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# EFFECT OF PRE-SOWING MAGNETIC FIELD TREATMENT TO GARDEN PEA (*PISUM SATIVUM* L.) SEED ON GERMINATION AND SEEDLING GROWTH

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**Abstract**

The seeds of garden pea (*Pisum sativum* L. cv. climax*)* were exposed to full-wave rectified sumusoidal non-uniform magnetic fields of strength 60 mT, 120 mT and 180 mT for 5, 10 and 15 min prior to sowing. The magnetically treated seeds were sown according to the protocol of International Seed Testing Association (ISTA). Magnetically treated seed showed significant increase in germination. The emergence index, final emergence index and vigor index increased by 86.43%, 13.21% and 204.60%, respectively. It was found that exposure of 5 min for magnetic field strengths of 60 mT and 180 mT significantly enhanced the germination parameters of the pea and these treatments can be used practically to accelerate the germination in garden pea.

## Introduction

Proper seed germination is vital for better crop yield. Various natural factors affect seed germination processes crops e.g., heavy metals present in soil restrain the enzyme activities as well as oxidative pathways of seeds metabolism, which affect the germination and subsequently the seedling growth. In addition to light and dark periods as well as temperature and salty soil has also a negative impact on seed germination (Achakzai *et al.,* 2010; Muhammad & Hussain, 2010; Mohammadi *et al*., 2010; Hamid *et al.,* 2010; Ashraf & Ashraf, 2012; Chutipaijit *et al.,* 2012; Kausar *et al.,* 2012). Chemical and physical pre-sowing seed treatments are being used for better seed germination (Dao-liang *et al.,* 2009; Khawar *et al*., 2010; Perveen *et al.,* 2011; Zia ul Haq *et al.,* 2012a). Chemical concerts were found to be effective for enhancing the seed germination and seedling growth, but are unfavorable to the environment. So far, for the last few years, there are growing concerns of eco-friendly agricultural practices. Of course, physical pre-sowing seed treatments are safer as compared to chemical ones (Jamil *et al.,* 2012). In this regard, Magnetic Field (MF) pre-sowing seed treatment is secure and inexpensive physical method to enhance the seed germination and seedling growth (Podlesny, 2004), because, it enhances the concentration of ions, free radicals and electrical charges physically without any degradation/alteration in the chemical profile of seed and resultantly makes the membranes permeable. Free movement of ions activates the metabolic pathways by enhancing the biochemical and physiological feedback (Zia ul Haq *et al.,* 2012b). According to a few reports the magnetic field strength, exposure time and modulation are important in this consideration (Iqbal *et al.,* 2012a; Tkalec *et al.,* 2009). Researchers world wide have reported that wheat, maize, sunflower, barley, corn, beans, tomato, fruit seeds treated with magnetic field show high performance of plant growth, height, yield, seed weight per spike as well as shoot and root length and total fresh and dry weights (Aladjadjiyan, 2002; Dagoberto *et al.,* 2000; Harichand *et al.,* 2002; Martinez *et al.,* 2002, Moon and Chung, 2002; Socorro & Carbonell, 2008; Fischer *et al.,* 2004; Florez *et al.,* 2007).

In this work, we have evaluated the effect of magnetic field pre-sowing seed treatment on mean emergence time, final emergence percentage, vigor index and emergence index of garden pea seeds.

## Material and Methods

**Seed samples:** The seeds of *Pisum sativum* L. were provided by the Ayub Agricultural Research Institute, Faisalabad, Pakistan. The seeds were exposed to magnetic field in the Department of Physics and sown in Vegetable Seed Laboratory, Institute of Horticultural Sciences, University of Agriculture, Faisalabad.

