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Effect of Magnetic Field on Seed Germination, Growth and Yield of Sweet Pepper (*Capsicum annuum* L.)

[1]M.E.M. Ahamed, [2]A.A. Elzaawely and [3]Y.A. Bayoumi

[1]Department of Horticulture, [2]Department of Agricultural Botany, Faculty of Agriculture, Tanta University, Tanta, Egypt

[3]Department of Horticulture, Faculty of Agriculture, Kafrelsheikh University, Kafrelsheikh, Egypt

Corresponding Author: A.A. Elzaawely, Department of Agricultural Botany, Faculty of Agriculture, Tanta University, Tanta, 31527 Egypt Tel: 201001397749 Fax: 20403455570

ABSTRACT

A study was carried out to understand the effect of magnetic field on the seed germination, growth, yield and fruit quality of sweet pepper (*Capsicum annuum* L.). Pepper seeds or irrigated water (separately or together) were passed through a magnetic funnel. Percent germination rate, growth and yield parameters of treated and non-treated pepper plants were recorded. Germination of all treated seeds began one day earlier than that of non-treated seeds and the germination percentage increased by 33.7-44.9% in treated seeds related to the control. Growth and flowering parameters were significantly increased in the treated plants comparing to the control. Fruit quality parameters were also enhanced by magnetic treatment while the fruit length, fruit diameter and pericarp thickness were not significantly affected. Leaf contents of chlorophyll a and b, caroteniods and phosphorus were significantly affected by the magnetic field. In addition, fruit concentrations of phosphorus and vitamin C were also increased. The obtained results indicated that magnetic field is an effective method for the pre-sowing treatment of the seeds that enhance their germination and increase yield capacity and fruit quality.

Key words: *Capsicum annuum*, growth, magnetic field, seed germination, sweet pepper, yield

INTRODUCTION

Sweet pepper (*Capsicum annum* L.) is one of the most important vegetables and popular crops grown in many countries including Egypt. Sweet pepper occupied 108026 feddan. (45389 ha) in Egypt during 2009 with an average of 7.4 ton per feddan. (AOAD, 2009). Its fruits have high nutritional values, as they are a very rich source for vitamin A and C (Elwan and El-Hamahmy, 2009; Rajput and Poruleker, 1998). Enhancement of the productivity and quality of sweet pepper is usually dependent on many factors that influence the plant growth throughout the growth period as well as improving agricultural treatments.

Different chemical and non-chemical methods have been applied to improve crop yield and quality, one of which is magnetic field (Jinapang *et al*., 2010). It has been reported that magnetic field affects plant growth and development processes such as seed germination and seedling growth (Aladjadjiyan, 2002). Furthermore, magnetic field may alter the characteristics of cell membrane and cell reproduction and may cause some changes in cell metabolism and various cellular functions including gene expression, protein biosynthesis and enzyme activities (Atak *et al*., 2003). Several studies have reported the influence of magnetic field on seed germination and vegetative growth of vegetable crops such as mung bean (Huang and Wang, 2008), tomato (De Souza *et al.*, 2005, 2006), snow pea and chickpea (Grewal and Maheshwari, 2011) and peas (Es'kov and Rodionov, 2010).

This study was designed to investigate the influence of magnetic field on seed germination, vegetative growth, yield and yield quality of sweet pepper cultivated under Egyptian soil conditions.

MATERIALS AND METHODS

Magnetic funnel: A magnetic funnel (Brand name: Magnetic Technologies L.L.C., Model No. MFL01, Dubai, U.A.E.) was used. Two cassettes with ceramic magnets are located inside the cylindrical part of the magnetic funnel. Length of each cassette is 75 mm, there are seven magnets installed inside of each cassette with intervals. North poles of magnets of one cassette are located opposite south poles of magnets of other cassette. Maximal magnetic induction along axis cylindrical part of the magnetic funnel is 57-60 mT (millitesla) between magnets in each pair and 4-6 mT in the intervals between the pairs of magnets.

