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Design, Fabrication and Evaluation of a Novel System for Magnetic Field Application to the Seeds- Case study of Onion Seed

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Abstract

Non-chemical treatments are an approach for improving seed germination. In order to evaluate the effects of the magnetic field application on onion seed germination and seedling growth indices, a quadrupole magnetic field system was designed and fabricated. It was also compared with a dipole magnetic field system. In the quadrupole system, each coil consisted of three layers and the cores were moved inside the coils. These arrangements make it possible to change the magnetic field intensity in addition to input current setting. The experiments were conducted based on factors including the type of system (bipolar and quadrupole), magnetic flux density (75, 150, 300 and 600 μT) and duration of the field application (15, 30, 60 and 120 min). Germination percentage, germination rate, mean germination time, seedling vigor index, shoot length, root length, fresh weight of shoot and root, fresh weight of seedling, dry weight of shoot and root were measured. The results showed significant effects on seed germination and seedling growth of onion. In most germination characteristics, the quadrupole system had a better impact than the bipolar system. For many traits (except for weights), the increase in field intensity degraded the traits. Quadrupole system that applied the magnetic field of 600 μT for 15 minutes, yielded 63% increase in the total seedling weight. Most of the germination traits were not affected by exposure time. Further investigations are required for shorter exposure times compared to used durations in this study.

Keywords: Magnetic field, Onion, Quadrupole system, Seed germination, Seedling growth

Introduction

The seed is a basis for crop production and as the first consumption input has been an undeniable role in the transmission of genetic traits of the product. Even with the abundant use of energy without the use of the proper seed, it cannot be achieved to the maximum yield and optimum performance. Many techniques have been considered to improve germination of seed or its properties such as seed coating (Ranjbar and Kianmehr, 2017), irrigation and nutrient treatments (Feyzollahzadeh *et al.*, 2013), and optimization of threshing operation (Iranmehr, 2014). Stimulation of seeds using magnetic fields is an inexpensive and nonchemical treatment. A magnetic field is an environmental factor for living organisms that affects biological processes in different ways. Living cells contain electrical charges which are produced by free ions or radicals. Magnetic fields can influence cells via interaction with ions and especially ferromagnetic materials, like iron (Rajabbeigi *et al.*, 2013). It may also affect enzyme activity. The influence of the static magnetic field, which is greater than local geomagnetic fields, on seed germination has been the topic of some research. Static or continuous fields were generated by magnets or direct current (DC). The effect of exposing sunflower seeds to static magnetic fields of 125 mT and 250 mT for 1, 10, 20, 60 minutes, 24 hours or in a chronically way was investigated during the germination process. The mean germination time achieved for seeds subjected to treatment was significantly less than control (Carnobell *et al.*, 2005). Tomato seeds were magnetically exposed to magnetic

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field strengths (125 or 250 mT) for different exposure time. The results showed a reduction of germination time for magnetic treatments. The germination parameters were lower than control values and the germination rate for treated seeds was higher than control (Martinez *et al.*, 2009). Germination and early growth of wheat and bean were studied under magnetic fields (4 or 7 mT) and osmotic conditions. The application of magnetic fields promoted the germination ratios of seeds (Cakmak *et al.*, 2010). Cucumber seeds were exposed to stationary magnetic field strength from 100 to 250 mT for 1, 2 or 3 h. Germination-percentage and rate of germination increased by 18.5% and 49%, respectively compared to unexposed seeds. The magnetic field of 200 mT for 1 h showed a significant influence on germination parameters (Bhardwaj *et al.*, 2012). Maize seeds were treated by magnetic fields of 50, 100, 150, 200, and 250 mT for 1, 2, 3, and 4 h for all field strengths. Results indicated that the magnetic field significantly enhanced seed performance in terms of percentage of germination, germination speed and seedling length compared to unexposed control. Field application of 200 mT for 1 h exposure gave the best results among the various combinations of field and exposure time (Vashisth & Joshi, 2016). Since the method of magnetic field application can be effective on treatment results, in this study design and implementation of a system was considered to apply a magnetic field to onion seeds and the results were evaluated.

Materials and Methods

Sample preparation

The onion seed used in this experiment was from a yellow short day cultivar named Texas early grano 502. Seeds were disinfected with sodium hypochlorite (1.5%) for two minutes and washed three times with distilled water, and then the onion seeds were macerated with mancozeb fungicide.

