Journal of Ornamental Plants
Available online on: www.jornamental.iaurasht.ac.ir
ISSN (Print): 2251-6433 ISSN (Online): 2251-6441

Effects of Phenylphthalamic Acid and Perfect Fertilizer on Vegetative and Reproductive Growth of Ornamental Pepper (*Capsicum annuum* L.)

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Received: 08 September 2018 Accepted: 10 December 2018
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Abstract

The impact of phenylphthalamic acid (PPA) rates including 0 (PPA_0), 1000 (PPA_{1000}), 2000 (PPA_{2000}) or 3000 (PPA_{3000}) mg L^{-1} and perfect fertilizer rates including 0 (PF_0), 100 (PF_{100}), 200 (PF_{200}) and 300 (PF_{300}) mg L^{-1} was studied on vegetative and reproductive growth of ornamental pepper plants. To realize this, a factorial experiment was conducted in a Completely Randomized Design with three replications. It was found that the interaction between 'PPA × PF' improved the measured traits; so that the shortest time to flower initiation (55.40 day), the shortest time to fruit set (62.93 day) and the highest fruit number (98.12 fruit) were related to the application of 'PPA_{2000} × PF_{200}'. Plants treated with 'PPA_{2000} × PF_{300}' exhibited the most number of flowers (117.36), number of flowering stems (7.4), diameter of flowering stem (3.7 mm), plant height (45.83 cm), fruit fresh weight (6.71 g), fruit dry weight (3.79 g), plant fresh weight (21.96 g) and plant dry weight (15.17 g). Also, this treatment exhibited the highest fruit anthocyanin content and total chlorophyll. Conclusively, the application of 'PPA_{2000}×PF_{200}' is recommended because of the lower consumption of perfect fertilizer and the greater effect on traits having a beautiful and economic value for ornamental peppers.

Keywords: Flowering, Fruit bearing, Phenylphthalamate, Pollination.

INTRODUCTION

Ornamental pepper (*Capsicum annuum* L.) belongs to the Solanaceae family. This species is a favorite garden, pot, and sometimes cut flower for many people owing to its unique morphological properties, easy propagation, resistance to environmental stresses, and long-term longevity (Stommel and Bosland, 2007; Ghasemi Ghahsare and Kafi, 2014; Gilman and How, 2014).

Effective pollination plays a key role in the yields of different plant species including those of the Cucurbitaceae family. Since the interesting part of ornamental peppers is their appealing and colorful fruits (Ghasemi Ghahsare and Kafi, 2014), it is expected to make this species produce more fruits by manipulating its pollination process. One way to manipulate pollination is to apply hormones and chemical compounds, such as phenylphthalamic acid (PPA). PPA is a growth regulator that is an auxin synergist and is indeed a sort of flowering activator in plants (Racsko, 2004; Thurzo *et al*., 2008). PPA contributes to maintaining flowers and freshly formed fruits by alleviating the adverse impacts of the environment and cultivar, thereby providing conditions for accomplishing an optimum yield (Heuvelink and Korner, 2001; Racsko *et al*., 2006; Javanpour *et al*., 2014; Khadivi-Khub, 2015). The positive effect of PPA has been reported on flower formation, fruit set, and yield of different cultivars of potatoes (Racsko, 2004; Racsko *et al*., 2006), tomatoes (Kowalsak, 2003, 2006), grapevines, sweet cherries (Nosrati *et al*., 2011, 2012) and different summer crops (Javanpour *et al*., 2014).

Despite the reports about the desirable effect of PPA on flowering and fruit set of different plant species, it should be noted that the role of nutrition cannot be denied in accomplishing the maximum yield (Hashemi Majd, 2014). It has been documented that although PPA increases the number of fruits, these fruits will be smaller and of poorer marketability in case of the lack of nutrients required by the plants (Javanpour *et al*., 2014). Similarly, Miri *et al*. (2017) emphasized the importance of nutrition along with PPA application in the yield of strawberry plants.

