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Germination and Seedling Development Performances of Some Soybean [*Glycine max* (L.) Merrill] Cultivars Under Salinity Stress

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A B S T R A C T

The aim of the study was to determine the effects of different salt concentrations on the germination and seedling development parameters of some grain and forage soybean [*Glycine max* (L.) Merrill] cultivars. The study was conducted under controlled conditions at the Field Crops Laboratory of the Faculty of Agriculture in Siirt University. The subject of the research consists of different salt concentrations (S_0= 0, S_1= 50, S_2= 100, S_3= 150, and S_4= 200 mM NaCl) applied to four different soybean cultivars (Adasoy, Nazlıcan, Yeşilsoy, and Anp-2018). The laboratory experiment was set up in Petri dishes according to the randomized complete design with 4 replications. In the study, germination parameters such as germination percentage (%), mean germination time (days), germination index, germination uniformity coefficient, and germination energy, and some seedling parameters such as radicle and stem length (cm), seedling fresh and dry weight (mg) and seedling vigor index were examined. Significant differences have been found among the examined cultivars in terms of all the parameters considered in the evaluations. While Adasoy cultivar came to the fore front for germination parameters, Adasoy, Anp-2018, and Yeşilsoy cultivars came to the fore front in seedling development characteristics. In the study, the effect of salt concentrations on germination and seedling development parameters (except seedling dry weight) was statistically significant ($p<0.01$). Increasing salt concentrations negatively affected germination and seedling development. The research results indicate that soybean plants are tolerant up to a salt concentration of 50 mM during germination and seedling development stages. It was concluded that the cultivation of suitable cultivars is important in areas affected by salt stress, and in this regard, the Adasoy cultivar was identified as a cultivar that can be evaluated under 50-100 mM NaCl conditions.

1. Introduction

Soybean [*Glycine max* (L.) Merrill], a highly nutritious legume, is commonly used as a food source for both humans and farm animals due to its rich nutritional content, including proteins, sugars, fats, fatty acids, amino acids, and vitamins (Zhang et al., 2015; Bayraklı et al., 2017; Valliyodan et al., 2017; Lin et al., 2021). Additionally, soybean contributes to soil fertility due to its high biological nitrogen fixation capacity (Rahman et al., 2023). Worldwide, soybean accounts for the highest proportion of total oilseed production at 53% (Pratap et al., 2016). Soybean oil is used in various industrial sectors, including pharmaceuticals, plastics, paper, ink, paint, varnish, cosmetics, and pesticide production (Pratap et al., 2012).

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Soybean, despite its outstanding agricultural characteristics on a global scale, exhibits sensitivity to soil salinity (Papiernik et al., 2005). In this sense, soybean is classified as moderately sensitive to salt (Munns and Tester, 2008). Globally, approximately 932 million hectares of land are affected by salinity (Fagodiya et al., 2022). In Türkiye, there is a salinity problem in 1.7% of the total production area (1.5 million hectares) (Kaplan and Kara, 2014; Çakmakcı et al., 2016). Salinity negatively impacts soil microbial diversity, enzymatic activities, and, consequently, carbon and nitrogen dynamics, as well as greenhouse gas emissions from the soil (Fagodiya et al., 2022). Furthermore, excessive soluble salts in the soil can generally limit crop productivity (Munns and Tester, 2008). The soybean plant is particularly susceptible to abiotic stresses such as drought and salinity during its growth and yield (Chen et al., 2023). In a study, soybean production decreased by 40% with the increasing salinity stress (Papiernik et al., 2005). Butcher et al. (2016), have reported that soybean is sensitive to salt, with yields decreasing by 20% per dS/m above 5.0 dS/m salinity levels. In this regard, soybean is classified as moderately salt-sensitive with a salinity threshold of 5.0 dS/m (Pavli et al., 2021). However, it has also been demonstrated that the soybean gene pool exhibits a spectrum of salt-tolerant phenotypes (Phang et al., 2008).