Magnetic field application systems

A bipolar system and a quadrupole system were used to apply the magnetic field. Figure 1 shows the system for producing the bipolar magnetic field used in this study (Zamiran *et al.,* 2013). The quadrupole magnetic field system was designed and fabricated (Figure 2).

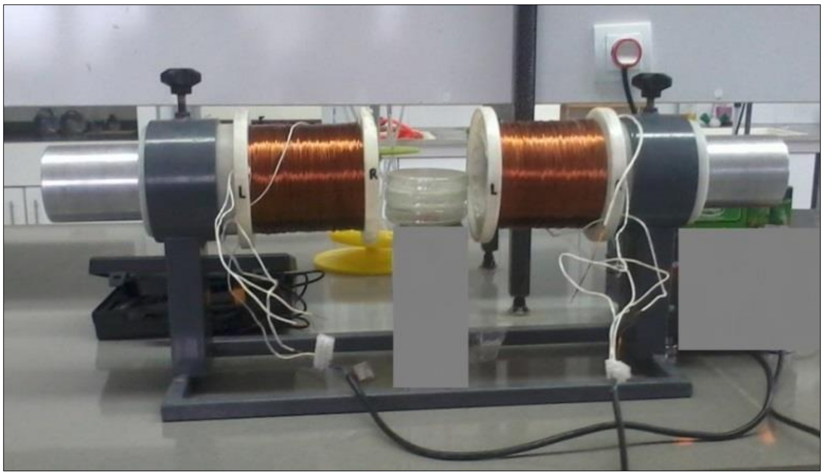

Fig.1. The system for producing the bipolar magnetic field

Design and fabrication of a novel magnetic field system

Quadrupole system consisted of stationary and movable retaining bases for keeping the cores and windings, conductive insulation (made of polytetrafluoroethylene) to avoid contacting the aluminum core with the iron body of the bases, cylindrical coils, central aluminum core, seed position and direct current power supply.

