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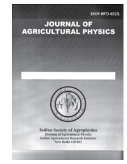

Research Article

Impact of Magnetic Treatment of Seeds on Germination Characteristics in Wheat (*Triticum aestivum* L.)

SWAGATA DAS, ANANTA VASHISTH*, P. KRISHNAN, MONIKA KUNDU AND SHIV PRSAD

ICAR-Indian Agricultural Research Institute, New Delhi-110012

ABSTRACT

This study aims to standardize the magnetic field for maximum enhancement in the germination characteristics of wheat seeds. Seeds of wheat were exposed to static magnetic fields of strength 50, 100, 150, 200 and 250 mT for ½ hour and 1 hour for all field strengths. The findings indicate that magnetic field application enhanced seed performance in terms of seedling length by 2-17% and 7-16%, seedling dry weight by 1-5.6 % and 1-10%, vigour index I by 2.4-17.8% and 7-17% and vigour II by 0.8-6.6% and 1-11% in case of 8 days and 12 days respectively compared to unexposed control. Among the various combinations of field strength and duration, 100 mT for ½ hour and 150 mT for ½ hour exposure gave the best results. Exposure of seeds to magnetic fields improved seed coat membrane integrity as it reduced cellular leakage and, consequently, electrical conductivity. A static magnetic field is a healthy, biologically safe, and environmentally friendly treatment and can be a tool for overcoming problems of low germination and seed quality when stored under unfavourable conditions.

Key words: Magnetic field, Seedling vigour, Seed leachate conductivity, Wheat

Introduction

Wheat (*Triticum aestivum* L.) is one of the most fundamental crops globally, playing a crucial role in shaping civilizations and economies. Believed to have been cultivated for over 10,000 years, wheat is primarily grown for its nutritious seeds, which are processed into flour for a variety of food products. Its adaptability enables cultivation across diverse climatic regions, from the vast plains of North America to the ancient fields of the Middle East. Wheat contributes approximately 205 calories per capita globally and is cultivated on approximately 219 million acres annually, yielding approximately 760 million tons (FAO, 2021). Apart from being a staple food for a significant portion of the world's population, wheat is a key commodity in international trade. Advances in wheat breeding and modern genetic modifications have significantly improved yield, disease resistance, and nutritional value, reinforcing wheat's position as a cornerstone of global agriculture and food security.

With the continuous rise in global population and the challenges posed by climate change, there is an urgent need to enhance wheat production sustainably. By 2050, global wheat production must increase by approximately 50% to meet the growing demand and address the widening gap between production and consumption (Namvar and Khandan, 2013). However, this must be achieved under increasingly challenging environmental conditions, including high temperatures and extreme weather events. Given the constraints of limited arable land, there is a need for innovative agricultural practices that maximize yield while maintaining environmental sustainability.

*Corresponding author,
Email: ananta.iari@gmail.com

Over the years, significant progress has been made in wheat productivity through the development of high-yielding varieties and the implementation of advanced agricultural technologies.

One crucial aspect of improving wheat production is ensuring better seed germination and seedling vigour, which are essential for crop establishment and yield optimization. To achieve this, agricultural scientists worldwide are investigating environmentally friendly techniques, particularly physical and biological seed treatments. Pre-sowing treatments, such as chemical and physical methods, enhance seed germination by breaking dormancy and protecting seeds from pests and diseases. However, some conventional pre-sowing priming techniques, including osmo-priming, hydro-priming, and halo-priming, require immediate sowing after treatment, limiting their applicability for long-term seed storage. Given this limitation, magnetic field seed treatment has emerged as a promising alternative. It is one of the safest, most cost-effective, and environmentally sustainable methods for enhancing seed germination, seedling vigour, and overall agricultural productivity (Vashisth and Nagarajan, 2010).