Given the role of PPA and nutrition on the vegetative and reproductive growth of plant species and the significance of quantity and quality of ornamental pepper fruits on their marketability, the present study was achieved to evaluate the improvement of the vegetative and reproductive growth of ornamental peppers through applying PPA and perfect fertilizer.

MATERIALS AND METHODS

To investigate the effect of phenylphthalamic acid (PPA) and perfect fertilizer on the vegetative and reproductive growth of ornamental peppers, a factorial experiment was carried out on the basis of a Completely Randomized Design with 16 treatments, 3 replications, 48 plots and 4 plants per plot. The experiment took 10 months (from February of 2015 until January of 2016) in an open space in Fuman County, Guilan province, Iran. The treatments were included PPA at the rates of 0, 1000, 2000 or 3000 mg L^{-1} (denoted by PPA_0, PPA_{1000}, PPA_{2000}, and PPA_{3000}, respectively) and perfect fertilizer at the rates of 0, 100, 200 or 300 mg L^{-1} (denoted by PF_0, PF_{100}, PF_{200}, and PF_{300}, respectively). The F1 seeds of ornamental pepper procured from Taki Chemical Co., LTD., Japan were used in the study. Two months after sowing, the seedlings were transferred into the main pots with a mouth diameter of 6 cm. The substrate was a mixture of garden soil + sand + mold (1:1:1) whose physical and chemical properties are presented in Table 1.

Table 1. Physical and chemical properties of the soil used in the experiment.

Soil garden+sand+ mold (1:1:1)					
Texture	**K (ppm)**	**P (ppm)**	**N (%)**	**EC (dS m^{-1})**	**pH**
Loamy-Clay	52.42	36	2.4	17.38	6

To apply PPA treatments, the fertilizer Barafshan 1 (produced under the license of Jihad-e Daneshghahi of Tehran in Iran) whose main ingredient is PPA with WP60 standard formulation was used. The plants were fed with the perfect fertilizer Kristalon (20-20-20). PPA was sprayed with the initiation of flowering after the first bud appearance. In addition, the whole plants were sprayed at the intervals of 5 days for at most three times during their flowering period. The plants were fed with the perfect fertilizer at the predetermined rates starting from 15 days after transplanting with the intervals of 15 days to one another.

The recorded traits included flower initiation, fruit set initiation, plant height, the number of flowers and fruits per plant, the number and diameter of the flowering stem, plant and fruit fresh and dry weight, chlorophyll (a, b and total) and anthocyanin content of the fruits. The initiation of flowering and fruit set were recorded by counting the number of days from transplanting until the emergence of the first flower and the first fruit. During the experiment, the number of flowers per plant was counted from the flower initiation until its end and the number of fruits was counted from the emergence of the first fruit until the end of the experiment. Also, their sum was reported as the number of flowers and fruits per plant. At the end of the experiment, the plant height was measured from the soil surface with a ruler and the flowering stem diameter was measured with a digital caliper. To measure the plant fresh and dry weight, two plants were sampled from each plot at the end of the experiment. Their fresh weight was determined with a digital scale (0.01-precision). Then, they were oven-dried at 72°C for 48 hours and their dry weight was reported in grams. To measure the fruit fresh and dry weight, eight fruits were randomly sampled from each plot at the end of the experiment. After measuring their fresh weight, those were oven-dried at 104°C for 24 hours and their dry weight was determined with a digital scale (0.01-precision) in grams. During the experiment, young leaves were sampled to find out their chlorophyll a, b and total contents, and fruits were sampled to find out their anthocyanin content. These traits were calculated by Mazumdar and Majumdar (2003) method. At the end of the experiment, data were analyzed by SPSS software package and the means were compared by the LSD test.