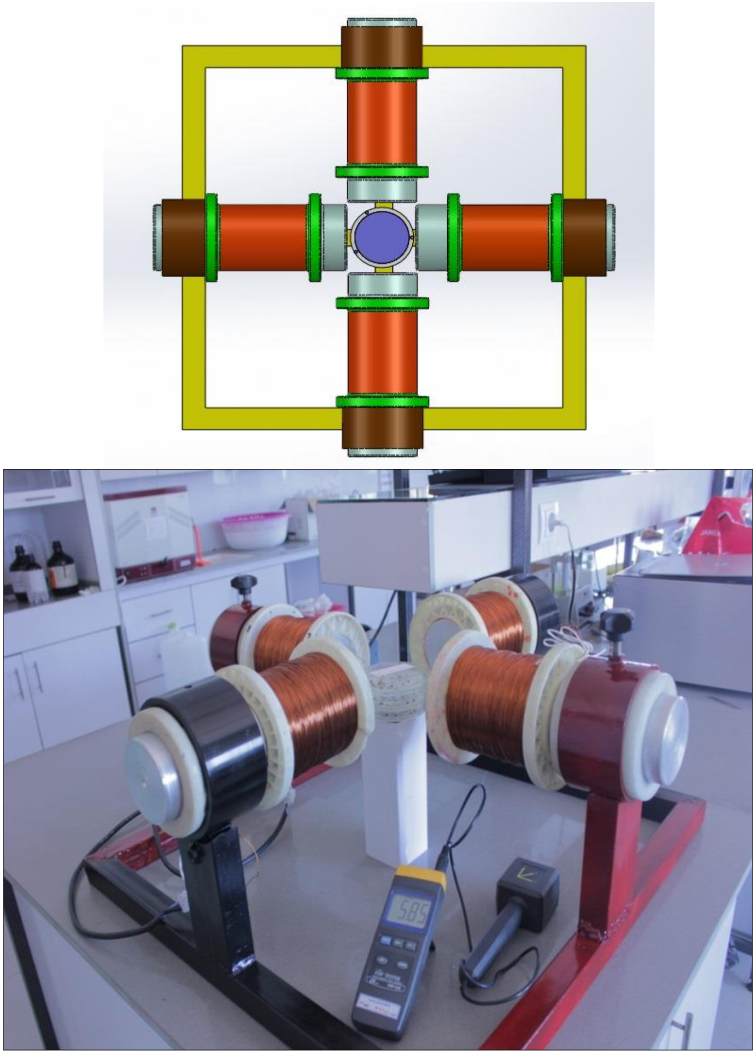

Fig.2. Quadrupole magnetic field system

Lacquer-coated wire (200 micron diameter) was used to form the coils. Each coil consisted of three layers, that is, each coil contains three input wires and three outlet wires. The first layer consisted of 450 rounds, the second layer had 650 rounds and in the third layer or the outer layer 1150 rounds were used. Therefore, the coil had 2250 rounds of copper wire and a resistance of each coil was 31 Ohm. The average diameter and the length of each coil were 105 mm and 128 mm, respectively. The purpose of wrapping coils with three layers was to receive magnetic fields with different intensities from each layer. So layers generated specific field intensity considering the input current. In order to have the minimum field strength, the first layer should be used, which has the smallest wire length as well as second and third layers should be applied to increase the magnetic flux density. If the desired magnetic strength is higher than the field strength of the third layer, it was possible to obtain the maximum field strength from the coil with layers connected in series. In order to improve the magnetic field, a solid aluminum core with a circular cross-section of 88 mm in diameter and a length of 300 mm was used in the middle of each coil. It worth noting that aluminum has paramagnetic properties. The core was easily moved inside the coil and, concerning the paramagnetic properties of aluminum, the backward and forward movement changed the magnetic field so that, as the core moved in the direction of the magnetic field, the intensity of the field was increased. The output current of the power supply is 12 volts of direct current. The power supply was able to produce four separate lines of 220/12 Volt DC which will be input to each coil and 500 W (Watt) active power. The power supply consisted of four transformers (12 Volt, 6 Amp), converting 220V to 12V. This output current from the transformers was also the AC, which is converted to DC using a rectifier diode bridge. The input current to each coil has the potential to produce a maximum magnetic field with an intensity of 700 μT, which can be changed by increasing the electrical current. The main purpose of using direct current is to have a constant magnetic field, while alternating current causes variable magnetic field. Magnetic flux density generated in each system was measured using a three-axis digital Teslameter (LMF-828 model, Lutron Company, Taiwan). Seeds were subjected to magnetic fields at the induction of 75, 150, 300 and 600 µT for 15, 30, 60 and 120 minutes. Control seeds were kept without magnetic treatment. Treatments were replicated three times and 25 seeds were used for each replication.

Germination test

Seeds were placed on filter paper in Petri dishes. Moisture content was provided by adding distilled water. Petri dishes were sealed with sterilized plastic bags and kept inside the incubator at the temperature of 25 °C. Germination of onion seeds lasted 13 days and the number of germinated seeds was recorded. Germination indices such as percentage, speed and mean time of germination, root and shoot length, fresh and dry weights of shoots and fresh and dry weights of roots were measured. The germination percentage (GP), germination rate (GR), mean germination time (MGT) and seedling vigour index (SVI) were calculated separately using equation (1), (2), (3) and (4):

$$GP=100(N_G/N_T) \quad (1)$$

Where N_G is the number of germinated seeds and N_T is the total number of seeds (Hoseyni and Rezvani Moghadam, 2009).

$$GR=\sum_{i=1}^{n}\frac{Si}{Di} \quad (2)$$

Where S_i is the number of germinated seeds per day, D_i is the number of days, and n is the number of counting days (Maguire, 1962).

$$MGT=\frac{A_1D_1+A_2D_2+\cdots A_nD_n}{A_1+A_2+\cdots A_n} \quad (3)$$

Where A is the number of seeds germinated at time D and n is the total number of days until the last day (Wang and Chang, 2003).

$$SVI = GP\times L \quad (4)$$

Where L is the mean seedling length (cm) and GP is the germination percentage (Aboutalebian *et al.*, 2005).

Five normal seedlings were selected from each petri dish and length of root and shoot and also the weight of fresh root and fresh shoot were measured. The selected seedlings were placed in an electric oven for 48 hours at a temperature of 70 °C to reach a constant weight and then dry weight was obtained.

Statistical analyses were performed using SAS software. Factorial analysis of variance (ANOVA) and Duncan tests were carried out on data.

