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Magnetic Field Treatment in Barley: Improved Salt Tolerance in Early Stages of Development

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HIGHLIGHTS

- Increased salt stress tolerance by treatment of magnetic field
- Effect of magnetic field treatment exposure time on growth parameters
- Treatment of environmentally friendly and innovative method for stress tolerance in barley

Abstract

It is known that salinity is one of the most important abiotic stress factors reducing productivity in agriculture. High salt concentration has a negative effect on seed germination and seedling formation. Magnetic field treatment can be considered as an environmentally friendly, innovative and inexpensive method to increase tolerance to stress, as a productivity-enhancing factor in agriculture. In this study, germination rate, germination strength, shoot and root length, fresh and dry weights, chlorophyll a, b and total chlorophyll content and ion leakage values of three different barley varieties under the influence of 150 mT constant magnetic field at different time intervals were determined. In light of the results, it was determined that although it varies according to the barley varieties, it has a significant positive effect on the germination rate and strength depending on the duration of the applied magnetic field. This study revealed that the magnetic field seed treatment has different effects according to the treatment time and the severity of the salt stress.

Keywords: Barley, salt stress; magnetic field treatment, improved tolerance

1. Introduction

Barley cultivation is in second place after wheat among the cereals in Turkey. Although the purpose of growing barley is for feed and partial malting production, its use for food is increasing with its rich carbohydrate content (Tafresh et al., 2023). Malting barley production has a very small place in total barley production in Turkey. However, the export potential and prices of malted barley are higher than forage barley, which is an important indicator of increasing production (Anonymous, 2019). Turkey is the country with the highest amount of barley production in the world, the fact that the quality of malting barley produced is not in line with world standards causes difficulties in meeting the needs. For this reason, it is necessary to develop

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high quality barley varieties with high malt extract ratio and in accordance with standards in order to close the current gap (Kerpes et al., 2023). Obtaining varieties with superior characteristics can be achieved by breeding studies. The most important factors determining quality are the variety and environmental conditions. In order to produce malting barley in the required quantity and quality, it is necessary to determine the barley varieties suitable for the region where the cultivation will be carried out (Yu et al., 2023).

Abiotic stress, which is a factor that seriously affects yield and quality in plants, is one of the leading factors limiting agricultural production. Although stress factors are quite diverse, one of the most important stress factors is salt (Dawood et al., 2022). Plants can easily absorb the soluble salt in the soil. Salt compounds entering the body of the plant show negative effects when they exceed a certain density. With the increase in the salt concentration in the soil, it becomes difficult for the plant to take water from the soil, the structure of the soil deteriorates and the plant growth slows down or even stops (Yavuz et al., 2022). It is known that salinity is one of the most important abiotic stress factors reducing productivity in agricultural areas, and high salt concentration has a negative effect on seed germination and seedling formation (Cavdar and Yildiz 2021). Plants are more sensitive to salt in the early stages of their development than in other stages of development (Budaklı Carpıcı and Erdel, 2016). For this reason, it is appropriate to carry out studies in which salinity tolerance is determined at early developmental stages. The amount of salt in the environment has an important effect on the germination, healthy emergence and survival of the seed (Ozyazici and Acikbas 2021). Yavuz et al. (2023) reported that salt treatment is a fast and effective technique for the determination of salt-tolerant wheat cultivars during the germination and early seedling development period. The negative effect of salinity is observed in more than 20% of agricultural lands in the world (Hickey et al., 2019). In addition, the rehabilitation of saline areas is very expensive and it cannot be expected to be a permanent solution unless the factors causing salinity are eliminated. For this reason, the determination of salt-resistant varieties is important for plant cultivation in these areas. In terms of salt tolerance, there are differences between families, genera and species as well as among varieties belonging to the same species (Xu et al., 2023). The high salt levels in the soil and the quality of the irrigation water used are among the factors of concern for future agriculture. Therefore, it is important to develop effective strategies to increase yields through salt tolerance (Salim and Raza 2020).

Physical processes affect physiological and biochemical processes in seeds, thus contributing to vegetative growth, increasing crop yield and quality. Magnetic field (MF) pretreatment, which has been used in agriculture as an environmentally friendly technique, is one of the physical processes reported to increase the germination of seeds and yield of crops (Rathebe et al., 2023) and improve the performance of various crops (El-Gizawy et al., 2016). Many scientists have studied the positive and negative biological effects of MF on plants. MF treatment, in addition to contributing to vegetative growth by affecting the physiological and biochemical processes in various seed materials; is a physical process that also improves yield and quality as in potato and sorghum x sudangrass hybrids (El-Gizawy et al. 2016; Beyaz et al. 2020). MF exposure to various plant species may result in different biological effects at the cell, tissue, and organ levels (Bilalis et al. 2013). MF treatment has been carried out in important plant species such as wheat (Pietruszewski et al. 2001), soybean (Atak et al. 2003), maize (Vashisth and Joshi 2017), lentil (Aladjadjiyan 2010), sunflower (Vashisth and Nagarajan 2010; Matwijczuk et al. 2012), potato (Bahadir et al. 2020) and sorghum (Beyaz et al. 2020).