**Magnetic field generation:** The pre-sowing magnetic treatments were administered using an electromagnet consisting of two pairs of cylindrical coils, each formed by 4,000 turns of 0.40 mm enamelled copper wire. Each pair of coils was wound 11 cm apart on an iron bar (dimensions 40 × 3.5 cm).The two bars were placed one above the other and their ends held by metallic supports. The coils were connected in series and fed through a power source of 220V and 50 Hz using a variac transformer. A 50 Hz full wave rectified sinusoidal voltage was fed to the coils. When electric current passed through the coils, a non-uniform and dynamic magnetic field was generated in the air space between the two bars. Magnetic field treatment was applied according to Iqbal *et al*., (2012a) with some modification. Figure 1 shows the placement of glass plate in seed stimulator (full-wave rectified sinusoidal non-uniform magnetic fields).

**Electromagnetic treatments:** The magnetic field exposure time and strength were applied to the pea seed as follows:

| Magnetic field strength (mT) | 5 min | 10 min | 15 min |
|---|---|---|---|
| 60 mT | $T_1$ | $T_2$ | $T_3$ |
| 120 mT | $T_4$ | $T_5$ | $T_6$ |
| 180 mT | $T_7$ | $T_8$ | $T_9$ |

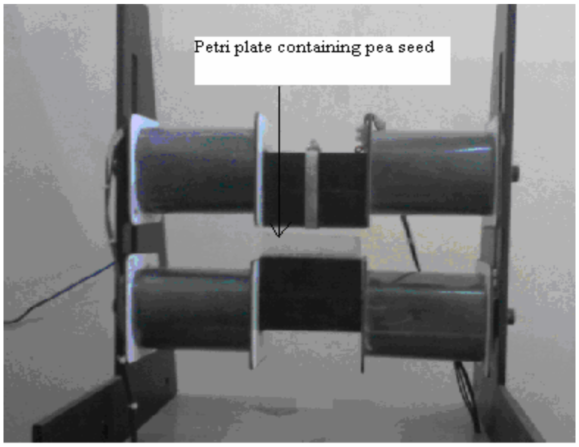


Fig. 1. The experimental electromagnet setup. A rectangular glass dish (Petri plate) is placed in the gap between two iron bars exposing pea seeds to magnetic field.

Non-exposed seeds were used as control ($T_0$). The dry, mature and healthy seeds were kept in Petri plates (dimensions 3×10 cm) between the poles of electromagnet having non-uniform magnetic strength for the required duration. The strength of the magnetic field was varied by changing the current in the coil of electromagnet. A magnetic flux meter was used to measure the strength of the magnetic field between the poles. All treatments in the experiments were run simultaneously under similar conditions. After appropriate treatment for specific period and magnetic field strength the seeds were washed with fungicide solution to save from fungus and then were placed on a filter paper in a circular glass Petri plate (15 cm diameter) and kept in germination incubator. 10 mL of distilled water were applied to each Petri plate daily. Seed germination was measured following the method of Anon., (2004). The number of germinated seeds was noted after germination. This process was repeated for 7 days. For the emergence test, 60 seeds per treatment were used in four replications and cultured in plastic bowls (25 cm diameter, 4 cm depth) containing sandy soil. Entire experiment was performed under the same laboratory conditions. The various germination parameters viz., mean emergence time, final emergence percentage, vigor index and emergence index were calculated following De Souza *et al*., (2006).

**Statistical analysis:** The data were analysed using SPSS-16 software. For the laboratory experiment, two factor analysis of variance (ANOVA) was performed on a factorial experiment keeping the magnetic field as the first factor and exposure time as the second one. The significant levels ($p$<0.05) of difference for all measured trials; magnetic field, exposure time and interactions were estimated.

## Results and Discussion

After sowing, fast and more uniform germination of pea seed treated with magnetic field was observed as compared to control. Pre-sowing magnetic field treatment significantly enhanced the germination parameters such as vigor index, final emergence percentage and emergence index. No significant change was observed in mean emergence time. The $T_1$ and $T_7$ treatments showed better response in terms of emergence index. The treatment $T_9$ showed the lowest value as compared to the control and $T_6$ and $T_8$ did not affect the emergence index (Fig. 2).

