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Effect of Magnetic Field and its Stability on Growth Indices of Parsley (Petroselinum Crispum) Seeds

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ABSTRACT

Recent research has proven that magnetic field application enhanced the percentage of germinated seed and shortened the period of seed germination. In present research in order to evaluation of the effect of magnetic field on seed germination and seedling growth indices of smooth leaf type parsley seeds and also the stability of magnetic properties on this seed, the quadrupole magnetic field was used. The experiment was conducted as factorial in a completely randomized design with three replications. Factors include; magnetic field intensity (150, 300 and 450 mT), time exposure (30, 60 and 90 min) and culture time (0, 7 and 14 days after the magnetic field application). The results of ANOVA showed the magnetic field had a significant effect on shoot length, fresh root weight and dry shoot weight ($p \leq 0.01$) and on fresh shoot weight ($p \leq 0.05$). Duration of the field application (time exposure), significantly affected on root length ($p \leq 0.01$). Culture time had a significant effect on root length, fresh root weight and dry shoot weight ($p \leq 0.01$) and also had a significant effect on other factors ($p \leq 0.05$). Culture time without delay after applying magnetic field (0 day) increased the root length and culture time at the 14 days after applying magnetic field increased the shoot length, fresh weight of root, fresh shoot weight, dry root weight and dry root weight. Our results suggest that magnetic field and culture time treatments can be used as a physical technique to improve the most of seedling growth indices of parsley seeds.

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INTRODUCTION

Parsley with scientific name *Petroselinum crispum* is a biennial vegetable of the family *Apiaceae* (*Umbelliferae*). Parsley is one of the most important vegetables that seed germination has taken a long time, and it is difficult to be germinated, especially under unfavorable environmental conditions (Ely and Heydecker, 1981). Research on the influence of magnetic fields on biological systems began many decades ago, with recent detailed reviews provided by Maffei (2014) and Teixeira da Silva and Dobránszki (2016). It is shown that the magnetic fields have positive effects on the protein synthesis, cell proliferation, biochemical activity, respiration rate, activity of enzymes, nucleic acids and growth rate (Cakmak et al., 2009). Ulgen et al., (2017) reported the effects of magnetic fields on *M. officinalis* seeds. *M. officinalis* seeds were magnetically exposed to static magnetic field intensity of 50 mT and 100 mT for different time of exposure, 1, 3, 6, 12, 24, 48, 72, 144 and 240 hours, respectively. They found that magnetic field application enhanced the percentage of germinated seed and shortened the period of seed germination. Another interesting experiment was conducted by Kırdar et al. (2016). In their study, the effects of magnetic field on the germination of seeds and growth of seedlings of stone pine (*Pinus Pinea* L.) were investigated. For this purpose, its seeds were treated by a magnetic field of 9.42 mT for a different period of time: 0 min (control), 15 min, 30 min, and 40 min. Considering the germination results as a whole, seeds exposed to a magnetic field for 30 and 45 minutes resulted in higher germination energy and percentage of germination, respectively. Magnetic field increased shoot height, root collar diameter, and also tap root length of stone pine seedlings. Zeidali et al., (2017) investigated the effect of the different intensity and times of magnetic field on seed criteria of wheat and wild oat. They found that the magnetic field effected on germination indexes in wild oat more than wheat, but the magnetic field of 200 MT for 45 minutes in both plants has similar effects on improving the germination indexes. Srikanth (2018) determined the effect of magnetic -electric field on the growth characteristics of chilli seeds. They were exposed to magnetic field of 250 gauss, 500 gauss, 750 gauss and 1000 gauss intensities for the duration of 30 minutes and electric field of 100mA, 200mA, 300mA and 400mA for duration of 1 minute. And also, combination of both magnetic and electric field was investigated. The research showed that high magnetic field enhances the germination capacity and seedling characteristics of seeds. Magnetic field exposure to seeds gives positive results when compared to electric field exposure.