The interaction between magnetic fields and biological systems, particularly plant cells, has been a subject of scientific interest for over a century. Early observations by Louis Pasteur in 1862 suggested that Earth's magnetic field influenced plant growth, marking the first scientific evidence of geomagnetic effects on plant development. In 1950, Dr. Albert Roy Davies patented a method for magnetically treating seeds to promote plant growth, leading to further research in the field. It is now well-established that plants respond to electromagnetic irradiation and magnetic stimulation, with responses varying based on field strength and exposure duration. Research over the past decade has provided strong evidence that pre-germination seed treatment using magnetic fields significantly enhances germination rates, plant growth, and overall crop performance.

Magnetic field treatment of seeds has been shown to positively influence several physiological and biochemical processes, ultimately improving seedling vigour and crop stand. This technique enhances plant metabolism by altering solute properties in plant cells and influencing key biochemical pathways. Studies by Podlesny *et al*. (2005) demonstrated that magnetic field exposure not only improves germination rates but also contributes to higher crop yields in an environmentally sustainable manner. Galland and Pazur (2005) further highlighted that magnetic fields impact the chemical composition of cytoplasmic solutes, irrigation water, and growth medium, which in turn affect plant growth. Additionally, several researchers have reported significant improvements in seed germination, seedling vigour, root development, and biochemical activity in plants subjected to magnetic treatment (Alikamanoglu and Sen, 2011; Selim and El-Nady, 2011; Radhakrishnan and Kumari, 2012; Selim *et al.,* 2019).

Several experiments have examined the effects of magnetic fields on various crops, focusing on key growth parameters such as germination, root and shoot development, and overall biomass production. Research conducted by Vashisth and Nagarajan (2007, 2008a, 2008b, 2010) indicated that exposing maize, chickpea, and sunflower seeds to static magnetic fields resulted in significant improvements in seedling vigour and root characteristics. Further studies have investigated the underlying biochemical and molecular mechanisms responsible for these growth enhancements, revealing that exposure to a magnetic field influences iron metabolism, energy production, and cellular responses within plant tissues (Belyavskaya, 2004; Vaezzadeh *et al.,* 2006). Aksenov *et al*. (2001) found that a 50 Hz, 30 mT magnetic field accelerated wheat growth, while Podlesny *et al*. (2005) confirmed the positive impact of magnetic treatment on pea seed germination and emergence.

Despite substantial research on the effects of magnetic fields on seed germination and early plant development, studies on wheat remain limited. Most existing studies focus on germination enhancement, seedling vigour, and root characteristics, yet a comprehensive and systematic investigation of the physiological, biochemical, and yield-related impacts of magnetic field exposure on wheat remains lacking. To bridge this research gap, it is essential to conduct further experiments to evaluate the influence of static magnetic fields on wheat seed germination, seedling growth, bio-physical parameters, and yield characteristics.

The present study aims to standardise the optimal magnetic field strength and exposure duration for pre-sowing wheat seed treatment to maximise germination characteristics. By identifying the most effective treatment conditions, this research seeks to provide an environmentally sustainable and cost-effective approach to improving wheat productivity.

Materials and Methods

This experiment was carried out in the laboratory of the Division of Agricultural Physics, ICAR-Indian Agricultural Research Institute, New Delhi, for wheat during *Rabi* 2023-24.

Wheat seeds (*Triticum aestivum*) crop variety HD-3086 were obtained from the seed production unit, ICAR- Indian Agricultural Research Institute, New Delhi. Seeds without visible defects, insect damage, or malformation were selected and stored in desiccators containing anhydrous calcium chloride.

Magnetic seed treatment

An electromagnetic field generator "Testron EM-20" with variable magnetic field strength (50-500 mT) with a gap of 5 cm between pole pieces was used for exposing seeds by magnetic field . The pole pieces are 9 cm in diameter, 16 cm in length. The number of turns per coil is 3000 and the resistance of the coil is 16 ohms. A DC power supply (80V/10A) with continuously variable output current was used for the electromagnet. A digital Gauss meter model DGM-30 operating on the principle of the Hall effect monitored the field strength produced in the pole gap. The probe is made of Indium Arsenide crystal and is encapsulated in a non-magnetic sheet of dimensions 5 mm × 4 mm × 1 mm and could measure 0-2 Tesla with a full-scale range in increments of 5 mT.

