Türkiye Tarımsal Araştırmalar Dergisi
dergipark.org.tr/tutad

Research Article

Turk J Agric Res
2021, 8(2): 133-143
© TÜTAD
ISSN: 2148-2306
e-ISSN: 2528-858X
doi: 10.19159/tutad.769463

# Effects of Different Salt Concentrations on Germination and Seedling Growth of Some Sweet Sorghum [*Sorghum bicolor* var. *saccharatum* (L.) Mohlenbr.] Cultivars

**Mehmet Arif ÖZYAZICI***, **Semih AÇIKBAŞ**
*Siirt University, Faculty of Agriculture, Department of Field Crops, Siirt, TURKEY*

**Received:** 14.07.2020 **Accepted:** 04.07.2021

**ORCID ID (By author order)**
orcid.org/0000-0001-8709-4633 orcid.org/0000-0003-4384-3908
*Corresponding Author: arifozyazici@siirt.edu.tr

**Abstract:** This study was carried out to determine the effects of different salt concentrations on germination and seedling growth of sweet sorghum [*Sorghum bicolor* var. *saccharatum* (L.) Mohlenbr.] cultivars. The research was carried out under laboratory conditions and sweet sorghum cultivars Ulusoy, Sorge, Biomarlı, Erdurmuş, and Gülşeker were used as plant material. Five different sweet sorghum cultivars and four different salt (NaCl) concentrations (0-, 100-, 200-, and 300 mM) were the subjects of the laboratory experiments which was set up in randomized plots in a factorial design with 4 replications. In the study, germination parameters such as germination percentage (GP), mean germination time (MGT), germination index (GI), coefficient of uniformity of germination (CUG) and germination speed (GS), and seedling growth parameters such as root and shoot fresh weight, root and shoot dry weight, root and shoot length, lateral root number and lateral root length were investigated. As a result of the research, it was determined that the germination and seedling growth parameters (excluding MGT) decreased as salt concentration increased. This decrease in germination characteristics was significant at 100 mM salt dose according to the average values of the cultivars, and it was observed that the cultivars were more sensitive to salt stress in the seedling development stage than the germination stage. In the study, it was determined that there were significant differences between sweet sorghum genotypes under salt-stressed conditions during germination and seedling stages. In this sense, Ulusoy and Erdurmuş sweet sorghum cultivars were prominent in terms of salt tolerance. It is important to use salt-tolerant cultivars considering the genotypic differences in sweet sorghum cultivation in salt-affected areas.

**Keywords:** Sweet sorghum, salinity, germination percentage, mean germination time, seedling root and shoot length

## 1. Introduction

Globally, climate change and global warming are among the most important problems that are widely discussed, and they are considered as triggers of important problems such as drought and salinity in soils. Agricultural areas are under the influence of climate, and especially arid, semi-arid, and coastal agricultural areas are very sensitive to the effects of climate change in terms of soil salinity (Pankova and Konyushkova, 2013; Corwin, 2021). In this sense, salinity is the most determinant environmental stress limiting the yield of crops especially in arid and semi-arid regions (Zörb et al., 2019), and it is one of the most important abiotic stress factors affecting plant growth and development negatively (Parida and Das, 2005; Hafsi et al., 2010; Rajabi Dehnavi et al., 2020; Sabagh et al., 2021). Salinity inhibits plant growth and development in relation to some physiological, morphological, and biochemical events such as osmotic stress, especially in young leaves, and ion toxicity in older leaves (Munns and Tester, 2008), decreased mineral nutrient uptake (Xu et al., 2016), slow and deficient germination (Ekmekçi et al., 2005). In addition, the toxicity of salinity varies greatly according to soil pH, so alkaline stress caused by high salt concentrations also has serious effects on germination, growth, and photosynthesis (Li et al., 2010).

As a result of the inappropriate and unconscious management of important agricultural practices, related to plant-water consumption and plant nutrition-fertilization, such as timing, quantity, and interval of irrigation and fertilization, salinity problem in agricultural areas is continuously and rapidly growing today. Therefore, in addition to water management improving strategies (Krishnamurthy et al., 2007) and adopting fertilization programs to low salt accumulation in soils, a number of cultural and crop management strategies should be considered to protect agricultural productivity of salinity-affected areas. For this purpose, it is important to reveal the effects of salinity and genotypic variation, especially during the germination and seedling development stages, and to improve the salinity tolerance of some economically important crops. High genotypic variation for salt stress was reported in many studies on different plant species (De Lacerda et al., 2005; Katerij et al., 2006; Krishnamurthy et al., 2007; Kara et al., 2011; Tigabu et al., 2012; Ali and Idris, 2015; Shakeri et al., 2017; Çakmakçı and Dallar, 2019).

Sweet sorghum [*Sorghum bicolor* var. *saccharatum* (L.) Mohlenbr.], a C4 crop with high photosynthetic efficiency (Almodares and Hadi, 2009), is used for animal feeding (Inal et al., 2021), and ethanol production (Guden et al., 2020), and is a drought and high-temperature tolerant species. High genetic variation for salt tolerance among sorghum genotypes that are generally tolerant to abiotic stresses such as drought and salinity was reported (Maiti et al., 1994; Rajabi Dehnavi et al., 2020). It is important to reveal the genetic variations to determine the most tolerant genotypes to salinity. And in this context, the determination of plants' response to salinity, especially during the germination and seedling stages, is important to obtain optimum yield under salinity-affected areas.

The aim of this study was to determine the germination and seedling development of sweet sorghum [*S. bicolor* var. *saccharatum* (L.) Mohlenbr.] cultivars under different salt concentrations and to reveal their salt tolerance potential.

## 2. Materials and Methods

### 2.1. Materials

The research was carried out in Siirt University (Turkey) Faculty of Agriculture, Department of Field Crops Laboratory. Ulusoy, Sorge, Biomarlı, Erdurmuş and Gülşeker sweet sorghum [*S. bicolor* var. *saccharatum* (L.) Mohlenbr.] cultivars were used as plant material. NaCl was the preferred salt form as it is the most detrimental form for crops and agricultural soils.

### 2.2. Research subject and germination experiment

Laboratory experiments included five different sweet sorghum cultivars (cvs.) and four different concentrations (0-, 100-, 200-, and 300 mM) of salt (NaCl) were the subject of research which was established in randomized plots in factorial design with four replications. For each replication were used 25 seeds. Seeds were surface sterilized with 70% ethanol for one minute and then rinsed three times with sterile water. Then, to deform the microorganisms on the seed surface, a subsequent step of surface sterilization was carried out by covering the seeds with a 10% sodium hypochlorite (NaOCl) + 0.01% tween20 solution for 10 minutes. The sterilized seeds were placed between two layers of Whatman No.2 filter paper in petri dishes (90 mm x 15 mm). Five ml of salt solutions were applied to each petri dish. Petri dishes were left to germinate in an incubator (BINDER, GmbH, Germany) set at 25±2 °C temperature. Until the end of the study, 5 ml of salt dose was added to the petri dishes according to the trial subjects every 48 hours (according to the humidity levels of the seeds in the petri dishes).

