Pol. J. Environ. Stud. Vol. XX, No. X (XXXX), 1-8
DOI: *10.15244/pjoes/203577* ONLINE PUBLICATION DATE: 2025-06-03

Original Research

Pre-Sowing Magnetic Stimulation Enhanced Germination and Growth Attributes of Maize (*Zea mays*) Seed

Kalsoom Asghar Ali[1], Mohamed A. El-Tayeb[2], Wahidah H. Al-Qahtani[3], Akram A. Alfuraydi[4], Bushra Hafeez Kiani[5], Irshad Arshad[6], Samar Abbas[1], Adeelanjum1, Zia-ul-Haq[1°]*

[1]Department of Physics, University of Agriculture, Faisalabad, Pakistan
[2]Botany and Microbiology department, College of Science, King Saud University, Saudi Arabia
[3]Department of Food Sciences & Nutrition, College of Food and Agricultural Sciences, King Saud University, P.O. Box 270677, Riyadh 11352, Saudi Arabia
[4]Botany and Microbiology department, College of Science, King Saud University, Saudi Arabia
[5]Department of Biology and Biotechnology, Worcester Polytechnic Institute, Worcester, Massachusetts, 01609, USA
[6]New Mexico Environment department, Santa Fe, New Mexico, 87507, USA

Received: 14 October 2024
Accepeted: 31 March 2025

Abstract

The necessity for sustainable agricultural methods to increase crop productivity while reducing environmental impact is a major issue. Numerous environmental conditions affect the germination process of seeds. Many techniques are used to increase the growth of plants and seed germination. A magnetic field is one of them that has shown positive effects on the germination and growth of plants. This study investigates magnetic field effects on maize seed germination, focusing on biophysical parameters. Traditional methods used for seed germination enhancement often involve chemical treatment, which may have a negative impact on the environment and public health. Thus, alternative techniques such as magnetic fields are being used. In this research, maize seeds were subjected to magnetic field intensities 100 mT, 150 mT, and 200 mT for a duration of 30 sec and 1 min. Various parameters like germination % age, seedling Vigor, root and shoot development, and chlorophyll contents, were measured. Results indicate that magnetic field application has significant positive effects on different biophysical parameters and chlorophyll contents as compared to the control. Treatment T_5 (200 mT for 30 sec) showed better results in all respects. This study contributes to the ongoing efforts to create environmentally friendly and productive sustainable agricultural practices.

Keywords: magnetic field treatment, maize seed, biophysical parameters, seed germination, chlorophyll contents environment friendly technique

*e-mail: zh_uaf@yahoo.ca
Tel.: +92-305-9734010
°ORCID iD: 0009-0006-4122-6606

Introduction

Since chemical treatments have adverse effects, scientists are investigating environment-friendly options to increase crop yield. Using a magnetic field to treat seeds before sowing was found beneficial [1]. Due to the relative simplicity, lower cost, and higher safety, pre-sowing magnetic field treatment may prove advantageous as compared to microwave and ionizing radiations (UV, X, and gamma rays) [2, 3]. It was reported that the magnetic field's effects depended on its direction [4]. The literature indicates that magnetic treatments can have certain advantages, whether they are used for pre-sowing seed treatment or irrigation with magnetized water [5]. Research has been done to demonstrate how magnetic fields affect biological processes [6, 7]. The pre-sowing magnetic seeds treatment is an environmentally-friendly technique that increases plant resistance to adverse environmental factors [8]. The United States, Australia, Turkey, China, Japan, England, Russia, Poland, and Egypt are using this technology. Due to its less harmful effects on living things and the environment, the application of magnetic fields to enhance plant growth has increased [9].

MF alters the properties of the cell membrane, enzyme activity, protein manufacturing, cell division, RNA, and protein synthesis during the cell reproduction cycle [10]. The Lorentz force affects the velocity direction of the ionic particles in plants and lipids in its composition, and the cell membrane works as a condenser [11]. The potential of the magnetic field to enhance seed germination in maize is intriguing due to the economic importance of the crop and the global demand for increased yield [12]. However, despite some encouraging findings, the precise mechanisms behind the magnetic field's effect on seed germination are still not well understood. Furthermore, there is a lack of agreement among researchers on the ideal parameters, such as field intensity, exposure duration, and timing to maximize the germination enhancement [13]. One of the most significant crops is maize, serving as a staple food worldwide [14] and is slightly sensitive to temperature, salinity, and drought. After wheat and rice, maize is the third most significant cereal in Pakistan [15]. Dent and flint are the most important types of maize. The smooth, spherical shape is the feature of flint kind [16]. Dent kernels are flatter and larger in size, their endosperm is made of soft starch, and they take time to dry. Flints are hybrids and are suitable for dumpy seasons. They are round, hard, and dry kernels. As there is a continuous need to improve maize production, a crucial aspect of this improvement is the enhancement of the germination of seeds [17]. The most basic form of germination occurs when a seedling from an angiosperm or gymnosperm seed sprouts [18]. In the imbibition phase of germination, the seed coat swells and softens at the optimum temperature. The radical and plumule emerge when the seed coverings break. This is the seed germination lag phase. Three elements are required for seed germination: water, oxygen, and temperature [19].

