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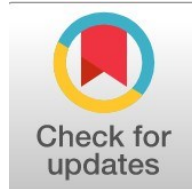
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Using Static Magnetic Field to Overcome Salt Stress in Maize Seeds

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Abstract

General Background: Salinity stress is a major environmental factor limiting crop productivity worldwide, particularly affecting early growth and germination stages in maize (*Zea mays* L.), a crop vital for food security and industry. Specific Background: Recent advances in agricultural biophysics have highlighted magnetic field treatment as a safe, cost-effective method to stimulate plant physiological responses and improve stress tolerance. However, its mechanisms and efficacy under salinity conditions remain insufficiently explored. Knowledge Gap: Few studies have systematically assessed the effect of static magnetic fields on maize germination and seedling vigor under salt-induced osmotic stress. Aims: This study aimed to evaluate the impact of static magnetic field pretreatment on maize seed germination, seedling growth, and proline accumulation under varying salinity levels. Results: Exposure to 100 mT for two hours significantly enhanced germination percentage, seedling vigor, proline content, and field emergence compared to untreated controls, particularly under 2000 mg/L NaCl stress. Novelty: The findings demonstrate that static magnetic fields can mitigate the negative effects of salt stress by promoting physiological resilience without chemical intervention. Implications: This technique provides an eco-friendly strategy to improve maize establishment and productivity in saline-prone agricultural systems.

Highlight :

- Exposure of maize seeds to static magnetic field enhanced germinability under salinity stress conditions.
- Magnetic pretreatment improved seedling vigor, proline content, and field emergence.
- The 100 mT for two hours treatment showed the best performance in mitigating salt stress.

Keywords : Maize, Magnetic Field, Salinity, Germinability, Field Emergence

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Introduction

Modern agricultural technology is based on physical seed pretreatment to promote vigor of seedling and crop establishment. Using a static field on dried seeds before sowing can improve plant development and yields in non-stressed settings. Dry maize seed magnetic fields exposure is safe and cost-effective physically presowing increasing post-germination development and boost crop output. Chemical fertilizers, herbicides, and proper genetic resources are widely employed to increase agricultural productivity [1]. Magnetic treatment can be either static or pulsed magnetic stimulation. Maize crop performance has an important role in the global economy and is a significant constituent in manufactured goods; its effectiveness is mostly attributed food security [2]. Maize considered salinity sensitive, particularly during the early stages of germination [3] and [4]. [5] found that the germination and seedling emergence stages of the plant life cycle are more vulnerable to saline stress than the adult stage. Early growth stages of seedling vulnerable for most crops, in addition, decreased growth as salt levels increased [6]. The purpose of this study was to assess the effectiveness of magnetic field pretreatment in alleviating salt stress in maize seedlings and boost seedling establishment. [7] found that maize seedlings elongated faster when exposed to magnetic circumstances and salt. The magnetic field enhanced maize shoot development, resulting in increased germinating energy, germinability, fresh weight, and shoot length. [8] indicated that one-month-old maize plants and chickpea seeds exposing to magnetic fields increased germination, seedling vigor, and shoot/root growth. In addition, germinating seeds enhanced in sunflower crop. [9] observed that maize seeds exposure to magnetic field 1000 Gauss for 2h can activate the metabolism cellular. [10] reported that 200 mT and 150 mT were more effective in increasing most of the seedling parameter. [10] reported that magnetic field treatment resulted in significant production of reactive oxygen species (ROS.). There are many physiological, biophysical and molecular changes that occur due to magnetic stimulation in plants but basis of magneto-reception is unclear. The boosted functional root parameters indicate that the magnetic treatment method applied on farms, where occurred better growth roots to allow extraction of moisture through layers of soils in deeper, and this treatment has no residual effect when compared to chemical treatment, so organic agriculture can be supplemented with this treatment. Crop productivity has declined due to global climatic variations and population growth. Seed germination and subsequent establishment of the vigorous seedling is an important juncture in the plant lifecycle and it decides the success of crop cultivation. Germination is the process in which the metabolically dormant seed becomes metabolically active leading to successful growth and establishment of a plant. Hormones and signaling molecules boost the germination mechanism, which can then trigger a suitable signaling cascade that leads to emergence radicle. Salinity considering a significant environmental stress that affects around 800 million hectares of land worldwide, accounting land area about 6% [11]. Salinity considered a substantial expense in agriculture and deteriorates environmental conditions. It also has a significant impact on loss of crops, reducing about 50 percent of intermediate yield for important crops [12]. Furthermore, water stress caused by salinity-reduced water potential, a typical side effect of both salinity [13], and had negative effect on seedling vigor. Salinity has a significant impact on seed germination, which is one of the most important stages of plant life [14]. High NaCl level in the salt solution enhances its osmotic potential, as shown in [15]. Furthermore, the significant salt absorption of Na or Cl through germination stages due to attributed to toxicity, which ultimately decline seed germination. Also, reduced the germination indices with increased stress of salt [16].