In the studies carried out so far, the magnetic field applied at low and high intensities increases the yield, increases the photosynthesis rate, decreases the antioxidant activity, reduces the effect of abiotic stresses (salinity, drought, heavy metal etc.), increases the germination rate and has positive effects on plant mass and root-stem development (Zuniga et al., 2016). However, magnetic field treatment exposure time is the most important factor for improved tolerance. With the agronomic and biotechnological studies to be done, the changes caused by the magnetic field in the plant can be determined, and environmentally friendly and inexpensive methods can be developed to increase the tolerance against environmental stresses.

In the current situation of the world, environmentally friendly and innovative agricultural approaches have become indispensable for ecological and sustainable life. There is a need for new solutions to alleviate the negative effects of abiotic stress factors such as drought, salinity and extreme temperature caused by the increasing global climate change in recent years. Although magnetic field treatments are not new, their effects and application methods on plants have not been efficiently studied. In this study, it was aimed to increase salt stress tolerance in barley varieties by different exposure times of MF.In this study, an alternative method has been examined to reduce the damage of increasing soil salinity on the plant. In this context, the physiological and biochemical effects of constant magnetic field treatment on barley at different exposure times were investigated for improved salt stress tolerance.

2. Materials and Methods

Plant Material

Three forage barley varieties "Baronesse", "Bolayır" and the malted variety"Aydanhanım" were used in the study. Seeds of barley varieties were obtained from Konya Selcuk University, Department of Field Crops Department. The "Aydanhanım" variety is developed by the Central Research Institute of Field Crops. It is bending-resistant. Also, it has high tillering and a good response to water and nitrogen (Anonymous, 2021a). "Baronesse" is a two-row, high-yielding forage variety developed in Germany and widely produced in the USA, and is used as a gene source in breeding programs to increase the yield of barley varieties in the USA (Saygılı, 2019). "Bolayır" variety has been registered by Trakya Agricultural Research Institute. It has a high tillering capacity and yields potential. It is a variety with good malting quality (Anonymous, 2021b).

Magnetic Field Treatment

Barley varieties seeds of Aydanhanım, Baronesse and Bolayır cultivars were exposed to 150 mT (militesla) MF (magnetic field) force at different time periods (0-control, 24, 48 and 72 hours). Magnetic field treatment was used according to Tanaka et al. (2010) with some changes from the method stated. In the study, sintered magnets with Nd-Fe-B band N35 Atech, Beijing, China (https://www.atechmagnet.cn/) were used for magnetic field treatment. These magnets are in the form of squares with dimensions of 50 mm x 50 mm x 10 mm and an average surface magnetic strength of 1.2 T (Tesla). A distance of 2.8 cm was set between the seeds and the magnets to ensure that the seeds were exposed to 150 mT MF force. The accuracy and uniformity of the MF power were checked with a digital tesla meter (ref. 13610-93, PHYWE, Göttingen, Germany).

Growing Conditions

The research was carried out in the laboratories of Selcuk University and Erciyes University, Faculty of Agriculture, Department of Field Crops. For seed sterilization, barley seeds were washed with 5% commercial bleach in a magnetic stirrer for 15 minutes. Then it was rinsed 3 times with distilled water for 5 minutes. After the seeds were dried on blotting paper for 10 minutes, they became ready for salt stress treatments. Three different NaCl doses, T0: 0 (control), T1: 3 g/L NaCl and T2: 6 g/L NaCl, were determined for salt stress treatment. For the germination test, sowing was carried out in glass petri dishes containing sterile filter paper, with 15 seeds in each petri dish. After 5 ml of the prepared salt solutions were added to them, they were covered with a second filter paper and 3 more ml of salt solution was added. Sterile distilled water was used in control treatments. Germination tests were carried out in a growth chamber at 24±1°C under dark conditions and constant humidity (50%).

On the other hand, a pot experiment was established under greenhouse conditions to determine the chlorophyll a, b and ion leakage parameters. For this purpose, the experiments were carried out in three replications, one seed in each pot, in pots filled with 500 g sterile soil. In pot experiments, seeds exposed to 150 mT MF at 4 different times (0, 24h, 48h, 72h) intervals were used. The pots in the experiment were regularly watered with 50 ml of T0, T1 and T2 salt solution. Analyzes were performed using fresh tissues at day 21 post-germination.

Examined Features

The examined morphological features were obtained by measuring and counting on the 4th and 8th days in accordance with the ISTA rules. Seeds with rootlets exceeding 2 mm were considered germinated and counted (Fuller et al. 2012). "Germination rate" was determined by counting the seeds germinated on the 4th day, and "germination power", "root length", "shoot length", "wet weight" and "dry weight" were determined by counting and measurements made on the 8th day. While determining the said characteristics, 10 seedlings randomly selected from each petri dish were used. Dry weight was determined by drying the wet shoots at 70°C for 24 hours (Atak et al., 2006; Saboora et al. 2006).

