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The influence of exogenous capsaicin application on the germination, seedling growth, and yield of pepper

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Abstract: The aim of this research was to investigate the effect of capsaicin application in different doses (0.0, 0.1, 1.0, 10.0, 25.0, 50.0, 100.0, and 200.0 ppm) on the germination, seedling growth, and yield of pepper plants (*Capsicum annuum* L. 'Burdem'). For this purpose, capsaicin was applied at several stages: (i) to the pepper seed before sowing, (ii) to the leaves during the 3rd to 4th true leaf stage for seedling quality evaluation, and (iii) to the leaves before planting in a greenhouse. There were no statistical differences among capsaicin doses and the control with respect to germination and emergence, but the highest germination and emergence values and the shortest germination and emergence time were observed for seeds treated with 0.1 ppm of capsaicin (even after 6 months of storage). For 50.0 ppm, the germination and emergence percentage decreased and the time significantly increased, while germination and emergence were not observed for 100.0 and 200.0 ppm. The seedlings treated with 1.0 ppm of capsaicin had the highest shoot fresh weight, stem diameter, number of leaves, and leaf area. There was no statistical difference among treatments in terms of relative water content, chlorophyll *a* and *b*, ascorbate peroxidase, and superoxide dismutase. The number of fruits/plant (100 fruits/plant) and fruit yield (0.89 kg/plant) in plants treated with 50.0 ppm of capsaicin were higher than in other treatments and the control. The results indicated that capsaicin has the potential for improving germination, seedling quality, and pepper yield.

Key words: Capsaicin, *Capsicum annuum* L., seed, seedling, fruit

1. Introduction

The term "vegetable" usually refers to the fresh edible portions of certain herbaceous plants' roots, stems, leaves, flowers, fruit, or seeds and these plant parts are either eaten fresh or prepared in a number of ways for nutritional purposes (Fadda et al., 2018; Galiana-Belaguer et al., 2018).

Pepper (*Capsicum* spp.) is one of the warm-climate vegetables grown widely in both open fields and greenhouses worldwide (Sarafi et al., 2018). Turkey is one of the top three pepper-producing countries with over 2 million tons (http://faostat3.fao.org/). The germination and emergence of pepper seeds is often slow and nonuniform under normal as well as stressed conditions (Lorenz and Maynard, 1988; Chartzoulakis and Klapaki, 2000) Also, when compared with other vegetable seeds, its viable storage period is very short and seeds deteriorate quickly (Demir and Okcu, 2004; Khan et al., 2009; Yadav et al., 2011). Nongerminating seeds and nonuniform and unhealthy plants increase the cost of plants growing per area. In recent years, there has been widespread vegetable-growing throughout Turkey that requires investment in establishing seedlings. Seedling quality is very important in species grown from seedlings because it is affected by the growth media, climatic conditions, and cultivar applications after planting, which affect the plant growth and yield (Sahin et al., 2002; Korkmaz et al., 2010; Rajjou et al., 2012). The aim of commercial seedling production is to obtain a high emergence rate as well as healthy and homogeneous seedlings in a short time period. There are some applications, called priming, that initiate the physiological process of germination with limited water intake under controlled conditions of seeds prior to sowing, to obtain high and homogeneous seed germination both from direct sowing in the field and seedling growth. This technique is used to improve the germination and emergence of some vegetable species (Bradford et al., 1990; Pill, 1995; Taylor et al., 1998). In works done on pepper where osmotic solutions of polyethylene glycol and K and Na salts are used, it has been shown that germination and emergence are generally improved, especially under biotic and abiotic stress conditions (Amjad et al., 2007; Korkmaz and Korkmaz, 2009; Yadav et al., 2011).

