Original Research

Enhancement in Germination, Seedling Growth and Yield of Radish (*Raphanus sativus*) Using Seed Pre-Sowing Magnetic Field Treatment

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Abstract

Radish seeds (*Raphanus sativus*, Mino variety) were exposed to full-wave rectified sinusoidal magnetic fields (MF) of strengths 40 mT, 80 mT, and 110 mT for 2.5, 5, and 10 min each, and its effects have been investigated on germination, seedling growth, and yield. Seeds were sown following the MF treatment according to the protocol of the International Seed Testing Association (ISTA) under controlled laboratory and field conditions. The MF treatment of seeds marginally reduced the days taken for germination while significantly ($P<0.05$) increasing seedling growth and yield. Plant height, root length, root mass, root girth, and yield increased up to 118.64%, 119.5%, 76.43%, 61.74%, and 76.41%, respectively, versus control. The results have shown that the environmentally friendly MF seed treatment could be used practically to enhance the germination and yield of radish crop.

Keywords: *Raphanus sativus*, magnetic treatment, seedling growth, germination

Introduction

The use of eco-friendly and cheap methods to enhance production to cope with the needs of a growing population is a common interest of agricultural scientists. The physical pre-sowing seed treatment by ionizing radiation, lasers, electrical field, ultraviolet, and MF has had a acceleratory effect on plant characteristics. These methods also are affordable, clean, and safe [1-6]. Among these, the least troublesome, inexpensive, and most harmless to the environment is probably the bio-stimulation of seeds using MF treatment. It has been reported that during seed germination, several complicated physical, chemical, and biochemical processes occur. There are substances of inorganic and organic nature present in plants and seeds that have magnetic as well as electrical properties. The action of an external MF may exert influence on the speed and displace the direction of polarized particles [7]. Furthermore, MF treatment changes the concentration of free radicals, ions, and electrical charges without any degradation or alteration in the chemical profile of seeds and, consequently, makes the membranes more permeable. This free movement of ions activates the metabolic pathways by enhancing biochemical and physiological feedback [8].

The acceleratory effect on various agricultural crops as well as on horticultural plants is well known regarding germination, growth, yield and other biochemical and physiological characteristics [8-10], and these positive responses

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can be achieved by exposing the seed to specific doses [12, 13]. Martínez et al. [11] observed that the MF treatment at 125 mT for 250 mT boosted the growth, mass, and height of pea (*Pisum sativum*, L.) and Lentil (*Lens culinaris*, M) plants.

The radish (*Raphanus sativus* L.) belongs to the family of cruciferae and originated in central and western China and the Indo-Pakistan subcontinent. It is grown for its fleshy edible roots, which are eaten raw as salad, or cooked as a vegetable. Radish has a cooling effect, prevents constipation, and increases appetite. Radish contains important nutrients such as protein, sugar, and vitamin C. It has been found to be useful as an herbal treatment for patients suffering from piles, liver trouble, enlarged spleen, and jaundice. Its leaves are cooked as leafy vegetables in different forms and are rich in minerals, and vitamins A and C [15]. Although radish can be grown on all soil types, it grows best in light, rich, and moist soils. Radish is estimated to grow in Pakistan on an area of 14,729 acres, whereas production was 111,753 tons during 2001-02 [16]. Very little research effort has been made pertaining to the input use, seasonal pattern of production, and other practices followed by farmers and nurserymen for the production of radishes.

The subcontinent of Pakistan and India are agro-based countries with diverse climatic conditions, fertile land, and the world's best canal irrigation system that all make the area suitable for growing a variety of crops. In spite of all these endowments, these regions are facing shortages of food supplies. So far, regardless of its importance, little attention has been given for the improvement of radish crops native to the land using pre-sowing MF seed treatment. In this work we have used MF produced by electromagnets to find its effect on the germination, seedling growth, and yield of the radish crop.

Materials and Methods

The seeds of radish were obtained from Ayyub Agricultural Research Institute, Faisalabad, Pakistan, and authenticated from the Institute of Horticulture Sciences, University of Agriculture, Faisalabad. Seeds of uniform size and shape were exposed to control MFs in the Department of Physics and sown in the Department of Plant Pathology for laboratory experiment, and for field experiments the seed were sown in the fields of the Institute of Horticultural Sciences, University of Agriculture, Faisalabad.