Analysis of chlorophyll a, chlorophyll b and total chlorophyll was performed according to Curtis and Shtty (1996). First, 50 mg of fresh shoot sample was kept in 3 ml of methanol at 23 oC' for 2 hours in a dark environment and homogenized. 0.3 ml of homogenized liquid was taken and optical density was measured in spectrophotometer at 650 and 665 nm, and the amounts of chlorophyll a, chlorophyll b and total chlorophyll were determined in μg chlorophyll/g fresh tissue and were calculated with the formulas given below.

Chlorophyll a = (16.5 x A665-8.3 x A650) x 3/ 0.05

Chlorophyll b = (33.8 x A650-12.5 x A665) x 3/ 0.05

Total chlorophyll = (25.8xA650-4.0 x A665) x 3/ 0.05

The ion leakage was done according to the method stated in Aydın (2012). After the fresh shoots (0.5 g) were washed with distilled water, they were kept in 10 ml distilled water at room temperature for 24 hours and the EC of the solution was measured (O.D1). Then, the ion leakage in the leaf tissues (O.D2) was calculated with the following equation after it was kept in the autoclave at 121 o C for 20 minutes, cooled and the EC was measured again.

% İon leake = (O.D1 / O.D2) x 100

Statistical analysis

The statistical analyses in this study were carried out on 3 repitations and 10 plants in each repitation. The data obtained for all the results that were measured and observed in the experiment were subjected to analysis of variance (ANOVA) in the JMP 13.2.0 program. The laboratory experiment was two factorial Split Plot Design. The salt stress treatment doses T0, T1, and T2 were the first factor, assigned to the main plots; and the different exposure times (0, 24h, 48h and 72h) of 150 mT MF treatment were the second factor allocated to the subplots (split plots). The differences between the means in the laboratory experiments were determined using the Duncan test at 0.05 level (Snedecor and Cochran, 1967).

3. Results and Discussion

Today, innovative and environmentally friendly approaches and strategies such as seed priming, organic and sustainable agricultural practices are of great importance (Oğuz et al., 2023). Similarly, MF techniques applied under suitable conditions are an innovative and environmentally friendly technique for improving seed germination, vegetative growth and different yield criteria in many species. In addition to contributing to vegetative growth, MF treatment affects physiological and biochemical processes in various seed materials; It is a physical process that also improves product yield and quality. (Beyaz et al., 2020; Bahadir, 2020). Many scientists have investigated the positive and negative biological effects of MFs on living organisms. MF exposure to various plant species can cause different biological effects at the cell, tissue and organ levels. (El-Gizawy et al., 2016). Biological effects of MF; It is directly related to the type, degree and exposure time of the MF treatment (Yildiz et al., 2017).

MF affects whole organism by modifying morphological, physiological and molecular properties (Pietruszewski and Martínez 2015). Exposure of seeds to higher MF strength increases seed germination and plant growth by increasing water assimilation and photosynthesis (Florez et al. 2007). Conversely, it has been reported that near-zero MF has a suppressive effect on biomass accumulation in generative period (Xu et al. 2013). This factor delays the floral transition, therefore to mature late and become vulnerable to negative effects of the environment. Seeds exposed to higher MF strength germinate not only faster but also more uniformly. Rapid and uniform growth is an indicator that plants will gain superiority against environmental conditions during vegetative development.

The results of Aydanhanım cultivar are given in Table 1. Germination rate of Aydanhanım cultivar decreased in parallel with increasing salt dose (Table 1). The germination rate, which was determined as 95.3% in T0 and MF control treatments, was measured as the highest value. According to MF exposure time in T0 stres treatment, the best germination rate was determined in control, 24 and 72 hours MF treatments. In T1 salt stress treatment, the best germination rate was determined at 93.0% in 72 h of treatment, while the best germination rate in T2 stress treatment was measured in 72 h of application with 93.0%. The difference between the germination rates at T0, T1 and T2 in 72 h magnetic field application is statistically insignificant (Table 1). The difference between salt stress treatments in germination power results was found to be statistically insignificant (Table 1). On the other hand, there is no statistical difference between the control, 24 and 72 h (95.3%, 98.4%, 96.9%, respectively) according to the effects of exposure to magnetic field on germination power; the germination power determined at 48 hours exposure time was the lowest (80.3%) (Table 1). The highest value in shoot length was determined at 13.6 cm in T0 and 72 h MF treatment (Table 1). The lowest shoot lengths in all MF application times were determined in T2 salt application. The difference between the root length values determined in T0 and MF control application (11.4 and 11.2 cm, respectively) and the root length (11.6 cm) determined in 72 hours MF application is insignificant. MF exposure time did not show a significant positive increase in the deterioration of root lengths compared to increasing salt stress treatments. The difference between the effects of magnetic field exposure times on wet weight values was found to be statistically insignificant. On the other hand, wet weight values decreased in increasing salt stress applications and the differences between them were statistically significant (Table 1). In dry weights, the difference between salt stress doses was found to be statistically insignificant, while the effects of magnetic field exposure times were significant. While the highest dry weight values were obtained in the 48 and 72 hours application, the difference between them and the control was insignificant. The mean values of chlorophyll decreased with the increase of salt stress. The highest chlorophyll value, which was measured as 273.2 μg/g in the T0 control application, decreased in T1 and T2 applications. The difference between T1 and T2 is statistically insignificant. The effects of magnetic field exposure times caused a significant increase compared to the.

