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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

The Effect of Salinity (NaCl) Stress and Different Magnetic Applications on The Germination of Cucumber Seeds (*Cucumis sativus* L.)

Tuzluluk (NaCl) Stresi ve Farklı Manyetik Uygulamaların Hıyar (*Cucumis sativus* L.) Tohumlarının Çimlenmesi Üzerine Etkisi

Muhammed ALSUVAİD [*1], Yusuf DEMİR [2]

Abstract

Salinity stress is one of the main factors that limit seed germination and plant growth. Therefore, magnetic water was used because it had a positive effect on seed germination. This study was conducted to investigate the effect of magnetic (MT1, MT2, MT3, MT4, and MT5) treatment of water passing through magnets 1, 2, 3, 5, and 8 times respectively, and non-magnetic (NMT) treatment on the germination of cucumber seeds (*Cucumis sativus* L.) under salinity stress (NaCl) (S1 = 0.38 dSm^{-1}, S2 = 4.0 dSm^{-1}, S3 = 8.0 dSm^{-1}). The experiment was conducted by the design of a one-way ANOVA with three replications. The results showed that water salinity stress a significantly decrease in the final germination percentage (FGP), germination index (GI), coefficient of the velocity of germination (CVG), germination percentage 4th day (GP), and germination rate index (GRI), while the mean germination time (MGT) increased significantly. In addition, the FGP, GP, GI, CVG, and GRI were significantly increased and the MGT was significantly decreased when using magnetic water compared to non-magnetic water. The highest values of FGP, GP, GI, CVG, and GRI were at S1 while they decreased by 7.8%, 10.0%, 15.8%, 2.4% and 16.2%, respectively in S3 (8.0 $dSm^{-1)}$, compared to S1 (0.38 dSm^{-1}). The highest FGP values of 92.20% at MT4 were obtained with S1 salinity (0.38 dSm^{-1}) and the lowest FGP value of 72.20% at NMT with water salinity S3 (8.0 dSm^{-1}). The results of the research showed that magnetic water treatment has a positive effect on the germination of cucumber seeds and that salinity stress reduced the germination of seeds. Finally, it can be recommended to apply MT4 (water passed through the magnetic 5 times) to achieve the best germination of cucumber seeds.

Keywords: Magnetic water treatment, Germination index, Salinity stress, Cucumber, Germination of seeds

[1]***Sorumlu Yazar/Corresponding Author:** Muhammed ALSUVAİD, Ondokuz Mayıs University, Faculty of Agriculture, Agricultural Structures and Irrigation Department, Samsun, Turkey. E-mail: mnsweed861@gmail.com. OrcID: 0000-0003-0146-781X
[2]Yusuf DEMİR, Ondokuz Mayıs University, Faculty of Agriculture, Agricultural Structures and Irrigation Department, Samsun, Turkey.. E-mail: yusufdd@omu.edu.tr OrcID: 0000-0002-5760-6551.
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Öz

Tuzluluk stresi, tohum çimlenmesini ve bitki büyümesini sınırlayan ana faktörlerden biridir. Bu nedenle tohum çimlenmesine olumlu etkisi olduğu için manyetik su kullanılmıştır. Bu çalışmada, tuzluluk (NaCl) Stresi ve farklı manyetik uygulamaların hıyar (*Cucumis sativus* L.) tohumlarının çimlenmesi üzerine etkisi belirlemek amacıyla yapılmıştır. Çalışma tesadüf parselleri deneme desenine göre üç tekerrürlü yürütülmüştür. Bu çalışma, beş farklı manyetik uygulama (MT1, MT2, MT3, MT4 ve MT5) manyetik ortamdan sırasıyla 1, 2, 3, 5 ve 8 defa geçirilmiş su ve manyetik olmayan (NMT) uygulamasının hıyar tohumlarının (*Cucumis sativus* L.) tuzluluk stresi (S1 = 0.38 dSm^{-1}, S2 = 4.0 dSm^{-1}, S3 = 8.0 dSm^{-1}) altında çimlenmesine etkisini araştırmak amacıyla yapılmıştır. Çalışma sonunda, su tuzluluğu stresindeki artış son çimlenme yüzdesi (FGP), çimlenme yüzdesi 4. gün (GP), çimlenme indeksi (GI), çimlenme hızı katsayısı (CVG) ve çimlenme oranı indeksinde (GRI) azalmaya neden olduğu göstermiştir. Bununla beraber ortalama çimlenme süresinde (MGT) artış görülmüştür. FGP, GP, GI, CVG ve GRI' nin en yüksek değerleri S1'de iken, S3'te (8.0 dSm^{-1}) S1'e (0.38 dSm^{-1}) göre sırasıyla %7.8, %10.0, %15.8, %2.4 ve %16.2 azalmıştır. Manyetik olan sulama suyu kullanıldığında FGP, GP, GI, CVG ve GRI' inde bir artışa neden olmuş ve manyetik olmayan sulama suyunun NMT olması durumunda ise azalmalar olduğu görülmüştür. En yüksek FGP değerleri %92.20 S1 tuzluluk (0.38 dSm^{-1}) ile MT4 konusunda, en düşük FGP değeri %72.20 su tuzluluğu S3 (8.0 dSm^{-1}) ile NMT konusunda belirlenmiştir. Araştırma sonuçları, manyetik su uygulamasının hıyar tohumlarının çimlenmesini olumlu etkilediğini ve tuzluluk stresinin tohumların çimlenmesini azalttığını göstermiştir. Çalışma sonucuna göre, hıyar tohumlarının en iyi çimlenmesini sağlamak için MT4 (manyetikten 5 defa geçirilmiş su) uygulanması önerilmiştir.