The other study was conducted to determine the effects of magnetic field (B) on in vitro seed germination, seedling growth, and shoot regeneration capacity of cotyledon node explants in Lathyrus chrysanthus Boiss. to obtain healthy seedlings in large quantities. The seeds of an ecotype (*Diyarbakir*) were subjected to 125 mT magnetic field strength for different exposure time periods (0-untreated, 24, 48, and 72 h). According to the results, it could be concluded that B treatment could clearly be used to improve germination by breaking dormancy not only in Lathyrus chrysanthus Boiss. but also, other plant species (Bahadir et al., 2018). Khade and Avinash (2018) used a novel 'short-term magnetic field exposure experimental method' where imbibed seedlings were exposed to higher gauss values ranging from 300 gauss to 0.2 Tesla for a short interval time of 10 minutes. They studied changing patterns in peas and chick-peas germination and growth, along with various photo-synthetic and biochemical parameters. They conclude that the magnetism had a significant positive effect on plant growth. Plant seeds under the influence of magnetic field had higher germination rate and these plants grew taller, larger and healthier. Konefał-Janocha et al., (2018) made an experiment in which seeds of radish seeds (*Raphanus sativus*) were exposed to a stationary magnetic field (with an intensity of 8 mT and 20 mT) and variable magnetic fields (with an intensity of 6 mT and a frequency of 50 Hz). Results indicate that magnetic fields increased the rate of germination, vigour index, and germination rate index for all samples treated with stationary magnetic field. All measured values decreased when the seeds were exposed to variable magnetic fields at the exposure time of 12 min.

The results of a literature review show that no research has been done in this regard therefore, the aim of this study was investigating the possible effects of the different intensities and duration of magnetic fields on some seedling growth indices of parsley seeds such as root length, shoot length, fresh root weight, dry root weight, fresh shoot weight and dry shoot weight and also study of the stability of field effect in seeds.

MATERIAL AND METHODS

Parsley seeds (*Petroselinum crispum*) were obtained from the Pakan Bazr Company (Isfahan, Iran). They were not treated with chemicals and had uniform germination rates with the same batch of seeds used for all experiments. Seeds were selected on the basis of having no visible defects, deformities, or the presence of insects. Before using the magnetic field device, the seeds were disinfected for three minutes by 1.5% sodium hypochlorite and then washed with distilled water.

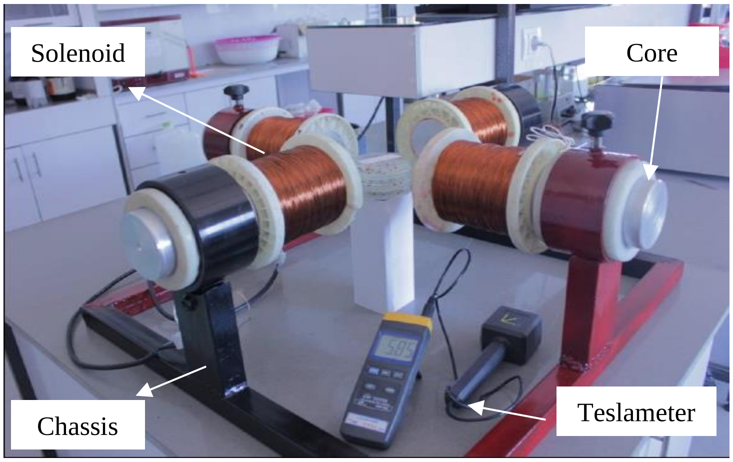

Figure 1. Quadrupole magnetic field used in the experiment

A quadrupole magnetic field was designed at the department of mechanical engineering of biosystems, University of Jiroft (Fig. 1). A digital teslameter (LB-828, Taiwan) was used to monitor the field strength produced in the pole gap of magnetic field generator. Seeds were sown in petri dishes with a diameter of 100 mm. Twenty-five seeds were placed in each petri dishes and they were used for each treatment. Factors include; magnetic field intensity (150, 300 and 450 mT), duration of the field application (30, 60 and 90 min) and culture time (0, 7 and 14 days after the magnetic field application). The time interval between the magnetic field application and seeding is done in order to investigate the magnetic field stability in the seeds. Root length and shoot length were measured using a digital caliper with an accuracy of 0.01 mm and dry weights of shoot and root were determined after drying at 75 °C for 24 h. They were measured by an electronic balance to an accuracy of 0.001 g. The experiments were conducted in factorial layout based on completely randomized design with three replications. Statistical analyzes were performed using SAS 9.4 Software. Means were compared using Duncan's multiple range at the 5% level.

