KSÜ Tarım ve Doğa Derg 24 (1): 108-115, 2021
KSU J. Agric Nat 24 (1): 108-115, 2021
https://doi.org/10.18016/ksutarimdoga.vi.728814

Response of Germination and Seedling Development of Cotton to Salinity under Optimal and Suboptimal Temperatures

Nurgül ERGIN[1], Engin Gökhan KULAN[2], Mehmet Akif GÖKÜKARA[3], Muhammed Fatih KAYA[4]
Şaban Özgür ÇETIN[5], Mehmet Demir KAYA[6]
[1]Department of Field Crops, Faculty of Agriculture and Natural Sciences, Bilecik Şeyh Edebali University, Bilecik, Turkey, [2,3,4,5,6]Department of Field Crops, Faculty of Agriculture, Eskişehir Osmangazi University, Eskişehir, Turkey
[1]https://orcid.org/0000-0003-3105-7504, [2]https://orcid.org/0000-0002-7147-6896, [3]https://orcid.org/0000-0002-2019-1487
[4]https://orcid.org/0000-0002-0875-7302, [5]https://orcid.org/0000-0002-1696-3819, [6]https://orcid.org/0000-0002-4681-2464
✉: nurgulergin180@gmail.com

ABSTRACT
The objective of the study was to investigate the effects of salinity stresses (50, 100, 150, 200 and 250 mM of NaCl) on germination and early seedling growth of six cotton varieties (Lydia, Carisma, Flash, BA151, BA525 and ST468) under optimum (25°C) and low temperature (18°C) conditions. Germination percentage, mean germination time, germination index, germination stress tolerance index, seedling length, vigor index, seedling fresh and dry weight of cotton varieties were investigated. Results showed that low temperature led to decreasing in germination and seedling growth, and caused retardation of mean germination time. Under suboptimal temperature, germination percentage reduced from 86.3% to 77.8% and seedling length decreased from 12.02 cm to 5.36 cm. Each increase in salinity levels higher than 50 mM resulted in decreasing in germination and seedling growth parameters of cotton varieties. No seedling growth was observed at 250 mM of NaCl at 18°C. Cotton varieties showed different tolerance levels to salinity, while they could tolerate it up to 100 mM. It was concluded that Flash and ST468 varieties exhibited better performance under salinity stresses both at optimal and suboptimal temperatures.

Research Article

Article History
Received : 28.04.2020
Accepted : 04.07.2020

Keywords
Cold
Cultivar
Germination
Gossypium hirsutum L.
NaCl

Normal ve Düşük Sıcaklıklarda Pamuğun Çimlenme ve Fide Gelişimine Tuzluluğun Etkisi

ÖZET
Bu araştırma, farklı tuz dozlarının (50, 100, 150, 200 ve 250 mM NaCl) altı pamuk çeşidinin (Lydia, Carisma, Flash, BA151, BA525 ve ST468) optimum (25°C) ve düşük sıcaklıkta (18°C), çimlenme ve erken fide büyümesine etkilerini belirlemek amacıyla yürütülmüştür. Araştırmada pamuk çeşitlerinin çimlenme yüzdesi, ortalama çimlenme süresi, çimlenme indeksi, çimlenme stres tolerans indeksi, fide uzunluğu, fide yaş ve kuru ağırlıkları belirlenmiştir. Sonuçlar, düşük sıcaklığın çimlenme ve fide büyümesinde azalmalara yol açtığını ve ortalama çimlenme süresinin gecikmesine neden olduğunu göstermiştir. Düşük sıcaklıkta, çimlenme yüzdesinin % 86.3'ten % 77.8'e ve fide uzunluğunun 12.02 cm'den 5.36 cm'ye düştüğü belirlenmiştir. Tuz dozlarındaki 50 mM'den yüksek her artış, pamuk çeşitlerinin çimlenme ve fide gelişiminde azalmalara neden olmuştur. Ayrıca 18° C'de 250 mM tuz dozunda fide gelişimi gözlenmemiştir. Pamuk çeşitleri, tuzluluğa farklı tolerans seviyeleri gösterirken, pamuğun 100 mM'ye kadar tuzluluğu tolere edebildiği belirlenmiştir. Flash ve ST468 çeşitlerinin hem optimum hem de düşük sıcaklıklarda tuzluluk stresleri altında daha iyi performans gösterdiği sonucuna varılmıştır.

Araştırma Makalesi

Makale Tarihçesi
Geliş Tarihi : 28.04.2020
Kabul Tarihi : 04.07.2020

Anahtar Kelimeler
Soğuk
Çeşit
Çimlenme
Gossypium hirsutum L.
NaCl.

To Cite : Ergin N, Kulan EG, Gözükara MA, Kaya MF, Çetin ŞÖ, Kaya MD 2021. Response of Germination and Seedling Development of Cotton to Salinity under Optimal and Suboptimal Temperatures. KSU J. Agric Nat 24 (1): 108-115. https://doi.org/10.18016/ksutarimdoga.vi.728814.

INTRODUCTION

Cotton (*Gossypium hirsutum* L.) is the most important fiber crop and is extensively cultivated for textile industry in the Aegean, Mediterranean and Southern Anatolian Regions of Turkey (Anonymous, 2020). Cotton is mainly produced for fiber, raw material of the ginning and textile industries, even oil and oil-cake are obtained from cottonseed. The oil of cottonseed is used for both edible oil and the production of biodiesel. Approximately 80% of world cotton production has been met by a few countries, including Turkey because of tropic or subtropic climatic requirements (Mert, 2017).