Plant material and germination experiment: Seeds of sweet pepper (cv. California Wonder) were purchased from Tanta, Egypt. The seeds were divided to four groups and each group contains 10 seeds in 10 replications. Seeds in the first group were passed through the magnetic funnel to be magnetized and then the seeds were placed in petri dishes (9 cm) containing Whatman No.1 filter paper soaked with normal distilled water (non-magnetized water). Seeds in the second group (non-magnetized seeds) were soaked in magnetized distilled water that was previously passed through the magnetic funnel. In the third group, magnetized seeds were soaked in magnetized distilled water. In the fourth group, non-magnetized seeds were soaked in non-magnetized distilled water to serve as a control. Seeds in all groups were left to germinate at room temperature (25±2°C) for 14 days to measure the percentage of germination according to Scott *et al.* (1984) and Bartlett (1937).

Experimental design: The experiment was carried out in duplicate at the experimental farm of the Faculty of Agriculture, Tanta University during 2011 and 2012.

Seedbed experiment: The seeds were sown in seedling trays in a plastic greenhouse on 16th and 17th January 2011 and 2012, respectively. Treatments in the seedbed were arranged in a complete randomized block design with three replications and the seeds were divided to four groups as mentioned above. The first group contained magnetized seeds irrigated with non-magnetized water. The second group contained non-magnetized seeds irrigated with magnetized water. The third group contained magnetized seeds irrigated with magnetized water, while the fourth group contained non-magnetized seeds irrigated with non-magnetized water (control).

Field experiment: Seedlings from each treatment were transplanted to the open field on 6th and 8th of March 2011 and 2012, respectively at 30 cm apart in one side of the ridges. The plot area was 11.2 m^2, which contained four rows with 4 m in length and 70 cm in width. Treatments in the field were arranged in a complete randomized block design with three replications. Normal cultural practices were carried out as recommended for the conventional pepper planting according to instructions of Egyptian Ministry of Agriculture. During this period, non-magnetized water was provided to all four treatments. The soil in the plots was a clay loam soil with organic matter 1.5%,

Table 1: Chemical analysis of the experimental soil

	Values	
Components	Total	Available
Nitrogen (mg/100 g soil)	236.5	42.1
Phosphorus (mg/100g soil)	34.8	6.4
Potassium (mg/100 g soil)	824.1	186.25
Soluble catious (meql^{-1})		
Ca^{++}	-	6.47
Mg^{++}	-	5.04
Na^{+}	-	12.25
Soluble anious (meql^{-1})		
HCO_3^{-}	-	5.11
Cl^{-}	-	8.04
SO_4^{--}	-	10.0

pH 7.25 and EC/25°C 4.03 mmhos cm^{-1}. Table 1 provides information on the soil's chemical analysis determined according to Ryan *et al*. (1996).

Seedlings growth parameters: During the seedbed period, 10 seedlings per treatment were sampled at 50 days post-sowing to measure seedling height, number of leaves per seedling, seedling fresh and dry weight and seedling leaf area.

Vegetative growth traits: Five plants from each plot were randomly sampled at 90 days after transplanting to determine plant height, number of branches per plant, number of leaves per plant, fresh and dry weight per plant and leaf area per plant.

Flowering growth traits: Five plants from each plot were randomly selected and labeled to determine the days after transplanting to 25% flowering, number of flowers per plant and percentage of fruit set.

Yield parameters: Ten representative marketable fruits from each treatment at the middle of harvesting season were collected and used for determination of yield parameters including fruit fresh and dry weight, fruit number per plant, fruit length, fruit diameter and pericarp thickness. In addition, fruits produced from each plot were harvested and used to determine early and total marketable fruit yield. Early marketable yield was determined from the first three harvestings.

Chemical composition of leaves: Contents of chlorophyll a and b, caroteniods, N, P and K in the leaves of sweet pepper were determined according to the Association of Official Analytical Chemists International (AOAC, 1995).

Chemical composition of fruits: Concentrations of vitamin C, nitrate (NO_3), Total Soluble Solids (TSS), titratable acidity, N, P, and K in the fruits of sweet pepper were determined according to the Association of Official Analytical Chemists International (AOAC, 1995).