RESULTS AND DISCUSSION

A number of studies have indicated that magnets have an effect on plants, but the effects vary due to a number of factors including the strength and type of magnet used, the placement of the magnet in relation to the plant or seed, and the type of plant used.

Root length

Analysis of variance showed that the effect of the exposure time (TB) and culture time (TC) and also interaction effects magnetic field× exposure time (B×TB), magnetic field× culture time (B×TC), exposure time ×culture time (TB×TC) and magnetic field× exposure time× culture time (B×TB×TC) were significant on the root length at 1% probability level (Table 1). According to table 2, the results revealed that root length of parsley decreased with raising B and culture time, while this growth index hasn't change smooth with raising durations of exposure. On the other hand, the treatments B and TC had an adverse effect on root length.

Table 1. Analysis of variance for some seedling growth indices parsley under magnetic field intensities, exposure times and culture times

S.O.V	df	Root Length	Shoot Length	Fresh Root Weight	Fresh Shoot Weight	Dry Root Weight	Dry Shoot Weight
B	2	4.226^{ns}	290.507**	0.000014**	0.00018*	8.641^{ns}	2.308**
TB	2	14.272**	64.424^{ns}	0.0000018^{ns}	0.000033^{ns}	1.604^{ns}	1.975^{ns}
TC	2	165.548**	119.333*	0.000010*	0.00084**	8.271*	2.345**
B×TB	4	11.924**	141.347**	0.000016**	0.00037**	1.604^{ns}	2.271**
B×TC	4	35.510**	79.556^{ns}	0.0000089*	0.00023^{ns}	1.049^{ns}	4.753^{ns}
TB×TC	4	14.725**	9.667^{ns}	0.0000068^{ns}	0.000011^{ns}	2.345^{ns}	7.530^{ns}
B×TB×TC	8	23.057**	46.364^{ns}	0.000019**	0.00017**	1.234^{ns}	9.104*
Erorr	54	1.448	31.842	0.0000029	0.000062	0.0000002	0.0000004
C.V (%)	-	21.032	15.032	20.484	15.441	36.824	22.314

ns: not significant, *: significant at/above 5% level, **: significant at/above 1% level, S.O.V: Source of variation, df: Degrees of Freedom, B: Magnetic field, TB: Exposure Time, TC: Culture time and CV: Coefficient of variances.

Root length can be used as the most important parameter in the vegetative growth process. Because, researchers believe that root length per unit volume of soil is the best feature for evaluating soil water and absorbing elements by plants (Eshghizadeh et al., 2012).

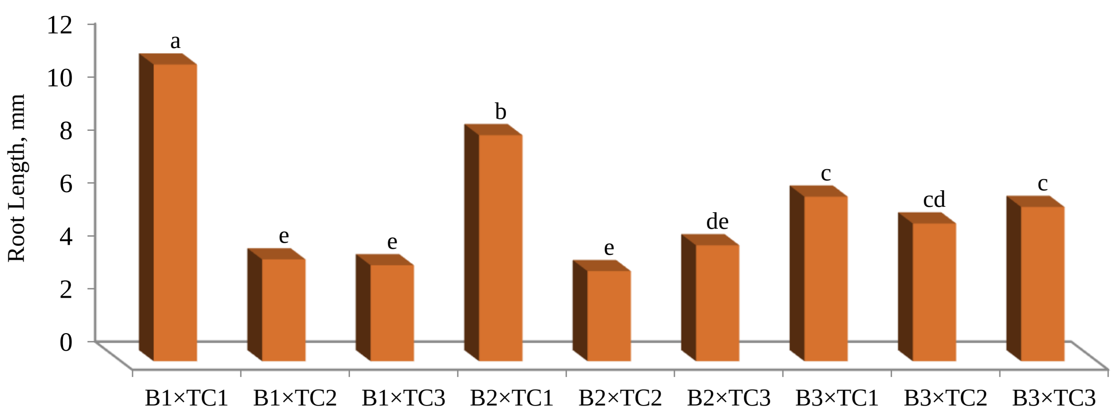

Figure 2. Interaction effects of B and TC on root length (B1: 150 mT, B2: 300 mT, B3: 450 mT, TC1: Instantly or 0 day, TC2: 7 days and TC3: 14 days after the magnetic field application)

In the parsley, increase days after the magnetic field application at 150 mT magnetic field intensity decreased the root length more than the other interaction effects. According to Fig. 2. in the case of 150 mT, 0 day treatment, the root length (11.2 mm) was higher than other treatments and was significant. A difficulty in interpreting the results of Fig. 2, 3 and other studies is disentangling possible confounding effects that may arise from using seeds with a different shape, size, and the mixture of using TC with other factors. This can be further complicated since the exact mechanisms by which magnetic fields might affect the seed and also stability of field effect are not yet understood. 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).