Soil salinity and low temperature are the most important stress factors that limit germination, seedling growth and the yield of cotton in Turkey and all over the world (Kalefetoğlu and Ekmekçi, 2005). Salinity risk in the areas of cotton cultivation has been continuously increased by intensive irrigation frequency and excessive water application, poor water management and high evaporation due to hot and dry weather during summer seasons. The salts in the soil prevent the water from entering the seed by either constituting osmotic pressure which creates a barrier to the seed or toxic effects caused by Na^+ and Cl^- ions (Khajeh-Hosseini et al., 2003). Cotton is classified as a relatively salt tolerant plant by Fowler (1986), while there are differences between cotton varieties (Gosset et al., 1994). Vulkan-Levy et al. (1998) found that increasing salinity resulted in decreasing the seed cotton yield. Maas (1986) reported that cotton yield decreased around 50% at the level of 17 dS m^{-1}. However, cotton plant is sensitive to low temperature during germination and low soil temperature delays germination and emergence, increases the risk of seedling diseases, and causes weak seedling development (Çokkizgin and Bölek, 2015). It was determined that root development and seedling growth of cotton were inhibited when the soil temperature drops below 14.5°C by Jackson (2012), but still farmers prefer earlier sowing to obtain higher yield and to avoid the lack of rainfall after planting. For these reasons, this research was undertaken to determine if there were genetic variations among cotton varieties under salinity stresses at low temperature in terms of germination and seedling growth.

MATERIAL and METHODS

A laboratory experiment was conducted at Department of Field Crops, Eskişehir Osmangazi University, Turkey. The seeds of six cotton varieties Lydia, Carisma, Flash, BA151, BA525 and ST468 were exposed to five concentrations of NaCl with 50, 100, 150, 200 and 250 mM under optimal (25°C) and suboptimal (18°C) temperatures. Distilled water was used as a control treatment.

Germination test was performed by the procedures of ISTA (2003) rules with two hundred (4×50) seeds of each cotton variety for each treatment. Fifty seeds were inserted into three-layer filter papers irrigated with 7 mL of the respective solutions for each paper. After filter papers with seeds were rolled, they were placed into a sealed plastic bag to prevent moisture loss. Each rolled paper was renewed every 2 days after incubation to avoid the salt accumulation. The packages were incubated at optimal 25°C and suboptimal 18 °C conditions in the dark and a seed with 2 mm radicle was counted every 24 h for 12 d as germinated. Mean germination time (MGT) was calculated to evaluate the speed of germination as defined by ISTA (2003) rules. MGT= $\Sigma(Dn)/\Sigma n$, where, n is the seed number germinated on day D, and D is the number of days from the beginning of germination test. Germination index (GI) was calculated according to the following formula. GI= Number of germinated seeds / days of first count +. . .+ Number of germinated seeds / days of final count (Salehzade et al., 2009). Germination stress tolerance index (GSTI, %) = [nd_2 (1.00) + nd_4 (0.75) + nd_6 (0.5) + nd_8 (0.25) of stressed seeds / nd_2 (1.00) + nd_4 (0.75) + nd_6 (0.5) + nd_8 (0.25) of control seeds] × 100, where n is the number of seeds germinated at day d (Ahmad et al., 2009). At 12^{th} day, ten seedlings selected randomly from each treatment were sampled for determination of seedling growth traits such as seedling length (SL), seedling fresh weight (SFW) and seedling dry weight (SDW). After the seedling fresh weight was directly weighed, the seedlings were transferred into an oven at 70°C for 48 hours for determination of dry weight.

The experimental data was statistically analyzed by two-factor factorial (salinity × variety) arranged in a completely randomized design (CRD) with 4 replicates for each temperature. Analysis of variance and comparison of means were performed by MSTAT-C program (Michigan State University v. 2.10).

RESULTS and DISCUSSION

The main effects of temperature, salinity and cotton variety were displayed in Table 1. As expected, low temperature caused a significant decrease in germination percentage, germination index, germination stress tolerance index and seedling growth characteristics, while mean germination time delayed. Germination and seedling growth of cotton were restricted, but mean time to germination retarded when salinity concentration increased. The results confirmed the findings of Varghese et al. (1995) and Qadir and Shams (1997), who reported that germination and emergence of cotton varieties were reduced and delayed by increasing salinity.

Table 1. Main effects of the temperature, salinity and variety on germination and seedling growth parameters of cotton (±SEM)

Tablo 1. Pamuğun çimlenme ve fide büyüme parametreleri üzerine sıcaklık, tuzluluk ve çeşit etkileri cotton (±Standart hata)

