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Research Article

The effect of salinity stress on germination parameters in *Satureja thymbra* L. (Lamiaceae)

Ummahan Oz [1,*]

[1]Manisa Celal Bayar University, Alaşehir Vocational School, Department of Plant and Animal Production, Medicinal and Aromatic Plants Programme, Manisa, Turkiye

Abstract: Salinity is an important problem all over the world. The destructive effect of salinity is observed from the seed germination stage. In this study, it was aimed to determine the effect of salinity on seed germination of the medically important *Satureja thymbra* L., whether pre-treatments are a factor in breaking the salinity stress, and to determine the level of salinity tolerance of this species. In the research, firstly, the seeds were exposed to two pre-treatments (80°C (5 minutes) + 10 ppm GA_3 (24 hours), 80°C (5 minutes) + 100 ppm GA_3 (24 hours)) and then 8 different NaCl concentrations (0.1 g/l, 1 g/l, 2.5 g/l, 5 g/l, 7.5 g/l,10 g/l, 15 g/l and 30 g/l) were tried. Germination seeds were counted every day and the effects of salinity on germination characteristics were investigated. The highest germination percentage (90%) was obtained at 0.1 g/l NaCl after 80°C (5 min.) + 100 ppm GA_3 (24 h.) pre-treatment. The results showed that the effect of salinity was significant on germination parameters in $p < 0.05$. Obtained results showed that the highest NaCl concentration at which *Satureja thymbra* seed could germinate was 10 g/l.

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1. INTRODUCTION

The world population is growing rapidly and is estimated to reach 9.7 billion by 2050. With the increasing population, the need for agricultural production also increases, it is inevitable that there will be an increase in the agricultural land allocated for food production, and it becomes necessary to produce even in unproductive lands. Today, only 37% of agriculture can be done due to problems such as drought, salinity and mineral deficiency (Bensidhoum & Nabti, 2021; Godoy *et al*., 2021; Leonardi *et al*., 2021; Turcios *et al*., 2021). Salinity is a major hazard in arid and semi-arid climatic regions and is an important limiting factor in global food production (Ahmed *et al*., 2020; Tolay, 2021). Desertification and high evaporation rate in arid and semi-arid areas cause rapidly salinization of soil and water (Bensidhoum & Nabti, 2021). Today, it is stated that there is a significant decrease in crop yield due to soil salinization worldwide and approximately 1125 million hectares of land are adversely affected by salt (Asgari & Diyanat, 2021; Karle *et al*., 2021). In many arid and semi-arid areas, groundwater aquifers are also saline. The trace amount of NaCl in the irrigation water increases the salinity in the arable land and

*CONTACT: Ummahan Oz ummahanoz48@gmail.com Manisa Celal Bayar University, Alaşehir Vocational School, Department of Plant and Animal Production, Medicinal and Aromatic Plants Programme, Manisa, Turkiye

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salinity becomes more and more a problem every day (Chandel *et al.*, 2021; Neji *et al.*, 2021; Tolay, 2021).

Salinity tolerance and response mechanisms differ according to many parameters such as salt exposure time, salt concentration, plant genotypes and environmental factors. In some plant species and varieties, stress factors cause a lot of damage, while in others, the level of this damage is less (Babalik & Göktürk Baydar, 2021; Tlahig *et al.*, 2021; Tokarz *et al.*, 2021). Since most crops are sensitive to salinity, an increase in salt content causes yield loss. Depending on the salt concentration in the environment, the decrease in yield varies between 10-50% (Godoy *et al.*, 2021). Salinity also changes the physicochemical and biological properties of the soil. Both the osmotic stress that causes water scarcity and the ionic effect caused by the accumulation of ions have a negative effect on plants (Karabay *et al.*, 2021).

Drought and high salinity have negative effects on important parameters such as seed germination, seedling growth, crop yield, food quality, etc. (Kang *et al.*, 2021; Liu *et al.*, 2021; Neji *et al.*, 2021). Seed germination includes the process that begins with the seed's absorption of water and ends with the formation of radicles and is a critical stage in the reproduction of plant species (Jiang *et al.*, 2021). Seed germination and seedling formation stages, which have vital importance in the plant, are the stages most affected by salinity in most plants (Fos *et al.*, 2021; Khaldi *et al.*, 2021). Salinity effects seed germination and plant growth as a result of biochemical events such as osmotic pressure imbalance, inhibition of the uptake of important plant nutrients, ion toxicity and production of reactive oxygen species (ROS) such as hydrogen peroxide and superoxide anions (Babaei *et al.*, 2021; Luo *et al.*, 2021; Mwando *et al.*, 2021). The increase in salinity stress causes a delay in germination of the seed and a decrease in the germination percentage, and even concentrations above the tolerance threshold cause complete inhibition of germination (Moghaddam *et al.*, 2020). Finding salinity-tolerant plants is one of the best solutions for improving agriculture in areas where salinity is detrimental to production (Al-shoaibi & Boutraa, 2021). In addition, it is necessary to develop appropriate methods to reduce the negative effect of salinity on seed germination in plants with low salinity tolerance. It has been stated that pretreatment of the seed with some substances such as plant growth regulators can stimulate some metabolic processes in germination and increase the performance of the seed under various environmental conditions (Ren *et al.*, 2020).