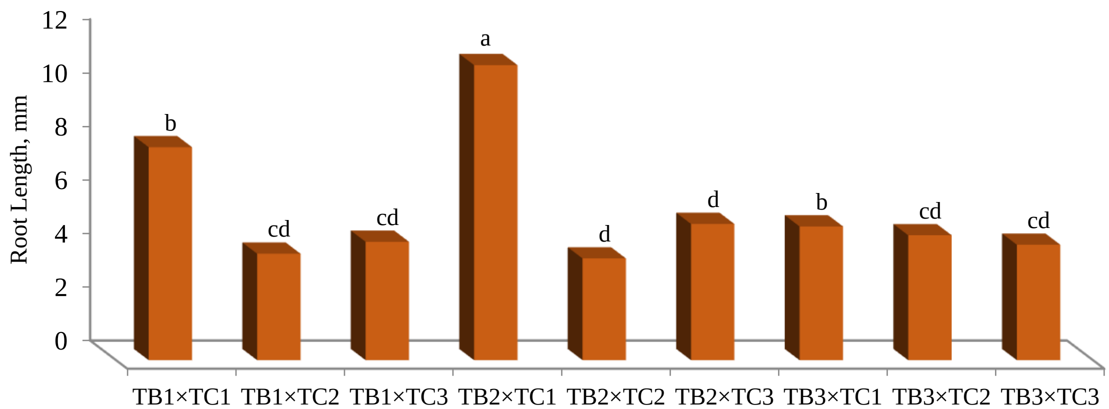

Figure 3. Interaction effects of TB and TC on root length (TB1: 30 min, TB2: 60 min, TB3: 90 min, TC1: Instantly or 0 day, TC2: 7 days and TC3: 14 days after the magnetic field application)

In the parsley, increase days after the magnetic field application at 60 min duration of the field application decreased the root length more than the other interaction effects. The highest root length was observed with 60 min, 0 day after the magnetic field application (Fig. 3).

Shoot length

Effect of B and interaction effect B×TB on shoot length was significant at the probability of 1% level, also effect of TC on this trait was significant at the probability of 5% level (Table 1). Increase in B increases the shoot length the seedlings from 35.09 to 41.26 mm. Also, we noted a decrease in the shoot length of parsley seedlings, and an increase in this trait by culture time progress (Table 2).

Fresh root weight

The results of variance analysis showed that, the most main effects and interaction effects on morphological traits of fresh root weight were significant (Table 1). According to Table 2 it was found that fresh root weight increased about 12% compared to the 0 day after the magnetic field application.

Fresh shoot weight

Analysis of variance showed that the effect of B on the fresh shoot weight was significant at the 5% level. Furthermore, the effect of TC and interaction effects B×TB and B×TB×TC were significantly different at 5% level (Table 1). Racuciu et al. (2007) observed some increasing in germination rate, the fresh weight of the shoot, the fresh weight of the total plant and also the length of corn seedlings under the influence of the magnetic field. The magnetically exposed parsley seeds show marginally higher fresh shoot weight. By increasing the TC, fresh shoot weight of parsley, had a significant increasing (about 21% according means of data) compared to the 0 day after the magnetic field application (Table 2). Fresh shoot weight had more increase than fresh root weight at 0 day culture time. This showed that the seedling growth indices of parsley could be improved by treatment of its seeds before they were grown, using magnetic fields. It was observed that culture time also has effects on parsley at the seedling growth indices including a significant effect in root length and shoot length, significant increase in fresh root weight, fresh shoot weight, dry root weight and dry shoot weight.

Dry root weight

It was found that TC was a very significant only factor on the dry root weight of parsley seedlings comparing with the other factors (Table 1). A significant difference was not observed among the different levels of B and TB in parsley plants (Table 2). Increasing magnetic field intensity (150 to 450 mT) and duration of the field application (30 to 90 min) not changed dry root weight and the lowest (0.0010 g) this trait was obtained with 0 day after the magnetic field application.

