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INVESTIGATING THE IMPACT OF SALT STRESS ON WILD WHEAT GERMPLASM COLLECTED FROM TURKEY

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Abstract

Wheat is among the staple crops providing daily food requirements for millions of people all over the world. However, wheat production is being to limited to various biotic and biotic stresses resulting through climate change. It is believed that if climate change activities continue at this pace, present and upcoming generations will pace a huge food crisis. Wheat wild relatives provide a cushion to the research community by acting a source of novel variations that can be used for the development of new cultivars. Wild wheat accessions belonging to various polyploidy levels i.e., *T. boeoticum*, *T. dicoccoides* and *T. durum* landraces collected from different locations of Fertil Crescent were used as plant material and were screened against salinity stress at the seedling stage. The ANOVA results showed significant differences between genotypes, stress treatments, and their interaction. The results indicate that *T. dicoccoides* genotypes were found more tolerant to salinity than other species for seedling weight. The results reveal that *T. boeoticum* genotypes were more tolerant to salinity than other species for seedling root length. The results indicate that *T. dicoccoides* genotypes were found more tolerant to salinity than other species for root weight. Regarding shoot length, *T. dicoccoides* genotypes performed better compared to others. *T. durum* genotypes had the highest STI value (0.53) for seed germination percentage. Thus, *T. durum* landraces were found to be more tolerant to salinity in terms of various studied traits and may serve as potential genetic sources for the development of salinity tolerance wheat cultivars.

Key words: *T. boeoticum, T. dicoccoides, T. durum,* NaCl, Willd relatives.

Introduction

Climate change is becoming a serious threat resulting in food scarcity. Climate change exerts various biotic and abiotic stresses ultimately lowering agricultural production (Hatfield *et al.,* 2011). Researchers and environmentalists concluded that if human activities continue at this pace, a huge food shortage problem is waiting for this and upcoming generations (Cook & Frank, 2008). Among the various abiotic stresses, agricultural productivity is affected by soil-based stress factors. These stresses affect the growth and development of crops, especially cereals, and cause heavy yield reductions globally (Shahid *et al.,* 2020). Insufficient moisture or high salt concentration in the soil results in erratic seed germination and decreases the germination rate of cereal crops such as wheat, barley, lentils, and chickpeas, particularly in semi-arid areas (Kalhoro *et al.,* 2016). Therefore, cereals may suffer from significant economic losses due to salinity and drought stresses. Hence, tolerance or resistance to drought and salinity during seed germination and seedling stage is of great significance in cereals.

Wheat (*Triticum aestivum* L.) is one of the oldest and most important domesticated crops. It is one of the cereals with the largest production and cultivation area in the world. Wheat has an important place in human nutrition as it provides carbohydrates, minerals, protein, and some vitamins (Shewry & Hey, 2015). In 2022, wheat was cultivated in an area of 219153830 ha which resulted in the production of 808441568.18 tonnes (Sharma *et al.,* 2022). However, wheat production is not enough to feed the existing population and a huge population living in least developed or developing countries. The recent estimates suggested that wheat production should be increased by 50% by 2050 to feed the rapidly increasing human population (Allen *et al.,* 2017). Abiotic (salinity, drought, etc.) and biotic stresses significantly decrease wheat productivity; therefore, these are the major obstacles to improving production to the desired level (Sharma *et al.,* 2022).

Excess soil salinity is a major abiotic stress that reduces the yield of cereals (Kalhoro *et al.,* 2016). Salinity prevents the seeds and plants from benefiting from the water in the environment and adversely affects seed germination, growth, and development of crop plants (Nikolić *et al.,* 2023). Wheat is a moderately tolerant crop to salinity and therefore, yield gradually decreases with increasing soil salinity (Tao *et al.,* 2021). Yield losses in wheat crop reaches >50% if soil salinity is 100 mM. Soil salinity affects agricultural production on ~800 million hectares globally (Ashraf, 2014). Therefore, salinity-tolerant crops have great importance for sustainable agricultural production.

Saline soils exhibit significant spatial heterogeneity in salinity level; therefore, it is almost impossible to determine exact tolerance levels of genetic materials under field conditions. Plants, including cereal crops, are sensitive to salinity throughout their developmental stages. However, the sensitivity/tolerance level of plants during the seedling stage is extremely critical (Cuartero *et al.,* 2006). The seedling stage is an important indicator of salinity tolerance of plants at all stages of development (Cuartero *et al.,* 2006). Thus, previous studies generally focused on salinity resistance at the seedling stage to identify salinity-tolerant crops (Meneguzzo *et al.,* 2000; El-Hendawy, 2005). For example, a study by Choudhary *et al.,* (2021) screened 314 wheat lines against salt stress and reported a positive and significant correlation between salt tolerance index (STI) of shoot length. Tao *et al.,* (2021) conducted a study to check the salinity stress tolerance in 30 bread wheat genotypes at the seedling stage and reported a significant impact of stress on the calculated agronomic and physiological traits.

Modern wheat cultivars generally have low tolerance to salinity and drought stresses. Therefore, new salinity-tolerant genetic resources are needed to increase agricultural productivity in stress-prone areas. Wheat landrace and wild wheat genotypes are considered as potential gene sources for developing salinity-resistant varieties. Wild wheat species, which are the ancestors of cultivated wheat, have a rich genetic variation and wide adaptability to drought and salinity. Furthermore, these genotypes possess several characteristics that impart resistance to these stresses and can be transferred to commercial genotypes (Peleg *et al*., 2005; Nevo *et al.*, 2010; Shavrukov *et al.*, 2010).

The Fertile Crescent region is the origin and domestication center of wheat. Turkiye located in the fertile crescent region has great importance being the origin and domestication center of various crops (Nadeem, 2021). Wheat was cultivated on an area of 6601805 ha with a production of 19750000 tonnes. The Southeast region of Turkiye exhibits a great diversity of wheat and its wild relatives and most of the present genetic resources in this region are unexplored. Therefore, studies should be conducted using the genetic resources belonging to this region to identify superior genotypes that can be used in wheat breeding programs. To benefit from these extremely valuable genetic resources, both international agricultural research institutions and private sector organizations have established pre-breeding programs, mainly in developed countries. The current study aimed to investigate the tolerance levels of different wheat genotypes to salinity stresses at the seedling stage. A total of 116 wheat genotypes (49 genotypes of wild diploid *T. boeoticum*, 37 genotypes of wild tetraploid *T. dicoccoides*, and 35 genotypes of *T. durum* landraces) were included in the study.

Material and Methods

Detailed information about the used plant material during this study is provided in Table 1. Wild wheat accessions belonging to various polyploidy levels i.e., *T. boeoticum*, *T. dicoccoides* and *T. durum* landraces collected from different locations of Fertil Crescent were used as plant material.

Experimentation in controlled condition: The salinity experiment was conducted in the laboratory of the Department of Seed Production of Mardin Artuklu University in 2020. Seeds were surface sterilized in 10% sodium hypochlorite solution for 10 minutes and then carefully washed three times thoroughly with distilled water to remove the sterilizing extract. Two different concentrations of NaCl, 0 (Control) and 200 mg/L were used. Twenty seeds of each genotype in 10 ml salt solution were germinated in each Petri dish (120 mm × 20 mm) with two layers of Whatman no.1 filter paper. All Petri-dishes were placed in the growing chamber at 24°C for 8 days with 18 hours light/6 hours dark photoperiod. In each of these treatments, a randomized complete design (RCD) with two replications was performed and placed on different shelves in the growth room. The number of germinated seeds on the 10th day was referred to as the percentage of germination (PG) and coleoptile length (CL). The percentage of germinated seeds on the 14th day was referred to as the shoot length (SL), root length (RL), seedling weight (SW), and root weight (RW). Stress indices tolerance (STI) was obtained from each genotype performance in stress conditions mean divided by the general mean of control performance (mean stress performance/control mean performance).

Statistical analysis

Data obtained was subjected to investigate the analysis of variance through JMP statistical software. The analysis over treatments was also performed by using SAS (SAS, 1999), and means were compared by using Fisher's least significant difference ($p<0.01$ and 0.05), respectively.

Results and Discussion

The results of variance analysis conducted on seed germination data of salinity and PEG applications are given in Table 2. The ANOVA results showed significant differences between genotypes, stress treatments, and their interaction (Table 1). Ahmed *et al.*, (2022) characterized the wheat accessions against salinity stress at the seedling stage and their ANOVA findings were in line with the results of this study.

Effect of salinity stress on seedling weight: Seedling weights of different genotypes belonging to 3 wheat species subjected to salinity (200 mg/L) under laboratory conditions are given in Table 3. The average seedling weight of *T. boeoticum* was 0.08 g subjected to salinity (in 250 mg/L concentration) stress. However, the average seedling weight in the control treatment was 0.154 g. The highest seedling weight under salinity stress was obtained for genotype G19 (0.173 g). Lines G8 (0.16 g), G25 (0.15 g), and G14 (0.14 g) were the other genotypes belonging to *T. boeoticum* with the highest seedling weight (Table 3 and Fig. 1).

