Anadolu, J. of AARI
ISSN:1300-0225 (Print)
E-ISSN: 2667-6087 (Online)
2025, 35 (1): 62-73
DOI: 10.18615/anadolu.1600805

The Effect of Salt and Drought Stresses on Germination and Early Seedling Growth of Different Linseed (Linum usitatissimum L.) Varieties

***Yasemin ERDOĞDU*[1]** ***İlkay ORHAN*[2]**

[1,2]Tarla Bitkileri Bölümü, Tekirdağ Namık Kemal Üniversitesi, Tekirdağ/ TÜRKİYE

[1]https://orcid.org/0000-0001-8393-3444 *[2]https://orcid.org/0009-0004-2235-9556*

**Corresponding author (Sorumlu yazar): yerdogdu@nku.edu.tr*

Received (Geliş tarihi): 13.12. 2024 *Accepted (Kabul tarihi): 25.03.2025*

ABSTRACT: *Salinity and drought are the primary stress factors that negatively impact crop production. This study evaluated the effects of sodium chloride (NaCl) and polyethylene glycol (PEG-6000)-induced osmotic stress on germination and early seedling growth in five linseed varieties (Kara Kız, Beyaz Gelin, Sarı Dane, Cemre, and Efe). The investigated parameters included germination rate (%), average germination time (days), root length (cm), fresh and dry root weight (mg), shoot length (cm), and fresh and dry shoot weight (mg). The results revealed that the differences among the tested linseed varieties were statistically significant for all examined characteristics. It was determined that the varieties exhibited considerable resistance to salt stress in terms of germination rates. Germination rates decreased by 2.3% at 12.0 dS m^{-1} NaCl and by 10.6% at 0.50 MPa PEG. Additionally, the average germination time increased with rising salinity (1.6–4.5 days) and drought stress (1.1–2.7 days). With increasing salinity and drought stress, root length (NaCl: 1.40–6.40 cm, PEG: 5.46–12.60 cm), shoot length (NaCl: 2.30–10.43 cm, PEG: 2.40–10.06 cm), fresh root weight (NaCl: 3.86–13.90 mg, PEG: 1.43–6.00 mg), dry root weight (NaCl: 0.20–1.53 mg, PEG: 0.26–1.03 mg), fresh shoot weight (NaCl: 29.30–86.33 mg, PEG: 21.00–82.40 mg), and dry shoot weight (NaCl: 2.00–7.23 mg, PEG: 2.10–7.76 mg) decreased gradually and significantly. Among the tested varieties, Sarı Dane exhibited greater resistance to salt stress, while Beyaz Gelin was more resistant to drought stress.*

Keywords: *Germination, Linum usitatissimum L., linseed, drought, NaCl, osmotic stress.*

Tuz ve Kuraklık Stresinin Farklı Keten (Linum usitatissimum L.) Çeşitlerinin Çimlenme ve Erken Fide Gelişimine Etkisi

ÖZ: *Tuzluluk ve kuraklık, bitkisel üretimi olumsuz yönde etkileyen başlıca stres faktörleridir. Bu çalışmada, 5 keten tohumu çeşidinde (Kara Kız, Beyaz Gelin, Sarı Dane, Cemre ve Efe) sodyum klorür (NaCl) ve polietilen glikol (PEG-6000) kaynaklı ozmotik stresin çimlenme ve erken fide dönemlerine etkileri değerlendirilmiş ve çeşitlerdeki çimlenme oranı (%), ortalama çimlenme süresi (gün), kök uzunluğu (cm), yaş kök ağırlığı (mg), kuru kök ağırlığı (mg), sürgün uzunluğu (cm), yaş sürgün ağırlığı (mg), kuru sürgün ağırlığı (mg) özellikleri incelenmiştir. Saptanan sonuçlarda, incelenen tüm özellikler açısından denemeye alınan keten çeşitlerindeki farklılıkların istatistiksel olarak önemli oldukları anlaşılmış; çeşitlerin çimlenme oranları açısından tuz stresine karşı oldukça dayanıklılık gösterdikleri saptanmış; çimlenme oranında (NaCl) 12,0 dS m^{-1}için %2,3, (PEG) 0,50 MPa için de %10,6 düzeyinde azalma olmuş; ortalama çimlenme süresi artan tuzluluk (1,6-4,5 gün) ve kuraklık stresi (1,1-2,7 gün) ile uzamıştır. Tuzluluk ve kuraklık stresinin arttırılmasıyla kök uzunluğu (NaCl 1.40-6.40 cm, PEG 5.46-12.60 cm), sürgün uzunluğu (NaCl 2,30-10,43 cm, PEG 2,40-10,06 cm), yaş kök ağırlığı (NaCl 3,86-13,90 mg, PEG 1,43-6,00 mg), kuru kök ağırlığı (NaCl 0,20-1,53 mg, PEG 0,26-1,03 mg), yaş sürgün ağırlığı (NaCl 29,30-86,33 mg, PEG 21,00-82,40 mg) ve kuru sürgün ağırlığı (NaCl 2,00-7,23 mg, PEG 2,10-7,76 mg) kademeli şekilde ve önemli ölçüde azalırken; Sarı Dane tuz stresine, Beyaz Gelin ise kuraklık stresine karşı daha dayanıklı bulunmuştur.*

Anahtar kelimeler: *Çimlenme, Linum usitatissimum L., keten, kuraklık, NaCl, osmotik stres.*

INTRODUCTION

Linseed (*Linum usitatissimum* L.) cultivation dates back to >6000 BC (Pavelek, 2015). It is an important industrial plant used in the production of both oil and fiber around the world (Jhala and Hall, 2010) with production of approximately 4 million tons (FAO, 2024). Linseed belongs to the Linaceae family, which includes 13 genera and nearly 300 species (Kocak and Bayraktar, 2011). Different Linum varieties were developed to produce both fiber and seeds. Linum varieties grown for fiber use are called flax, and oilseed varieties are called linseed, simply flax or oilseed flax (Nykter et al., 2006).

Linseed contains 40.0% oil, 30.0% fiber, 20.0% protein, 4.0% ash and 6.0% moisture (Wang *et al.*, 2008). Linseed oil contains up to 65.0% α-linolenic acid and polymerizes rapidly with exposure to oxygen, making it suitable for industrial purposes such as the production of paints, linoleum, varnishes, inks and cosmetics (Hall *et al.*, 2016). Linseed oil is an important oil for human health due to its containing polyunsaturated fatty acids and additionally, it contains antioxidants and phytosterols. It is a valuable animal feed oil and its by-products are evaluated as fiber (Bekhit *et al.*, 2018).

Seed germination and emergence are among the most important physiological stages in crop plants. From these growth stages, seed germination performance both directly and indirectly affects crop establishment, crop health and ultimately crop yield (Lamichhane *et al.*, 2018). Biotic and abiotic stress factors such as viruses, bacteria, fungi, insects, weeds, drought, and salinity can greatly affect seed germination and seed emergence. Salt and water stresses are responsible for both inhibition or delayed seed germination and seedling establishment (Murillo-Amado *et al.*, 2002).

Drought and salt stress are major threats to plant cultivation. Almost every aspect of plant physiology and cellular metabolism is affected by salt and drought stress in plant production (Mahajan and Tuteja, 2005). Stress is increasing due to changes in global climate and increased irrigation practices. 118 countries covering 85% of global land area, it shows that more than 424 million hectares of topsoil (0-30 cm) and 833 million hectares of subsoil (30-100 cm) are salt-affect. (FAO, 2023a). Similarly, drought stress is one of the most challenging issues for agriculture due to the effects of climate change. Currently, 2.3 billion people live in water-stressed countries and agriculture is responsible for 72.0% of global freshwater use (FAO, 2023b).

