18.06	55.47	25.17^{ad}
	S	62.46^{ac}	5.88	33.82	47.05	13.22^{cd}
200 Pro-Ca	D	64.16^{ac}	1.85	21.40	59.78	16.96^{bd}
	S	63.40^{ac}	8.05	18.61	52.22	21.11^{ad}
250 Pro-Ca	D	58.10^{bd}	7.14	67.56	22.91	2.38^{cd}
	S	58.28^{bd}	12.49	57.81	20.30	9.37^{cd}
300 Pro-Ca	D	63.60^{ac}	10.26	25.44	38.39	25.89^{ad}
	S	65.66^{ab}	5.62	37.95	53.78	2.94^{cd}
100 x 2 Pro-Ca	D	62.53^{ac}	2.00	38.00	50.00	10.00^{cd}
	S	65.55^{ab}	2.08	19.20	51.26	27.44^{ac}
125 x 2 Pro-Ca	D	60.96^{ac}	7.14	32.14	47.07	13.64^{cd}
	S	65.69^{ab}	6.25	15.25	36.39	42.09^{ab}
150 x 2 Pro-Ca	D	63.99^{ac}	2.50	24.16	58.33	15.00^{cd}
	S	51.14^{d}	42.85	40.47	5.55	0.00^{d}
2000 CCC	D	68.09^{a}	0.00	22.05	32.56	45.38^{a}
	S	62.0^{ac}	2.77	34.91	48.01	14.28^{cd}
Control		56.69^{cd}	17.64	42.37	34.42	5.55^{cd}
Level of significance		$P < 0.05$	ns	ns	ns	$P < 0.05$

[1]Mean separation by Duncan's multiple range test ($P < 0.05$); ns, non-significant. Means within the same column with different letters are significantly different. AP, application method; D, medium drench application and S, spray application. Spray applications were performed under shading cloth in order to maximize chemical uptake due to uniform pro-Ca drench; is critical for uniform height control, root applications limited to 15 ml for each pot (Ø 3.5 cm).

application of this chemical was more effective on reducing seedling height when it is applied at three-leaf stage, while the spray applications can performed both at the two and three leaf stage.

The specific inhibitory effect of Pro-Ca on seedling height is further supported by other reporters for several species, such as okra (Ilias et al., 2007), cabbage (Hamano et al., 2002), petunia and impatient (Ilias and Rajapakse, 2005).

100 mg l^{-1} pro-Ca D was the second ranking group after CCC D for total and early yield, and early fruit number. Both CCC treatments and 100 mg l^{-1} pro-Ca D treatment produced the highest total fruit number. Total yield was almost 59 and 34% higher with 100 mg l-1 pro-Ca D and S treatments respectively and 86 and 38% higher with CCC D and S treatments respectively than that of the control. It is apparent from the results that while pro-Ca positively affected the total and early yields with some rates, it did not present desirable results or caused considerable reduction in yield with some rates. The total and early yields, and total and early fruit numbers were higher with drench application of CCC than all the pro-Ca treatments, while the average fruit weight with drench and spray applications of CCC were lower than several pro-Ca applications. Similar response was observed with 100 mg l^{-1} pro-Ca. With drench application of 100 mg l^{-1} pro-Ca, which was the second ranking group on total and early yields, yields were higher than with spray application of the same rate but average fruit weight was higher with the spray application. These results indicate that yield reduction from these applications may have resulted from fruit number. Considering one time application of pro-Ca, it was observed that, while 300 mg l^{-1} did not reduce total and early yields, 250 mg l^{-1}

Table 5. Effects of CCC and pro-Ca on flowering and fruit set of tomato[1].