Germination controls were applied every 24 hours during the experiment and the germination test was completed on the 10$^{th}$ day. The observation of at least 2 mm radicle was the germination criterion of the seeds (Scott et al., 1984; Soleymani and Shahrajabian, 2018). Measurements were conducted on ten randomly selected seedlings in each petri dish, and on all germinated plants in petri dishes that did not contain adequate number of seedlings due to salt stress.

### 2.3. Germination and seedling growth assessments

In the study, germination parameters such as germination percentage (GP), mean germination time (MGT), germination index (GI), coefficient of uniformity of germination (CUG), germination speed (GS), and seedling growth parameters such as root and shoot length, root and shoot fresh weight, root and shoot dry weight, number of lateral roots and lateral root length were examined.

Seeds germinating every 24 hours were counted and Equation 1 of Scott et al. (1984) was used for the determination of the GP parameter.

$$GP = (NGS/TS) \times 100 \quad (1)$$

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

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

$$MGT= \sum(N_i T_i / N_i) \quad (2)$$

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

Germination index was calculated with the help of Equation 3 (Wang et al., 2004), CUG by Equation 4 (Bewely and Black, 1994), and GS by Equation 5 (Abazarian et al., 2011).

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

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

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

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

$$GS= (N_1/T_1)+(N_2/T_2)+\ldots\ldots+(N_n/T_n) \quad (5)$$

N is the number of germinated seeds and T is the number of days required for germination.

Before weighting measurements, excess water on seeds was removed with filter paper, and immediately afterward, the fresh weights were determined with a precision scale. For the observations, randomly selected root and shoot samples were scanned with a color scanner (Iscan Color Mini Portable Scanner) at 300 DPI resolution. ImageJ software (Rueden et al., 2017) were used for precise and detailed measurements of root and shoot lengths, lateral root numbers, and length parameters (Açıkbaş and Özyazıcı, 2021). Dry weights were measured after the samples dried in an oven at 70 $^{o}$C for 48 hours.

ArcSin transformation was applied to the percentage expressed data before analysis of variance. The obtained data were subjected to analysis of variance according to the randomized plots in factorial design. The differences between the means were checked with the TUKEY's HSD multiple comparison test (Açıkgöz and Açıkgöz, 2001).

## 3. Results

### 3.1. Germination assessment

Data on germination parameters of sweet sorghum [*S. bicolor* var. *saccharatum* (L.) Mohlenbr.] cultivars at different salt concentrations are presented in Table 1. As a result of the evaluations, the effects of salt applications and cultivars on all germination parameters (GP, MGT, GI, CUG, and GS) were found to be statistically significant ($p<0.01$) (Table 1).

As a result of the research, although increasing salt concentrations decreased the GP, the difference between the control (0 mM) and 100 mM salt dose was statistically insignificant, and significant decreases were obtained after 100 mM salt dose. Accordingly, the highest GP was determined as 63.5- and 61.6% in control and 100 mM applications, respectively, while the lowest value (42.9%) was determined at the highest dose (300 mM). When the average results of sweet sorghum cultivars were examined in terms of GP, the highest value was determined in cv. Erdurmuş with 76.7% as the means salt concentrations, and the difference between cvs. Erdurmuş and Ulusoy was not significant in terms of GP. The lowest GP was determined in Biomarlı with 17.3% (Table 1).

In the study, it was observed that germination was delayed due to increasing salt concentrations. In this sense, while the MGT was 2.39 days in control, the MGT was 3.95 days at 300 mM salt concentration. When the effects of cultivars were examined in terms of MGT, it was determined that the latest germinated cultivar was Biomarlı with an average of 4.55 days, followed by Gülşeker (3.06 days) and Sorge (2.82 days) (Table 1).

Salinity significantly reduced the GI and CUG. Significant decreases in both germination parameters were obtained after 100 mM salt dose, the differences between 0- and 100 mM salt applications were found to be statistically insignificant. The highest values for GI and CUG with these two salt concentrations were found as 7.44 and 6.77 for GI, 29.1 and 26.3 for CUG, respectively. When the differences between sweet sorghum cultivars were examined, a significant difference in terms of GI and CUG was observed between Ulusoy and Erdurmuş compared to other cultivars, and the highest values were determined in terms of both germination parameters in these two cultivars. Also, in terms of GI and CUG, the cultivar x salt concentration interactions were found to be statistically significant at the $p<0.01$ level. In general, the increased salt concentration decreased GI and CUG values for all cultivars compared to the control. However, while decreases in GI were not significant even at high salt doses for some cultivars (such as Biomarlı), there was a statistically insignificant increase at 100 mM salt dose compared to control as in Erdurmuş. Similar fluctuations were also observed in the CUG values. This was among the most important reasons for the significance of interactions (Table 1).

It was determined that the GS decreased in parallel with the increasing salt concentration.

