Review paper on Magnetic Field Effect on Germination, Growth and Development of Seeds

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Abstract

In Vedic literature provides some of the earliest written record of Agriculture in India. Rig-Veda say, describing plowing, fallowing, irrigation, fruit and vegetable cultivation. Good and better-quality seed plays a great role in increasing the agriculture production. It is also increasing the good productivity. A first American President George Washington said that, "Agriculture is the most healthful, most useful and most noble employment of man." Quality seed plays pivotal role in increasing the agriculture production as well as productivity. National economy progress depends on growth of its agriculture, which depends on the seed. Seed act as bases for enhancing yield or productivity and about 25-30% increase in yield is possible by use of high-quality seeds alone. Green revolution was possible through the use of high-quality seed of improved varieties. The seed quality can be improved by the various seed invigoration techniques such seed hardening, seed priming, seed plating, seed coating with film and some other physical methods. Physical methods for seed treatment such as low ionizing radiation, laser irradiation, ultraviolet, microwave and ultrasound treatments, electric and magnetic field of different frequencies significantly improve the seed germination. Among these physical methods, uses of the magnetic field intensity of different frequencies are known to produces the positive effect on the seed quality attributes.

Keywords: *Magnetic Field(MF), Seeds, Treatment, Germination.*

1. Introduction

In order to improve quality of seed in respect of crop stand, many researchers studied the effect of magnetic field stimulus on seed viability, vigour, seed germination and seedling growth and found positive results. Physical methods of stimulation are an innovative area of research and emerged as a magic tool which could improve the yield of crops. Seed is an extremely complex system and its state cannot always be controlled by changing of seed vitality indices viz., germinating energy, germination and uniformity of germination.

The first publications with positive outcome of the effect of magnetic field on plantation were noted in 19th century (Tolomei, 1893). The phenomenon of magneto tropism discovered by Tolomei was subsequently studied more thoroughly by Audus (1960). After that several researches done in this area. The further research outcome shows that by using magnetic field treatment on plantation gives better growth.

2. Literature review

2.1 Ahamed et al. (2013) was carried out study to understand the effect of magnetic field on the seed germination, growth, yield and fruit quality of sweet pepper (*Capsicum annuum L.*). Germination of all treated seeds began one day earlier than that of non-treated seeds and the germination percentage increased by 33.7-44.9% in treated seeds related to the control. Growth and flowering parameters were significantly increased in the treated plants comparing to the control. Fruit quality parameters were also enhanced by magnetic treatment while the fruit length, fruit diameter and pericarp thickness were not significantly affected. Leaf contents of chlorophyll a and b, carotenoids and phosphorus were significantly affected by the magnetic field. The obtained results indicated that magnetic field is an effective method for the pre-sowing treatment of the seeds that enhance their germination and increase yield capacity and fruit quality.

2.2 Alattar and Radwan (2021) observed the effects of magnetic water treatment on the growth of corn (*Zea mays*) plants. The results showed that the corn plants watered with magnetized water had higher shoot length than those of normal tap water. Magnetized water significantly increased the dry weight of corn plants when compared with the non-magnetized plants. The results revealed that magnetizing water with 6 magnets was the most influential in increasing the length of plants (194.10 ± 66.74 cm) and dry weight (52.22 ± 12.63 g). On the other hand, root length, stem thickness, and fresh weight were not significantly affected by magnetized water.

2.3 Anand et al. (2012) Introduced the effect of magnetic field (MF) treatments of maize (*Zea mays L.*) Seeds on the growth, leaf water status, photosynthesis and antioxidant enzyme system under soil water stress was investigated under greenhouse conditions. The seeds were exposed to static mfs of 100 and 200 mt for 2 and 1 h, respectively. The treated seeds were sown in sand beds for seven days and transplanted in pots that were maintained at -0.03, -0.2 and -0.4 mpa soil water potentials under greenhouse conditions. MF exposure of seeds significantly enhanced all growth parameters, compared to the control seedlings. The significant increase in root parameters in seedlings from magnetically-exposed seeds resulted in maintenance of better leaf water status in terms of increase in leaf water potential, turgor potential and relative water content. Photosynthesis, stomatal conductance and chlorophyll content increased in plants from treated seeds, compared to control under irrigated and mild stress condition. Leaves from plants of magnetically-treated seeds showed decreased levels of hydrogen peroxide and antioxidant defense system enzymes (peroxidases, catalase and superoxide dismutase) under moisture stress conditions, when compared with untreated controls. Mild stress of -0.2 mpa induced a stimulating effect on functional root parameters, especially in 200 mt treated seedlings which can be exploited profitably for rain fed conditions.

2.4 **Azimi et al. (2018)** Conducted study to evaluate the effect of magnetically treated water on the growth, antioxidant activity, and other physiological parameters of Lentil (*Lens culinaris L.*) During both vegetative and reproductive phases. The seeds of Lentil were cultured in greenhouse for 8 months between 10th September 2014 and 8th may 2015. The lentil crop was irrigated with magnetically treated water or no magnetically treated water (control experiment). Tap water was used in this study which was allowed to pass through magnetic field of 110 mt produced by electromagnet and the water becomes magnetically treated water. The results indicated that the values of ferric reducing/antioxidant power, carotenoid, flavonoid, sugar and protein contents in the leaf of the lentil for magnetically treated water were 6.64 μg/g, 2.54 mg/g, 3742.81, 138.35, and 1.64 μg/g, respectively, while the corresponding values for no magnetically treated water were 5.20 μg/g, 2.02 mg/g, 3700.09, 87.52, and 1.48 μg/g. For the seed, the values of ferric reducing/antioxidant power and protein contents with magnetically treated water were 2.25 and 3.50, while the corresponding values with no magnetically treated water (control experiment) were 1.39 and 3.22 μg/g. The analysis of proteins of seeds and leaves by SDS-PAGE also confirmed their increase in those plants which were treated with magnetically treated water. The number of seed in legumes, fresh and dry weights of the seeds was also significantly higher with lentil plant irrigated with magnetically treated water.

2.5 **Baghel et al.(2016)** Find the effectiveness of magneto-priming was assessed for alleviation of salt-induced adverse effects on soybean growth. Soybean seeds were pre-treated with static magnetic field (SMF) of 200 mt for 1 h to evaluate the effect of magneto-priming on growth, carbon and nitrogen metabolism, and yield of soybean plants under different salinity levels (0, 25, and 50 mm nacl). The adverse effect of nacl-induced salt stress was found on growth, yield, and various physiological attributes of soybeans. Results indicate that SMF pre-treatment significantly increased plant growth attributes, number of root nodules, nodules, fresh weight, biomass accumulation, and photosynthetic performance under both non-saline and saline conditions as compared to untreated seeds. Polyphasic chlorophyll a fluorescence (OJIP) transient from magnetically treated plants gave a higher fluorescence yield at J-I-P phase. Nitrate reductase activity, PIABS , photosynthetic pigments, and net rate of photosynthesis were also higher in plants that emerged from SMF pre-treated seeds as compared to untreated seeds. Leghemoglobin content and hemechrome content in root nodules were also increased by SMF pre-treatment. Thus, pre-sowing exposure of seeds to SMF enhanced carbon and nitrogen metabolism and improved the yield of soybeans in terms of number of pods, number of seeds, and seed weight under saline as well as non-saline conditions.