Anahtar Kelimeler: Manyetik su arıtma, Çimlenme indeksi, Tuzluluk stresi, Hıyar, Tohumların çimlenmesi

1. Introduction

Salinity is one of the main problems of both soil and irrigation water and a serious threat to agriculture (Munns and Tester, 2008; Alsuvaid et al., 2022). One of the causes of salinity problems in agricultural lands in arid and semi-arid areas is irrigation with low-quality water (Hossain, 2019). Soil salinity affects 10% of the total area on the earth's surface and there is a continuous increase in the area of saline lands (Marcum, 2006; Carrow and Duncan 1998). While 1.5 million hectares of land in Turkey suffer from salinity problems (Ekmekçi et al., 2005; Asci, 2011; Demirkol et al., 2019). Although there are many different salts in nature, the most common is sodium chloride (Kusvuran and Biology, 2012). Sodium chloride negatively affects plant life by creating osmotic stress and/or toxic effects (Çulha and Çakırlar, 2011; Houle et al., 2001). Salt stress inhibits the growth and development of plants by causing osmotic and ion stress (Parida et al., 2005; Alsuvaid et al., 2022). Salt stress affects cell division and elongation, causing a decrease in the number of cells in the root and stem, mitotic activity, and cell division rate in plants (Burssens et al., 2000). Salt stress, a major environmental problem in arid, semi-arid, and coastal regions, shows its first negative impact during the germination stage of plants (Passam and Kakouriotis, 1994). Salt damage during the germination period causes a decrease in water intake, structural effects of protein organization, and changes in the transport of stored nutrients (Foolad and Lin, 1997). The speed of seed germination and early seedling growth are the main factors limiting the growth and development of plants under saline conditions and are considered the most important stage in plant life under harsh conditions (Tsegay and Gebreslassie, 2014; Kitajima and Fenner, 2000). Salt stress may cause a significant decrease in the rate and final germination percentage of seeds, which in turn leads to a decrease in yield (Tsegay and Gebreslassie, 2014).

Seed germination is improved by different seed treatments by magnetic fields, electric fields, microwave radiation, and laser radiation (Hozayn et al., 2015; Pietruszewski and Kania, 2010). Recently, many researchers found that the magnetic field was influential on seed germination and seedling growth (Namba et al.,1994; Hozayn et al., 2015; Hozayn et al., 2014; Ul Haq et al., 2016). There are two types to study the effect of magnetic treatment, the effect of magnetic treatment of seeds and the effect of magnetically treated water on seeds. Magnetic treatment of the seeds increased plant growth and protein biosynthesis (Kordas, 2002). (Hozayn et al., 2015; Racuciu et al., 2008) reported that when the seeds were exposed to a magnetic field, the activities of some enzymes were increased. The use of magnetic technology is a new environmentally friendly technology (Ul Haq et al., 2016; Nimmi and Modhu 2009). When using magnetic water compared to non-magnetic water, the percentage of seed germination was increased. Magnetically treated water greatly affects the change of the chemical properties of water, and the change of hydrogen bonds between water molecules, which leads to a change in the size of large salt crystals into small salt crystals. This leads to a change in osmotic pressure (Amiri et al. 2006; Alsuvaid et al., 2022). Magnetic water compared to non-magnetic water can enhance germination and enzymatic activities of seeds (Ul Haq et al. 2016). Magnetically treated water activates hormones and enzymes involved in the seed germination process (Ahamed et al., 2013; Ismail et al., 2020). The use of magnetic water significantly improves seed germination and emergence compared to non-magnetic water (Podlesny et al., 2004; Pietruszewski and Kania, 2010; Samarah et al. 2021). The magnetic field has led to an increase in the germination rate of some plants such as soybeans, tomato, pepper, sunflowers, snap bean and wheat (Martinez et al., 2017; Atak et al., 2000; Oldacay, 2002; Yalçin, 2018; De Souza et al., 2006; Dalia et al., 2009; Grewal and Maheshwari, 2011; Fatahallah et al., 2014). However, there are still few studies on the interaction effects of magnetically treated water irrigation and saline water irrigation on seed germination. Therefore, the objective of this work was to study the effect of salinity (NaCl) stress and different magnetic applications on seed germination.

2. Materials and Methods

2.1. Experimental conditions

This study was conducted to determine the responses of cucumber seeds (Cucumis sativus L.) to different salinity (NaCl) stresses and different magnetic applications during the germination period. It was conducted in the laboratories of Ondokuz Mayıs University, Faculty of Agriculture, Agricultural Structures and Irrigation Department in Samsun, Turkey, in 2021.