Factors	GP	MGT	GI	GSTI	SL	SFW	SDW	DM
Temperature								
18°C	77.8 ±1.51 b	5.83 ±0.71 a	8.39 ±0,34 b	56.0 ±3.11 b	5.36 ±0.30 b	190 ±9.56 b	40.9 ±1.60 b	62.8 ±2.44 b*
25°C	86.3 ±0.80 a	3.19 ±0.08 b	15.73 ±0,50 a	75.4 ±1.79 a	12.02 ±0.39 a	381 ±11.10 a	48.8 ±0.41 a	85.4 ±0.48 a
Salinity								
Control	91.3 ±0.65 a	3.08 ±0.13 f	17.14 ±0.56 a	100.0±14.43 a	12.46 ±0.69 a	439 ±17.75 a	48.9 ±0.79 a	87.6 ±0.68 a
50 mM	89.2 ±0.84 a	3.35 ±0.16 e	15.60 ±0.68 b	93.8 ±1.77 b	12.81 ±0.83 a	413 ±16.08 b	49.7 ±0.70 a	86.9 ±0.59 a
100 mM	86.0 ±1.93 b	3.71 ±0.15 d	13.40 ±0.61 c	78.0 ±1.88 c	9.98 ±0.56 b	321 ±15.53 c	49.1 ±0.67 a	82.9 ±0.87 b
150 mM	84.5 ±1.21 b	4.37 ±0.22 c	11.67 ±0.68 d	59.5 ±2.58 d	7.89 ±0.46 c	236 ±12.00 d	48.8 ±0.86 a	76.8 ±1.18 c
200 mM	80.3 ±1.66 c	5.60 ±0.28 b	8.58 ±0.54 e	39.8 ±2.97 e	5.74 ±0.40 d	197 ±10.88 e	48.7 ±1.03 a	71.8 ±1.44 d
250 mM	64.3 ±3.12 d	6.93 ±0.34 a	5.96 ±0.52 f	23.1 ±3.00 f	3.19 ±0.47 e	106 ±15.59 f	24.1 ±3.52 b	38.5 ±5.57 e
Variety								
Lydia	75.4 ±3.06 d	5.33 ±0.30 a	9.42 ±0.67 e	56.3 ±4.59 d	8.05 ±0.85 de	276 ±22.81 b	51.4 ±2.32 a	71.0 ±3.35 d
Carisma	84.3 ±1.98 b	4.27 ±0.27 c	12.80 ±0.83 b	69.4 ±4.65 a	7.84 ±0.65 e	277 ±22.08 b	42.8 ±1.93 d	74.2 ±3.45 c
Flash	91.0 ±1.33 a	3.99 ±0.26 d	14.16 ±0.81 a	71.3 ±4.11 a	8.52 ±0.58 bc	292 ±22.08 a	40.8 ±1.89 e	76.5 ±3.44 a
BA151	80.1 ±1.56 c	4.34 ±0.29 c	11.92 ±0.78 c	65.5 ±4.43 bc	8.25 ±0.82 cd	292 ±23.09 a	47.0 ±2.12 b	73.6 ±4.17 c
BA525	78.4 ±2.40 d	4.75 ±0.31 b	11.02 ±0.77 d	67.2 ±5.05 b	8.87 ±0.85 b	284 ±23.67 ab	45.2 ±2.05 c	73.7 ±3.46 c
ST468	84.9 ±1.35 b	4.35 ±0.32 c	13.03 ±0.86 b	64.4 ±4.50 c	10.55 ±0.78 a	291 ±21.05 a	42.1 ±1.88 de	75.6 ±3.51 b

*: Means followed by same letter(s) in each column are not significant at $p<0.05$. GP: Germination percentage, MGT: mean germination time, GI: Germination index, GSTI: Germination stress tolerance index, SL: Seedling length, SFW: Seedling fresh weight, SDW: Seedling dry weight, DM: Dry matter, SEM: Standart error of mean

The interaction of salinity × variety was significant for all characteristics ($p<0.05$) and the results of germination percentage were shown in Table 2. Germination percentage of cotton varieties was different in each salinity level under optimum and low temperature. It was declined with increasing NaCl and decreasing temperature. NaCl level of 100 mM inhibited germination of cotton varieties except for Flash and ST468. In addition, Flash and ST468 were the least affected varieties by salinity at 25°C and 18°C. Adverse effects of salinity on germination were also observed by Ashraf et al. (2002), who observed the hazardous effects of 100 mM NaCl on germination percentage. Results of the current research showed that germination rate was considerably inhibited by low temperature. This finding was supported by Krzyzanowski and Delouche (2011) indicated that germination percentage dropped at 18°C and a significant reduction in germination rate from %92.5 at 24°C to %81.2 at 16°C.

The most rapid mean time to germination was obtained from Flash at all NaCl levels except for 100 mM under optimum condition. Furthermore, it gave the minimum time to germination at 18°C. Increasing salinity concentrations resulted in delaying germination and cvs. Carisma and BA151 showed faster mean time to germination after Flash compared to other varieties. Similar findings are in line with the results of Day et al. (2008) in sunflower, Kan et al. (2015) in soybean and Sarkar et al. (2019) in rice, who observed that mean germination time was delayed by increasing salinity.

Seedling length was severely depressed with increasing NaCl levels and decreasing temperature. At 25°C, seedling length of Carisma and BA151 was not significantly affected up to 100 mM NaCl. Similar results related with seedling length had been reported by Bauer and Bradow (1996), Javid et al. (2001), Ashraf et al. (2002) and Barpete et al. (2015) who found an apparent reduction in seedling growth of cotton due to salinity. However, the most sensitive variety to low temperature was Lydia because a dramatic reduction occurred between 18°C and 25°C, Flash and ST468 produced longer seedling under low temperature. No seedling growth to be measured was observed at 250 mM at 18°C.

Seedling fresh weight of cotton varieties was obviously reduced as salinity increased and temperature decreased. Salinity level of 150 mM led to depressing fresh weight of cotton seedling, while ST468 produced heavier seedling at 18°C and 25°C under NaCl. Fresh weight of BA525 and ST468 at 25°C increased with 50 mM NaCl compared to control. Barpete et al. (2015) supported this finding by demonstrating a dramatic reduction in fresh weight of cotton seedlings under low temperature. Also, an apparent difference was observed the seedling growth between 18°C and 25°C. This result agrees with Khan et al. (1995), Ashraf (2002) and Hanif et al. (2008). They reported that seedling fresh weight decreased in higher salt concentrations compared to control.

Increasing salinity caused considerably decreases in seedling dry weight (Table 3). Cotton varieties exhibited different responses to each salinity level and Lydia produced the highest dry weights in 200 mM NaCl at 18°C and 250 mM at 25°C. At suboptimal temperature, Flash and Carisma gave the minimum dry weight at 200 mM NaCl.