Capsaicin, which is synthesized and accumulated in the placental tissues of the fruit, is the major pungent

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component of *Capsicum* spp. (Ishikawa et al., 1998; Dias, 2012). It is not only adding flavor and spice to food but it is also used for medical or therapeutic purposes due to its pharmacological and physiological effects in humans (Kogure et al., 2002; Luo et al., 2011). While there are a number of studies on the effects of capsaicin on human health, information about its formation and metabolism is inadequate, and its physiological role in plants is not fully explained (Basu and De, 2003; Kato-Noguchi and Tanaka, 2003; Aza-Gonzalez et al., 2011; Arin, 2018). In relation to the use of capsaicin in agriculture, it was stated by Gonzales et al. that capsaicin can be used in weed management due to its allelopathic effects (1997). It decreased germination and root and shoot growth in several plant species (Kato-Noguchi and Tanaka, 2003; Siddiqui and Zaman, 2005). Capsaicin has antifungal and nematicidal properties (Kraikruan et al., 2008; Neves et al., 2009) and might be useful as a biopesticide (Aza-Gonzalez et al., 2011). It has been shown that it can protect seeds from squirrel damage (Curtis et al., 2000) and lettuce from rabbit attack as a repellent (Bosland and Bosland, 2001). Barchenger and Bosland (2016) demonstrated that 500 or 1000 ppm doses of capsaicin reduced and delayed germination in two sweet pepper cultivars. The physiological role of capsaicin in plants is not clear and only limited information is available in the published literature with regard to its effectiveness on seedling and plant growth. In the literature searched by the authors on the effects of capsaicin on seedling growth and yield of pepper, no published reports were found. Thus, the aim of this study was to determine the effects of capsaicin applications at different concentrations on the germination/emergence of pepper seeds and on seedling growth and fruit yield.

2. Materials and methods

2.1. Plant material and capsaicin treatments

The experiment was conducted in 2014 and 2015 under laboratory conditions in the growth chamber and unheated greenhouse of the Namık Kemal University Agricultural Faculty's Department of Horticulture (Tekirdağ, Turkey).

The seeds of the Burdem sweet salad-type pepper (*Capsicum annuum* L.) were obtained from Bursa Seed Co., Bursa, Turkey. The initial seed moisture, which was determined by low-constant temperature oven methods (ISTA, 2007), was 8.4% (dry weight basis). Seeds were disinfected by dipping them in a 1% sodium hypochlorite solution for 10 min to eliminate possible seed-borne pathogens, then rinsed 3 times with distilled water and dried on a paper towel until reaching the initial moisture content at room temperature.

Synthetic capsaicin (V9130 N-vanillylnonanamide, 293.40 g/mol, purity 97%; Sigma-Aldrich Chemie GmbH, Steinheim, Germany) was dissolved in 30% methanol and 70% distilled water to obtain stock solutions (Bosland and Bosland, 2001; Kraikruan et al., 2008; Mortensen and Mortensen, 2009). The stock solution was diluted with distilled water to obtain different capsaicin concentrations [0.0 (control) 0.1, 1.0, 10.0, 25.0, 50.0, 100.0, and 200.0 ppm].

The seeds were placed in covered transparent polystyrene boxes (17 × 12 × 6 cm) on double layers of filter paper wetted with 50 mL of solutions supplemented with the abovementioned concentrations of capsaicin. The boxes were closed and kept at 23 ± 1 °C in the dark for 24 h. After treatment, the seeds were washed in a sieve and rinsed under running tap water for 1 min. Then the seeds were dried back to their original moisture content on paper towels at room conditions. The seeds were divided into two groups. The first group was immediately used for germination and emergence tests, while the other seeds were stored in airtight containers in a refrigerator for 6 months at 5 ± 1 °C to evaluate the effect of the treatments after storage.

2.2. Germination/emergence tests

Germination tests were carried out in 12-cm petri dishes containing two sheets of filter paper to which 5 mL of distilled water had been added. Fifty seeds were sown in a petri dish, and this was replicated three times for a total of 200 seeds (four replications in total) and then the dishes were incubated in a germination cabinet in darkness at 25 ± 2 °C. Germination counts were taken every 24 h for 14 days. When radicle emergence was ≥2 mm, it was considered to be a germinated seed (Demir and Okcu, 2004).