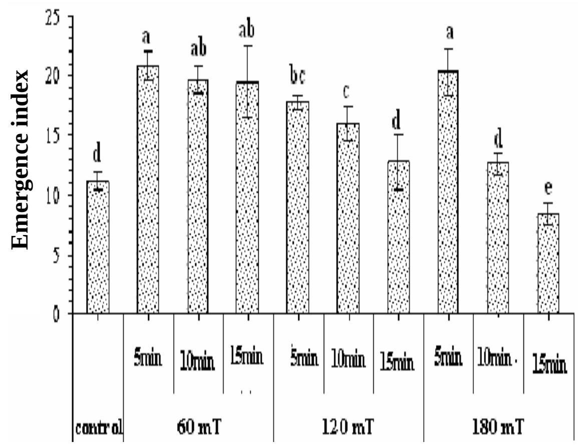


Fig. 2. Effect of different magnetic field strength and exposure duration of pea seed on emergence index. The same letters on bars show non-significant difference ($p$<0.05).

No significant effect of magnetic field treatment was found on mean emergence time. Electromagnetically treated seeds showed a negative response as compared to untreated seeds (Fig. 3). The vigor index response was improved to a great extent; the dose $T_7$ showed the highest value followed by $T_2$ (Fig. 6). Final emergence percentage was observed positive for various magnetic field strengths. The effect of $T_{1,}$ $T_{2,}$ $T_3$, $T_4$ and $T_7$ was found similar but higher than the other treatments including control (Fig. 4).

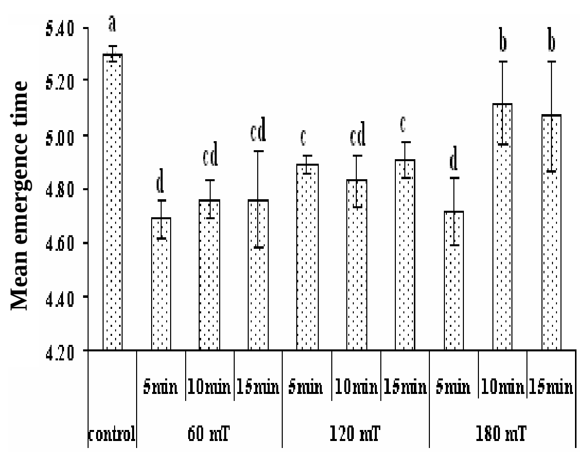


Fig. 3. Effect of different magnetic field strength and exposure duration of pea seed on mean emergence time. The same letters on bars present statistically similar effects ($p$<0.05).

The percent improvement of germination rate over untreated seeds has been found to be 75.11% to 86.43% for the emergence index, 1.89% to 13.21% for final emergence percentage and 12% to 204.60% for vigor index, while no significant effects were observed on mean emergence time. Over all, percent enhancement in germination rate was not consistent in all estimated parameters. The treatment of 60 mT was found superior for emergence index and final emergence percentage, while 180 mT was found relatively better for vigor index (Fig. 5). Seed stimulation with magnetic field had a profound effect on later stages of growth and development of pea. For example, the $T_2$ exposure dose had a more pronounced effect on seedling height, while $T_9$ showed the minimum response. All treatments affected the seedling length in the following decreasing order; $T_2 > T_7 > T_4 = T_5 > T_3 > T_1 = T_8 > T_6 > T_9 > T_0$. The height of all seedlings raised from treated seeds varied from 14-20.5 cm, which was considerably higher than that of control (9 cm) (Fig. 6).

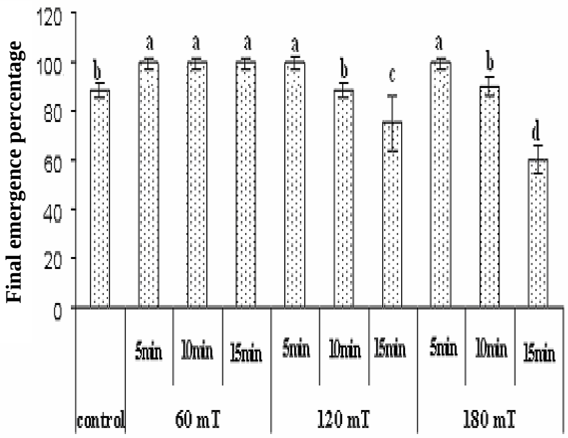


Fig. 4. Effect of different magnetic field strength and exposure duration of pea seed on final emergence percentage. The same letters on bars present statistically similar effects ($p$<0.05).