In previous researches, reduction of seedling fresh and dry weight under saline conditions in cotton had been reported by Javid et al. (2001), Hanif et al. (2008) and Shaheen et al. (2012). Furthermore, low dose of NaCl resulted in a decline of dry matter in cotton seedlings. Higher dry matter production was achieved at 25°C than at 18°C, but increasing salinity reduced dry matter of the varieties. Flash showed the superiority under low temperature, while ST468 and Flash accumulated heavier dry matter than the others at 25°C.

Table 2. Germination percentage, mean germination time and seedling length of cotton varieties under low temperature and salinity stresses

Tablo 2. Düşük sıcaklık ve tuzluluk stresleri altında pamuk çeşitlerinin çimlenme yüzdesi, ortalama çimlenme süresi ve fide uzunluğu

		Salinity (mM)	Variety Lydia	Carisma	Flash	BA151	BA525	ST468
Germination percentage (%)±SEM								
Temperature	18°C	Cont.	91.0 ±1.29 [a-e]	93.0 ±1.29 [a-d]	95.0 ±1.00 [ab]	92.0 ±0.82 [a-e]	87.5 ±1.26 [b-f]	91.5 ±0.50 [a-e]*
		50	89.5 ±2.06 [a-e]	94.5 ±1.50 [abc]	97.0 ±1.29 [a]	86.5 ±1.71 [c-g]	84.5 ±1.71 [efg]	92.0 ±3.37 [a-e]
		100	80.0 ±2.45 [f-j]	89.0 ±2.65 [a-e]	96.0 ±1.41 [a]	79.0 ±2.65 [g-j]	73.0 ±3.46 [h-k]	85.5 ±1.71 [d-g]
		150	80.0 ±3.46 [f-j]	79.0 ±2.08 [g-j]	94.0 ±1.63 [abc]	78.5 ±2.22 [g-j]	69.0 ±1.29 [k]	81.0 ±3.00 [fgh]
		200	53.5 ±2.22 [m]	72.5 ±0.96 [ijk]	84.5 ±2.87 [efg]	72.0 ±2.16 [jk]	73.5 ±3.50 [h-k]	80.5 ±3.30 [f-i]
		250	14.5 ±1.26 [o]	47.5 ±3.78 [mn]	67.5 ±4.50 [k]	52.5 ±3.30 [m]	42.0 ±4.69 [n]	60.5 ±3.78 [l]
	25°C	Cont.	91.5 ±1.50 [a-e]	93.0 ±2.38 [a-d]	94.5 ±2.99 [abc]	88.5 ±0.96 [b-g]	84.5 ±4.27 [d-i]	94.0 ±1.63 [abc]
		50	79.5 ±2.06 [ghi]	89.0 ±1.00 [a-f]	96.5 ±0.96 [ab]	87.5 ±0.96 [b-h]	87.5 ±2.22 [b-h]	86.5 ±1.50 [c-i]
		100	82.5 ±2.63 [e-i]	87.5 ±3.78 [b-h]	96.0 ±1.63 [ab]	82.5 ±2.63 [c-i]	86.5 ±2.87 [c-i]	91.0 ±0.58 [a-e]
		150	83.5 ±6.65 [e-i]	94.0 ±1.83 [abc]	90.0 ±1.41 [a-e]	84.5 ±2.99 [d-i]	83.0 ±1.92 [e-i]	86.0 ±2.16 [c-i]
		200	80.5 ±2.36 [f-i]	86.0 ±2.16 [c-i]	97.5 ±0.50 [a]	79.0 ±4.80 [h-i]	88.0 ±2.16 [b-h]	87.5 ±0.50 [b-h]
		250	79.0 ±2.08 [hi]	86.0 ±3.46 [c-i]	83.5 ±2.57 [e-i]	79.0 ±3.00 [hi]	77.5 ±4.72 [i]	82.5 ±1.71 [e-i]
Mean germination time (day) ±SEM								
Temperature	18°C	Cont.	4.30 ±0.45 [hij]	3.59 ±0.29 [kl]	3.21 ±0.02 [l]	3.73 ±0.30 [jkl]	4.34 ±0.34 [hij]	3.37 ±0.21 [kl]