Salt stress is a very complex abiotic stress that negatively affects germination and seedling development. Abundant water is needed for the germination of seeds. Salinity stress can cause osmotic stress, which reduces the amount of water available to plants, and ionic stress, which causes the amount of ions to reach a toxic level (Muchate *et al.*, 2016; Qayyum *et al.*, 2019). Continuation of ionic and osmotic stress can cause oxidative stress (Liang *et al.*, 2018) and toxicity (Niu *et al.*, 1995). Plants are much more sensitive to salinity stress during seed germination and early seedling development to achieve healthy growth (Sevgi and Leblebici, 2023). In studies conducted on linseed, as in many plant species, seed germination and early seedling development under salinity stress were significantly affected by salinity stress (Kadkhodaie and Bagheri, 2011; Guo *et al.*, 2013; Qayyum *et al.*, 2015;; Kiremit *et al.*, 2017; Moghaddam *et al.*, 2018; Kocak *et al.*, 2022). In linseed, salinity stress prevented germination through osmotic and toxic effects, and lipid mobilization was delayed in the early germination stage (Sebei *et al.*, 2007). Guo *et al.* (2014) reported that salinity stress caused osmotic stress and ion damage in linseed. In addition, genetic diversity in plants is important in terms of salinity tolerance (Deinlein *et al.*, 2014). Previous studies showed that germination and seedling development in linseed under different salinity stress levels depends on genotype (Sebei *et al.*, 2007; Qayyum *et al.*, 2015; Kocak *et al.*, 2022).

Drought is the major cause of crop yield loss among abiotic factors around the World (Begna, 2020). Plants can be negatively affected by drought in all stages of growth, but the first and most important effect is on seed germination (Fahad *et al.*, 2017). The amount of water required for seed germination decreases significantly with increasing osmotic stress levels (Heikal *et al.*, 1982). Drought limits the cell growth process mainly due to the loss of turgor (Taiz and Zeiger, 2008). Selection of drought tolerance at the early seedling stage is often accomplished using simulated drought caused by chemicals such as polyethylene glycol (PEG6000) (Almaghrabi, 2012). Numerous studies were conducted to examine the effect of water stress on seed germination. In general, the germination ability of seeds decreases as water stress increases, and similar results were obtained in studies conducted on flax (Heikal *et al.*, 1982; Mostafavi *et al.*, 2011; Guo *et al.*, 2012; Guo, 2013). Although the effects of salinity and drought on germination and early seedling development in linseed have been investigated, significant differences were found among genotypes in response to these stress factors. Understanding how new improved varieties respond to stress factors such as drought and salinity, which are thought to increase with climate change, may guide breeders in coping with stress conditions.

The main aim of this study was to compare the effects of induced salt and drought stress on germination and early seedling growth in different linseed varieties.

MATERIAL AND METHOD

This research was carried out in the Seed laboratory of the Department of Field Crops, Faculty of Agriculture, University of Tekirdağ Namık Kemal, Turkiye, in 2023. Five varieties of linseed including Kara Kız, Beyaz Gelin, Sarı Dane, Cemre and Efe were used as the experimental material. Seeds of the varieties were provided by the Thrace Agricultural Research Institute, Edirne.

In two separate experiments, the effect of salt and drought stresses induced by different osmotic potential levels of NaCl and polyethylene glycol 6000 (PEG 6000) treatments on the seed germination and early seedling development of linseed varieties were studied. In the first experiment, the factor was NaCl levels (0, 2.0, 4.0, 8.0, 12.0, 16.0, 20.0 dSm^{-1} electrical conductivity). In the second experiment, the factor was PEG levels (0, 0.25, 0.50 and 0.75 MPa). The experiments were arranged in a two-factor, Completely Randomized Design (CRD) with three replications. At each level of stress, 20 seeds of the varieties were selected and surface sterilized in 4.0% sodium hypochlorite (NaClO) solution for 15 min (Wanasundara *et al.*, 1999). The seeds were then washed in distilled water five times. Twenty seeds were placed on two layers of sterile filter paper (Whatman No.1) in 9.0 cm-diameter sterile petri dishes which contained 10 ml of NaCl and PEG solutions. Petri dishes were covered with cling film to prevent evaporation. All seeds were germinated in the climate chamber (temperature, 22.0± 1°C; relative humidity, 78.0 ± 2.0% in the dark). The numbers of germinated seeds were recorded every day (Ellis and Roberts (1980). Seeds were considered germinated when the emergent radical reached 2 mm in length according to Mostafavi (2011). The names and descriptions of measurements for linseed were:

Germination rate (GR)% (No. of germinated seeds/No. of total seeds) x 100.

Mean germination time (MGT) $MGT = \sum(fx) / \sum f$

Where, f is the number of germinated seeds in the day of counting; x is number of days (Ellis and Roberts, 1980).

Every day the number of seeds germinated (2.0 mm radical) was recorded for 7 days and continued on the 10th days as root and shoot measurements.

Root length (RL) and shoot length (SL) were measured with a ruler (in cm).

Root fresh weight (RFW) and shoot fresh weight (SFW) were measured in mg with an analytical balance (Mettler Toledo, Switzerland).

Root and shoot tissues were dried to a constant weight at 70.0 °C for 48 h in an oven (Bohm, 1979). Root dry weight (RDW) and shoot dry weight (SDW) were measured in mg with an analytical balance.

Since root and shoot development did not occur after 8.0 dSm^{-1} NaCl level and 0.25 Mpa PEG stress level in some linseed varieties used in the experiment, the data from these treatments were not evaluated in the study.

Data were statistically analyzed using analysis of variance with the JMP Pro 16.0 (SAS Institute Inc.) program. The differences between the means were analyzed with the least significant difference (LSD) test ($P \leq 0.05$) (Steel and Torrie, 1981).

RESULTS AND DISCUSSION

Salt Stress Experiment: Significant differences ($p \leq 0.05$) were recorded among the linseed varieties at different NaCl salt stress levels for GR, MGT, RL, RFW, RDW, SL, SFW, and SDW (Table 1).

Table 1. Germination rate (%), mean germination time (day), root length (cm), root fresh weight (mg), root dry weight (mg), shoot length (cm), shoot fresh weight (mg), shoot dry weight (mg) of linseed varieties at different salinity levels.
Çizelge 1. Farklı tuzluluk düzeylerindeki keten tohumu çeşitlerinin çimlenme oranı (%), ortalama çimlenme süresi (gün), kök uzunluğu (cm), yaş kök ağırlığı (mg), kuru kök ağırlığı (mg), sürgün uzunluğu (cm), yaş sürgün ağırlığı (mg), kuru sürgün ağırlığı (mg).