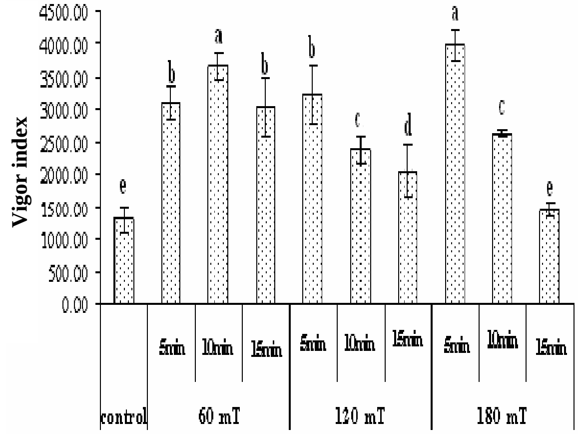


Fig. 5. Effect of different magnetic field strength and exposure duration of pea seed on vigor index. The same letters on bars present statistically similar effects ($p$<0.05).

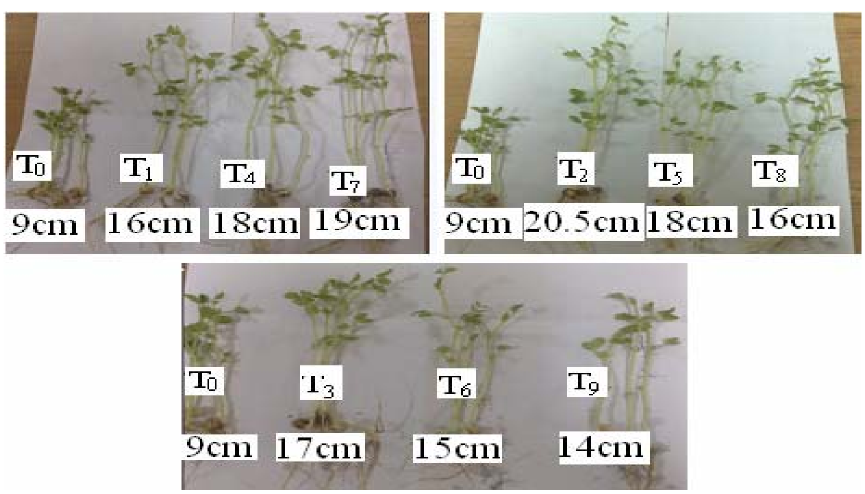


Fig. 6. Showing the comparative effect of magnetic field treatment on the height of pea plant: $T_0$ (control), $T_1$, $T_4$, $T_7$ (60, 120 and 180 mT for 5 min), $T_2$, $T_5$, $T_8$ (60, 120 and 180 mT for 10 min) and $T_3$, $T_6$, $T_9$ (60, 120 and 180 mT for 15 min), respectively.

In case of percent enhancement of germination rate, dose $T_1$ was found more effective for enhancing the emergence index followed by $T_7$, while $T_1$, $T_2$, $T_3$ and $T_4$ were found superior in improving the final emergence percentage. The highest percent increase in vigor index was found in dose $T_7$ (204.60%). Magnetic field exposure time of 5 to 10 min significantly enhanced the germination parameters. However, exposure of 5 min was more effective as compared to longer time intervals (Figs. 2-5).

The interaction of magnetic field strength and exposure time are presented in Table 1. Among most of the field strengths, the enhancement of germination rate was noted significantly higher for 5 min duration. The speed of germination was significantly superior to control of 5 min exposure, either MF applied at 60 mT or 180 mT. Of all the magnetic field strengths applied, enhancement of emergence index was higher for $T_1$ and $T_7$. As the magnetic field strength exposure increased from 5 to 15 min, a continuous decrease in emergence index was observed. For treatment $T_3$, the percent increment in emergence index was 75.11%, while for $T_9$ the response was -23.99%. Similarly, percent decrease in emergence index was -15.09% and -32.07% for $T_6$ and $T_9$.