		50	5.11 ±0.21 [fg]	3.87 ±0.05 [ijk]	3.63 ±0.09 [kl]	3.72 ±0.03 [jkl]	4.26 ±0.25 [hij]	4.71 ±0.32 [gh]
		100	5.93 ±0.23 [e]	4.40 ±0.10 [hi]	4.29 ±0.12 [hij]	4.49 ±0.06 [hi]	4.64 ±0.10 [gh]	3.93 ±0.06 [ijk]
		150	7.29 ±0.43 [d]	5.35 ±0.17 [f]	5.24 ±0.09 [fg]	5.23 ±0.10 [fg]	6.25 ±0.05 [e]	5.23 ±0.07 [fg]
		200	8.70 ±0.18 [b]	7.26 ±0.12 [d]	6.03 ±0.06 [e]	6.93 ±0.03 [d]	8.03 ±0.02 [c]	7.37 ±0.10 [d]
		250	9.63 ±0.18 [a]	8.49 ±0.37 [bc]	8.64 ±0.13 [b]	9.34 ±0.21 [a]	9.42 ±0.15 [a]	9.82 ±0.16 [a]
	25°C	Cont.	3.15 ±0.21 [hi]	2.37 ±0.02 [nop]	2.08 ±0.03 [p]	2.19 ±0.02 [p]	2.53 ±0.06 [l-o]	2.16 ±0.06 [p]
		50	3.43 ±0.13 [fgh]	2.42 ±0.08 [m-p]	2.13 ±0.02 [p]	2.25 ±0.08 [op]	2.52 ±010 [l-o]	2.13 ±0.04 [p]
		100	3.26 ±0.12 [ghi]	2.37 ±0.05 [nop]	2.94 ±0.02 [ijk]	2.94 ±0.04 [ijk]	2.72 ±0.05 [j-m]	2.55 ±0.13 [l-o]
		150	3.97 ±0.13 [e]	2.96 ±0.08 [ijk]	2.52 ±0.07 [l-o]	2.82 ±0.04 [ijk]	2.97 ±0.09 [ij]	2.64 ±0.05 [k-n]
		200	4.33 ±0.05 [d]	3.61 ±0.13 [f]	3.52 ±0.13 [fg]	3.93 ±0.11 [e]	3.94 ±0.11 [e]	3.61 ±0.07 [f]
		250	4.90 ±0.07 [b]	4.63 ±0.35 [bcd]	3.67 ±0.09 [ef]	4.46 ±0.22 [cd]	5.43 ±0.08 [a]	4.73 ±0.24 [bc]
Seedling length (cm) ±SEM								
Temperature	18°C	Cont.	3.93 ±0.15 [jk]	7.14 ±0.24 [efg]	12.04 ±0.79 [b]	6.21 ±0.33 [gh]	9.72 ±0.11 [d]	14.88 ±0.58 [a]
		50	6.03 ±0.47 [gh]	6.33 ±0.45 [gh]	9.91 ±0.48 [d]	7.84 ±0.21 [e]	7.60 ±0.49 [ef]	10.86 ±0.82 [c]
		100	4.65 ±0.28 [klm]	6.10 ±0.24 [hij]	8.89 ±0.33 [e]	5.31 ±0.17 [jkl]	6.06 ±0.41 [hij]	9.87 ±0.03 [d]
		150	3.93 ±0.15 [mno]	4.41 ±0.10 [lmn]	5.45 ±0.06 [ijk]	4.64 ±0.09 [klm]	4.79 ±0.16 [klm]	6.66 ±0.36 [fgh]
		200	2.79 ±0.05 [p]	3.44 ±0.21 [nop]	3.94 ±0.13 [mno]	3.04 ±0.08 [op]	2.97 ±0.10 [op]	3.49 ±0.13 [nop]
		250	- [q]	- [q]	- [q]	- [q]	- [q]	- [q]
	25°C	Cont.	21.20 ±0.72 [b]	12.62 ±0.29 [hij]	15.05 ±0.55 [ef]	14.54 ±0.58 [efg]	15.09 ±0.43 [ef]	17.02 ±0.34 [cd]
		50	16.48 ±0.63 [de]	13.43 ±0.52 [f-i]	11.94 ±0.46 [ijk]	21.23 ±0.86 [b]	23.39 ±1.18 [a]	18.65 ±0.81 [c]
		100	12.98 ±0.40 [ghi]	16.37 ±1.42 [de]	9.79 ±0.35 [lm]	14.13 ±0.37 [fgh]	10.86 ±0.26 [jkl]	14.80 ±0.60 [efg]
		150	9.13 ±0.64 [lmn]	10.54 ±0.51 [kl]	10.76 ±0.85 [jkl]	10.03 ±0.82 [klm]	10.86 ±0.26 [jkl]	13.54 ±0.88 [f-i]
		200	8.49 ±0.44 [mno]	7.59 ±0.25 [nop]	7.82 ±0.39 [nop]	5.54 ±0.40 [q]	9.88 ±0.17 [lm]	9.91 ±0.67 [lm]
		250	6.96 ±0.33 [opq]	6.10 ±0.39 [pq]	6.69 ±0.27 [opq]	6.34 ±0.51 [pq]	5.24 ±0.16 [q]	6.98 ±0.70 [opq]