Statistical analysis: Data were analyzed by MSTATC computer software program adopted by Bridker (1991) using ANOVA with the Least Significant Difference (LSD) at the 0.05 probability level.

RESULTS

Seed germination: Figure 1 shows the percent germination rate of pepper seeds treated with magnetic field. Germination of all treated seeds began one day earlier than that of non-treated seeds. After the 14th day of soaking, 83.3, 84.7 and 90.3% germination were achieved in magnetized seeds, magnetized water and magnetized seeds+water, respectively; while, it was 62.3% in non-treated seeds (LSD = 5.14 at 5%). Highest germination rate was achieved for magnetized seeds that were soaked in magnetized water rather than magnetized seeds soaked in non-magnetized water or non-magnetized seeds soaked in magnetized water. However, no significant difference was observed between the germination rate of magnetized seeds and magnetized water when used separately. Germination percentage increased by 33.7, 35.8 and 44.9% over control in magnetized seeds, magnetized water and magnetized seeds+water, respectively.

Seedlings growth: As shown in Table 2, growth of all seedlings produced from treated seeds was significantly promoted than those produced from non-treated seeds in both 2011 and 2012 seasons. As for instance, seedling height increased significantly by 21.2, 29.3 and 47% in magnetized seeds, magnetized water and magnetized seeds+water, respectively in 2011, while the increase was by 21.1, 28.1 and 45%, respectively in 2012. Likewise, seedling leaf area increased by 15.2, 29.5 and

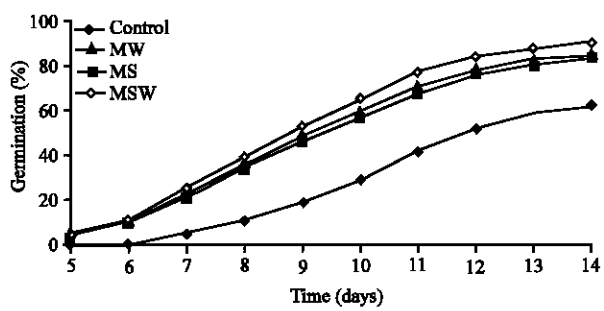

Fig. 1: Effect of magnetic field on percent germination rate of sweet pepper seeds, Values are expressed as the mean (n = 10), LSD for germination% = 5.14 , MS: Magnetized Seed; MW: Magnetized Water; MSW: Magnetized Seed+Water

Table 2: Effect of magnetic field on growth of sweet pepper seedlings

Magnetic treatments	Seedling height (cm)	No. of leaves/ seedling	Seedling fresh weight (g)	Seedling dry weight (g)	Seedling leaf area (cm^2)
Season 2011					
Control	16.40	7.00	2.45	0.294	27.79
Magnetized Seed	19.87	7.81	3.42	0.355	32.02
Magnetized Water	21.20	8.04	3.69	0.371	35.99
Magnetized Seed+Water	24.11	8.76	4.09	0.418	41.85
L.S.D. at 5%	2.15	0.35	0.15	0.035	3.99
Season 2012					
Control	17.24	6.85	2.51	0.259	28.04
Magnetized Seed	20.87	7.61	3.43	0.367	33.99
Magnetized Water	22.08	7.94	3.74	0.389	38.07
Magnetized Seed+Water	24.99	8.88	4.00	0.417	43.91
L.S.D. at 5%	1.99	0.59	0.21	0.025	5.95

Values are means of 3 replications

50.6% in treated seedlings in 2011 and by 21.2, 35.8 and 56.6% in 2012. This effect was more positive when seeds and water were both magnetized. Generally, no significant differences were found in the growth parameters of the seedlings produced from magnetized seeds only and those produced from magnetized water only.