The magnetic device VR-WS-D-001 (total length 120 mm, connector port 1/2-inch, diameter 51mm) used for water treatment was purchased from Vigorrain Technology Co., Ltd., China. Water is magnetically treated by passing it through the device *(Figure 1).*

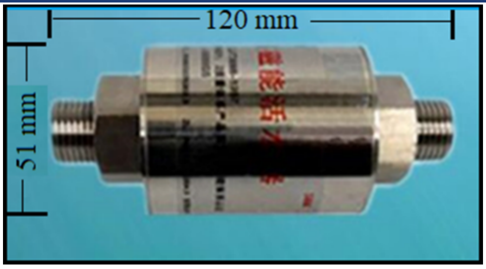

Figure 1. Magnetic treatment device

2.2. Experimental design and water treatments

The experiment was conducted by the design of a one-way ANOVA with three replications. Magnetized water is obtained by passing water through a magnet device. Magnetic treatment was applied on six different levels, NMT (non-magnetic water treatment), MT1 (water passed through the magnetic once), MT2 (water passed through the magnetic 2 times), MT3 (water passed through the magnetic 3 times), MT4 (water passed through the magnetic 5 times) and MT5 (water passed through the magnetic 8 times). Three different types of salinity (NaCl) were used for water (S2 = 4 dSm^{-1} and S3 = 8 dSm^{-1}) and tap water (S1 = 0.38 dSm^{-1}). To obtain the appropriate salinity, salt (NaCl) was added to tap water for the corresponding treatment.

Seeds were sterilized in 5% sodium hypochlorite solution for 10 min to ensure surface sterilization and rinsed with distilled water. Sterilized seeds were placed in 9 cm diameter Petri dishes on two layers of filter paper (Whatman's No: 1) and each Petri dish contained 30 seeds. 15 mL of lab-prepared and magnetically treated saline was added to each Petri dish. Petri dishes were placed in an incubator left to germinate for 7 days at 12,000 lux light, temperature 25±1 °C and 70% humidity. During the experiment, germinated seeds were counted every day, and seeds with a root length of 2 mm were accepted as germinated according to the rules of the International Seed Testing Association.

2.3. Calculation of germination parameters

Final germination percentage (FGP, %) and germination percentage 4th day (GP, %) were calculated from Eq. 1 and Eq. 2, respectively. It is clear that the higher the final germination percentage value, the higher the seed germination (Scott et al. 1984; Mzibra et al. 2021).

$$\text{FGP} = \frac{\text{Final Number of seeds germinated}}{\text{Total number of seeds}}\ x\ 100 \qquad \text{(Eq.1)}$$

$$\text{GP} = \frac{\text{Number of seeds germinated in the 4th day}}{\text{Total number of seeds}}\ x\ 100 \qquad \text{(Eq.2)}$$

Mean Germination Time (MGT, day) was calculated as shown in Eq. 3, and the lower the mean germination time, the faster the seed germination (Orchard and technology, 1977; Mzibra et al., 2021). Where F is the number of seeds germinated on day x.

$$\text{MGT} = \frac{\sum \text{F.x}}{\sum \text{F}} \qquad \text{(Eq.3)}$$

Germination index (GI, %/day) was calculated as shown in Eq. 4, The GI value emphasizes both the percentage of germination and its speed. The higher the GI value, the higher the percentage and germination rate. Where n_1, n_2, ...n_7 are the number of seeds germinated on days 1^{st},2^{nd}....7^{th} (Benech Arnold et al., 1991).

$$\text{GI} = (7 \times n_1) + (6 \times n_2) + \cdots + (1 \times n_7) \qquad \text{(Eq.4)}$$

The coefficient of Velocity of Germination (CVG) was calculated as shown in Eq. 5, as the number of germinated seeds increases, CVG increases and gives an indication of germination speed. Where N is the number of seeds germinated every day, T is the number of days from seeding corresponding to N (Jones and Sanders, 1987).

$$\text{CVG} = 100\ \text{x}\ (\text{N1} + \text{N2}+\ldots+\text{Ni} / \text{N1T1}+\ldots+\text{NiTi}) \qquad \text{(Eq.5)}$$

Germination Rate Index (GRI) was calculated as shown in Eq. 6, the higher the GRI values, the higher the rate and speed of germination. Where G1, G2, ...G7 are the germination percentage on days 1st, 2nd, ...7th (Esechie and Science, 1994).

$$GRI = G1/1 + G2/2 + \cdots \ldots + G7/7 \quad \text{(Eq.6)}$$

2.4. Statistical analysis

The relationships between different water salinity and seed germination in different magnetic water conditions were evaluated using JMP version 13.2 software for statistical analysis. The data were statistically analyzed by analysis of variance (ANOVA) at the level of significance (HSD, $P<0.05$).

3. Results

3.1. The number of germinated seeds

Figure 2 shows the effect of different magnetic treatments on the number of germinated seeds of cucumber seeds. Magnetic water led to an increase in the number of germinated seeds for all magnetic treatments as compared to NMT water. The number of germinated seeds in the second day increased by 5.56%, 19.44%, 38.89%, 69.44%, and 22.22% for the MT1, MT2, MT3, MT4, and MT5 treatments, respectively, compared to the NMT treatment. While the number of germinated seeds in the seventh day increased by 1.49%, 5.45%, 9.90%, 14.36%, and 4.46% for the MT1, MT2, MT3, MT4, and MT5 treatments, respectively, compared to the NMT treatment. The highest number of germinated seeds was observed with the MT4 treatment, while the lowest rate was observed with the NMT treatment. In addition, we observed that as water salinity levels increased, the number of germinated seeds decreased. As shown in *Figure 3*, the highest number of germinated seeds (24.78 seeds) was found in treatment S1, while the lowest value (22.83 seeds) was found in treatment S3 on the seventh day.