2.6 **Belyavskaya (2004)** Noted that the role of weak magnetic fields and their influence on functioning of biological organisms are still insufficiently understood, and is actively studied. Numerous experiments with seedlings of different plant species placed in weak magnetic field have shown that the growth of their primary roots is inhibited during early germination stages in comparison with control. The proliferative activity and cell reproduction in meristem of plant roots are reduced in weak magnetic field. Cell reproductive cycle slows down due to the expansion of G1 phase in many plant species (and of G2 phase in flax and lentil roots), while other phases of cell cycle remain relatively stable. In plant cells exposed to weak magnetic field, the functional activity of genome at early pre-replicate period is shown to decrease. Weak magnetic field causes intensification of protein synthesis and disintegration in plant roots. Mitochondria were found to be very sensitive to weak magnetic field: their size and relative volume in cells increase, matrix becomes electron-transparent, and cristae reduce. Cytochemical studies indicate that cells of plant roots exposed to weak magnetic field show Ca2+ over-saturation in all organelles and in cytoplasm unlike the control ones. The data presented suggest that prolonged exposures of plants to weak magnetic field may cause different biological effects at the cellular, tissue and organ levels. They may be functionally related to systems that regulate plant metabolism including the intracellular Ca2+ homeostasis.

2.7 **Bhardwaj et al. (2012)** Find that Seeds of cucumber were exposed to static magnetic field strength from 100 to 250 mt for 1, 2 or 3 h. Germination-percentage, rate of germination, length of seedling and dry weight increased by 18.5, 49, 34 and 33% respectively in magneto-primed seeds compared to unexposed seeds. Among different magnetic field doses, 200 mt for 1 h showed significant effect on germination. Water uptake and T2 values were significantly higher in treated seeds during imbibition. The activities of hydrolytic enzymes, amylase and protease were greater than the untreated controls by 51% and 13% respectively. Superoxide radicals also enhanced by 40% and hydrogen peroxide by 8% in magnetically exposed seeds. In magneto-primed seeds, increased activities of antioxidant enzymes, superoxide dismutase (8%), catalase (83%) and glutathione reductase (77%) over control was recorded.

2.8 **Bilalis et al. (2012)** Investigated that Two different pre-sowing techniques have their influence in an important industrial plant, namely cotton. Priming methods are very useful for agricultural practices because they improve crop seedling establishment, especially when environmental conditions are not optimum. Pulsed electromagnetic fields have been found to promote germination and improve early growth characteristics of cotton seedlings. PEG treatment showed an enhancement in some measurements, however in some cases the results were not statistically different compared to control plants. In addition, PEG treatment is a sophisticated method that is far from agricultural practices and farmers. In this research, two different ages of seeds were used

(1 year and 2-year-old) in order to investigate the promotory effects of priming techniques. Magnetic field treatment of 15 min was found to stimulate germination percentage and to promote seeds, resulting in 85% higher values than control seeds under real field conditions. Furthermore, seeds that were treated with magnetic field performed better in terms of early-stage measurements and root characteristics.

2.9 **Bilalis et al. (2012)** Studied on Pre-sowing treatment of pulsed electromagnetic fields in corn seeds, in both indoor and outdoor conditions, in order to investigate the effect on plant growth and yield. The results of this research showed that pulsed electromagnetic fields can enhance plant characteristics, both under controlled environmental conditions and uncontrolled field conditions. The two varieties responded differently in the duration of magnetic field. Seeds were treated for 0, 15, 30, and 45 min with pulsed electromagnetic field (MF-0, MF-15, MF-30, and MF-45). Common corn variety performed better results in MF-30 treatment, while sweet corn variety performed better in MF-45 treatment. Magnetic field improved germination percentage, vigor, chlorophyll content, leaf area, plant fresh and dry weight, and finally yields. In the very interesting measurement of yield, seeds that have been exposed to magnetic field for 30 and 45 min have been found to perform the best results with no statistical differences among them. Another interesting finding was in root dry weight measurements, where magnetic field has a negative impact in MF-30 treatment in both hybrids, however without affecting other measurements.

2.10 **Cakmak And Erdal (2010)** Observed that Magnetic field (MF) can have different effects on plant metabolism depending on its application style, intensity, and environmental conditions. This study reports the effects of different intensities of static MF (4 or 7 mt) on seed germination and seedling growth of bean or wheat seeds in different media having 0, 2, 6, and 10 atmosphere (atm) osmotic pressure prepared with sucrose or salt. The germination percentages of the treated seeds were compared with untreated seeds germinated in different osmotic pressure during 7 days of incubation. Growth data measured on the 7th day showed that the treated plants grew faster than control. After 7 days of incubation, the mean length of treated seedlings was statistically higher than control plants in all the media. The greatest germination and growth rates in both plants were exposed to 7 mt MF. Strikingly, effects of static MF on germination and growth increased positively with increasing osmotic pressure or salt stress compared to their respective controls. On the other hand, MF application caused an increase in dry biomass accumulation of root and shoots of both seedlings; however, this effect was found statistically important in all the conditions for wheat but not for bean, in general.

2.11 **Chen et al. (2011)** Studied To alleviate toxicological effect induced by cadmium in mungbean seedlings, seeds were divided into four groups: The controls groups (CK, without treatment), magnetic field treated groups (MF), cadmium treated groups (CS), and magnetic field treated followed by cadmium treated groups (MF + CS).The results showed: (i) the seedlings treated with 600 mt magnetic field followed by cadmium stress the concentration of malondialdehyde, H2O2 and O2−, and the conductivity of electrolyte leakage decreased, while the above mentioned NO concentration, NOS activity, photosynthesis and growth parameters increased compared to cadmium stress alone. (ii) In the case of the HB and ST treatment followed by magnetic field and then the seedling subjected to CS, the seedlings growth was better than that of hemoglobin (HB) followed by CS and ST followed by CS. The seeds were treated with SNP and cacl2 followed by MF, and then subjected to CS, the seedlings growth was better than that of SNP followed by CS, and cacl2 followed by CS. These results suggested that magnetic field compensates for the toxicological effects of cadmium exposure are related to NO signal.

2.12 De Souza at al. (2008) Observed Influence of pre-sowing magnetic treatments on plant growth and final yield of lettuce (cv. Black Seeded Simpson) under organophilic conditions. Lettuce seeds were exposed to full-wave rectified sinusoidal non uniform magnetic fields (mfs) induced by an electromagnet at 120 mt (rms) for 3 min, 160 mt (rms) for 1 min, and 160 mt (rms) for 5 min. Non treated seeds were considered as controls. Plants were grown in experimental stonemasons (25.2 m(2)) of an organophilic and cultivated according to standard agricultural practices. During nursery and vegetative growth stages, samples were collected at regular intervals for growth analyses. At physiological maturity, the plants were harvested from each stonemason and the final yield and yield parameters were determined. In the nursery stage, the magnetic treatments induced a significant increase of root length and shoot height in plants derived from magnetically treated seeds. In the vegetative stage, the relative growth rates of plants derived from magnetically exposed seeds were greater than those shown by the control plants. At maturity stage, all magnetic treatments increased significantly ($p < 0.05$) plant height, leaf area per plant, final yield per area, and fresh mass per plant in comparison with the controls.