Lamiaceae is a family with approximately 7173 species, mostly distributed in the Mediterranean basin. Many plants belonging to this family are used a lot in fields such as medicine, pharmacy, perfumery and culinary culture due to their fragrance and medicinal properties (Bouriah *et al.*, 2021; Li *et al.*, 2021; Sarıkaya *et al.*, 2021). The genus *Satureja* L. belongs to the Lamiaceae family and consists of more than 200 species (Khalil *et al.*, 2020). One of these species, *Satureja thymbra* L., is a xerophilous and heliophilous plant mostly distributed in the Eastern Mediterranean Basin (Pinna *et al.*, 2021). *S. thymbra* is widely consumed as a tea by applying the infusion method, it is used in the form of decoction in gingivitis and in the kitchen due to its antiviral effect (Gürdal & Kültür, 2013; Roviello & Roviello, 2021). In the researches, it was also stated that this species is used in traditional medicine due to its antiseptic, antimicrobial, antifungal, anti-inflammatory, antidiarrheal, cardiotonic and blood purifying properties (Khoury *et al.*, 2016). The feature that gives plants their medicinal properties is the essential oil contained in these plants and the substances found in their composition.

The essential oil of *S. thymbra* contains important chemical components such as *p*-cymene, *γ*-terpinene, thymol, carvacrol, β-caryophyllen, α-humulene (Khalil *et al.*, 2020). It has been stated in studies that the essential oil obtained from this species has antifungal effects against *Mycogone perniciosa*, acaricidal effects against *Hyalomma marginatum*, insecticidal effects against *Culex pipiens*, and antibacterial effects against *Aeromonas salmonicida* (Cetin *et al.*, 2010; Dawood *et al*., 2021; Gea *et al*., 2021; Reis *et al*., 2021). It was emphasized that the essential oil of this species also showed an in vitro inhibitory effect against SARS-CoV and HSV-I replication (Khalil *et al*., 2020). In addition, it has been stated that the essential oil of this species has antimicrobial effect especially against *Chryseomonas luteola* and *Stenotrophomonas maltophilia* (Jafari *et al*., 2016). In another study, it was revealed that the essential oil was highly effective against *Pseudomonas fragi* and *Escherichia coli* when grown as a mixed biofilm with *Staphylococcus aureus* and *Listeria monocytogenes* (Chorianopoulos *et al*., 2008). It has been reported that emulsions enriched using *S. thymbra* maintain their phenolic content and oxidative stability at refrigeration temperatures (Choulitoudi *et al*., 2021). In another study, it was stated that the essential oil obtained from this species has an antinociceptive effect (Scuteri *et al*., 2021). Another study using *S. thymbra* essential oil concluded that this species can protect people against oxidative stress and amnesia without any side effects (Abd Rashed *et al*., 2021). The essential oil of this species is also used in muscle and joint pain, in the treatment of rheumatism, in arthritis and as a wound healer (Khalil *et al*., 2020). In addition to all these, it has antioxidant, cytotoxic, antidiabetic, insect repellant, herbicidial, antiplasmoidal and ovicidal effects (Giweli *et al*., 2012; Tepe & Cilkiz, 2016).

There is no study that determines the effect of salinity on seed germination of *Satureja thymbra,* which has high medicinal value. In this study, it was aimed to reveal the effect of salinity on seed germination of *S. thymbra*, to determine whether gibberellic acid seed priming reduces the negative effect of salinity and to contribute to future studies.

2. MATERIAL and METHODS

2.1. Sample Collection

The research was conducted in February 2021 at Department of Plant and Animal Production, Alaşehir Vocational School, Manisa Celal Bayar University, Turkey. The seeds of the *Satureja thymbra*, which constitute the study material, were collected from their natural habitats in Milas, Muğla, in July 2019. The collected seeds were stored in paper envelopes at +4°C in the refrigerator until the study was conducted.

2.2. Germination experiments

Before starting the experiment, seeds with similar characteristics were selected and surface sterilization was performed with 0.5% sodium hypochlorite solution for two minutes. Then the seeds were rinsed with deionized water and dried at room temperature. This study was planned in two groups, as the best results in the previous study (Oz, 2020) conducted with the same seed were obtained by exposing the seeds to 80°C for 5 minutes and keeping them in 10 ppm GA_3 and 100 ppm GA_3 for 24 hours. All seeds were kept in an oven at 80°C for 5 minutes and then the first group was kept in 10 ppm GA_3 solution for 24 hours, and the second group was kept in 100 ppm GA_3 for 24 hours. In order to determine the effect of salinity on germination, solutions containing 8 different concentrations of NaCl (0.1 g/l,1 g/l, 2.5 g/l, 5 g/l, 7.5 g/l, 10 g/l, 15 g/l and 30 g/l) were prepared after temperature and gibberellic acid pretreatments. Germination experiment was carried out at room temperature with 3 replicates and 10 seeds in each replicate. 10 seeds in each experiment were inserted to the three-layer filter paper and 5 ml of the salt concentrations to be applied were dropped on to them. Then the filter papers were rolled up and placed in a sealed plastic bag to prevent moisture loss. The seeds in the control group were only soaked with distilled water. Each roll of paper was changed every two days to prevent salt accumulation and the same procedures were repeated (Ergin *et al*., 2021). Germination was checked every day and all seeds with a radicle length of 2 mm were considered germinated. The obtained data were recorded every day. The germination experiment was continued for 28 days.