The pre-sowing magnetic treatments were administered using an electromagnet consisting of two pairs of cylindrical coils, each formed by 4,000 turns of 0.42 mm enameled copper wire. Each pair of coils was wound 10 cm apart on an iron bar (dimensions 40×3.5 cm).The two bars were placed one above the other, their ends held by metallic supports. The coils were connected in series and fed through a power source using a variable transformer. A 50 Hz full wave rectified sinusoidal voltage was fed to the coils. When electric current passed through, the coils of MF were generated in the air space between the two bars. The MF treatment was applied according to Iqbal et al. [8]. Before treatment the seeds were disinfected with fungicide solution, washed thoroughly under tap water and in the end with distilled water. Seed were spread on moist filter paper in 15 cm Petri dishes for 16 hours and 16 seeds were kept in each plate. The soaked radish seeds were exposed to MF doses (Table 1).

Table 1. The soaked radish seeds were exposed to MF doses.

MF,s	2.5 min	5 min	10 min
40 mT	T_1	T_2	T_3
80 mT	T_4	T_5	T_6
110 mT	T_7	T_8	T_9

Non-exposed seed were considered control (T_0). A rectangular glass dish with radish seeds was placed between the poles of electromagnets, having quantified magnetic strength for the required duration. The strength of the MF was controlled by regulating the current in the electromagnet coil. A magnetic flux meter (ELWE, 8533996, Cremlingen, Germany) was used to measure the strength of MF between the poles. After respective treatment for specific duration and strength, the seeds were sown in a laboratory as well as in field conditions. The germination experiments were performed in laboratory conditions, while the growth and yield experiments were conducted in field conditions under randomized complete block design (RCBD). For germination laboratory experiments, 9 seeds were seeded in each Petri dish and distilled water was given daily to such an extent that the filter papers remained wet. For field experiments the seed beds (ridges) of 2.5×12 feet dimension were prepared; seeds were sown on both sides of the ridges with a seed-to-seed distance of 9 inches and irrigated immediately after dibbling the seeds. The meteorological conditions during field experiment are shown in Table 2. The number of germinated seeds was counted sharply after germination and the process was repeated for 7 days. Growth parameters such as plant height (cm), root length (cm), root weight (g), and root girth (cm) were determined according to [8, 13], and data thus obtained was analyzed statistically to calculate the level of significance of various parameters using the analysis of variance technique by Minitab Software Package Version 14.0 (Minitab, Inc., State College, PA, USA).

Results

It has been found that MF irradiation resulted in more uniform germination, fast seedling growth, and high yield of radish versus control. Pre-sowing MF treatment significantly ($P<0.05$) enhanced growth characteristics such as root length, mass, and girth, along with yield. Table 3 depicts the mean values of germination, seedling growth and yield versus control at 95% confidence interval of mean. In the case of days taken to germinate, marginal difference between magnetically treated and untreated seeds

Table 2. Climatic conditions during the experimental period (November 2010 to January 2011).

Meteorological variables	November 2010	December 2010	January 2011
Mean maximum temperature (ºC)	26.2±0.4	21.5±0.7	15.9±0.6
Mean minimum temperature (ºC)	15.8±0.4	5.1±0.5	4.3±0.5
Mean temperature (ºC)	23.0± 0.5	18.3±0.7	10.4±0.6
Sunshine (h)	8.5±0.4	7.3±0.3	5.4±0.4
Relative humidity (%)	62.5±2.0	74.7±2.6	66.4±1.5
Mean rainfall (mm)	0.0±0	0.0±0	0.0±0

Table 3. Mean values for the effects of magnetic treatment on germination and seedling growth and yield of radish.

MF	GT	PH	RL	S/R	RM	RG	Y
Dose	Days	(cm)	(cm)		(cm)	(cm)	(ton)
T_0	11^{a}	26.23^{cd}	24.86^{c}	1.033^{b}	207.62^{de}	10.09^{b}	10.05^{c}
T_1	11^{a}	28.22^{cd}	25.98^{c}	0.97^{c}	201.79^{de}	9.17^{c}	9.76^{d}
T_2	11^{a}	29.95^{cd}	33.58^{bc}	1.042^{b}	224.28^{de}	7.86^{c}	10.86^{c}
T_3	11.66^{a}	30.88^{cd}	41.24^{ab}	1.036	229.35^{de}	10.38^{b}	11.10^{c}
T_4	12.33^{a}	44.97^{cd}	43.84^{bc}	1.11^{a}	300.47^{c}	12.21^{b}	14.55^{a}
T_5	13^{a}	48.20^{b}	46.85^{b}	1.14^{a}	366.31^{a}	14.52^{a}	17.73^{a}
T_6	13.33^{a}	57.35^{a}	54.57^{a}	1.069^{b}	324.27^{b}	14.25^{a}	15.69^{a}
T_7	12^{a}	41.80^{bc}	39.16^{abc}	1.047^{b}	263.69^{cd}	16.32^{a}	12.76^{b}
T_8	11.33^{a}	23.50^{cd}	24.34^{c}	0.969^{c}	247.11^{d}	10.83^{b}	11.96^{b}
T_9	10.33^{c}	20.87^{d}	21.45^{c}	0.958^{c}	185.17^{e}	8.23^{c}	8.96^{e}