**Table 1.** Some germination parameters of sweet sorghum cultivars at different salt concentrations*

| Cultivars | Salt concentration (mM, NaCl) | | | | |
|---|---|---|---|---|---|
| | 0 | 100 | 200 | 300 | Average |
| | | | Germination percentage (%) | | |
| Ulusoy | 85.3 (67.6) | 80.0 (63.5) | 69.3 (56.4) | 65.3 (54.1) | 75.0 (60.4) AB |
| Sorge | 77.3 (62.0) | 74.7 (59.8) | 68.0 (55.7) | 53.3 (46.9) | 68.3 (56.1) B |
| Gülşeker | 50.7 (45.4) | 44.0 (41.5) | 32.0 (34.4) | 26.7 (30.9) | 38.3 (38.1) C |
| Biomarlı | 22.7 (28.3) | 26.7 (31.1) | 16.0 (23.5) | 4.0 (11.5) | 17.3 (23.6) D |
| Erdurmuş | 81.3 (64.5) | 82.7 (65.3) | 77.3 (61.6) | 65.3 (54.1) | 76.7 (61.5) A |
| Average | 63.5 (53.4) A | 61.6 (52.3) A | 52.5 (46.3) B | 42.9 (39.5) C | |
| | | | Mean germination time (day) | | |
| Ulusoy | 2.02±0.03 | 2.08±0.03 | 2.40±0.01 | 3.34±0.65 | 2.46 C |
| Sorge | 2.19±0.04 | 2.47±0.15 | 3.13±0.30 | 3.50±0.33 | 2.82 BC |
| Gülşeker | 2.44±0.56 | 2.57±0.18 | 3.03±0.35 | 4.20±0.26 | 3.06 B |
| Biomarlı | 3.19±0.60 | 4.68±0.61 | 5.00±1.00 | 5.33±0.58 | 4.55 A |
| Erdurmuş | 2.10±0.05 | 2.11±0.07 | 2.38±0.10 | 3.36±0.65 | 2.49 C |
| Average | 2.39 C | 2.78 BC | 3.19 B | 3.95 A | |
| | | | Germination index | | |
| Ulusoy | 10.61±0.3 a | 9.78±0.6 abc | 7.53±0.3 cde | 5.47±1.3 ef | 8.35 A |
| Sorge | 9.11±1.1 abc | 7.97±0.6 bcd | 5.99±1.0 def | 4.22±0.4 fg | 6.82 B |
| Gülşeker | 5.70±1.0 ef | 4.62±1.2 fg | 2.93±0.5 gh | 1.74±0.5 hı | 3.75 C |
| Biomarlı | 1.96±0.7 hı | 1.52±0.3 hı | 0.86±0.2 hı | 0.19±0.0 ı | 1.14 D |
| Erdurmuş | 9.83±0.2 ab | 9.97±0.6 ab | 8.58±0.4 abc | 5.47±1.3 ef | 8.46 A |
| Average | 7.44 A | 6.77 A | 5.18 B | 3.42 C | |
| | | | Coefficient of uniformity of germination | | |
| Ulusoy | 42.3±1.5 a | 38.7±2.5 ab | 28.8±1.1 cde | 20.1±4.8 ef | 32.5 A |
| Sorge | 35.3±4.1 abc | 30.4±2.6 bcd | 21.9±4.3 def | 15.3±1.8 fgh | 25.7 B |
| Gülşeker | 21.6±5.2 def | 17.3±5.2 fg | 10.8±2.4 ghı | 6.4±2.1 hıj | 14.0 C |
| Biomarlı | 7.3±2.6 hıj | 5.7±1.0 ıj | 3.2±0.7 ıj | 0.8±0.1 j | 4.2 D |
| Erdurmuş | 38.8±0.6 ab | 39.1±1.8 ab | 32.5±1.1 bc | 20.1±4.8 ef | 32.6 A |
| Average | 29.1 A | 26.3 A | 19.5 B | 12.5 C | |
| | | | Germination speed (%) | | |
| Ulusoy | 10.6±0.4 a | 9.8±0.6 abc | 7.5±0.3 cde | 5.5±1.3 ef | 8.4 A |
| Sorge | 9.1±1.1 abc | 8.0±0.6 bcd | 6.0±1.0 def | 4.2±0.4 fgh | 6.8 B |
| Gülşeker | 5.7±1.0 ef | 4.6±1.2 fg | 2.9±0.5 ghı | 1.7±0.5 ıj | 3.8 C |
| Biomarlı | 2.0±0.7 hıj | 1.5±0.3 ıj | 0.9±0.2 ıj | 0.2±0.0 j | 1.1 D |
| Erdurmuş | 9.8±0.2 ab | 10.0±0.6 ab | 8.6±0.4 abc | 5.5±1.3 ef | 8.5 A |
| Average | 7.5 A | 6.8 A | 5.2 B | 3.4 C | |

| Significance level (P) | | | |
|---|---|---|---|
| | NaCl | Cultivar (C) | NaCl x C |
| GP | 0.0001** | 0.0001** | 0.4174ns |
| MGT | 0.0001** | 0.0001** | 0.1151ns |
| GI | 0.0001** | 0.0001** | 0.0068** |
| CUG | 0.0001** | 0.0001** | 0.0022** |
| GS | 0.0001** | 0.0001** | 0.0068** |

( ): ArcSin transformation values, $\bar{x}$ ± Standard Deviation, *: The difference between the means indicated by the same letter in the same column / in the same row / in the same group is not statistically significant, **: Significant at level of p<0.01, ns: Non significant

According to this, the highest GS were found at 0 mM (7.5%) and 100 mM (6.8%) salt concentrations which were in the same group, while the lowest values were found at 300 mM (3.4%) salt concentration. In the study, the highest GS were observed at cvs. Erdurmuş (8.5%) and Ulusoy (8.4%). In terms of GS, cultivar x salt concentration interaction was statistically significant at the p<0.01 level. Although, in general, the GS of the cultivars tended to decrease with the increase in salt concentrations, this decrease was not significant even at 200 mM for cv. Erdurmuş and even an insignificant increase at the 100 mM dose played an important role in the significance of the interaction (Table 1).

### 3.2. Seedling growth assessment

Effects of salt concentrations and cultivars were statistically significant (p<0.01) on root and shoot fresh weights. Increased salt doses were related to decreased root and shoot fresh weights. The highest average root and shoot fresh weights were 24.6 and 52.3 mg, respectively at the control (0 mM), and the lowest values were found at the highest salt dose (300 mM), as 4.0, and 1.7 mg, respectively. When the effects of the cultivars were examined, the highest values in both traits were determined at Ulusoy (22.6 and 30.6 mg, respectively) and Erdurmuş (24.0 and 34.3 mg, respectively), which were the top statistical group, and the lowest value was determined at Biomarlı (3.5 and 10.2 mg, respectively). Also, in the study, salt concentration x cultivar interaction was found to be statistically significant at $p<0.01$ level in terms of root and shoot fresh weights. In general, although root and shoot fresh weights decreased due to the increase in salt concentration for all cultivars, there was a statistically significant increase at 100 mM salt dose at Biomarlı, which was the reason for significant interaction (Table 2).

**Table 2.** The root and shoot fresh and dry weight values of sweet sorghum cultivars with different salt concentrations*