The following parameters were calculated using the necessary equations based on the data obtained. Germination percentage (GP): (Number of germinated seeds/Total number of seeds incubated)× 100 (Mwando *et al*., 2021), Germination speed (GS): $\sum(\frac{Gt}{Dt})$, Gt is the number of seeds newly germinated on day t and Dt is the number of days (Mzibra *et al*., 2021), Mean germination time (MGT): $\sum(D \times n)$ / $\sum n$, n is the number of seeds newly germinated on day D and D is the number of days counted from the beginning of the test, and expressed as days (Mzibra *et al*., 2021), The first day of germination (day): was the day on which the first germination is observed (Adilu & Gebre, 2021), The last day of germination (day): was the day on which the last germination is observed (Adilu & Gebre, 2021), Germination tolerance index (GTI): (Number of seeds germinated under NaCl stress/Number of seeds germinated under deionised water) × 100 (Mwando *et al*., 2021).

2.3. Statistical Analyzes

The obtained data were subjected by one-way analysis of variance (ANOVA), the means were analyzed by Duncan's test at 5% level of significance and the correlation between the NaCl treatments and studied parameters was evaluated with Pearson's correlation coefficient using IBM SPSS Statistics 25 software.

3. RESULTS

This study was carried out in two groups and the data of each group is explained in detail with tables and graphs below.

3.1. 80°C (5 min) + 10 ppm GA_3 (24 h) treatment

In this treatment, 8 different NaCl concentrations were used and the effects of these concentrations on germination parameters such as germination percentage, germination speed, mean germination time, the first day of germination, the last day of germination and germination tolerance index were observed (Table 1 and Figure 1). As a result of the germination test, it was determined that there was no germination at 15 g/l and 30 g/l. The highest germination percentage (70%) was obtained from the second replicate of the control . When we compared the averages of germination percentages, it was determined that the highest germination percentage was in the control and the least germination percentage was in 10 g/l NaCl. The highest germination speed (57%) was observed in the second replicate of the control, and when the average germination speed were examined, the highest germination speed was in the control group and the lowest germination speed was obtained in 10 g/l NaCl.

Table 1. The effect of NaCl concentrations on seed germination of *Satureja thymbra* in 80°C (5 min) + 10 ppm GA_3 (24 h) treatment