Overall average seedling weight of *T. dicoccoides* was 0.13 g under salinity (250 mg/L) stress, whereas it was 0.19 g in the control treatment. The highest seedling weight among *T. dicoccoides* genotypes were noted for genotype G5 (0.22 g) under salinity stress. The other genotypes with higher seedling weight were G3 (0.20 g), G19 (0.2 g) and G10 (0.19 g) (Table 3 and Fig. 1). According to a previous study, there are differences in salt tolerance among plants, families, genera and species, as well as among varieties of the same species (Kızılgeçi, 2021). In wheat landrace genotypes (*T. durum* varieties), the average seedling weight was 0.31 g under salinity stress, while it was 0.50 g in the control treatment (Table 3 and Fig. 1). According to Gholizadeh *et al.*, (2021), seedling weight decreases with the increase in salt stress and it was observed in this study compared to the control treatment. They concluded that this decrease in seedling weight might be due to ionic effects occurring as a result of a proportional increase in $Na+$ concentration. The genotypes resulting in the highest values of seedling weight under salinity stress were G4 (0.46 g), G8 (0.46 g), G3 (0.45 g), G9 (0.45 g), and G12 (0.44 g).

Table 1. Passport data of plant material used in this study.

Gen. No.	***T. boeoticom***			***T. dicoccoides***			***T. durum* (Landraces)**
	Location	**Altitude**	**Coordinates**	**Location**	**Altitude**	**Coordinates**	**Location**
1.	ELZ	1060		KRCD	1250	N:37.50.400; E: 39.57.471	Adıyaman-Gerger
2.	ELZ	1060		KRCD	1100	N:37.44.810: E: 39.39.670	Adıyaman-Gerger
3.	KRCD	1100	N:37.44.820;E 39.39.670	KRCD	1200	N: 37.44.040; E: 39.38.160	Adıyaman-Gerger
4.	ERGC	830	N:38.12.772; E:39.44.349	KRCD	1200	N: 37.44.040; E: 39.38.160	Kahta-Gerger Yol
5.	ERGC	799	N:38.12.772; E:39.44.349	KRCD	1114	N:37.49.917; E:39.44.111	Kahta-Gerger Yol
6.	ERGC	810	N:38.12.772; E:39.44.349	KRCD	1114	N:37.49.917; E:39.44.111	Kahta-Gerger Yolu
7.	ERGC	799	N:38.12.772; E:39.44.349	KRCD	1286	N:37.49.004; E. 39.40.409	Kahta-Gerger Yolu
8.	ERGC	799	N:38.07.763; E:29.41.431	KRCD	1254	N:37.50.200; E: 39.42.771	Gerger-Kesentaş k
9.	SRNK	1519	N:37.33.250; E:42.24.592	KRCD	1283	N:37.48.741; E: 39.46.243	Gerger-Kesentaş k
10.	SRNK	1519	N:37.33.250; E:42.24.592	KRCD	1283	N:37.48.741; E: 39.46.243	Gerger-Çifthisar K
11.	SRNKE	1201	N.37.42.357; E:42.15.795	KRCD	1283	Karabahçe	Gerger-Çifthisar K
12.	SRNKE	1201	N.37.42.357; E:42.15.795	KRCD	1283	Karabahçe	Gerger-Çifthisar k
13.	SRNKU	1290	N. 37.28.940; E: 42.35.395	KRCD	1290	N: 37.49.222; E: 39.46.505	Kahta-Kıkpınar k
14.	SRNKU	1290	N. 37.28.940; E: 42.35.395	KRCD	1182	N: 37.45.969; E: 39.43.344	Kahta-Kıkpınar k
15.	SRNKU	1386	N: 37.29.399: E: 42.31.760	KRCD	1182	N: 37.45.969; E: 39.43.344	Mardin-Midyat-A
16.	SRNKE	1202	N:37.42.196; E: 42.10.093	KRCD	1182	N: 37.45.969; E: 39.43.344	Mardin-Midyat-A
17.	SRNKE	1202	N:37.42.196; E: 42.10.093	KRCD	1182	N: 37.45.969; E: 39.43.344	Mardin-Midyat-S
18.	KRCD	1250	N:37.50.385; E: 39.47.644	KRCD	1290	N: 37.49.786; E: 39.46.580	Mardin-Midyat-S
19.	KRCD	1100	N:37.49.124; E: 39.43.898	KRCD	1230	N: 37.46.252; E:39.43.910	Mardin- Savur
20.	ERGC	825	N: 38.12.772; E:39.44.341	KRCD	1202	N:37.46.250; E: 39.43.904	Mardin- Savur
21.	TNCK	1080		KRCD	1260	N:37.49.785; E: 39.46.580	Mardin- Savur
22.	TNCK	1080		KRCD	1228	N:37.46.584; E: 39.44.565	Midyat-Ömerli y
23.	KRCD	959	N: 37.62.296; E: 39.54.177	KRCD	1252	N:37.50.699; E: 39.48.008	Midyat-Ömerli y
24.	KRCD	1110	N:37.44.510; E: 39.39.880	CRMK	906	N:37.57.104; E: 39.42.991	Mardin-Midyat-Ov
25.	KRCD	858	N:37.58.903; E: 39.39.905	CRMK	906	N:37.57.104; E: 39.42.991	Mardin-Midyat-Ov
26.	KRCD	1031	N: 37.58.187; E: 39.42.633	CRMK	906	N:37.57.104; E: 39.42.991	Diyarbakır- Çün
27.	KRCD	1031	N: 37.53.174; E: 39.42.614	KRCD	1110	N:37.44.510; E: 39.39.887	Diyarbakır- Çün
28.	KRCD	865	N:37.57.863; E: 39.40.588	KRCD	1110	N:37.44.510; E: 39.39.887	Diyarbakır- Çün
29.	KRCD	906	N:37.57.104; E: 39.42.991	KRCD	1225	KrdgKerteş Köyü -Siverek	Çermik
30.	SRNKE	1212		KRCD	1225	KrdgKerteş Köyü -Siverek	Çermik
31.	SRNKE	1250		KRCD	1225	KrdgKerteş Köyü -Siverek	Çermik
32.	SRNKE	1212		CRMK	906	N:37.57.104; E: 39.42.991	Siverek
33.	SRNKE	1410		KRCD	1251	N:37.49.819; E: 39.46.590	Siverek
34.	KRCD	1287	N: 37.45.970; E: 39.43.345	KRCD	1251	N:37.49.819; E: 39.46.590	Malatya
35.	KRCD	1283	N:37.45.970; E: 39.46.243	KRCD	1251	N:37.49.819; E: 39.46.590	Malatya
36.	KRCD	1285	N 37.49.678; E: 39.43.826	KRCD	1285	N:37.45.970; E: 39.43.350	
37.	KRCD	1202	N: 37.46.252; E: 39.43.910	KRCD	1285	N:37.45.970; E: 39.43.350	
38.	KRCD	1202	N: 37.46.252; E: 39.43.910				
39.	KRCD	1234	N: 37.50.200; E: 39.46.771				
40.	KRCD	1114	N:37.49.917; E: 39.44.111				
41.	KRCD	1088	N: 37.49.489; E: 39.43.364				
42.	KRCD	1088	N: 37.49.489; E: 39.43.364				
43.	KRCD	1290	N: 37.49.228; E: 39.46.505				
44.	MZD	1300	Mazıdağı-Şebe				
45.	KRCD	1252	N: 37.48.042; E: 39.45.366				
46.	KRCD	955	N: 37.52.295; E: 39.54.197				
47.	KRCD	1252	N: 37.50.699; E: 39.48.008				
48.	KRCD	1228	N: 37.46.534; E: 39.44.465				
49.	KRCD	1260	N: 37.49.786; E: 39.46.580				
50.	KRCD	1200	Krcdğ-Kynk				
51.	MZD	1220	Mazıdağı-Şebe				
52.	KRCD	1100	Mazıdağı-Çaye				
53.	ERGC	810	N:37.49.819; E: 39.46.590				
54.	SRNK	1519					
55.	SRNKE	1201					
56.	SRNKU	1290					

Table 2. Analysis of variance (ANOVA) for the evaluated traits under salt stress application.

	Source	DF	SL	PG	SW	RL	RW
T. Boeoticum	Rep	1	60,62 ns	8,2 ns	0,0002 ns	0,005 ns	0,00001ns
	Gen	48	33840**	34174**	0,32**	1319**	0,019**
	SA	1	132028**	128574**	0,24**	529**	0,031**
	Gen*SA	48	11664**	13252**	0,063**	334**	0,007**
	Error	97	3282	842	0,009	35,8	0,0015
	Total	195	180960	176849	0,63	2218	0,06
T. dicococides	Rep	1	77,4 ns	10,8 ns	0,0006 ns	3,65 ns	0,000002ns
	Gen	36	75698**	84294**	0,49**	28,8**	0,05**
	SA	1	66322**	74925	0,19**	546**	0,018**
	Gen*SA	36	15855**	17036**	0,053**	5,84**	0,019**
	Error	73	3907	539,2	0,005	102,3	0,0003
	Total	147	161860	176807	0,74	2621	0,087
T. durum (Landraces)	Rep	1	1,61 ns	13,21 ns	0,0003 ns	2,5 ns	0,00002ns
	Gen	34	62881**	58696**	1,05**	868**	0,26**
	SA	1	73372**	61446**	1,25**	1215**	0,23**
	Gen*SA	34	22560**	15925**	0,27**	403**	0,13**
	Error	69	1161	1370	0,02	156	0,004
	Total	139	159975	137450	2,6	2646	0,62**

SA: Salt aplication; SL: Shoot lenght; PG: Percentage of germination; CL: Coleoptile lenght; SW: Seedling weight; RL: Root length; RW: Root weight

The tolerance levels of the genotypes included in the study to salinity stress are given in Fig. 2 as the stress tolerance index (STI). The STI values were calculated by dividing the difference between the values obtained from normal and stress conditions by the value obtained under normal conditions. *T. dicoccoides* genotypes had the highest STI value (0.82) for seedling weight. However average STI values were 0.65 and 0.60 for *T. durum* and *T. boeoticum* genotypes, respectively. The results indicate that *T. dicoccoides* genotypes were found more tolerant to salinity than other species for seedling weight. Therefore, it was concluded that *T. dicoccoides* genotypes (with high STI values) can be used as a potential gene source for developing salinity-tolerant varieties. According to Nevo & Chen, (2010), *T. dicoccoides* is the progenitor of durum wheat and has compatibility with durum wheat and also can be crossed with bread wheat. Keeping this in view, *T. dicoccoides* genotypes may serve as a potential source for developing salt resistant bread wheat cultivars. In addition, *T. durum* genotypes G4, G8, G9, and G12 (with high STI values) can also be used in the development of salt-tolerant varieties. It has been reported that seedling and root fresh weight in wheat is one of the traits that are highly affected by environmental factors (Balkan, 2019; Feldman & Sears, 1981).