Table 1. Effects of magnetic field treatment exposure times on the investigated parameters of Aydanhanım variety

MF exposure time	Germination rate				Germination power				Shoot length (cm)			
	T_0	T_1	T_2	Avg	T_0	T_1	T_2	Avg	T_0	T_1	T_2	Avg
Control	95.3^{a}	84.3^{abc}	77.7^{bcde}	85.8	97.7	93.0	95.3	95.3^{a}	12.9^{abc}	12.6^{abcd}	11.2^{de}	12.2
24 h	93.0^{a}	80.0^{bcd}	70.7^{def}	81.2	100.0	100.0	95.3	98.4^{a}	9.5^{f}	7.8^{g}	5.8^{h}	7.7
48 h	73.0^{cdef}	64.0^{f}	66.3^{ef}	67.8	86.0	77.3	77.7	80.3^{b}	12.0^{bcd}	11.6^{cd}	11.3^{de}	11.7
72 h	86.3^{ab}	93.0^{a}	93.0^{a}	90.8	95.3	97.7	97.7	96.9^{a}	13.6^{a}	13.2^{ab}	10.0^{ef}	12.3
Avg	86.9	80.3	76.9		94.7	92.0	91.5		12.0	11.3	9.6	

MF exposure time	Root lenght (cm)				Wet weight (g)				Dry weight (g)			
	T_0	T_1	T_2	Avg	T_0	T_1	T_2	Avg	T_0	T_1	T_2	Avg
Control	11.4^{a}	8.6^{b}	7.1^{d}	9.0	2.8	2.5	2.2	2.5	0.30	0.30	0.26	0.28^{ab}
24 h	11.2^{a}	9.0^{b}	8.8^{b}	9.7	2.8	2.4	2.0	2.4	0.26	0.30	0.20	0.25^{b}
48 h	8.4^{bc}	7.4^{cd}	7.1^{d}	7.6	2.8	2.7	2.4	2.6	0.30	0.30	0.33	0.31^{a}
72 h	11.6^{a}	8.3^{bc}	7.0^{d}	9.0	3.1	2.7	2.2	2.7	0.30	0.30	0.30	0.30^{a}
Avg	10.6	8.3	7.5		2.9^{a}	2.6^{b}	2.2^{c}		0.29	0.30	0.27	

MF exposure time	Chlorophyll a (μg/g)				Chlorophyll b (μg/g)				Total chlorophyll (μg/g)			
	T_0	T_1	T_2	Avg.	T_0	T_1	T_2	Avr.	T_0	T_1	T_2	Avg
Control	180,3	157,8	139,9	159.3^{c}	101.2^{de}	87,7^{e}	86,3^{e}	94.2	159,6^{f}	149,7^{f}	135,7^{g}	147.2
24 h	334,1	296,5	270,1	300.2^{a}	151,7^{bc}	148.0^{ab}	128,3^{cd}	141.6	269,0^{a}	244.1^{c}	222,4^{d}	246.3
48 h	270,7	225,5	218,6	238.2^{b}	132,9^{bcd}	123,2^{cde}	102,1^{de}	119.4	226,6^{d}	199,5^{e}	207,8^{e}	211.3
72 h	307,6	302,7	296,	302.4^{a}	146,3^{bc}	150,0^{bc}	195,6^{a}	163.9	253,5^{bc}	254,6^{bc}	263,8^{ab}	257.3
Avg	273.2^{a}	245.6^{b}	231.3^{b}		133,0	127,2	128,0		227.2	212.8	206.6	

*T_0 : 0 g/L NaCI (control) T_1 : 3 g/L NaCI T_2 : 6 g/L NaCI

*The differences between the values indicated with different letters in the properties examined are statistically significant ($p<0.01$)

Table 2. Effects of magnetic field treatment exposure times on the investigated parameters of Baronese variety

MF exposure time	Germination rate (%)				Germination power (%)				Shoot length (cm)			
	T_0	T_1	T_2	Avg	T_0	T_1	T_2	Avg	T_0	T_1	T_2	Avg
Control	77.7^{bc}	82.0^{b}	64.0^{d}	74.5	95.3^{ab}	90.7^{abc}	86.3^{bc}	90.8	10.7^{bc}	10.8^{bc}	9.0^{d}	10.2
24 h	97.7^{a}	82.0^{b}	73.0^{c}	84.2	95.3^{ab}	84.0^{c}	90.7^{abc}	90.0	10.6^{bc}	7.8^{e}	6.3^{f}	8.2
48 h	80.0^{bc}	97.7^{a}	82.0^{b}	86.5	86.3^{bc}	97.7^{a}	84.0^{c}	89.3	11.3^{ab}	6.4^{f}	9.9^{cd}	9.2
72 h	95.3^{a}	90.7^{a}	97.7^{a}	94.5	95.3^{ab}	93.0^{abc}	100.0^{a}	96.1	12.1^{a}	11.3^{ab}	7.8^{e}	10.4
Avg	87.7	88.1	79.2		93.1	91.3	90.2		11.2	9.1	8.3	