Materials and Methods

During 2024, experiments of pots and laboratory were demonstrated in greenhouse. Sample of maize seeds investigated on maize hybrid single white, exposure dry seeds to magnetic field and sowing under three salinity levels induced by NaCl; i.e. Tap water 320 mg/l, 2000, and 4000 mg/l.

Treatments and Experiments Design:

Two types of agriculture cradles were used to carry out lab and pot trials in greenhouse conditions. The lab experiment used Petri plates after sterilized with 15cm diameter set on filter paper beds in growth chambers. Each dish has 25 seeds placed on filter paper beds. The pot experiment was carried out in a greenhouse using 15 cm diameter plastic pot filled 1 kilogram of air-dried loamy soil and placed in 75°C in oven 1 day. 25 maize seeds were seeded in every pot at 3 cm depth of and duplicated three times; applied irrigation when needed; data on emergence of seedling up to 14 days from planting seeds; after 15 days of germination the plants were harvested. The treatments were distributed in (RCBD) in three replicates.

Measurements

(GP) Germination percentage: Normal seedling counting seven days according rules of [17].

$GP = \text{Normal seedlings} / \text{Total seeds} \times 100.$

Shoot and root length (cm): Ten random seedlings taken to measure the shoot/ root length.

(SDW) Seedlings Dry Weight: Tested following oven drying at 70°C until consistent weight [18].

(MGT) Mean Germination Time: Was calculated by equation to [19].

$MGT = \sum Dn / \sum n$, where n is the number of seeds which were germinated on day time, D is the number of days counted from the beginning of germination test.

(SVI) Seedling Vigor Index: Calculated according to [20]. $SVI_1 = (GP) GP \times \text{seedling length}.$

$SVI_2 = (GP) \text{ Germination percentage} \times (SDW)\text{seedling dry weight}.$

Proline content: Weighing the leaf samples 200 mg were pulverized in nitrogen liquid and homogenized in 5 mL of sulphosalicylic. Mixed the extract acid ninhydrine 2 mL, and glacial acetic acid 2 mL. Heated the samples to 100°C. The mixture was extracted by toluene, and measured free toluene at 520 nm spectrophotometrically [21].

Field emergence: Pots of 25 cm diameter air-dried loamy soil filled by 5 kg of. 50 maize seeds were sown per each plot according to [17].

Statistical analysis: (ANOVA) of RCBD of variance were used according to [22]. LSD. at 0.05 level of significance compare between means used.

Results and Discussion

Concerning static magnetic field on germinability parameters. **Table 1 and Figure 1** showed highly significant differences statistically, under lab the main effects of static magnetic field of tested maize seed and the salinity levels (control 320, 2000 and 4000 ppm NaCl) on germinability.

condition; i.e. Germination %, root, shoot, seedling length and SDW of maize seedling as influenced of salinity stress. The results demonstrated substantial differences across static magnetic fields, with 100 mT for 2 hours recording the greatest mean values when compared to other treatments. Control recorded the lowest results for germination percentage and seedling length. [1] stated that magnetic fields influence plant survival in harsh environments and that needed further research to understand mechanism of their interaction to protect difficulties that facing stress. [9] demonstrated that exposing maize seeds to a 1000 Gauss (100 mT) magnetic field for 2 hours activates maize cellular metabolism. [10] found that treatments at 200 and 150 mT were more effective in raising the majority of seedling parameters. [10] found that magnetic field therapy increased (ROS; Reactive Oxygen Species). [23] exposure to the static field increases nitrogen and carbon metabolism of salinity. Increasing salinity stress levels had negatively impact on all examined parameters. Therefore, the main effect of salinity on germination parameters affected negatively when increased salinity levels up to high level 4000 ppm NaCl in comparing to control (**Figure 2**). [16] indicated that the germination decreased under salt stress. Regarding the content of proline and field emergence, the best tolerance salinity, and the seed superiority due to to genetic make-up. Germination percentage declined in related to absorbed water salted [24]. [25] and [26]. Treatment of 320 mg/l is the best salinity level of shoot, root lengths, fresh seedling, dry seedling weights in compared with salinity levels increased [27], they noticed that maize with white grain advanced yellow grain in vigor. Maize response against different salinity levels recorded highly significant, more that salt stress adversely affected the vigor and germination measurements [28]. Furthermore, proline content and field emergence revealed a positive association between rising NaCl and proline content, with the maximum values recorded at 4000 mg/l treatment compared to the 320 mg/l. Proline buildup during osmotic pressure of the vacuole and adverse conditions which protect the cells [29]. Proline is a significant enzyme stabilizing factor under NaCl salt stress [30]. Salinity, active osmotic solutes like proline appears better plant mechanisms. In additions, proline may cellular interact macromolecules [31].