The vigor index also showed highest response for 5 min ($T_7$). The emergence index, final emergence percentage and vigor index generally showed better response at lower magnetic field strength ranging from 5 to 15 min exposure or at higher magnetic field strength for shorter time (5 min). The percent increase observed in emergence index were 86.43, 76.46 and 75.11 for 5, 10 and 15 min, respectively, while at 180 mT for 5 min was 82.30% and then there was a sudden decrease for 10 min (13.39%) and 15 min (-23.99 %). Similarly, the maximum response (59.66%) of emergence index was found at $T_4$ treatment and then there was a consistent decrease as time of exposure increased. Treatment for shorter time exposure showed similar results for final emergence percentage, however, by increasing the field strength and exposure time, the response decreased significantly. However, the positive effect of magnetic field treatment was observed, when seeds were treated for shorter time at higher magnetic strength or at lower strength for longer as well as shorter time intervals.

**Table 1. Percent effect (positive/negative) on emergence index (EI), mean emergence time (MET), final emergence percentage (FEP) and vigor index (VI) of pea seed, CP (Calculated Parameters) and T (Time of exposure).**

| CP | T(min) | MF(mT) | Percent effect (+/-) | CP | T(min) | MF(mT) | Percent effect (+/-) |
|---|---|---|---|---|---|---|---|
| EI | 0 | 0 | 0.00 | FEP | 0 | 0 | 0.00 |
| | 5 | 60 | 86.43 | | 5 | 60 | 13.21 |
| | 10 | 60 | 76.46 | | 10 | 60 | 13.21 |
| | 15 | 60 | 75.11 | | 15 | 60 | 13.21 |
| | 5 | 120 | 59.66 | | 5 | 120 | 13.21 |
| | 10 | 120 | 44.03 | | 10 | 120 | 0.00 |
| | 15 | 120 | 14.73 | | 15 | 120 | -15.09 |
| | 5 | 180 | 82.30 | | 5 | 180 | 13.21 |
| | 10 | 180 | 13.39 | | 10 | 180 | 1.89 |
| | 15 | 180 | -23.99 | | 15 | 180 | -32.07 |
| MET | 0 | 0 | 0.00 | VI | 0 | 0 | 0.00 |
| | 5 | 60 | -11.51 | | 5 | 60 | 137.55 |
| | 10 | 60 | -10.19 | | 10 | 60 | 179.69 |
| | 15 | 60 | -10.19 | | 15 | 60 | 131.80 |
| | 5 | 120 | -7.74 | | 5 | 120 | 147.13 |
| | 10 | 120 | -8.87 | | 10 | 120 | 82.63 |
| | 15 | 120 | -7.55 | | 15 | 120 | 57.47 |
| | 5 | 180 | -11.13 | | 5 | 180 | 204.60 |
| | 10 | 180 | -3.40 | | 10 | 180 | 101.34 |
| | 15 | 180 | -4.34 | | 15 | 180 | 12.77 |