MF exposure time	Root lenght (cm)				Wet weight (g)				Dry weight (g)			
	T_0	T_1	T_2	Avg	T_0	T_1	T_2	Avg	T_0	T_1	T_2	Avg
Control	10.1^{b}	8.2^{cd}	7.1^{d}	8.9	2.6^{ab}	2.4^{bc}	2.0^{de}	2.3	0.23^{ab}	0.20^{bc}	0.23^{ab}	0.20
24 h	10.4^{b}	9.4^{bc}	7.3^{e}	9.0	2.7^{ab}	2.4^{bc}	1.8^{ef}	2.3	0.23^{ab}	0.13^{c}	0.23^{ab}	0.20
48 h	10.3^{b}	12.0^{a}	7.6^{de}	9.9	2.5^{bc}	2.6^{ab}	2.5^{bc}	2.5	0.20^{bc}	0.20^{bc}	0.23^{ab}	0.20
72 h	12.0^{a}	9.3^{bc}	7.8^{de}	9.7	2.8^{a}	2.2^{cd}	1.6^{f}	2.2	0.20^{bc}	0.30^{a}	0.20^{bc}	0.20
Avg	10.7	9.9	7.6		2,61	2,40	1,97		0.21	0.83	0.22	

MF exposure time	Chlorophyll a (µg/g)				Chlorophyll b (µg/g)				Total chlorophyll (µg/g)			
	T_0	T_1	T_2	Avg.	T_0	T_1	T_2	Avr.	T_0	T_1	T_2	Avg
Control	199.7	162.5	128.9	163.7^{c}	105.8	92.8	82.8	93.·8^{b}	173.9	147.3	124.8	148.6^{b}
24 h	240.7	318.4	203.5	254.2^{a}	122.9	140.6	171.4	144.8^{a}	205.1	253.0	204.5	220.8^{a}
48 h	195.4	195.5	179.7	190.1^{bc}	106.7	106.4	100.1	104.4^{b}	172.9	172.6	136.5	160.7^{b}
72 h	246.2	242.3	232.6	240.3^{ab}	129.3	127.0	124.7	127.0^{a}	213.4	209.8	208.0	210.4^{a}
Avg	192.6^{b}	229.7^{a}	186.2^{c}		106.1^{c}	116.7^{b}	119.8^{a}		171.2^{b}	195.7^{a}	168.4^{c}	

*T_0: 0 g/L NaCI (control) T_1: 3 g/L NaCI T_2 : 6 g/L NaCI

*The differences between the values indicated with different letters in the properties examined are statistically significant ($p<0.01$)

Table 3. Effects of magnetic field treatment exposure times on the investigated parameters of Bolayır variety

MF exposure time	Germination rate (%)				Germination power (%)				Shoot length (cm)			
	T_0	T_1	T_2	Avg	T_0	T_1	T_2	Avg	T_0	T_1	T_2	Avg
Control	75.3^{c}	86.3^{ab}	73.0^{c}	78.2	97.7^{ab}	97.7^{ab}	93.0^{ab}	96.1	11.9^{cd}	12.9^{ab}	12.0^{bc}	12.3
24 h	90.7^{a}	77.7^{bc}	50.7^{d}	73.0	93.0^{ab}	95.3^{ab}	91.0^{abc}	93.1	9.1^{f}	6.6^{g}	5.6^{h}	7.1
48 h	90.7^{a}	70.7^{c}	73.0^{c}	78.1	100.0^{a}	90.7^{bc}	82.0^{c}	90.9	12.6^{abc}	10.9^{de}	8.2^{f}	10.6
72 h	75.3^{c}	95.3^{a}	73.0^{c}	81.2	93.0^{ab}	93.0^{ab}	97.7^{ab}	94.6	13.5^{a}	12.5^{bc}	10.7^{e}	12.2
Avg	83.0	82.5	67.4		95.9	94.2	90.9		11.8	10.7	9.1	

MF exposure time	Root lenght (cm)				Wet weight (g)				Dry weight (g)			
	T_0	T_1	T_2	Avg	T_0	T_1	T_2	Avg	T_0	T_1	T_2	Avg
Control	8.3^{f}	7.0^{gh}	7.7^{fg}	7.6c	2.9	2.7	2.6	2.7^{a}	0.20	0.20	0.23	0.21
24 h	12.4^{a}	10.7^{bc}	8.4^{ef}	10.5	2.7	2.6	2.0	2.4^{ab}	0.20	0.20	0.20	0.20
48 h	9.4^{de}	6.7^{h}	7.5^{fgh}	7.9	3.0	2.7	2.4	2.6^{ab}	0.23	0.23	0.20	0.21
72 h	9.8^{cd}	11.4^{ab}	6.8^{gh}	9.3	3.0	2.1	2.2	2.3^{b}	0.23	0.17	0.23	0.21
Avg	9.9	9.0	7.6		2.9^{a}	2.5^{b}	2.1^{c}		0.22	0.22	0.23	