Table 1. Magnetic field and salinity levels effects on germination, shoot, root, seedling length and seedling dry weight.

Treats	G %	oot Length. (cm)	oot Length. (cm)	Seedling Length. (cm)	Seedling Weight. (gm)	Dry
A. Magnetic field						
Control	95.2	15.7	13.6	29.2	0.430	
100 2h	97.6	17.6	14.3	31.8	0.501	
200 1h	96.2	16.4	14.1	30.5	0.353	
LSD 0.05	0.736	1.036	-	1.303	0.029	
B. Salinity						
Control	96.4	16.7	14.3	31.0	0.417	
2000	96.1	16.8	14.3	31.2	0.45	
4000	95.4	15.9	13.3	29.29	0.416	
LSD 0.05	-	-	-	1.303	0.029	
Interaction						
A X B	NS	*	NS	*	NS	

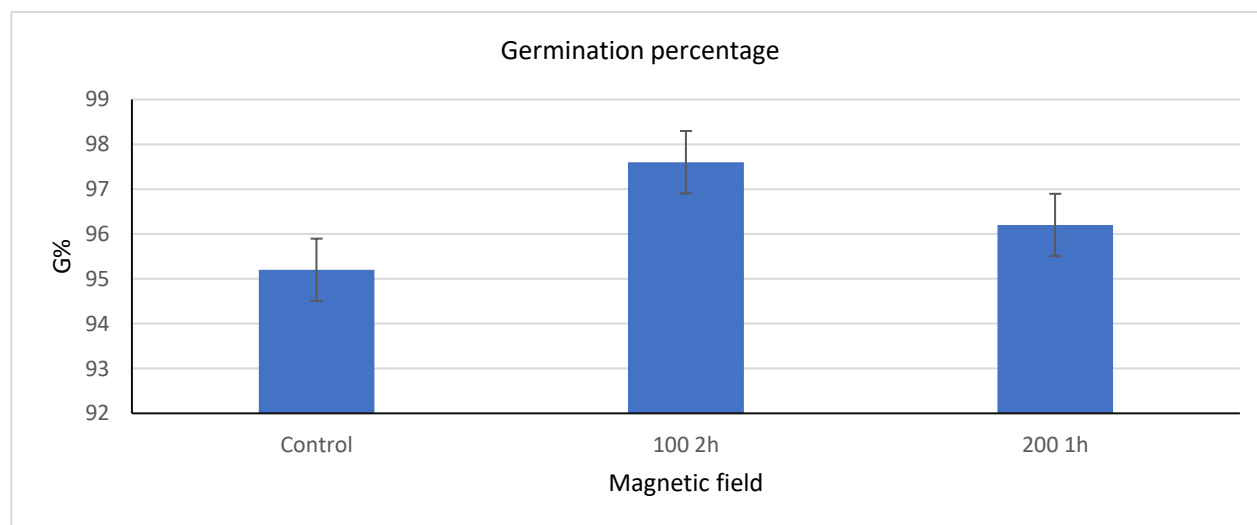


Figure 1. Magnetic field effects on germination percentage.