Mean values carrying the same letters are not significantly different (P<0.05), GT – germination time, PH – plant height, RL – root length, S/R – shoot/root ratio, RM – root mass, RG – root girth, and Y – yield.

was observed for the doses of T_6, followed by T_5 and T_4 for plant height. However, treatments T_3 and T_8 slightly enhanced the germination rate, while treatment T_9 showed negative effect, and T_2 and T_1 were found ineffective as compared to control.

The MF dose effect was found to be similar in case of plant height and root length. Significant (P<0.05) differences between magnetically treated and untreated seeds were observed for doses T_6, T_5, T_4, and T_7 for plant height and root length. Although treatments T_3, T_2, and T_3 seemed to enhance the germination rate the effect was statistically non-significant, while treatments T_9 and T_8 showed negative effects versus control. The effect of MF treatment on root mass was found to be significant at 95% confidence interval of mean, but this effect was not similar to germination, plant height, and root length. Here, treatment T_5 showed the highest response in contrast to T_6, but treatment T_6 was found also to be significant followed by T_4, and other treatment like T_2, T_3, T_7, and T_8 increased the root mass marginally, while treatments T_1 and T_9 showed negative responses in comparison to control.

In case of root girth, the lowest increment was observed for treatment T_8, while treatment T_7 enhanced the root girth significantly at 95% confidence interval of mean. Again treatments T_1 and T_9 negatively affected root girth like root mass, while other treatments (T_4, T_5, and T_6) showed moderate effect versus control. The yield of radish was found to be significant (P<0.05) and MF treatment T_5 showed higher value of yield followed by T_4 and T_6, and the effects of T_2, T_3, T_7, and T_8 were found to be slightly higher than control. The effect of MF treatment on shoot and root ratio was found to be non-significant at 95% confidence interval of mean.

Of the various MF strengths and exposure times, a treatment of 80 mT for 10 min increased germination rate, plant height, and root length, and that of 80 mT for 5 min significantly enhanced the shoot/root, root mass, and yield of radish crop. The root girth was higher for 2.5 min exposure at 120 mT of MF treatment, while the treatment of 40 mT for all duration exposure and 180 mT for 5 and 10 min mostly showed negative effects. Table 4 shows the percentage effect (positive/negative) of MF-treated over untreated

Table 4. Percentage effect (positive/negative) on various parameters of radish plant after MF irradiation.

MF	GT	PH	RL	S/R	RM	RG	Y
Dose	Days	(cm)	(cm)		(cm)	(cm)	(ton)
T_1	0	7.58	4.50	-5.9	-2.8	-9.11	-2.88
T_2	0	14.28	35.07	0.87	8.02	-22.1	8.05
T_3	6.09	17.72	65.88	0.29	10.46	2.87	10.44
T_4	12.18	71.44	76.34	8.03	44.72	21.01	44.77
T_5	18.18	83.75	88.45	10.35	76.43	43.9	76.41
T_6	21.27	118.64	119.5	3.48	56.18	41.22	55.12
T_7	9.09	59.35	57.52	1.35	27	61.74	26.96
T_8	3.09	-10.43	-2.09	-6.19	19.02	7.33	19
T_9	-6.09	-20.4	-13.71	-7.26	-10.81	-18.43	-10.84

GT – germination time, PH – plant height, RL – root length, S/R – shoot/root ratio, RM – root mass, RG – root girth, and Y – yield

Table 5. Mean squares for effect of magnetic treatments and replications on germination and seedling growth and yield of radish.

SOV	GT	PH	RL	S/R	RM	RG	Y
Replication (R)	2.800^{NS}	734.71*	723.64*	0.022^{NS}	16972.83*	15.186^{NS}	39.734*
Treatment (T)	2.774^{NS}	418.52*	348.77*	0.011^{NS}	10315.67*	24.445^{NS}	24.172*

* Significant, NS – non-significant at 95 % confidence interval of mean, GT – germination time, PH – plant height, RL – root length, S/R – shoot/root ratio, RM – root mass, RG – root girth, and Y – yield

samples. The percent increments (positive MF effect) were found to be 21.27%, 118.64%, 119.5%, 10.35%, 76.43%, 61.74%, and 76.41% for germination, plant height, root length, shoot/root ratio, root mass, root girth, and yield of radish, respectively, while negative responses were found up to -6.09%, -20.4%, -13.71%, -7.26%, -10.81%, -18.43%, and -10.84%, respectively, as compared to control.