MF exposure time	Chlorophyll a (µg/g)				Chlorophyll b (µg/g)				Total chlorophyll (µg/g)			
	T_0	T_1	T_2	Avg.	T_0	T_1	T_2	Avr.	T_0	T_1	T_2	Avg
Control	276.3^{d}	244.1^{e}	206.9^{g}	245.8	121.9^{ef}	117.2^{ef}	111.8^{f}	109.4	232.2	198,4	182.0	204,2^{b}
24 h	341.5^{b}	251.2^{e}	230.5^{f}	274.4	281.3^{a}	139.2^{d}	118.0^{ef}	180.6	328.6	226.9	227.1	260.9^{a}
48 h	179.7^{h}	168.4^{i}	162.3^{i}	170.1	98.3^{g}	97.6^{g}	96.5^{g}	97.5	159.1	153.9	151.2	154.7^{c}
72 h	364.4^{a}	308.4^{c}	202.5^{g}	291.8	201.3^{b}	130.3^{de}	170.4^{c}	167.3	315.7	243.0	201.5	253.4^{a}
Avg	293.0	243.0	200.6		178.2	122.0	115.8		258.9^{b}	350.7^{a}	190.4^{c}	

*T_0 : 0 g/L NaCI (control) T_1 : 3 g/L NaCI T_2 : 6 g/L NaCI

*The differences between the values indicated with different letters in the properties examined are statistically significant ($p<0.01$)

Table 4. Effects of magnetic field treatment exposure times on ion leakage (%)

MF exposure time	Aydanhanım			Baronesse			Bolayır		
	Ion leakage								
	T_0	T_1	T_2	T_0	T_1	T_2	T_0	T_1	T_2
Control	46,8^{f}	51,1^{d}	67,2^{a}	44.7^{cd}	55.1^{b}	65.4^{a}	47.1^{d}	52.0^{b}	63.8^{a}
24 h	31,7^{k}	38,6^{j}	50,0^{e}	56.4^{b}	43.3^{cd}	50.9^{bc}	35.8^{l}	38.0^{j}	40.0^{h}
48 h	38,5^{j}	45,0^{g}	55,9^{b}	32.0^{e}	41.4^{d}	45.2^{cd}	36.8^{k}	45.4^{f}	48.4^{c}
72 h	39,9^{j}	42,2^{h}	53,8^{c}	32.1^{e}	41.1^{d}	49.0^{bc}	38.2^{ı}	42.5^{g}	45.5^{e}

*T_0 : 0 g/L NaCI (control) T_1 : 3 g/L NaCI T_2 : 6 g/L NaCI

*The differences between the values indicated with different letters in the properties examined are statistically significant ($p<0.01$)

control application (159.3 μg/g). Chlorophyll a values determined in 24 and 72 hours applications are higher than 48 hours (300.2 μg/g, 302.4 μg/g and 238.2 μg/g, respectively). The highest value in chlorophyll b values was measured as 195.6 μg/g in T_2 salt and 72 hours MF application. On the other hand, the lowest chlorophyll b value was measured in the control MF application as 86.3 μg/g in the T_2 application. Accordingto these results, it was determined that 72 hours of MF application showed a positive significant increase on chlorophyll b value. The lowest Total chlorophyll values were determined in control MF applications at all salt stress doses. On the other hand, the highest total chlorophyll value was determined as 269.9 μg/g in 24 hours of exposure time. Although MF exposure times showed a significant positive effect in mitigating the negative effects of increased salt stress, the best positive effect was determined as 263.8 μg/g in 72 h of MF exposure time. This value gave good results even in applications without salt stress. It reveals the therapeutic effect of magnetic field application for 72 h exposure time. The highest value in ion leakage values was determined at the T_2 stress level of 67.2%. A low ion leakage value indicates tolerance to salt stress. In this context, the lowest ion leakage value was determined at a T_2 stress level of 53.8% in 72 hours of MF application. On the other hand, the lowest ion leakage determined at all stress levels was determined at 31.7% in the 24h application (Table 4).

Pietruszewski et al. (2001) determined the effects of a static magnetic field on germination capacity of wheat and reported that MF densities of 100 and 180 mT gave the best results. Another study was carried out on lentil seeds by Aladjadjiyan (2010). The 150 mT static magnetic field on lentil seed has concluded better germination. Carbonell et al. (2000), reported that 150 and 200 mT MF treatments on rice and barley seeds caused faster germination under field conditions. Florez et al. (2007) emphasized that corn seeds exposed to 125 or 250 mT continuously gave the best results in terms of germination and early growth of seedlings. In another study; treatment of maize seeds with 60-200 mT static magnetic field caused stem growth and yield increase in plants (Aladjadjiyan 2007). It has been stated that exposure of seeds to magnetic fields improves the integrity of the seed coat membrane and reduces cellular leakage and electrical conductivity (Vashisth and Nagarajan 2010). Similarly, in our study, MF treatment showed positive effects on important growing parameters.

Under salt stress, plants are severely damaged during their first development period, and their growth and development periods are significantly reduced (Okumus and Uzun 2022). Salt stress can kill the plant directly, as well as significantly reduce plant growth, seed germination, root length, plant height and grain yield (Yavuz et al., 2022), it is more effective in older leaves and causes chlorosis and necrosis by chlorophyll and cell membrane breakdown (Kalisz et al., 2023). The tolerance of plants to high salt doses is determined in the first developmental stages. In this period; germination percentage, germination rate and strength are important parameters that should be examined against salt stress (Zhu et al. 2018).