Results and Discussion

Results of factors affected on onion seed germination parameters were shown in tables 1 and 2.

Table 1- Analysis of variance of magnetic field effect on some onion seed germination traits

Source	df	Mean Square					
		GP	GS	MGT	SVI	Shoot L.	Root L.
Type	1	326.34*	1259.16**	63.19**	12519.52	1127.51**	135.37*
Intensity	3	650.4**	195.26**	0.22	277130.63**	328.04*	212.13**
Time	3	216.84	44.62	0.15	13566.37	128.59	19.74
Type × Intensity	3	171.01	46.10	0.22*	91423.84**	827.90	13.40
Type × Time	3	132.12	9.04	0.07	30743.15	171.01	43.46
Intensity × Time	9	116.55	12.92	0.11	42830.36*	128.35	42.37
Type × Intensity × Time	9	125.97	30.69	0.17*	45423.69*	37.51	61.63

*: significant at the 5% level, **: significant at the 1% level, L.: Length

Table 2- Analysis of variance of magnetic field effect on some onion seed germination traits

Source	df	Mean Square				
		Shoot wet W.	Shoot dry W.	Root wet W.	Root dry W.	Total W.
Type	1	24193.50*	666.76**	4537.50**	63.37**	7776.00
Intensity	3	3785.03	18.79	446.40	6.79*	4656.46
Time	3	4205.42	17.09	1139.60	5.12*	3212.57
Type × Intensity	3	25793.19**	18.79	1283.42	7.68**	24975.53**
Type × Time	3	1277.97	24.82*	1331.28	13.74**	4617.25
Intensity × Time	9	3483.13	17.62*	505.70	2.47	5345.50
Type × Intensity × Time	9	5943.78	13.36	1083.60	1.71	9290.48

*: significant at the 5% level, **: significant at the 1% level, W.: Weight

Table 3- Means comparison of magnetic treatments and control for germination percentage, germination rate and mean germination time of onion seeds

System type	Magnetic flux density(μT)	Exposure time (min)	GP (%)	GR (Seed Day^{-1})	MGT (Day)
Bipolar	75	15	69.33^{abcdef}	24.61^{abcd}	7.57^{defgh}
		30	77.33^{abcd}	26.04^{abc}	7.71^{bcdefg}
		60	73.33^{abcde}	21.90^{abcde}	7.84^{bcdefg}
		120	76.00^{abcd}	27.50^{a}	7.58^{cdefgh}
	150	15	84.00^{a}	25.42^{abc}	7.80^{bcdefg}
		30	80.00^{abc}	26.82^{ab}	7.64^{bcdefg}
		60	70.67^{abcde}	21.96^{abcde}	7.79^{bcdefg}
		120	76.00^{abcd}	21.01^{abcdef}	7.93^{abcdef}
	300	15	73.33^{abcde}	19.63^{cdefg}	8.03^{abcde}
		30	62.67^{cdef}	16.43^{efg}	8.10^{abcd}
		60	65.33^{abcdef}	18.39^{defg}	7.94^{abcdef}
		120	60.00^{def}	19.40^{cdefg}	7.76^{bcdefg}
	600	15	56.00^{ef}	13.94^{g}	8.20^{ab}
		30	70.67^{abcde}	18.53^{defg}	8.00^{abcdef}
		60	62.67^{cdef}	15.86^{fg}	8.20^{ab}
		120	74.67^{abcde}	20.49^{bcdefg}	7.94^{abcdef}
Quadrupole	75	15	79.33^{abc}	20.92^{abcdef}	7.85^{bcdefg}
		30	78.67^{abcd}	21.39^{abcdef}	7.65^{bcdefg}
		60	77.33^{abcd}	21.72^{abcde}	7.35^{gh}
		120	84.00^{a}	21.11^{abcdef}	7.88^{bcdefg}
	150	15	64.67^{bcdef}	20.87^{abcdef}	7.57^{defgh}
		30	72.00^{abcde}	21.13^{abcdef}	7.36^{gh}
		60	79.33^{abc}	21.47^{abcdef}	7.65^{bcdefg}
		120	76.67^{abcd}	20.25^{bcdefg}	7.56^{defgh}
	300	15	66.00^{abcdef}	19.91^{cdefg}	7.79^{bcdefg}
		30	83.33^{ab}	22.04^{abcde}	7.46^{fgh}
		60	62.67^{cdef}	22.74^{abcde}	7.81^{bcdefg}
		120	76.67^{abcd}	20.18^{bcdefg}	7.56^{defgh}
	600	15	52.00^{f}	20.55^{bcdefg}	7.07^{h}
		30	62.67^{cdef}	20.03^{bcdefg}	7.54^{efgh}
		60	65.33^{abcdef}	21.62^{abcdef}	8.12^{abc}
		120	77.33^{abcd}	21.52^{abcdef}	7.66^{bcdefg}
Control	0	0	69.33^{abcdef}	14.07^{g}	8.42^{a}