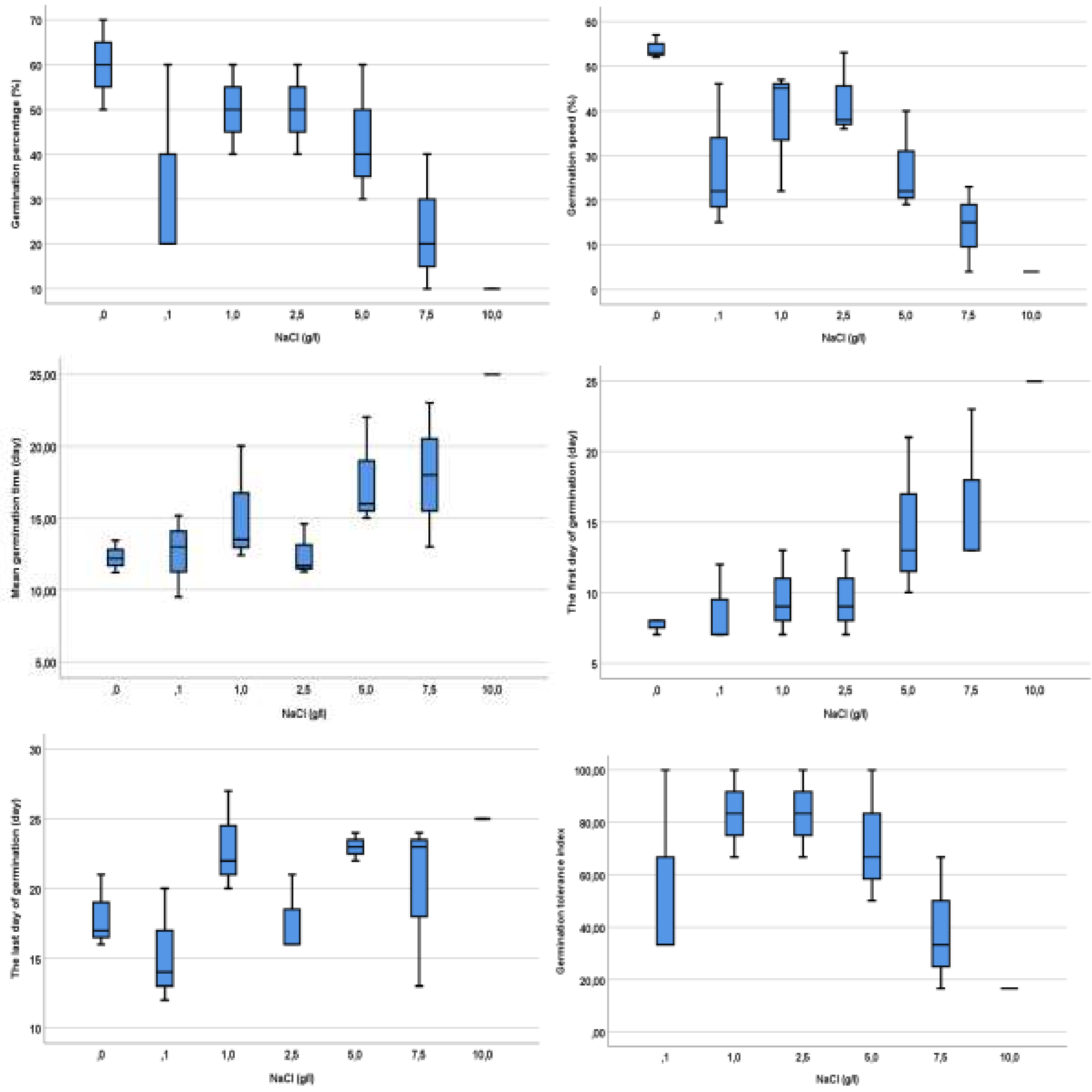
NaCl (g/l)	Germination percentage (%)	Germination speed (%)	Mean germination time (day)	The first day of germination (day)	The last day of germination (day)	Germination tolerance index
0.1	33.33±23.09a-c	27.67±16.26bc	12.56±2.86a	8.67±2.89a	15.33±4.16a	55.55±38.49ab
1	50±10cd	38±13.89cd	15.30±4.11a	9.67±3.06ab	23±3.61bc	83.33±16.66b
2.5	50±10cd	42.33±9.29cd	12.51±1.82a	9.67±3.06ab	17.67±2.89ab	83.33±16.66b
5	43.33±15.28b-d	27±11.36bc	17.67±3.78a	14.67±5.69ab	23±1bc	72.22±25.46b
7.5	23.33±15.28ab	14±9.54ab	18±5a	16.33±5.77b	20±6.08a-c	38.89±25.46ab
10	10a	4a	25b	25c	25c	16.67a
Control	60±10d	54±2.65d	12.27±1.12a	7.67±0.58a	18±2.65ab	-

*The data in the table are represented as the mean ± standard deviation, and different lowercase letters in the same column indicate significant differences between NaCl concentrations at $p<0.05$.

When compared in terms of mean germination time, the lowest mean (9.5) was determined at the second replicate of 0.1 g/l NaCl treatment. When we consider the mean of the replicates, it was observed that the lowest mean germination day was in the control and the highest was in 10 g/l NaCl. The first germination was observed on day 7 at the first replicate of the control, the first and second replicates of 0.1 g/l NaCl, the second replicate of 1 g/l NaCl and 2.5 g/l NaCl. When we examined in terms of the mean of replicates, the earliest germination was determined in the control group, and the latest was in 10 g/l NaCl. Final germination was observed on day 27, at the first replicate of 1 g/l NaCl treatment.

When we examined the average of replicates of the last day of germination, it was revealed that the last day of germination was earlier in the control and the latest in the treatment of 10 g/l NaCl. The highest germination tolerance index (100) was determined at the first replicate of 0.1 g/l NaCl treatment, and at the third replicates of 1 g/l NaCl, 2.5 g/l NaCl and 5 g/l NaCl treatments. When we consider the average values, the highest germination tolerance index was determined at 1 g/l NaCl and 2.5 g/l NaCl, and the lowest at 10 g/l NaCl.

Figure 1. The effect of NaCl concentrations on germination parameters of *Satureja thymbra* in 80°C (5 min) + 10 ppm GA_3 (24 h) treatment.



3.2. 80°C (5 min) + 100 ppm GA_3 (24 h) treatment

In this group, the effects of 8 different salt concentrations on seed germination parameters such as germination percentage, germination speed, mean germination time, first and last germination days and germination tolerance index were observed (Table 2 and Figure 2). As a result of the germination test, it was determined that there was no germination at 15 g/l and 30 g/l. The highest germination percentage (90%) was observed in the first replicate of 0.1 g/l NaCl treatment. When evaluated in terms of average germination percentage, the highest germination was determined at 0.1 g/l NaCl and the lowest at 10 g/l NaCl.

Germination speed was the highest (159%) in the control group. When compared in terms of average germination speed, the highest value was observed in 0.1 g/l NaCl treatment, and the lowest value was observed in 10 g/l NaCl. When compared in terms of mean germination day, it was determined that the lowest mean (4.17) was obtained from the third replicate of the control. In addition, when analyzed as the average of the replicates, it was observed that the lowest mean germination day was in the control group, and the highest was in the treatment of 10 g/l NaCl.