Effect of salinity stress on root length (cm): Root length is an important factor playing a key role in the growth and development of any crop. Root hairs absorb the water from the soil and transfer it to the plant. Salt accumulation in the root vicinity effect the root length and lowers the water accumulation and ultimately affect the growth and germination of crops. Therefore, cultivars having higher root length and tolerance to salt stress are present-day requirement. Root length results obtained from salinity (in 200 mg/ L concentration) stress for different wheat genotypes of three species used in the study are given in Table 4.

The average root length of *T. boeoticum* genotypes under salinity (200 mg/L) stress ranged from 1.5 cm (G39) to 12 cm (G19). The mean value of root length during this study using whole germplasm was 6.6 cm. However, the average root length in the control treatment was 9.9 cm (Table 3 and Fig. 3). The G19 (12 cm), G20 (11 cm), G17 (11 cm), G30 (11 cm) and G25 (10.5 cm) belonging to *T. dicoccoides* genotypes reflected the longest root length under salinity stress (Fig. 3). Overall root length average of *T. dicoccoides* was 8.17 cm subjected to salinity stress. However, the average root length in the control treatment was 12 cm (Fig. 3). The longest root length was measured (13.5 cm) in G30 while the shortest was in G14 (3 cm). G14 (13.5 cm), G5 (12 cm), G6 (11.5 cm), and G13 (13 cm) were the other genotypes belonging to *T. dicoccoides* with the longest seedling root length under salinity stress. In *T. durum* genotypes, the general mean root length was 13.6 cm under salinity stress, while it was 19.5 cm in the control treatment (Fig. 3). *T. durum* genotypes resulting in the longest seedling root lengths under salinity stress were G11 (18.5 cm), G14 (18 cm), G19 (17 cm), and G23 (17 cm). The shortest seedling root length was recorded for the genotype G1 (6.5 cm). Ahmed *et al.*, (2022) screened bread wheat germplasm against salt stress and root length in their study was lesser compared to reported in this study using various polyploidy wheat species. Our results again confirmed the higher potential of wild relative against salinity stress. The salinity tolerance levels of the genotypes (STI values for seedling root lengths) included in the study are given in Fig. 4. The STI values were calculated by dividing the difference between the values obtained from normal and stress conditions by the value obtained under normal conditions. Munns *et al.*, (2005) reported that plants under salt stress develop various mechanisms in response to osmotic and ionic stress caused by salinity. In the present study, the increase in root dry weight in salt treatment may be due to the fact that plants accumulate soluble carbohydrates in their roots in order to get the water they need from the environment (Balkan, 2019).

Table 3. Mean seedling weights of different wheat species subjected to salinity stress.

Gen. No.	*T. boeoticum*			*T. dicoccoides*			*T. durum*		
	Control	**NaCl Apl.**	**STI**	**Control**	**NaCl Apl.**	**STI**	**Control**	**NaCl Apl.**	**STI**
1.	0,097^{pr}	0,055^{lo}	0,22	0,32^{ab}	0,18^{de}	1,60	0,31st	0,12^{n}	0,15
2.	0,096^{pr}	0,035^{op}	0,14	0,23^{d}	0,18^{de}	1,15	0,51^{jl}	0,41^{cd}	0,84
3.	0,155^{j}	0,115^{eg}	0,75	0,26^{c}	0,20^{bc}	1,44	0,53$^{\text{ıj}}$	0,45^{ab}	0,95
4.	0,125^{ln}	0,065^{kn}	0,34	0,25^{c}	0,18^{de}	1,25	0,72^{a}	0,46^{a}	1,32
5.	0,215^{cd}	0,115^{eg}	1,04	0,26^{c}	0,22^{a}	1,58	0,37^{r}	0,28^{jk}	0,41
6.	0,191^{fh}	0,125^{df}	1,01	0,23^{de}	0,13^{g}	0,83	0,52^{jk}	0,42^{bd}	0,87
7.	0,128^{lm}	0,068^{kn}	0,37	0,23^{d}	0,11^{hj}	0,70	0,58^{eg}	0,34^{fg}	0,79
8.	0,245^{a}	0,16^{ab}	1,65	0,27^{c}	0,16^{f}	1,20	0,60^{cf}	0,46^{a}	1,10
9.	0,236^{ab}	0,14^{bd}	1,39	0,27^{c}	0,10^{jk}	0,75	0,62^{bc}	0,45^{a}	1,12
10.	0,195^{eg}	0,15^{bc}	1,23	0,21^{f}	0,19^{bd}	1,11	0,61^{bd}	0,36^{fg}	0,88
11.	0,075^{s}	0,06^{kn}	0,19	0,22^{df}	0,18^{de}	1,10	0,55$^{\text{hı}}$	0,40^{de}	0,88
12.	0,195^{eg}	0,065^{kn}	0,53	0,23^{de}	0,12$^{\text{gı}}$	0,76	0,62^{b}	0,44^{ac}	1,09
13.	0,146^{jk}	0,06^{kn}	0,37	0,21^{ef}	0,19^{ce}	1,11	0,54$^{\text{hı}}$	0,29$^{\text{ıj}}$	0,63
14.	0,195^{eg}	0,14^{bd}	1,15	0,20^{fg}	0,17^{ef}	0,94	0,52^{jk}	0,40^{de}	0,83
15.	0,209^{de}	0,09^{hj}	0,79	0,22^{df}	0,10^{jk}	0,61	0,58^{fg}	0,19^{m}	0,44
16.	0,11^{np}	0,065^{kn}	0,30	0,22^{df}	0,13^{gh}	0,79	0,45^{pq}	0,30^{hj}	0,54
17.	0,182$^{\text{gı}}$	0,06^{kn}	0,46	0,22^{df}	0,13^{gh}	0,79	0,56^{gh}	0,13^{n}	0,29
18.	0,205^{df}	0,072^{jm}	0,62	0,25^{c}	0,10$^{\text{ık}}$	0,69	0,47^{oq}	0,37^{ef}	0,70
19.	0,215^{cd}	0,173^{a}	1,57	0,30^{b}	0,20^{ab}	1,66	0,47^{np}	0,33^{gh}	0,62
20.	0,038^{t}	0,02^{p}	0,03	0,32^{a}	0,18^{ce}	1,60	0,60^{ce}	0,28^{jl}	0,67
21.	0,19$^{\text{fı}}$	0,06^{kn}	0,48	0,11^{k}	0,07^{mo}	0,21	0,60^{cf}	0,35^{fg}	0,84
22.	0,085^{rs}	0,051^{mo}	0,18	0,11^{jk}	NG	NG	0,46^{oq}	0,29^{j}	0,53
23.	0,11^{np}	0,08$^{\text{ık}}$	0,37	0,12$^{\text{ık}}$	0,07^{mo}	0,23	0,60^{cf}	0,29^{j}	0,70
24.	0,198^{eg}	0,098$^{\text{gı}}$	0,82	0,11^{jk}	0,08^{lm}	0,24	0,33^{s}	0,25^{kl}	0,33
25.	0,175$^{\text{ı}}$	0,15^{bc}	1,11	0,19^{g}	0,12$^{\text{gı}}$	0,63	0,50^{km}	0,33$^{\text{gı}}$	0,66
26.	0,147^{jk}	0,11^{fh}	0,68	0,11^{jk}	NG	NG	0,46^{oq}	0,35^{fg}	0,64
27.	0,248^{a}	0,125^{df}	1,31	0,11^{jk}	NG	NG	0,45^{q}	0,24^{l}	0,43
28.	0,11^{np}	0,06^{kn}	0,28	0,14^{h}	0,10^{jk}	0,39	0,49^{ln}	0,29^{j}	0,57
29.	0,19$^{\text{fı}}$	0,134^{ce}	1,07	0,13$^{\text{hı}}$	0,09^{kl}	0,32	0,58^{eg}	0,30^{hj}	0,70
30.	0,208^{de}	0,158^{ab}	1,39	0,11^{jk}	NG	NG	0,37^{r}	0,19^{m}	0,28
31.	0,175$^{\text{ı}}$	0,06^{kn}	0,44	0,14^{h}	0,07^{mo}	0,27	0,59^{df}	0,28^{jk}	0,66
32.	0,137^{kl}	0,07^{jn}	0,40	0,13^{hj}	0,07^{mn}	0,25	0,30^{t}	0,19^{m}	0,23
33.	0,235^{ab}	0,06^{kn}	0,59	0,11^{jk}	NG	NG	0,48^{mo}	0,29^{j}	0,56
34.	0,146^{jk}	0,06^{kn}	0,37	0,11^{jk}	NG	NG	0,36^{r}	0,27^{jl}	0,39
35.	0,158^{j}	0,06^{kn}	0,40	0,13^{hj}	0,06^{no}	0,22	0,31st	0,19^{m}	0,24
36.	0,135^{kl}	0,075^{jl}	0,43	0,11^{jk}	NG	NG			
37.	0,155^{j}	0,068^{kn}	0,44	0,11^{jk}	0,06^{mo}	0,18			
38.	0,099^{pr}	0,075^{jl}	0,31						
39.	0,11^{np}	0,05^{no}	0,23						
40.	0,112^{np}	0,055^{lo}	0,26						
41.	0,108^{oq}	0,07^{jn}	0,32						
42.	0,125^{ln}	0,058^{ln}	0,31						
43.	0,178$^{\text{hı}}$	0,065^{kn}	0,49						
44.	0,117^{mo}	0,055^{lo}	0,27						
45.	0,093^{qr}	0,055^{lo}	0,22						
46.	0,11^{np}	0,055^{lo}	0,26						
47.	0,125^{ln}	0,098$^{\text{gı}}$	0,52						
48.	0,11^{np}	0,053^{mo}	0,25						
49.	0,225^{bc}	0,12^{df}	1,14						
Mean	0,154	0,08	0,60	0,19	0,13	0,82	0,50	0,31	0,65
Lsd	0,016**	0,022**		0,018**	0,015**		0,034**	0,024**	