For the emergence tests, the seeds were sown in 4 replicates (50 seeds per replication) at a depth of 1.0 cm in sterilized plastic trays (54 × 26 × 9 cm) filled with commercial seedling growing medium (Klasmann TS1, pH 6.0, N: 140 ppm, P_2O_5: 160 ppm, K_2O: 180 ppm, Mg: 100 ppm; Doktor Tarsa Inc., Antalya, Turkey). Trays were watered and kept in a growth chamber at 23 ± 2 °C. The counts were done every day and the seedlings with fully opened cotyledons were recorded as "emergence".

Mean germination/emergence time was calculated by using the following formula (Demir and Okcu, 2004):

Mean germination/emergence time = $\Sigma nd/\Sigma n$,

where n = number of seeds that germinate/emerge on day d and d = number of days counted from the beginning of the germination/emergence test.

Vigor Index (VI, germination/emergence rate) was calculated according to Mereddy et al. (2000):

VI = (G1/D1) + G2/D2) + ……. + (GL/DL),

where G1 = number of germinated/emerged seeds (first count), D1 = number of days to first count, GL = number of germinated/emerged seeds (last count), and DL = number of days to last count.

Germination/emergence tests were repeated to determine the effect of treatments after 6 months of storage in the conditions previously described.

2.3. Seedling treatments and growth and development measurements

The seeds were planted at a depth of 1.0 cm in multicell trays (32 cells, 100 cm^3/cell) filled with growth medium as mentioned above. Trays were watered and kept in a climate-controlled room at 23 ± 2 °C in the day and 18 ± 2 °C at night under cool-white fluorescent lamps (150 µmol m^{-2} s^{-1}) for a photoperiod with 16 h of light. When the seedlings had 3 to 4 true leaves (37 days after sowing), capsaicin solutions [0.0 (control) 0.1, 1.0, 10.0, 25.0, 50.0, 100.0, and 200.0 ppm] were applied to seedlings until both sides of the leaf were completely wetted. Tween 20 (0.1%, v/v) was added to the capsaicin solution as a surfactant (Leskovar and Cantliffe, 1992).

Randomly selected seedling samples were then taken 10 days after leaf application for measurements and analysis. Shoots of the seedlings were cut at the growth medium line and their fresh weights were recorded. The roots of the seedlings were carefully washed under running water to remove the growth medium and dried with paper towels to remove the surface water. Their fresh weights were then recorded. Stem diameter was measured with a digital caliper just above the cotyledons. Stem length was measured from the shoot apex to the cut end and true leaf numbers were recorded. The leaf area was determined by the Flaeche program (A-Kraft, 1995).

2.4. Determination of relative water content (RWC)

Leaf disks of 1 cm in diameter were taken from randomly chosen seedlings using a hole-punch. Disks were weighed (fresh weight, FW) and then immediately submerged in distilled water for 5 h in the dark. The turgid weight (TW) of leaf disks were obtained after drying the excess surface water with paper towels. The dry weight (DW) of the disks was measured after drying at 80 °C for 24 h.

RWC was calculated using the equation below (Turner, 1981):

$$RWC\ (\%) = 100 \times [(FW - DW)/(TW - DW)].$$

2.5. Membrane stability

Electrolyte leakage was used to assess membrane stability. Leaf disks of 1 cm in diameter were taken from randomly chosen seedlings and washed with distilled water. The disks were put into covered tubes (150 mm × 25 mm) containing distilled water and were shaken in a water bath at room temperature for 24 h. Afterwards, the electrical conductivity of the solutions (EC_1) was measured. The same samples were placed in an autoclave at 120 °C for 20 min and a second reading (EC_2) was done after cooling the solution to room temperature. The membrane stability was calculated as EC_1/EC_2 and expressed as a percentage (Korkmaz et al., 2010).