Salinity levels (dSm^{-1}), Tuzluluk seviyeleri levels (dSm-1)	Beyaz Gelin	Cemre	Efe	Kara Kız	Sarı Dane	Mean/Ortalama
	Germination rate (%)/ Çimlenme oranı (%)					
0	96.6 abc	95.0 a-d	98.3 ab	86.6 d-g	96.6 abc	94.6 a
2	96.6 abc	91.6 a-e	96.6 abc	88.3 c-f	100 a	94.6 a
4	96.6 abc	98.3 ab	96.6 abc	85.5 efg	95.0 a-d	94.3 a
8	98.3 ab	100 a	96.6 abc	81.6 fg	95.0 a-d	94.3 a
12	98.3 ab	91.6 a-e	95.0 a-d	83.3 efg	96.6 abc	92.3 a
16	88.3 c-f	91.6 a-e	96.6 abc	60.0 h	95.0 a-d	86.3 b
20	66.6 h	78.3 g	88.7 b-g	35.0 ı	90.0 b-f	71.7 c
Mean	91.6 a	91,9 a	95.5 a	74.2 b	95.4 a	89.7
CV:6.53	LSD: varieties: 4.41***	salinity level: 4.28***	varieties x salinity level: 9.58***			
	Mean germination time (day)/ Ortalama Çimlenme süresi (gün)					
0	2.0 ı-l	2.0 ı-l	1.8 k-n	2.0 ı-m	1.9 j-n	1.9 e
2	2.0 ı-l	1.8 j-n	1.9 ı-m	1.9 ı-m	1.8 lmn	1.9 e
4	1.9 ı-n	1.8 lmn	1.6 n	2.0 ı-m	1.9 ı-n	1.8 e
8	3.2 ef	1.9 ı-m	1.7 m-n	2.5 h	2.1 ıjk	2.3 d
12	2.1 ıj	2.5 h	2.1 ıjk	3.0 fg	2.6 h	2.4 c
16	2.9 fg	2.2 ı	2.0 ıjk	3.3 de	2.9 g	2.7 b
20	4.5 a	3.9 b	3.5 cd	3.9 b	3.6 c	3.9 a
Mean	2.6 a	2.3 c	2.1 c	2.6 a	2.4 b	2.4
CV:6.64	LSD: varieties:0.19***	salinity level:0.12***	varieties x salinity level:0.26***			
	Root length (cm)/Kök uzunluğu (cm)					
0	6.40 a	3.10 hı	4.66 d	5.10 c	4.43 de	4.74 a
2	4.26 e	3.16 hı	4.36 de	5.33 bc	5.53 b	4.53 b
4	3.83 f	3.80 fg	3.43 gh	4.06 ef	6.23 a	4.27 c
8	3.20 hı	1.40 k	3.26 hı	2.53 j	3.00 ı	2.68 d
Mean	4.42 b	2.86 d	3.93 c	4.25 b	4.80 a	4.05
CV:5.78	LSD: varieties:0.18***	salinity level:0.17***	varieties x salinity level:0.39***			
	Root fresh weight (mg)/Yaş kök ağırlığı (mg)					
0	12.56 bc	8.53 f	9.66 e	12.80 bc	10.43 de	10.80 a
2	11.00 d	7.26 g	7.33 g	13.23 ab	12.06 c	10.18 b
4	9.96 e	8.60 f	6.63 g	9.93 e	13.90 a	9.80 c
8	8.66 f	3.86 ı	5.70 h	7.00 g	5.33 h	6.11 d
Mean	10.55 a	7.06 b	7.33 b	10.74 a	10.43 a	9.22
CV:5.30	LSD: varieties:0.53***	salinity level:0.36***	varieties x salinity level:0.81***			
	Root dry weight (mg)/Kuru kök ağırlığı (mg)					
0	1.40 ab	0.50 h	0.91 ef	1.13 cd	1.10 cd	1.00 a
2	0.91 ef	0.46 h	0.83 ef	1.23 bc	1.53 a	0.99 a
4	0.75 fg	0.53 h	0.54 h	0.96 de	0.76 fg	0.71 b
8	0.62 gh	0.20 ı	0.47 h	0.50 h	0.50 h	0.46 c
Mean	0.92 a	0.42 c	0.69 b	0.95 a	0.97 a	0.79
CV:12.77	LSD: varieties:0.08***	salinity level:0.07***	varieties x salinity level:0.16***			
	Shoot length (cm)/ Sürgün uzunluğu (cm)					
0	8.50 a	4.56 l	6.66 ef	10.43 a	7.70 c	7.57 a
2	6.23 fg	5.50 ıj	5.66 hı	8.23 b	8.36 b	6.80 b
4	5.16 jk	6.13 gh	5.50 ıj	7.13 de	7.53 cd	6.29 c
8	4.86 kl	2.30 n	3.63 m	4.80 kl	3.36 m	3.79 d
Mean	6.19 c	4.62 e	5.36 d	7.65 a	6.74 b	6.11
CV:4.69	LSD: varieties:0.30***	salinity level:0.21***	varieties x salinity level:0.47***			
	Shoot fresh weight (mg)/ Yaş sürgün ağırlığı (mg)					
0	70.60 b	46.06 kl	66.66 d	86.33 a	56.00 g	65.13 a
2	61.20 e	49.30 ı	58.53 f	69.53 bc	67.63 cd	61.24 b
4	52.73 h	59.30 ef	55.70 g	60.26 ef	68.86 bcd	59.37 c
8	48.66 ıj	29.30 m	43.90 l	47.13 ıjk	46.60 jk	43.12 d
Mean	58.30 b	45.99 d	56.20 c	65.81 a	59.77 b	57.21
CV:2.41	LSD: varieties:1.51***	salinity level:1.03***	varieties x salinity level:2.30***			
	Shoot dry weight (mg)/Kuru sürgün ağırlığı (mg)					
0	5.96 b	2.83 hı	6.00 b	7.23 a	4.90 c	5.38 a
2	3.86 ef	3.30 gh	4.40 d	6.00 b	5.70 b	4.65 b
4	2.73 ı	4.33 de	3.76 fg	5.00 c	5.03 c	4.17 c
8	2.06 j	2.00 j	3.46 fg	2.76 ı	4.26 de	2.91 d
Mean	3.65 c	3.11 d	4.40 b	5.25 a	4.97 a	4.28
CV:6.80	LSD: varieties:0.37***	salinity level:0.21***	varieties x salinity level:0.48***			

CV: Coefficient of variation, LSD: Least significant difference, ***:Significant at 0.1%. Different letters indicate significant differences according to LSD test ($P \leq 0.05$)

Germination rate (GR-%)

GR was significantly affected by salinity levels, where increases in the severity of salinity stress reduced GR (Table 1, Figure 1). While no significant differences were observed under salinity levels 0 (control), 2.0, 4.0, 8.0 and 12.0 dS m^{-1}, increasing salinity to higher levels did affect GR. Over 90.0% of the seeds germinated at the lower salinity levels. GR decreased when salinity stress increased above 12.0 dS m^{-1}. The lowest GR (71.7%) was obtained at 20.0 dS m^{-1} salinity level. These results showed that the varieties used may be salt tolerant in terms of GR because 12.0 dS m^{-1} salinity stress is an environment that can cause osmotic and oxidative stress. Zeng *et al.* (2015) reported that salinity stress negatively affects plant metabolism through ion toxicity, osmotic stress and oxidative stress. Similarly, researchers stated that GR was diminished by salinity stress in linseed (Sebei *et al.*, 2007; Kadkhodaie and Bagheri, 2011; Guo, 2013; Qayyum *et al.*, 2015; Kiremit *et al.*, 2017; Moghaddam *et al.*, 2018; Kocak *et al.*, 2022). The differences between the mean GR of linseed varieties were significant. Except for the Kara Kız variety, the GRs of the other varieties were found to be high and were included in the same statistical group. The highest mean GR across all levels of stres belonged to the Efe variety (95.5%) and the lowest was for the Kara Kız variety (74.2%). In addition, interaction means showed maximum GR (100%) was present in the Sarı Dane (2.0 dS m^{-1}) and Efe (8.0 dS m^{-1}) varieties (Figure 1). These results show that linseed varieties have different salt tolerance and that genotype selection in terms of salt stress resistance is important in linseed breeding. Similarly, genotypes responded differently to salinity stress in other salt tolerance studies conducted with linseed (Sebei *et al.*, 2007; Qayyum *et al.*, 2015; Mahdavi and Alasyandyari, 2018; Kocak *et al.*, 2022).