NG: No germination; * Signifigant at 0.05; ** Signifigant at 0.01

Table 4. Effect of salinity stress to root length of studied wheat species.

Gen. No.	*T. boeoticum*			*T. dicoccoides*			*T. durum* (landraces)		
	Control	**NaCl**	**STI**	**Control**	**NaCl**	**STI**	**Control**	**NaCl**	**STI**
1.	$8,00^{l}$	$7,00^{h}$	0,57	$17,0^{ac}$	$11,0^{ad}$	1,30	$11,0^{k}$	$6,50^{m}$	0,19
2.	$8,00^{l}$	$5,50^{\imath}$	0,45	$15,25^{bg}$	$11,0^{ad}$	1,16	$18,5^{g\imath}$	$15,5^{bg}$	0,75
3.	$8,50^{kl}$	$8,00^{dg}$	0,69	$17,5^{ab}$	$11,0^{ad}$	1,34	$19,5^{eh}$	$16,8^{ae}$	0,86
4.	$10,5^{g\imath}$	$5,00^{\imath j}$	0,54	$16,5^{ad}$	$8,50^{dg}$	0,97	$18,25^{g\imath}$	$16,0^{af}$	0,77
5.	$12,0^{df}$	$9,00^{d}$	1,10	$7,50^{np}$	$12,0^{ac}$	0,63	$18,8^{f\imath}$	$11,8^{hk}$	0,58
6.	$5,25^{mn}$	$4,00^{kl}$	0,21	$16,0^{ae}$	$11,5^{ac}$	1,28	$15,8^{\imath j}$	$11,5^{\imath l}$	0,48
7.	$5,25^{mn}$	$4,50^{jk}$	0,24	$14,5^{dh}$	$6,00^{g\imath}$	0,60	$20,8^{bh}$	$15,3^{cg}$	0,83
8.	$5,50^{m}$	$4,00^{kl}$	0,22	$13,0^{gj}$	$10,5^{be}$	0,95	$18,5^{g\imath}$	$18,0^{ab}$	0,88
9.	$4,00^{n}$	$3,75^{kl}$	0,15	$15,5^{bf}$	$6,00^{g\imath}$	0,65	$22,8^{ae}$	$15,3^{cg}$	0,91
10.	$10,80^{f\imath}$	$10,0^{c}$	1,10	$14,5^{dh}$	$9,50^{cf}$	0,96	$20,0^{ch}$	$14,8^{dg}$	0,78
11.	$10,0^{hj}$	$5,00^{\imath j}$	0,51	$14,0^{e\imath}$	$8,50^{dg}$	0,83	$25,0^{a}$	$18,5^{a}$	1,22
12.	$11,8^{dg}$	$5,00^{\imath j}$	0,60	$13,5^{f\imath}$	$6,00^{g\imath}$	0,56	$18,8^{f\imath}$	$14,0^{f\imath}$	0,69
13.	$11,5^{eg}$	$5,50^{\imath}$	0,65	$16,5^{ad}$	$13,0^{ab}$	1,49	$17,8^{h\imath}$	$15,0^{cg}$	0,70
14.	$9,00^{jl}$	$8,25^{dg}$	0,76	$15,0^{cg}$	$13,5^{a}$	1,41	$19,3^{fh}$	$18,0^{ab}$	0,91
15.	$13,0^{cd}$	$4,00^{kl}$	0,53	$18,0^{a}$	$8,00^{eh}$	1,00	$23,0^{ad}$	$9,00^{lm}$	0,54
16.	$8,50^{kl}$	$7,00^{h}$	0,61	$13,5^{f\imath}$	$5,50^{hj}$	0,52	$20,5^{bh}$	$14,3^{eh}$	0,77
17.	$12,0^{df}$	$11,0^{b}$	1,35	$13,5^{f\imath}$	$6,00^{g\imath}$	0,56	$23,3^{ac}$	$13,0^{gj}$	0,79
18.	$13,5^{bc}$	$7,00^{h}$	0,96	$14,0^{e\imath}$	$6,00^{g\imath}$	0,58	$23,8^{ab}$	$16,0^{af}$	1,00
19.	$13,5^{bc}$	$12,0^{a}$	1,65	$12,5^{hk}$	$10,0^{cf}$	0,87	$19,3^{fh}$	$17,0^{ad}$	0,86
20.	$12,3^{ce}$	$11,0^{b}$	1,37	$18,0^{a}$	$11,0^{ad}$	1,38	$22,0^{af}$	$10,0^{kl}$	0,58
21.	$12,3^{ce}$	$10,0^{c}$	1,25	$9,00^{lo}$	$7,75^{fh}$	0,48	$19,8^{dh}$	$17,5^{ac}$	0,91
22.	$9,00^{jl}$	$8,50^{df}$	0,78	$7,00^{op}$	NG	NG	$20,5^{bh}$	$9,00^{lm}$	0,49
23.	$4,50^{mn}$	$4,00^{kl}$	0,18	$9,50^{ln}$	$3,50^{\imath j}$	0,23	$21,5^{bg}$	$17,0^{ad}$	0,96
24.	$12,0^{df}$	$8,50^{df}$	1,04	$11,0^{jl}$	$8,00^{eh}$	0,61	$12,8^{jk}$	$12,0^{hk}$	0,40
25.	$11,0^{eh}$	$10,5^{bc}$	1,18	$13,0^{gj}$	$9,50^{cf}$	0,86	$18,8^{f\imath}$	$15,8^{af}$	0,78
26.	$11,0^{eh}$	$7,75^{fh}$	0,87	$7,00^{op}$	NG	NG	$19,0^{f\imath}$	$14,3^{eh}$	0,71
27.	$13,0^{cd}$	$8,50^{df}$	1,13	$6,50^{p}$	NG	NG	$19,8^{dh}$	$10,0^{kl}$	0,52
28.	$4,00^{n}$	$1,50^{m}$	0,06	$8,00^{np}$	$8,00^{eh}$	0,44	$21,3^{bg}$	$11,0^{jl}$	0,61
29.	$10,0^{hj}$	$8,75^{de}$	0,89	$10,75^{jm}$	$8,00^{eh}$	0,60	$17,8^{h\imath}$	$15,0^{cg}$	0,70
30.	$14,5^{ab}$	$11,0^{b}$	1,63	$7,00^{op}$	$3,00^{j}$	0,15	$20,3^{ch}$	$9,50^{kl}$	0,51
31.	$14,5^{ab}$	$5,50^{\imath}$	0,81	$10,5^{km}$	$5,00^{\imath j}$	0,36	$21,0^{bh}$	$15,0^{cg}$	0,83
32.	$10,8^{f\imath}$	$9,00^{d}$	0,99	$12,0^{\imath k}$	$8,00^{eh}$	0,67	$20,8^{bh}$	$13,5^{fj}$	0,74
33.	$12,0^{df}$	$5,50^{\imath}$	0,67	$7,00^{op}$	NG	NG	$18,5^{g\imath}$	$12,0^{hk}$	0,58
34.	$15,0^{a}$	$5,00^{\imath j}$	0,77	$7,00^{op}$	NG	NG	$20,5^{bh}$	$12,0^{hk}$	0,65
35.	$14,5^{ab}$	$5,00^{\imath j}$	0,74	$8,50^{mp}$	$5,00^{\imath j}$	0,30	$14,0^{jk}$	$6,50^{m}$	0,24
36.	$13,0^{cd}$	$8,25^{dg}$	1,09	$7,00^{op}$	NG	NG			
37.	$10,5^{g\imath}$	$5,75^{\imath}$	0,62	$7,00^{op}$	$3,00^{j}$	0,15			
38.	$10,0^{hj}$	$9,00^{d}$	0,92						
39.	$4,00^{n}$	$1,50^{m}$	0,06						
40.	$10,0^{hj}$	$5,00^{\imath j}$	0,51						
41.	$8,00^{l}$	$7,50^{gh}$	0,61						
42.	$8,00^{l}$	$5,00^{\imath j}$	0,41						
43.	$12,0^{df}$	$7,50g^{h}$	0,92						
44.	$10,5^{g\imath}$	$5,00^{\imath j}$	0,54						
45.	$9,00^{jl}$	$3,50^{l}$	0,32						
46.	$4,00^{n}$	$1,50^{m}$	0,06						
47.	$9,50^{\imath k}$	$8,25^{dg}$	0,80						
48.	$5,00^{mn}$	$2,00^{m}$	0,10						
49.	$12,0^{df}$	$10,0^{c}$	1,22						
Mean	9,90	6,60	0,72	12,0	8,17	0,66	19,5	13,6	0,71
Lsd	1,43**	098**		2,31**	2,51**		3,5**	2,61**	