Effects of treatments on germination percentage, germination rate and mean germination time of onion seeds were presented in Table 3. A significant change was not observed for germination percentage compared to untreated seeds but germination rate was significantly increased. The fastest germination was occurred using the bipolar system and 75 μT. A significant reduction of mean germination time was observed. One of the possible causes to explain the positive effects of the magnetic field can be paramagnetic properties of atoms found in plant cells. Applying an external magnetic field can spin the atoms in order of the magnetic field. Magnetic properties of molecules and their ability to absorb energy and then changing the magnetic field to transfer energy to other forms of energy as well as other structures in plant cells, leading to activate them (Zeidali *et al.*, 2017).

The results presented in Table 4 showed a significant impact of some magnetic fields on seedling vigour index, length of shoot and root of onion seeds. It seems the quadrupole system with minimum intensity and treatment time results in the highest value among other treatments for these parameters. Length of shoot and root were longer in the quadrupole magnetic treatment and weaker fields.

Table 4- Means comparison of magnetic treatments and control for seedling vigour index, length of shoot and root of onion seeds

System type	Magnetic flux density(μT)	Exposure time (min)	SVI	Shoot length (mm)	Root length (mm)
Bipolar	75	15	833.70^{abcdef}	$89.00^{abcdefgh}$	30.00^{cde}
		30	964.20^{abcde}	83.33^{cdefgh}	42.33^{ab}
		60	909.30^{abcdef}	$90.67^{abcdefg}$	33.00^{abcde}
		120	883.90^{abcdef}	80.33^{efgh}	35.33^{abcde}
	150	15	1030.40^{abc}	$86.67^{abcdefgh}$	35.33^{abcde}
		30	965.10^{abcde}	$86.00^{abcdefgh}$	35.33^{abcde}
		60	908.80^{abcdef}	95.00^{abcdef}	32.67^{bcde}
		120	822.80^{abcdef}	79.33^{fgh}	29.00^{def}
	300	15	885.10^{abcdef}	82.67^{defgh}	38.00^{abcd}
		30	718.30^{efg}	$86.00^{abcdefgh}$	29.33^{cdef}
		60	766.20^{cdefg}	$88.00^{abcdefgh}$	28.33^{def}
		120	618.70^{fg}	73.67^{gh}	29.33^{cde}
	600	15	632.40^{fg}	$87.33^{abcdefgh}$	26.00^{ef}
		30	897.10^{abcdef}	95.00^{abcdef}	32.00^{bcde}
		60	729.90^{defg}	$88.00^{abcdefgh}$	28.33^{def}
		120	854.00^{abcdef}	$89.33^{abcdefgh}$	25.67^{ef}
Quadrupole	75	15	1099.90^{a}	104.00^{a}	44.00^{a}
		30	965.60^{abcde}	99.67^{abcde}	35.67^{abcde}
		60	1018.00^{abcd}	103.33^{ab}	38.00^{abcd}
		120	1053.90^{abc}	100.33^{abcde}	36.33^{abcde}
	150	15	782.00^{cdefg}	96.00^{abcdef}	34.00^{abcde}
		30	797.50^{bcdefg}	$90.33^{abcdefg}$	29.00^{def}
		60	1048.90^{abc}	101.00^{abcd}	40.67^{abc}
		120	88.40^{abcdef}	$91.00^{abcdefg}$	34.67^{abcde}
	300	15	834.40^{abcdef}	102.67^{abc}	33.00^{abcde}
		30	1075.30^{ab}	104.00^{a}	35.00^{abcde}
		60	651.70^{fg}	$85.00^{abcdefgh}$	26.00^{ef}
		120	900.80^{abcdef}	$93.00^{abcdefg}$	34.00^{abcde}
	600	15	539.90^{g}	$84.33^{abcdefgh}$	28.67^{def}
		30	656.70^{fg}	81.00^{defgh}	33.67^{abcde}
		60	625.90^{fg}	70.67^{h}	31.67^{bcde}
		120	846.50^{abcdef}	$83.67^{bcdefgh}$	33.67^{abcde}
Control	0	0	689.20^{efg}	81.67^{defgh}	18.67^{f}