2.6. Determination of chlorophyll content

To determine the chlorophyll *a* and *b* content of leaves, fresh leaf samples were homogenized with 15 mL of acetone (80%, v/v). The extracts were filtered through a filter paper. Absorbance readings were performed with a UV spectrophotometer (Hitachi U-5100) at a wavelength of 663 nm for chlorophyll *a* and at 645 nm for chlorophyll *b*. The chlorophyll contents were calculated according to the following equations (Arnon, 1949):

$$Chl\ a\ (mg/g\ FW) = 11.75 \times A_{663} - 2.35 \times A_{645},$$

$$Chl\ b\ (mg/g\ FW) = 18.61 \times A_{645} - 3.96 \times A_{663}.$$

2.7. Determination of SOD and APX enzyme activity

By consideration of the results of Crombie (1999), who stated that capsaicin can cause an increase in the enzyme levels of plants, superoxide dismutase (SOD) and ascorbate peroxidase (APX) enzyme analysis was performed. The activities of SOD and APX enzymes were determined after enzymatic extraction. For this, fresh leaf samples (0.5 g) taken from the middle part of the leaf were ground in a mortar by adding liquid nitrogen and homogenized in 10 mL of extraction buffer containing 50 mM phosphate buffer (pH 7.6), 1 mM Na-EDTA, and 1 mM ascorbic acid. The extract was centrifuged at 15,000 × *g* for 15 min. The supernatant was used for APX and SOD analysis.

The APX activity was determined by measuring the oxidation of ascorbate at a wavelength of 290 nm according to Cakmak and Marschner (1992), and the SOD activity was determined by the reduction of nitroblue tetrazolium (NBT) at 560 nm, as defined by Kusvuran et al. (2007).

2.8. Yield experiment in an unheated greenhouse

The seedlings treated with different capsaicin solutions just before planting, as described in Section 2.3, were transplanted on 19 April 2015 to an unheated greenhouse where the temperature was 15/38 °C during the experiment. The seedling trays were dipped in a solution containing 1% imidacloprid as a precaution against sucking insects, termites, and some soil insects. The planting distance was 40 cm and 70 cm between plants and rows, and each plot of three replications consisted of 20 plants. The chemical properties of the greenhouse soil are given in Table 1.

A drip irrigation system was used for irrigation and fertilization. Monoammonium phosphate (9.62 g/L; MAP), 73.69 g/L of potassium nitrate (KNO_3), and 9.93 g/L of ammonium nitrate (NH_4NO_3) were added to the irrigation water once, taking into account the soil analysis, for the pepper plants at each of two irrigations until the fruit was harvested. The plants were irrigated with a nutrient solution containing 9.62 g/L of MAP, 38.92 g/L of NH_4NO_3, and 67 g/L of potassium sulfate (K_2SO_4) during harvest. Fruits were harvested from 15 plants per replication (plot). Weeds were mechanically controlled with a hoe. In order to control disease, propamocarb, fosetyl, and thiram were applied twice during the pepper crop season.

Table 1. Some physical and chemical properties of the greenhouse soil.

Depth (cm)	pH	EC (%)	Org. matter (%)	N (ppm)	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)
0–30	7.9	0.03	1.28	0.06	23.6	181.7	5569.0	465.3
30–60	7.8	0.03	1.06	0.05	31.0	210.7	5591.2	500.8

Peppers were harvested twice a week during the production period and the fruits were evaluated for marketable properties. The initiation of flowering (days to first flowering) was recorded. The number of fruits/plants, fruit yield/plant, and average fruit weight were determined.

In the greenhouse, the average minimum and maximum temperatures during the growing period were 15 °C and 38 °C, respectively.

2.9. Statistical analysis

Data recorded as germination/emergence percentages were transformed to their respective angular (arcsine) values before subjecting them to statistical analyses. However, the real values are given in the related tables. In seeds treated with 100 and 200 ppm capsaicin, germination and emergence were not observed so they were not included in statistical evaluations. Data were analyzed using analysis of variance (ANOVA) with the MSTAT statistics software program. The differences among the means were compared using Duncan's multiple range test ($P < 0.05$).