In summary, germination, seedling growth, and yield of radish crop were significantly higher and superior to control as a result of MF pre-sowing seed treatment and the MF treatment of low frequency for larger time and high strength for shorter time had a marginal effect on germination and highly acceleratory effect on seedling growth and yield in radish crop.

Discussion

The seeds sown after magnetic field pre-treatment showed uniform germination, fast seedling growth and enhanced yield radish plant as compared to control. Our results are in accordance with Vashista and Nagarajan [12-13], who observed considerable improvement in germination and growth characteristics in magnetically treated maize, chickpea, and sunflower seeds. Marks and Szecowka, [18] reported the positive impact of variable MF stimulation on aboveground parts growth of potato plants. Florez et al. [19-20] pointed out that better germination, growth, or even yield are dependent on appropriate MF strength and exposure time combinations. It is well understood from literature that the best outcome of seed germination is achievable when optimal exposure doses were applied. The results of radish germination, seedling growth and yield also seemed to be dose-dependent. MF doses such as 80 mT for 5-10 min and 110 mT for 2.5 min showed highly considerable response verses control (Table 4). This observation indicates that seed germination following growth and development take place at appropriate combinations of MF exposure duration and strength [8, 9, 12-14]. The effect of magnetic treatments and replications on germination and seedling growth and yield is shown in Table 5. We found that MF pre-treatment could enhance germination, seedling growth, and yield at specific combinations of MF doses, and same response has been shown by sunflower, wheat, pea, barley and bean seeds [7, 11, 17-20].

The MF mechanisms of action on plant germination and seedling growth is not yet well known. However, several theories have been proposed, including biochemical changes or altered enzyme activities [10]. Seed germination stimulation might be attributed to a combined effect of biochemical, physiological, metabolic, and enhanced enzymatic action. It is assumed that the magnetic field treatment influences the structure of cell membranes and in this way increases their permeability and ion transport in the ion channels, which as a result affects the metabolic pathways. The enzymes necessary for seed germination at particular stages of germination were found to be higher in magnetically treated seeds during seed germination. The magnetic field affects the biological objects by non-conventional spins, free radicals, liquids crystals or mobile electron charges. These free radicals are very active species that take part in fast reactions and cause changes in the biochemical and physiological processes during seed germination, and an increase in water uptake rate due to magnetic field treatment was found, which may be responsible for increased radish seed germination as well as seedling growth and yield [8]. It is well known that enzymes degrade the food reserves of the seedling during germination. An increase in germination speed in magnetically treated seeds can be attributed to a consequence of increased activity of enzymes compared to unexposed controls [10]. These results are in accordance with the results of [12, 13] that magnetically treated seeds had significantly higher ($P<0.01$) enzyme activity than the control. An increase in dehydrogenase activity has been reported in primed soybean, carrot, and tomato compared with unprimed seeds. Also, greater glucose-6-phosphate dehydrogenase activity has been reported in primed sweet corn seeds. Exposure of a magnetic field appears to act like priming, with similar enhancement effects [8]. One theory of the MF interaction with biological systems is the 'radical-pair mechanism' consisting of the modulation of single-triplet inter-conversion rates of a radical pair by MF. Magnetic field increased the average radical concentration, prolonging their life time and enhancing the probability of radical reaction with cellular components, because the particles of inorganic and organic natural substances are in most parts of the plant structure as well as in seed, which might be influenced by external MF application due to their magnetic and electrical properties [7, 21].

Conclusions

The radish seeds (*Raphanus sativus*, Mino variety) were exposed to full-wave rectified sinusoidal MF of strengths 40 mT, 80 mT, and 110 mT for 2.5, 5, and 10 min. Among various combinations of MFs and duration, 80 mT for 5-10 min and 110 mT 2.5 min exposure yielded superior results. The improved germination suggests that magnetically treated seeds can be used in practical agricultural fields. There has been significant increase in root length, which suggests that this technique can be used in rain-fed areas, as longer roots can absorb more water from deep soil and plants can tolerale longer periods without irrigation, and it can reduce the frequency of irrigation. The MF treatments of low strength for longer time and high strength for shorter time of exposure are good combinations to enhance the germination, growth, and ultimately the yield of radishes.