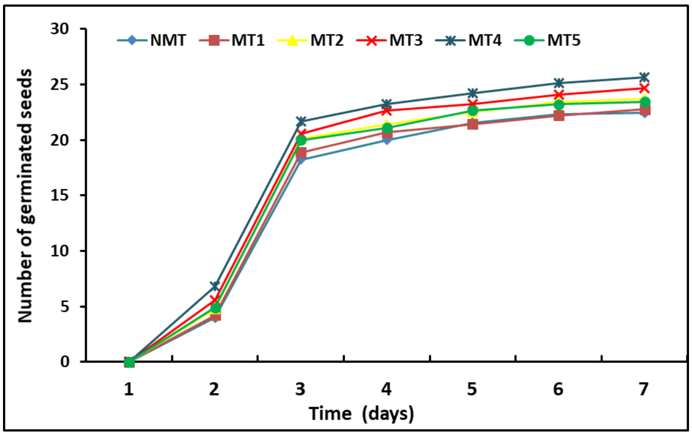

Figure 2. Effect of different magnetic treatments on the number of germinated seeds of cucumber seeds. NMT: non-magnetic water treatment; MT1, MT2, MT3, MT4, and MT5 represent water passed through the magnetic 1, 2, 3, 5, and 8 times respectively

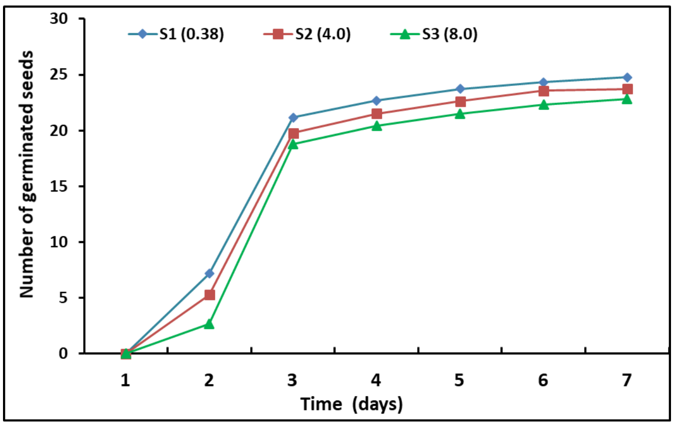

Figure 3. Effect of salinity (NaCl) stress on the number of germinated seeds of cucumber seeds

3.2. Final germination percentage (FGP) (%)

The effect of salinity stress and magnetic treatments on the final germination percentage of cucumber seeds was statistically significant ($p \leq 0.0001$), as shown in *Table 1*. The values of the FGP decreased significantly with increasing water salinity levels *(Figure 4A)*. The highest FGP 82.59% was found in treatment S1, while the lowest value 76.11% was found in treatment S3 *(Figure 4A)*. However, the FGP was significantly increased by the magnetic treatment (MT) compared to NMT *(Figure 4B)*. According to the HSD test, the magnetic treatments, NMT and MT1, were in one group, MT2 and MT5 in another group. There was no significant difference between the FGP values of these groups. The FGP values were 74.81%, 75.93%, 78.89%, 82.22%, 78.15% and 79.26% for the NMT, MT1, MT2, MT3, MT4 and MT5 treatments, respectively. The interaction effects between salinity stress and magnetic treatments on the FGP of cucumber seeds were statistically significant ($p \leq 0.05$) *Table 1*. The highest values of FGP were obtained in MT4 with a salinity of S1 (0.38 dSm^{-1}) and the lowest FGP in NMT with the salinity of irrigation water S3 (8.0 dSm^{-1}) *(Figure 5)*. FGP was positively correlated to GP (r = 0.90), GI (r = 0.92), CVG (r = 0.71), and GRI (r = 0.93) and negatively correlated with MGT (r = -0.70) that was significant at the 1% level *(Figure 6)*.

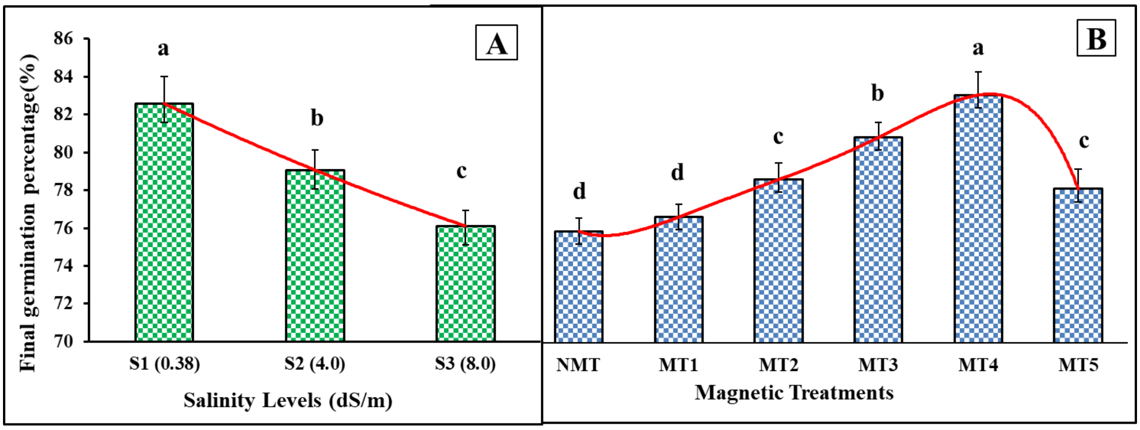

Figure 4. Effect of salinity (NaCl) stress (A) and different magnetic treatments (B) on the final germination percentage of cucumber seeds. NMT: non-magnetic water treatment; MT1, MT2, MT3, MT4, and MT5 represent water passed through the magnetic 1, 2, 3, 5, and 8 times respectively. Mean values in the same columns followed by the same letters are not significantly different according to the HSD test (P <0.05)