## Discussion

Treatments of different magnetic fields generally enhanced the germination rate of pea seed (Figs. 2-5). Similar results have also been reported by various researchers for seeds of different crops. For example, a considerable improvement in germination characteristics such as seedling vigor, shoot and root growth was observed in maize and chickpea seeds when treated magnetically (Aladjadjiyan**,** 2002; Fischer *et al.*, 2004; Florez *et al.*, 2007; Vashisth & Nagarajan, 2007 & 2008). Fischer *et al*., (2004) observed higher germination and growth of sunflower seed as compared to untreated seeds. Florez *et al*., (2004 & 2007) reported enhanced germination in rice when exposed to 125 mT/250 mT magnetic fields for specific time intervals, which indicates that the better results are dependent to specific magnetic field strength and exposure duration. It is well understood from the literature that the best outcome of seed germination is possible when optimal exposure doses are applied. It has been widely reported that different doses of magnetic field treatment stimulate seed germination and seedling growth for shorter exposure time, while that of higher doses for longer time having no significant improvement in germination rate (Zia ul Haq *et al.*, 2012b; Florez *et al.*, 2007). The longer time exposure might be detrimental, because throughout the study not a single result was found better for longer exposure of seed. The results for emergence index, final emergence percentage and vigor index pointed out that specific combination of magnetic field strength and exposure duration such as $T_1$ and $T_7$ are exceedingly efficient in enhancing the germination rate (Table 1). This observation indicates that seed germination takes place at appropriate magnetic field exposure duration and strength (Iqbal *et al.,* 2012a), which was also reported by Jamil *et* *al*., (2012) that the higher crops yield can be obtained by applying the magnetic field strength for specific time intervals. The mechanism of seed germination stimulation might be attributed to changes in biochemical, physiological processes as well as acceleration in metabolism and that of enzymes accelerated activities (Podlesny *et al.,* 2003). It is considered that the magnetic field influence the structure of cell membranes and in this way increase their permeability and ion transport in the ion channels, which as a result affects the metabolic pathways. The enzymes which are necessary for seed germination at particular stages of germination were found higher in magnetically treated seeds during germination (Aksyonov *et al.,* 2000; Jamil *et al.,* 2012). According to Iqbal *et al*., (2012a) magnetic field affects the biological objects by non-conventional spins, free radicals, liquids crystals or mobile electron charges. Chemically, these free radicals are very active particles, which enter into fast reactions with oxygen and in this way they cause changes in the biochemical and physiological processes in seed germination. Garcia & Arza (2001) reported an increase in water uptake rate due to magnetic field treatment, which may be responsible for increased germination speed in pea seeds.

Results of pea seed germination in present study were found parallel to those of Yinan *et al*., (2005) for wheat crop and cucumber. Similarly, the effect of magnetic field doses (strength and exposure time) tested in the present study are in agreement with those of other workers (Aladjadjiyan, 2002; Dagoberto *et al.,* 2000; Harichand *et al.,* 2002; Martinez *et al.,* 2002, Moon & Chung, 2002; Socorro and Carbonell, 2008; Fischer *et al.,* 2004; De Souza *et al.,* 2006; Florez *et al.,* 2007). From the results it is concluded that positive effect can be achieved of seed germination at specific doses of magnetic field for specific exposure duration. Different magnetic field strength treatments increased the germination rate, when the seed were treated particularly for shorter time and high magnetic field strength or longer exposure duration for low magnetic field strength. Furthermore, the optimization of the magnetic field doses (strength and exposure time) can be performed using response surface methodology. Iqbal *et al*., (2012b) has reported the use of response surface methodology in pre-sowing magnetic field treatment for chili seed and pointed out the actual magnetic field doses to enhance the germination, biochemical, physiological and enzymatic attributes in chili can be achieved using response surface methodology.

## Conclusion

Exposure of pea seed to magnetic fields significantly enhanced the germination rate such as emergence index, final emergence percentage and vigor index as compared to control seeds. The results showed that the germination rate was more uniform comparatively in shorter period under the effect of magnetic field as compared to control. Of the various combinations of field strengths and exposure time, 60 mT and 180 mT for 5 min treatments yielded the better results. This improved germination rate suggests that magnetically treated pea seeds can be used practically in agriculture, where the environmental factors are limiting for the germination of seeds.

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### References

Achakzai, A.K.K., S.A. Kayani and A. Hanif. 2010. Effect of salinity on uptake of micronutrients in sunflower at early vegetative stage. *Pak. J. Bot.,* 42: 129-139.

Aksyonov, S.I., A. Buchylev, T.Y. Grunina, S.N. Goryachev and V.B. Turovvetssky. 2000. Physiochemical mechanisms of efficiency of treatment by weak ELF-EMF of wheat seeds at different stages of germination. Proc. 22th Annual Meeting Eur. Bioelectromagnetics Ass., Munich, 112-113.

Aladjadjiyan, A. 2002. Study of the influence of magnetic field on some biological Characteristics of *Zea mays*. *J. Central Eur. Agricu.,* 3: 89-94.