RESULTS

Flower initiation

Analysis of variance indicated that the interaction effect of 'PPA × PF' was significant ($P < 0.01$) on flower initiation of the ornamental peppers (Table 2). According to means comparison, the longest time to flower initiation was 70.33 days observed in the plants treated with '$PPA_0 \times PF_0$', but it was not significantly different from those of the plants treated with '$PPA_0 \times PF_{100}$', '$PPA_0 \times PF_{200}$', '$PPA_{1000} \times PF_0$', '$PPA_{1000} \times PF_{100}$', '$PPA_{2000} \times PF_0$', or '$PPA_{3000} \times PF_0$'. The shortest time to flowering of the ornamental peppers belonged to the two treatments '$PPA_{2000} \times PF_{200}$' (55.40 days) and '$PPA_{3000} \times PF_{200}$' (56.22 days), with no significant difference between them (Table 3).

Fruit set

The effect of 'PPA × PF' was significant ($P < 0.01$) on fruit set of the ornamental peppers (Table 2). Means comparison for fruit set revealed that the shortest time to fruit set (62.93 days) was observed in plants treated with 'PPA2000 × PF200'. Plants exposed to '$PPA_0 \times PF_0$', '$PPA_0 \times PF_{100}$', '$PPA_{1000} \times PF_0$', '$PPA_{1000} \times PF_{100}$', '$PPA_{2000} \times PF_0$', or '$PPA_{3000} \times PF_0$' initiated their fruit set later than other treatments, so these treatments are not appropriate in terms of this trait (Table 3).

Table 2. Analysis of variance for the effect of different treatments on the measured traits.

SoV	df	Fruit set	Flower initiation	Fruit no.	Branch no.	Flower no.	Stem diameter	Plant height	Fruit fresh weight	Fruit dry weight	Plant dry weight	Plant fresh weight	Fruit anthocyanin	Total chlorphyll	Chlorphyll b	Chlorphyll a
PPA	3	94.32^{**}	95.88^{ns}	243.85^{**}	9.277^{ns}	344.9^{**}	2.095^{ns}	62.33^{**}	4.47^{**}	1.29^{**}	12.31^{**}	29.35^{**}	9274^{**}	17.41^{**}	0.8109^{**}	11.93^{**}
PF	3	286.6^{**}	64.46^{**}	462.6^{**}	13.32^{**}	458.4^{**}	4.974^{**}	59.16^{**}	5.74^{**}	0.617^{*}	12.17^{**}	51.16^{*}	26004^{**}	31.42^{**}	2.374^{**}	12.63^{**}
PPA × PA	9	120.4^{**}	70.52^{**}	36.15^{**}	4.39^{*}	115.85^{**}	0.085^{*}	32.107^{**}	4.19^{**}	0.712^{*}	6.31^{*}	26.91^{*}	49619^{**}	23.69^{**}	0.336^{*}	22.18^{**}
Error	32	9.91	9.23	6.5	1.920	14.75	0.031	1.230	0.603	0.21	2.406	11.38	562.19	0.412	0.089	0.378
CV (%)		4.32	4.83	19.05	24.95	18.44	6.88	2.74	20.61	19.71	27.13	23.61	7.94	11.28	25.12	14.64

*, ** and ^{ns}: Significant at $P < 0.05$, $P < 0.01$ and insignificant respectively.

Table 3. Means comparison for the effect of different treatments on the measured traits.