Mean germination time (MGT-day)

MGT varied between 1.9 and 3.9 days at different salinity levels. No statistical difference was observed at 0, 2.0 and 4.0 dS m^{-1} salinity levels and germination occurred in the shortest time (Table 1, Figure 1). After 4.0 dS m^{-1} salinity stress, MGT gradually lengthened. The longest MGT was related to 20.0 dS m^{-1} salinity stress. Oxidative stress may have occurred with increased salt stress, and as a result of oxidative stress, the seed may have taken longer to absorb and use water. Similarly, researchers reported that MGT increased with increasing salt stress (Kaya *et al.*, 2008; Balkan *et al.*, 2015; Desheva *et al.*, 2020). Efe variety germinated in the shortest time (2.1) days, while the Kara Kız and Beyaz Gelin varieties germinated in the longest time (2.6) days. When interaction was examined, the Efe variety germinated at 4.0 dS m^{-1} salinity level in 1.6 days.

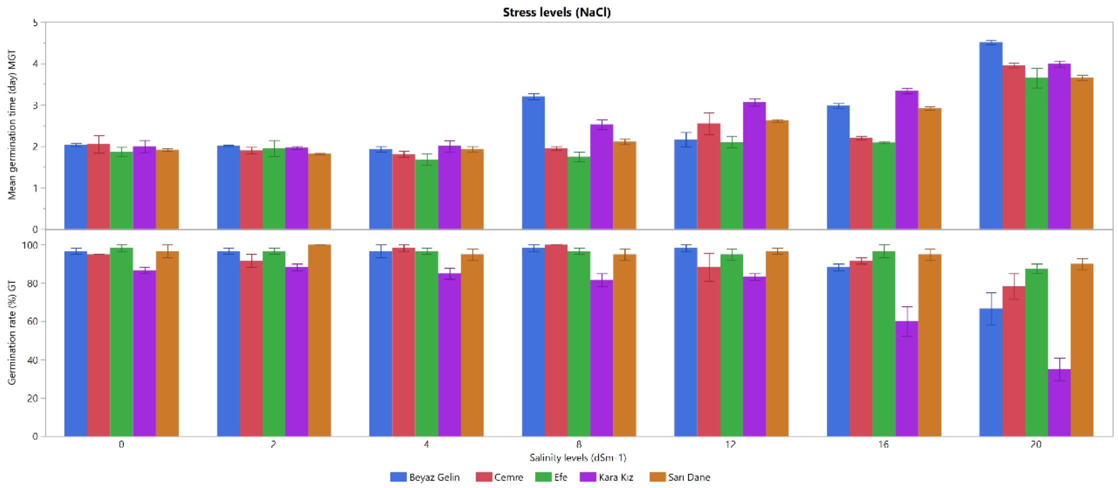


Figure 1. Germination rate (GR) and mean germination time (MGT) of five linseed varieties (Beyaz Gelin, Cemre, Efe, Kara Kız, Sarı Dane) under different NaCl Stress.
Şekil 1. Farklı tuz stresi altında beş keten çeşidinin (Beyaz Gelin, Cemre, Efe, Kara Kız ve Sarı Dane) çimlenme oranı (ÇO) ve ortalama çimlenme zamanı (OÇZ).

Root length (RL-cm) and shoot length (SL-cm)

By increasing the salinity levels, the lengths of root and shoot decreased. The longest RL (4.74 cm) and SL (7.57 cm) were determined for 0 (Control), followed by (2.0 -4.0) dS m^{-1}. RL and SL decreased especially after 4.0 dSm^{-1} salinity stress (Table 1, Figure 2). The reason for this decrease in RL and SL may be physiological drought stress caused by salinity. Sodium ions enter the roots passively, so root cells must use energy to actively expel Na+ back into the external solution (Taiz and Zeiger, 2008). Root and shoot length provide important information about the plant's response to salt stress (Jamil *et al.*, 2006) because roots are in direct contact with soil and absorb water from the soil and supply it to the rest of the plant (Moghaddam *et al.*, 2018). Researchers reported that salinity negatively affected root and shoot length in germination studies on linseed (Kaya *et al.*, 2012; Kiremit *et al.*, 2017; Mahdavi and Alasyandyari, 2018; Kocak *et al.*, 2022). The highest RL (4.80 cm) was determined for the Sarı Dane variety and SL (7.65 cm) was determined for the Kara Kız variety at all salinity levels. The lowest RL (2.86 cm) and SL (4.62 cm) belonged to the Cemre variety. For the interaction of varieties and salinity levels, the highest RL belonged to the Beyaz Gelin (6.40 cm/Control) and Sarı Dane (6.23 cm/4.0 dSm^{-1}) varieties, and the highest SL was for the Kara Kız (10.43 cm/Control) and Beyaz Gelin (8.50 cm/Control) varieties. In terms of RL and SL, Cemre variety was the most sensitive to stress. RL and SL are important parameters in determining linseed varieties that are resistant to salinity. Kiremit *et al.* (2017) reported in their study that root length is an important criterion in selecting salinity-resistant flax. Researchers reported that the responses of flax and linseed genotypes to salinity are different (Kaya *et al.*, 2012; Singh *et al.*, 2021).

Root fresh weight (RFW-mg), root dry weight (RDW-mg), shoot fresh weight (SFW-mg) and shoot dry weight (SDW-mg)

According to Table 1, by increasing the salinity levels, RFW, RDW, SFW and SDW gradually decreased. A striking decrease was observed, especially after 4.0 dS m^{-1} salt stress (Figure 2). The highest RFW, RDW, SFW and SDW belonged to control and the lowest was for 8.0 dSm^{-1} level of salinity. These results show that root and shoot growth of linseed were significantly affected by low salinity levels. Decreases in root and shoot development due to the increase in the salt concentration are caused by physicochemical effects or by osmotic-toxic salts that exist in saline solutions (Moghaddam *et al.*, 2018). Increasing the salt concentration in water reduces the osmotic potential by increasing electrical conductivity (Taiz and Zeiger, 2008). The decreases in RFW, RDW, SFW and SDW can be attributed to the increase in osmotic pressure in the germination medium, resulting in a decrease in water potential and growth inhibition related to osmotic effects under salt stress (Munns, 2002). Findings by Moghaddam *et al.* (2018) for flax confirm our research results, reporting that high salinity levels caused a significant reduction in seed germination and seedling length at the early growth stage. Kocak *et al.* (2022) reported that salinity negatively affected the early growth stage in of flax. The highest RFW, RDW, SFW and SDW in variety averages were found for the Kara Kız, Sarı Dane and Beyaz Gelin varieties. Cemre variety had the lowest value in terms of these characteristics. Considering these results, Cemre variety is sensitive to salinity. For the interaction of varieties and salinity levels, the highest RFW and RDW belonged to control and low salinity levels in the Sarı Dane variety and the lowest related to (8.0) dS m^{-1} for all varieties. The highest SFW and SDW development was observed in control with the the Kara Kız variety. In the interaction, the lowest RFW, RDW, SFW and SDW were obtained for the Cemre variety. It was the most sensitive genotype among the varieties used in the study. In their study with flax varieties, Kocak *et al.* (2022) reported that salt stress is important for the germination of flax plants and that there are differences among varieties. Mahdavi and Alasvandyari (2018) reported that salinity stress reduced the germination and seedling growth characteristics of different flax ecotypes and that genotypes were affected differently by salt stress.