2.13 Dhawi (2014) Stated that the most important applications of a magnetic field are the treatments of irrigation water, dry seeds, wet seeds and seedlings. The studies also included the application of magnetic fields at different periods of times (minutes, hours and days) and different doses. The effect of different magnetic fields varies depending on the plant species and age during exposure, as well as the intensity of magnetic field and period of exposure. The variation of MF exposure intensities may transform the effect on the plants from a positive to stressful factor. In this review article we highlighted the influence of a magnetic field, and why it is one of the best methods to enhance a plant’s growth and productivity.

2.14 El-Yazied et al. (2011) noted that Tomato (*Lycopersicon esculentum Mill*) cv. Castlerock seeds were exposed to different magnetic strengths (0.1, 0.15 and 0.2 Tesla) for periods of 1, 5, 10 and 15 minutes and the treated seeds were germinated under distilled water or in saline concentration levels of 2500, 5000 and 7500 ppm. The results indicated that the magnetic field treatments led to a significant increase in the germination percentage reduced the time needed for germination and improved seed germination under saline conditions. The best results were found by magnetic seed treatment with 0.1 Tesla for 15 min. On the contrary, high salinity concentrations decreased the germination of seeds, as for the saline concentration of the 2500 ppm activated the seed germination.

2.15 Ercan et al. (2022) Showed the magnetic field (MF) interacts with biological systems and has the potential to increase germination, plant growth and productivity. The effect of different MF strengths (20, 42, 125, and 250 mt) was investigated on barley (*Hordeum vulgare L.*). In addition to phenological parameters, possible cell damage, electron transport rate, chlorophyll fluorescence, magnetic character and elemental status of tissues were determined. Results showed that lower strengths (≤125 mt) of MF treatment improve germination. Confocal microscopy analyzes revealed MF-induced cell membrane damage in roots that could alter the elemental content of tissues. Elemental analyzes found that the content of macro elements (Ca, Mg, P, and K) is gradually reduced with increasing MF forces; in opposite the microelement contents (Fe, B, Cu, Mn, Zn, and Mo) are increased in roots. Diamagnetism is the dominant magnetic character in all root and leaf samples. However, the roots became surprisingly superparamagnetic in 250 mt application. It seems that MF treatment at higher strength (250 mt in this study) could influence the orientation of magnetic moments. These findings suggest that MF application: i) can alter the magnetic character of plants, ii) enhances the germination, photosynthetic machinery, and growth, and iii) affects the nutrient uptake and abundance in tissues, depending on the MF strength.

2.16 Garcia et al. (2013) observed the effects of stationary magnetic field on two soybean varieties and three magnetic induction values: 100, 150 and 200 mt during 30 seconds of exposure. The germination percent, root and stem length as well as fresh and dry mass were measured under laboratory conditions, at the second week after sowing. The plant grown from treated samples (100 and 150 mt) and non-treated (B=0) were also evaluated under field conditions. The values of plant height (65 days after sowing) and the values of pod number, pod length and yield at 110 days (at the end of the plant cycle), were obtained. The results showed the enhanced of the germination percentage and root length of the *Conquista* and *Incasoy-24* varieties treated with stationary magnetic field of 150 mt and 100 mt respectively. The rest of the parameters evaluated did not show differences with respect to the non-treated sample. These respective exposure regimes also provoked a significant stimulation on the yield and an inhibition on the plant height at 110 days, while the magnetic treatment of 100 mt enhanced significantly the plant height of *Incasoy-24* variety at 65 days after sowing ($P<0.05$).

2.17 Ghanati And Payez (2015) Studied on useful effects of SMF on wheat plant (*Triticum aestivum L.*) Via improvement of antioxidant system and iron/ferritin fortification were evaluated. The plants were cultivated in pots and in their reproductive stages were treated with or without a 30 mt SMF for 4 days, each 5h. The activity of antioxidant system, iron and ferritin contents was evaluated. In comparison with the control groups, SMF treatment significantly increased the contents of iron, ferritin, and Fe-bound proteins in edible parts of the plants. Treatment with SMF also significantly increased catalase activity and radical scavenging capacity of wheat seeds which led in turn to decrease of membrane lipid peroxidation.

2.18 Grewal and Maheshwari (2011) noted that the effects of magnetic treatment of irrigation water and snow pea (*Pisum sativum L var. Macrocarpon*) and Kabuli chickpea (*Cicer arietinum L*) seeds on the emergence, early growth and nutrient contents of seedlings were investigated under glasshouse conditions. The treatments included (i) magnetic treatment of irrigation water (MTW), (ii) magnetic treatment of seeds (MTS), (iii) magnetic treatment of irrigation water and seeds (MTWS) and (iv) no magnetic treatment of irrigation water or seeds as control treatment. The results showed that MTW led to a significant ($P < 0.05$) increase in emergence rate index (ERI; 42% for snow pea and 51% for chickpea), shoot dry weight (25% for snow pea and 20% for chickpea) and contents of N, K, Ca, Mg, S, Na, Zn, Fe and Mn in both seedling varieties compared to control seedlings. Likewise, there were significant increases in ERI (33% for snow peas and 37% for chickpea), shoot dry weight (11% for snow pea and 4% for chickpea) and some nutrients of snow pea and chickpea seedlings with MTS in comparison with the controls. The results of this study suggest that both MTW and MTS have the potential to improve the early seedling growth and nutrient contents of seedlings.

2.19 Hirota et al. (1999) Noted the effects of a nonuniform magnetic field on the germination of plants. When a 10 T magnetic field was applied at the center of a superconducting magnet, a cucumber shoots germinating in a horizontal bore leaned towards the field center. In contrast, the root grew in the direction opposite the shoot. The observed result seemed to have occurred as a result of the magnetic force influencing the geotaxis of the cucumber. This idea was supported qualitatively by analysis results of the experimental data.

2.20 Huang and Wang (2008) reported the effects of magnetic fields generated by inverter systems on the early growth of plants using mung beans as an example. In the experiment, an inverter which can produce sinusoidal pulsed width modulation (SPWM) voltages was used to drive 3 specially made circular coils and an AC motor. Six SPWM voltages with different fundamental frequencies (10, 20, 30, 40, 50, and 60 Hz) set on the inverter drive the circuit to produce the specific kinds of magnetic fields. The results indicate that the magnetic field induced by a 20 or 60 Hz SPWM voltage has an enhancing effect on the early growth of mung beans, but the magnetic fields induced by SPWM voltages of other frequencies (30, 40, and 50 Hz) have an inhibitory effect, especially at 50 Hz.

2.21 Ijaz et al. (2012) Observed that the invigoration impact of magnetized seed and water on germination, wheat seeds with low viability (45%) were subjected to magnetization treatments. Seed and water were passed through specifically designed magnetic funnels. Magnetized water (structured water) was more invigorative to seed germination with linearity to number of passing as compared to seed magnetization. A 13.3% increase in germination was observed as compared to control using magnetized water, whereas increase in germination was insignificant with the seed magnetization. The interaction exhibited no effect on germination. It was concluded that wheat seeds with low vigor can be invigorated with the use of magnetized water; whereas, the potential to use magnetized seed remain to be extensively studied on larger groups of crops.