The first germination was observed at the first replicate of 1 g/l NaCl treatment and the third replicate of the control on the 3rd day. When we examined in terms of the mean of replicates, the earliest germination was determined in the control group, and the latest was in 10 g/l NaCl. Final germination was determined on the 28th day in the treatment of 10 g/l NaCl . When the data were evaluated in terms of the average of the replicates, it was observed that the last germination day was earlier at 0.1 g/l NaCl and later at 10 g/l NaCl . The highest germination tolerance index (168.86) was determined at the first replicate of 0.1 g/l NaCl treatment. When we consider the average values, the highest germination tolerance index was determined at 0.1 g/l NaCl, and the lowest at 10 g/l NaCl.

Table 2. The effect of NaCl concentrations on seed germination of *Satureja thymbra* in 80°C (5 min) + 100 ppm GA_3 (24 h) treatment.

NaCl (g/l)	Germination percentage (%)	Germination speed (%)	Mean germination time (day)	The first day of germination (day)	The last day of germination (day)	Germination tolerance index
0.1	76.67±11.55c	109.33±30.27c	6.89±1.23a	5.33±0.58ab	9±1.73a	143.84±21.67c
1	56.67±5.77bc	101±42.53c	6.55±2.54a	5±2ab	9.33±4.16a	106.32±10.83bc
2.5	63.33±20.82bc	92.33±31.94bc	7.67±1.40a	5ab	13.33±6.51ab	118.82±39.05bc
5	43.33±15.28b	45±1.73ab	10.36±4.36ab	7.33±2.52ab	13.67±6.03ab	81.30±28.66b
7.5	46.67±15.28b	39±17.58ab	13.79±2.95bc	9.33±2.08bc	18.67±2.31ab	87.55±28.66b
10	13.33±5.77a	10±6.93a	16.50±0.87c	13±5.20c	20±6.93b	25.01±10.83a
Control	53.33±11.55bc	108.33±44.79c	5.89±1.94a	4±1a	10±5.20a	-

*The data in the table are represented as the mean ± standard deviation, and different lowercase letters in the same column indicate significant differences between NaCl concentrations at $p < 0.05$.

After pre-treatment of 10 ppm GA_3 and 100 ppm GA_3, the effect of different NaCl doses on germination parameters was observed and it was determined that 100 ppm GA_3 pre-treatment slightly reduced the negative effect of NaCl (Figure 3).

Figure 2. The effect of NaCl concentrations on germination parameters of *Satureja thymbra* in 80°C (5 min) + 100 ppm GA_3 (24 h) treatment.