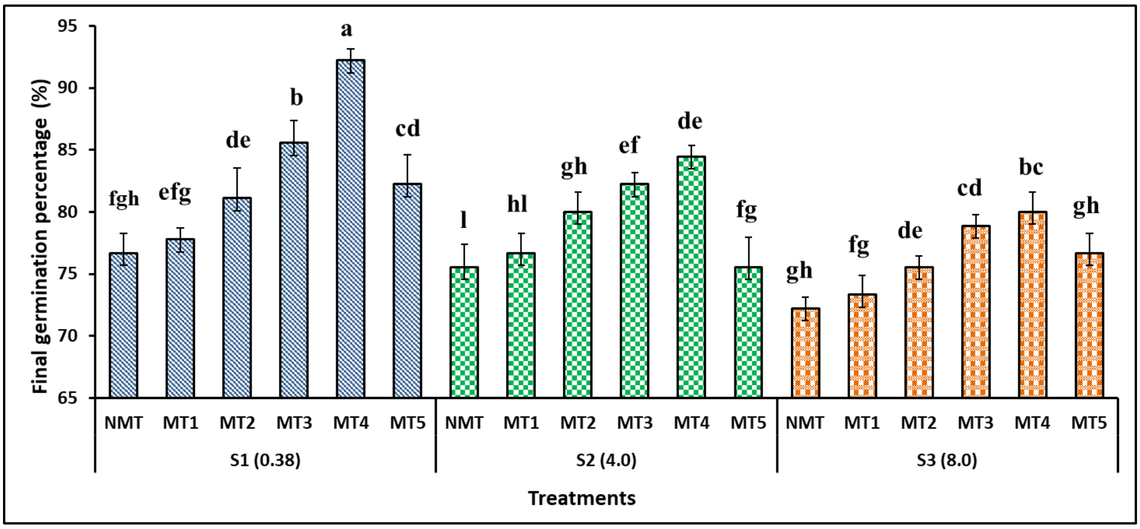

Figure 5. Effect of magnetic treatments x salinity levels interaction on the final germination percentage of cucumber seeds. NMT: non-magnetic water treatment; MT1, MT2, MT3, MT4, and MT5 represent water passed through the magnetic 1, 2, 3, 5, and 8 times respectively. Mean values in the same columns followed by the same letters are not significantly different according to the HSD test (P <0.05)

3.3. Germination percentage 4th day (GP, %)

GP values decreased with increasing water salinity levels and increased with MT use. Both salinity stress and magnetic treatments have significantly affected the GP *(Table 1)*. The increase in salinity negatively affected the GP values, for instance, S1 and S3 had a decrease of 6.9 and 10.0%, respectively *(Table 2)*. While the GP values increased by 3.4, 9.4, 15.6, 18.5, and 7.7% for the MT1, MT2, MT3, MT4, and MT5 treatments, respectively, compared to the NMT treatments *(Table 2)*. The interaction between salinity stress and magnetic treatments significantly affected the GP of cucumber seeds *(Table 1)*. The highest GP values were obtained at the MT4S1 treatment *(Table 2)*. GP was positively correlated to GI (r = 0.92), CVG (r = 0.71), and GRI (r = 0.93) and negatively correlated with MGT (r = -0.70) that was significant at the p≤0.0001 levels *(Figure 6)*.

Table 1. Summary of analysis of variance (ANOVA) for the effects of salinity levels (SL) and different magnetic treatments (MT) on the FGP, final germination percentage, GP, germination percentage 4th day, MGT, mean germination time, GI, germination index, COV, coefficient of the velocity of germination, and GRI, germination rate index of cucumber seeds

Source of variation	dF	FGP		GP		GRI	
		Mean Square	$HSD_{0.05}$	Mean Square	$HSD_{0.05}$	Mean Square	$HSD_{0.05}$
C. Total	53						
MT	5	145.68***	2.62	190.97***	3.33	31.29***	1.02
S L	2	189.47***	1.51	271.80***	1.91	107.09***	0.58
MT*SL	10	11.03*	5.67	17.98*	7.19	2.19**	2.20
Error	34	3.40		5.47		0.51	
CV (%)	-		2.33		3.28		2.59
Source of variation	dF	MGT		GI		CVG	
		Mean Square	$HSD_{0.05}$	Mean Square	$HSD_{0.05}$	Mean Square	$HSD_{0.05}$
C. Total	53						
MT	5	0.0051***	0.028	4866.12***	16.53	0.0812***	0.103
S L	2	0.0667***	0.016	16604.39***	9.49	1.0525***	0.059
MT*SL	10	0.0003^{NS}	0.610	441.28*	35.72	0.0060^{NS}	0.222
Error	34	0.0004		134.93		0.0052	
CV (%)	-		0.40		3.28		0.36