2.22 Jinapang et al. (2010) observed the effects of electromagnetic source's power and duration (defined as power-duration level) on the growth of two different species. Mung beans and water convolvuluses were exposed to electromagnetic fields inside a specially designed chamber for optimum field absorption, and the responses of the seeds to a constant frequency at various power levels and durations of exposure were monitored. The frequency used in the experiments was 425 MHz, the field strengths were 1 mw, 100 mw, and 10 W, and the exposure durations were 1, 2, and 4 h. Results show that germination enhancement is optimum for the mung beans at 100 mw/1 h power-duration level, while for water convolvuluses the optimum germination power-duration level was 1 mw/2 h. When both seed types were exposed at the early sprouting phase with their respective optimum power-duration levels for optimum seed growth, water convolvuluses showed growth enhancement while mung bean sprouts showed no effects. Water content analysis of the seeds suggests thermal effects only at higher field strength.

2.23 Kareem (2018) Observed that Magnetic water treatment is considered as one of many techniques used worldwide that affects plant growth and development. In this study three experiments were performed involving three crops (eggplant, faba beans and tomato) with different salinity tolerance thresholds ecw 0.7, 1.1 and 1.7 ds/m, respectively. Two types of irrigation water were applied magnetically treated and non-magnetically treated. The experiments were carried out at Wadi EL Natroon station of Water Management Research Institute, El-Behira Governorate, Egypt during two sequentially winter seasons of 2015/2016 and 2016/2017 in a complete randomized design analysis with four replicates. There was a decrease of ph of the soil irrigated with magnetically treated water (MTW) compared with the non-MTW. The ph reached neutral values in some locations, especially the area cultivated with the faba beans (ph between 7.05 and 7.08). Results showed significant increases of water productivity for the MTW compared with non-MTW equal to 1.65, 1.88 and 1.78 for eggplant, faba beans and tomato, respectively. It was also observed that the MTW affected the amounts of irrigation water added to different crops during its growing period. The percentages of water savings were 11%, 13.5% and 14.2% for eggplant, faba beans and tomato, respectively. As a result, the net return increased by 1.97, 3.0 and 2.45 for the three crops, respectively.

2.24 Kavitha et al. studied to find out the suitable pre-sowing seed treatments for Kodo millet. During the Kharif season 2019- 2020 total of 12 pre- sowing seed treatments were subjected with Botanicals, Magnetic and Electric fields, Thermal (Hot water) treatments and to fix the best treatment based on Seed Quality and Morphological traits of treated seeds. Morphological traits play a major role in crop growth and development whereas, the present investigation was carried out with farmer's variety in field (RBD) design in 3 replications and laboratory (CRD) design in 4 replications in order to "Standardization of different pre- sowing seed treatments on growth, yield and yield attributing traits of Kodo millet (*Paspalum scorbiculatum*). Seeds were subjected to various pre- sowing seed treatments viz. (T0) control, exposure to Magnetic field at 100 mt, 200 mt, 400 mt for 15,30 and 45 min; exposure to Electric field at 50 ma, 100 ma, 150 ma for 5,10, 15 min. Treatment with botanicals cow dung (5 gm) and Datura leaf extract (2.5 ml) for 12 hrs.; Thermal hot water treatment at 46□C and 50□C for 10 min.

2.25 Kordas (2002) Conducted a pot experiment in a greenhouse in 1999-2000. He was aimed at finding the effect of a constant magnetic field on the root system and green tops, as well as on yield of spring wheat. In all cases there was observed a slight stimulating effect of the factors examined. The growth dynamics were weakened. The plants were shorter, and so were their culms and ears. Moreover, the effect of a magnetic field on the crop of spring wheat and its structure was small.

2.26 Krawiec et al. (2018) reported that Due to the common trend towards limitation of excessive use of chemicals in agriculture, there is a growth of interest in methods of seed quality improvement that would be safe for the environment. These include methods based on the effect of various physical factors, such as laser light, magnetic field, seed treatment with magnetized water, electric field. The work provides detailed information on the impact of seed stimulation of these factors on germination, growth, development and yielding of horticultural plants. Summarizing the results of the study, it can be concluded that the application of physical factors in appropriate doses can be an effective way to enhance many plant parameters that increase their productivity.

2.27 Lazim (2021) Studied the effect of a static magnetic field (SMF) of 125 mt on barley seeds. For evaluation of these experiments, some germination parameters have been recorded. Also, two mathematical models, Logistic (Log) and Gompertzian (Gom) functions were performed in each treatment, for comparative analyses of parameters of the cumulative germination curves and mean square error (MSE). The best values have been found at treatment MG3 in FGP (95%), S.G (5.66 seed day-1), MGT (3.61 days), GRI (28.31% day-1), and GI (84). The highest value of asymptotic germination barley seeds was recorded in the Gom equation (96.78%) at the exposure time of 6 h (MG3). As well as, the best maximum germination rates reached 2.07% h-1 with Gom functions at MG2, while the highest value of the germination percentage of the inflection point has been reported in the Log function for 47.21 at MG3.

2.28 Maffei (2014) reported that the geomagnetic field (GMF) is a natural component of our environment. Plants, which are known to sense different wavelengths of light, respond to gravity, react to touch and electrical signaling, cannot escape the effect of GMF. While phototropism, gravitropism, and tigmotropism have been thoroughly studied, the impact of GMF on plant growth and development is not well-understood. This review describes the effects of altering magnetic field (MF) conditions on plants by considering plant responses to MF values either lower or higher than those of the GMF. The possible role of GMF on plant evolution and the nature of the magnetoreceptor is also discussed.

2.29 Mahajan and Pandey (2014) studied the Effect of static magnetic field on germination of mung beans is described. Seeds of mung beans, were exposed in batches to static magnetic fields of 87 to 226 mt intensity for 100 min. Magnetic time constant - 60.743 Th (Tesla hour) was determined experimentally. High value of magnetic time constant signifies lower effect of magnetic field on germination rate as this germination was carried out at off-season (13°C). Using decay function, germination magnetic constant was calculated. There was a linear increase in germination magnetic constant with increasing intensity of magnetic field. Calculated values of mean germination time, mean germination rate, germination rate coefficient, germination magnetic constant, transition time, water uptake, indicate that the impact of applied static magnetic field improves the germination of mung beans seeds even in off-season.

2.30 Martinez et al. (2017) Noted an increase in the percentage and rate of germination of seeds as positive response to magnetic field treatment in rice, wheat, maize and barley seeds for all treatments applied. The mean germination time and parameters were reduced for all the magnetic treatments applied. Most significant differences were obtained for time of exposure of chronically exposure and 24 hours. External magnetic fields enhance seed vigor by influencing the biochemical processes by stimulating activity of proteins and enzymes. Numerous studies suggested that magnetic field increases ions uptake and consequently improves nutrition value.

2.31 Matwijczuk et al. (2012) Showed that the impact of a variable magnetic field, magnetically treated water and a combination of both these factors on the germination of seeds. Investigations were carried out in pots filled with sand, tin an air-conditioned plant house with no access to daylight using fluorescent light as illumination. A statistical significance positive impact was achieved for the samples subjected to the interaction of both stimulating factors simultaneously, the magnetic field and the impact of treated water several times on the speed of seed germination and final plant mass. Negative impacts were obtained for the majority of the test cases, for the magnetically treated water, the short duration of activity of the magnetic field and for the connection of the magnetic field and low-flow times.