NG: No germination; * Signifigant at 0.05; ** Signifigant at 0.01

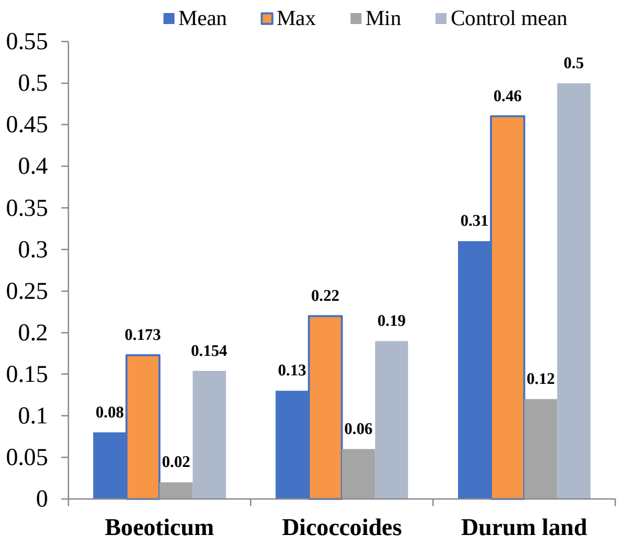

Fig 1. Mean of seedling weight obtained from NaCL application.

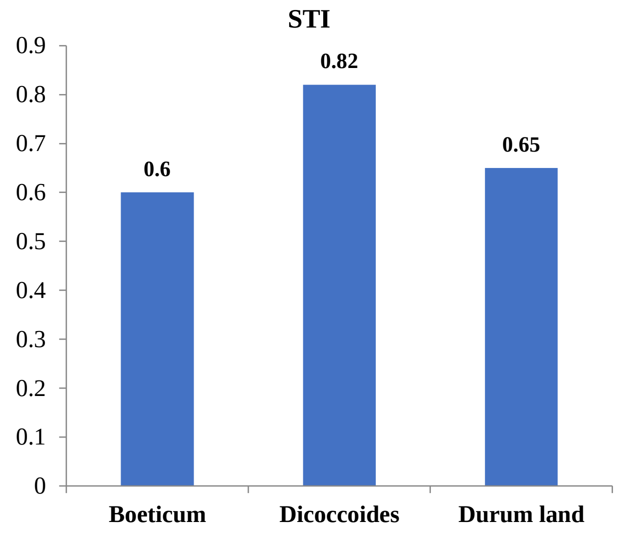

Fig. 2. Stress tolerance index (STI) for the investigated wheat species.

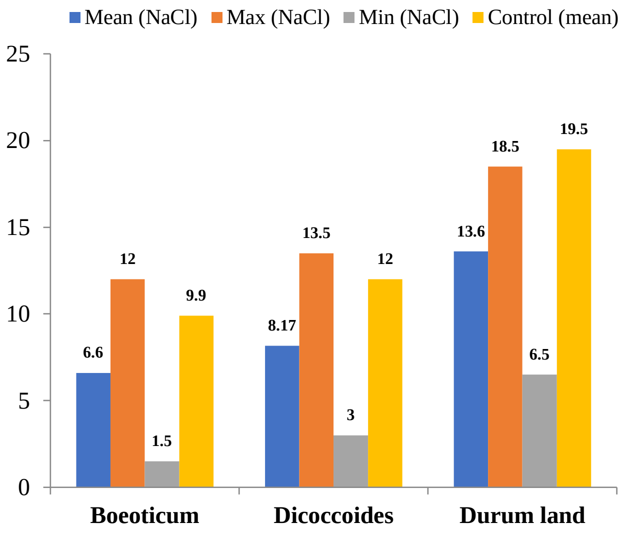

Fig. 3. Effect of salt stress on root length (cm) of various studied wheat species.

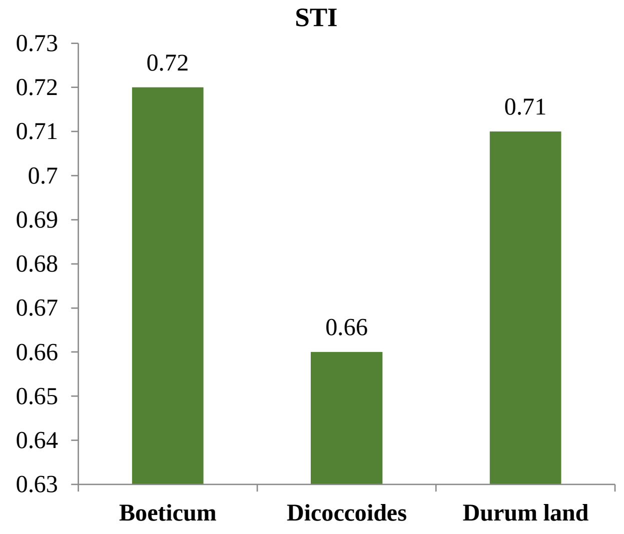

Fig. 4. Stress tolerance index (STI) for root length of various studied wheat species.

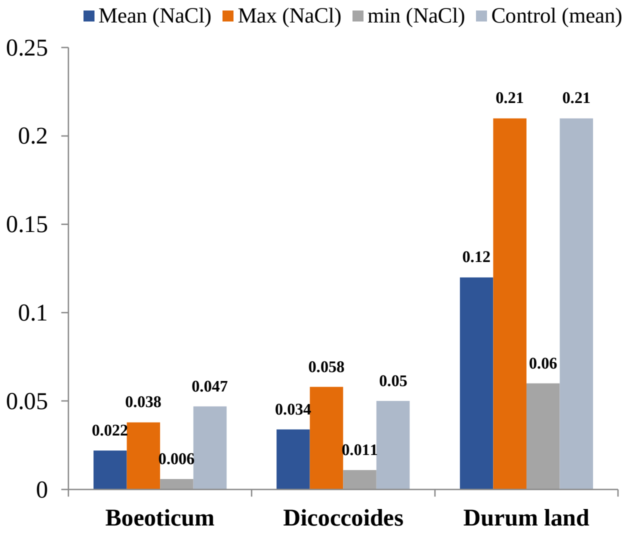

Fig. 5. Effect of salt stress on root weights of the seedlings (gr) of various studied wheat species.

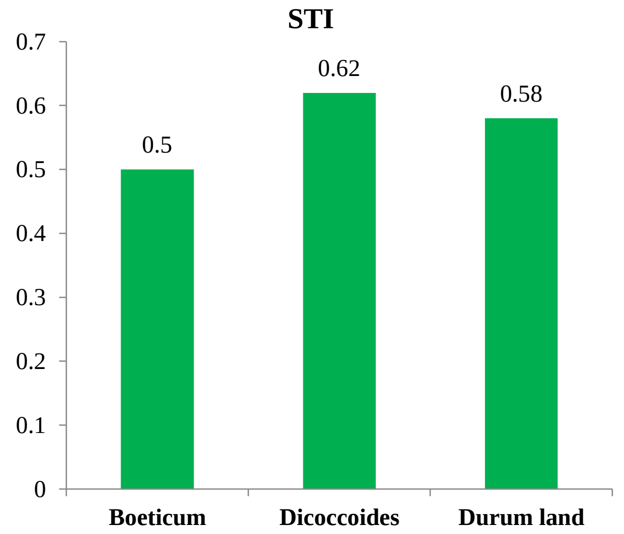

Fig. 6. Stress tolerance index (STI) for root weights of the seedlings (gr) of various studied wheat species.

T. boeoticum genotypes had the highest mean STI value (0.72) for seedling root length (Fig. 4). However average STI values were 0.71 and 0.66 for *T. durum* and *T. dicoccoides* genotypes, respectively (Fig. 4.). The results reveal that *T. boeoticum* genotypes are more tolerant to salinity than other species for seedling root length. However, it should be noted that there are resistant genotypes in all 3 wheat species. The genotypes G17, G19, G20, G21, G25, G27 and G49 of *T. boeoticum* species, G1, G2, G3, G6, G13, G14, G15 and G20 of *T. dicoccoides*, and G9, G1, G14, G18, G21 and G23 of *T. boeoticum* proved salinity resistant at the seedling stage, considering the root length STI values. These genotypes can be considered as potential genetic material to develop drought resistant wheat varieties.

Effect of salinity stress on root weight of the seedlings: Root weight results obtained from salinity (in 200 mg/ L concentration) stress for different wheat genotypes of three species used in the study are given in Table 5 and Fig. 5. The average root weight of genotypes of *T. boeoticum* species under salinity (200 mg/L) stress ranged from 0.007 g (G48) and 0.038 g (G19). The mean value of all *T. boeoticum* genotypes was 0.022 g. However, the average root weight in the control treatment was 0.047 g (Fig. 5). G19 (0.038 g), G17 (0.035 g), G10 (0.032 g), G21 (0.031 g), G25 (0.031 g), G30 (0031 g), and G49 (0.030 g) were the genotypes belonging to *T. boeoticum* with the highest seedling root weights under salinity stress.