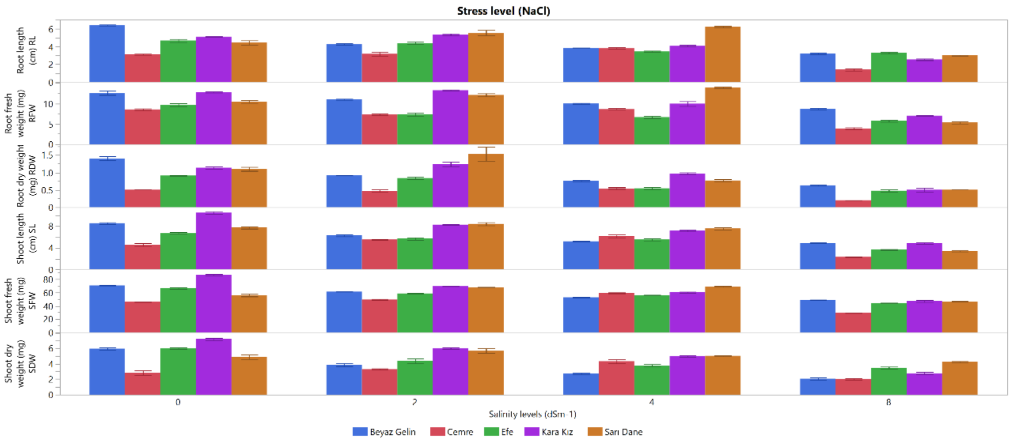


Figure 2. Effects of different NaCl stress on root length (cm), root fresh weight (RFW-mg), root dry weight (RDW-mg), shoot length (cm), shoot fresh weight (SFW-mg) and shoot dry weight (SDW-mg) in five linseed varieties.

Şekil 2. Beş keten çeşidinde farklı NaCl stresinin kök uzunluğu (cm), yaş kök ağırlığı (YKA-mg), kuru kök ağırlığı (KKA-mg), sürgün uzunluğu (cm), yaş sürgün ağırlığı (YSA-mg) ve kuru sürgün ağırlığı (KSA-mg)'nda etkileri.

Drought Stress Experiment

Significant differences ($p \leq 0.05$) were recorded among the linseed varieties at different concentrations of PEG for GR, MGT, RL, RFW, RDW, SL, SFW, and SDW (Table 2).

Germination rate (GR-%)

According to the results, GR decreased after 0.25 MPa drought stress. The lowest GR occurred at 0.75 MPa. Guo *et al.* (2012) reported that the germination percentage of seeds was severely reduced by increasing PEG concentrations, ceasing altogether at 0.36 MPa PEG. However, in our study, germination completely stopped at 1.00 MPa PEG concentration. Drought may have caused cell dehydration and osmotic imbalance because almost every aspect of plant physiology and cellular metabolism is affected by drought stress (Mahajan and Tuteja, 2005). Similar studies on linseed also showed that GR decreases with increasing drought stress (Kadkhodaie and Bagheri, 2011; Guo, 2013). The responses of varieties to drought stress in terms of GR were different. The highest GR belonged to the Beyaz Gelin variety (93.7%) and the lowest was obtained with the Kara Kız variety (73.7%). Similarly, in a germination study conducted with four linseed varieties, there were significant differences among the varieties in terms of drought resistance (Mahfouze *et al.*, 2017). These results are similar to those of Mostafavi (2011), linseed varieties responded differently to drought during germination and early seedling development. When the interaction was examined, the GR of the Kara Kız variety was lower than all other varieties. The highest GR belonged to 0 (Control) for all varieties, except the Kara Kız variety (Table 2, Figure 3).

Mean germination time (MGT-day)

According to the results, no statistical difference was recorded in MGT under 0.25 drought stress. However, by increasing osmotic potential, MGT gradually lengthened. The highest MGT (2.49) was found with 0.75 MPa drought stress (Table 2, Figure 3). Similarly, drought stress increased the average germination time in crop plants (Willenborg *et al.*, 2004; Khodarahmpour, 2011) because osmotic stress may have delayed the water uptake of the seed. When the MGTs of the varieties were examined, the Sarı Dane variety germinated in the shortest time (1.5) days, while the Kara Kız variety germinated in the longest time (2.3) days. When the interaction was examined, the shortest MGT was observed for Beyaz Gelin, Efe and Sarı Dane varieties at 0 (Control) and 0.25 MPa drought stress. The longest MGT was observed for Beyaz Gelin, Cemre, Efe and Kara Kız varieties under 0.75 MPa drought stress.

Table 2. Germination rate (%), mean germination time (day), root length (cm), root fresh weight (mg), root dry weight (mg), shoot length (cm), shoot fresh weight (mg), shoot dry weight (mg) of linseed varieties at different drought stress levels.
Çizelge 2. Farklı kuraklık stresi seviyelerindeki keten tohumu çeşitlerinin çimlenme oranı (%), ortalama çimlenme süresi (gün), kök uzunluğu (cm), yaş kök ağırlığı (mg), kuru kök ağırlığı (mg), sürgün uzunluğu (cm), yaş sürgün ağırlığı (mg), kuru sürgün ağırlığı (mg).

Drought stress level (MPa), Kuraklık stress seviyesi (MPa	Beyaz Gelin	Cemre	Efe	Kara Kız	Sarı Dane	Mean/Ortalama
	Germination rate (%)/ Çimlenme oranı (%)					
0	98.3 a	95.0 abc	96.6 ab	85.0 d-h	98.3 a	94.6 a
0.25	96.6 ab	91.6 a-e	91.6 a-e	76.6 h	95.0 abc	90.3 b
0.50	93.3 a-d	88.3 b-f	83.3 e-h	66.6 ı	88.3 b-f	84.0 c
0.75	86.6 c-g	78.3 gh	53.3 j	66.6 ı	81.6 fgh	73.3 d
Mean	93.7 a	88.3 ab	81.2 b	73.7 c	90.8 a	85.5
CV:6.99	LSD: varieties: 7.16***	drought level: 3.88***	varieties x drought level:8.67***			
	Mean germination time (day)/ Ortalama çimlenme süresi (gün)					
0	1.4 hı	1.8 fgh	1.1 ı	1.9 ef	1.3 ı	1.5 c
0.25	1.3 ı	1.9 efg	1.5 ghı	2.1 def	1.4 hı	1.6 c
0.50	2.4 a-d	2.2 b-f	2.2 c-f	2.6 ab	1.4 hı	2.2 b
0.75	2.6 a	2.7 a	2.3 a-e	2.5 abc	2.1 def	2.4 a
Mean	1.9 b	2.1 a	1.8 c	2.3 a	1.5 d	1.9
CV:12.24	LSD: varieties: 0,15**	drought level: 0.19***	varieties x drought level:0.43***			
	Root length (cm)/ Kök uzunluğu (cm)					
0	11.46 b	7.56 d	11.10 b	12.60 a	9.83 c	10.51 a
0.25	9.30 c	5.23 f	6.10 e	6.16 e	5.46 f	6.45 b
Mean	10.38 a	6.40 e	8.60 c	9.38 b	7.65 d	8.48
CV:3.93	LSD: varieties:0.70***	drought level:0.27***	varieties x drought level:0.60***			
	Root fresh weight (mg)/ Yaş kök ağırlığı (mg)					
0	6.00 a	3.03 d e	5.33 b	4.96 b	4.33 c	4.73 a
0.25	4.13 c	1.43 f	3.23 d	2.76 e	1.53 f	2.62 b
Mean	5.06 a	2.23 e	4.28 b	3.86 c	2.93 d	3.67
CV:6.62	LSD: varieties:0.36***	drought level:0.19***	varieties x drought level:0.44*			
	Root dry weight (mg)/ Kuru kök ağırlığı (mg)					
0	0.90 b c	0.56 d	0.86 c	1.00 ab	1.03 a	0.87 a
0.25	0.50 d	0.26 e	0.36 e	0.36 e	0.33 e	0.36 b
Mean	0.70 a	0.41 c	0.61 b	0.68 a b	0.68 a b	0.62
CV:11.77	LSD: varieties: 0.074***	drought level: 0.059***	varieties x drought level: 0.13**			
	Shoot length (cm)/ Sürgün uzunluğu (cm)					
0	7.33 b	4.50 e	5.83 c	10.06 a	7.10 b	6.96 a
0.25	5.16 d	2.40 f	4.83 d e	5.96 c	2.80 f	4.23 b
Mean	6.25 b	3.45 d	5.33 c	8.01 a	4.95 c	5.6
CV:4.34	LSD: varieties: 0.41***	drought level: 0.19***	varieties x drought level: 0.44***			
	Shoot fresh weight (mg)/ Yaş sürgün ağırlığı (mg)					
0	48.63 c	45.90 d	49.26 c	82.40 a	53.16 b	55.87 a
0.25	35.86 f	21.00 h	41.66 e	49.30 c	26.90 g	34.94 b
Mean	42.25 c	33.45 e	45.46 b	65.85 a	40.03 d	45.41
CV:3.01	LSD: varieties: 2.07***	drought level: 1.11***	varieties x drought level: 2.49**			
	Shoot dry weight (mg)/ Kuru sürgün ağırlığı (mg)					
0	4.23 c	2.96 e	4.96 b	7.76 a	4.76 b	4.94 a
0.25	3.46 d	2.10 f	4.16 c	4.83 b	2.50 f	3.41 b
Mean	3.85 c	3.53 d	4.56 b	6.30 a	3.63 c	4.17
CV:5.63	LSD: varieties: 0.32***	drought level: 0.19***	varieties x drought level: 0.42***			