The effect of a magnetic field on maize seed germination was evaluated in this study. Seedling growth and maize seed germination can be significantly improved by exposure to a magnetic field. The previous study offers valuable information about how to use magnetic field to enhance methods of agriculture, increase crop yield, and also describes the magnetic field effect on the growth (chlorophyll, root/shoot length, fresh/dry weight) [20]. Not much research was carried out on the effect of the pre-sowing magnetic field approach for enhancing maize seed germination. Our research was mainly designed to reveal the possible effects of a magnetic field on the metabolic machinery of the maize plants and detect changes occurring in germination processes and growth patterns. Thus, the purpose of this study was to find out whether, under normal conditions, the pre-sowing magnetic field treatment of seeds may have a unique effect on the germination of seeds and seedling growth of maize (*Zea mays* L.).

Materials and Methods

A pot experiment was conducted to evaluate the growth and germination of maize seeds treated with different magnetic fields (100 mT, 150 mT) for time duration (30 sec and 1 min). Healthy, well-ripened seeds were selected, washed with distilled water, and then disinfected with 3% formaldehyde for ten mins. All the treated seeds, including the control, were sown in three replicates [21]. The pre-sowing magnetic treatment of seeds was carried out by using an electromagnetic seed stimulator. The magnetic field was applied to T_1 (100 mT for 30 sec), T_2 (100 mT for 1 min), T_3 (150 mT for 30 sec), T_4 (150 mT for 1 min), T_5 (200 mT for 30 sec), and T_6 (200 mT for 1 min) of maize seeds. A total of 336 seeds were picked up. To check the germination, two experiments were conducted: one in plastic pots and another in Pyrex Petri dishes.

The maize seed germination percentage, seed germination index, average time of emergence, length of the root, length of the shoot, length of the root and shoot, fresh weight of the root, fresh weight of the shoot, dry weight of the shoot, dry weight of the shoot, Vigor index I, II and chlorophyll contents were measured. Magnetic field increases germination and improves their quality.

Maize Seeds Germination

In vitro studies: 21 Petri dishes were used. After 48 hours, the germination process was initiated. After 48, 72, and 96 hours of seeding, the total number of seeds that germinated were counted. Every day, the germination data was recorded. Data was recorded until constant germination.

In Vivo studies: Maize seeds were placed in plastic bowls, and the sand was cleaned using tap water and then again with distilled water. The sand was air-dried and then run through a sieve [22]. Wet sand was kept on the bottom filter for use as sand culture [23]. 10 seeds were distributed at a uniform half-inch depth in each pot. Untreated seeds were used as control. The number of germinated seeds was measured after 72, 96, 146, and 194 hours of sowing. After 30 days of planting, the length of roots and shoots, as well as their total length, were calculated by measuring tape. Root/shoot fresh/dry weight was measured using an electric balance. Chlorophyll contents were directly measured with the help of a chlorophyll meter.

The following formulas were used to calculate the percentage germination [24]:

$$Germination(\%) = seeds\frac{germinated}{total} \times 100 \quad (1)$$

$$Germination\ Index = \sum Gt/Dt \quad (2)$$

Where on day t, *Gt* is the number of seeds that germinated, and *Dt* is the time period that corresponds in days.

The formula below was used to find the average time for germination (Ellis and Roberts, 1981) [25].

$$Average\ time\ for\ germination = \sum Dn/\sum n \quad (3)$$

At the final stage of the experiment, n is the number of seeds that emerged, the test was conducted for 30 days, and the number of seeds that germinated on each day was n.