Overall average root weight of *T. dicoccoides* was 0.034 g under salinity (200 mg/L) stress, whereas it was 0.050 g in the control treatment. The highest root weight among *T. dicoccoides* genotypes were noted for genotype G1 (0.058 g) under salinity stress. The other genotypes with high root weights were G2 (0.056 g), G3 (0.054 g), G13 (0.056 g) and G14 (0.056 g). The genotypes with the lowest root weights were G21 and G35 (0.011 g) (Table 5 and Fig. 5). The average root weight in wheat landrace genotypes (*T. durum* landraces) was 0.12 g under salinity stress, while it was 0.21 g in the control treatment (Fig. 5). The average root weight of local wheat genotypes under salinity stress ranged from 0.1 g (G23) and 0.21 g (G9). The genotypes belonging to *T. durum* with the highest seedling root weights under salinity stress were G9 (0.21 g), G8 (0.20 g), G2 (0.20 g), G4 (0.19 g) and G12 (0.19 g) (Table 5 and Fig. 5).

The tolerance levels of the tested genotypes in the study to salinity stress are given in Fig. 6. The results indicated that *T. dicoccoides* genotypes had the highest STI value (0.62) for seedling root weights. The STI values for *T. durum* and *T. boeoticum* were 0.58 and 0.50, respectively. However, salinity-resistant and sensitive genotypes were determined for all 3 wheat species. G17, G19, G21, G30, G39 and G49 genotypes of *T. boeoticum* species, G1, G2, G3, G4, G9, G19 and G20 of *T. dicoccoides*, and G2, G4, G8, G9, G12, G6 and G16 of *T. durum*, proved salinity resistant at the seedling stage, regarding STI values of the root weights. These genotypes can be evaluated as a potential genetic resource for the development of drought-resistant wheat varieties in future studies.

Effect of salinity stress on shoot length (cm) of the seedlings: Seedling shoot lengths of different genotypes belonging to three 3 species subjected to salinity (in 200 mg/L concentration) under laboratory conditions are given in Table 6. The average shoot length of *T. boeoticum* genotypes subjected to salinity stress ranged from 2 cm (GG27) to 5.5 cm (G28). The general shoot length mean of *T. boeoticum* species was 3.84 cm subjected to salinity (in 200 mg/L concentration) stress. However, the average shoot length in the control treatment was recorded as 10.44 cm (Fig. 7). G27 (5.5 cm), G1 (5 cm), G19 (5 cm), and G30 (5 cm) were the genotypes belonging to *T. boeoticum* with the highest shoot length (Table 6). The average shoot length of *T. dicoccoides* genotypes subjected to salinity stress ranged from 3.25 cm (G31) to 6.75 cm (G3 and G19). The general shoot length mean of *T. dicoccoides* species was 5.44 cm subjected to salinity (in 200 mg/L concentration) stress. However, the average shoot length in the control treatment was recorded as 11.6 cm (Fig. 7). The genotypes belonging to *T. dicoccoides* resulting in the highest values of shoot length under salinity stress were G3 (6.75 cm), G19 (6.75 cm), G2 (6.5 cm), G5 (6.5 cm), G6 (6.5 cm), and G13 (6.25 cm) (Table 6). Overall average shoot length in landraces wheat genotypes (*T. durum* landraces) was 6.7 cm under salinity stress, while it was 12.7 cm in the control treatment (Fig. 7; Table 5). The average shoot length of *T. durum* varieties subjected to salinity stress ranged from 4.75 cm (G30) to 8.5 cm (G11) (Fig. 7). G11 (8.5 cm), G23 (7.75 cm), G6 (7.5 cm), G7 (7.5 cm), G13 (7.5 cm) and G21 (7.5 cm) were the genotypes belonging to *T. durum* with the highest seedling shoot length (Table 6).

The tolerance levels of the genotypes included in the study to salinity stress are given in Fig. 8, as stress tolerance index (STI). The STI values were calculated by dividing the difference between the values obtained from control and salinity stress treatments by the value obtained under control treatment. *T. dicoccoides* genotypes had the highest STI value (0.48) for shoot lengths of seedlings. The average STI values were 0.47 and 0.37 for *T. durum* and *T. boeoticum* genotypes, respectively. It was also reported by Sadat & McNeilly, (2000) and Kızılgeçi, (2021) that shoot length decreased in salt concentration treatment.

The results reveal that *T. dicoccoides* and *T. durum* genotypes are more tolerant than *T. boeoticum* genotypes for shoot lengths in general. However, it should be noted that there are drought-resistant and sensitive genotypes in all species included in the study. G1, G17, G19, G20, G21, G27, G30, G32, G45 and G49 genotypes belong to *T. boeoticum* species, G1, G2, G3, G4, G5, G6, G7, G10, G11, G13, G14 and G19 of *T. dicoccoides*, and G3, G6, G7, G10, G11, G13, G16, G21, G22, G23 and G25 of *T. durum*, proved drought resistant at the seedling stage, regarding the shoot length STI values. Therefore, it was concluded that genotypes, regardless of species, with high STI values can be used as a potential gene source for developing salinity-resistant varieties (Table 6). It has been reported that the applied salt concentration decreases the enzyme activity and therefore the coleoptile length decreases (Öner & Kırlı, 2018).

Table 4. Effect of salinity stress on root weights of the seedlings (gr).

Gen. No.	***T. boeoticum***			***T. dicoccoides***			***T. durum* (Landraces)**		
	Control	**NaCl**	**STI**	**Control**	**NaCl**	**STI**	**Control**	**NaCl**	**STI**
1.	0,038^{j}	0,023^{dk}	0,40	0,13a	0,058a	2,09	0,16pq	0,06n	0,22
2.	0,038^{j}	0,018^{fl}	0,31	0,12b	0,056ab	1,87	0,22eh	0,2bc	1,00
3.	0,041$^{\imath j}$	0,026$^{b\imath}$	0,48	0,09d	0,054bc	1,35	0,19kn	0,12gı	0,52
4.	0,049^{gh}	0,018^{gl}	0,40	0,08e	0,041f	0,91	0,29b	0,19bc	1,25
5.	0,058^{cd}	0,029^{ae}	0,76	0,03op	0,051cd	0,43	0,17op	0,1jk	0,39
6.	0,027^{kl}	0,014^{kn}	0,17	0,07f	0,028gh	0,54	0,22gı	0,19c	0,95
7.	0,027^{kl}	0,015^{jn}	0,18	0,06ıj	0,018ı	0,30	0,21gj	0,12gh	0,57
8.	0,028^{k}	0,014^{kn}	0,18	0,06jk	0,026h	0,43	0,27c	0,2b	1,22
9.	0,019^{m}	0,013kn	0,11	0,09d	0,051cd	1,28	0,28bc	0,21a	1,33
10.	0,051^{eg}	0,032ad	0,74	0,06k	0,046e	0,77	0,21gj	0,1jk	0,48
11.	0,048^{gh}	0,018gl	0,39	0,06l	0,041f	0,68	0,21hl	0,14f	0,67
12.	0,056^{de}	0,018gl	0,46	0,07gh	0,018ı	0,35	0,24df	0,19bc	1,03
13.	0,054^{df}	0,018fl	0,44	0,05lm	0,056ab	0,78	0,21gk	0,16d	0,76
14.	0,043$^{\imath}$	0,027bh	0,53	0,06k	0,056ab	0,93	0,19lo	0,14ef	0,60
15.	0,062^{bc}	0,014kn	0,39	0,07f	0,026h	0,51	0,22fı	0,15e	0,75
16.	0,041$^{\imath j}$	0,023dk	0,43	0,07hı	0,018ı	0,35	0,4a	0,1jk	0,91
17.	0,058^{cd}	0,035ab	0,92	0,05m	0,018ı	0,25	0,2ım	0,06mn	0,27
18.	0,064^{b}	0,023dk	0,67	0,06jk	0,018ı	0,30	0,19mo	0,16d	0,69
19.	0,064^{b}	0,038a	1,10	0,07fg	0,051cd	0,99	0,19mo	0,14ef	0,60
20.	0,05^{fh}	0,028bg	0,63	0,09c	0,048de	1,20	0,28bc	0,09l	0,57
21.	0,058^{cd}	0,031ad	0,81	0,03r	0,011j	0,09	0,23eg	0,12gh	0,63
22.	0,043$^{\imath}$	0,025cj	0,49	0,03op	NG	NG	0,13rs	0,1jk	0,29
23.	0,023^{lm}	0,014kn	0,15	0,03op	0,018ı	0,15	0,25d	0,1k	0,57
24.	0,058^{cd}	0,028bf	0,74	0,03pq	0,021ı	0,18	0,09t	0,11ıj	0,22
25.	0,052^{eg}	0,031ad	0,73	0,06jk	0,021ı	0,35	0,16pq	0,12g	0,44
26.	0,052^{eg}	0,024cj	0,56	0,03op	NG	NG	0,15oqr	0,11gı	0,37
27.	0,062^{bc}	0,028bf	0,79	0,03op	NG	NG	0,17op	0,06mn	0,23
28.	0,019^{m}	0,006n	0,05	0,03r	0,031g	0,26	0,18np	0,1jk	0,41
29.	0,048^{gh}	0,028bf	0,61	0,04n	0,021ı	0,23	0,25d	0,12g	0,68
30.	0,068^{a}	0,034ac	1,05	0,02s	NG	NG	0,17pq	0,06n	0,23
31.	0,068^{a}	0,018fl	0,55	0,02s	0,018ı	0,10	0,24de	0,07m	0,38
32.	0,051^{eg}	0,029ad	0,67	0,03q	0,051cd	0,43	0,12s	0,08l	0,22
33.	0,058^{cd}	0,018fl	0,47	0,03op	NG	NG	0,2jm	0,1k	0,45
34.	0,07^{a}	0,018gl	0,57	0,03op	NG	NG	0,13rs	0,11hı	0,32
35.	0,068^{a}	0,018gl	0,55	0,04o	0,011j	0,12	0,12s	0,08l	0,22
36.	0,062^{bc}	0,028bg	0,79	0,03oq	NG	NG			
37.	0,049^{gh}	0,019el	0,42	0,03op	0,051cd	0,43			
38.	0,048^{gh}	0,029ae	0,63						
39.	0,019^{m}	0,006n	0,05						
40.	0,048^{gh}	0,017hm	0,37						
41.	0,038^{j}	0,024dj	0,41						
42.	0,038^{j}	0,016ın	0,28						
43.	0,058^{cd}	0,024dj	0,63						
44.	0,049^{gh}	0,018gl	0,40						
45.	0,043$^{\imath}$	0,013ln	0,25						
46.	0,019^{m}	0,027bg	0,23						
47.	0,045$^{h\imath}$	0,025bj	0,51						
48.	0,024^{kl}	0,007mn	0,08						
49.	0,058^{cd}	0,03ad	0,79						
Mean	0,047	0,022	0,50	0,05	0,034	0,62	0,21	0,12	0,58
Lsd	0,0047**	0,01*	0.0033**	0.0037**			0.019**	0.0095**	