Anonymous. 2004. International Rules for Seed Testing. ISTA Press, Zurich, Switzerland.

Ashraf, M.A. and M. Ashraf. 2012. Salt-induced variation in some potential physio-chemical attributes of two genetically diverse spring wheat (*Triticum aestivum* L.) cultivars: photosynthesis and photosystem II efficiency. *Pak. J. Bot.,* 44: 53-64.

Carbonnel, M., E. MartÃ-nez, M. Florez, R. Maqueda, A. Pintor-Lopez and J. Amaya. 2008. Magnetic field treatments improve germination and seedling growth in *Festuca arundinacea* Schreb. and *Lolium perenne* L. *Seed Sci Technol.,* 36: 31-37.

Chutipaijit, S., S. Cha-um and K. Sompornpailin. 2012. An evaluation of water deficit tolerance screening in pigmented indica rice genotypes. *Pak. J. Bot.,* 44: 65-72.

Dagoberto, G.F., D.S.T. Angel and S.P. Lilita. 2002. Effect of magnetic treatment of onion (*Allium cepa*) seeds on the germination and growth of seedlings. *Alimentaria,* 39: 181-186.

Dao-liang, Y., G. Yu-Qi, Z. Xue-ming, W. Shu-Wen and Q. Pei. 2009. Effect of electromagnetic fields exposure on rapid micro-propagation of beach plum (*Prunus maritima*). *Ecol. Engineer.,* 35: 597-601.

De Souza, A., D. Garcia, L. Sueira, F. Gilart, E. Porras and L. Licea. 2006. Pre-sowing magnetic treatments of tomato seeds increases the growth and yield of plants. *Bioelectromagnetics,* 27: 247-257.

Fischer, G., M. Tausz, M. Kock and D. Grill. 2004. Effect of weak 16 2/3 HZ magnetic fields on growth parameters of young sunflower and wheat seedlings. *Bioelectromagnetics,* 25: 638-41.

Florez, M., M.V. Carbonell and E. Martinez. 2004. Early sprouting and first stages of growth of rice seeds exposed to a magnetic field. *Electromagnetobiol.,* 23(2): 167-176.

Florez, M., M.V. Carbonell and E. Martinez. 2007. Exposure of maize seeds to stationary magnetic fields: effects on germination and early growth. *Environ. Exp. Bot.,* 59: 68-75.

Garcia, F and L.I. Arza. 2001. Influence of a stationary magnetic field on water relation in lettuce seeds. Part 1: Theoretical consideration. *Bioelectromagnetics*, 22: 589-595.

Hamid, N., N. Bukhari and F. Jawaid. 2010. Physiological responses of *Phaseolus vulgaris* to different lead concentrations. *Pak. J. Bot.,* 42: 239-246.

Harichand, K.S., V. Narula, D. Raj and G. Singh. 2002. Effect of magnetic fields on germination, vigour and seed yield of wheat. *Seed Res.,* 30: 289-293.

Iqbal, M., Z. Haq, Y. Jamil and M.R. Ahmad. 2012a. Effect of pre-sowing magnetic treatment on growth and chlorophyll contents of pea. *Int. Agrophys.,* 26: (In press, DOI: W∕4710∕2011).

Iqbal. M., Y. Jamil, Zia ul Haq and I. Ahmad. 2012b. Application of response surface methodology: pre-sowing seed magnetic field treatment and irrigation by magnetized water effect on germination, biochemical, physiological and enzymatic attributes in chili (*C. lycopersycom*). *Plant Physiol. Biochem.,* (Submitted).

Jamil, Y., Z. Haq, M. Iqbal, T. Jamil and N. Amin. 2012. Enhancement in growth and yield of mushroom (*Pleurotus ostreatus*) using magnetic field treatment. *Int. Agrophys.,* (In press).

Kausar, A., M.Y. Ashraf, I. Ali, M. Niaz and Q. Abbass. 2012. Evaluation of sorghum varieties/lines for salt tolerance using physiological indices as screening tool. *Pak. J. Bot.,* 44(1): 47-52.