Abdul-Baki and Anderson's (1973) formulas were used to calculate the Vigor index [26].

$$Vigourindex1 = Germination(\%) \times seedlinglength(root + shoot) \quad (4)$$

$$Vigourindex2 = Germination(\%) \times seedlingdryweight(root + shoot) \quad (5)$$

Analysis of Maize Seed Growth and Its Parameters

The biophysical parameters and plant growth of these six plants were observed till 30 days after the completion of the germination. The software SPSS-10 was used to analyze the data. Two-factor analysis of variance (ANOVA) was carried out for the laboratory experiment using a split plot randomized full block design (CRD). The least significant difference (LSD) across treatments for each treatment was calculated.

Results and Discussion

The germination performance of treated maize seedlings was significantly higher than that of untreated seeds ($P \leq 0.05$). The pre-sowing magnetic field treatment indicated improvement in the percentage of germination, seed germination index, and root/shoot length, plant height, the root/shoot fresh/dry weight, Vigor indices I and II, and chlorophyll content as shown in Fig. 1. The germination percentage enhanced up to 15-50%, length of the roots increased 3.3 to 55%, shoot length was 8.7-60.8%, the increase in plant height was found to be 9.3-61.3% than untreated seeds (Table. 1). The root/shoot fresh/ dry weight were increased significantly as 7.7-92.3% (fresh weight root), 2.9-84.7% (fresh weight shoot), 20-150% (dry weight root), and 13-85.5% (dry weight shoot) as compared to control. There is improvement in the Vigor indices I and II, which were calculated at 32.7-118.3% and 35.8-130% over control. The increase in chlorophyll contents was 7.8-32.9% in comparison with the control. The plant total fresh weight increased significantly by 8.9-85.4% and plant total dry weight by 14-86.4% compared to control (Table. 2). These results showed that the magnetic field improved plant characteristics as compared to the control. Data analysis showed that T_5 (200 mT for 30 sec) showed the best results in all parameters. The enhancement of %germination and less mean germination time was noted higher in T_5 (200 mT for 30 sec). The plant's root and shoot length showed a significantly greater response in almost all treatments. However, the shoot length decreased for some exposure 100 mT in 30 sec, 100 mT for 1 min, and control. Root length was reduced in T_6 (200 mT for 1 min) and T_1 (100 mT for 30 sec) treatments. Plant length was best in $T_{5,}$ and we noticed it decreased in T_6. Root and shoot fresh weight was maximum in T_5 (200 mT for 30 sec), root fresh weight was minimum in T_2 (100 mT for 30 sec), and shoot fresh weight was less in T_6 (200 mT for 1 min) as compared to other treatments. Seedling dry weight was greater in T_5 (200 mT for 30 sec) and T_4 (150 mT for 1 min) treatments. Root and shoot dry weight was observed better in T_5 (200 mT for 30 sec), root dry weight was lowest in T_1 (100 mT for 30 sec) as well as in T_3 (150 mT for 30 sec), and shoot dry weight was at a minimum in T_6 (200 mT for 1 min). On the basis of germination and seedling length percentage, Seedling Vigor I showed a trend like that of seedling root and shoot length. Based on the percentage of germination and dry weight of the seedlings, the seedling Vigor II values were higher for T_2 (100 mT for 1 min), T_4 (150 mT for 1 min), and T_6 (200 mT for 1 min). The magnetic field also had a positive impact on chlorophyll contents as it was increased in all the treatments when compared with control.

The results regarding germination and growth reveal that magnetic treatment increases the germination rate and initial stages of growth of maize plants. In comparison with untreated seeds, the seedlings from magnetically treated seeds grew heavier and larger. Maize seeds exposed to different magnetic field strengths were found to be better compared to the control seeds. It has been observed that maize and