Dry shoot weight

Dry shoot weight was significantly affected by B, TC, B×TB at the probability of 1% level and the interaction effect B×TB×TC at the probability of 5% level (Table 1). By increasing the TC, dry shoot weight of parsley, had a significant increasing (about 1.5 times) compared to the 0 day after the magnetic field application. This experiment demonstrated that culture time influence on this trait of parsley (Table 2). 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 2 show combination of interaction effects of B, TB and TC on root length, shoot length, fresh root weight, fresh shoot weight, dry root weight and dry shoot weight.

This table showed that the root length in parsley with magnetic field of 150 mT for 60 minutes and culture time of 0 days had the highest value (18.36 mm) and caused a 311% increase in root length and an increase of 13.9 mm compared to the control. The combination of interaction 300 mT, time exposure 30 min and culture time 7 days significantly increased the fresh root weights (0.012 g) compared to control (0.003 g) and was significantly different with the untreated seeds. There is improvement in fresh shoot weight of the seeds treated with magnetic field of 450 mT at 60 min and culture time 14-day combinations compared to control. This value was 0.068 g and caused a 23% increase compare to untreated seeds (0.055 g). According to the results of table 2, magnetic field intensities seem to have a good effect on dry shoot weight of parsley seeds, and the best effect was observed in the intensity of 450 mT at 90 minutes and culture time 14 day. That was 0.0043 g and caused a 65% increase compare to untreated seeds (0.0026 g). In general, the seedling shoots from seeds magnetically pretreated grew taller and heavier than untreated controls.

Table 2. Combination of interaction effects of B, TB and TC on root length, shoot length, fresh root weight, fresh shoot weight, dry root weight and dry shoot weight