Wheat seeds (*Triticum aestivum*) crop var. HD-3086 were exposed to the magnetic field of 50 mT to 250 mT in steps of 50 mT for ½ hour and 1 hour in all the field strengths in a sample holder, cylindrical in shape and made of non- magnetic thin transparent plastic sheet. Visibly sound, mature, healthy 300 seeds were held inside a plastic container in the space between the poles of the electromagnet having a uniform magnetic field (Fig. 1). The required strength of the magnetic field was obtained by monitoring the current in the coils of the electromagnet. At low field (50 mT), from the centre to the end of the poles, the variation was 0.6% in the horizontal direction and 1.6% in the vertical direction of the applied field. At high field (250 mT), they were 0.4% and 1.2% of the applied field, respectively. A Gauss meter was used to measure the strength of the magnetic field between the poles. The local geomagnetic field was less than 10 mT. All treatments in the experiments were run simultaneously along with controls under similar conditions.

Seed germination

The germination of the seeds was determined by using the paper method (ISTA, 1985). One hundred seeds in four replications of 25 seeds each

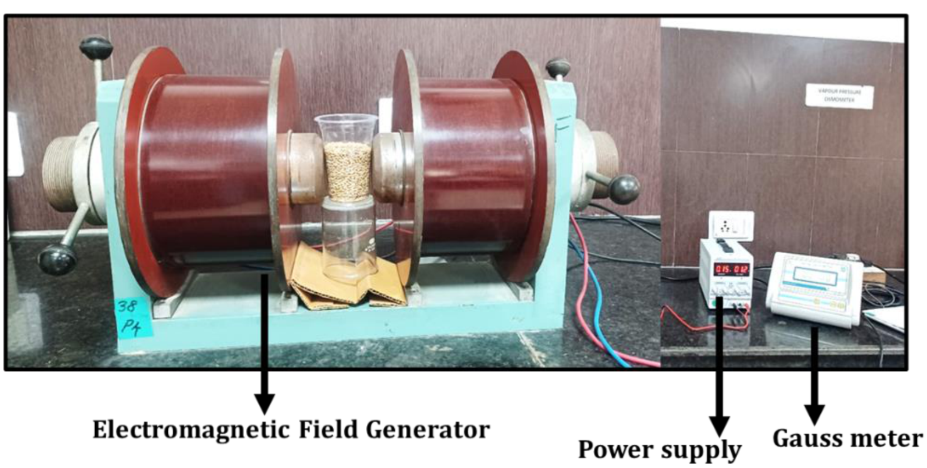

Fig. 1. Seed treatment by Magnetic Field in electromagnetic field generator

were placed between two layers of moist germination papers, rolled carefully and wrapped in a sheet of wax paper to reduce surface evaporation ensuring that no excess pressure was placed on the seeds. These were placed in the germination incubator at 20°C temperature in an upright position. After 8 days and 12 days, the germinated seeds were evaluated for normal, abnormal seedlings, fresh ungerminated and dead seeds. Germination percentage is given based on normal seedlings only.