Salinity is one of the most significant limiting factors for crop production in arid and semi-arid regions. Although 90% of soybean production in Türkiye takes place in the Mediterranean Region; in recent years, its cultivation has started in provinces such as Diyarbakır, Şırnak, Konya and Muş, where arid and semi-arid climates prevail (TÜİK, 2023). Seed germination and early seedling growth, in particular, are critical stages in plant development. In this sense, the germination stage is the most sensitive to salinity among plants (Acikbas et al., 2021; Açıkbaş and Özyazıcı, 2022a). Numerous studies have reported that high salt concentrations inhibit seed germination and reduce the percentage of germinated seeds (Shannon and Grieve, 1999; Khan and Weber, 2008; Ceritoğlu and Erman, 2020; Özyazıcı, 2021a and b, 2022a and b; Özyazıcı and Açıkbaş, 2021a). On the other hand, salt damage is not only depend on the growth stage, environmental factors, and the structure of salts but is also significantly influenced by the plant species and variety, as well as the quantity of salt. Recognizing genotypic differences, especially in the responses of genotypes to salinity during germination and seedling growth stages, is crucial for identifying salt-tolerant varieties (Özyazıcı and Açıkbaş, 2021b). Some morphological indicators such as germination rate, germination potential, and shoot length during the germination stage are easy and quick to measure. These indicators can better reflect the true salt tolerance level of soybean (Zhou et al., 2023). Therefore, this stage is commonly used to assess salt tolerance (Ali and Elozeiri, 2017; Zhang et al., 2019).

The aims of this research was to determine the germination and seedling development of various soybean [*G. max* (L.) Merrill] cultivars under different salt concentrations and to elucidate the salt tolerance potential of these cultivars.

2. Materials and Methods

2.1. Material

The research was conducted at the Field Crops Department Laboratory of Siirt University, Faculty of Agriculture. Grain (Adasoy, Nazlıcan, and Anp-2018) and forage (Yeşilsoy) soybean [*G. max* (L.) Merrill] cultivars (C) were used as plant material. Sodium chloride (NaCl) was used as the salt form.

2.2. Study subject and experimental design

The subject of the study is formed by different salt concentrations (S_0= 0, S_1= 50, S_2= 100, S_3= 150 ve S_4= 200 mM NaCl) applied to four different soybean cultivars. The laboratory experiment was set up with four replicates following a randomized complete design. For each replicate, 25 seeds were used. After sterilizing the seeds in 70% ethyl alcohol for 1 minute and rinsing them three times with sterile water, surface sterilization was performed by covering the seeds with a solution of 10% sodium hypochlorite (NaOCl) and 0.01% Tween20 for 10 minutes to deform any microorganisms on the seed surface. The sterilized seeds were placed between Whatman Grade 2 (Little Chalfont, Buckinghamshire, UK) filter paper (90 mm x 15 mm) in Petri dishes. Salt concentrations prepared in four different levels were applied to each Petri dish separately for each variety, with 5 ml of the solution in each dish. Petri dishes were placed in an oven (BINDER, GmbH, Germany) set at 25±1 °C for germination. Until the end of the study, an additional 5 ml of the appropriate salt dose was added to the Petri dishes every 48 hours (based on the moisture level of the seeds in the Petri dishes). Germination checks were performed every 24 hours throughout the experiment, and the germination experiment was completed on the 10th day. The emergence of at least a 2 mm radicle as the germination criterion was used to determine seed germination (Scott et al., 1984; Soleymani and Shahrajabian, 2018).

2.3. Evolution of germination and seedling growth

Measurements were obtained from ten randomly selected plants within each Petri dish. In cases where inadequate germination occurred due to salt-induced stress, measurements were instead taken from the germinated plants.

Germination percentage (GP) (%): Seeds germinating every 24 hours were counted and Equation 1 used for the determination of the GP (Scott et al., 1984).

$$GP= (NGS/TS)x100 \quad (1)$$

In the equation, *NGS* is the number of normal germinated seeds, *TS* is the total number of utilized seeds.