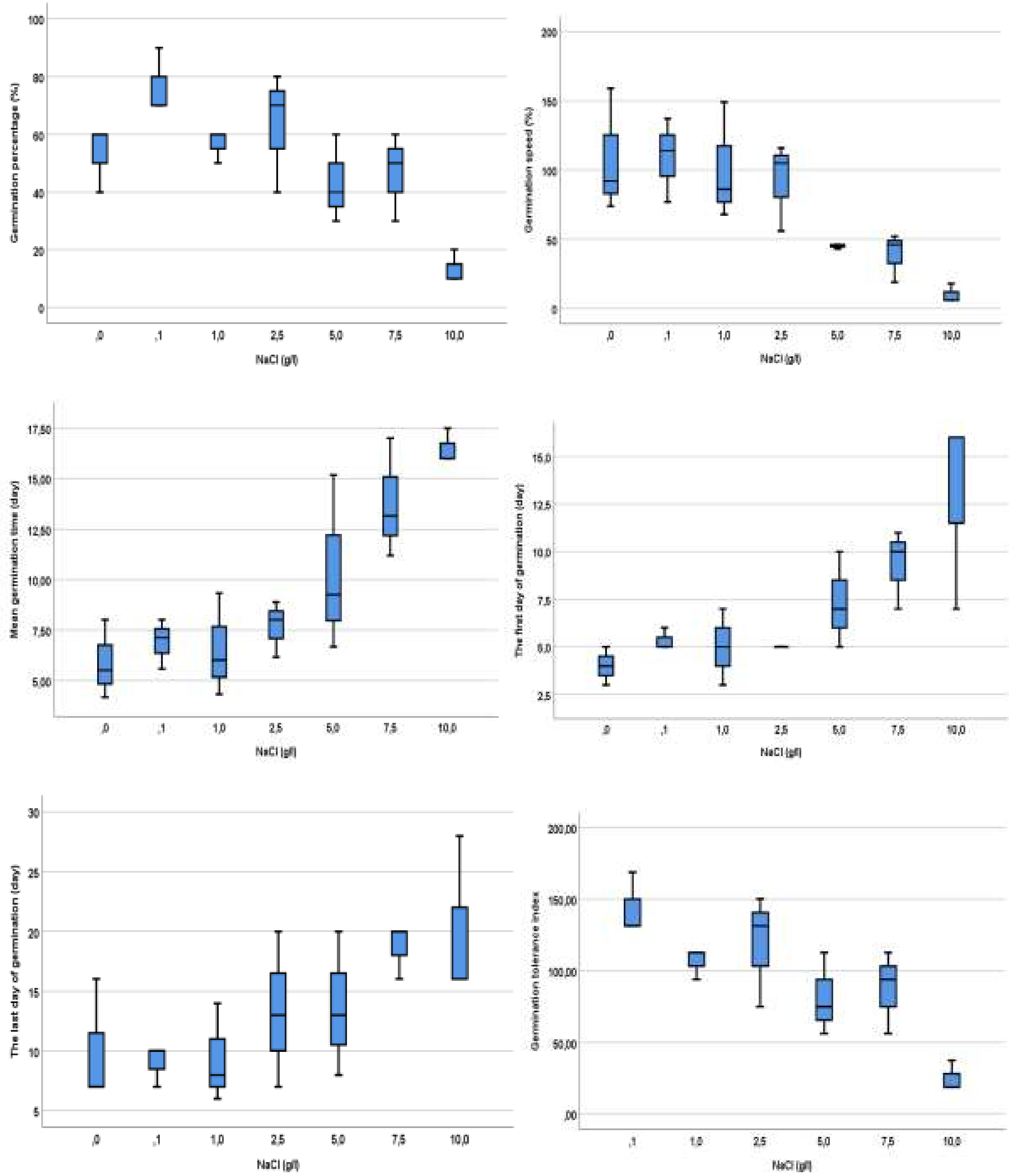
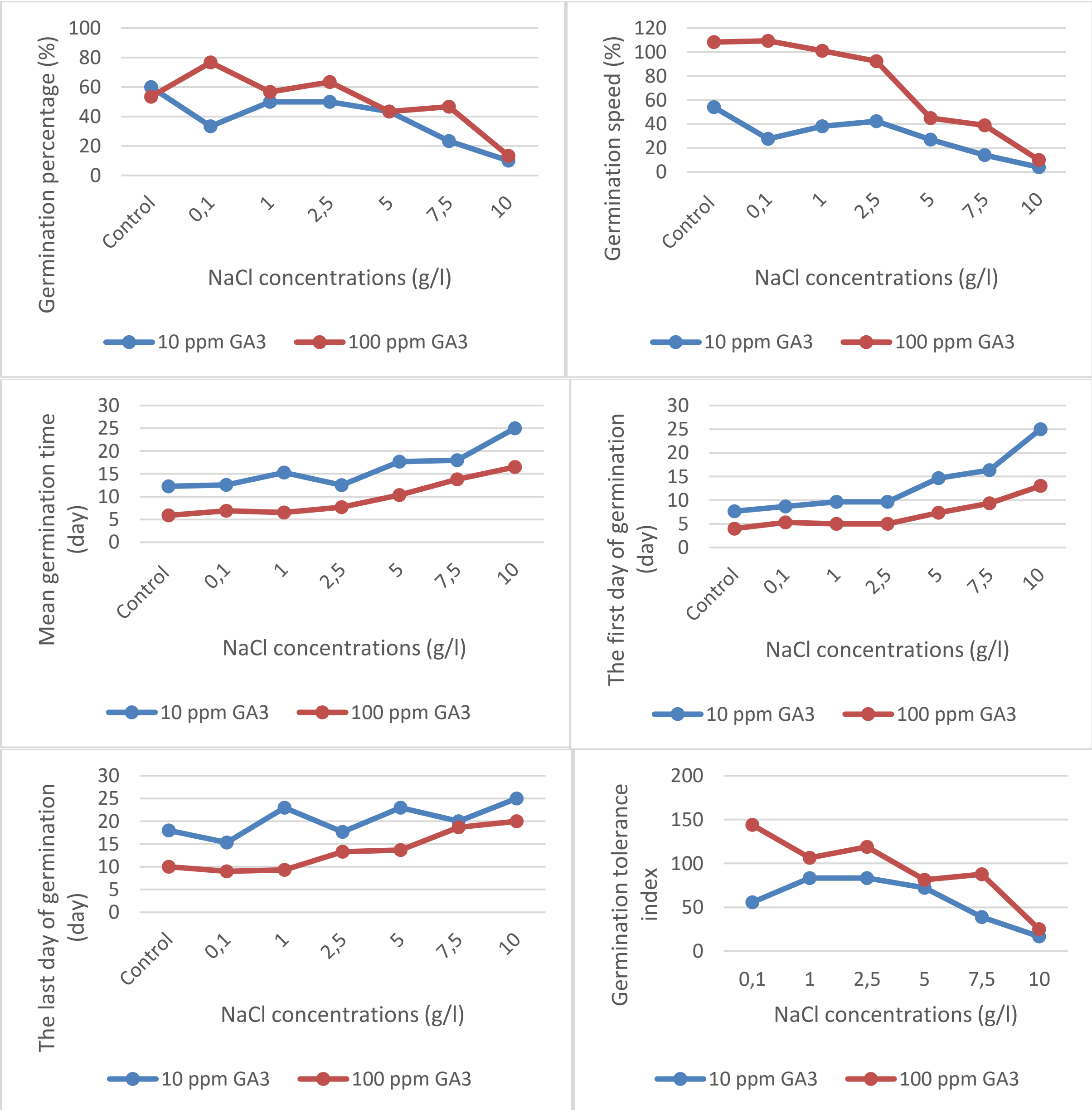


Figure 3. Comparison of the effects of different NaCl doses applied together with 10 ppm GA_3 and 100 ppm GA_3 pre-treatments on germination parameters.