NG: No germination

Table 6. Effect of salinity stress on shoot length (cm)of the seedlings (cm).

Gen. No.	*T. boeoticum*			*T. dicoccoides*			*T. durum* (Landraces)		
	Control	**NaCl**	**STI**	**Control**	**NaCl**	**STI**	**Control**	**NaCl**	**STI**
1.	10,8cf	5bc	0,50	12,25ce	5,5bd	0,50	13,5df	6cf	0,40
2.	10fh	4f	0,37	12,25ce	6,5a	0,59	12,75f	5,75df	0,36
3.	10,75cf	4,5de	0,44	13ab	6,75a	0,65	15,8a	6,75be	0,53
4.	11,25bd	4,8bd	0,50	13ab	6ac	0,58	14,25cd	7bd	0,49
5.	11,25bd	3g	0,31	12,5bd	6,5a	0,60	14.00ce	6cf	0,42
6.	8,5j	2,65gh	0,21	13,5a	6,5a	0,65	14,75bc	7,5ab	0,55
7.	8,05j	2,25ıj	0,17	12,5bd	5,5bd	0,51	14,25cd	7,5ab	0,53
8.	8,05j	2,25ıj	0,17	12df	5,5bd	0,49	13,5df	6,5be	0,44
9.	8,75ıj	2,5hı	0,20	13ab	4,5e	0,43	14.00ce	7bd	0,49
10.	11,25bd	4,8bd	0,50	12,5bd	6ac	0,56	14.5bd	7,25ac	0,52
11.	10,5dg	2,5hı	0,24	12,5bd	6ac	0,56	15,5ab	8,5a	0,65
12.	11be	3g	0,30	13,5a	4,5e	0,45	14.00ce	7bd	0,49
13.	11be	3g	0,30	12df	6,25ab	0,56	14,25cd	7,5ab	0,53
14.	11,75ab	4f	0,43	11,75ef	5,95ac	0,52	14.00ce	7bd	0,49
15.	10,75cf	4,5de	0,44	11,5fg	5,5bd	0,47	14.25cd	6,75be	0,48
16.	9,75gh	4,25ef	0,38	12,75bc	4,5e	0,43	14,75bc	7,25ac	0,53
17.	10,75cf	5bc	0,49	12df	4,5e	0,40	14,75bc	6cf	0,44
18.	10,95be	4f	0,40	12,25ce	5,5bd	0,50	14.50bd	6,75be	0,49
19.	10,5dg	5bc	0,48	12,75bc	6,75a	0,64	13.50df	7bd	0,47
20.	11,75ac	4,5de	0,49	13ab	5de	0,48	14,75bc	6,75be	0,49
21.	10,75cf	5bc	0,49	11gh	5de	0,41	14,25cd	7,5ab	0,53
22.	10,5dg	4f	0,39	10ıj	NG	NG	15.5ab	6,75be	0,52
23.	9,75gh	2,75gh	0,25	11gh	3,5f	0,29	14,75bc	7,75ab	0,57
24.	9,75gh	4f	0,36	10,5hı	5de	0,39	13.00ef	6cf	0,39
25.	10fh	4f	0,37	11gh	5,5bd	0,45	14,25cd	7,25ac	0,51
26.	10fh	4,5de	0,41	9k	NG	NG	14,25cd	6,75be	0,48
27.	10,75cf	5,5a	0,54	9k	NG	NG	13,75cf	6cf	0,41
28.	8,55j	2j	0,16	11,5fg	6ac	0,51	14.50bd	6cf	0,43
29.	10,5dg	4,75cd	0,46	11gh	5,5bd	0,45	13,75cf	6,5be	0,44
30.	11be	5bc	0,50	9k	NG	NG	13.00ef	4,75f	0,31
31.	11,75ab	3g	0,32	9,5jk	3,25f	0,23	14,75bc	6,5be	0,48
32.	11,5ac	4,5de	0,47	11,75ef	6ac	0,52	13.50df	5,5ef	0,37
33.	11,5ac	3g	0,32	10,5hı	NG	NG	14,25cd	7bd	0,49
34.	10,75cf	3g	0,30	9,5jk	NG	NG	13.5df	5,75df	0,38
35.	12,25a	3g	0,34	11gh	5,25ce	0,43	13.5df	6cf	0,40
36.	11be	5bc	0,50	11gh	NG	NG			
37.	11be	5bc	0,50	10,75h	4,5e	0,36			
38.	11be	5,25ab	0,53						
39.	8,55j	2,5hı	0,20						
40.	10,5dg	2,5hı	0,24						
41.	9,5hı	4f	0,35						
42.	10,25eh	4,05ef	0,38						
43.	11be	4f	0,40						
44.	10fh	2,5hı	0,23						
45.	11be	5bc	0,50						
46.	8,55j	2,4hj	0,19						
47.	11,5ac	4,75cd	0,50						
48.	9,5hı	3,05g	0,27						
49.	11,5ac	4,5de	0,47						
Mean	10,44	3,84	0,37	11,6	5,44	0,48	14.2	6,7	0,47
Lsd	0,81**	0,48**		0,70**	0,90**		1,03**	1,25**	

NG: No germination; * Signifigant at 0.05; ** Signifigant at 0.01

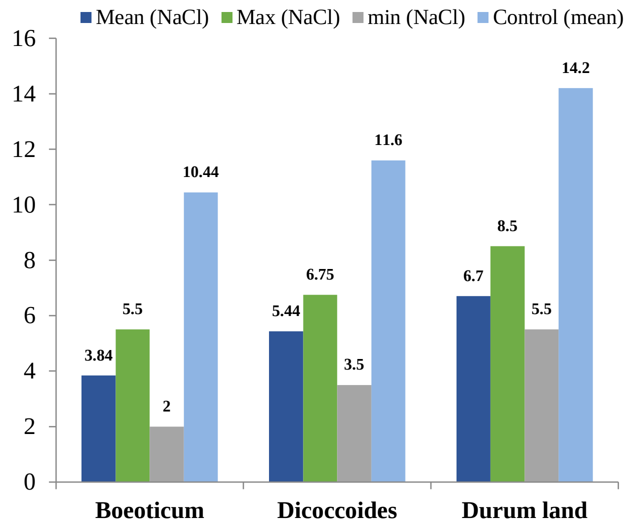

Fig. 7. Effect of salt stress on shoot length of the seedlings of various studied wheat species.

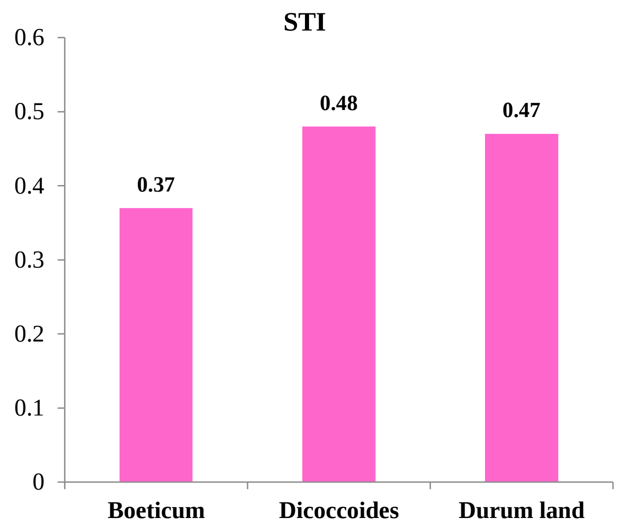

Fig. 8. Stress tolerance index (STI) for shoot length of the seedlings of various studied wheat species.