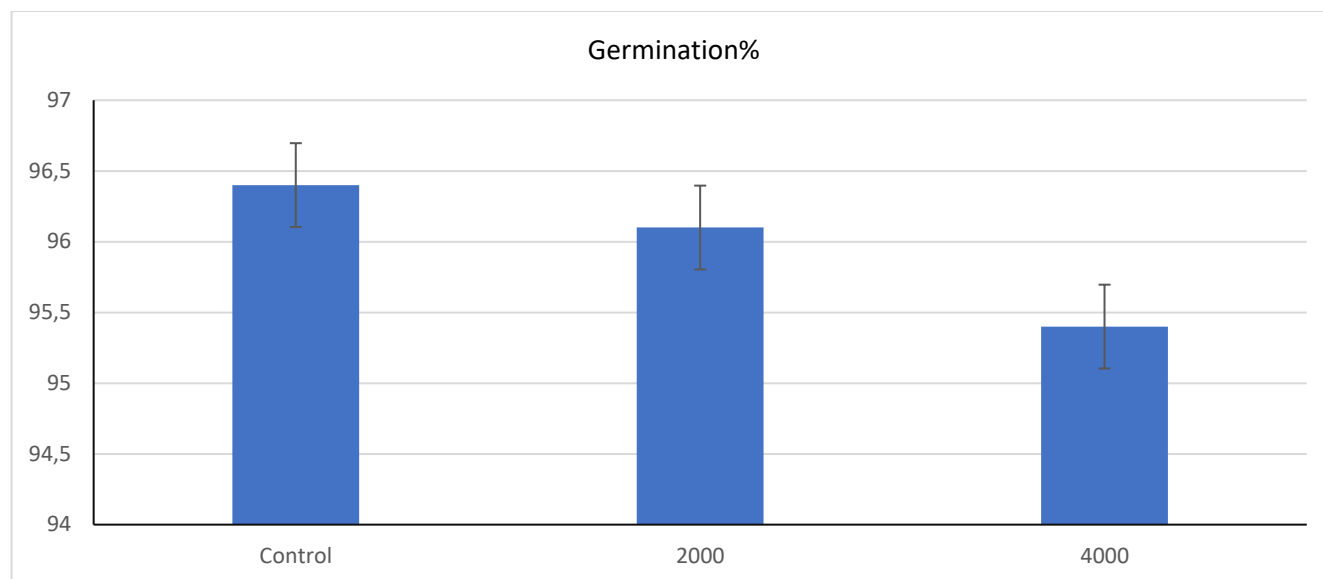


Figure 2. Germination percentage as affected by levels of salinity.

Highly differences of significant reported at main effect of a static magnetic field as shown in **Table 2** which indicated that the main effect of magnetic field and salinity levels on SVI 1, SVI 2, proline content, mean germination time, and field emergence. 100 mT for 2 hours gave the highest values of seedling vigor index1 and 2. Also, increase proline content as well as recorded lowest mean germination time and enhanced the field emergence comparing to untreated magnetic field followed by 200 mT for 1 hour.

Table 2. Magnetic field and salinity levels impacts on SVI 1, SVI 2, proline content, mean germination time and field emergence.

Treats	Seedling vigor index1	Seedling vigor index2	Proline content	1 Germination Time	1 emergence %
A. Magnetic field					
Control	2810.4	41.4	3.245	3.8	92.0
100 2h	3059.2	48.2	3.942	3.4	95.4
200 1h	2900.6	33.5	3.513	3.6	92.2
LSD 0.05	126.7	2.76	0.119	0.116	2.1
B. Salinity					
Tap water	2986.9	40.2	3.267	3.6	93.3
2000	2974.5	43.0	3.514	3.7	92.7
4000	2808.7	39.9	3.919	3.6	93.
LSD 0.05	126.65	2.76	0.119	0.116	1.38
Interaction					
AXB	NS	NS	**	**	NS

Table 3 showed static magnetic field and stress of salinity interaction on G%, (SL) shoot, (RL) root length, (SL) seedling length, (SDW) dry weight of seedling, (SVI2) seedling vigor index 2, proline content, (MGT) mean germination time and (FE.) field emergence. 100 mT for two hours improved germination percentage and seedling establishment. On the other hand, stress of salinity generated NaCl increased quantity from 320mg/l to 4000mg/l, causing a substantial decrease in all seedling growth metrics (G%, shoot, root, length of seedling, SDW and SVI. The control treatment (320mg/l) produced the best results, whereas the salinity level (4000mg/l) led to the greatest reduction of all characteristics. 100mT for two hours reduced significantly and improved seedling metrics at moderate salinity levels of 2000 ppm NaCl. In terms of field emergence, salinity stress levels of 320 mg/l had the highest germination percentage 88% compared to each NaCl concentrations, while 4000 mg/l had the lowest reduction (60%).