3. Results

3.1. Germination and emergence

There were no statistical differences among the treatments with respect to germination percentage, except for 50.0 ppm (Table 2). A drastic decline in germination percentage was observed in seeds treated with 50 ppm capsaicin, while there was no germination of seeds at either 100 or 200 ppm capsaicin. A similar result was observed for the emergence percentage (Table 3). Although the difference among capsaicin doses and control was not important statistically (except 50 ppm), the highest value of germination was recorded in seeds treated with 0.1 ppm of capsaicin. They also gave the lowest mean germination time and the highest vigor index value. The same result was observed in the germination/emergence tests carried out after 6 months of storage of the seeds. Capsaicin did not adversely affect the germination/emergence performance of seeds after 6 months of storage compared with the control (except 50.0 ppm).

3.2. Seedling characteristics

Table 4 shows the effects on some seedling characteristics after the application of capsaicin. Despite some treatments falling into the same statistical group, the seedlings treated with 1.0 ppm capsaicin were larger in size, as indicated by shoot FW, stem diameter, number of leaves, and leaf area, compared to those treated with other capsaicin doses and the control. Stem length was not affected by capsaicin application. Capsaicin treatment did not result in an increase in root FW. At 100 and 200 ppm, root FW decreased significantly.

3.3. RWC, membrane stability, chlorophyll, APX, and SOD

The values of RWC, membrane stability, chlorophyll *a* and *b*, and APX and SOD enzyme activities as affected by various capsaicin doses are presented in Table 5. The data revealed that there were no significant differences among treatments, except for membrane stability. The lowest membrane stability (48.46%) was recorded in seeds treated with 50.0 ppm capsaicin, while the highest value (53.05%) was obtained with 100.0 ppm.

3.4. Fruit and yield

The effects of capsaicin treatment on seedlings can be expressed in terms of field performance. Therefore, the seedlings treated with different capsaicin doses were planted in an unheated greenhouse and fruit data were recorded. The effects of different capsaicin doses related to fruits and yield are presented in Table 6. Although there were no marked differences among capsaicin doses and the control, the plants treated with 0.1 ppm capsaicin flowered earlier, and the number of fruits and fruit yield of plants treated with 50.0 ppm capsaicin were higher than those of the other treatments.

4. Discussion

Capsaicin is one of the secondary metabolites and a substance with an unknown direct function in basic metabolism, but it can provide some important adaptive significances in protection against herbivory and/or microbial infection. Despite numerous research findings regarding the role of exogenous capsaicin in relation to human health (Kogure et al., 2002; Mortensen and Mortensen, 2009; Luo et al., 2011), there are few studies dealing with the effects of capsaicin on seed germination and plant growth (Kato-Noguchi and Tanaka, 2003; Siddiqui and Zaman, 2005; Barchenger and Bosland, 2016).

In this study, germination/emergence was reduced significantly in seeds treated with 50.0 ppm capsaicin, and no germination/emergence occurred with 100 or 200 ppm. Seeds treated with 0.1 ppm capsaicin had a higher

Table 2. The effect of different capsaicin doses on germination percentage, mean germination time, and vigor index.

Capsaicin doses (ppm)	Germination percentage (%)		Mean germination time (days)		Vigor index	
	After 6 months		After 6 months		After 6 months	
0.0	91.5 a	89.5 a	7.11 a	7.51 a	6.94 b	6.31 a
0.1	94.0 a	93.0 a	6.63 a	7.23 a	8.01 a	6.73 a
1.0	92.5 a	90.5 a	7.24 a	8.28 b	6.78 b	5.79 b
10.0	89.0 a	86.5 a	8.17 b	9.60 c	5.69 c	4.61 c
25.0	93.0 a	89.0 a	8.48 bc	10.08 c	5.68 c	4.46 c
50.0	45.5 b	39.5 b	9.30 c	10.68 d	2.58 d	1.87 d

Within columns, values followed by different letters are significantly different ($P < 0.05$).