*: Means followed by same letter(s) in each temperature are not significant at $p<0.05$. Bracket (-) shows no data due to insufficient seedling growth. SEM: Standard error of mean.

Table 3. Seedling fresh and dry weight and dry matter ratio of cotton varieties under low temperature and salinity stresses

Tablo 3. Düşük sıcaklık ve tuzluluk stresleri altında pamuk çeşitlerinin fide yaş ve kuru ağırlığı ile kuru madde oranı

	Salinity (mM)	Variety					
		Lydia	Carisma	Flash	BA151	BA525	ST468
Seedling fresh weight (mg plant^{-1}) ±SEM							
Temperature 18°C	Cont.	314 ±15.31^{c}	291 ±6.87^{cd}	362 ±15.05^{a}	316 ±11.09^{c}	297 ±6.56^{cd}	358 ±7.86^{a*}
	50	268 ±11.46^{de}	317 ±28.18^{c}	308 ±10.39^{c}	352 ±12.07^{ab}	313 ±22.51^{c}	324 ±13.47^{bc}
	100	203 ±14.66^{h}	210 ±10.61^{gh}	240 ±4.12^{ef}	194 ±7.66^{hi}	236 ±7.57^{fg}	250 ±4.37^{ef}
	150	157 ±2.92^{jk}	159 ±2.99^{jk}	157 ±6.03^{jkl}	172 ±4.41^{ij}	144 ±3.24^{j-m}	162 ±8.40^{j}
	200	146 ±3.80^{j-m}	108 ±7.46^{n}	125 ±21.93^{lmn}	127 ±4.49^{k-n}	123 ±5.42^{mn}	125 ±4.28^{lmn}
	250	-^{o}	-^{o}	-^{o}	-^{o}	-^{o}	-^{o}
Temperature 25°C	Cont.	623 ±9.11^{a}	525 ±12.10^{def}	563 ±17.50^{bcd}	575 ±11.72^{bc}	545 ±21.04^{cde}	497 ±14.83^{fg}
	50	448 ±11.47^{hi}	476 ±9.35^{gh}	500 ±11.68^{fg}	504 ±32.61^{efg}	604 ±7.79^{ab}	545 ±11.89^{cde}
	100	437 ±11.09^{hi}	473 ±22.48^{gh}	406 ±8.82^{i}	458 ±19.80^{gh}	342 ±29.67^{j}	405 ±14.01^{i}
	150	244 ±19.02^{mn}	323 ±3.89^{jk}	333 ±20.33^{jk}	328 ±16.68^{jk}	317 ±6.69^{jk}	344 ±6.05^{j}
	200	255 ±4.87^{mn}	263 ±8.79^{lmn}	287 ±8.58^{klm}	262 ±7.50^{lmn}	303 ±14.02^{jkl}	245 ±9.48^{mn}
	250	234 ±15.43^{n}	179 ±9.55^{o}	227 ±3.44^{n}	217 ±9.68^{no}	180 ±7.66^{o}	234 ±16.56^{n}
Seedling dry weight (mg plant^{-1}) ±SEM							
Temperature 18°C	Cont.	59.4 ±1.85^{a}	49.9 ±1.16^{c-g}	45.4 ±1.97^{ghi}	52.2 ±1.25^{cd}	52.1 ±1.03^{cde}	41.6 ±1.46^{ijk}
	50	57.8 ±0.76^{ab}	49.4 ±1.85^{d-g}	45.2 ±0.97^{ghi}	52.3 ±1.61^{cd}	50.7 ±1.68^{c-f}	48.0 ±0.92^{d-g}
	100	57.3 ±2.52^{ab}	46.8 ±1.75^{fgh}	48.2 ±1.27^{d-g}	47.4 ±1.29^{efg}	49.7 ±1.53^{c-g}	47.4 ±1.22^{efg}
	150	59.3 ±0.44^{a}	49.0 ±1.51^{d-g}	40.5 ±1.74^{jk}	54.1 ±2.28^{bc}	42.6 ±0.87^{hij}	47.9 ±0.87^{d-g}
	200	56.9 ±1.54^{ab}	39.1 ±0.51^{k}	33.3 ±0.88^{l}	50.2 ±1.82^{c-f}	51.9 ±2.83^{cde}	48.1 ±1.31^{d-g}
	250	-^{m}	-^{m}	-^{m}	-^{m}	-^{m}	-^{m}
Temperature 25°C	Cont.	53.8 ±2.03^{a-d}	45.3 ±1.21^{ghi}	43.5 ±0.71^{i}	48.9 ±1.02^{c-i}	49.1 ±1.22^{c-i}	45.0 ±2.26^{ghi}
	50	56.3 ±2.75^{ab}	45.3 ±1.44^{ghi}	47.0 ±1.20^{f-i}	49.5 ±0.50^{c-i}	50.5 ±1.20^{a-h}	44.3 ±1.92^{hi}
	100	54.7 ±2.24^{abc}	46.3 ±0.72^{ghi}	45.5 ±0.77^{ghi}	53.0 ±0.97^{a-f}	48.6 ±2.15^{c-i}	44.6 ±1.42^{hi}
	150	51.7 ±3.99^{a-g}	48.1 ±0.74^{d-i}	47.9 ±1.30^{d-i}	53.3 ±1.01^{a-f}	45.5 ±3.40^{ghi}	45.8 ±1.11^{ghi}
	200	56.6 ±2.78^{a}	49.3 ±0.40^{c-i}	47.0 ±1.50^{f-i}	53.7 ±1.16^{a-e}	51.8 ±0.76^{a-g}	47.1 ±3.17^{e-i}
	250	53.1 ±2.19^{a-f}	46.2 ±2.02^{ghi}	45.9 ±1.36^{ghi}	48.8 ±5.57^{c-i}	49.8 ±1.67^{b-i}	45.4 ±1.66^{ghi}
Dry matter (%)±SEM							
Temperature 18°C	Cont.	79.2 ±2.86^{fgh}	82.9 ±0.41^{cde}	87.2 ±1.07^{ab}	83.4 ±0.53^{cd}	82.5 ±0.52^{c-f}	87.6 ±1.21^{a}
	50	78.3 ±0.76^{ghi}	84.1 ±1.34^{bcd}	85.3 ±0.53^{abc}	85.0 ±0.65^{abc}	83.5 ±1.51^{cd}	85.1 ±0.83^{abc}
	100	71.8 ±0.55^{klm}	77.6 ±0.79^{hi}	80.0 ±0.25^{e-h}	75.5 ±0.46^{ij}	79.1 ±0.75^{fgh}	81.1 ±0.33^{d-g}
	150	62.3 ±0.67^{no}	69.1 ±1.10^{lm}	74.2 ±0.51^{jk}	68.5 ±0.55^{m}	70.5 ±1.10^{lm}	72.0 ±0.67^{kl}
	200	61.0 ±1.28^{op}	64.3 ±2.31^{n}	71.5 ±3.48^{klm}	60.4 ±0.09^{op}	57.9 ±0.59^{o}	61.6 ±0.64^{no}
	250	-^{q}	-^{q}	-^{q}	-^{q}	-^{q}	-^{q}
Temperature 25°C	Cont.	91.4 ±0.27^{ab}	91.4 ±0.23^{ab}	92.3 ±0.16^{a}	91.5 ±0.20^{ab}	91.0 ±0.22^{abc}	90.9 ±0.60^{abc}
	50	87.5 ±0.46^{d-g}	90.5 ±0.37^{abc}	90.6 ±0.42^{abc}	89.6 ±0.50^{a-d}	91.4 ±0.20^{ab}	92.0 ±0.35^{a}
	100	87.4 ±0.40^{d-g}	90.2 ±0.38^{a-d}	88.8 ±0.42^{b-e}	88.4 ±0.61^{c-f}	86.6 ±1.69^{efg}	89.0 ±0.17^{b-e}
	150	78.8 ±0.54^{kl}	85.1 ±0.39^{gh}	85.5 ±0.85^{fgh}	83.7 ±0.65^{hi}	85.7 ±0.92^{fgh}	86.7 ±0.49^{efg}
	200	77.2 ±1.63^{l}	81.2 ±0.69^{ijk}	83.6 ±0.44^{hi}	79.5 ±0.61^{kl}	82.8 ±0.67^{hij}	80.7 ±0.75^{jk}
	250	77.1 ±0.73^{l}	74.0 ±1.24^{m}	79.8 ±0.70^{kl}	77.3 ±3.07^{l}	73.7 ±1.30^{m}	80.4 ±1.49^{jk}