2.32 **Michalak et al. (2019)** Observed the effect of the static and alternating magnetic field applied individually and in combination with an algal extract on the germination of soybean seeds (*Glycine max (L.) Merrill*). Also, chlorophyll content was examined. The exposure time of seeds to the static magnetic field was 3, 6, and 12 min, whereas to the alternating magnetic field was 1, 2.5, and 5 min. The static magnetic field was obtained by means of a permanent magnets system while the alternating magnetic field by means of magnetic coils. Algal extract was produced from a freshwater macroalga-Cladophora glomerata using ultrasound homogenizer. In the germination tests, 10% extract was applied to the paper substrate before sowing. The best effect on the germination and chlorophyll content in seedlings had synergistic action of the static magnetic field on seeds for 3 min applied together with the extract and alternating magnetic field used for 2.5 min. It is not possible to clearly state which magnetic field better stimulated the germination of seeds, but the chlorophyll content in seedlings was much higher for alternating magnetic field.

2.33 **Mridha et al. (2016)** Stated that Soil moisture stress during pod filling is a major constraint in production of chickpea (*Cicer arietinum L.*), a fundamentally dry land crop. They investigated effect of pre-sowing seed priming with static magnetic field (SMF) on alleviation of stress through improvement in radiation and water use efficiencies. Experiments were conducted under greenhouse and open field conditions with desi and kabuli genotypes. Seeds exposed to SMF (strength: 100 mt, exposure: 1 h) led to increase in root volume and surface area by 70% and 65%, respectively. This enabled the crop to utilize 60% higher moisture during the active growth period (78-118 days after sowing), when soil moisture became limiting. Both genotypes from treated seeds had better water utilization, biomass, and radiation use efficiencies (17%, 40%, and 26% over control).

2.34 **Naz et al. (2012)** Studied on the effect of pre-sowing magnetic treatments on germination, growth and yield of okra (*Abelmoschus esculentus cv. Sapz pari*). The dry okra seeds were exposed to sinusoidal magnetic field induced by an electromagnet. The average magnetic field exposure was 99 mt for 3 and 11 min and seeds with no magnetic field treatment were considered as control. Both treated and non-treated seeds were sown in experimental plots (120 m2) under similar conditions. Samples were collected at regular intervals for statistical analysis. A significant increase ($P < 0.05$) was observed in germination percentage, number of flowers per plant, leaf area (cm2), plant height (cm) at maturity, number of fruits per plant, pod mass per plant and number of seeds per plant. The 99 mt for 11 min exposure showed better results as compared to control.

2.35 Noran et al. (1970) Observed that applications of MTW are abundant in industry where it is used to prevent scaling on inner walls of pipes conveying fluids, especially water. In recent years scientists investigating the subject have concluded that the magnetic field interacts with the surface charges of particles in the fluid solutions affecting the crystallization and precipitation of the solids in them. These processes are of significant effect on the translocation of minerals in irrigated soil. In this work the concentrations of K, N, P, Na, Ca and Mg, as well as the total mineral content in the MTW-irrigated soil were compared with the same data in soil irrigated with ordinary water. The soil was sampled at three different locations at three different distances from the dripper line, representing three different leaching states of the soil. Differences in concentrations were found in at least one of the three locations with respect to each mineral and including the total mineral content. Most of the differences appeared in the less leached parts of the soil, in the bed margin. It appears that there is a general tendency of minerals to precipitate out of the solution faster in MTW conditions.

2.36 Nyakane et al. (2019) have documented that magnetic treatment can conserve both the quantity and quality of water and crop yield. This paper presents an extensive survey of studies on the effects of the fields on plants over the past 20 years. Many aspects of plants growth, seed germination, yield, quality and water as affected by magnetic fields (MF) are investigated. The inconsistency and contradictory outcomes from the studies appear to indicate that the effects of MF on plants may be dependent on species and/or MF characteristics such as intensity and exposure time.

2.37 Payez et al. (2013) Noted that when the seeds of wheat (*Triticum aestivum L. Cv. Kavir*) were imbibed in water overnight and then treated with or without a 30-mt static magnetic field (SMF) and a 10-khz electromagnetic field (EMF) for 4 days, each 5 h. Water uptake of seeds reduced 5 h of the treatment with EMF but did not show changes in SMF treatment. Exposure to both magnetic fields did not affect germination percent of the seeds but increased the speed of germination, compared to the control group. Treatment with EMF significantly reduced seedling length and subsequently vigor index I, while SMF had no effects on these parameters. Both treatments significantly increased vigor index II, compared to the control group. These treatments also remarkably increased catalase activity and proline contents of seedlings but reduced the activity of peroxidase, the rate of lipid peroxidation and electrolyte leakages of membranes. The results suggest promotional effects of emfs on membrane integrity and growth characteristics of wheat seedlings.

2.38 Pietruszewski S. and Kania K. (2010) Reported that effect of magnetic field on germination and yields of spring wheat is presented. In the performed experiment two magnetic doses: D11=D13= 12.9 and D21=D23=17.9 kj m-3 s was applied. The germination kinetic and yield of wheat depended on both magnetic field exposure doses. In both cases the better germination of seeds as compared to control seeds was observed. The yield of wheat for the exposure doses D11=D13 was 12.5% higher and for doses D21=D23 was 14.5% higher than obtained for the control.

2.39 Radhakrishnan (2018) Noted that increase in crop productivity is an urgent need of the time to reduce scarcity of food in underdeveloped countries. Several biological, chemical and physical methods have been applied to promote crop yield. Application of magnetic field (MF) is an emerging physical method used to increase plant growth and yield. The reports on MF pretreatment-induced nutritional changes in harvested seeds are scarce. This study was aimed to investigate the effect of MF treatment on storage proteins and fatty acids in harvested soybean seeds. The results showed that MF triggered globulin production and suppressed prolamin production. However, lipid content in seeds increased, because MF exposure caused an elevation of several fatty acids including caprylic acid, palmitic acid, heptadecanoic acid, linoleic acid, lignoceric acid and eicosatetraenoic acid. This study suggests that MF treatment improves seed quality by regulating the metabolism of storage proteins and fatty acids.

2.40 Radhakrishnan (2019) Proposed that Global climatic fluctuations and the increasing population have been responsible for the decline in the crop productivity. The chemical fertilizers, pesticides, and suitable genetic resources are commonly used for improving the crop yield. Magnetic field (MF) therapy for plants and animals has been found to be an effective and emerging tool to control diseases and increase tolerance against the adverse environment. This review aims to highlight the mitigating effect of MF on plants against abiotic and biotic stresses. MF interacts with seeds and plants and accelerates metabolism, which leads to an improved germination. The primary and secondary metabolites, enzyme activities, uptake of nutrient and water are reprogrammed to stimulate the plant growth and yield under favorable conditions. During adverse conditions of abiotic stress such as drought, salt, heavy metal contamination in soil, MF mitigates the stress effects by increasing antioxidants and reducing oxidative stress in plants. The stunted plant growth under different light and temperature conditions can be overcome by the exposure to MF.