Vegetative growth traits: Table 3 summarizes the values of vegetative growth traits of pepper plants affected by magnetic field in seasons of 2011 and 2012. Values of vegetative growth were significantly higher in treated plants than those in non-treated plants in both seasons. Reported values were significantly superior in the plants generated from magnetized seeds that were irrigated with magnetized water. For example, 11, 12, 14.1, 21.8, 12.2 and 23.5% increase were recorded in the plant height, number of branches per plant, number of leaves per plant, fresh and dry weight per plant and leaf area per plant, respectively for pepper plants generated from magnetized seeds+water treatment in 2011 compared to the non-magnetized treatment. While in the 2012, same traits increased by about 12.4, 10.2, 11.6, 12.6, 9.2 and 22.5%, respectively.

Flowering growth traits: Table 4 shows the flowering traits of pepper plants influenced by magnetic field. Although magnetic field had no significant effect on number of flowers per plant

Table 3: Effect of magnetic field on the vegetative growth traits of sweet pepper

Magnetic treatments	Plant height (cm)	No. of branches/ plant	Leaf area / plant (cm^2)	Whole plant fresh weight (g)	Whole plant dry weight (g)	No. of leaves/ plant
Season 2011						
Control	70.20	8.47	3077	238.1	61.98	46.12
Magnetized Seed	73.80	8.91	3284	270.5	66.12	53.19
Magnetized Water	74.60	9.12	3308	275.8	66.87	55.87
Magnetized Seed+Water	77.90	9.49	3512	289.9	69.54	56.96
L.S.D. at 5%	2.01	0.45	196.85	10.19	2.99	4.55
Season 2012						
Control	68.40	8.79	3157	264.3	68.27	41.20
Magnetized Seed	71.80	9.21	3359	287.1	70.82	47.31
Magnetized Water	73.30	9.26	3290	288.2	71.89	46.88
Magnetized Seed+Water	76.90	9.69	3522	297.5	74.55	50.47
L.S.D. at 5%	1.69	0.40	158.47	14.05	3.78	3.19

Values are means of 3 replications

Table 4: Effect of magnetic field on flowering traits of sweet pepper

Magnetic treatments	Days to 25% flowering	No. of flowers $plant^{-1}$	Fruit set (%)
Season 2011			
Control	58.7	51.2	41.0
Magnetized Seed	57.0	53.7	43.3
Magnetized Water	56.7	54.2	43.3
Magnetized Seed+Water	55.9	55.9	43.9
L.S.D. at 5%	1.59	NS	NS
Season 2012			
Control	59.1	53.8	42.0
Magnetized Seed	58.1	55.2	44.2
Magnetized Water	57.8	55.1	44.1
Magnetized Seed+Water	56.7	56.2	44.9
L.S.D. at 5%	1.21	NS	N.S

Values are means of 3 replications, NS: Not significant

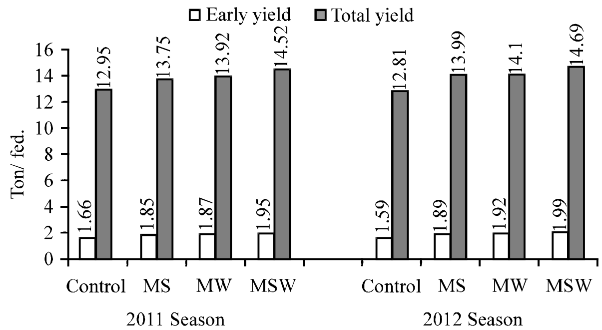

Fig. 2: Effect of magnetic field on early and total fruit yield of sweet pepper, Values are expressed as the mean (n = 3), LSD for early yield = 0.09 and 0.14 for 2011 and 2012 season, respectively, LSD for total yield = 0.25 and 0.36 for 2011 and 2012 season, respectively, MS: Magnetized Seed; MW: Magnetized Water; MSW: Magnetized Seed+Water