B×TB×TC	Root Length (mm)	Shoot Length (mm)	Fresh Root Weight (g)	Fresh Shoot Weight (g)	Dry Root Weight (g)	Dry Shoot Weight (g)
150-30-0	9.067^{bc}	41.333^{abcdef}	0.0113^{a}	0.046^{defghi}	0.0010^{a}	0.0020^{d}
150-30-7	3.667^{hi}	30.867^{efgh}	0.0100^{abc}	0.048^{efghi}	0.0013^{a}	0.0030^{abcd}
150-30-14	3.600^{hi}	35.333^{cdefgh}	0.0070^{cdef}	0.055ab^{cdefg}	0.0013^{a}	0.0036^{abc}
150-60-0	**18.367^{a}**	41.733^{abcde}	0.0056^{efg}	0.045^{efghi}	0.0010^{a}	0.0026^{bcd}
150-60-7	3.933^{ghi}	37.067^{bcdefg}	0.0093^{abcd}	0.061^{abcde}	0.0016^{a}	0.0036^{abc}
150-60-14	3.333^{hi}	38.333^{abcdefg}	0.0060^{defg}	0.051^{bcdefghi}	0.0013^{a}	0.0033^{abcd}
150-90-0	6.167^{defgh}	34.867^{cdefgh}	0.0066^{cdef}	0.042^{fghi}	0.0016^{a}	0.0040^{ab}
150-90-7	3.933^{ghi}	25.067^{h}	0.0056^{efg}	0.036^{i}	0.0013^{a}	0.0026^{bcd}
150-90-14	3.933^{ghi}	31.267^{efgh}	0.0080^{bcdef}	0.053^{bcdefgh}	0.0016^{a}	0.0030^{abcd}
300-30-0	6.600^{cdefg}	35.800^{cdefgh}	0.0056^{efg}	0.049^{defghi}	0.0010^{a}	0.0030^{abcd}
300-30-7	4.267^{ghi}	38.067^{bcdefg}	0.0120^{a}	0.057^{abcdef}	0.0016^{a}	0.0030^{abcd}
300-30-14	5.200^{efghi}	43.933^{abcd}	0.0096^{abc}	0.066^{ab}	0.0013^{a}	0.0033^{abcd}
300-60-0	9.467^{b}	37.600^{bcdefg}	0.0090^{abcde}	0.049^{defghi}	0.0013^{a}	0.0020^{d}
300-60-7	3.000^{i}	33.467^{defgh}	0.0090^{abcde}	0.041^{ghi}	0.0013^{a}	0.0023^{cd}
300-60-14	4.267^{ghi}	37.000^{bcdefg}	0.0106^{ab}	0.057^{abcdef}	0.0016^{a}	0.0030^{abcd}
300-90-0	9.533^{b}	38.467^{abcdefg}	0.0093^{abcd}	0.045^{efghi}	0.0013^{a}	0.0020^{d}
300-90-7	2.933^{i}	29.933^{fgh}	0.0060^{defg}	0.044^{fghi}	0.0010^{a}	0.0026^{bcd}
300-90-14	3.667^{hi}	32.000^{efgh}	0.0113^{a}	0.053^{abcdefgh}	0.0013^{a}	0.0020^{d}
450-30-0	8.200^{bcd}	36.867^{bcdefg}	0.0076^{bcdef}	0.050^{cdefghi}	0.0010^{a}	0.0023^{cd}
450-30-7	4.000^{ghi}	36.733^{bcdefg}	0.0063^{def}	0.043^{fghi}	0.0013^{a}	0.0023^{cd}
450-30-14	4.467^{fghi}	39.200a^{bcdef}	0.0076^{bcdef}	0.048^{defghi}	0.0016^{a}	0.0033^{abcd}
450-60-0	5.233^{efghi}	39.867^{abcdef}	0.0070^{cdef}	0.047^{defghi}	0.0010^{a}	0.0026^{bcd}
450-60-7	4.467^{fghi}	37.33^{bcdefg}	0.0060^{defg}	0.050^{cdefghi}	0.0016^{a}	0.0036^{abc}
450-60-14	7.667^{bcde}	**49.200^{a}**	0.0100^{abc}	0.068^{a}	0.0016^{a}	0.0040^{ab}
450-90-0	5.200^{efghi}	39.133^{abcdef}	0.0070^{cdef}	0.050^{cdefghi}	0.0013^{a}	0.0030^{abcd}
450-90-7	7.133^{bcdef}	47.773^{ab}	0.0116^{a}	0.062^{abcd}	0.0016^{a}	0.0036^{abc}
450-90-14	5.333^{efghi}	45.333^{abc}	0.0100^{abc}	0.067^{abc}	0.0016^{a}	**0.0043^{a}**
C0	4.467^{fghi}	27.333^{gh}	0.0046^{fg}	0.037^{hi}	0.0010^{a}	0.0026^{bcd}
C7	4.933^{fghi}	33.133^{defgh}	0.0030^{g}	0.048^{defghi}	0.0013^{a}	0.0030^{abcd}
C14	4.133^{ghi}	31.133^{efgh}	0.0066^{cdef}	0.055^{abcdefg}	0.0013^{a}	0.0026^{bcd}

Means in columns followed by the same letters are not significantly different at 0.05 level according to Duncan's test. C0: Culture instantly, C7: Culture in 7th day and C14: Culture in 14th day.

CONCLUSION

The application of magnetic fields with culture time appears to produce changes in some physiological and biochemical processes of parsley seeds, including encouraging their development. The results of ANOVA showed the magnetic field had a significant effect on shoot length, fresh root weight and dry shoot weight ($p \leq 0.01$) and on fresh shoot weight ($p \leq 0.05$). Duration of the field application (time exposure), significantly affected on root length ($p \leq 0.01$). Culture time had a significant effect on root length, fresh root weight and dry shoot weight ($p \leq 0.01$) and also had a significant effect on other factors ($p \leq 0.05$). The shoot length and fresh shoot weight of parsley were the highest in the magnetic field of 450 mT for 60 minutes and culture time 14 days 49.20 mm and 0.068 g, respectively. The dry shoot weight was the highest (0.0043 g) in the magnetic field of 450 mT for 90 minutes and culture time 14 days. The combination of interaction 300 mT, time exposure 30 min and culture time 7 days significantly increased the fresh root weights (0.012 g) compared to control (0.003 g). It is obvious that the optimal conditions can be selected according to each required parameter.

REFERENCES

Abdul-Baki, A. A., & Anderson, J. D. (1973). Vigor determination in soybean seed by multiple criteria 1. *Crop science*, *13*(6), 630-633. https://doi.org/10.2135/cropsci1973.0011183X001300060013x

Khade, A., & Avinash, M. (2018). Effects of short-term Magnetic Field on germination and growth of plants. *Journal of science & Engineering*, 83-8.