| Cultivars | Salt concentration (mM, NaCl) | | | | |
|---|---|---|---|---|---|
| | 0 | 100 | 200 | 300 | Average |
| **Root fresh weight (mg)** | | | | | |
| Ulusoy | 37.0±2.0 a | 27.3±0.6 bc | 19.7±2.5 cde | 6.3±2.5 hıj | 22.6 A |
| Sorge | 27.3±2.3 bc | 12.7±2.1 e-h | 9.7±1.5 f-ı | 3.7±0.6 ıj | 13.3 B |
| Gülşeker | 17.0±1.0 def | 15.7±1.5 d-g | 4.0±1.0 ıj | 3.7±1.5 ıj | 10.1 C |
| Biomarlı | 3.7±1.2 ıj | 8.3±1.5 ghı | 2.0±1.0 ıj | 0.0±0.0 j | 3.5 D |
| Erdurmuş | 38.0±3.6 a | 28.0±3.0 b | 23.7±3.2 bcd | 6.3±1.5 hıj | 24.0 A |
| Average | 24.6 A | 18.4 B | 11.8 C | 4.0 D | |
| **Shoot fresh weight (mg)** | | | | | |
| Ulusoy | 71.3±2.9 a | 36.3±1.5 cd | 13.0±1.7 ghı | 1.7±0.6 ıj | 30.6 A |
| Sorge | 56.7±2.5 b | 26.7±3.8 def | 11.3±2.0 g-j | 1.0±0.0 j | 23.9 B |
| Gülşeker | 47.0±2.0 bc | 30.3±2.5 de | 8.3±0.6 g-j | 1.7±0.6 ıj | 21.8 B |
| Biomarlı | 15.7±3.2 fgh | 18.7±1.2 fg | 6.3±1.5 hıj | 0.0±0.0 j | 10.2 C |
| Erdurmuş | 71.0±1.7 a | 42.3±1.2 c | 19.3±0.6 efg | 4.3±1.2 hıj | 34.3 A |
| Average | 52.3 A | 30.87 B | 11.7 C | 1.7 D | |
| **Root dry weight (mg)** | | | | | |
| Ulusoy | 2.87±0.3 ab | 2.62±0.3 abc | 2.03±0.1 cd | 1.00±0.1 f | 2.13 A |
| Sorge | 2.80±0.2 ab | 2.23±0.3 bcd | 1.09±0.2 ef | 0.59±0.1 fgh | 1.68 B |
| Gülşeker | 1.74±0.2 de | 2.01±0.1 cd | 0.80±0.1 fg | 0.45±0.1 fgh | 1.25 C |
| Biomarlı | 0.40±0.2 fgh | 0.65±0.2 fgh | 0.09±0.1 gh | 0.00±0.0 h | 0.29 D |
| Erdurmuş | 3.15±0.5 a | 2.56±0.3 abc | 1.92±0.3 cd | 0.98±0.1 f | 2.15 A |
| Average | 2.19 A | 2.01 A | 1.19 B | 0.60 C | |
| **Shoot dry weight (mg)** | | | | | |
| Ulusoy | 7.21±1.0 a | 4.37±0.4 c | 1.89±0.4 de | 0.34±0.1 fg | 3.45 A |
| Sorge | 5.97±1.0 b | 3.67±0.4 c | 1.49±0.4 def | 0.15±0.0 g | 2.82 B |
| Gülşeker | 4.19±0.3 c | 3.56±0.3 c | 1.13±0.1 d-g | 0.23±0.2 g | 2.28 C |
| Biomarlı | 1.09±0.3 d-g | 0.83±0.1 efg | 0.23±0.1 g | 0.00±0.0 h | 0.54 D |
| Erdurmuş | 6.04±0.3 ab | 4.57±0.2 c | 2.20±0.2 d | 0.27±0.0 fg | 3.27 AB |
| Average | 4.90 A | 3.40 B | 1.39 C | 0.20 D | |
| **Significance level (P)** | | | | | |
| | | NaCl | Cultivar (C) | NaCl x C | |
| Root fresh weight | | 0.0001** | 0.0001** | 0.0001** | |
| Shoot fresh weight | | 0.0001** | 0.0001** | 0.0001** | |
| Root dry weight | | 0.0001** | 0.0001** | 0.0001** | |
| Shoot dry weight | | 0.0001** | 0.0001** | 0.0001** | |

*: The difference between the means indicated by the same letter in the same column / in the same row / in the same group is not statistically significant, x̄ ± Standard Deviation, **: Significant at the level of $p<0.01$

It was observed that root and shoot dry weights decreased with increased salt concentrations, as in fresh weight values, and this decrease was statistically significant at the $p<0.01$ level. In terms of both parameters, the highest values were determined as the average of the cultivars at control (2.19 and 4.90 mg, respectively), and the lowest values were found at 300 mM salt doses (0.60 and 0.20 mg, respectively). In the study, the difference between the cultivars in terms of root and shoot dry weights was also statistically significant at a $p<0.01$ level. This significant difference was between Ulusoy and Erdurmuş, and other cultivars. When the salt concentration x cultivar interaction was examined, it was determined that for all cultivars, the root and shoot dry weights decreased as salt concentration increased, but for some cultivars, there were significant increases at salt doses compared to the control. This situation resulted in a significant interaction ($p<0.01$) (Table 2).

Salinity significantly ($p<0.01$) decreased the root and shoot length of the studied sweet sorghum cultivars. As the average of the cultivars, the highest root and shoot length values were determined at the control (8.13 and 8.67 cm, respectively), while the lowest values (1.76 and 0.40 cm, respectively) were determined at the highest dose (300 mM). The variation between cultivars for root and shoot length was also statistically significant (p<0.01). Accordingly, the cv. Ulusoy had the longest (7.75 cm) root length, while Ulusoy (5.03 cm) and Erdurmuş (4.81 cm) had the longest shoot lengths. In the study, salt concentration x cultivar interaction was found to be significant (p<0.01) in terms of both seedling growth parameters. In general, it was thought that root and shoot lengths were decreased as salt concentrations increased, but this decrease was not significant compared to salt doses in some cultivars, which was effective in the significance of the interaction (Table 3).