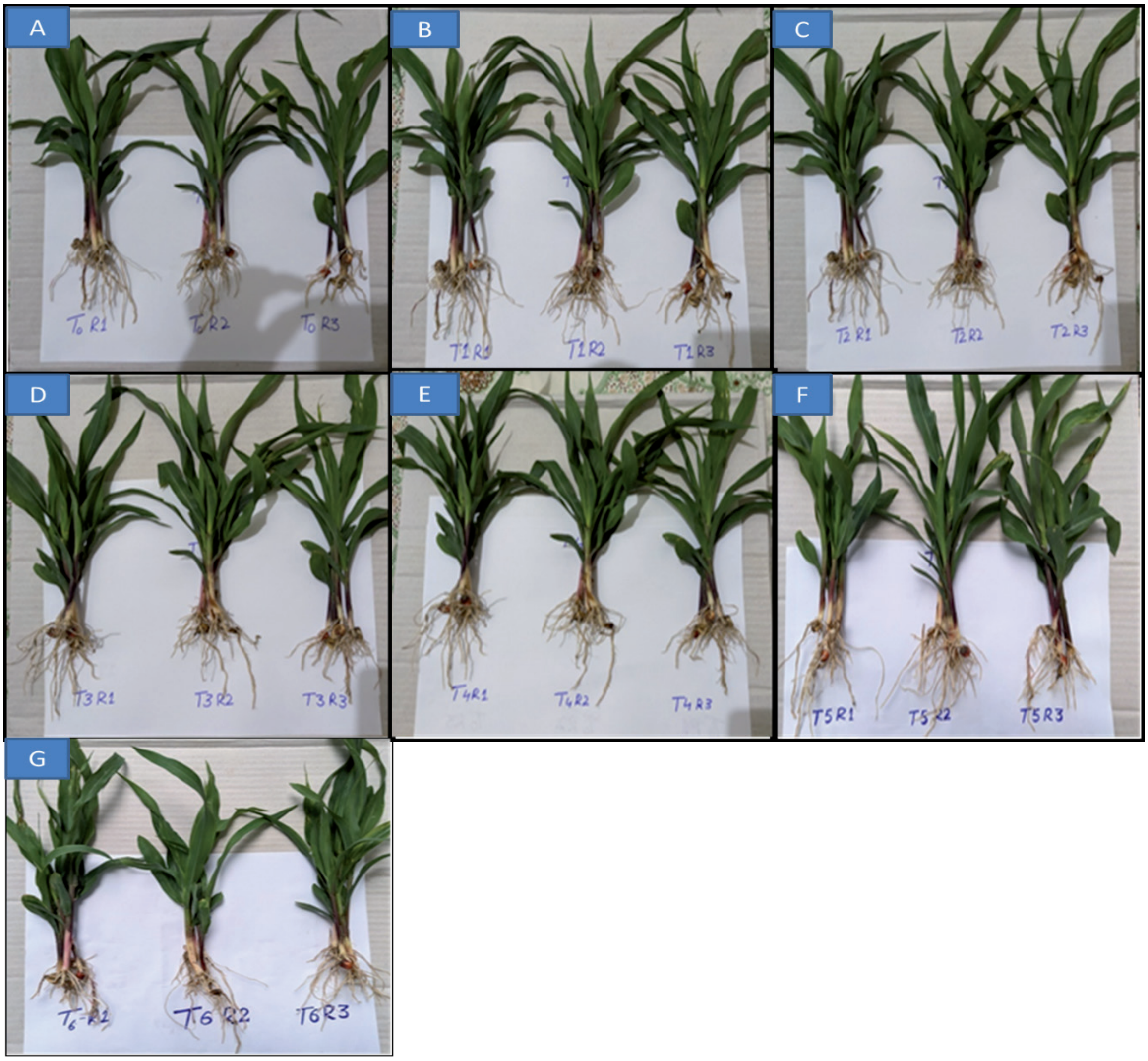

Fig. 1. Magnetic field treatment's impact on maize seed emergence, root length, and shoot length.

other crops show such improved seed performance in germination parameters [27]. In previous studies on wheat seeds, [28] it was demonstrated that seedlings developed from magnetically treated seeds grew quicker, increased their moisture absorption, slowed down their respiration, and decreased their heat energy release as compared to control. In soybeans, [29] it was shown that seeds treated to a magnetic field can hold onto moisture more effectively. The length, weight, and Vigor indices of seedlings increased by physiological activity based on the treated seeds' increased absorption of moisture.

Table 1. The effects of magnetic field exposure on the length of the roots, shoots, mean emergence time, germination percentage, and root and shoot length of maize seeds.