2.41 Razmjoo and Alinian (2017) Noted that an environment friendly technique is desirable for enhancing of crop production. In this study, seeds of cumin (*Cuminum cyminum L.*) Yazd accession were treated with 0, 150 mt, 250 mt, 500 mt and 1 T magnetic field strengths for min and germination parameters were determined. All of the treatments improved germination parameters and seedling growth as compared with the control. However, 500 and 150 mt were the most effective treatments and thus selected for field studies. Seeds were exposed to 150 mt and 500 mt static magnetic field of strengths for 12 min, planted in the field during 2010-2012 in Isfahan, Iran. Static magnetic field treatment shortened the days to emergence, flowering and maturity, increased chlorophyll and reduced proline contents. Highest biological, seed and essential oil yield, oil content, and oil yield were recorded under 500 mt followed by 150 mt and control, respectively. The results suggested that the pretreatment of cumin seeds with static magnetic field can improve germination, growth and oil and essential contents of the cumin seed under the field.

2.42 **Sarraf et al. (2020)** observed that exposure of seeds to a low-to-medium level magnetic field (MF), in pulsed and continuous modes, as they have shown positive results in a number of crop seeds. On the basis of the sensitivity of plants to MF, different types of MF have been used for magneto priming studies, such as weak static homogeneous magnetic fields (0–100 µt, including GMF), strong homogeneous magnetic fields (milli Tesla to Tesla), and extremely low frequency (ELF) magnetic fields of low-to-moderate (several hundred µt) magnetic flux densities. The agronomic application of mfs in plants has shown potential in altering conventional plant production systems; increasing mean germination rates, and root and shoot growth; having high productivity; increasing photosynthetic pigment content; and intensifying cell division, as well as water and nutrient uptake. Furthermore, different studies suggest that mfs prevent the large injuries produced/inflicted by diseases and pests on agricultural crops and other economically important plants and assist in reducing the oxidative damage in plants caused by stress situations. An improved understanding of the interactions between the MF and the plant responses could revolutionize crop production through increased resistance to disease and stress conditions, as well as the superiority of nutrient and water utilization, resulting in the improvement of crop yield. In this review, they summarize the potential applications of MF and the key processes involved in agronomic applications. Furthermore, in order to ensure both the safe usage and acceptance of this new opportunity, the adverse effects are also discussed.

2.43 **Shabrangi and Majid (2009)** Studied on seeds of Lentil (*Lens culinaris L.*) were magnetically pretreated by different magnetic field intensities from 0.06 to 0.36 tesla (T) by using Zeeman system for different periods of time 5, 10 and 20 minutes. Seedlings growth data were measured in green house condition with natural light cycle 14-h light/10-h darkness and 25 ± 3 ◦C daily and night temperature. Activity changes assay of Ascorbate peroxidase (APX) and Superoxide Dismutase (SOD) were carried out by spectrophotometer in 15 days seedlings. The greatest root growth in 3 days seedlings was observed in seedlings which were grown up from pretreated seeds by 0/3 tesla magnetic field intensity in 20 minutes pretreatment. The greatest shoot growth was also seen in 0/24 tesla magnetic field intensity in 20 minutes pretreatment. The results of experiments suggested that in 15 days seedlings, the greatest growth and biomass was observed in 0.18 T. Root had more growth than shoot under effect of magnetic fields. Leaf size and stem thickness were increased too. These seedlings were more resistant to drought stress. Activity enzymes assay suggested that APX activity increased in both root and shoot by increasing magnetic field intensities and SOD activity also increased in root of pretreated plants. All the results suggested that pretreated plants by magnetic fields are more resistant against harmful environmental factors.

2.44 Shahin et al. (2016) Evaluate the effect of different magnetic field strengths (0.0, 20.0, 40.0 and 60.0 m T), at different time intervals ranging from 0 to 300 minutes on some properties of irrigation water the ph, electric-conductivity (EC), and total dissolved salts (TDS). The results showed that the ph significant increased under different magnetic field strength, while EC and TDS significant decreased by magnetic treatment under different magnetic field strength and time of treatment by15.60% after 300 minutes. The results also show that water remembers and keeps the impact of passing through the magnetic field (water magnetic memory) for several hours, and ph decreased by 0.40 after 16 hours from treatment. Magnetized seeds of cucumber were growing for complete growth season (winter 2012) under controlled greenhouse condition. Cucumber magnetized seeds were growing and irrigated with magnetized water (40.0mt) the growth parameters, yield production, and some nutrients (N, P, K, Fe, Mn, Zn and Cu) content of cucumber crop were determined and discussed. The results demonstrated that the magnetic treatments improved plant height, yield (kg/m2), fruit length, fruit diameter, and leaves dry matter percentage of cucumber plant compared to control treatment. This study appears that utilization of magnetized water technology may be considered a promising technique to improve cucumber yield productivity.

2.45 Shokrollahi et al. (2018) Examined the relationship between ferrous content and gene expression and activity of ferritin and catalase in soybean plants under the influence of 0, 20, and 30 mt SMF for 5 day, 5 h each. Exposure to 20 mt decreased gene expression of Fe transporter, ferrous and H2O2 contents and gene expression, content and activity of ferritin and catalase. Opposite responses were observed under 30 mt treatments. The results suggest that SMF triggered a signaling pathway that is mediated by iron. The structure and activity of purified ferritin and apoferritin from horse spleen, and catalase from bovine liver proteins under SMF were evaluated as well. Secondary structure of proteins was not influenced by SMF (evidenced by far-UV circular dichroism), whereas their tertiary structure, size, and activity were altered (shown by fluorescence spectroscopy and dynamic light-scattering). From these results, it is likely that the number of iron atoms is involved in the nature of influence of SMF on protein structure.

2.46 **Srikanth et al. (2018)** have studied that aimed to determine the effect of magnetic-electric field on the growth characteristics of chilly was set to establish baseline data for farmers on the possible utilization of Electro-Magnetic Field (EMF). The application of magnetic and electric fields appears to produce changes in some physiological and biochemical processes of plants, including encouraging their development.

2.47 **Sunita et al. (2015)** Studied that the SMF pre-treated soybean and maize seeds showed improved germination related parameters like germination-percentage, water uptake, seedling length, fresh and dry weight of seedlings and vigor indices as compared to untreated seeds. Amylase and protease activities were also higher in SMF treated seeds as compared to untreated seeds in both soybean and maize seedlings. Thus, faster hydrolytic activity of enzymes in SMF treated seeds leads to higher rate of germination. Increased levels of hydrogen peroxide and superoxide radical in germinating magneto primed seeds of both soybean and maize suggested their role in promotion of germination. SMF treatment influences the physiological and biochemical process in the seeds and thereby contributes to better vigor and improved crop stand.

2.48 **Teixeira And Dobranszki (2016)** Proposed that the mfs range from the nanotesla (nt) to geomagnetic levels, up to very strong mfs greater than 15 Tesla (T) and also super-weak mfs (near 0 T) can positively influence the morphogenesis of several plants which allows them to be used in practical situations. Mfs have thus far been shown to modify seed germination and affect seedling growth and development in a wide range of plants, including field, fodder, and industrial crops; cereals and pseudo-cereals; grasses; herbs and medicinal plants; horticultural crops (vegetables, fruits, ornamentals); trees; and model crops. This is important since mfs may constitute a non-residual and non-toxic stimulus. In addition to presenting and summarizing the effects of mfs on plant growth and development, they also provide possible physiological and biochemical explanations for these responses including stress-related responses of plants, explanations based on dia-, para-, and ferromagnetism, oriented movements of substances, and cellular and molecular changes.