Mean germination time (MGT) (day): MGT is generally used to determine the germination day of seeds and was calculated using Equation 2 (Ellis and Roberts, 1981).

$$MGT= \Sigma(N_iT_i / N_i) \quad (2)$$

N_i is the number of seeds germinated on the T_i day; T_i refers to the number of days from the beginning of germination.

Germination index (GI): It was calculated with the help of Equation 3 reported by Wang et al. (2004).

$$GI= \Sigma(G_i/T_t) \quad (3)$$

G_i is the germination percentage at the i^{th} day, and T_t is the days of germination test duration.

Coefficient of uniformity of germination (CUG): It was calculated with the help of Equation 4 reported by Bewley and Black (1994).

$$CUG= \Sigma n / \Sigma[(MGT-t)^2 n] \quad (4)$$

t is the time in days starting from day 0, the day of sowing, and *n* is the number of seeds completing germination on day *t*.

Germination energy (GE): It was calculated with the help of Equation 5 reported by Li et al. (2020).

$$GE= (T_1/N) \text{ x } 100 \quad (5)$$

In the equation, T_1 represents the number of seeds germinated on the first day, and *N* represents the total number of seeds.

Root length (RL) and shoot length (SL) (cm): At the end of the study, the lengths of root and shoots were scanned in color with a random selection using an Iscan Color Mini Portable Scanner with a resolution of 600 dpi. The RL and SL parameters were precisely and meticulously measured using (Acikbas et al., 2021) the ImageJ image analysis software (Rueden et al., 2017).

Seedling fresh weight (SFW) and dry weight (SDW) (mg): The SFW was determined at the end of the study by weighing ten randomly selected seedlings from each Petri dish and calculating the average fresh weight of seedlings. Following that, the fresh seedlings were dried in an oven at 70 ^{o}C for 48 hours to determine the average SDW.

Seedling vigor index (SVI): It was calculated using Equation 6 as reported by Kalsa and Abebie (2012).

$$SVI= GPxSDW \quad (6)$$

2.4. Statistical assessment

Before performing the analysis of variance, ArcSin transformation was applied to the germination percentage values, following the method described by Zar (1996). The obtained data was subjected to analysis of variance using the randomized complete design, and differences between means were assessed using the TUKEYS HSD multiple comparison test (Açıkgöz and Açıkgöz, 2001).

3. Results

3.1. Germination parameters

Data on germination parameters of soybean cultivars at different salt concentrations are given in Table 1. The statistical analysis revealed that the effects of applied salt concentrations and cultivars on all examined germination parameters were highly significant based on the evaluations ($p<0.01$) (Table 1).

Table 1. Germination parameter results of soybean cultivars at different salt concentrations*