Table 5: Effect of magnetic field on the yield of sweet pepper

Magnetic treatments	Fruit fresh weight (g)	Fruit dry weight (%)	No. of fruits/ plant	Fruit length (cm)	Fruit diameter (cm)	Pericarp thickness (cm)
Season 2011						
Control	53.72	7.89	11.78	9.21	5.08	0.18
Magnetized Seed	59.02	8.12	13.99	9.35	5.11	0.19
Magnetized Water	58.89	8.16	14.00	9.34	5.11	0.19
Magnetized Seed+Water	63.36	8.33	14.12	9.42	5.13	0.20
L.S.D. at 5%	5.020	0.11	1.690	NS	NS	NS
Season 2012						
Control	55.76	7.99	12.00	9.87	5.19	0.20
Magnetized Seed	61.97	8.21	13.41	9.92	5.24	0.20
Magnetized Water	61.88	8.27	13.69	9.94	5.25	0.20
Magnetized Seed+Water	65.79	8.46	14.65	9.99	5.28	0.21
L.S.D. at 5%	3.050	0.15	1.210	NS	NS	NS

Values are means of 3 replications, NS: Not significant

and fruit set percentage, it significantly shorted the period to 25% flowering in both seasons. Flowering was accelerated by 1.7, 2 and 2.8 days in pepper plants emerged from magnetized seeds, magnetized water and magnetized seeds+water, respectively in 2011 compared to the non-magnetized treatment. While in the 2012, magnetized treatments took 1, 1.3 and 2.4 days shorter to 25% flowering over control, respectively.

Yield parameters: Fruit fresh and dry weight, number of fruits per plant, early and total marketable fruit yield significantly increased by magnetic field (Table 5, Fig. 2), while the differences among fruit length, fruit diameter and pericarp thickness were insignificant. Total marketable fruit yield increased significantly by about 6.2, 7.4 and 12.1% in pepper plants generated from magnetized seeds, magnetized water and magnetized seeds+water, respectively in (2011) compared to the non-magnetized treatment. In 2012, increase was by 9.2, 10.1 and 14.7%, respectively. This raise is due to the gain in the fruit fresh weight and the number of fruits per plant.

Table 6: Effect of magnetic field on the chemical composition of sweet pepper leaves

Magnetic treatments	Chlorophyll a ($mg\ g^{-1}$ DW)	Chlorophyll b ($mg\ g^{-1}$ DW)	Careteniods ($mg\ g^{-1}$ DW)	N (% DW)	P (% DW)	K (% DW)
Season 2011						
Control	1.968	0.569	1.738	3.54	0.474	3.28
Magnetized Seed	2.077	0.643	1.798	3.63	0.499	3.29
Magnetized Water	2.094	0.648	1.806	3.62	0.496	3.31
Magnetized Seed+Water	2.196	0.689	1.845	3.69	0.509	3.31
L.S.D. at 5%	0.066	0.051	0.840	NS	0.015	NS
Season 2012						
Control	2.092	0.742	1.709	3.70	0.498	3.35
Magnetized Seed	2.128	0.764	1.762	3.82	0.514	3.36
Magnetized Water	2.154	0.776	1.764	3.83	0.516	3.38
Magnetized Seed+Water	2.207	0.799	1.779	3.83	0.522	3.37
L.S.D. at 5%	0.096	0.035	0.049	0.09	0.021	NS

Values are means of 3 replications, DW: Dry weight, N: Nitrogen, P: Phosphorus, K: Potassium, NS: Not significant

Table 7: Effect of magnetic field on chemical composition of sweet pepper fruits

Magnetic treatments	Vitamin C (mg 100 g^{-1} FW)	NO_3 (mg kg^{-1})	TSS %	Titratable acidity (g citric acid 100 mL^{-1} juice)	N (% DW)	P (% DW)	K (% DW)
Season 2011							
Control	101.5	10.1	5.47	0.195	1.47	0.215	1.74
Magnetized Seed	112.3	10.0	5.61	0.197	1.49	0.226	1.75
Magnetized Water	115.7	10.0	5.55	0.195	1.50	0.227	1.76
Magnetized Seed+Water	124.9	9.9	5.75	0.199	1.52	0.229	1.78
L.S.D. at 5%	10.50	NS	NS	NS	NS	0.013	NS
Season 2012							
Control	94.7	10.2	4.99	0.201	1.42	0.221	1.71
Magnetized Seed	101.4	10.2	5.85	0.202	1.42	0.226	1.70
Magnetized Water	100.7	10.1	6.04	0.204	1.41	0.228	1.73
Magnetized Seed+Water	105.9	10.0	6.51	0.203	1.43	0.232	1.71
L.S.D. at 5%	5.90	NS	0.69	NS	NS	0.010	NS