Treatment	Germination Percentage	Seed Germination Index	Mean Emergence Time	Length of root (cm)	Length of shoot (cm)	Length of root+shoot (cm)
T_0	20±0.943 d	1.4±0.93 ab	6.1±0.853c	6±1.045 d	23±1.322 e	29±0.593 e
T_1	26±0.753 c	1.23±0.89 c	6.1±0.98 c	6.7±1.05c	25±0.74 d	31.7±1.42 d
T_2	23±0.29 b	1.6±1.04 a	7.8±0.84 a	7.5±0.49 b	26±0.49 b	33.5±0.73 b
T_3	28±0.85 c	1.3±1.95 d	6.9±0.89 b	7.8±0.74 a	29±0.84 c	36.8±0.75 c
T_4	26±0.74 a	1.13±0.83 d	6.2±1.04 c	7.1±0.74 b	31±0.73 b	38.1±0.58 b
T_5	30±1.04 d	1.3±1.02 d	5.8±1.95d	9.3±0.85 b	37±1.32 a	46.8±0.72 a
T_6	23±1.103 b	1.13±0.93 d	7.5±0.74 a	6.2±0.64 e	34±0.85 b	39.2±1.001c

Table 2. Effect of pre-sowing magnetic field on the root and shoot fresh and dry weight, Vigor index I, II, fresh weight of root+shoot, dry.

Treatment	T_0	T_1	T_2	T_3	T_4	T_5	T_6
Fresh Root Weight (g)	1.3±0.073c	1.4±0.583b	1.6±0.983b	1.7±1.032d	2.2±1.322c	2.5±1.492c	2.4±0.843a
Fresh Shoot weight (g)	14.4±0.922d	17.8±0.742e	25.4±0.643a	19.2±1.032c	23.2±1.302b	26.6±1.021d	14.7±0.643a
Root Dry Weight (g)	0.1±1.492e	0.12±1.032c	0.15±1.302b	0.12±0.722d	0.22±0.854b	0.25±0.893c	0.18±0.833a
Shoot Dry Weight (g)	6.9±0.853e	8.4±0.583b	10.3±0.633a	9.8±0.873d	11.6±0.783b	12.8±0.393c	7.8±0.482a
Vigor index I	580±0.872f	824.2±0.042d	770.5±0.643e	1072.4±1.032b	990.6±1.302c	947.6±1.021c	1266±0.643a
Vigor Index II	240±1.492f	357.76±1.032f	476.1±1.302c	428.4±0.722e	499.2±0.854b	326.6±0.893d	552±0.833a
Chlorophyll content	29.4±0.853d	37.2±0.583a	31.7±0.633a	33.7±0.873b	33.1±0.783b	39.1±0.393c	38.3±0.482a
Fresh weight of Root & Shoot (g)	15.7±0.85 f	19.2±0.58 g	27.0±0.63 b	20.9±0.87 d	25.4±0.78 c	29.1±0.39 e	17.1±0.48 a
Root &shoot dry weight (g)	7.0±0.87 d	8.52±0.04 b	10.45±0.98 a	9.92±0.84	11.82±0.89 b	13.05±1.04 c	7.98±1.95 a

There was no linear growth with increasing field intensities; some fields were more effective than others. Similarly, there was variation in the response to exposure duration, and there was no correlation found between the amount of exposure time and the improvement in seedling parameters. Furthermore, in our study, a magnetic field was applied to some dry seeds, whereas the study conducted by them involved the soaking of the seeds in water before the exposure. The relation between exposure time and the magnetic field in the most recent research showed that, as compared to other combinations and control, a particular combination of most of the germination properties was significantly increased by the magnetic field and 200 mT for 30 sec. When the ragi (*Eleusine coracana* Gaertn) seeds were subjected to a magnetic field, this increases the potential that the internal energy of the seeds is increased by phenomena like resonance. By correctly selecting the exposure duration and magnetic field, higher yields could be produced [30]. When compared to the control, the leachate from seeds given to a 200 mT field had lower conductivity, showing that the seeds' seed coat membrane integrity was higher [31]. On the other hand, the 37.5 mT field did not affect the amount of cellular electrolyte leakage in barley seeds [32].

In field studies, when compared to the control, the field emergence index increased. This is according to our observations in the lab, where the application of magnetic treatment enhanced the germination process [33]. Similar enhancement in germination speed has been observed in maize seedlings exposed to magnetic fields [34] and in wheat [35]. Most useful observations were significantly increased. Plants produced from magnetically treated seeds showed enhanced root properties and increased shoot/root weights. [36] Demonstrated that significant improvements in the mitotic index and the incorporation of thymidine into DNA were found in Vicia faba seedlings exposed to an electromagnetic field with a power frequency of 100 μT. These are apparent indications that exposed seedlings to a magnetic field showed better growth. The increase in the system's free Ca^{2+} concentration is thought to be enabled by interfering with Ca^{2+} ion sequestration in the ion-cyclotron resonance.