NS: Not significant, * Significant at p≤0.05, ** Significant at p≤0.001, *** Significant at p≤0.0001. CV¼: coefficient of variation, dF: degrees of freedom

3.4. Mean Germination Time (MGT, day)

The effect of water salinity stress on the MGT of cucumber seeds was statistically significant (p≤0.0001) *(Table 1)*. MGT values increased with increasing water salinity levels. The MGT values were 4.90, 4.95, and 5.02 (day) for the S1, S2, and S3 treatments, respectively *(Table 2)*. The effect of magnetic treatments on the MGT of cucumber seeds was statistically significant (p≤0.0001) *(Table 1)*. In addition, MGT was significantly reduced using MT compared with NMT *(Table 2)*. CVG values were 4.99, 4.97, 4.96, 4.95, 4.92, and 4.95 (day) for the NMT, MT1, MT2, MT3, MT4, and MT5 processors, respectively. The interaction effects between salinity stress and magnetic treatments on the MGT of cucumber seeds were not statistically significant *(Table 1)*. MGT was negatively correlated to GI (r = -0.87), and CVG (r = -0.99) which was significant at the p≤0.0001 levels *(Figure 6)*.

3.5. Germination Index (GI, %/day)

It was determined that the GI by different water salinity levels was statistically significant (p≤0.0001) *(Table 1)*. With the increase of water salinity levels from S1 to S3, GI values decreased by 7.5 and 15.8% respectively in the S2 and S3 treatments *(Table 2)*. The effect of magnetic treatments on the GI of cucumber seeds was statistically significant (p≤0.0001) *(Table 1)*. GI was significantly increased using MT compared with NMT. While GI values increased by 2.2, 8.1, 13.0, 19.4, and 7.6% for the MT1, MT2, MT3, MT4, and MT5 treatments, respectively, compared to the NMT treatments *(Table 2)*. The interaction effects between salinity stress and magnetic treatments on the GI of cucumber seeds were statistically significant (p≤0.05) *(Table 1)*. The highest GI values of 437.00 (%/day) at MT4 were obtained with S1 salinity (0.38 dSm^{-1}) and the lowest GI value of 301.33 (%/day) at NMT with water salinity S3 (8.0 dSm^{-1}) *(Table 2)*. GI was positively correlated with CVG (r = 0.87) that was significant at p≤0.0001 levels *(Figure 6)*.

Table 2. The effect of salinity (NaCl) stress and different magnetic treatments on the GP, germination percentage 4th day, MGT, mean germination time, GI, germination index, COV, coefficient of the velocity of germination, and GRI, germination rate index of cucumber seeds

Magnetic Treatments effect ±SEM		GP	GRI	MGT	GI	CVG
NMT		65.3 ± 0.9d	25.5 ±0.6d	4.99 ±0.02a	326.9 ±6.8d	20.0 ±0.06c
MT1		67.5 ± 0.5cd	26.0 ±0.5d	4.97 ±0.02ab	334.0 ±6.4d	20.1 ±0.07bc
MT2		71.5 ± 1.5b	27.5 ±0.7c	4.96 ±0.02bc	353.2 ±8.6bc	20.2 ±0.07b
MT3		75.6 ± 1.6a	28.8 ±0.8b	4.95 ±0.02cd	369.3 ±10.7b	20.2 ±0.08ab
MT4		77.4 ± 2.0a	30.6 ±1.0a	4.92 ±0.02d	390.4 ±12.5a	20.3 ±0.08a
MT5		70.4 ± 1.1bc	27.3 ±0.8c	4.95 ±0.02bc	351.8 ±9.6c	20.2 ±0.08bc
Salinity Levels effect ±SEM						
S1 (0.38 dSm^{-1})		75.6 ±1.6a	30.0 ±0.6a	4.90 ±0.01c	384.2 ±8.1a	20.4 ±0.03a
S2 (4.0 dSm^{-1})		70.3 ±0.9b	27.7 ±0.4b	4.95 ±0.01b	355.2 ±4.5b	20.2 ±0.02b
S3 (8.0 dSm^{-1})		67.9 ±0.8c	25.1 ±0.3c	5.02 ±0.01a	323.4 ±4.3c	19.9 ±0.03c
Magnetic Treatments x Salinity Levels interaction ±SEM						
S1 (0.38 dSm^{-1})	**NMT**	66.7 ±1.6fg	26.9 ±0.4efg	4.95 ±0.01	341.7 ±4.4efg	20.20 ±0.06
	MT1	68.9 ±0.9defg	27.4 ±0.3def	4.92 ±0.01	347.7 ±5.0def	20.31 ±0.05
	MT2	76.7 ±0.8bc	29.5 ±0.4bcd	4.90 ±0.01	382.3 ±4.8bcd	20.41 ±0.05
	MT3	81.1 ±0.9ab	31.6 ±0.6b	4.88 ±0.01	408.0 ±7.0ab	20.50 ±0.03
	MT4	85.6 ±0.9a	34.3 ±0.2a	4.86 ±0.01	437.0 ±3.3a	20.56 ±0.03
	MT5	74.4 ±1.2bcde	30.3 ±0.3bc	4.89 ±0.01	388.3 ±5.9bc	20.45 ±0.05
S2 (4.0 dSm^{-1})	**NMT**	66.0 ±0.6fg	26.1 ±0.4fgh	4.97 ±0.01	337.7 ±5.0efg	20.10 ±0.02
	MT1	67.0 ±0.6fg	26.7 ±0.2efg	4.96 ±0.01	345.0 ±5.9efg	20.18 ±0.02
	MT2	70.0 ±0.5cdefg	27.8 ±0.5def	4.96 ±0.01	353.7 ±6.6cde	20.16 ±0.05
	MT3	75.6 ±1.3bcd	28.6 ±0.2cde	4.95 ±0.01	365.0 ±4.1cde	20.20 ±0.03
	MT4	74.4 ±0.9bcde	30.4 ±0.2bc	4.91 ±0.01	387.0 ±3.3bc	20.36 ±0.06
	MT5	68.9 ±0.7edfg	26.5 ±0.5efg	4.95 ±0.01	343.0 ±6.9efg	20.22 ±0.03
S3 (8.0 dSm^{-1})	**NMT**	63.3 ±1.6g	23.4 ±0.4l	5.05 ±0.01	301.3 ±6.1h	19.82 ±0.05
	MT1	66.7 ±0.5fg	23.9 ±0.1hl	5.04 ±0.01	309.3 ±2.7gh	19.88 ±0.06
	MT2	67.8 ±2.4efg	25.1 ±0.4ghl	5.02 ±0.01	323.7 ±5.0fgh	19.94 ±0.03
	MT3	70.0 ±0.5cdefg	26.3 ±0.4fg	5.01 ±0.01	335.0 ±8.0efg	19.96 ±0.03
	MT4	72.2 ±0.9cdef	27.0 ±0.4efc	4.99 ±0.02	347.3 ±6.1def	20.05 ±0.06
	MT5	67.8 ±0.9efg	25.1 ±0.2ghl	5.03 ±0.01	324.0 ±4.1fgh	19.90 ±0.02