Cultivars	NaCl concentration (mM)					
	S_0	S_1	S_2	S_3	S_4	Average
Germination percentage (GP) (%)						
Adasoy	98.3 a	95.0 ab	81.7 bcd	73.3 de	30.0 jk	75.7 A
Nazlıcan	65.0 efg	56.7 fgh	46.7 hı	28.3 jk	6.7 l	40.7 D
Yeşilsoy	90.0 abc	83.3 a-d	71.7 def	63.3 efg	21.7 kl	66.0 B
Anp-2018	81.7 bcd	78.3 cde	51.7 ghı	38.3 ıj	8.3 l	51.7 C
Average	83.8 A	78.3 A	62.9 B	50.8 C	16.7 D	
Mean germination time (MGT) (day)						
Adasoy	3.34 ef	3.08 f	3.61 def	3.78 c-f	4.70 c	3.70 C
Nazlıcan	3.94 c-f	4.11 c-f	4.26 cde	6.47 ab	7.17 a	5.19 A
Yeşilsoy	3.06 f	3.14 f	3.20 ef	4.57 cd	5.82 b	3.96 C
Anp-2018	3.57 def	3.17 f	4.01 c-f	4.57 cd	6.67 ab	4.40 B
Average	3.48 C	3.38 C	3.77 C	4.85 B	6.09 A	
Germination index (GI)						
Adasoy	6.32 ab	6.46 a	4.84 cd	4.02 def	1.32 ıjk	4.59 A
Nazlıcan	3.48 efg	2.87 fgh	2.46 ghı	0.90 jk	0.19 k	1.98 D
Yeşilsoy	6.45 a	5.53 abc	4.74 cde	2.89 fgh	0.76 jk	4.07 B
Anp-2018	4.99 cd	5.12 bcd	2.68 gh	1.76 hıj	0.26 k	2.96 C
Average	5.31 A	4.99 A	3.68 B	2.39 C	0.63 D	
Coefficient of uniformity of germination (CUG)						
Adasoy	29.5 ab	31.1 a	22.7 cd	19.5 def	6.4 ıjk	21.8 A
Nazlıcan	16.5 efg	13.8 fgh	11.0 ghı	4.4 jk	1.0 k	9.3 D
Yeşilsoy	29.6 ab	26.5 abc	22.4 cde	14.0 fgh	3.7 jk	19.3 B
Anp-2018	22.9 cd	24.7 bcd	13.0 gh	8.5 hıj	1.3 k	14.1 C
Average	24.6 A	24.0 A	17.3 B	11.6 C	3.1 D	
Germination energy (GE)						
Adasoy	60.0 ab	63.3 a	36.7 bcd	5.0 e	3.7 e	36.7 A
Nazlıcan	26.7 cde	15.0 de	10.0 e	5.0 e	2.3 e	23.2 B
Yeşilsoy	43.3 abc	60.0 ab	43.3 abc	10.0 e	1.0 e	31.5 A
Anp-2018	43.3 abc	53.3 ab	13.3 de	5.0 e	1.0 e	11.8 C
Average	43.3 A	47.9 A	25.8 B	10.0 C	2.0 C	

Significance level (P)	NaCl	Cultivar (C)	NaClxC
GP	0.0001**	0.0001**	0.0065**
MGT	0.0001**	0.0001**	0.0001**
GI	0.0001**	0.0001**	0.0001**
CUG	0.0001**	0.0001**	0.0001**
GE	0.0001**	0.0001**	0.0002**

*: The difference between the means indicated by the same letter in the same group is not statistically significant, **: Significant at the level of $p<0.01$

As a result of the study, GP, GI, CUG, and GE values all decreased significantly as salt concentrations increased; however, this decrease was not significant at 0 and 50 mM salt concentrations. In other words, there was no statistical difference between the control treatment and the 50 mM salt dose, and the highest values for these four germination parameters were obtained at 0 and 50 mM doses. The lowest values for the same germination parameters occurred at the highest salt concentration. The application of salt to soybean seeds extended the MGT, the MGT at 0, 50, and 100 mM salt doses ranged between 3.38 and 3.77 days, statistically in the same group for the varieties. In the study, the highest salt dose (200 mM) resulted in the longest MGT of 6.09 days (Table 1).

When the average performance of the cultivars was examined, the Adasoy cv. had the highest results for the average GP (75.7%), GI (4.59), and CUG (21.8) as the mean of salt concentrations. Adasoy (3.70 days) and Yeşilsoy (3.96 days) cultivars developed faster under the effect of salt, making them the varieties with the shortest MGT. These same cultivars also showed the highest performance in terms of GE values (36.7 and 31.5, respectively) (Table 1). In terms of GP, MGT, GI, and CUG, the cultivar with the poorest germination performance as the mean of salt concentrations was Nazlıcan, while the Anp-2018 cv. had the lowest GE (Table 1).

The C x S interaction was found to be significant ($p<0.01$) for all examined germination parameters in the study. In terms of GP, values decreased in all cultivars in general as salt concentrations increased. However, the cultivars varied considerably at the same salt concentrations. In addition, although the MGT generally increased with the increase in salt doses, for example, at a dose of 50 mM, the germination time was shortened in Adasoy and Anp-2018 cultivars, which were in a statistically different group. In terms of the GI, CUG, and GE parameters, it is noteworthy that while the overall trend among varieties inversely correlated with increasing salt doses, certain cultivars displayed deviations from this pattern at some doses. For instance, Adasoy and Anp-2018 cultivars exhibited such a deviation at 50 mM salt concentration. The reasons listed above were effective in making the interaction significant (Table 1).