Table 3. Interactions effect between static field and salinity stress on germination (%), root, shoot, length of seedlings, (SDW) seedling dry weight and (SVI1) seedling index 1.

Magnetic field	Salinity levels	Germination%	Shoot Length (cm)	Root Length (cm)	Seedling Length (cm)	Seedling Dry Weight (gm)	Seedling Vigor Index 1
Control	Tap water	96.7	14.9	14.0	28.9	0.41	2796.1
	2000	96.0	15.9	14.0	29.9	0.447	2873.3
	4000	96.0	16.1	12.67	28.8	0.4343	2761.6
100 2hours	Tap water	97.0	17.9	14.3	32.27	0.472	3119.3
	2000	98.0	17.3	14.3	31.7	0.537	3040.7
	4000	97.7	17.1	13.0	31.4	0.494	3017.6
200 1hours	Tap water	95.7	17.2	14.7	31.8	0.37	3045.2
	2000	94.3	17.2	14.7	31.9	0.366	3009.5
	4000	95.7	14.7	13.0	27.7	0.318	2647.0
LSD 0.05		-	1.7938	-	2.2571	0.0494	219.37

[28] discovered that decreasing the osmotic potential of NaCl solution reduced percentage of germination, however high germination percentage were reached at the control. Loss in vigor and decline germination under high salt due to primarily to osmotic Na Cl, as well as a variety of impacts on the metabolism of plant cells that can disintegrate as a result of salt stress [32]. Under osmotic potential mean germination time delayed under salt conditions. Mean germination time was delayed under the stress conditions. [28]and [29] parameter of seedlings (G%, SVI) declined at high level of NaCl. [33] and [34], they found, decrease vegetative growth with high salinity. [35], they reported that genotypic variation among cultivars at the early seedling under salt index.

Table 4. Interaction between the magnetic field and salinity effects on seedling vigor index 2, proline content, mean germination time, and field emergence.

Magnetic field	Salinity	Seedling Vigor 2	Proline Content	Mean Germination Time	Field Emergence
control	320	39.63	2.867	3.8	91.7
	2000	42.94	3.4	3.9	91.7
	4000	41.69	3.43	3.5	92.7
100 2h	320	45.61	3.60	3.3	95.3
	2000	51.53	3.83	3.4	95.7
	4000	47.46	4.39	3.5	95.3
200 1h	320	35.39	3.3330	3.5	93.0
	2000	34.53	3.2733	3.67	90.7
	4000	30.42	3.9333	3.7	93.0
LSD 0.05		4.7782	0.2074	0.2006	2.3876

As shown in **Table 4** highly significant effects on seedling vigor index 2, proline content, mean germination time and, field emergence under static magnetic field and salinity stress. 100 mT for two hours recorded highest seedling vigor index 2 under high salinity levels, while enhancing proline content in maize seedlings at high salinity level. [36] reported that under salinity proline folded the normal. At high salinity conditions the proline content was significant [37] and [38]. The plant growth declined when salinity raising owing to major stress which adversely affect viability [15]. Maize is recognized as salinity sensitive particularly early growth [11; 29].

Conclusion

The present study concluded that exposing dry seeds to static magnetic field boost germinability as well as crop stand under saline conditions. Magnetic treatment, can relieve the deleterious effects of salt, particularly during the early stage. Germination reduced with increasing salt stress. A high NaCl quantity causing cell toxicity and inhibiting germination, ultimately resulting in a fall in germination percentage. The findings may be useful to farmers or seed production stakeholders looking for solutions to boost crop stand and yield while preserving crop stand in the face of potential hazards to plant growth from salt stress. Thus, pretreatment with a magnetic field enhancement salt stress in maize seedlings. The approach has the potential to improve maize seed germinability and field emergence in salinity-prone environments. It's only a few researchers have explored how static magnetic fields affect the fundamental physiological crop under stresses. To understand the mechanism of mitigation when exposure to static magnetic field and plant under adverse conditions (biotic and abiotic stress), a thorough bio stimulation

activity of magnetic field in many cellular metabolisms, as well as its subsequent impacts on tissue proliferation, must be explained. Future studies needed to utilize the benefits of static and pulse magnetic field on seeds and productions.

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