Note: NMT: non-magnetic water treatment; MT1, MT2, MT3, MT4, and MT5 represent water passed through the magnetic 1, 2, 3, 5, and 8 times respectively. Mean values in the same columns followed by the same letters are not significantly different according to the HSD test (P <0.05). SEM: Standard error of the mean.

3.6. Coefficient of Velocity of Germination (CVG)

The effect of salinity stress and magnetic treatments on the CVG of cucumber seeds was statistically significant (p≤0.0001) *(Table 1)*. CVG values decreased with increasing water salinity levels. The GRI values were 20.41, 20.20, and 19.92 for the S1, S2, and S3 treatments, respectively *(Table 2)*. In addition, GRI was significantly increased using MT compared with NMT *(Table 2)*. CVG values were 20.04, 20.12, 20.17, 20.22, 20.32, and 20.19 for the NMT, MT1, MT2, MT3, MT4, and MT5 treatments, respectively. The interaction effects between salinity stress and magnetic parameters on the CVG of cucumber seeds were not statistically significant *(Table 1)*.

3.7. Germination Rate Index (GRI)

GRI values decreased with increasing water salinity levels and increased with MT use as salinity stress and magnetic treatments significantly affected GRI *(Table 1)*. As the water salinity levels increased from S1 to S3, the GRI values decreased by 7.7 and 16.2%, respectively, in the S2 and S3 treatments *(Table 2)*. GRI was significantly increased using MT compared with NMT. While the GRI values increased by 2.2, 7.8, 13.2, 20.0, and 7.2% for the MT1, MT2, MT3, MT4, and MT5 treatments, respectively, compared to the NMT treatments *(Table 2)*. The interaction between salinity stress and magnetic treatments significantly affected the GRI of cucumber seeds *(Table 1)*. The highest GRI values were obtained in the MT4S1 treatment *(Table 2)*. GRI was positively correlated to GI (r = 0.99), and CVG (r = 0.88) negatively correlated with MGT (r = -0.87) that was significant at the p≤0.0001 levels *(Fig. 6)*.

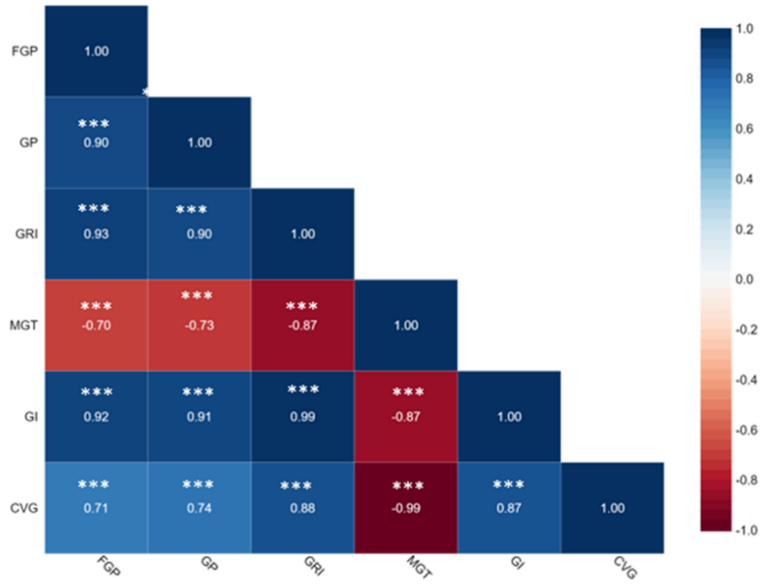

Figure 6. Correlation coefficients between cucumber germination parameters resulting from magnetic treatments and salinity levels using the mean values of the studied traits. (FGP, final germination percentage, GP, germination percentage 4th day, MGT, mean germination time, GI, germination index, COV, coefficient of the velocity of germination, and GRI, germination rate index). NS: Not significant, * Significant at p≤0.05, ** Significant at p≤0.001, *** Significant at p≤0.0001