Treatments	Fruit set (day)	Flower initiation (day)	Fruit no.	Branch no.	Flower no.	Stem diameter (mm)	Plant height (cm)	Fruit D.W. (g)	Fruit F.W. (g)	Plant D.W. (g)	Plant F.W. (g)	Fruit anthocyanin (mg 100 g^{-1} FW)	Total chlorophyll (mg g^{-1} FW)	Chlorophyll b (mg g^{-1} FW)	Chlorophyll a (mg g^{-1} FW)
$PPA_0 \times PF_0$	80.75^{a}	70.33^{a}	33.6^{h}	2.85^{f}	50.89^{i}	1.23^{i}	35.51^{j}	1.53^{e}	3.00^{ef}	11.71^{e}	15.11^{d}	210.1^{h}	2.82^{h}	0.44^{f}	1.91^{h}
$PPA_0 \times PF_{100}$	78.28^{abc}	67.80^{ab}	37.92^{gh}	3.67^{ef}	59.64^{hi}	1.90^{h}	39.20^{fgh}	1.65^{e}	3.40^{e}	11.91^{e}	16.12^{cd}	246.5^{fgh}	3.83^{fgh}	0.85^{ef}	3.54^{efg}
$PPA_0 \times PF_{200}$	74.83^{b-f}	65.27^{a-e}	44.72^{gh}	3.95^{ef}	69.86^{ghi}	2.25^{fg}	40.33^{ef}	1.97^{de}	4.02^{d}	12.14^{d}	17.06^{c}	283.2^{ef}	4.77^{def}	0.97^{de}	3.76^{def}
$PPA_0 \times PF_{300}$	72.72^{d-g}	64.41^{b-f}	51.68^{fg}	4.29^{def}	84.14^{efg}	2.63^{e}	41.03^{de}	2.67^{c}	4.61^{c}	13.15^{cd}	19.04^{bc}	314.0^{cde}	5.20^{cde}	1.12^{de}	3.67^{d-g}
$PPA_{1000} \times PF_0$	78.99^{ab}	66.83^{abc}	40.4^{gh}	3.68^{ef}	53.55^{fgh}	1.35^{i}	37.34^{hij}	2.26^{cde}	4.33^{cd}	11.54^{e}	15.70^{d}	241.6^{gh}	3.44^{gh}	0.70^{ef}	2.65^{gh}
$PPA_{1000} \times PF_{100}$	76.14^{a-e}	65.57^{a-d}	65.84^{ef}	4.66^{cde}	73.98^{efg}	2.28^{fg}	40.33^{ef}	2.53^{bc}	4.93^{c}	12.23^{d}	17.62^{c}	282.1^{ef}	4.50^{efg}	0.99^{de}	3.55^{efg}
$PPA_{1000} \times PF_{200}$	70.46^{fgh}	58.61^{gh}	72.00^{de}	4.89^{cde}	81.36^{cde}	2.67^{e}	41.89^{cde}	2.98^{bc}	5.81^{b}	13.42^{c}	19.78^{bc}	300.8^{de}	5.81^{cd}	1.15^{cde}	4.08^{cde}
$PPA_{1000} \times PF_{300}$	66.66^{hi}	60.16^{fgh}	89.84^{bc}	6.00^{abc}	99.84^{cde}	3.36^{b}	43.55^{bc}	3.01^{b}	6.00^{abc}	13.97^{c}	19.91^{bc}	333.1^{bcd}	7.43^{b}	1.64^{bc}	4.92^{bc}
$PPA_{2000} \times PF_0$	76.38^{a-e}	66.05^{a-d}	42.4^{gh}	4.21^{def}	52.8^{fgh}	2.02^{gh}	39.11^{fgh}	2.53^{cd}	4.70^{c}	12.60^{d}	16.75^{cd}	248.0^{fgh}	4.62^{ef}	0.84^{ef}	2.82^{fgh}
$PPA_{2000} \times PF_{100}$	73.03^{c-g}	61.60^{d-g}	61.76^{ef}	4.98^{cde}	79.26^{def}	2.78^{cde}	40.72^{def}	2.89^{bc}	5.63^{b}	13.98^{c}	19.80^{bc}	323.0^{cd}	5.88^{c}	1.12^{de}	4.48^{b-e}
$PPA_{2000} \times PF_{200}$	62.93^{i}	55.40^{h}	98.12^{a}	5.67^{bcd}	110.4^{bc}	3.04^{c}	42.23^{cd}	3.00^{b}	5.87^{b}	14.73^{b}	19.87^{bc}	344.4^{abc}	7.52^{b}	1.64^{bc}	5.48^{ab}
$PPA_{2000} \times PF_{300}$	67.93^{ghi}	59.99^{fgh}	86.08^{bcd}	7.40^{a}	117.36^{a}	3.70^{a}	45.83^{a}	3.79^{a}	6.71^{a}	15.17^{a}	21.96^{a}	372.9^{a}	8.91^{a}	2.01^{ab}	6.42^{a}
$PPA_{3000} \times PF_0$	77.70^{a-d}	65.92^{a-d}	41.6^{gh}	4.95^{ef}	53.00^{fgh}	2.32^{f}	39.32^{fg}	2.33^{cde}	4.69^{c}	12.64^{d}	16.52^{cd}	250.8^{fg}	4.49^{efg}	0.83^{ef}	3.49^{efg}
$PPA_{3000} \times PF_{100}$	72.04^{efg}	62.14^{c-g}	61.92^{ef}	4.96^{cde}	81.39^{efg}	2.74^{de}	41.71^{cde}	2.98^{bc}	5.41^{b}	13.78^{c}	19.84^{bc}	316.0^{cde}	5.72^{cd}	1.05^{de}	4.60^{bcd}
$PPA_{3000} \times PF_{200}$	66.23^{hi}	56.22^{h}	93.88^{b}	5.58^{bcd}	102.38^{bcd}	2.99^{cd}	42.53^{cd}	3.17^{b}	5.82^{b}	14.48b	19.89^{bc}	343.0^{abc}	7.33^{b}	1.36^{cd}	5.34^{b}
$PPA_{3000} \times PF_{300}$	70.69^{fgh}	60.45^{e-h}	82.96^{cd}	6.74^{ab}	113.56^{ab}	3.39^{b}	44.78^{ab}	3.34^{ab}	6.32^{ab}	14.95^{ab}	20.51^{b}	369.1^{ab}	8.70^{a}	2.24^{a}	6.46^{a}