The cell might start an early mitotic cycle in response to the elevated Ca^{2+} concentration. Furthermore, increased Ca^{2+} ion absorption in meristematic tissues in stems, roots, and leaf growth were observed in rice seedlings grown from seeds treated with pulsed magnetic fields [27]. In soybeans, [12] demonstrated that seeds with a 300 mT magnetic field were better able to absorb moisture. [2] Bitter gourd seedlings in a magnetic field showed signs of cellular water redistribution in comparison to controls that did not. [8] Found that young maize plants were enhanced by magnetic fields between 50 and 250 mT in strength. The advantages of magnetic treatment on the emergence and germination of two large bean varieties were published. For all exposed samples, the length of the plants was greater than what was observed during the first 20 days of growth. [37] conducted experimental research on the absorption of water by seeds of lettuce that had been treated in a magnetic field that was steady with the strength of 1-10 mT. They showed that the rate of water absorption was accelerated by the applied magnetic field, which might be responsible for the treated lettuce seeds' increased germination speed [38]. When seeds were magnetically exposed as compared to controls that were not exposed, larger levels of cytoplasmic bulk water and hydration water, as well as the early formation of structural and hydration water, were revealed by the analysis of the NMR relaxation time of the seed water. Additionally, as seen by their respective relaxation periods, the treated seeds had increased molecular mobility for both the bulk water in the cytoplasm and the hydration water of macro-molecules. This could be the cause of the treated seedling's earlier germination and greater Vigor than the untreated plants. The cytoplasmic bulk water's relaxation time, along with the activity of enzymes involved in germination, generally showed a highly significant connection, demonstrating the importance of this water fraction for the metabolic processes involved in the germination process. The tissues exhibit diamagnetic behavior under both control and MF conditions, according to the magnetic studies. Interestingly, the roots treated with 250 mT showed super-paramagnetic activity in addition to diamagnetism. A significant amount of biological materials are actually diamagnetic [39]. By breaking down and separating salt molecules, MTW irrigation aids in soil leaching, and the magnetic approach allows the use of salty materials that are typically unsuitable, like water with a salt level of 2,000 ppm to 5,000 ppm, which becomes effective for crop irrigation. Even in saline soil, magnetizing treated water improves plant absorption of water nutrients and improves various growth parameters, which results in higher biomass compared to untreated plants. Specifically, compared to untreated water, irrigation with magnetized water from underground showed a much higher germination percentage and an enhanced germination ratio. Because electrical and magnetic fields have a significant impact on the hydrogen bond in liquid water, the stimulatory effect of applying a magnetic field to the water with regard to increasing the seed germination ratio causes magnetized treated water to have different chemical and physical characteristics from untreated water. It becomes clear from the experiments and studies that the impact of magnetic treatment on the growth of plants and seed germination is dependent on the magnetic field strengths and exposure time. Being the primary photochemically active substance, chlorophyll is essential to plant growth and environmental adaptation. In barley, canola, chickpea, date palm, maize, microalga, soybean, sweet pepper, and wheat, magnetic field treatments significantly increased the amount of chlorophyll. Exposures for 240-360 min with static magnetic fields with strength of 100 mT raised the concentration of carotenoids, chlorophyll, and photosynthetic pigments above 10% [40]. Seedling length, dry weight, and Vigor indices may have increased overall, possibly because of treated seeds' higher physiological activity based on their increased absorption of moisture.

Conclusions

Many techniques are used to increase the growth of plants and seed germination. Maize seed germination and emergence were enhanced by magnetic induction of the seed. Plant emergence was more uniform because of this treatment and occurred two to three days earlier compared to the control. The magnetic field's effect on plants, which are sensitive to them, boosts their energy. The results indicate that different magnetic treatment intervals were found to have an impact on the enhancement of soil qualities, as well as the growth and production of maize. Treatment T_5, 200 mT for 30 sec exposure, showed the best results compared to all the different field strength and duration combinations. Seeds exposed to the above treatment showed an increase that was significant in germination (%), overall plant length (cm), weight (g) of fresh/dried roots and shoots, and chlorophyll contents. Magnetically treated maize seeds may be used in rain-fed agriculture. Lastly, we stressed that the application of a magnetic field in agriculture may be a potential method for improving agriculture; more study is still needed to completely understand its workings.

Acknowledgements

The authors extend their appreciation to the ongoing Research Funding Programme (ORF-2025-293) King Saud University, Riyadh, Saud Arabia.

Conflict of Interest

The authors declare no conflict of interest.

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