CV: Coefficient of variation, LSD: Least significant difference, **:Significant at 1%. Different letters indicate significant differences according to LSD test (P≤0.05)

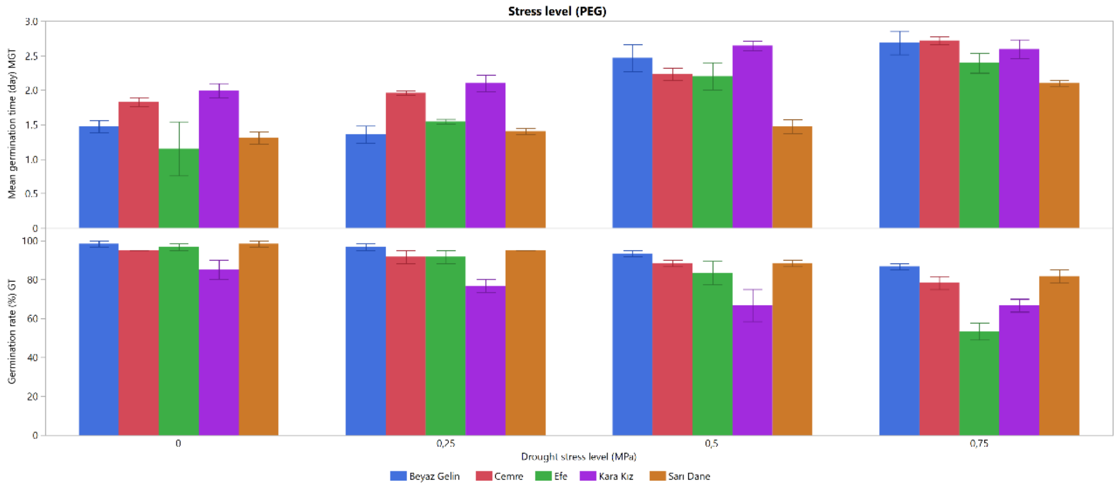


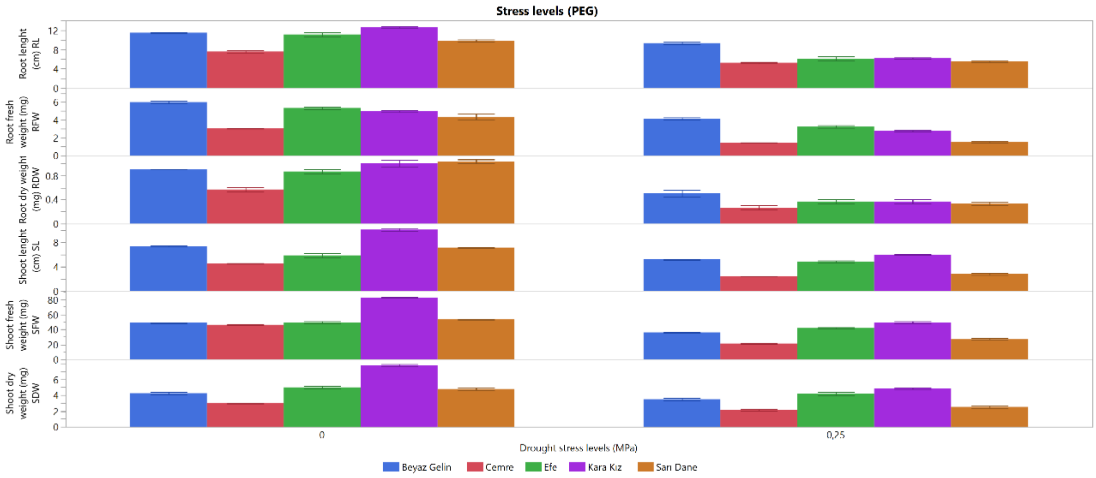
Figure 3. Germination rate (GR) and mean germination time of five linseed varieties (Beyaz Gelin, Cemre, Efe, Kara Kız and Sarı Dane) under different drought stress (PEG).
Şekil 3. Farklı kuraklık stresi (PEG) altında beş keten çeşidinin (Beyaz Gelin, Cemre, Efe, Kara Kız ve Sarı Dane) çimlenme oranı (ÇO) ve ortalama çimlenme zamanı (OÇZ).

Root length (RL-cm) and shoot length (SL-cm)

Linseed varieties examined in the study were sensitive to drought in terms of RL and SL. Even at 0.25 MPa drought stress, there were significant decreases in RL and SL (Table 2, Figure 4). The highest RL and SL were obtained in the 0 (Control), and the lowest RL and SL were obtained under 0.25 MPa drought stress. The reason why drought stress negatively affects root and shoot development may be due to the decrease in cell division and expansion (Bahrami *et al.*, 2012). In a study conducted on linseed, the relative growth rate and water content decreased with increasing PEG concentration. Additionally, the percentages of the main inorganic ions involved in osmotic regulation changed under water stress in root and shoot (Guo *et al.*, 2012). These results may explain the reason for the decrease in root and shoot development obtained in the study. In similar studies conducted on linseed, PEG drought stress negatively affected root and shoot development (Mostafavi, 2011; Guo, 2013). The average RL and SL of the varieties obtained from the study were significantly different. The highest RL (10.38 cm) was obtained from the Beyaz Gelin variety, the highest SL (8.01 cm) was obtained from the Kara Kız variety, and the lowest SL (3.45 cm) and RL (6.40 cm) were obtained from Cemre variety. Mostafavi (2011) reported that there were significant differences in terms of drought resistance among the varieties in studies conducted with four different flax varieties. When the interactions were examined, the highest RL (12.60 cm) and SL (10.06 cm) were obtained from the Kara Kız variety in the 0 (Control) application.