*In each column, means with the similar letters are not significantly different ($P < 0.05$) using the LSD test. FP_0: 0 mg L^{-1} perfect fertilizer, FP_{100}: 100 mg L^{-1} perfect fertilizer, FP_{200}: 200 mg L^{-1} perfect fertilizer, FP_{300}: 300 mg L^{-1} perfect fertilizer; PPA_0:0 mg L^{-1} phenylphthalamic acid, PPA_{1000}:1000 mg L^{-1} phenylphthalamic acid, PPA_{2000}:2000 mg L^{-1} phenylphthalamic acid, PPA_{3000}:3000 mg L^{-1} phenylphthalamic acid.

Plant height

Table 2 shows a significant ($P < 0.01$) difference among the various rates of 'PPA × PF' in plant height of the ornamental peppers. According to means comparison, in four levels of PPA, plant height was improved with the increase of perfect fertilizer rate. The treatments of '$PPA_{2000} \times PF_{300}$' and '$PPA_{3000} \times PF_{300}$' were related to the maximum plant height of 45.83 and 44.78 cm, respectively. The lowest plant height (35.51 cm) was obtained by '$PPA_0 \times PF_0$' (Table 3).

Flowering stem diameter

Analysis of variance showed the significant ($P < 0.05$) effect of 'PPA × PF' on flowering stem diameter (Table 2). It was observed that this trait was added with the increase in the perfect fertilizer rate at all levels of PPA. As can be observed in Table 3, the widest flowering stem was obtained from perfect fertilizer rate of 300 mg L^{-1} at four levels of PPA. In total, the lowest flowering stem diameters of 1.23 and 1.35 mm were related to plants treated with '$PPA_0 \times PF_0$' and '$PPA_{1000} \times PF_0$', respectively, which were not significantly different. Among all treatments, plants treated with '$PPA_{2000} \times PF_{300}$' produced the highest flowering stem diameter (3.70 mm) (Table 3).

Flowering branch number

The difference between 'PPA × PF' treatments in terms of the number of flowering branch was significant at the $P < 0.05$ level (Table 2). Means comparison showed that the most number of flowering branch was obtained from the treatment of 300 mg L^{-1} perfect fertilizer at all PPA levels. Among all treatments, the highest number of flowering branch (7.40 stems) was obtained from the plants treated with '$PPA_{2000} \times PF_{300}$', but this did not differ significantly from that of the plants treated with '$PPA_{3000} \times PF_{300}$' (6.74 stems) or with '$PPA_{1000} \times PF_{300}$' (6 stems). The lowest number of flowering branch (2.85 stems) was related to the treatment of '$PPA_0 \times PF_0$' (Table 3).