Table 3. The effect of different capsaicin doses on emergence percentage, mean emergence time, and vigor index.

Capsaicin doses (ppm)	Emergence percentage (%)		Mean emergence time (days)		Vigor index	
	After 6 months		After 6 months		After 6 months	
0.0	91.5 a	90.0 a	14.32 ab	12.50 a	3.22 a	3.73 ab
0.1	95.5 a	94.0 a	13.87 a	11.98 a	3.47 a	3.95 a
1.0	90.5 a	89.0 a	14.44 ab	12.15 a	3.14 a	3.69 ab
10.0	95.0 a	92.5 a	14.56 ab	12.64 ab	3.26 a	3.69 ab
25.0	90.0 a	90.0 a	14.14 ab	13.05 bc	3.18 a	3.50 b
50.0	42.5 b	42.5 b	15.40 b	13.66 c	1.39 b	1.56 c

Within columns, values followed by different letters are significantly different ($P < 0.05$).

Table 4. The effect of different capsaicin doses on some seedling characteristics.

Capsaicin doses (ppm)	Shoot FW (g)	Root FW (g)	Stem length (cm)	Stem diameter (mm)	Number of leaves	Leaf area (cm^2)
0.0	3.48 ab	1.06 a	8.98	2.61 ab	8.08 b	121.84 ab
0.1	3.65 ab	0.93 abc	8.82	2.56 b	8.58 ab	130.69 ab
1.0	4.18 a	0.97 ab	9.35	2.87 a	9.00 a	149.09 a
10.0	3.71 ab	0.90 abc	8.68	2.71 ab	8.42 ab	129.85 ab
25.0	3.41 ab	0.97 ab	9.08	2.70 ab	8.33 ab	119.13 ab
50.0	3.39 ab	0.98 ab	8.69	2.66 ab	7.92 b	119.87 ab
100.0	3.11 b	0.69 c	8.71	2.57 b	8.00 b	108.93 b
200.0	3.48 ab	0.74 bc	8.63	2.55 b	8.42 ab	118.59 ab

Within columns, values followed by different letters are significantly different ($P < 0.05$).

germination percentage, vigor index, and shorter mean germination time than the others (including after 6 months of storage) (Tables 2 and 3). Barchenger and Bosland (2016) also found that high doses of capsaicin treatment resulted in reduced and delayed germination at different rates depending on pepper varieties. Kato-Noguchi and Tanaka (2003) stated that capsaicin suppressed the seed germination of six plant species, and increasing the dose

Table 5. The effect of different capsaicin doses on RWC, membrane stability, chlorophyll *a* and *b*, APX, and SOD.

Capsaicin doses (ppm)	RWC (%)	Membrane stability (%)	Chl *a* (mg g^{-1} FW)	Chl *b* (mg g^{-1} FW)	APX (μmol min^{-1} FW)	SOD (U g^{-1} FW)
0.0	88.15	51.16 ab	19.12	6.64	39.88	271.54
0.1	89.03	52.67 ab	19.27	5.73	40.07	286.55
1.0	88.92	50.63 ab	19.99	5.23	37.80	285.41
10.0	88.54	51.39 ab	21.20	7.16	35.34	241.90
25.0	89.37	52.43 ab	19.83	5.83	37.46	228.45
50.0	89.26	48.46 b	17.25	5.01	37.99	253.14
100.0	88.20	53.05 a	21.11	6.27	41.21	300.84
200.0	89.33	50.68 ab	19.72	5.84	38.53	338.12

Within columns, values followed by different letters are significantly different ($P < 0.05$).

Table 6. The effect of different capsaicin doses on days to first flowering, number of fruits/plant, fruit yield/plant, and mean fruit weight.