Root fresh weight (RFW-mg), root dry weight (RDW-mg), shoot fresh weight (SFW-mg) and shoot dry weight (SDW-mg)

As the drought stress applied in the experiment increased, the values obtained for RFW, RDW, SFW and SDW decreased. The highest RFW (4.73 mg), RDW (0.87 mg), SFW (55.87 mg) and SDW (4.94 mg) were obtained in 0 (Control) conditions (Table 2, Figure 4). The lowest RFW (2.62 mg), RDW (0.36 mg), SFW (34.94 mg) and SDW (3.41 mg) were determined with 0.25 MPa drought stress. Reductions in RFW, RDW, SFW and SDW could be due to reductions in root and shoot lengths. Drought stress may have directly affected growth as it reduces the absorption and utilization of water. Guo *et al.* (2012) found that shoot and root carbohydrate content decreased at the high PEG concentrations in the linseed. When the variety means were examined, the highest RFW (5.06) mg) and RDW (0.70) mg were for the Beyaz Gelin variety, with highest SFW (65.85) mg and SDW (6.30) mg for the Kara Kız variety. The Cemre variety had the lowest values in terms of RFW, RDW, SFW and SDW. When the interactions were examined, the highest RFW (6.00) mg was found in the Beyaz Gelin variety at 0 (Control). The highest RDW (1.03-1.00) mg, SFW (82.40) mg, and SDW (7.76) mg under 0 (Control) were found for the Kara Kız variety. The lowest RFW, RDW, SFW and SDW were observed in the Cemre variety at 0.25 MPa drought stress.



Şekil 4: Beş keten çeşidinde farklı kuraklık (PEG) stresinin kök uzunluğu (cm), yaş kök ağırlığı (YKA-mg), kuru kök ağırlığı (KKA-mg), sürgün uzunluğu (cm), yaş sürgün ağırlığı (YSA-mg) ve kuru sürgün ağırlığı (KSA-mg) üzerine etkileri.
Figure 4: Effects of different drought (PEG) stress on root length (cm), root fresh weight (RFW-mg), root dry weight (RDW-mg), shoot length (cm), shoot fresh weight (SFW-mg) and shoot dry weight (SDW-mg) in five linseed varieties.

CONCLUSION

Germination and early seedling growth were inhibited by increasing salinity and drought levels in the germination medium. It was concluded that the five linseed varieties (Kara Kız, Beyaz Gelin, Sarı Dane, Cemre and Efe) used in this study showed differential responses to salinity and drought stress. While no significant differences were observed under salinity levels 0 (Control), 2.0, 4.0, 8.0 and 12.0 dS m^{-1}, increasing salinity to higher levels did affect GR. The GR decreased when salinity stress increased above 12.0 dS m^{-1}. Except for the Kara Kız variety, the GRs of the other varieties were found to be high and were included in the same statistical group. Root and shoot growth significantly decreased, especially after 4.0 dSm^{-1} salinity stress. All examined characteristics were statistically significantly affected by drought stress. The GR of seeds was severely reduced by the increasing PEG concentrations, ceasing altogether. Linseed varieties examined in the study were sensitive to drought in terms of RL and SL. Even at 0.25 MPa drought stress, there were significant decreases in RL and SL. Considering these results, the linseed variety Sarı Dane can be recommended for cultivation in high salinity conditions, and the linseed variety Beyaz Gelin can be recommended for cultivation in high drought conditions. Further research is also needed to improve our understanding of the effects of salt and drought stress throughout the entire growth cycle of linseed varieties. The study we conducted is a study conducted during the germination and early seedling stages. However, the effects of salinity and drought should be tested by growing plants in advanced vegetative and generative periods.

REFERENCES

Almaghrabi, O. A. 2012. Impact of drought stress on germination and seedling growth parameters of some wheat cultivars. Life Science Journal. 9(1):590-598.

Bahrami, H., J. Razmjoo, and A. O. Jafari. 2012. Effect of drought stress on germination and seedling growth of sesame cultivars (*Sesamum indicum* L.). International Journal of Agri. Sci. 2(5):423-428.

Balkan, A., T. Genctan, O. Bilgin, and H. Ulukan. 2015. Response of rice (*Oryza sativa* L.) to salinity stress at germination and early seedling stages. Pak. J. Agri. Sci. 52(2):453-459.

Begna, T. 2020. Effects of drought stress on crop production and productivity. International Journal of Research Studies in Agricultural Sciences 6(9): 34-43.

Bekhit, A. E. D. A., A. Shavandi, T. Jodjaja, J. Birch, S.Teh, I. A. M. Ahmed, F. Y. Al-Juhaimi, P. Saeedi and A. A. Bekhit. 2018. Flaxseed: Composition, detoxification, utilization, and opportunities. Biocatalysis and Agricultural Biotechnology. 13:129-152.

Deinlein, U., A. B. Stephan, T. Horie, W. Luo, G. Xu, and J. I. Schroeder. 2014. Plant salt-tolerance mechanisms. Trends in Plant Sci. 19(6):371-379.

Desheva, G., G. N. Desheva, and S. K. Stamatov. 2020. Germination and early seedling growth characteristics of *Arachis hypogaea* L. under salinity (NaCl) stress. Agriculturae Conspectus Sci. 85(2):113-121.

Ellis, R. H. and E .H. Roberts.1980. Towards a rational basis for testing seed quality. English, Miscellaneous, UK, London, Seed production. 605-635.

Fahad, S., A. A. Bajwa, U. Nazir, S. A. Anjum, A. Farooq, A. Zohaib, S. Sadia, W. Nasim, S. Adkins, S. Saud, M. Z. Ihsan, H. Alharby, C. Wu, D. Wang, and J. Huang. 2017. Crop production under drought and heat stress: plant responses and management options. Frontiers in Plant Sci. 8:1147.

FAO. 2023a. Food and Agriculture Organization of the United Nations. Global map of salt-affected soils. Available at: https://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/global-map-of-salt-affected-soils/ar/ (22.12.2023).

FAO. 2023b. Food and Agriculture Organization of the United Nations. Water Conference. Available at: https://www.fao.org/newsroom/detail/United-Nations-2023-water-conference-FAO-hunger-drought-financing-mechanisms (22.12.2023)

FAO. 2024. Food and Agriculture Organization of the United Nations, World production linseed. Available at: https://www.fao.org/faostat/en/#data/QCL (05.08.2024).

Guo, R., J. Zhou, G. Ren, and W. Hao. 2013. Physiological responses of linseed seedlings to iso-osmotic polyethylene glycol, salt, and alkali stresses. Agronomy Journal 105(3):764-772.

Guo, R., J. Zhou, W. Hao, F. Gu, Q. Liu, H. Li, X. Xia and L. Mao. 2014. Germination, growth, chlorophyll fluorescence and ionic balance in linseed seedlings subjected to saline and alkaline stresses. Plant Production Sci. 17(1):20-31.

Guo, R., W. Hao, and D. Gong. 2012. Effects of water stress on germination and growth of linseed seedlings (*Linum usitatissimum* L), photosynthetic efficiency and accumulation of metabolites. Journal of Agricultural Sci. 4 (10):253.

Hall, L. M., H. Booker, R. M. Siloto, A. J. Jhala, and R. J. Weselake. 2016. Flax (*Linum usitatissimum* L.). AOCS Press. In Industrial Oil Crops. ISBN: 978-1-893997-98-1:157-194.