Rate (mg l^{-1})	AP	W 1	W 3		W 4			W 5				W 6			
		T1	T1	T2	T1	T2	T3	T1	T2	T3	T4	T1	T2	T3	T4
50 Pro-Ca	D	-	A	A	FS	FS	-	B	B	B	-	W	W	W	FS
	S	-	FS	FS	H	H	A	MG	W	H	FS	MG	MG	MG	W
100 Pro-Ca	D	-	A	A	A	FS	A	A	W	H	FS	FS	MG	MG	W
	S	-	FS	A	H	FS	-	W	H	A	-	MG	W	FS	-
200 Pro-Ca	D	-	A	FS	A	FS	A	A	H	H	FS	FS	MG	MG	W
	S	-	A	A	A	FS	A	A	H	FS	-	A	MG	W	A
250 Pro-Ca	D	-	A	A	H	B	A	W	W	FS	A	MG	MG	W	FS
	S	-	FS	-	FS	A	-	FS	W	H	FS	FS	MG	W	W
300 Pro-Ca	D	-	FS	A	B	FS	A	W	H	B	A	MG	W	W	FS
	S	-	A	A	A	FS	A	A	W	FS	FS	A	W	W	W
100 x 2 Pro-Ca	D	-	A	A	FS	FS	A	H	W	B	A	W	MG	W	FS
	S	-	A	A	A	FS	A	A	W	H	FS	A	MG	MG	W
125 x 2 Pro-Ca	D	-	A	A	A	FS	-	A	H	A	-	A	W	A	A
	S	-	A	A	A	FS	-	A	FS	A	-	A	FS	A	-
150 x 2 Pro-Ca	D	-	A	-	FS	A	-	FS	B	B	A	FS	B	W	FS
	S	-	A	FS	A	FS	-	A	B	B	-	A	H	W	A
2000 CCC	D	A	H	A	W	B	A	MG	W	W	FS	MG	MG	MG	W
	S	A	H	A	W	FS	A	MG	W	H	FS	MG	MG	W	H
Control		-	H	FS	W	H	A	MG	W	B	FS	MG	MG	W	FS

[1]Starting from transplanting. W, week; A, anthesis; FS, fruit set; B, bean size; H, hazelnut size; W, walnut size; MG, mature green; AP, application method; D, medium drench application and S, spray application.

resulted in lower yields related to control. Regarding two times applications, 125 × 2 and 150 × 2 mg l^{-1} of pro-Ca did reduce yields statistically.

Zandstra et al. (2006) pointed out that Apogee was not as effective as the uniconazole on yields. Also Asín et al. (2007) reported that paclobutrazol was associated with the highest return bloom. These findings are in line with this work, in that CCC treated plants. CCC, when when applied as a drench solution, gave the highest total and early yields. CCC is among the most used plant growth regulator likewise uniconazole and paclobutrazol (Pasian and Bennett, 2001; Ilias and Rajapakse, 2005). However these chemicals also have disadvantages of being persistent in the environment and degrading in higher plants and in the soil with a considerably long period (Ilias and Rajapakse, 2005), and lead to poor crop quality. Uniconazole may decrease the setting ratio of fruits and inhibit the development of pseudoembryos of genetic parthenocarpic tomato line, and cause the smaller fruits at maturation (Kataoka et al., 2003). According to the findings of Zandstra et al. (2006) in uniconazole (2.5 × 3 and 5 × 2 ppm) treated seedlings, slight distortions were observed. All plants treated with uniconazole had a more horizontal leaf orientation and crooked stems, which increased as the rate of uniconazole increased. In addition, phosphorous (up to eight times) and nitrogen and potash (two times) were required to produce transplants of marketable size when 10 ppm uniconazole was applied at the two leaf stage as compared to untreated transplants.

The yield promoting effect of pro-Ca is supported by Kang et al. (2010) on Chinese cabbage. Authors have reported that all growth attributes significantly improved with the application of pro-Ca whereas in the same study, in contrast with the presented results here, the level of this chemical showed no significant effect. Although they have pointed out that fresh head weight was highest with the 400 ppm application of pro-Ca, and earlier application resulted in higher yields. Asín et al. (2007) determined that pro-Ca did not have any significant negative effect on either return bloom or yield of pear and Smit et al. (2005) found out that pro-Ca application improved fruit set but decreased final fruit size in some of the pear cultivars. Also, in the work of Duval (2002), pro-Ca significantly increased early yields of strawberry compared to the control.