2.49 **Vashisth and Nagarajan (2008)** reported that Seeds of chickpea (*Cicer arietinum L.*) Were exposed in batches to static magnetic fields of strength from 0 to 250 mt in steps of 50 mt for 1–4 h in steps of 1 h for all fields. Results showed that among the various combinations of field strength and duration, 50 mt for 2 h, 100 mt for 1 h and 150 mt for 2 h exposures gave best results. Exposure of seeds to these three magnetic fields improved seed coat membrane integrity as it reduced the electrical conductivity of seed leachate. In soil, seeds exposed to these three treatments produced significantly increased seedling dry weights of 1-month-old plants. The root characteristics of the plants showed dramatic increase in root length, root surface area and root volume. The improved functional root parameters suggest that magnetically treated chickpea seeds may perform better under rainfed (un-irrigated) conditions where there is a restrictive soil moisture regime.

2.50 Vian et al. (2016) Noted that High frequency nonionizing electromagnetic fields (HF-EMF) that are increasingly present in the environment constitute a genuine environmental stimulus able to evoke specific responses in plants that share many similarities with those observed after a stressful treatment. In the present review, they illustrate some of the observed responses after exposure to HF-EMF at the cellular, molecular, and whole plant scale. Indeed, numerous metabolic activities (reactive oxygen species metabolism, α- and β-amylase, Krebs cycle, pentose phosphate pathway, chlorophyll content, terpene emission, etc.) Are modified, gene expression altered (calmodulin, calcium-dependent protein kinase, and proteinase inhibitor), and growth reduced (stem elongation and dry weight) after low power (i.e., nonthermal) HF-EMF exposure. These changes occur not only in the tissues directly exposed but also systemically in distant tissues.

3. Summary

The results indicate the beneficial of the pre-sowing seed stimulation in the magnetic field on the physical features and yield of seeds. However, studies also show that high intensity of magnetic field (above 30 mT) has positive effect of better seed germination and growth whereas low intensity magnetic field (nT range or below 30 mT) not have much effect on seed germination and growth. The obtained results show the beneficial influence of this kind of treatment.

4. Conclusion

The effect of magnetic treatment on seeds depended not only on MF strength but also on the duration of exposure. The pre-sowing magnetic field treatment significantly enhanced the seedling length, dry and wet mass in comparison to controls. The considerable improvement in germination rate, growth and yield was observed as compare to control due to pre-sowing magnetic treatments.

5. Scope of work

Many researches get good outcome using magnetic field treatment on seeds but still there is so much scope in this area of research. We can use different types of exposure with different magnetic field intensity and time, use different types of fields, different types of seeds, etc. Thus, further study needed in this area of research.

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6. LITERATURE CITED

1) Ahamed, M. E. M., Elzaawely, A. A., & Bayoumi, Y. A. (2013). Effect of magnetic field on seed germination, growth and yield of sweet pepper (*Capsicum annuum L.*). *Asian Journal of Crop Science*, 5(3), 286-294.
2) Alattar, E., Elwasife, K., & Radwan, E. (2021). Effects of magnetic field treated water on some growth parameters of corn (*Zea mays*) plants. *AIMS Biophysics*, 8(3), 267-280.
3) Anand, A., Nagarajan, S., Verma, A. P. S., Joshi, D. K., Pathak, P. C., & Bhardwaj, J. (2012). Pre-treatment of seeds with static magnetic field ameliorates soil water stress in seedlings of maize (*Zea mays L.*). *Indian Journal of Biochemistry & Biophysics*, Vol. 49, 63-70.
4) Audus, L. J. (1960). Magnetotropism: a new plant-growth response. *Nature*, 185(4707), 132-134.
5) Azimi, N., Majd, A., Nejadsattari, T., Ghanati, F., & Arbabian, S. (2018). Effects of Magnetically Treated Water on Physiological Characteristics of *Lens culinaris L. Iranian Journal of Science and Technology*, Transactions A: Science, 42(2), 331-337.
6) Baghel, L., Kataria, S., & Guruprasad, K. N. (2016). Static magnetic field treatment of seeds improves carbon and nitrogen metabolism under salinity stress in soybean. *Bioelectromagnetics*, 37(7), 455-470.
7) Belyavskaya, N. A. (2004). Biological effects due to weak magnetic field on plants. *Advances in space Research*, 34(7), 1566-1574.
8) Bhardwaj, J., Anand, A., & Nagarajan, S. (2012). Biochemical and biophysical changes associated with magnetopriming in germinating cucumber seeds. *Plant Physiology and Biochemistry*, 57, 67-73.
9) Bilalis, D. J., Katsenios, N., Efthimiadou, A., & Karkanis, A. (2012). Pulsed electromagnetic field: an organic compatible method to promote plant growth and yield in two corn types. *Electromagnetic Biology and Medicine*, 31(4), 333-343.
10) Bilalis, D. J., Katsenios, N., Efthimiadou, A., Karkanis, A., & Efthimiadis, P. (2012). Investigation of pulsed electromagnetic field as a novel organic pre-sowing method on germination and initial growth stages of cotton. *Electromagnetic Biology and Medicine*, 31(2), 143-150.

11) 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*, 31(2), 120-129.
12) Chen, Y. P., Li, R., & He, J. M. (2011). Magnetic field can alleviate toxicological effect induced by cadmium in mungbean seedlings. *Ecotoxicology*, 20(4), 760-769.
13) De Souza, A., Sueiro, L., Gonzalez, L. M., Licea, L., Porras, E. P., & Gilart, F. (2008). Improvement of the growth and yield of lettuce plants by non-uniform magnetic fields. *Electromagnetic biology and medicine*, 27(2), 173-184.
14) Dhawi, F. (2014). Why magnetic fields are used to enhance a plant's growth and productivity? *Annual Research & Review in Biology*, 886-896.
15) El-Yazied, A. A., Shalaby, O. A., El-Gizawy, A. M., Khalf, S. M., & El-Satar, A. (2011). Effect of magnetic field on seed germination and transplant growth of tomato. *The Journal of American Science*, 7(12), 306-312.
16) Ercan, I., Tombuloglu, H., Alqahtani, N., Alotaibi, B., Bamhrez, M., Alshumrani, R., ... & Kayed, T. S. (2022). Magnetic field effects on the magnetic properties, germination, chlorophyll fluorescence, and nutrient content of barley (*Hordeum vulgare L.*). *Plant Physiology and Biochemistry*, 170, 36-48.
17) García, A. S., Reina, F. G., Franco, Y. P., & Paez, D. D. (2013). Stimulation of germination and growth in soybean seeds by stationary magnetic field treatment. *Asian J Agri Biol*, 1(2), 85-90.
18) Ghanati, F., & Payez, A. (2015). Iron biofortification and activation of antioxidant system of wheat by static magnetic field. *Iranian Journal of Science and Technology (Sciences)*, 39(31), 355-360.
19) Grewal, H. S., & Maheshwari, B. L. (2011). Magnetic treatment of irrigation water and snow pea and chickpea seeds enhances early growth and nutrient contents of seedlings. *Bioelectromagnetics*, 32(1), 58-65.
20) Hirota, N., Nakagawa, J., & Kitazawa, K. (1999). Effects of a magnetic field on the germination of plants. *Journal of applied physics*, 85(8), 5717-5719.
21) Huang, H. H., & Wang, S. R. (2008). The effects of inverter magnetic fields on early seed germination of mung beans. *Bioelectromagnetics*, 29(8), 649-657.
22) Ijaz, B., Jatoi, S. A., Ahmad, D., Masood, M. S., & Siddiqui, S. U. (2012). Changes in germination behavior of wheat seeds exposed to magnetic field and magnetically structured water. *African Journal of Biotechnology*, 11(15), 3575-3585.