3.2. Seedling growth parameters

The results of some seedling growth parameters of soybean cultivars at different salt concentrations are presented in Table 2. The effect of applied salt concentrations on seedling growth parameters was statistically significant ($p<0.01$). The values of the examined seedling growth parameters decreased with increasing salt concentrations on mean for the cultivars (especially for SDW, beyond 50 mM). Except for SDW, the highest values for all other parameters were observed in the control treatment without salt application, and the lowest values were found at 200 mM dose for all seedling growth parameters. In terms of SDW, the highest values were obtained at 50 mM salt concentration with 48.8 mg. However, SDW was not adversely affected by salt doses other than 200 mM, and the difference between 0, 50, 100, and 150 mM doses was statistically insignificant (Table 2).

When the average performance of the cultivars was evaluated, the highest values as the mean of salt concentrations were determined as follows: RL for Adasoy (5.59 cm) and Anp-2018 (5.55 cm), SL for Anp-2018 (4.96 cm), SFW for Adasoy (244.0 mg), Yeşilsoy (259.2 mg), and Anp-2018 (220.2 mg), and SVI for Adasoy (22.2) and Yeşilsoy (21.5). The lowest values for these parameters were found in the Nazlıcan cultivar. The difference between cultivars in terms of RL, SL, SFW, and SVI was statistically significant at $p<0.01$. The difference between cultivars in terms of SDW was statistically insignificant, and the SDW values of the cultivars varied between 11.8-37.4 mg as the average salt concentrations (Table 2).

Except for SDW, the C x S interaction was found to be statistically significant at $p<0.01$ for all other seedling growth parameters. It is thought that the interaction for these seedling development parameters examined is due to the fact that cultivars are affected by salt concentrations at different rates and some cultivars are more resistant to salt (Table 2).

4. Discussion

4.1. Effect of salt concentrations on germination and seedling growth parameters

Salinity is one of the most significant stress factors that have adverse effects on seed germination, plant development, and crop productivity, limiting the productivity of agricultural crops. The toxic effect of salts begins with the initiation of the germination process, leading to a decrease in water potential and hindering the water uptake by the seeds (Shanko et al., 2017). As Zapata et al. (2004) have also pointed out, high salt concentrations in the soil or growth medium negatively affect the germination process in almost all species, with a few exceptions.

Salinity is one of the major obstacles to increasing soybean production in cultivation areas (Kandil et al., 2015). High salinity adversely affects the entire life cycle of soybeans (Abel and MacKenzie, 1964). The germination stage in soybean, like many other crop plants, is the most sensitive to salinity. Abel and MacKenzie (1964) reported that the germination of soybean seeds was delayed under low salt conditions (0.05% and 0.1% NaCl) and that higher salt concentrations led to a significant reduction in germination percentage. In the current study, all germination and seedling characteristics were negatively affected due to increasing salt concentrations, both within the cultivars and according to the average results. Sudden declines in germination and seedling development were observed at high salt concentrations (Table 1 and 2). In studies conducted with soybean, salinity stress has been reported to have a negative impact on various aspects, including seed germination, plant height, shoot dry weight (Essa, 2002), seedling fresh weight (Farhoudi and Tafti, 2011), germination percentage (Neves et al., 2005; Ahmadvand et al., 2012; Ndifon, 2013; Ahmed et al., 2023), plant height, and root length (Ahmed et al., 2023). High salt concentration (100 mM NaCl) has been shown to reduce shoot dry weight (Le et al., 2021) and increase the mean germination time (Farhoudi and Tafti, 2011; Ahmed et al., 2023). Based on the findings of Neves et al. (2005), the germination percentage within the control group averaged at 61%, but at higher salt concentrations (200 mM), this rate significantly declined to 5%.