*: Means followed by same letter(s) in each temperature are not significant at $p<0.05$. Bracket (-) shows no data due to insufficient seedling growth. SEM: Standard error of mean

Vigor index of cotton varieties was severely influenced by each salinity level under optimal and low temperatures. It was higher at 25°C compared to 18°C, but increased NaCl reduced vigor index. Vigor index could not be calculated in NaCl level of 250 mM because of no seedling development. The highest value was obtained in Flash and ST468 under all salinity levels at 18°C (Table 4). These results agree with Liu et al. (2010) in sunflower, Kandil et al. (2012) and El Naim et al. (2012) in sorghum, and Çarpıcı et al. (2009) in maize, they indicated that salinity and low temperature severely influenced vigor index with significant reduction.

The germination index of cotton varieties declined as salt levels increased. However, cotton varieties showed different responses to NaCl both at 18°C and at 25°C. The highest germination index was attained in Flash and ST468 (Fig. 1). Also, Wang et al. (2007) determined that no significant change in germination index was observed in low salinity but drastically decreased as salinity increased. Similarly, germination stress tolerance index reduced with increasing salinity and low temperature. Among cotton varieties, Flash was the least affected variety by salinity under low temperature (Fig. 2).

The germination stress tolerance index drastically decreased due to increasing NaCl doses and this finding was reported in several crops by Karimi et al. (2011) in safflower, Abbaszadeh et al. (2012) in rapeseed, Kausar et al. (2012) in sorghum, and Vibhuti et al. (2015) in rice.

CONCLUSION

Germination and seedling growth of cotton varieties were severely restricted by low temperature and salinity stress. In this study, there were significant differences among cotton varieties for tolerance to salinity and low temperature; however, Flash and ST468 varieties were found to be more tolerant to salinity stress under optimal and suboptimal temperature. They should be suggested to farmers who prefer early sowing to achieve higher and rapid germination at cotton fields suffering from salinity problem.

Table 4. Vigor index of cotton varieties under low temperature and salinity stresses (±SEM)
Tablo 4. *Düşük sıcaklık ve tuzluluk stresleri altında pamuk çeşitlerinin güç indeksi (±Standart hata)*

Temperature	Salinity (mM)	Variety					
		Lydia	Carisma	Flash	BA151	BA525	ST468
18°C	Cont.	357 ±16.0 ^{ijk}	664 ±27.9 ^{e}	1142 ±71.3 ^{b}	571 ±32.0 ^{fg}	850 ±11.5 ^{d}	1361 ±50.4 ^{a*}
	50	540 ±47.7 ^{g}	600 ±50.0 ^{efg}	961 ±48.6 ^{c}	677 ±21.6 ^{e}	643 ±50.0 ^{ef}	996 ±75.8 ^{c}
	100	372 ±25.3 ^{ijk}	541 ±9.4 ^{g}	853 ±24.5 ^{d}	421 ±26.1 ^{ij}	442 ±32.1 ^{hi}	844 ±17.6 ^{d}
	150	315 ±22.5 ^{kl}	348 ±12.1 ^{ijk}	513 ±14.0 ^{gh}	363 ±9.6 ^{ijk}	331 ±14.1 ^{jkl}	541 ±44.2 ^{g}
	200	149 ±5.0 ^{n}	248 ±13.3 ^{lm}	331 ±4.0 ^{jkl}	219 ±9.8 ^{mn}	218 ±16.6 ^{mn}	305 ±24.3 ^{klm}
	250	-^{o}	-^{o}	-^{o}	-^{o}	-^{o}	-^{o}
25°C	Cont.	1942 ±96.4 ^{ab}	1173 ±41.2 ^{ghi}	1426 ±92.8 ^{def}	1302 ±62.4 ^{fg}	1279 ± 92.5 ^{fg}	1600 ±39.4 ^{cd}
	50	1286 ±48.6 ^{fg}	1195 ±54.3 ^{gh}	1152 ±46.1 ^{ghi}	1834 ±70.8 ^{b}	2095 ±71.8 ^{a}	1616 ±93.5 ^{c}
	100	1071 ±50.1 ^{hij}	1488 ±99.0 ^{cde}	941 ±49.2 ^{jkl}	1164 ±36.2 ^{ghi}	941 ±49.3 ^{jkl}	1346 ±48.8 ^{efg}
	150	797 ±75.6 $^{k-n}$	992 ±62.5 ^{ijk}	965 ±65.4 ^{jk}	876 ±63.8 $^{j-m}$	902 ± 41.2 ^{jkl}	1194 ±75.6 ^{gh}
	200	686 ±53.0 $^{m-p}$	653 ±32.5 ^{nop}	762 ±34.1 $^{l-o}$	443 ±57.8 ^{q}	870 ±35.1 ^{klm}	842 ±37.0 $^{k-n}$
	250	552 ±40.3 ^{pq}	528 ±52.9 ^{pq}	556 ±11.4 ^{pq}	505 ±58.5 ^{pq}	406 ±30.4 ^{q}	577 ±63.5 ^{opq}