3.3. Correlation Analyzes

According to the Pearson correlation coefficients between the NaCl treatments and studied parameters, there were positive and negative correlations. At 80°C (5 min) + 10 ppm GA_3 (24 h) treatment, a strong negative correlation was found between salt concentration and germination speed (r=-0.76; p<0.01), and also a moderate negative correlation was determined between salt concentration with germination percentage and germination tolerance index (r=-0.68; p<0.01, r= -0.62; p<0.01, respectively). In addition, while a strong positive correlation was determined between salt concentration with mean germination time (r= 0.79; p< 0.01) and the first day of germination (r= 0.85; p<0.01), a positive, moderate correlation was observed between salt concentration and the last day of germination (r= 0.50; p<0.05).

At 80°C (5 min) + 100 ppm GA_3 (24h) treatment, a strong negative correlation was determined between salt concentration with germination percentage (r=-0.74; p<0.01), germination speed (r=-0.82; p<0.01) and germination tolerance index (r=- 0.80; p<0.01). On the other hand, there was a strong positive correlation between salt concentration and mean germination time (*r*= 0.87; *p*<0.01) and the first day of germination (*r*= 0.80; *p*<0.01), and a moderate positive correlation between salt concentration and the last day of germination (*r*=0.69; *p*<0.01).

4. DISCUSSION

With the rapid increase in the world population, the demand for food is increasing day by day. For this reason, it has become one of the urgent needs to increase the productivity of plants grown in salty areas and used for both food and treatment purposes and to find a solution to salinity stress (Shahid *et al*., 2021). Salinity tolerance during the germination and emergence stages is an important indicator of salt tolerance in other subsequent growth stages (Feghhenabi *et al*., 2021).

It is thought that seed priming can be used technically to increase the salt tolerance of plants (Bahmani Jafarlou *et al*., 2021). Seed priming treatment using hormone solutions is important in seed metabolism and it has been revealed that this application using herbal hormones such as auxin, cytokinin, gibberellic acid plays a role in the functioning of biochemical and molecular metabolisms that are involved in creating tolerance against abiotic stress (Rhaman *et al*., 2021).

Gibberellic acid is an important hormone in defending the plant against stress conditions (Alharby *et al*., 2021). Studies have shown that externally applied gibberellic acid can increase seed germination and salt tolerance of seeds (Chauhan *et al*., 2019; Oral *et al*., 2019; Ali *et al*., 2021). In this study, it was determined that the negative effect of salinity could be reduced by gibberellic acid pre-treatment. In *Satureja thymbra*, it was observed that 100 ppm GA_3 application had more positive effects than 10 ppm on seed germination parameters and 100 ppm GA_3 was more effective in coping with salinity stress condition. In addition, even if the salt concentration increased (up to a certain concentration), the germination percentage was found to be higher in seeds with 100 ppm giberrelic acid pre-treatment compared to the control. It was observed that even giving 100 ppm giberrelic acid and 2.5 g/l NaCl to this species gave better results in terms of germination percentage compared to the control group. In a study conducted in *Hordeum vulgare* L. (Adjel-Lalouani *et al*., 2021), it was reported that when NaCl was applied together with GA_3, GA_3 attenuated the inhibitory effect of salinity on germination percentage and germination rate.

In present study, when the data were examined in terms of germination percentage, it was observed that as the salt concentration increased, the germination percentage decreased and germination was inhibited in *Satureja thymbra* at 15 g/l and 30 g/l NaCl concentrations. In *Satureja hortensis* L., which is in the same genus as the species used in the study, it was stated that increasing the salt concentration decreased the germination percentage (Nejatzadeh, 2021). The effect of salinity on seed germination of *Salvia hispanica* L., another species belonging to the Lamiaceae family, was tested and it was revealed that salinity stress minimized the germination percentage compared to the control (Younis *et al*., 2021). In the studies conducted with *Marrubium vulgare* L. and *Mentha pulegium* L., which are also members of the same family, it was concluded that the increase in salinity decreased the germination percentage (Nedjimi *et al*., 2020; Azad *et al*., 2021). In other studies on salinity (Akram *et al*., 2020; Dadaşoğlu *et al*., 2020; Dehnavi *et al*., 2020; Mondal *et al*., 2020; Singh *et al*., 2020; Wang *et al*., 2020; Zhumabekova *et al*., 2020; Bahrabadi *et al*., 2021; De Rossi *et al*., 2021; El Hamdaoui *et al*., 2021; Shariatinia *et al*., 2021; Tonguç *et al*., 2021; Zeng *et al*., 2021), it has been reported that increasing the salt concentration decreases the germination percentage.