Seedling growth and seedling vigour

Ten normal seedlings from each replicate were randomly selected. Shoot length and root length were recorded using a linear scale. Seedlings were dried overnight in an oven set to 65°C, and the dry weight of 10 seedlings per replicate were measured. Seedling vigour was calculated following Abdul Baki and Anderson [1973] as

Vigour index I = Germination % × Seedling length (Root + Shoot)

Vigour index II = Germination % × Seedling dry weight (Root + Shoot)

Speed of germination

Magnetically treated and untreated seeds in four replications with 25 each were placed over moistened filter paper in a petri dish and kept in an incubator at 20°C. Daily germination counts were taken until no more seeds germinated. The speed of germination (X) was calculated following Maguire (1962) as

$$= \frac{\text{Number of seeds germinated}}{\text{Day of the first count}} + \ldots + \frac{\text{Number of seeds germinated}}{\text{Day of the final count}}$$

Seed leachate conductivity

Twenty-five seeds in four replicates were soaked in 25 ml of distilled water at 25°C for 24 hours in all the magnetic treatments. A control with distilled water (without seeds) was also prepared. The seed leachate was decanted off in a clean 50 ml beaker. The membrane stability based on seed leachate was measured after 8 and 24 hours at room temperature using a digital conductivity meter (Systronics India).

Statistical analysis

The data were analyzed using the Excel package (version 2407) and R software. Analysis of variance as valid for randomized block design was used to test least significant differences among the different treatment means and their interactions using statistical analysis, keeping the magnetic field as the main plot and duration as sub-plot. The significant differences in all measured traits across magnetic fields, exposure duration, and their interactions were calculated. The MS Excel software package was used to draw the required graphs. The means of all treatments were separated by DMRT at the 5% significance level, as per standard ANOVA.

Results and Discussion

Effect of magnetic field on germination characteristics

All magnetic field treatments with different strengths (50–250 mT) and duration (1/2 hour and 1 hour) had no significant effect on the germination of wheat seeds over untreated control (Fig. 2). The

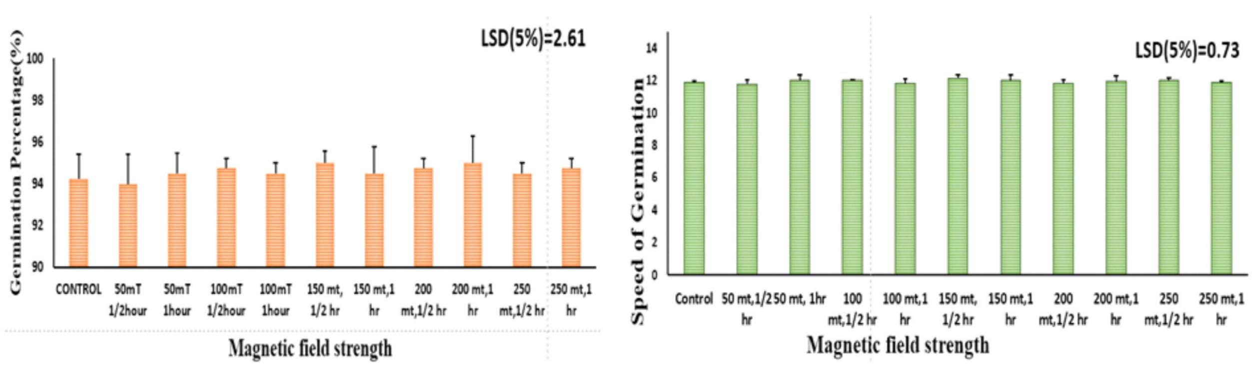

Fig. 2. Effect of different doses and duration of magnetic field exposure of wheat seeds on germination percentage and speed of germination.

germination percentage was between 94- 95% in case of treated seeds, whereas in the control it was 94 %. A similar trend followed in the case of the speed of germination also (Fig. 2). The non-toxic and non-residual properties of the magnetic field in stimulating seed germination have been highlighted by several studies (Da Silva *et al*., 2016). However, optimizing the strength and duration of SMF exposure for each plant species remains a critical area of research (Maffei, 2014; Hafeez *et al*., 2023).