*: Means followed by same letter(s) in each temperature are not significant at $p<0.05$. Bracket (-) shows no data due to insufficient seedling growth. SEM: Standard error of mean

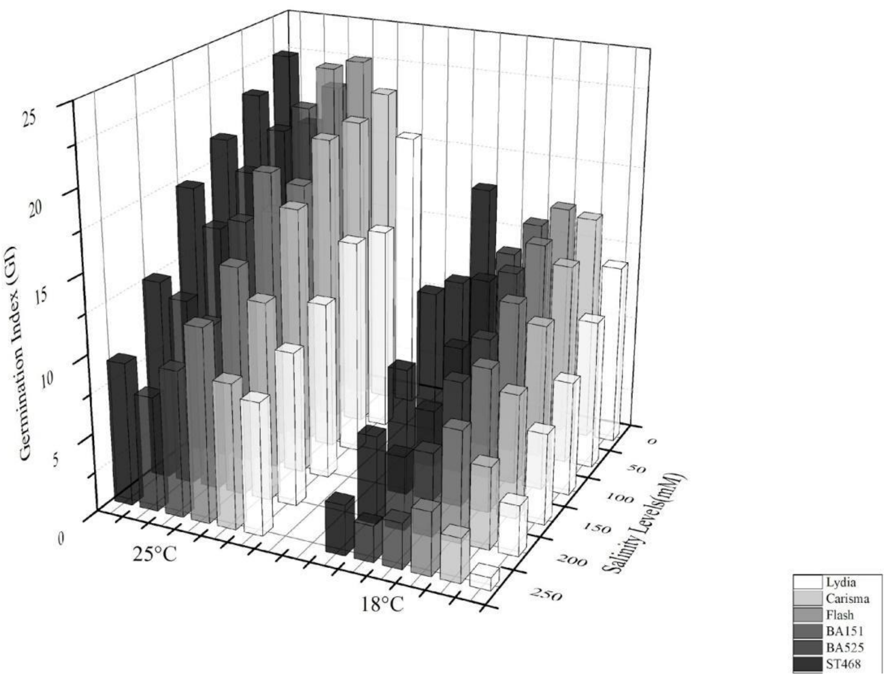

Figure 1. Germination index of cotton varieties under low temperature and salinity stresses
Şekil 1. Düşük sıcaklık ve tuzluluk stresleri altında pamuk çeşitlerinin çimlenme indeksi

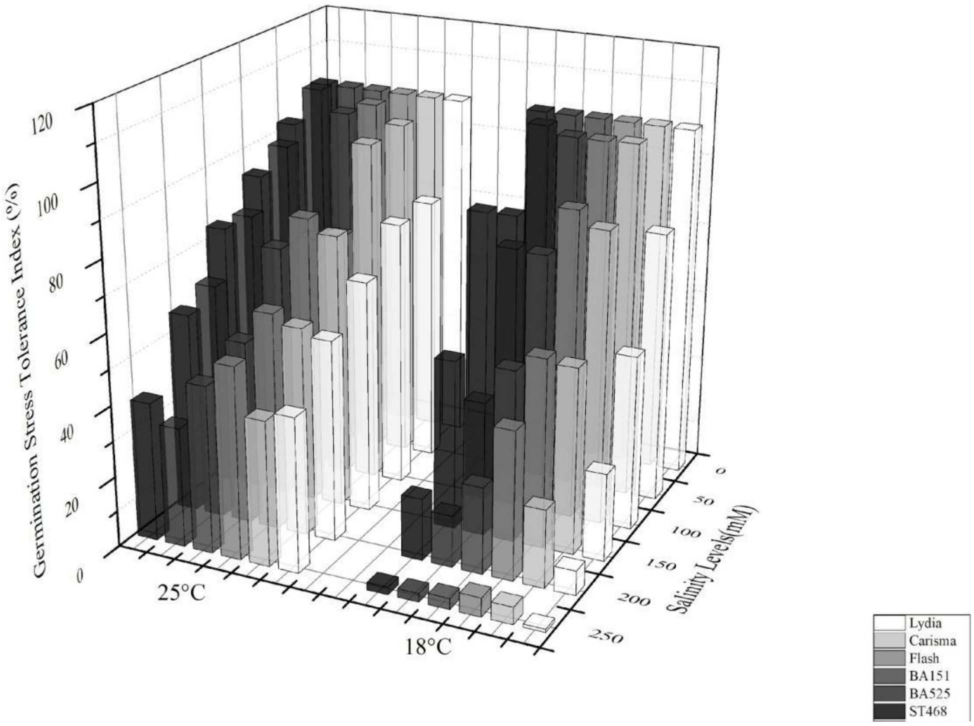

Figure 2. Germination stress tolerance index of cotton varieties under low temperature and salinity stresses
Şekil 2. Düşük sıcaklık ve tuzluluk stresleri altında pamuk çeşitlerinin çimlenme stres tolerans indeksi

Statement of Conflict of Interest

Authors have declared no conflict of interest.

Author's Contributions

The contribution of the authors is equal.

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