Pro-Ca applications, in exception of 150 × 2 mg l^{-1}, increased average fruit weight but this did not reflect in the yield in all pro-Ca applications. It might be argued that it was due to the reduced fruit number in these treatments. However, in contrast with the work of Smit et al. (2005), in which authors pointed out that pro-Ca reduced fruit size due to a direct effect of higher fruit set, in the present study, with pro-Ca applications, which had similar number of fruit with the control, average fruit weights were higher. Thus, it may be argued that an increase in average fruit weight resulted from an increase in fruit diameter in these treatments. Fruit diameters were increased with the pro-Ca in most treatments.

Regarding other fruit characteristics such as percentage of fruits in the small, medium and large classes from the viewpoint of pro-Ca rates, the main effects were not statistically significant, even so in some of the pro-Ca rates percentages of fruits that fall into large classes were higher in comparison to those from the control plants, and the control plants produced very small percentage of extra large fruit. Additionally, majority of fruits in the control plots were in the small and medium class and percentage of large + extra large fruits was 40%.

It was interesting that, in some pro-Ca treatments, flowers in florescences remained either at athesis or fruit set through the growing period. However, flower and fruit developments were normal in the 2nd, 3rd and 4th trusses in these treatments. In the control plants, while fruit development was normal in the beginning of the productive period, it slowed in the remaining period of the experiment, and development of 3rd and 4th trusses was slower than most pro-Ca applications.

Delayed initiation of flowering or delayed fruit set was reported by Ilias et al. (2007), which corroborates with this present findings. Authors reported that pro-Ca took more time to bloom in okra. However, this is contrary to the reports of Asín et al. (2007) which suggested that pro-Ca did not have any significant negative effect on return bloom in pear, and of Ratiba and Blanco (2004) which pointed out that flower initiation in the following year was not affected by 100 to 200 mg l^{-1} pro-Ca application in apple. Ilias and Rajapakse (2005) on the other hand, revealed that while 100 ppm pro-Ca delayed anthesis and greater concentration inhibited flowering of impatients in first experiment which was conducted form November to February, it had no effect in the second experiment which was conducted from February to April. Authors have argued that this differential response is due to the seasonal environmental conditions of the experiments. Also, Giudice et al. (2004) observed that application of 250 mg l^{-1} pro-Ca to single clusters of Cabernet Sauvignon and Chardonnay at bloom, or in one to two weeks prebloom period, decreased fruit set whereas postbloom application reduced berry weight with no impact on fruit set. Furthermore, Mandemaker et al. (2005) reported that three times treated trees with pro-Ca tended to have the most fruit per tree on average in avocado.

It is known that pro-Ca inhibits stem elongation acting as a structural mimic of 2-oxoglutorale thereby inhibiting dioxygenases which catalyze distinct steps in gibberillin (GA) biosynthesis (Rademacher, 2000). In doing so, due to the higher rates of chemical and two times applications which are evaluated here, it affected the endogeneous gibberellin activity which took place in inducing an increase of the auxin content in the ovary to levels that are adequate to trigger fruit growth (de Joung et al., 2009).

According to the results obtained from this work and from earlier studies, the fact that pro-Ca was not effective on flower initiation and fruit set but still induced higher yields with some rates applied, it may be thought that the improving effect of pro-Ca depends on rates, application time, environmental conditions, species, cultivar and even on individual plant. It seems likely that initial negative effects of pro-Ca on flowering and fruit set may diminish later in the growing period with some rates, (300 mg l^{-1}). If these factors can be considered as the factors influencing the effectiveness of this chemical, in general, it may be suggested that appropriate rates and application time for subjected crops may be helpful in bringing about the desired effect of pro-Ca.

Conclusıon

From the viewpoint of the results of this experiment, it seems likely that pro-Ca have an inhibiting effect on stem elongation with no negative effect on total and early yields and fruit quality for several rates, moreover, with 100, 100 × 2 and 300 mg l^{-1} of pro-Ca applications confering an advantage over the control plants, they would be sufficient to control stem elongation. Regarding the cost of the chemical and difficulty of two times application in mass production, it could be concluded that 100 mg l^{-1} of pro-Ca will be sufficient to reduce seedling height with improved total and early yields and fruit quality of tomato. However, there is need to cary out further researches on the use of pro-Ca on seedling height control of tomato.

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