Means of findings for the fresh and dry weight of shoot and root were compared in Table 5. It was demonstrated that the magnetic treatment can increase these indices. Shoot fresh weight was enhanced by 67% compared to the control using optimum treatment. The magnetic field not only causes the faster penetration of water into the seed but also affects the speed of enzymatic reactions. Water uptake in the first stage accelerates the seeds swelling and their weight. This may be associated with increased metabolism and more water content in plants (Fischer *et al.*, 2004).

Table 5- Means comparison of magnetic treatments and control for the fresh and dry weight of shoot and root of onion seeds

System type	Magnetic flux density (µT)	Exposure time (min)	Shoot fresh weight (µg)	Root fresh weight (µg)	Shoot dry weight (µg)	Root dry weight (µg)
Bipolar	75	15	378.33^{bcde}	102.33^{abcd}	10.33^{fgh}	5.33^{defgh}
		30	360.33^{bcde}	110.67^{abcd}	11.33^{efgh}	5.67$^{c\ defgh}$
		60	393.00^{bcde}	96.67^{bcd}	12.33^{efgh}	5.00^{efgh}
		120	373.67^{bcde}	115.33^{abc}	12.33^{efgh}	4.33^{fgh}
	150	15	392.33^{bcde}	87.33^{bcd}	11.67^{efgh}	5.33^{defgh}
		30	426.33^{abcde}	92.00^{bcd}	14.00^{cdefg}	5.33^{defgh}
		60	392.67^{bcde}	96.00^{bcd}	10.67^{fgh}	5.00^{efgh}
		120	358.00^{bcde}	83.67^{bcd}	9.00^{gh}	4.33^{fgh}
	300	15	352.67^{cde}	110.67^{abcd}	11.67^{efgh}	5.33^{defgh}
		30	349.67^{de}	85.00^{bcd}	13.67^{cdefgh}	5.00^{efgh}
		60	400.67^{abcde}	94.33^{bcd}	12.67^{defgh}	5.33^{defgh}
		120	312.00^{e}	88.33^{bcd}	8.33^{h}	4.00^{gh}
	600	15	401.67^{abcde}	85.67^{bcd}	10.67^{fgh}	5.67$^{c\ defgh}$
		30	447.00^{abcde}	104.00^{abcd}	10.67^{fgh}	5.67$^{c\ defgh}$
		60	487.33^{abc}	85.67^{bcd}	11.00^{efgh}	4.67^{efgh}
		120	470.33^{abcd}	127.67^{ab}	16.00^{bcdef}	3.33^{h}
Quadrupole	75	15	398.67^{abcde}	74.00^{cd}	13.67^{cdefgh}	5.33^{defgh}
		30	429.33^{abcde}	80.67^{bcd}	15.33^{bcdef}	5.33^{defgh}
		60	406.33^{abcde}	77.33^{bcd}	14.33^{cdefg}	4.67^{efgh}
		120	422.33^{abcde}	83.67^{bcd}	15.33^{bcdef}	6.67^{bcdef}
	150	15	416.00^{abcde}	144.67^{a}	18.00^{abcd}	7.00^{bcde}
		30	406.00^{abcde}	78.33^{bcd}	13.67^{cdefgh}	4.33^{fgh}
		60	470.00^{abcd}	81.33^{bcd}	20.00^{ab}	8.00^{abc}
		120	405.00^{abcde}	81.67^{bcd}	16.67^{bcde}	8.00^{abc}
	300	15	427.00^{abcde}	72.33^{cd}	18.00^{abcd}	7.67^{abcd}
		30	469.33^{abcd}	72.67^{cd}	18.67^{abc}	6.67^{bcdef}
		60	529.00^{a}	74.67^{cd}	20.00^{ab}	10.00^{a}
		120	424.67^{abcde}	78.33^{bcd}	19.00^{abc}	7.67^{abcd}
	600	15	488.67^{ab}	127.00^{ab}	14.33^{cdefg}	5.33^{defgh}
		30	339.00^{de}	74.67^{cd}	12.67^{defgh}	4.67^{efgh}
		60	376.33^{bcde}	72.67^{cd}	22.33^{a}	8.33^{ab}
		120	396.33^{abcde}	71.67^{cd}	18.67^{abc}	5.67^{cdefgh}
Control	0	0	317.00^{e}	61.00^{d}	16.67^{bcde}	6.33^{bcdefg}