The results of Baronesse cultivar are given in Table 2. The germination rate of the Baronesse cultivar decreased with increasing salt stress doses (Table 2). The lowest germination rate was determined as 64.0% at T_2 stress treatment. This rate reached 97.7% at 72 h of MF exposure time. The results showed that 72 exposure time in MF application was successful in treating the negative effect caused by salt stress. Similarly, increasing salt stress doses had a negative effect on germination power results. MF applications have shown significant positive effects in improving this negative effect. At the T_1 stress treatment, 48 h MF exposure time resulted in 97.7%, and at the T_2 stress level, 72 h MF exposure time resulted in 100% germination power. Shoot length values were best determined in 72 and 48 hours applications in the T_0 control application (12.1 and 11.3 cm, respectively). The highest value of root length in the T_0 control application was measured as 12.0 cm in 72 h exposure time. A similar, 12.0 cm root length was determined in 48 h exposure time at the T1 stress level and it was measured as the best root length in the all trial. While wet weight gain occurs with cell expansion (Ismail et al., 2023), dry weight increase occurs as a result of cell division and new material synthesis due to high photosynthetic activity (Khan et al., 2023). The highest value in the Baronesse cultivar, wet weight values was determined as 2.8 g in 72 h exposure time, but the difference between the control and 24 hours is important. The effects of MF applications in increasing salt stress levels did not show a statistically significant positive effect. In dry weight values, the highest value at the T_1 stress level was determined as 0.30 g in 72 hours of MF application. In dry weight values at T_2 and T_1 levels, MF applications did not give better results than the control. Chlorophyll a values were measured as 192.6, 229.7 and 186.2 μg/g at T_0, T_1 and T_2 stress levels, respectively. In MF applications, the best chlorophyll a values were determined on average at all stress levels in 24-hour and 72-hour applications (254.2 μg/g and 240.3 μg/g, respectively). The best results in terms of mean values on chlorophyll b values of magnetic field applications were measured as 144.8 μg/g in 24 hours and 127.0 μg/g in 72 hours. The difference between them was found to be statistically insignificant. The effect of salt stress on the total amount of chlorophyll was different. The total chlorophyll value of 171.2 μg/g determined in T_0 application was determined as 195.7 μg/g in T_1 and 168.4 μg/g in the T_2 stress treatment. This difference supports the idea that the plant tends to increase its photosynthetic capacity to provide stress tolerance. In addition, the decrease in the total amount of chlorophyll at the increased stress level can be interpreted as the plant is adversely affected by stress and loses its tolerance. Among the MF exposure times, the highest total chlorophyll amount was determined at all stress levels, on average, at 72 h and 24 h (210.4 μg/g and 220.8 μg/g, respectively). The highest ion leakage value was calculated as 65.4% at the T_2 stress treatment. The 45.2% ion leakage value determined in 48 h exposure time of MF determines that the treatment is successful. In addition, other MF practices had significant positive effects (Table 4).

The results of the Bolayır cultivar are given in Table 3. The highest germination rate in Bolayır cultivar was determined in T0 stress treatment at 24 h and 48 h exposure times (both 90.7%) (Table 3). There was no statistical difference between 72 h and control MF exposure time application in the T0 stress treatment. The best germination rate at the T1 stress level was 95.3% in 72 h exposure time of MF, but the difference between control MF exposure time (86.3%) was statistically insignificant. No significant positive effect of MF exposure time on germination rate was determined at the T2 stress level (Table 3). The difference between the effect of MF exposure time on germination power in T0 stress treatment is statistically insignificant. Similarly, the difference between control, 24h and 72h MF applications at T1 stress level was found to be insignificant. The same is true for the T2 stress level. The lowest germination power was determined in 48h MF application at T1 and T2 stress levels (90.7% and 82.0%, respectively). In general, the increased salt dose negatively affected the germination rate and strength parameters, and it shows parallelism with other studies (Benlioglu and Ozkan 2018, Okumus and Uzun 2022, Doruk Kahraman and Gokmen 2022). Studies have shown that magnetic field treatment reduces the damage caused by salt at high doses (Shabalkin et al., 2023). Considering other studies (Wang et al., 2016), increasing salt doses negatively affected shoot and root lengths. However, it has been determined that magnetic field treatment has a positive effect at high salt doses, and the results have shown parallelism in similar studies (Abdellaoui et al., 2004; Beyaz et al., 2020).