4. Discussion

The results of the study showed that the final germination percentage, germination percentage 4th day, germination index, coefficient of the velocity of germination, and germination rate index decreased significantly with the increase of water salinity levels, while the mean germination time increased significantly. The highest values of FGP, GP, GI, CVG, and GRI were at S1 while they decreased by 7.8, 10.0, 15.8, 2.4 and 16.2%, respectively in S3, compared to S1 *(Table 2)*. When studying the effect of salt stress on maize (*Zea mays* L.) (Carpýcý et al. 2009), *Vicia sativa* L. seeds (Akhtar and Hussain, 2009), (Benlioğlu and Özkan, 2020) Mung Bean (*Vigna radiata* (L.) Wilczek) and (Kadıoğlu, 2021) Sage (*Salvia* ssp.), they found that due to the increase in salt concentration, germination rates were decreased. The germination rate was significantly reduced or delayed due to increased salinity levels (Pessarakli et al., 1991; Van Hoorn, 1991). Increased salinity levels decrease germination; the cause can be due to the toxicity of certain ions or increased osmotic pressure (Haileselasie, 2012). The decrease in germination rate is due to increased salinity levels and increased osmotic pressure which results in preventing the entry of water required for germination to the seeds (Gheidary et al., 2017). The high levels of salinity led to a decrease in the rate of germination, and the inhibition of enzymes required during germination (Mansour 1994; Sadeghian et al. 2004). The detrimental effect of NaCl on germination was due to the osmotic effect, salt stress, and toxicity of some elements (Castroluna et al., 2014). The increased salinity level delayed the germination of seeds and reduced the germination rate (Hajer et al., 2006). Salinity and osmotic stress affect the delay in the speed of germination and the decrease in germination percentage, which impedes the water uptake of the seeds (Romero-Aranda et al., 2001; Samarah et al., 2021).

In addition, the FGP, GP, GI, CVG, and GRI were significantly increased and the MGT was significantly decreased when using magnetic water compared to non-magnetic water. The effect of magnetic treatments on the FGP, GP, GI, CVG, MGT, and GRI of cucumber seeds was statistically significant (p≤0.0001) *Table 1*. While the

FGP values increased by 1.5, 5.4, 9.9, 14.4, and 4.5% for the MT1, MT2, MT3, MT4, and MT5 treatments, respectively, compared to the NMT treatments *(Fig. 3B)*. The values of FGP, GP, GI, CVG, and GRI were increased with the use of magnetic water and the highest values were obtained at MT4. The increase started from MNT to MT4 and then started to decrease from MT4 to MT5.

The reason for this is that magnetic water greatly affects the chemical composition of water, which affects the solubility of minerals in the water. In magnetic water, the hydrogen bonds between the water molecules change, which breaks the large salt crystals into small salt crystals. When magnetic water is used, it causes a change in the chemical properties of water, and a change in the hydrogen bond angle, which leads to a change in the osmotic pressure (Grewal and Maheshwari, 2011; Alsuvaid et al., 2022). The magnetic effect of water is due to changes in the chemical and physical properties of water, which leads to an improvement in its solubility properties (Chang and Weng, 2008; Amiri et al., 2006). The use of magnetic water significantly improves the germination and emergence of seeds (Samarah et al., 2021; Aladjadjiyan 2002; Podlesny et al., 2004; Pietruszewski and Kania, 2010; Qados et al., 2010). The magnetic water interacts with the ions in the cell membrane of the seed embryo, which leads to a decrease in the osmotic pressure (Yaycili et al., 2005) or an increase in the seed's absorption of water (Reina et al., 2001). Magnetic water may be responsible for the activation of hormones and enzymes involved in the germination process (Ismail et al., 2020). The increase in the rate of germination when using magnetic water compared with non-magnetic water. It may be due to the effect of magnetic water on the amount of water absorption in the seed cell membrane, and to the changes that occur in the osmotic pressure and the ionic concentration of water that regulates the entry of water into the seeds (Mahmood and Usman, 2014). Magnetic water activates the formation of proteins and accelerates seed germination (Ahamed et al., 2013). Magnetic water can enhance the germination and enzymatic activities of seeds, the activities of amylase and protease are higher in seed germination. Enzymes have an important role in providing nutrition for seed germination. (Ul Haq et al., 2016) .

5. Conclusions

The results of the present study showed the significant effects of salinity stress and magnetic and non-magnetic water on the germination of cucumber seeds. Salinity stress reduced the final germination percentage, germination percentage 4th day, germination index, coefficient of the velocity of germination, and germination rate index, while the average germination time decreased significantly. The highest values for FGP, GP, GI, CVG, and GRI were found at S1 and the lowest values were at S3.

The results showed that magnetic water treatment improved FGP, GP, GI, CVG, and GRI, especially under salinity stresses 4 and 8 $dS.m^{-1}$. Magnetic water treatment was an effective method for promoting the germination of cucumber seeds. Magnetic water is recommended due to its positive effect on the germination of cucumber seeds and reducing the negative effect of salinity stress.

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