**Table 3.** Some seedling growth parameters of sweet sorghum cultivars under different salt concentrations*

| Cultivars | Salt concentration (mM, NaCl) | | | | |
|---|---|---|---|---|---|
| | 0 | 100 | 200 | 300 | Average |
| Root length (cm) | | | | | |
| Ulusoy | 12.15±0.5 a | 9.56±0.9 b | 6.62±0.1 cde | 2.67±0.2 fgh | 7.75 A |
| Sorge | 9.78±0.7 b | 7.75±0.4 bc | 3.78±0.6 fgh | 1.97±0.3 hı | 5.82 B |
| Gülşeker | 7.15±0.1 c | 6.16±0.2 cde | 4.83±0.3 def | 1.93±0.2 hı | 5.02 B |
| Biomarlı | 3.26±0.5 fgh | 3.01±0.6 fgh | 1.72±0.5 hı | 0.00±0.0 ı | 2.00 C |
| Erdurmuş | 8.30±0.9 bc | 7.07±0.1 cd | 4.45±0.7 efg | 2.24±0.3 ghı | 5.52 B |
| Average | 8.13 A | 6.71 B | 4.28 C | 1.76 D | |
| Shoot length (cm) | | | | | |
| Ulusoy | 11.41±0.9 a | 5.73±0.3 de | 2.55±0.4 fgh | 0.41±0.0 ıj | 5.03 A |
| Sorge | 8.80±0.3 b | 4.21±0.5 ef | 1.89±0.3 g-j | 0.47±0.1 ıj | 3.84 B |
| Gülşeker | 8.30±0.2 bc | 4.31±0.3 ef | 2.32±0.1 f-ı | 0.41±0.1 ıj | 3.84 B |
| Biomarlı | 6.41±0.6 cd | 3.28±0.2 fg | 0.63±0.1 hıj | 0.00±0.0 j | 2.58 C |
| Erdurmuş | 8.43±0.8 bc | 6.86±0.9 bcd | 3.28±0.2 fg | 0.69±0.1 hıj | 4.81 A |
| Average | 8.67 A | 4.88 B | 2.13 C | 0.40 D | |
| Lateral root number (pieces) | | | | | |
| Ulusoy | 9.2±0.1 b | 6.9±0.2 c | 8.5±0.3 b | 0.4±0.2 h | 6.27 A |
| Sorge | 11.7±0.2 a | 5.7±0.2 d | 2.0±0.2 fg | 0.4±0.1 h | 4.94 B |
| Gülşeker | 8.6±0.3 b | 5.3±0.2 d | 2.2±0.2 fg | 0.0±0.0 ı | 4.03 C |
| Biomarlı | 2.6±0.2 ef | 1.1±0.1 gh | 0.0±0.0 ı | 0.0±0.0 ı | 0.93 D |
| Erdurmuş | 9.0±0.2 b | 3.5±0.2 e | 2.9±0.2 ef | 0.4±0.1 h | 3.96 C |
| Average | 8.22 A | 4.50 B | 3.12 C | 0.25 D | |
| Lateral root length (cm) | | | | | |
| Ulusoy | 14.8±1.1 a | 4.9±0.3 d | 4.0±0.2 de | 0.1±0.0 j | 5.94 A |
| Sorge | 11.6±0.9 b | 2.5±0.3 fg | 0.5±0.2 ıj | 0.2±0.0 j | 3.69 C |
| Gülşeker | 9.5±0.5 c | 2.6±0.3 fg | 1.1±0.1 hıj | 0.0±0.0 j | 3.28 C |
| Biomarlı | 3.0±0.2 ef | 1.7±0.2 ghı | 0.0±0.0 j | 0.0±0.0 j | 1.16 D |
| Erdurmuş | 10.5±0.7 bc | 4.1±0.2 de | 2.1±0.1 fg | 0.2±0.0 j | 4.18 B |
| Average | 9.85 A | 3.15 B | 1.52 C | 0.08 D | |
| Significance level (P) | | | | | |
| | | NaCl | Cultivar (C) | NaCl x C | |
| Root length | | 0.0001** | 0.0001** | 0.0001** | |
| Shoot length | | 0.0001** | 0.0001** | 0.0001** | |
| Lateral root number | | 0.0001** | 0.0001** | 0.0001** | |
| Lateral root length | | 0.0001** | 0.0001** | 0.0001** | |

*: The difference between the means indicated by the same letter in the same column / in the same row / in the same group is not statistically significant, $\bar{x}$ ± Standard Deviation, **: Significant at the level of p<0.01

Salinity resulted in significant (p<0.01) decreases in the number of lateral roots and lateral root length values. While the number and length of lateral roots were 8.22 pieces and 9.85 cm, respectively in control, these values decreased as salt dose increased, and the lowest values were obtained in 300 mM as 0.25 pieces and 0.08 cm, respectively. In the study, the cultivars were statistically significantly effective on the number of lateral roots and lateral root length at p<0.01 level. In this context, the highest values were determined at the cv. Ulusoy as in all germination and seedling growth parameters, followed by Sorge in the number of lateral roots and Erdurmuş in lateral root length. Salt concentration x cultivar interaction was statistically significant at p<0.01 level. In general, although the number of lateral roots and lateral root length values decreased for all cultivars as salt concentration increased, for some cultivars, statistically significant increases in groups and/or insignificant decreases in some doses were effective on the significance of the interaction (Table 3).

## 4. Discussion and Conclusion

Crop establishment is very important to obtain an optimum yield in field agriculture. In this sense, adequate and early seedling development with quality and uniform germination of the seeds following sowing is critical for obtaining optimum plant population and crop development. Germination and quality seedling development do depend on the characteristics of the seed material, as well as on many existing biotic and abiotic stress factors in the growth environment, especially soil salinity. Although sweet sorghum species are more tolerant to salt stress compared to traditional crops (such as wheat and rice) (Ratanavathi et al., 2004), poor germination under severe salt stress is one of the most important problems limiting sweet sorghum production (Zhu et al., 2019). It is well known that an increase in salt dose negatively affects germination, growth, and development, and the most sensitive time to salinity during the development of plants is germination.

In the study, there were significant decreases in all germination parameters (except MGT) due to the increase in salt concentrations on each cultivar and the average results of the cultivars (Table 1). As many researchers were stated (Munns, 2005; Dan and Brix, 2007; Tavili and Biniaz, 2009; Day and Uzun, 2016; Önal Aşçı and Üney, 2016; Chen et al., 2020), inhibition of water uptake and embryo poisoning as a result of the high salt level was the reason for the decreased germination percentage. The results obtained for germination parameters, especially for the GP, were found to be compatible with other studies (Almodares et al., 2007; Asfaw and Woldemariam, 2008; Akhtar and Hussain, 2009; Mustafa et al., 2010; Nakaune et al., 2012; Aydinşakir et al., 2013; De Souza et al., 2014; Ahmed Nimir et al., 2014; Önal Aşçı and Üney, 2016; Ceritoğlu and Erman, 2020; Rajabi Dehnavi et al., 2020) conducted with sorghum species and some other plants exposed to salt stress.

In our study, significant differences were also observed between sweet sorghum cultivars for all examined germination parameters (Table 1). This difference was thought to be due to the genotypic differences of the cultivars. As a matter of fact, in many studies conducted with sorghum (Almodares et al., 2007; Krishnamurthy et al., 2007; Ahmed Nimir et al., 2014; Ali and Idris, 2015; Shakeri and Emam, 2017; Shakeri et al., 2017; Rajabi Dehnavi et al., 2020) and with other plants species (Okçu et al., 2005; Kaya et al., 2008; Kara et al., 2011; Aydinşakir et al., 2013; Day and Uzun, 2016; Çakmakçı and Dallar, 2019; Ceritoğlu et al., 2020), high genotypic variation among genotypes for salt tolerance and different genotypic responses in germination parameters were determined.

Mean germination time reflects the speed of seed germination (Bijanzadeh and Egan, 2018). In our study, it was determined that the MGT was prolonged due to the increased salt content for all sweet sorghum cultivars and showed significant changes between the cultivars (Table 1). In some other studies conducted with different plant species and cultivars; such as studies of Okçu et al. (2005) with *Pisum sativum* L., Atak et al. (2006) and Kara et al. (2011) with triticale, Almodares et al. (2007) with sweet sorghum, Kaya et al. (2008) with *Cicer arietinum* L., Bijanzadeh and Egan (2018) with *Triticum durum* desf. and Rajabi Dehnavi et al. (2020) with *S. bicolor* (L.) Moench, it was reported that salt doses extended the germination time and there were differences between the cultivars in terms of MGT.

Shoot and roots were the first organs of plants affected by salt stress, and the developmental course of these parts of the plant gives an important idea in terms of salt tolerance. In the study, it was observed that the seedling growth parameters of each cultivar and the average data of all cultivars decreased as salt concentrations increased (Tables 2 and 3). These results were similar to other studies conducted with sorghum species (Netondo et al., 2004a, 2004b; Asfaw and Woldemariam, 2008; Bashir et al., 2011; Ahmed Nimir et al., 2014; Rajabi Dehnavi et al., 2020).