The exact mechanisms by which salt affects germination are not fully elucidated. However, it has been suggested that osmotic (Kingsbury and Epstein, 1986; Kumar and Sharma, 1990) and/or toxic effects (Cramer et al., 1994) may be responsible for salt injury (Essa, 2002). Additionally, Munns (2002) has proposed that soluble salts induce osmotic stress, leading to specific ion toxicity and ionic imbalance, with potential consequences that could ultimately result in plant mortality.

Table 2. The seedling development parameter results of soybean varieties at different salt concentrations*

Cultivars	NaCl concentration (mM)					
	S_0	S_1	S_2	S_3	S_4	Average
Root length (RL) (cm)						
Adasoy	11.40 ab	9.59 bc	4.86 e	1.61 fg	0.47 g	5.59 A
Nazlıcan	7.02 d	3.97 e	1.37 g	0.86 g	0.26 g	2.69 C
Yeşilsoy	11.36 b	4.68 e	1.54 g	1.48 g	0.32 g	3.88 B
Anp-2018	13.37 a	8.56 cd	3.55 ef	1.51 g	0.75 g	5.55 A
Average	10.89 A	6.70 B	2.83 C	1.37 D	0.45 E	
Shoot length (SL) (cm)						
Adasoy	8.90 b	6.25 de	2.75 f	1.62 g	0.56 ı	4.02 BC
Nazlıcan	9.08 b	5.73 e	2.61 f	1.42 gh	0.54 ı	3.88 C
Yeşilsoy	9.64 b	6.65 cd	2.61 f	1.67 g	0.75 hı	4.27 B
Anp-2018	12.23 a	7.19 c	2.88 f	1.56 gh	0.92 ghı	4.96 A
Average	9.97 A	6.45 B	2.71 C	1.57 D	0.69 E	
Seedling fresh weight (SFW) (mg)						
Adasoy	479.8 abc	389.4 bc	227.4 efg	98.3 ghı	25.3 hı	244.0 A
Nazlıcan	340.2 cde	228.9 efg	127.2 ghı	85.3 ghı	9.8 ı	158.3 B
Yeşilsoy	613.8 a	429.7 bcd	142.9 ghı	82.6 ghı	27.1 hı	259.2 A
Anp-2018	534.2 ab	311.6 def	163.1 fgh	72.2 hı	20.0 hı	220.2 A
Average	492.0 A	340.0 B	165.1 C	84.6 D	20.5 E	
Seedling dry weight (SDW) (mg)						
Adasoy	34.4	118.3	21.3	10.7	2.0	37.4
Nazlıcan	20.8	16.1	12.6	8.9	0.8	11.8
Yeşilsoy	42.3	37.4	16.3	9.9	3.1	21.8
Anp-2018	61.5	23.1	14.4	6.5	1.1	21.3
Average	39.8 AB	48.8 A	16.1 AB	9.0 AB	1.7 B	
Seedling vigor index (SVI)						
Adasoy	47.4 ab	37.0 bc	10.3 d-g	7.3 efg	0.8 g	22.2 A
Nazlıcan	22.2 cde	13.0 d-g	5.9 fg	2.4 g	0.1 g	8.7 C
Yeşilsoy	55.3 a	35.9 bc	5.3 fg	5.3 fg	0.6 g	21.5 A
Anp-2018	43.8 ab	24.5 cd	8.4 efg	2.8 g	0.2 g	15.9 B
Average	42.2 A	27.6 B	10.8 C	4.4 D	0.4 D	
Significance level (P)						
	NaCl		Cultivar (C)		NaClxC	
RL	0.0001**		0.0001**		0.0001**	
SL	0.0001**		0.0001**		0.0001**	
SFW	0.0001**		0.0001**		0.0004**	
SDW	0.0082**		0.2696^{ns}		0.3131^{ns}	
SVI	0.0001**		0.0001**		0.0001**	

*: The difference between the means indicated by the same letter in the same group is not statistically significant, **: Significant at the level of $p<0.01$, ns: not significant