Wheat seeds exposed to different magnetic field strengths prior to germination increased significantly all the seedling characteristics, namely, shoot length, root length, total length, seedling dry weight, seedling vigour I and seedling vigour II. The per cent enhancement of different parameters was not linearly related to the field strength of the magnetic field. However, all magnetic field treatments yielded better results than the control across magnetic field strength and treatment duration. The progress in seeds treated by magnetic field over untreated control seeds for 8 days seedling was between 2.2-7.5 % for shoot length,1-22% for root length, 2-17% for total length, 1-5.6 % for seedling dry weight, 2.4-17.8% for vigour index I and 0.8-6.6% for vigour index II (Fig. 3).

A similar trend was found in 12-day seedlings. The improvement in magnetically treated seeds over untreated controlled was between 4-11% for shoot length, 6- 20% for root length, 7-16% for total seedling length, 1-10% for seedling dry weight, 7-17% for vigour index I and 1-11% for vigour index II (Fig. 4). The observed improvements in germination characteristics suggest that the interaction between magnetic field strength and exposure duration plays a crucial role. A resonance-like phenomenon may occur when the magnetic field and exposure duration are optimally balanced, thereby increasing the seed's internal energy. One hypothesis explaining the stimulatory effects of magnetic fields is based on the paramagnetic properties of certain atoms within plant cells, particularly in chloroplasts. When exposed to an external magnetic field, these atoms align their magnetic moments, potentially facilitating energy absorption and conversion into biochemical energy