In many other studies with conducted with different plant species exposed to salt stress such as *Pisum sativum* L. (Okçu et al., 2005), *Trifolium* sp. (Vahdati et al., 2012), *Hordeum vulgare* L. (Benlioğlu and Özkan, 2015), *Elymus farctus* (El-Katony et al., 2015), *Trigonella foenum-graceum* L. (Ivani et al., 2018; Özyazıcı and Açıkbaş, 2021a) and *Vicia narbonensis* L. (Özyazıcı and Açıkbaş, 2021b), results on seedling growth characteristics such as root and shoot length, fresh weight and dry weight were compatible with our study.

The slowed growth in root and shoot development due to the increase in salt concentration may be explained by the decrease in water and nutrient uptake as a result of the toxic effects of salt. Salinity has negative effects on plant tissues and organs (Koyro, 2002; Welfare et al., 2002; Rasheed, 2009), and also prevents nutrient uptake required for plant growth with its osmotic and specific ionic toxicity effects (Vishnu et al., 2017), as a result, a restrictive effect on root formation and seedling growth was reported

(Krishnamurthy et al., 2007; Abari et al., 2011; Bilgili et al., 2011).

Lateral roots play an important role in water and nutrient uptake (Rostamza et al., 2013). It was observed that the number and length of lateral roots were affected by salt stress during the germination and seedling period. High salt concentrations significantly reduced the number and lengths of lateral roots (Table 3). It was also reported in some studies (Açıkbaş and Özyazıcı, 2021; Ceritoglu and Erman, 2021; Özyazıcı and Açıkbaş, 2021b) that as the salinity intensity increases in the rhizosphere, the number, and length of lateral roots get decrease.

In the study, it was determined that there were significant changes in terms of seedling growth parameters among cultivars (Tables 2 and 3). In the studies of Benlioğlu and Özkan (2015) with *H. vulgare* L., Day and Uzun (2016) with *V. sativa* L., Çakmakçı and Dallar (2019) with *Zea mays* L., Ali and Idris (2015) and Rajabi Dehnavi et al. (2020) with *S. bicolor* (L.) Moench, it was reported that genotypes were affected at different rates in terms of root and shoot development.

Sorghum, which is considered more salt-tolerant compared to maize, has a high potential to be grown in salt-affected areas. However, there is a great variation among the sorghum genotypes in terms of salt tolerance. With this study, it can be concluded that sweet sorghum cultivars show significant differences in terms of salt tolerance during germination and seedling stages. As a result of the research, Ulusoy and Erdurmuş cultivars were prominent in terms of salt tolerance among tested sweet sorghum cultivars.

While significant decreases were observed in germination parameters after 100 mM salt dose, cultivars were found more sensitive to salt stress during the seedling development compared to the germination stage, and negative effects were started at 100 mM dose in the seedling stage. In general, increased salt doses adversely affected all the properties examined in the study. It is important to use salt-tolerant cultivars considering the genotypic differences in sweet sorghum cultivation in salt-affected areas.

## References

Abari, A.K., Nasr, M.H., Hojjati, M., Bayat, D., 2011. Salt effects on seed germination and seedling emergence of two Acacia species. *African Journal of Plant Science*, 5(1): 52-56.

Abazarian, R., Yazdani, M.R., Khosroyar, K. Arvin, P., 2011. Effects of different levels of salinity on germination of four components of lentil cultivars. *African Journal of Agricultural Research*, 6(5): 2761-2766.

Açıkbaş, S., Özyazıcı, M.A., 2021. The effects of silicon priming application on germination in common grasspea (*Lathyrus sativus* L.). *3rd International African Conference on Current Studies*, 27-28 February, Abomey-Calavi, Benin, pp. 404-412. (In Turkish).

Açıkgöz, N., Açıkgöz, N., 2001. Common mistakes in the statistical analyzes of agricultural experiments I. Single factorials. *ANADOLU Ege Tarımsal Araştırma Enstitüsü Dergisi*, 11(1): 135-147. (In Turkish).

Ahmed Nimir, N.E., Lu, S., Zhou, G., Ma, B.L., Guo, W., Wang, Y., 2014. Exogenous hormones alleviated salinity and temperature stresses on germination and early seedling growth of sweet sorghum. *Agronomy Journal*, 106(6): 2305-2315.

Akhtar, P., Hussain, F., 2009. Growth performance of *Vicia sativa* L. under saline conditions. *Pakistan Journal of Botany*, 41(6): 3075-3080.

Ali, S.A., Idris, A.Y., 2015. Response of sorghum (*Sorghum bicolor* L.) cultivars to salinity levels at early growth stages. *Journal of Agricultural Science and Engineering*, 1(1): 11-16.

Almodares, A., Hadi, M.R., 2009. Production of bioethanol from sweet sorghum: A review. *African journal of agricultural research*, 4(9): 772-780.

Almodares, A., Hadi, M.R., Dosti, B., 2007. Effects of salt stress on germination percentage and seedling growth in sweet sorghum cultivars. *Journal of Biological Sciences*, 7(8): 1492-1495.

Asfaw, G.K., Woldemariam, G.M., 2008. Response of some lowland growing sorghum (*Sorghum bicolor* L. Moench) accessions to salt stress during germination and seedling growth. *African Journal of Agricultural Research*, 3(1): 44-48.

Atak, M., Kaya, M.D., Çiftçi, C.Y., 2006. Effect of seedling growth on triticale cultivars irradiated with various doses of gamma radiation. *Journal of Agricultural Sciences*, 12(3): 233-238. (In Turkish).

Aydınşakir, K., Erdal, Ş., Pamukçu, M., 2013. The effects of different salt concentrations on germination and seedling parameters of silage corn (*Zea mays* L.) varieties. *Anadolu Journal of Agricultural Sciences*, 28(2): 94-100.

Bashir, F., Ali, M., Hussain, K., Majeed, A., Nawaz, K., 2011. Morphological variations in sorghum (*Sorghum bicolor* L.) under different levels of $Na_2SO_4$ salinity. *Botany Research International*, 4(1): 1-3.

Benlioğlu, B., Özkan, U., 2015. Determination of responses of some barley cultivars (*Hordeum vulgare* L.) to salt stress in different doses at the germination period. *Jornal of Central Research Institute for Field Crops*, 24(2): 109-114. (In Turkish).

Bewely, J., Black, M., 1994. Seeds: Physiology of Development and Germination. New York.

Bijanzadeh, E., Egan, T.P., 2018. Silicon priming benefits germination, ion balance, and root structure in salt-stressed durum wheat (*Triticum durum* desf.). *Journal of Plant Nutrition*, 41(20): 2560-2571.