Comparison of seedling weights is illustrated in Figure 3. Some treatments significantly increased this important germination parameter. Quadrupole system that applied the magnetic field of 600 µT for 15 minutes, yielded 63% increase in total weight.

The magnetic field can have various effects on plant metabolism according to application style, intensity and environmental conditions (Cakmak *et al.*, 2010).

The low-frequency magnetic field (20 mT) was induced to onion seeds at 10, 30 and 60 minutes. For the magnetic treatment of 60 minutes, an increase in energy of germination, germination capacity, and the seedling length was observed. The results were different for two cultivars of onion (Holubowicz *et al.*, 2014). Exposure of dry onion seeds to low frequency non-uniform magnetic fields (160 mT for 15 and 20 min) increased germination compared to unexposed controls. The best finding was found for 160 mT for 15 min (De

Souza *et al.*, 2014). Onion seeds were also pretreated by the static magnetic field (0.03 or 0.06 T) for 30, 60 and 90 minutes. Exposed seeds to 0.06 T with 30 minute gave the maximum values of germination percentage, germination rate, seedling length and seedling dry weight (Hozyan *et al.*, 2015). In present research, weaker magnetic fields were used than many similar studies.

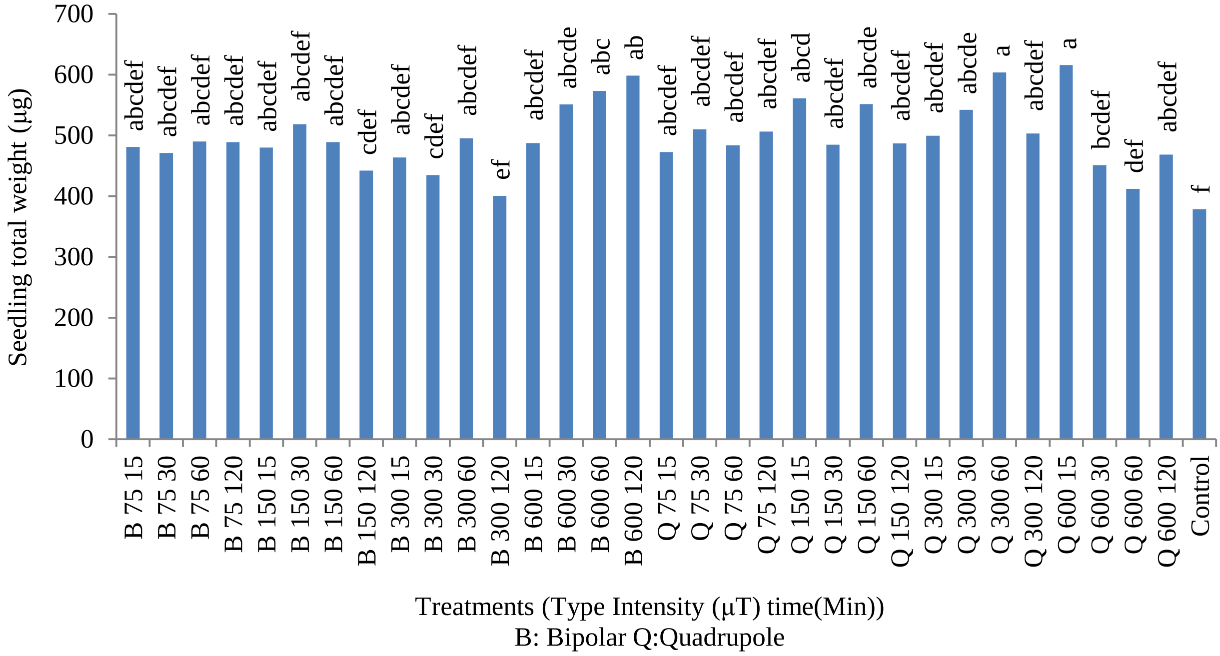

Fig.3. Effect of magnetic treatments on the seedling total weight

Conclusions

It is concluded that the designed system which was optimized to quadrupole has a potential to improve germination seed. Evaluation of the system with onion seed showed significant results. In most germination characteristics, the quadrupole system had better effect than the bipolar system. Generally, in many traits (except for traits related to weight), the increase in field intensity degraded the traits. Most of the germination traits were not affected by exposure time. Therefore short durations are efficient regarding cost and time. Further investigations are suggested for shorter exposure times compared to used durations in this study. Optimum magnetic treatments should be determined for every product. Investigation of the alternative current utilization in this system is also suggested. Meanwhile it may be useful to study the combination of a magnetic field with other treatments. Although the findings were obtained by a laboratory system, it is also possible to develop it in industrial technology.