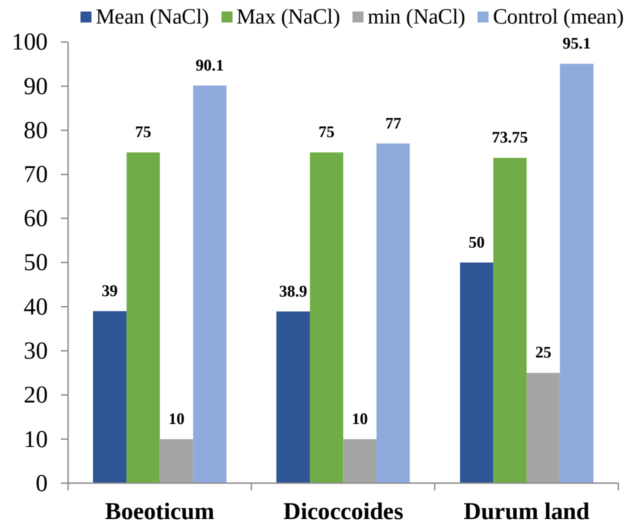

Fig. 9. Effect of salt stress on germination percentage of the seedlings of various studied wheat species.

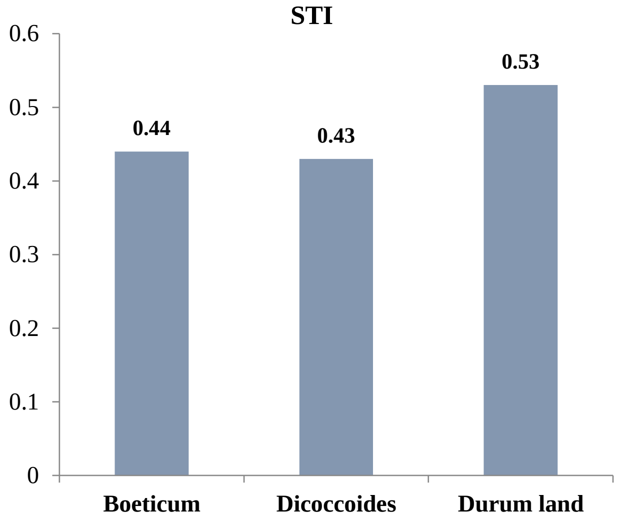

Fig. 10. Stress tolerance index (STI) for germination percentage of the seedlings of various studied wheat species.

Effect of salinity stress on seed germination percentage (cm) of the seedlings: Seed germination percentages of different genotypes belonging to three 3 species subjected to salinity (in 200 mg/L concentration) under laboratory conditions are given in Table 7. The average seed germination percentage of *T. boeoticum* genotypes subjected to salinity (in 200 mg/L concentration) stress ranged from 10% (G48) to 75% (G9). The average seed germination percentage of *T. boeoticum* was 39% subjected to salinity stress. However, the average seed germination percentage in the control treatment was 90.1% (Table 7 and Fig. 9). The highest seed germination percentage under salinity stress was obtained for genotypes G9 (75%), G15 (75%), G24 (75%), and G29 (75% and G8 (72.5%) (Table 7). The seed germination percentage average of *T. dicoccoides* genotypes subjected to salinity stress ranged from 15% (G37) to 75% (G19 and G20). The overall seed germination percentage of *T. boeoticum* was 38.9% under salinity stress, whereas it was 77% in the control treatment (Fig. 9 and Table 7). The highest germination percentages among *T. dicoccoides* genotypes were noted for G19-20 (75%), G1 (70%), G3 (70%), and G6 (65%) (Table 7 and Fig. 9).

The average germination percentage of wheat landrace genotypes (*T. durum* varieties) subjected to salinity stress ranged from 25% (G1-5-6-15-22-29-35) to 73.5% (G13). Overall seed germination percentage of *T. durum* species was 50% under salinity stress, while it was 95.1% in the control treatment (Table 7 and Fig. 9). G13 (73.5%), G2 (72.2%), G3 (73.5%), G4 (72.5%), G7 (72.5%), G8 (72.5%), G19 (72.5%), G25 (70%), G16 (70%) and G14 (63.75%) were determined as the genotypes with the highest germination percentage under salt stress conditions (Fig. 9 and Table 6). The tolerance levels of the genotypes included in the study to salinity stress are given in Table 7 and Fig. 10 as the stress tolerance index (STI).

T. durum genotypes had the highest STI value (0.53) for seed germination percentage. However, the mean STI value of the *T. boeoticum* genotypes was 0.44, while the mean STI value of the *T.dicoccoides* genotypes was 0.43. Thus, *T. durum* landraces was found to be more tolerant to salinity in terms of seed germination than other species, in general. However, it should be noted that there are resistant and sensitive genotypes in all 3 wheat species used in the study. The results showed that the genotypes G2, G13, G4, G7, G8, G12, G13, G19 and G25 of *T. durum* species, G1, G3, G6, G19 and G20 of *T. dicoccoides*, and G8, G9, G15, G18, G24, G26 and G29 of *T. boeoticum* was drought resistant. These genotypes can be considered as genetic material to develop drought-resistant wheat varieties, based on seed germination STI values (Table 7). Salinity in soil or irrigation water can adversely affect the growth and yield of most crops through molecular, biochemical, and physiological processes at different life stages (Shannon *et al*., 1985).

Table 7. Effect of salinity stress on seed germination percentage.

Gen. No.	***T. boeoticum***			***T. dicoccoides***			***T. durum* (Landraces)**		
	Control	**NaCl**	**STI**	**Control**	**NaCl**	**STI**	**Control**	**NaCl**	**STI**
1.	90bc	25ı	0,28	100a	70b	0,87	90b	25j	0,25
2.	90bc	25ı	0,28	85bc	55e	0,58	100a	72,5a	0,80
3.	100a	30h	0,37	100a	70b	0,87	100a	72,5a	0,80
4.	85cd	25ı	0,26	100a	50e	0,62	100a	72,5a	0,80
5.	100a	50e	0,62	90b	42,5f	0,48	100a	25j	0,28
6.	100a	50e	0,62	90b	65c	0,73	50e	25j	0,14
7.	85cd	40f	0,42	100a	10k	0,12	100a	72,5a	0,80
8.	100a	72,5ab	0,89	100a	50e	0,62	100a	72,5a	0,80
9.	100a	75a	0,92	87,5b	25g	0,27	100a	50dh	0,55
10.	77,5ef	25ı	0,24	87,5b	50e	0,54	100a	57,5ce	0,64
11.	85cd	20j	0,21	100a	20ı	0,25	100a	57,5ce	0,64
12.	85cd	20j	0,21	100a	10k	0,12	100a	72,5a	0,80
13.	100a	25ı	0,31	85bc	45e	0,48	100a	73,75a	0,82
14.	77,5ef	25ı	0,24	100a	50e	0,62	75d	63,75ac	0,53
15.	100a	75a	0,92	87,5b	45f	0,49	100a	25j	0,28
16.	82,5de	50e	0,51	100a	10k	0,12	100a	70ab	0,77
17.	85cd	60d	0,63	85bc	20ı	0,21	100a	25j	0,28
18.	100a	67,5c	0,83	100a	37,5f	0,47	100a	52,5cg	0,58
19.	77,5ef	25ı	0,24	100a	75a	0,93	100a	72,5a	0,80
20.	87,5cd	25ı	0,27	100a	75a	0,93	100a	40hı	0,44
21.	87,5cd	25ı	0,27	87,5b	50e	0,54	90b	45fı	0,45
22.	82,5de	25ı	0,25	25 g	NG	NG	100a	25j	0,28
23.	100a	40f	0,49	87,5b	10k	0,11	85c	60bd	0,56
24.	100a	75a	0,92	90b	45f	0,50	85c	40hı	0,38
25.	100a	50e	0,62	85bc	35g	0,37	100a	70ab	0,77
26.	100a	70bc	0,86	20 g	NG	NG	100a	50dh	0,55
27.	77,5ef	30h	0,29	20 g	NG	NG	100a	41gı	0,45
28.	70gh	20j	0,17	80cd	25h	0,25	100a	37,5ı	0,41
29.	95ab	75a	0,88	67,5e	10k	0,08	85c	25j	0,23
30.	100a	60d	0,74	25 g	NG	NG	100a	37,5ı	0,41
31.	100a	25ı	0,31	77,5d	20ı	0,19	100a	55cf	0,61
32.	90bc	35g	0,39	87,5b	25h	0,27	100a	50dh	0,55
33.	100a	20j	0,25	25 g	NG	NG	77,5d	47,5eı	0,41
34.	100a	60d	0,74	20 g	NG	NG	100a	50dh	0,55
35.	67,5h	20j	0,17	87,5b	57,5d	0,63	90 b	25j	0,25
36.	100a	30h	0,37	25 g	NG	NG			
37.	82,5de	40f	0,41	40f	15j	0,07			
38.	100a	60d	0,74						
39.	75fg	10k	0,09						
40.	100a	20j	0,25						
41.	85cd	50e	0,52						
42.	85cd	50e	0,52						
43.	85cd	35g	0,37						
44.	85cd	20j	0,21						
45.	100a	50e	0,62						
46.	75fg	10k	0,09						
47.	90bc	60d	0,67						
48.	75fg	10k	0,09						
49.	100a	20j	0,25						
Mean	90,1	39	0,44	77	38,9	0,43	95,1	50	0,53
Lsd	6,95**	4,73**		6,73**	3,96**		4,32**	12,2**	

NG: No germination; * Signifigant at 0.05; ** Signifigant at 0.01

Conclusion

The present investigation comprehensively explained the impact of salt stress on studied wheat species. Significant impacts were observed for the studied traits. Superior wheat genotypes were observed to have better performance regarding root length, shoot length, and germination percentage under salinity conditions. The investigated superior genotypes will be helpful for future wheat breeding to develop salt tolerance cultivars.

Statements & Declarations

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Data availability: All data recorded in this study is provided within the manuscript.

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