Shoot length values in Bolayır cultivar were determined as 13.5 cm in the T_0 application for 72 hours in the MF application (Table 3). With increasing salt stress, shoot length values decreased and could not be treated with MF applications. The best effect on root length was measured as 12.4 cm in 24 hours MF application. At T_1 salt stress level, the highest root length was determined in 72 hours of MF treatment. The best average value was determined in T_0 application in wet weight values (2.9 g). As the salt stress level increased, the wet weight value decreased (2.5 g and 2.1 g, respectively). There is no statistical difference between 24 h and 48 h MF exposure times and control. There was no statistical difference between the effects of salt stress and MF exposure times on dry weight values (Table 3). The best positive effect on chlorophyll a value at T_0 stress level was determined in 72 hours of application (364.4 μg/g). The best value at the T_1 stress level was again measured as 308.4 µg/g in 72 hours of application. There was no positive effect of MF applications on T_2 stress level. The best result in chlorophyll b values was determined in the T_0 application during 24 hours of exposure to MF (281,3 µg/g). No significant positive effect of MF applications was found at other stress levels. Total chlorophyll values were measured as 258.9 µg/g in the T_0 control treatment, 350.7 µg/g in the T_1 stress treatment and 190.4 µg/g in the T_2 stress treatment. The increase in the total amount of chlorophyll in the T_1 stress level was interpreted as the low-level stress trying to increase the tolerance of the plant by creating a triggering effect. 24 and 72 hour applications on total chlorophyll amounts are the applications in which the best values are determined at all stress levels (Table 3). A decrease in the total amount of chlorophyll was determined in parallel with the increasing salt dose. Similar results were found in studies (Ru et al., 2023; Song et al., 2023). Chlorophyll content directly affects photosynthesis (Nalley et al., 2023) and is accepted as an indicator of photosynthetic capacity in tissues (Song et al., 2023). Since the high photosynthetic activity will increase the production of the substance, it also increases the yield (Ru et al., 2023). Chlorophyll coverage can be used as a measure of growth (Joshi et al., 2023). This shows that the magnetic field strength increases the rate of photosynthetic activity (Ercan et al., 2022; Hafeez et al., 2023). The highest ion leakage in Bolayır variety was determined at T_2 stress level and 63.8% in control MF application. The lowest ion leakage value at the T_2 stress level was measured as 40.0% in 24 hours of MF application. The lowest ion leakage values in the whole experiment were determined in the 24-hour MF application (Table 4).

All organisms are under the influence of the Earth's magnetic field, called the geographic magnetic field (GMF) (Maffei, 2014; Pietruszewski and Martínez, 2015). Although the density of GMF varies according to the regions; this value varies between 25 and 65 µT. (Occhipinti et al., 2014). Exposure of seeds to higher MF than GMF (from the current magnetic field of the environment) increases seed germination and plant growth by increasing water assimilation and photosynthesis (Cotrina Cabello et al., 2023). Seeds exposed to higher MF exposure than GMF not only germinate faster, but also more uniformly. Rapid and uniform development is an indication that plants will gain superiority against adverse conditions during vegetative development. Another important parameter in the MF effect is the MF intensity. Cecchetti et al. (2022); in their study to determine the effects of a static magnetic field on the germination capacity of wheat, it was reported that the density of 100 and 180 mT gave the best results. Besides, the study carried out by Aladjadjiyan (2010) on lentil seeds and 150 mT static MF showed better germination of lentil seeds. Florez et al. (2007) reported that 150 and 200 mT MF treatment of rice and barley seeds resulted in faster germination of seeds under field conditions. Florez et al. (2007) emphasized that maize seeds continuously exposed to 125 or 250 mT performed best in terms of germination and early growth of seedlings. The treatment of a constant magnetic field intensity of 150 mT in our study is important in determining the effect on the investigated parameters. Pietruszewski and Martínez (2015) stated that MF effect studies performed have reported that it varies in a wide range from µT to mT and T, and the results vary up to 109 times. However, with these wide differences in applied MF values, it is seen that their effects are similar to each other and result in positive results. It has been reported that the important factor here is the exposure time to the magnetic field. In the results of the current study; in addition to the yield increases obtained at certain exposure times, decreases were also observed. This result supports that the fixed MF effect does not always have a positive effect at different exposure times. In MF effect studies, in addition to magnetic field type and intensity, the most important parameter is exposure time. Vashisth and Joshi (2017); In the study, they investigated the effects of different MF doses on certain seedling parameters in maize plants. The increase in MF strength did not show parallelism with the increase in physiological development; similarly, they reported that there was no linear relationship between physiological development and exposure time. Therefore, it is of great importance to investigate the effect of continuous and constant MF at different time intervals on different physiological and molecular responses of the plant. In this way, it is predicted that results that will enable the elucidation and association of the MF effect mechanism will be obtained.

4. Conclusions

Environmentally friendly and innovative agricultural approaches have become essential for ecological and sustainable life in the current order of the world. Especially in the last years negative effects of fertilizers, pesticides, insecticides to environment have led to finding new solutions. Even though magnetic field treatments are not new, their effects and applications are still not common enough among people working in agriculture. Considering all the examined properties, the results revealed that the magnetic field treatment exposure time had a significant effect on seed germination, plant growth, seedling height and root length. In the light of the data obtained, results have been obtained that will provide important contributions to innovative biotechnological approaches to improve new variety development, yield and yield parameters needed in agricultural production. On the other hand, in the treatment of magnetic field to increase the tolerance against salt stress in barley, researchers are recommended to perform optimization studies for the exposure time and power of the magnetic field. It is suggested that magnetic field treatments be carried out on different plant species and varieties, especially considering the possible differences due to plant variety differences. Experimenting with this study with other plant species and cultivars in both laboratory and field conditions will increase the success rate.

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