High salt concentration is a limiting factor for the germination process, reducing the amount of water available, affecting both germination percentage and germination speed (dos Santos *et al*., 2019). In this study, it was observed that seeds exposed to NaCl concentrations generally had a lower germination speed than control; however, when we compare the salt concentrations with each other, it was observed that the germination speed increased as the salinity increased up to 2.5 g/l NaCl in 10 ppm GA_3 application, and the germination speed decreased after this concentration. In 100 ppm GA_3 application, it was determined that the germination speed decreased as the salinity increased. If we compare the 10 ppm GA_3 and 100 ppm GA_3 treatments, it is seen that the germination speed is higher at 100 ppm, as expected. The reason for this is the breaking effect of gibberellic acid on salinity stress. It has been reported that the germination speed decreases as NaCl and KCl concentrations increase in *Camelina sativa* (L.) Crantz. (Yohannes *et al.*, 2020). It has been stated that increasing salinity decreases the germination speed in *Lens culinaris* Medic. (Ceyhan & Çakır, 2021). In a study with *Vigna umbellata* (Thunb.) Ohwi & H. Ohashi, 50 mM, 100 mM and 200 mM NaCl levels were tested and it was concluded that as the salinity increased, the germination speed decreased (Atta *et al*., 2021).

In present study, it was determined that the mean germination time increased as the salt concentration increased. When we examine Table 1, the reason for the sudden increase in the mean germination time at 1 g/l NaCl is that germination is observed even on the 27th day. When we examined the other data, it was concluded that the increase in salinity increased the mean germination time. In addition, it was observed that 100 ppm GA_3 pre-treatment reduced the negative effect of salinity and reduced the mean germination time compared to 10 ppm GA_3 pre-treatment. The reason for this, gibberellic acid is involved in inducing hydrolytic enzymes such as ɑ-amylase and hydrogenase to initiate the germination process in the seed and accelerate the germination process (Aziz & Pekşen, 2020). In the study in which the effect of salinity on the germination of *Carthamus tinctorius* L. was observed (Tonguç *et al*., 2021), it was stated that the mean germination time increased as the salinity increased. In a study using *Lactuca sativa* L. (Alves *et al*., 2020), it was concluded that salinity increased mean germination time in seeds exposed to salt stress (NaCl) without any pretreatment. In another study, it was revealed that increasing salinity in *Chloris gayana* Kunth. had a negative effect on germination percentage and mean germination time (Daba *et al*., 2019). In a study conducted in *Avena sativa* L., it was concluded that salinity stress greatly effects parameters such as germination percentage and mean germination time (Kumar *et al*., 2021). Other similar studies (Melendo & Giménez, 2019; Ceritoğlu & Erman, 2020; Ku-Or *et al*., 2020; Székely *et al*., 2021) on this subject also support our results.

In this study, it was determined that generally increasing NaCl doses decreased the germination tolerance index and the germination tolerance index was higher in 100 ppm GA_3 treatment. The reason for this is the stress breaking effect of GA_3 as we mentioned in the previous parameters. In a study on this subject, it was revealed that increasing NaCl dose caused a significant decrease in the germination stress tolerance index (Ergin *et al*., 2021).In a study in which the effect of salinity on the germination of *Lolium perenne* L. was observed, it was concluded that the salt tolerance index decreased as the salinity increased (Kusvuran *et al*., 2015). In another study on this subject, it was determined that as the NaCl concentration increased, the Germination Stress Tolerance Index decreased (Marium *et al*., 2019).

It is thought that there is mostly a positive relationship between the response to salinity during the germination and seedling stages and the response to salinity in other growth stages of the plant, and therefore, the results in the germination and seedling stages can provide information about the salinity resistance of that plant (Güldüren & Elkoca, 2012). When the data were examined, it was observed that when 80°C (5 min) + 100 ppm GA_3 (24 h) was applied as a pre-treatment, even at 7.5 g/l NaCl concentration (0.75% NaCl), it was observed that approximately control germination was achieved, and it is thought that this species can be resistant to salinity.

5. CONCLUSION

In the study, it was determined that salinity has a negative effect on seed germination, but appropriate doses of gibberellic acid reduce the negative effect of salinity on parameters related to seed germination. In addition, it was observed that the resistance of *Satureja thymbra* seed to salinity was up to 10 g/l NaCl and higher amount of NaCl prevented germination.

Declaration of Conflicting Interests and Ethics

The author declares no conflict of interest. This research study complies with research and publishing ethics. The scientific and legal responsibility for manuscripts published in IJSM belongs to the author.

Authorship contribution statement

Ummahan Oz: Investigation, Methodology, Resources, Visualization, Software, Formal Analyzes, Validation and Writing original draft.

Orcid

Ummahan Oz https://orcid.org/0000-0002-0281-1048

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