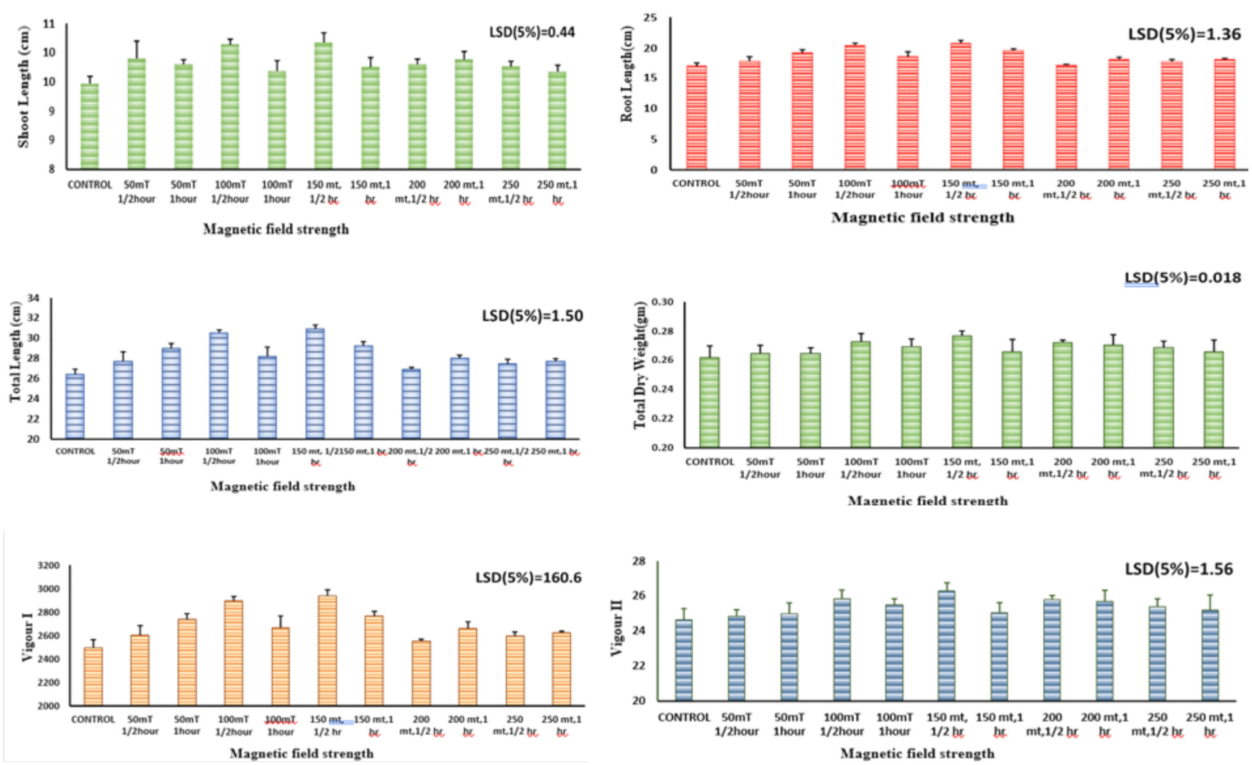

Fig. 3. Effect of different doses and duration of magnetic field exposure of wheat seeds on shoot length, root length, total length, total dry weight, vigour index I and vigour index II at 8 days

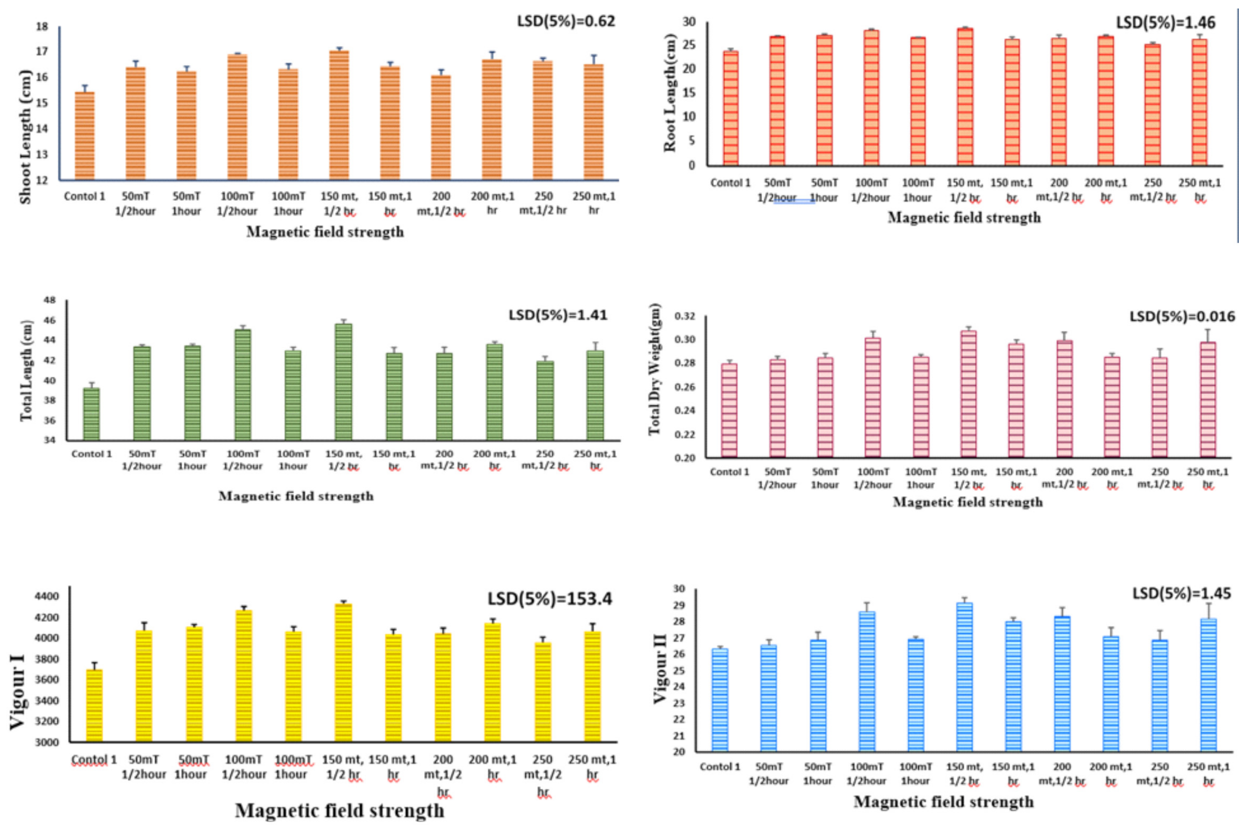

Fig. 4. Effect of different doses and duration of magnetic field exposure of wheat seeds on shoot length, root length, total length, total dry weight, vigour index I and vigour index II at 12 days