Bahadir, A., Beyaz, R., & Yildiz, M. (2018). Effect of magnetic field on in vitro seedling growth and shoot regeneration from cotyledon node explants of Lathyrus chrysanthus boiss. *Bioelectromagnetics*, *39*(7), 547-555. https://doi.org/10.1002/bem.22139

Cakmak, T., Dumlupinar, R., & Erdal, S. (2010). Acceleration of germination and early growth of wheat and bean seedlings grown under various magnetic field and osmotic conditions. *Bioelectromagnetics: Journal of the Bioelectromagnetics Society, The Society for Physical Regulation in Biology and Medicine, The European Bioelectromagnetics Association*, *31*(2), 120-129. https://doi.org/10.1002/bem.20537

Ely, P. R., & Heydecker, W. (1981). Fast germination of parsley seeds. *Scientia Horticulturae*, *15*(2), 127-136. https://doi.org/10.1016/0304-4238(81)90100-X

Eshghizadeh, H. R., Kafi, M., Nezami, A., & Khoshgoftarmanesh, A. (2012). Studies on the role of root morphology attribution in salt tolerance of blue-panicgrass (Panicum antidotale Retz.) using artificial neural networks (ANN). *Research on Crops*, *13*(2), 534-544.

Fischer, G., Tausz, M., Köck, M., & Grill, D. (2004). Effects of weak 162\over3 Hz magnetic fields on growth parameters of young sunflower and wheat seedlings. *Bioelectromagnetics: Journal of the Bioelectromagnetics Society, The Society for Physical Regulation in Biology and Medicine, The European Bioelectromagnetics Association*, *25*(8), 638-641. https://doi.org/10.1002/bem.20058

Kırdar, E., Yücedağ, C., & Balaban, B. (2016). The effects of magnetic field on germination of seeds and growth of seedlings of stone pine. *Journal of forests*, *3*(1), 1-6. https://doi.org/10.18488/journal.101/2016.3.1/101.1.1.6

Konefał-Janocha, M., Banaś-Ząbczyk, A., Bester, M., Bocak, D., Budzik, S., Górny, S., ... & Cholewa, M. (2018). The effect of stationary and variable electromagnetic fields on the germination and early growth of radish (Raphanus sativus). *Polish Journal of Environmental Studies*, *28*(2), 709-715. https://doi.org/10.15244/pjoes/84920

Maffei, M. E. (2014). Magnetic field effects on plant growth, development, and evolution. *Frontiers in plant science*, *5*, 445. https://doi.org/10.3389/fpls.2014.00445

Majd, A., & Shabrangi, A. (2009). Effect of seed pretreatment by magnetic fields on seed germination and ontogeny growth of agricultural plants. In *the Proceeding of 2009 Electromagnetics Research Symposium, Beijing, China* (Vol. 1137, p. 1141).

Racuciu, M., Creanga, D., & Amoraritei, C. (2007). Biochemical changes induced by low frequency magnetic field exposure of vegetal organisms. Rom. J. Phys, 52(5-7), 645-651.

Srikanth, D. (2018). Influence of magnetic and electric field on germination attributes of chilli (Capsicum annum L.) seeds. *International Journal of Pure & Applied Bioscience*, *6*(3), 496-501. https://doi.org/10.18782/2320-7051.6723.

Teixeira da Silva, J. A., & Dobránszki, J. (2016). Magnetic fields: how is plant growth and development impacted? *Protoplasma*, *253*(2), 231-248. https://doi.org/10.1007/s00709-015-0820-7.

Ulgen, C., Yıldırım, A. B., & Turker, A. U. (2017). Effect of magnetic field treatments on seed germination of melissa officinalis L. *International Journal of Secondary Metabolite*, *4*(3, Special Issue 1), 43-49. https://doi.org/10.21448/ijsm.356283.

Zeidali, E., Rostami, Z., Darabi, F., Soheyli, E., Nabiyouni, G., & Naseri, R. (2017). Germination and Growth of Wheat and Wild Oat Seedling as Affected by Different Intensities and Times of Magnetic Fields. *Biological, Environmental and Agricultural Sciences*, *2*(2017), 86-100.