Capsaicin doses (ppm)	Days to first flowering	Number of fruits/plant	Fruit yield/plant (kg)	Mean fruit weight (g)
0.0	39.23 a	83.70 ab	0.76 ab	9.05 ab
0.1	38.30 a	87.10 ab	0.79 ab	9.00 ab
1.0	39.68 ab	77.03 b	0.68 b	8.77 b
10.0	41.58 bc	75.43 b	0.69 b	9.13 a
25.0	41.55 bc	88.85 ab	0.80 ab	8.96 ab
50.0	39.03 a	100.10 a	0.89 a	8.86 ab
100.0	42.28 c	76.78 b	0.70 b	9.05 ab
200.0	42.96 c	78.48 b	0.71 b	9.08 ab

Within columns, values followed by different letters are significantly different ($P < 0.05$).

of capsaicin increased the inhibition. Also, Siddiqui and Zaman (2005) revealed that *Capsicum* leachate inhibited the germination of *Vigna radiata* seeds.

Length, stem diameter, etc. are useful data tools for identification of plants with desirable horticultural characteristics. The ideal seedling transplant must have a substantial weight, thick stem, adequate leaf area, etc. (Song and Tan, 1989). Regarding all the seedling characteristics, the highest values were recorded in those treated with 1.0 ppm capsaicin, except for root fresh weight (Table 4). It has been reported that capsaicin could have an allelopathic effect on germination and plant growth, especially at high doses. In a study conducted by Kato-Noguchi and Tanaka (2003), the seeds of six plant species were treated with different doses of capsaicin, and it was determined that capsaicin concentration-dependently inhibited the germination and root and shoot growth of all species, and the greatest inhibiting effect was on root growth. In the study mentioned, it was determined that capsaicin suppressed the germination of lettuce seeds and inhibited the growth of their roots and shoots at concentrations greater than 3, 0.1, and 0.3 mM, respectively. While high doses of capsaicin suppressed the plant growth, seed treatments with low doses of capsaicin can have a stimulatory effect on seedling growth. This may be explained as the low concentration of capsaicin is accelerated by the metabolic activity in plants.

RWC, chlorophyll *a* and *b*, APX, and SOD were unaffected by the application of capsaicin (Table 5). The reason for that could be the favorable growing conditions for pepper seedlings. It is known that capsaicin is a secondary metabolite, and its effect can be more remarkable under stress conditions (Barchenger and Bosland, 2016). It has been reported by a number of researchers that the RWC and membrane stability of plants get out of balance specifically under stressful conditions, and the activities of

enzymes like SOD and APX increase when coping with this stress. For instance, Korkmaz et al. (2012) indicated that the application of glycine betaine (GB) did not have a notable effect on photosynthesis parameters or the proline content of seedlings grown under optimum conditions, but they exerted a positive effect in plants grown under salt stress conditions, and treatment with GB caused only a slight increase in the SOD enzyme activity under optimum conditions. Yiu et al. (2012) observed that SOD and APX activities of pepper seedlings grown under salt stress conditions increased, but there were no changes in plants grown under stress-free conditions. It has been determined that when 6-day-old mung bean seedlings were exposed to high-temperature stress, leaf chlorophyll and leaf RWC decreased while APX activity increased (Nahar et al., 2015).

Among the treatments, the highest fruit yield/plant was obtained from plants treated with 50 ppm capsaicin with an increase of 17% compared to the control (Table 6). Considering the planting distances (70 × 40 cm), it can easily be seen that approximately 4500 kg more fruit yield per hectare will be obtained.

In conclusion, the results demonstrated that using exogenous capsaicin at low doses may be advantageous to improve germination, seedling growth, and yield of pepper. Also, it is confirmed that high doses of capsaicin prevent germination and emergence. Besides those findings, it is highly recommended to perform further studies. The extent of capsaicin, the transportation mechanisms among the organs of the plants, and the effects on the growth/development and yield need to be clarified by future studies. Also, the possible effect of exogenous capsaicin application, especially under abiotic stress conditions, which is one of the most important problems in plant production, should be involved in those studies. For this purpose, there is ongoing research to determine whether capsaicin is effective on seedlings and plants grown under different abiotic stresses.

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