that activates cellular processes. Magnetic field treatment appears to influence water dynamics within seeds. Vashisth and Nagarajan (2009) observed that seeds treated with magnets exhibited enhanced water-binding properties and membrane integrity, leading to improved germination rates. Additionally, relaxation times for hydration and cytoplasmic bulk water were longer in magnetically treated seeds, suggesting that these changes contribute to early seedling vigour. Several researchers have confirmed the beneficial effects of stationary magnetic fields on plant growth. Pietruszewski *et al.* (2007) found that applying a magnetic field to seeds enhances both germination rate and seed quality. The effect of pre-sowing magnetic field exposure has been investigated across various crop types, including legumes (De Souza *et al.,* 2006; Martínez *et al.,* 2009b; Podleocny *et al.,* 2004, 2005; Vashisth & Nagarajan, 2008b), grains (Torres *et al.,* 2008; Vashisth & Nagarajan, 2008) and perennials (Celik *et al.,* 2008; Dardeniz *et al.,* 2006; Dhawi & Al-Khayari, 2009). Studies on cucumber seedlings indicate that pre-sowing magnetic field treatment enhances growth and development (Yinan *et al.*, 2005). Additionally, Cakmak *et al.* (2010) demonstrated that static magnetic fields improve bean seedling germination and increase dry biomass accumulation in roots and shoots. This study aims to examine the impact of stationary magnetic fields on wheat seed germination and subsequent seedling development. The findings of this study demonstrate that exposure to magnetic fields generally stimulates wheat seed germination. When compared to untreated control seeds, those exposed to a magnetic field exhibited increased seedling shoot length, root length, dry weight and vigour indices I and II. Among the different treatments, seeds exposed to 150 mT for ½ hour showed the most significant improvement, followed by those treated with 100 mT for the same duration. Similar observations have been reported in studies on maize, chickpea, and sunflower (Vashisth & Nagarajan, 2007, 2008, 2010). These results suggest that magnetic field treatment enhances early seedling growth, potentially increasing plant vigour and productivity.

Membrane integrity and seed leachate conductivity

Seeds treated by a magnetic field had lower leachate conductivity than the unexposed control, which indicates greater membrane integrity and reduced seed leakage in magnetically treated seeds. Decrease in seed leachate conductivity for 8 hours and 24 hours in different treatments as compared to the control was between 8 to 16% and 4.3 to 12.7% (Fig. 5). The lowest value was found in 250 mT 1 hour, followed by 150mT ½ hour and 100mT ½ hour.

From the analysis of the data on the effect of the magnetic field and the time of exposure, it was found that when all seedling characteristics were taken into consideration, the best results were obtained with 100 mT for ½ hour and 150 mT for ½ hour. Research has shown that magnetic field treatment may enhance enzymatic activity during germination. Arababian *et al.* (2001) observed an increase in esterase enzyme activity in seeds exposed to magnetic fields. The treatment appears to break seed dormancy by reducing cell wall pH and stimulating metabolic processes. Further studies indicate that magnetic fields influence normal cell metabolism and division in plant meristem cells, thereby promoting faster, easier germination. This aligns with the hypothesis proposed by Commoner *et al.* (1956), which suggests that organelles such as mitochondria exhibit paramagnetic properties similar to those of chloroplasts. Free radicals present in plant tissues, which play a role in chemical reactions and electron transport, can also align with external magnetic fields. This interaction may enable seeds to absorb and convert microwave energy into chemical energy, thus accelerating key metabolic processes essential for germination.