Values are means of 3 replications, FW: Fresh weight, DW: Dry weight, N: Nitrogen, P: Phosphorus, K: Potassium, Ns: Not significant

Chemical composition of leaves and fruits: Leaf contents of chlorophyll a and b, careteniods and P in 2011 season were significantly affected by the magnetic field, while in 2012; only K concentrations were insignificant (Table 6).

In fruits, the magnetic field significantly increased concentrations of vitamin C and P but NO_3, TSS, acidity, N and K were not affected in 2011 (Table 7). In 2012, concentrations of vitamin C, TSS and P significantly increased in treated plants, while there were no significant differences in contents of NO_3, acidity, N and K.

DISCUSSION

Treating pepper seeds and/or irrigated water by magnetic field led to a considerable enhancement in their germination and subsequently in the growth and yield of the plants, they produced.

Percent germination rate and seedlings growth of pepper plants were increased in response to magnetic field (Fig. 1, Table 2). It was previously proposed that magnetic field accelerates seed germination, seedling growth and activates proteins formation and root development (Aladjadjiyan, 2002; Atak *et al*., 2003). These effects may be due to that magnetic field interacts with ionic current in the plant embryo cell membrane that induces changes both osmotic pressure and ionic concentrations on both sides of the membrane (Yaycili and Alikamanoglu, 2005). Reina and Pascual (2001) reported that changes in the ionic fluxes across cell membrane cause alterations in the mechanism of water uptake, due to the fact that osmo-regulation in embryo cells is controlled by the ionic transport across the membrane.

Magnetic field also increased vegetative and flowering growth of pepper plants (Table 3 and 4). The enhancement in vegetative parameters including plant height, number of branches, number of leaves, leaf area and leaf fresh and dry weight in the plants derived from the treated seeds may be due to the increase in the concentration of photosynthetic pigments such as chlorophyll a and b and caroteniods (Table 6) that provided greater amount of assimilates available for vegetative growth. This resulted in a remarkable increase in the vegetative and flowering growth of pepper plants that produced from seeds treated by magnetic field. It has been stated that magnetic field caused alterations in the transport properties of cellular plasmatic membranes, which play an extremely important role in regulating the assimilation by a cell of the nutrients needed for its functioning (Azharonok *et al*., 2009).

Fruit fresh and dry weight, number of fruits per plant, early and total marketable fruit yield significantly increased by magnetic field (Table 5, Fig. 2). The considerable improvement in fruit yield parameters (Table 5) as well as concentration of vitamin C (Table 7) may be resulted from an increase in the number of harvested fruits per plant and average fruit weight induced by the magnetic treatments. Similar effects have been reported on mung bean (Huang and Wang, 2008), tomato (De Souza *et al*., 2005, 2006), snow pea and chickpea (Grewal and Maheshwari, 2011) and peas (Es'kov and Rodionov, 2010).

The positive effects of magnetic fields may be a result of bioenergetic structural excitement causing cell pumping and enzymatic stimulation as they might affect the regulation of crucial ion mechanisms such as the ATP hydrogen pump, and possibly the configuration of pivotal proteins (De Souza *et al*., 2005). However, the effects of magnetic field on plant growth still require proper explanation especially for the late growth period such as flowering and fruiting stages.

CONCLUSION

The present results indicate that pre-sowing magnetic treatments enhance the percent germination rate, growth and development of pepper plants and improve their fruit yield parameters. Furthermore, magnetic field treatment can be considered as an alternative to chemical and biological methods that are commonly used in the production of vegetable crops.

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