Flower number per plant

Analysis of variance showed that the interaction of 'PPA × PF' was significant ($P < 0.01$) on the number of flowers per plant (Table 2). The treatments of '$PPA_{2000} \times PF_{300}$' (related to 117.36 flower) and '$PPA_{3000} \times PF_{300}$' (related to 113.56 flowers) recorded the highest number of flowers per plant, but there was notsignificant difference between them. As is evident in Table 3, '$PPA_0 \times PF_0$' among all treatments exhibited the least number of flowers per plant (50.89).

Fruit number per plant

The number of fruits per plant was influenced significantly by the interaction of 'PPA × PF' at the $P < 0.01$ level (Table 2). According to means comparison, the application of PPA caused the increase in fruit number as compared to control (no PPA application), and among all treatments, the most and least number of fruits were 98.12 and 33.6 fruits produced by plants treated with '$PPA_{2000} \times PF_{200}$' and '$PPA_0 \times PF_0$', respectively (Table 3).

Plant fresh and dry weight

Analysis of variance showed that the interaction of 'PPA × PF' influenced plant fresh and dry weight significantly at the $P < 0.05$ level (Table 2). At all four levels of PPA, the highest fresh weight was related to perfect fertilizer rate of 300 mg L^{-1} and the lowest was related to no perfect fertilizer application. Overall, the highest plant fresh weight (21.96 g) was related to the treatment of '$PPA_{2000} \times PF_{300}$'. The treatments of '$PPA_0 \times PF_0$' and '$PPA_{1000} \times PF_0$' had the lowest plant fresh weight of 15.11 and 15.70 g, respectively. With respect to the plant dry weight, the highest was related to '$PPA_{2000} \times PF_{300}$' and '$PPA_{3000} \times PF_{300}$', which were related to plant dry weights of 15.17 and 14.95 g, respectively. The lowest plant dry weight was obtained from three treatments including '$PPA_{1000} \times PF_0$' (11.54 g), '$PPA_0 \times PF_0$' (11.71 g) and '$PPA_0 \times PF_{100}$' (11.91 g), but they did not show statistically significant differences (Table 3).

Fruit fresh and dry weight

The fresh and dry weight of the fruits were ($P < 0.01$) influenced significantly by 'PPA × PF' (Table 2). According to means comparison, the treatments '$PPA_0 \times PF_0$' and '$PPA_0 \times PF_{100}$' were related to the lowest fruit fresh weight of 3 and 3.4 g, respectively, and the treatments 'PPA_{2000} × PF300', '$PPA_{3000} \times PF_{300}$' and '$PPA_{1000} \times PF_{300}$' were related to the highest fruit fresh weight of 6.71, 6.32 and 6 g, respectively. With regard to fruit dry weight, the treatments '$PPA_{2000} \times PF_{300}$' and '$PPA_{3000} \times PF_{300}$' were found to be the most appropriate and produced the highest fruit dry weight of 3.79 and 3.34 g, respectively. The lowest fruit dry weight was observed in the treatments of '$PPA_0 \times PF_0$' (1.53 g) and '$PPA_0 \times PF_{100}$' (1.65) with no significant differences between them (Table 3).

Chlorophyll a, b and total

According to the results of analysis of variance, the effect of interaction between 'PPA × PF' was significant on chlorophyll a, chlorophyll b and total chlorophyll at the $P < 0.01$, $P < 0.05$ and $P < 0.01$ levels, respectively (Table 2). Means comparison for the effect of the treatments on chlorophyll a content showed that the highest content was related to the treatments '$PPA_{3000} \times PF_{300}$' (6.46 mg g^1 F.W.), '$PPA_{2000} \times PF_{300}$' (6.42 mg g^{-1} F.W.) and '$PPA_{2000} \times PF_{200}$' (5.48 mg g^1 F.W.); and also these three treatments did not differ significantly with one another. The lowest one (1.91 mg g^{-1} F.W.) was observed in plants treated with '$PPA_0 \times PF_0$' (Table 3).