The stimulatory effects of the magnetic field are particularly pronounced during the early stages of plant ontogeny. Exposure to low static magnetic fields (e.g. 50 mT) has been found to increase fresh tissue mass, chlorophyll levels, nucleic acid content, and plant height while enhancing membrane integrity. Lower conductivity levels in seed leachate indicate stronger seed coats in magnetically treated seeds compared to controls. Studies confirm that wheat (Bhatnagar & Deb, 1977), rice (Carbonell *et al*., 2000), and maize (Florez *et al*., 2007) exhibit accelerated germination when exposed to a magnetic field.

Ferrimagnetic resonance theory suggests that when the size and shape of magnetic particles are suitable for resonance at a given frequency, the magnetization vector within the seed resonates, leading to physical and biochemical changes. Vibrations in the magnetite crystal lattice may interfere with normal cellular functions, depending on the magnetite's location within the cell. Furthermore, ferritin proteins, which store iron in plants and animals, may play a role in magnetoreception by modulating iron availability

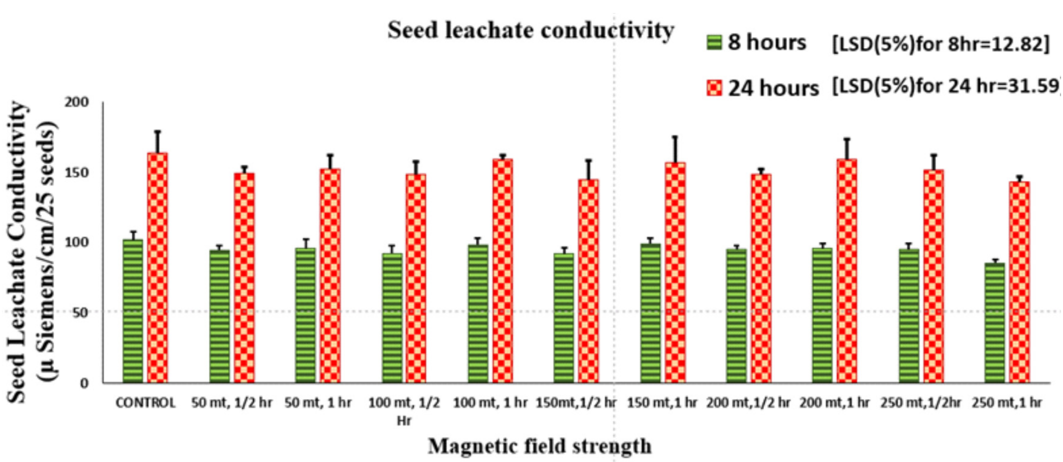

Fig. 5. Effect of different doses and duration of magnetic field exposure of wheat seeds on seed leachate conductivity

and redox reactions (Fleissner *et al*., 2007). Oxidative stress, a common metabolic phenomenon, can also be influenced by magnetic fields. Sahebjamei *et al*. (2007) reported that oxidative stress impacts cell development, membrane structure, and programmed cell death, potentially linking magnetic field exposure to alterations in these processes. The increased activity of germination-related enzymes, such as á-amylase, dehydrogenase, and protease, further supports the hypothesis that magnetic fields modulate seed metabolism (Vashisth & Nagarajan, 2010b).

Conclusion

Exposure of dry wheat (*Triticum aestivum* L.) seeds to a static magnetic field significantly enhanced seedling growth parameters, including seedling length, dry weight, vigour indices, and membrane stability, compared to unexposed controls, while germination percentage remained unaffected. Among the different combinations of magnetic field strength and exposure duration, treatments of 100 mT for ½ hour and 150 mT for ½ hour were better for improving seedling vigour. The reduction in seed leachate conductivity in magnetically treated seeds further confirms improved membrane integrity and physiological seed quality, which are critical for uniform crop establishment. Overall, magnetic seed treatment emerges as a non-chemical, biologically safe, and environmentally friendly pre-sowing technique with strong potential for enhancing early wheat growth.

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