Bilgili, U., Carpici, E.B., Asik, B.B., Celik, N., 2011. Root and shoot response of common vetch (*Vicia sativa* L.), forage pea (*Pisum sativum* L.) and canola (*Brassica napus* L.) to salt stress during early seedling growth stages. *Turkish Journal of Field Crops*, 16(1): 33-38.

Ceritoglu, M., Erman, M., 2021. Effect of silicon priming treatments on germination and some agronomic traits in lentil. *3rd International African Conference on Current Studies*, 27-28 February, Abomey-Calavi, Benin, pp. 436-444.

Ceritoğlu, M., Erman, M., 2020. Mitigation of salinity stress on chickpea germination by salicylic acid priming. *International Journal of Agriculture and Wildlife Science*, 6(3): 582-591.

Ceritoğlu, M., Erman, M., Yıldız, F., 2020. Effect of salinity on germination and some agro-morphological traits in chickpea seedlings. *ISPEC Journal of Agricultural Sciences*, 4(1): 82-96.

Chen, T., Pineda, I.M.G., Brand, A.M., Stützel, H., 2020. Determining ion toxicity in cucumber under salinity stress. *Agronomy*, 10(5): 677.

Corwin, D.L., 2021. Climate change impacts on soil salinity in agricultural areas. *European Journal of Soil Science*, 72(2): 842-862.

Çakmakçı, S., Dallar, A., 2019. Effects of different temperatures and salt concentrations on the germination of some corn silage varieties. *Journal of Tekirdag Agricultural Faculty*, 16(2): 121-132. (In Turkish).

Dan, T.H., Brix, H., 2007. The influence of temperature, light, salinity and seed pre-treatment on the germination of sesbania sesban seeds. *African Journal of Biotechnology*, 6(19): 2231-2235.

Day, S., Uzun, S., 2016. Impact of different NaCl doses on germination and early seedling growth of common vetch cultivars (*Vicia sativa* L.). *Turkish Journal of Agriculture-Food Science and Technology*, 4(8): 636-641. (In Turkish).

De Lacerda, C.F., Cambraia, J., Oliva, M.A., Ruiz, H.A., 2005. Changes in growth and in solute concentrations in sorghum leaves and roots during salt stress recovery. *Environmental and Experimental Botany*, 54(1): 69-76.

De Souza, C.L.M., De Souza, M.O., De Oliveira, L.M., Pelacani, C.R., 2014. Effect of priming on germinability and salt tolerance in seeds and seedlings of *Physalis peruviana* L. *African Journal of Biotechnology*, 13(19): 1955-1960.

Ekmekçi, E., Apan, M., Kara, T., 2005. The effect of salinity on plant growth. *Anadolu Journal of Agricultural Sciences*, 20(3): 118-125. (In Turkish).

Ellis, R.A., Roberts, E.H., 1981. The quantification of ageing and survival in orthodox seeds. *Seed Science and Technology*, 9(2): 373-409.

El-Katony, T.M., Khedr, A.H.A.F., Soliman, N.G., 2015. Nutrients alleviate the deleterious effect of salinity on germination and early seedling growth of the psammophytic grass *Elymus farctus*. *Botany*, 93(9): 559-571.

Guden, B., Erdurmus, C., Erdal, S., Uzun, B., 2020. Evaluation of sweet sorghum genotypes for bioethanol yield and related traits. *Biofuels, Bioproducts and Biorefining*, 15(2): 545-562.

Hafsi, C., Romero-Puertas, M.C., Gupta, D.K., Del Rio, L.A., Sandalio, L.M., Abdelly, C., 2010. Moderate salinity enhances the antioxidative response in the halophyte *Hordeum maritimum* L. under potassium deficiency. *Environmental and Experimental Botany*, 69(2): 129-136.

Inal, I., Yucel, C., Yucel, D., Hatipoglu, R., 2021. Nutritive value and fodder potential of different sweet sorghum genotypes under mediterranean conditions. *Turkish Journal of Field Crops*, 26(1): 1-7.

Ivani, R., Sanaei Nejad, S.H., Ghahraman, B., Astaraei, A.R., Feizi, H., 2018. Role of bulk and nanosized $SiO_2$ to overcome salt stress during fenugreek germination (*Trigonella foenum-graceum* L.). *Plant Signaling & Behavior*, 13(7): e1044190.

Kara, B., Akgün, İ., Altındal, D., 2011. Effects of salinity (NaCl) on germination and seedling growth in triticale genotypes. *Selcuk Journal of Agriculture and Food Sciences*, 25(1): 1-9. (In Turkish).

Katerij, N., Van Hoorn, J.W., Hamdy, A., Mastrorilli, M., Fares, C., Ceccarelli, S., Grando, S., Oweis, T., 2006. Classification and salt tolerance analysis of barley varieties. *Agricultural Water Management*, 85(1-2): 184-192.

Kaya, M., Kaya, G., Kaya, M.D., Atak, M., Sağlam, S., Khawar, K.M., Çiftçi, C.Y., 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*(5): 371-377.

Koyro, H.W., 2002. Ultrastructural effects of salinity in higher plants. In: A. Läuchli and U. Lüttge (Eds.), *Salinity: Environment-Plants-Molecules*, Springer, Dordrecht, pp. 139-157.

Krishnamurthy, L., Serraj, R., Hash, C.T., Dakheel, A.J., Reddy, B.V.S., 2007. Screening sorghum genotypes for salinity tolerant biomass production. *Euphytica*, 156(1): 15-24.

Li, R., Shi, F., Fukuda, K., Yang, Y., 2010. Effects of salt and alkali stresses on germination, growth, photosynthesis and ion accumulation in alfalfa (*Medicago sativa* L.). *Soil Science and Plant Nutrition*, 56(5): 725-733.

Maiti, R.K., De La Rosa-Ibarra, M., Sandowal, N.D., 1994. Genotypic variability in glossy sorghum lines for resistance to drought, salinity and temperature-stress at seedling stage. *Journal of Plant Physiology*, 143(2): 241-244.

Munns, R., 2005. Genes and salt tolerance: bringing them together. *New phytologist*, 167(3): 645-663.

Munns, R., Tester, M., 2008. Mechanisms of salinity tolerance. *Annual Review of Plant Biology*, 59: 651-681.

Mustafa, M., Shabber, S., Hussain, K., 2010. Growth retitence of maize (*Zea mays* L.) under different levels on NaCl stres. *American-Eurasian Journal of*

*Agricultural and Environmental Science*, 7(5): 583-585.

Nakaune, M., Hanada, A., Yin, Y.G., Matsukura, C., Yamaguchi, S., Ezura, H., 2012. Molecular and physiological dissection of enhanced seed germination using short-term low-concentration salt seed priming in tomato. *Plant Physiology and Biochemistry*, 52*:* 28-37.

Netondo, G.W., Onyango, J.C., Beck, E., 2004a. Sorghum and salinity. I. Response of growth, water relations, and ion accumulation to NaCl salinity. *Crop Science*, 44(3): 797-805.