Khawar, A., I.A. Bhatti, Q.M. Khan, H.N. Bhatti and M.A. Sheikh. 2010. A germination test: An easy approach to know the irradiation history of seeds*. Pak. J. Agri. Sci*., 47: 279-285.

Martinez, E., M.V. Carbonell and J.M. Amaya. 2000. A static magnetic field of 125 mT stimulates the initial growth stages of barley (*Hordeum vulgare*, L.). *Electromagnetobiol.,* 19: 271-277.

Martinez, E., M.V. Carbonell and M. Florez. 2002. Magnetic biostimulation of initial growth stages of wheat (*Triticum aestivum*, L.). *Electromagnetic Biol. Med.,* 21: 43-53.

Mohammadi, J., J.A. Olfati-Chirani, S.A.K. Sabet, M. Golshani, S.N. Mortazavi and F. Jafari. 2010. Effect of incubation temperature, seed age and scarification on germination and emergence of Persian Shallot. *Pak. J. Agri. Sci*., 47: 317-319.

Moon, J.D. and H.S. Chung. 2000. Acceleration of germination of tomato seed by applying AC electric and magnetic fields. *J. Electrostatics,* 48: 103-114.

Muhammad, Z and F. Hussain. 2010. Vegetative growth performance of five medicinal plants under NaCl salt stress. *Pak. J. Bot.,* 42: 303-316.

Perveen, R., Y. Jamil, M. Ashraf, Q. Ali, M. Iqbal and M.R. Ahmad. 2011. He-Ne laser-induced improvement in biochemical, physiological, growth and yield characteristics in sunflower (*Helianthus annuus* L.). *Photochem. Photobilol*., 87: 1453-1463.

Podlesny, J, W. Lenartowicz and M. Sowinski. 2003. the effect of pre-sowing treatment of seeds magnetic biostimulation on morphological feature formation and white lupine yielding . *Zesz. Probl. Post. Nauk Roln*., 495: 399-406.

Podlesny, J., S. Pietruszewski and A. Podlesna. 2004. Efficiency of the magnetic treatment of broad bean seeds cultivated under experimental plot conditions. *Int. Agrophys.,* 18: 65-71.

Socorro, A and M.V. Carbonell. 2002. Magnetic treatment of wheat seeds (*Triticum aestivum*) as a growth stimulating technique. *Alimentaria,* 39: 167-170.

Tkalec, M., K. Malaric, M. Pavlica, B. Pevalek-Kozlina and Z. Vidakovic-Cifrek. 2009. Effects of radiofrequency electromagnetic fields on seed germination and root meristematic cells of *Allium cepa* L. *Mutation Res.,* 672: 76-81

Vashisth, A and S. Nagarajan. 2007. Effect of pre-sowing exposure to static magnetic field of maize (*Zea mays* L.) seeds on germination and early growth characteristics. *Agric. Sci.,* 30: 48-55.

Vashisth, A and S. Nagarajan. 2008. Exposure of seeds to static magnetic field enhances germination and early growth characteristics inchick pea (*Cicer arietinum* L.). *Bioelectromagnetics,* 29: 571-578.

Yinan, Y., L. Yuan, Y. Yongqing and L. Chunyang. 2005. Effect of seed pretreatment by magnetic field on the sensitivity of cucumber (*Cucumis sativus*) seedlings to ultraviolet-B radiation. *Environ. Exp. Bot.,* 54: 286-294.

Zia-ul-Haq, Y. Jamil, M.R. Raza and M. Iqbal. 2012a. Enhancement in the germination, growth and yield of okra (*Abelmoschus esculentus*) using pre-sowing magnetic treatment of seeds. *Ind. J. Biophys. Biochem.,* (In press).

Zia-ul-Haq, Y. Jamil, S. Irum, M.A. Randhawa, M. Iqbal and N. Amin. 2012b. Enhancement in the germination, seedling growth and yield of radish (*Raphanus sativus*) using seed pre-sowing magnetic field treatment. *Polish J. Environ. Studies* (In press).

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