With respect to chlorophyll b content, the lowest one was obtained from '$PPA_0 \times PF_0$' (0.44 mg g^{-1} F.W.) and the highest one from '$PPA_{3000} \times PF_{300}$' (2.24 mg g^{-1} F.W.) and '$PPA_{2000} \times PF_{300}$' (2.01 mg g^{-1} F.W.) without significant differences between them (Table 3).

Means comparison for total chlorophyll content indicated that the increase in perfect fertilizer rate resulted to higher total chlorophyll content at all four levels of PPA. As is evident in Table 3, the highest total chlorophyll (8.91 mg g^{-1} F.W.) was obtained from '$PPA_{2000} \times PF_{300}$', but this treatment was in the same statistical group with '$PPA_{3000} \times PF_{300}$' (8.70 mg g^{-1} F.W.). The lowest total chlorophyll content (2.82 mg g^{-1} F.W.) was obtained from plants treated with '$PPA_0 \times PF_0$' (Table 3).

Fruit anthocyanin

The interaction 'PPA × PF' influenced fruit anthocyanin content significantly at the $P < 0.01$ level (Table 2). According to means comparison, the lowest anthocyanin content (210.2 mg 100 g^{-1} FW) was related to '$PPA_0 \times PF_0$'. But, the highest one was obtained from the treatment '$PPA_{2000} \times PF_{300}$' (372.9 mg 100 g^{-1} F.W.) which did not exhibit a significant difference with the treatments '$PPA_{2000} \times PF_{200}$' (344.4 mg 100 g^{-1} F.W.), '$PPA_{3000} \times PF_{200}$' (343.0 mg 100 g^{-1} F.W.), and '$PPA_{3000} \times PF_{300}$' (369.1 mg 100 g^{-1} F.W.) (Table 3).

DISCUSSION

PPA is a plant growth regulator whose converging effect with auxin has been documented in biological trials. By stimulating flowering system and extending the longevity of stigmas, this compound increases the effective pollination period. It, also ramps up the number of flowers and fruits by controlling the yield fluctuations of the plants (Holb and Heijne, 2001; Holb *et al*., 2003; Racsko, 2004). Holb and Heijne (2001) argue that if phenyl phthalamic acid is applied at the right growth stage of the plant, it can partially alleviate the adverse impacts of production conditions, climate, and cultivar and can improve yield and food security remarkably.

However, it should be noted that as crop production is increased in different plant species, the lack of balanced and appropriate nutrients will aggravate the competition of the fruits on nutrients, resulting in the development of low-quality fruits. So, to maintain the quantity and quality of crops, a special attention should be paid to their nutrition during pollination and flower and fruit formation (Racsko and Lakatos, 2003; Javanpour *et al*., 2014). It has been suggested that the in-adequate nutrient supply to plants treated with phenyl phthalamic acid reduces the size (diameter, length, and width) and quality of fruits and impairs crop marketability (Racsko, 2006; Hadadinejad *et al*., 2014).

In the present study, the foliar application of PPA improved fruit number and reduced the time to fruit set of ornamental pepper through increasing the number of flowers and accelerating flower initiation. This can be attributed to the effect of PPA, as well as appropriate nutrition with perfect fertilizer, on pollination, maintaining more flowers and transforming more flowers to fruits. This finding is consistent with the results of studies in which the researchers argue that PPA should be accompanied with appropriate nutrition in order to increase crop production and yield (Racsko and Lakatos, 2003; Javanpour *et al*., 2014; Khadivi-Khub, 2015). According to Racsko (2006), the application of phenyl phthalamic acid increased flowering and flower opening rate in different cultivars of potato. He reported that phenyl phthalamic acid improved flowering period but not significantly. However, it played an important role in protecting the buds against chilling and simultaneous flowering of the cultivars.