23) Jinapang, P., Prakob, P., Wongwattananard, P., Islam, N. E., & Kirawanich, P. (2010). Growth characteristics of mung beans and water convolvuluses exposed to 425-mhz electromagnetic fields. *Bioelectromagnetics*, 31(7), 519-527.

24) Kareem, N. S. A. (2018). Evaluation of Magnetizing Irrigation Water Impacts on the Enhancement of Yield and Water Productivity for Some Crops. *J. Agric. Sci. Technol.,* A, 8, 271-283.

25) Kavitha, M., Rai, P. K., & Haritha, B. Standardization of Different Pre-sowing Seed Treatments on Growth, Yield and Yield Attributing Traits of Kodo Millet (*Paspalum scorbiculatum*). *Indian Journal of Agricultural Research*, 1, 8.

26) Kordas, L. (2002). The effect of magnetic field on growth, development and the yield of spring wheat. *Polish Journal of Environmental Studies*, 11(5), 527-530.

27) Krawiec, M., Dziewulska-Hunek, A., & Kornarzynski, K. (2018). The use of physical factors for seed quality improvement of horticultural plants. *Journal of Horticultural Research*, 26(2), 81-94.

28) Lazim, S. K. (2021). Effect of static magnetic field on some parameters of germination barley seeds using two mathematical models. *Biochem. Cell. Arch.*, Vol. 21, Supplement 1, 2707-2712.

29) Maffei, M. E. (2014). Magnetic field effects on plant growth, development, and evolution. *Frontiers in plant science*, 5, 445.

30) Mahajan, T. S., & Pandey, O. P. (2014). Magnetic-time model at off-season germination. *International agrophysics*, 28(1), 57-62.

31) Martinez, E., Florez, M., & Carbonell, M. V. (2017). Stimulatory effect of the magnetic treatment on the germination of cereal seeds. *International Journal of Environment, Agriculture and Biotechnology*, 2(1), 375-381.

32) Matwijczuk, A., Kornarzynski, K., & Pietruszewski, S. (2012). Effect of magnetic field on seed germination and seedling growth of sunflower. *International Agrophysics*, 26(3), 271-278.

33) Michalak, I., Lewandowska, S., Niemczyk, K., Detyna, J., Bujak, H., Arik, P., & Bartniczak, A. (2019). Germination of soybean seeds exposed to the static/alternating magnetic field and algal extract. *Engineering in Life Sciences*, 19(12), 986-999.

34) Mridha, N., Chattaraj, S., Chakraborty, D., Anand, A., Aggarwal, P., & Nagarajan, S. (2016). Pre-sowing static magnetic field treatment for improving water and radiation use efficiency in chickpea (*Cicer arietinum L.*) Under soil moisture stress. *Bioelectromagnetics*, 37(6), 400-408.

35) Naz, A., Jamil, Y., Iqbal, M., Ahmad, M. R., Ashraf, M. I., & Ahmad, R. (2012). Enhancement in the germination, growth and yield of okra (*Abelmoschus esculentus*) using pre-sowing magnetic treatment of seeds. *Indian Journal of Biochemistry & Biophysics*, Vol. 49, 211-214.
36) Noran, R., Shani, U., & Lin, I. (1970). The effect of irrigation with magnetically treated water on the translocation of minerals in the soil. *Magnetic and Electrical Separation*, 7, 109-122.
37) Nyakane, N. E., Markus, E. D., & Sedibe, M. M. (2019). The effects of magnetic fields on plants growth: a comprehensive review. *Int J Food Eng*, 5, 79-87.
38) Payez, A., Ghanati, F., Behmanesh, M., Abdolmaleki, P., Hajnorouzi, A., & Rajabbeigi, E. (2013). Increase of seed germination, growth and membrane integrity of wheat seedlings by exposure to static and a 10-khz electromagnetic field. *Electromagnetic biology and medicine*, 32(4), 417-429.
39) Pietruszewski, S., & Kania, K. (2010). Effect of magnetic field on germination and yield of wheat. *Int. Agrophys*, 24(3), 297-302.
40) Radhakrishnan, R. (2018). Seed pretreatment with magnetic field alters the storage proteins and lipid profiles in harvested soybean seeds. *Physiology and Molecular Biology of Plants*, 24(2), 343-347.
41) Radhakrishnan, R. (2019). Magnetic field regulates plant functions, growth and enhances tolerance against environmental stresses. *Physiology and Molecular Biology of Plants*, 25(5), 1107-1119.
42) Razmjoo, J., & Alinian, S. (2017). Influence of magnetopriming on germination, growth, physiology, oil and essential contents of cumin (*Cuminum cyminum L.*). *Electromagnetic Biology and Medicine*, 36(4), 325-329.
43) Sarraf, M., Kataria, S., Taimourya, H., Santos, L. O., Menegatti, R. D., Jain, M., ... & Liu, S. (2020). Magnetic field (MF) applications in plants: An overview. *Plants*, 9(9), 1139.
44) Shabrangi, A., & Majd, A. (2009). Effect of magnetic fields on growth and antioxidant systems in agricultural plants. *PIERS Proceedings*, Beijing, China, March, 23-27.
45) Shahin, M. M., Mashhour, A. M. A., & Abd-Elhady, E. S. E. (2016). Effect of magnetized irrigation water and seeds on some water properties, growth parameter and yield productivity of cucumber plants. *Curr. Sci. Int*, 5(2), 152-164.
46) Shokrollahi, S., Ghanati, F., Sajedi, R. H., & Sharifi, M. (2018). Possible role of iron containing proteins in physiological responses of soybean to static magnetic field. *Journal of plant physiology*, 226, 163-171.
47) Srikanth, D., Rai, P. K., Khandka, S., & Jyothi, G. B. N. (2018). Influence of magnetic and electric field on germination attributes of chilli (*Capsicum annum L.*) Seeds. *Int. J. Pure App. Biosci*, 6(3), 496-501.

48) Sunita, K., Lokesh, B., & Guruprasad, K. N. (2015). Acceleration of germination and early growth characteristics of soybean and maize after pre-treatment of seeds with static magnetic field. *International Journal of Tropical Agriculture*, 33(2 (Part II)), 985-992.

49) Teixeira da Silva, J. A., & Dobránszki, J. (2016). Magnetic fields: how is plant growth and development impacted? *Protoplasma*, 253(2), 231-248.

50) Tolomei, G. (1893). Azione del magnetismo sulla germinazione. *Malpighia*, *7*(470), 183-195.

51) Vashisth, A., & Nagarajan, S. (2008). Exposure of seeds to static magnetic field enhances germination and early growth characteristics in chickpea (*Cicer arietinum L.*). *Bioelectromagnetics*, 29(7), 571-578.

52) Vian, A., Davies, E., Gendraud, M., & Bonnet, P. (2016). Plant responses to high frequency electromagnetic fields. *Biomed research international*, Vol. 2016.