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نشریه ماشین‌های کشاورزی
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طراحی، ساخت و ارزیابی یک سامانه جدید اعمال میدان مغناطیسی به بذر محصولات کشاورزی – مطالعه موردی بذر پیاز

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چکیده

استفاده از روش‌های غیرشیمیایی یکی از راهکارهای بهبود جوانه‌زنی بذر به‌شمار می‌رود. به‌منظور بررسی اثر اعمال میدان مغناطیسی بر شاخص‌های جوانه‌زنی بذر و رشد گیاهچه پیاز، یک سامانه‌ی میدان مغناطیسی چهار قطبی طراحی و ساخته شد و با سامانه دوقطبی مورد مقایسه قرار گرفت. در سامانه چهارقطبی، هر یک از چهار کلاف سیم پیچ شامل سه‌لایه سیم‌پیچ و یک هسته فلزی است که هسته قابلیت حرکت در درون سیم‌پیچ را دارد. این قابلیت باعث تغییر شدت میدان مغناطیسی، علاوه بر تغییر از طریق تغییر جریان ورودی، خواهد شد. دو آزمایش مستقل با دو سامانه‌ی میدان مغناطیسی به‌صورت فاکتوریل در قالب طرح کاملاً تصادفی با سه تکرار انجام شد. فاکتورها شامل نوع سامانه (دو قطبی و چهار قطبی)، شدت میدان مغناطیسی (۷۵، ۱۵۰، ۳۰۰ و ۶۰۰ میکروتسلا) و مدت زمان اعمال میدان (۱۵، ۳۰، ۶۰ و ۱۲۰ دقیقه) بود. شاخص‌های مورد بررسی عبارت بودند از: درصد جوانه‌زنی، سرعت جوانه‌زنی، متوسط زمان جوانه‌زنی، شاخص بنیه، طول ساقه‌چه، طول ریشه‌چه، وزن تر ساقه‌چه، وزن‌تر ریشه‌چه، وزن تر گیاهچه، وزن خشک ریشه‌چه و وزن خشک ساقه‌چه شد. به‌طور کلی نتایج نشان داد که میدان مغناطیسی بر روی شاخص‌های جوانه‌زنی و رشد گیاهچه پیاز تاثیر معنی‌دار داشته و سامانه چهارقطبی نسبت به سامانه دوقطبی در بیشتر شاخص‌های مورد مطالعه عملکرد بهتری داشته است. در مورد غالب صفات (به‌جز وزن)، افزایش شدت میدان، منجر به کاهش صفات شد. سیستم چهارقطبی که میدان مغناطیسی ۶۰۰ میکروتسلایی را به مدت ۱۵ دقیقه به بذر اعمال کرد، باعث افزایش ۶۳ درصدی وزن گیاهچه گردید. غالب صفات جوانه‌زنی تحت تأثیر مدت زمان اعمال میدان به بذر قرار نگرفتند. به هرحال بررسی‌های بیشتر در خصوص مدت زمان اعمال میدان نسبت به زمان اعمال شده در این مطالعه ضروری است.

واژه‌های کلیدی: پیاز، جوانه‌زنی بذر، رشد گیاهچه، سامانه چهار قطبی، میدان مغناطیسی

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