The number of fruits, fruit fresh and dry weight, and fruit color (anthocyanin content) of ornamental peppers were significantly increased with concurrent application of PPA and perfect fertilizer. This finding implies the positive effect of PPA and perfect fertilizer application on the quantitative and qualitative traits of ornamental pepper. It has been documented in a study that the highest fruit fresh and dry weight of strawberries were obtained from plants treated with '5 g L^{-1} potassium nitration × 50 mg L^{-1} PPA'. The researchers argue that PPA application influences on tissue growth and fruit development and speculate that due to its semi-auxin effects and its impact on the fertility of carpel. PPA not only increased fruit number, but it also contributed to uniform growth of strawberry fruits and the production of fruits with higher fresh and dry weight (Miri *et al*., 2017). The positive effect of PPA has been reported on flower and fruit formation of tomatoes, cucumbers, eggplants and cabbage (Javanpour *et al*., 2014), which is consistent with our results. Racsko (2006) reported that the application of phenyl phthalamic acid along with an adequate dosage of NPK enhanced the number of fruits in potato cultivars. The highest fruit fresh and dry weights were related to the treatment of phenyl phthalamic acid + fertilizer, whereas the application of phenyl phthalamic acid alone resulted in the loss of fruit fresh and dry weights. Racsko (2006) related this finding to nutrient unavailability to the trees so that the trees could not mobilize adequate amount of nutrients to fruits.

Researchers have been associated the desirable impact of PPA on the yield of different plants species to the effect of this compound on extending the longevity of stigmas and the effective pollination period, which increases the fertility and fruit production (Racsko, 2004; Racsko *et al*., 2006). May (2004) argued that PPA contributes to the availability of carbohydrate and nitrogen resources to flowers and growing fruits by reducing terminal dominance and proper distribution of these resources across the plant, thereby increasing grapevine yield.

There are many reports about the positive effect of PPA and nutrition on quantitative and qualitative traits of fruits, flowers, and yield of different crops including sweet cherries (Thurzo *et al*., 2008), potatoes (Racsho, 2004), and grapevine (Racsko and Lakatos, 2003), which is consistent with this study.

In our study; plant fresh and dry weight, leaf chlorophyll, plant height, flowering stem diameter, the number of flowering branches, flower initiation and fruit set were influenced by different rates of PPA and perfect fertilizer. This finding is not surprising given the role of PPA in distributing carbohydrate and nitrogen resources across the plant (May, 2004) and alleviating factors contributing to yield fluctuations (Racsko and Lakatos, 2003; Racsko, 2004) as well as the role of perfect fertilizer in nutrient availability. In a study on the concurrent use of potassium nitrate and PPA, Miri *et al*. (2017) reported the significant increase in yield and leaf chlorophyll. In another study on PPA, 100 mg L^{-1} PPA improved plant height and flower number of carnation (Nejadsahebi *et al*., 2011), which is in agreement with our findings.

CONCLUSION

It was found that the concurrent use of PPA and perfect fertilizer could be effective on optimal vegetative and reproductive traits of ornamental peppers. The treatment '$PPA_{2000} \times PF_{300}$' was the superior treatment for most studied traits. Also, the treatment '$PPA_{2000} \times PF_{200}$' was among the superior treatments for flower initiation, fruit number and fruit color. Since these traits are among the best and eminent traits for ornamental plants and the fertilizer rate is lower in this treatment, so this treatment can be recommended as the best treatment for the production of marketable ornamental pepper.

ACKNOWLEDGEMENT

This paper has been derived from a research project conducted by the Young Researchers and Elite Club of Rasht Branch, Islamic Azad University, Rasht, Iran. So, the authors are so grateful to this club for its financial supports.

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How to cite this article:
Zahiri Barsari, S., Hashemabadi, D., and Zaredost, F. 2018. Effects of Phenylphthalamic Acid and Perfect Fertilizer on Vegetative and Reproductive Growth of Ornamental Pepper (*Capsicum annuum* L.). *Journal of Ornamental Plants, 8*(4), 217-226.
URL: http://jornamental.iaurasht.ac.ir/article_544913.html