References

1. KELEŞ S., SIVRIKAYA F., ÇAKIR G., BAŞKENT E.Z., KÖSE S. Spatial and temporal changes in forest cover in Turkey's Artvin forest, 1972-2002, Pol. J. Environ. Stud. **17**, (4), 491, **2008**.
2. WITEK Z., JAROSIEWICZ A. Long-term changes in nutrient status of river water, Pol. J. Environ. Stud. **18**, 6, **2009**.
3. RYSZARD S., MARCIN G., GÓRECKI T. Utilization of waste wool as substrate amendment in pot cultivation of tomato, sweet pepper, and eggplant, Pol. J. Environ. Stud. **19**, 1083, **2010**.
4. BUKOWSKA B. Toxicity of 2, 4-Dichlorophenoxyacetic acid-molecular mechanisms, Pol. J. Environ. Stud. **15**, (3), 365, **2006**.
5. OLESZEK W., TERELAK H., MALISZEWSKA-KORDYBACH B., KUKUŁA S. Soil, food and agroproduct contamination monitoring in Poland, Pol. J. Environ. Stud. **12**, 261, **2003**.
6. PERVEEN R., ALI Q., ASHRAF M., AL-QURAINY F., JAMIL Y., AHMAD M.R. Effects of different doses of low power continuous wave He-Ne laser radiation on some seed thermodynamic and germination parameters, and potential enzymes involved in seed germination of sunflower (*Helianthus annuus* L.), Photochemistry and Photobiology **85**, 1050, **2010**.
7. KORDAS L. The effect of magnetic field on growth, development and the yield of spring wheat, Pol. J. Environ. Stud. **11**, 527, **2002**.
8. IQBAL M., HAQ Z., JAMIL Y., AHMAD M.R. Effect of pre-sowing magnetic treatment on growth and chlorophyll content of pea (*Pisum sativum* L.), International Agrophysics **26**, **2012** [In Press].
9. MUSZYŃSKI S., GAGOŚ M., PIETRUSZEWSKI S. Short-term pre-germination exposure to ELF magnetic field does not influence seedling growth in durum wheat (*Triticum durum*), Pol. J. Environ. Stud. **18**, 6, **2009**.
10. ÇELIK Ö., BÜYÜKUSLU N., ATAK Ç., RZAKOULIEVA A. Effects of magnetic field on activity of superoxide dismutase and catalase in glycine max (L.) Merr. Roots, Pol. J. Environ. Stud. **18**, 175, **2009**.
11. MARTÍNEZ E., FLÓREZ M., MAQUEDA R., CARBONELL M.V., AMAYA J.M. Pea (*Pisum sativum*, L.) and lentil (*Lens culinaris*, Medik) growth stimulation due to exposure to 125 and 250 mT stationary fields, Pol. J. Environ. Stud. **18**, 657, **2009**.
12. VASHISTA A., NAGARAJAN S. Exposure of seeds to static magnetic field enhances germination and early growth characteristics inchick pea (*Cicer arietinum* L), Bioelectromagnetics **29**, 571, **2008**.
13. VASHISTH A., NAGARAJAN S. Effect on germination and early growth characteristic in sunflower (*Helianthus annuus*) seeds exposed to static magnetic field. Journal of plant physiology **167**, 149, **2010**.
14. BAKHSH K., AHMAD B., GILL Z A., HASSAN S. Estimating indicators of higher yield in radish cultivation, International Journal of Agriculture and Biology **8**, 783, **2006**.
15. BALOCH A.F. Vegetable Crops Horticulture, National Book Foundation, Islamabad, **1994**.
16. Bureau of Statistics, Government of Punjab, Punjab Development Statistics, Lahore, Pakistan, **2000**.
17. FISCHER G., TAUSZ M., KOCK M., GRILL D. Effect of weak 162/3 HZ magnetic fields on growth parameters of young sunflower and wheat seedlings, Bioelectromagnetics **25**, 638, **2004**.
18. MARKS N., SZECOWKA P.S. Impact of variable magnetic field stimulation on growth of aboveground parts of potato plants, International Agrophysics **24**, 165, **2010**.

19. FLOREZ M., CARBONELL M.V., MARTINEZ E. Early sprouting and first stages of growth of rice seeds exposed to a magnetic field, Electro-and Magnetobiology **23**, 167, **2004**.
20. FLOREZ M., CARBONELL M.V., MARTINEZ E. Exposure of maize seeds to stationary magnetic fields: effects on germination and early growth, Environmental Experimental Botany **59**, 68, **2007**.
21. ATAK C., ÇELIK Ö.A., OLGUN S., ALIKAMANOĞLU A. R. Effect of magnetic field on peroxidase activities of soybean tissue culture, Biotechnology and Biotechnological Equipment **21**, 166, **2007**.