In the study, it can be argued that soybean seeds are more tolerant to salt stress during the germination stage, but become more sensitive during the seedling growth stage. When the results were examined, it was discovered that the negative effects of salt stress on germination began at a concentration of 100 mM, whereas seedling growth parameters (except SDW) showed a decreasing trend after a dose of 50 mM (Table 1 and 2). Similar findings were also reported by Ahmed et al. (2023), the researchers found that germination rate values at 0 and 50 mM NaCl concentrations (90.74% and 79.63%, respectively) were statistically in the same group, and germination rate significantly decreased at the 100 mM dose. Conversely, plant height and root length characteristics were adversely affected starting from the 50 mM NaCl dose. Islam et al. (2019) suggested that salt concentrations up to 80 mM are tolerable for soybeans, but concentrations higher than that would have a negative impact on germination.

In some studies conducted with different legume species, the adverse effects of salinity stress on germination and seedling development stages have been reported to occur at a 50 mM salt concentration for bitter vetch (Açıkbaş and Özyazıcı, 2022b), chickpea (Ceritoglu et al., 2020), and hairy fruit vetch (Özyazıcı and Açıkbaş, 2022). In a study with Hungarian vetch, the germination rate significantly decreased at a 125 mM NaCl dose, root length at 75 mM, and root fresh and dry weight at 100 mM (Önal Aşçı and Üney, 2016). Another study involving forage pea genotypes (Demirkol et al., 2019) found that salt doses less than 90 mM NaCl had no effect on germination and seedling development.

4.2. Cultivar performance

In terms of the characteristics examined in the study, it was observed that cultivars were differently affected by salt concentrations. Additionally, cultivars that exhibited high salt tolerance during the germination stage did not demonstrate a similar tolerance at more advanced developmental stages. For instance, the Adasoy cv. was identified as a prominent cultivar in terms of germination parameters. However, in the same cultivar, the detrimental effect of salt on shoot length was higher compared to some other varieties. While some cultivars are very affected by salt during the germination stage, it has been observed that the same cultivars become more tolerant to salt during the seedling development stages. Similar distinctions among cultivars have also been emphasized by Essa (2002). Furthermore, some research results have reported variability in salt tolerance among soybean cultivars during the germination and seedling development stages. For instance, Kondetti et al. (2012) reported that increasing salinity levels reduced all examined traits in all cultivars. Ahmadvand et al. (2012) noted differences among cultivars in terms of germination and emergence percentages, while Ndifon (2013) found that salt stress significantly reduced the germination percentage of the TGX849-313D cultivar. Several other studies (Wang and Shannon, 1999; Xu et al., 2011; Ramana et al., 2012; Kandil et al., 2015; Ahmed et al., 2023) have also reported that soybean cultivars exhibit different responses to salinity stress during germination and seedling development stages. Differences between varieties in terms of salt tolerance can be attributed to differences in water-holding capacity, membrane permeability, osmoprotection, and/or genetic and morphological factors. Thanh Le et al. (2023) reported that the genetic diversity in salt tolerance in soybeans is attributed to differences, particularly in the 'exclusion' of ions from shoots in photosynthetically active mesophyll cells. The degree of salt tolerance conferred by soybean genes varies between different developmental stages (Phang et al., 2008).

5. Conclusion

According to the research findings, soybean is generally very sensitive to salinity stress at the seedling stage compared to the germination stage. Salt stress is a significant abiotic stress factor for soybean and have adverse effects on plant growth. Therefore, although soybean is tolerant to salt concentrations up to 100 mM during germination, considering that this dose can inhibit post-germination growth, it may negatively affect nodulation and other agricultural characteristics in the later stages of plant development, potentially leading to reduce soybean yield. Among the factors that limit soybean production, especially under salt stress, achieving high and uniform germination and emergence in the field is essential. In this regard, a salt concentration of 50 mM NaCl can be considered as a threshold value for soybean during germination and seedling growth. However, understanding the responses of varieties to the stress caused by salt is also crucial. Based on the research results, considering both germination and seedling growth parameters, it is recommended to cultivate the Adasoy cv. under salt stress. As a result, in today's environment, where salinity is becoming an increasing issue, defining the performance of salt-tolerant soybean varieties under field conditions is critical.

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