Netondo, G.W., Onyango, J.C., Beck, E., 2004b. Sorghum and salinity. II. Gas exchange and chlorophyll fluorescence of sorghum under salt stress. *Crop Science*, 44(3): 806-811.

Okçu, G., Kaya, M.D., Atak, M., 2005. Effects of salt and drought stresses on germination and seedling growth of pea (*Pisum sativum* L.). *Turkish Journal of Agriculture and Forestry*, 29(4): 237-242.

Önal Aşçı, Ö., Üney, H., 2016. The effect of different salt concentrations on germination and plant growth of hungarian vetch (*Vicia pannonica* Crantz). *Academic Journal of Agriculture*, 5(1): 29-34. (In Turkish).

Özyazıcı, G., Açıkbaş, S., 2021a. Determination of germination characteristics of fenugreek (*Trigonella foenum-graecum* L.) plant under salt stress. *International Hazar Scientific Researches Conference-II*, 10-12 April, Bakü, Azerbaijan pp. 347-353. (In Turkish).

Özyazıcı, M.A., Açıkbaş, S., 2021b. Effects of salt stress on germination in narbon vetch (*Vicia narbonensis* L.). *2. International Baku Scientific Research Conference*, 28-30 April, Bakü, Azerbaijan. pp. 310-317. (In Turkish).

Pankova, E.I., Konyushkova, M.V., 2013. Climate and soil salinity in the deserts of Central Asia. *Eurasian Soil Science*, 46(7): 721-727.

Parida, A.K., Das, A.B., 2005. Salt tolerance and salinity effects on plants: A review. *Ecotoxicology and Environmental Safety*, 60(3): 324-349.

Rajabi Dehnavi, A., Zahedi, M., Ludwiczak, A., Cardenas Perez, S., Piernik, A., 2020. Effect of salinity on seed germination and seedling development of sorghum (*Sorghum bicolor* (L.) Moench) genotypes. *Agronomy*, 10(6): 859.

Rasheed, R., 2009. Salinity and extreme temperature effects on sprouting buds of sugarcane (*Saccharum ficinarum* L.): Some histological and biochemical studies. Ph.D. thesis, University of Agriculture, Faisalabad, Pakistan.

Ratanavathi, C.V., Dayakar Rao, B., Seetharama, N., 2004. Sweet Sorghum: A New Raw Material for Fuel Alcohol. Study Report on Technological Aspects in Manufacturing Ethyl Alcohol from Cereal Grains in Maharashtra, Part II, Prepared by Department of Scientific & Industrial Research, Ministry of Science & Technology, Government of India, New Delhi and Mitcon Cinsultancy Services Limited, Pune, pp. 32-41.

Rostamza, M., Richards, R.A., Watt, M., 2013. Response of millet and sorghum to a varying water supply around theprimary and nodal roots. *Annals of Botany*, 112(2): 439-446.

Rueden, C.T., Schindelin, J., Hiner, M.C., DeZonia, B.E., Walter, A.E., Arena, E.T., Eliceiri, K.W., 2017. ImageJ2: Imagej for the next generation of scientific image data. *BMC Bioinformatics*, 18(1): 529.

Sabagh, A.E.L., Hossain, A., Islam, M.S., Iqbal, M.A., Amanet, K., Mubeen, M., Nasim, W., Wasaya, A., Llanes, A., Ratnasekera, D., Singhal, R.K., Kumari, A., Meena, R.S., Abdelhamid, M., Hasanuzzaman, M., Raza, M.A., Özyazici, G., Ozyazici, M.A., Erman, M., 2021. Prospective role of plant growth regulators for tolerance to abiotic stresses. In: T. Aftab and K.R. Hakeem (Eds.), *Plant Growth Regulators*, Springer, Cham., Switzerland AG., pp. 1-38.

Scott, S.J., Jones, R.A., Williams, W.A., 1984. Review of data analysis methods for seed germination. *Crop Science*, 24(6): 1192-1199.

Shakeri, E., Emam, Y., 2017. Selectable traits in sorghum genotypes for tolerance to salinity stress. *Jomo Kenyatta University of Agriculture and Technology*, 19(6): 1319-1332.

Shakeri, E., Emam, Y., Tabatabaei, S., Sepaskhah, A., 2017. Evaluation of grain sorghum (*Sorghum bicolor* L.) lines/cultivars under salinity stress using tolerance indices. *International Journal of Plant Production*, 11(1): 101-115.

Soleymani, A., Shahrajabian, M.H., 2018. Changes in germination and seedling growth of different cultivars of cumin to drought stress. *Cercetări Agronomice în Moldova*, 1(173): 91-100.

Tavili, A., Biniaz, M., 2009. Different salts effects on the germination of *Hordeum vulgare* and *Hordeum bulbosum*. *Pakistan Journal of Nutrition*, 8(1): 63-68.

Tigabu, E., Andargie, M., Tesfaye, K., 2012. Response of sorghum (*Sorghum bicolor* (L.) Moench) genotypes to NaCl levels at early growth stages. *African Journal of Agricultural Research*, 7(43): 5711-5718.

Vahdati, N., Tehranifar, A., Neamati, S.H., Selahvarzi, Y., 2012. Physiological and morphological responses of white clover (*Trifolium repens*) and red clover (*Trifolium pratense*) plants of salinity stress. *Journal of Ornamental and Horticultural Plants*, 2(4): 233-241.

Vishnu, V., Usadadia, V.P., Mawalia, A.K., Patel, M.M., Patel, V.K.A., 2017. Impact assessment of land configuration and bio-organic on nutrient uptake and quality of chickpea (*Cicer arietinum* L.) under coastal salt affected soil. *International Journal of Pure and Applied Biosource*, 5(3): 726-734.

Wang, Y.R., Yu, L., Nan, Z.B., Liu, Y.L., 2004. Vigor tests used to rank seed lot quality and predict field emergence in four forage species. *Crop Sciences*, 44(2): 535-541.

Welfare, K., Yeo, A.R., Flowers, T.J., 2002. Effects of salinity and ozone, individually and in combination, on the growth and ion contents of two chickpeas

(*Cicer arietinum* L.) varieties. *Environmental Pollution*, 120(2): 397-403.

Xu, G., Zhang, Y., Sun, J., Shao, H., 2016. Negative interactive effects between biochar and phosphorus fertilization on phosphorus availability and plant yield in saline sodic soil. *Science of The Total Environment*, 568: 910-915.

Zhu, G., An, L., Jiao, X., Chen, X., Zhou, G., McLaughlin, N., 2019. Effects of gibberellic acid on water uptake and germination of sweet sorghum seeds under salinity stress. *Chilean Journal of Agricultural Research*, 79(3): 415-424.

Zörb, C., Geilfus, C.M., Dietz, K.J., 2019. Salinity and crop yield. *Plant Biology*, 21(Suppl. 1): 31-38.