Heikal, M.M., M.A. Shaddad, A.M. Ahmed. 1982. Effect of water stress and gibberellic acid on germination of flax, sesame and onion seeds. Biologia Plantarum 24:124-129.

Jamil, M., L. DeogBae, L. KwanYong, M. Ashraf, L. SheongChun, and R. E. EuiShik. 2006. Effect of salt (NaCl) stress on germination and early seedling growth of four vegetable species. Journal of Central European Agriculture 2:273–82.

Jhala, A. J., and L. M. Hall. 2010. Flax (*Linum usitatissimum* L.): current uses and future applications. Aust J Basic Appl Sci. 4(9):4304-4312.

Kadkhodaie, A. and M. Bagheri. 2011. Seed treatment during germination in linseed to overcome salt and drought stresses (*Linum usitatissimum* L.). International Journal of Agricultural and Biosystems Engineering 5(1): 12-16.

Kaya, M., G. Kaya, M. D. Kaya, M. Atak, S. Saglam, K. M. Khawar, and C. Y. Ciftci. 2008. Interaction between seed size and NaCl on germination and early seedling growth of some Turkish cultivars of chickpea (*Cicer arietinum* L.). Journal of Zhejiang University Science B. 9:371-377.

Kaya, M., S. Day, Y. Cikili, and N. Arslan. 2012. Classification of some linseed (*Linum usitatissimum* L.) genotypes for salinity tolerance using germination, seedling growth, and ion content. Chilean Journal of Agricultural Research 72(1):37-32.

Khodarahmpour, Z. 2011. Effect of drought stress induced by polyethylene glycol (PEG) on germination indices in corn (*Zea mays* L.) hybrids. African Journal of Biotechnology 10(79):18222-18227.

Kiremit, M. S., M. S. Hacıkamiloglu, H. Arslan, and K. Orhan. 2017. Farklı sulama suyu tuzluluk seviyelerinin keten (*Linum usitatissimum* L.)'in çimlenme ve erken fide gelişimi üzerine etkisi. Anadolu Tarım Bilimleri Dergisi 32(3):350-357.

Kocak, M. Z., M. Göre, and O. Kurt. 2022. The effect of different salinity levels on germination development of some flax (*Linum usitatissimum* L.) varieties. Turkish Journal of Agriculture-Food Science and Technology 10(4):657-662.

Kocak, N. ve N. Bayraktar. 2011. Türkiye'de Keten Tarımı. Ziraat Mühendisliği (357):13-17.

Lamichhane, J. R., P. Debaeke, C. Steinberg, M. P. You, M. J. Barbetti, and J. N. Aubertot. 2018. Abiotic and biotic factors affecting crop seed germination and seedling emergence: a conceptual framework. Plant and Soil 432:1-28.

Liang, W., X. Ma, P. Wan, and L. Liu. 2018. Plant salt-tolerance mechanism: A review. Biochemical and Biophysical Research Communications. 495(1):286-291.

Mahajan, S. and N. Tuteja. 2005. Cold, salinity and drought stresses: an overview. Archives of Biochemistry and Biophysics 444(2):139-158.

Mahdavi, B. and F. Alasvandyari. 2018. Germination and morphophysiological responses of flax (*Linum usitatissimum* L.) ecotypes to salinity stress. Journal of Plant Physiology and Breeding 8(2):77-87.

Mahfouze, H., S. Mahfouze, M. El-Enany, and M. Ottai. 2017. Assessment of flax varieties for drought tolerance. Annu Res Rev Bio. 21:1-12.

Moghaddam, M., K. Babaei, and P. E. Saeedi. 2018. Germination and growth response of flax (*Linum usitatissimum*) to salinity stress by different salt types and concentrations. Journal of Plant Nutrition 41(5):563-573.

Mostafavi, K. 2011. A study effects of drought stress on germination and early seedling growth of flax (*Linum usitatissimum* L.) cultivars. Advances in Environmental Biology 3307-3312.

Muchate, N. S., G. C. Nikalje, N. S. Rajurkar, P. Suprasanna, and T. D. Nikam. 2016. Plant salt stress: adaptive responses, tolerance mechanism and bioengineering for salt tolerance. The Botanical Review 82: 371-406.

Munns, R. 2002. Comparative physiology of salt and water stress. Plant, Cell & Environment 25(2):239-250.

Murillo-Amador, B., R. López-Aguilar, C. Kaya, J. Larrinaga-Mayoraland, A. Flores-Hernández. 2002. Comparative effects of NaCl and polyethylene glycol on germination, emergence and seedling growth of cowpea. Journal of Agronomy and Crop Sci. 188(4):235-247.

Niu, X., R. A. Bressan, P. M. Hasegawa, and J. M. Pardo. 1995. Ion homeostasis in NaCl stress environments. Plant Physiology 109(3):735.

Nykter, M., H. R. Kymäläinen, and F. Gates. 2006. Quality characteristics of edible linseed oil. Agricultural and Food Science 15(4):402-413.

Pavelek, M., E. Tejklová, and M. Bjelková. 2015. Flax and linseed. Industrial crops. breeding for bioenergy and bioproducts. 233-263.

Qayyum, M. A., F. Bashir, M. M. Maqbool, A. Ali, S. Bashir, and Q. Abbas. 2019. Implications of saline water irrigation for linseed on seed germination, seedling survival and growth potential. Sarhad J. Agric. 35(4): 1289-1297.

Qayyum, M. A., J. Akhtar, Z. A. Saqib, and S. M. A. Basra. 2015. Phenotyping of linseed (*Linum usitatissimum* L.) genotypes for potential against NaCl stress. Soil & Environment 34(2):200-206.

Sebei, K., A. Debez, W. Herchi, S. Boukhchina, and H. Kallel. 2007. Germination kinetics and seed reserve mobilization in two flax (*Linum usitatissimum* L.) cultivars under moderate salt stress. Journal of Plant Biology 50:447-454.

Sevgi, B., S. Leblebici. 2023. Tuz stresinin bitkiler üzerindeki etkileri ve geliştirilen tolerans mekanizmaları. Düzce Üniversitesi Bilim ve Teknoloji Dergisi 11(3):1498-1516.

Singh, A., S. Shekhar, S. Marker, and P. W. Ramteke. 2021. Changes in morpho-physiological attributes in nine genotypes of linseed (*Linum usitatissimum* L.) under different levels of salt (NaCl) stress. Vegetos. 34(3): 647-653.

Steel, R. G., and J. H. Torrie. 1981. Principles and Procedures of Statistics, A Biometrical Approach. Ed. 2. McGraw-Hill Kogakusha. USA

Taiz, L., and E. Zeiger. 2008. Plant Physiology and Development. ISBN:0-87893-823-0. 611 s.

Wang, Y., D. Li, L. J. Wang, Y. L. Chiu, X. D. Chen, Z. H. Mao, and C.F. Song. 2008. Optimization of extrusion of flaxseeds for *in vitro* protein digestibility analysis using response surface methodology. Journal of Food Engineering 85(1):59-64.

Willenborg, C. J., R. H. Gulden, E. N. Johnson, and S. J. Shirtliffe. 2004. Germination characteristics of polymer-coated canola (*Brassica napus* L.) seeds subjected to moisture stress at different temperatures. Agronomy Journal. 96(3):786-791.

Zeng, Y., L. Li, R. Yang, X. Yi, and B. Zhang. 2015. Contribution and distribution of inorganic ions and organic compounds to the osmotic adjustment in Halostachys caspica response to salt stress. Scientific Reports 5(1): 13639.