


## The effect of silicon applications on seedling growth stress parameters in lettuce (*Lactuca sativa* L.) under salt stress conditions

Tuz stresi koşullarında marulda (*Lactuca sativa* L.) silikon uygulamalarının fide büyüme stresi parametrelerine etkisi

Yusuf ÇELİK<sup>1</sup> 

<sup>1</sup>Mersin University, Silifke Vocational School, Department of Plant and Animal Production, Silifke, Türkiye.

ARTICLE INFO	ABSTRACT
<p><b>Article history:</b> Received / Geliş: 06.06.2024 Accepted / Kabul: 16.11.2024</p> <p><b>Keywords:</b> Lettuce seedling Potassium silicate NaCl Tolerance</p> <p><b>Anahtar Kelimeler:</b> Marul fidesi Potasyum silicat NaCl Tolerans</p> <p>✉Corresponding author: Yuusuf ÇELİK ycelik33@mersin.edu.tr</p> <p>Makale Uluslararası Creative Commons Attribution-Non Commercial 4.0 Lisansı kapsamında yayınlanmaktadır. Bu, orijinal makaleye uygun şekilde atıf yapılması şartıyla, eserin herhangi bir ortam veya formatta kopyalanmasını ve dağıtılmasını sağlar. Ancak, eserler ticari amaçlar için kullanılamaz. © Copyright 2022 by Mustafa Kemal University. Available on-line at <a href="https://dergipark.org.tr/tr/pub/mkutbd">https://dergipark.org.tr/tr/pub/mkutbd</a></p> <p>This work is licensed under a Creative Commons Attribution-Non Commercial 4.0 International License.</p> 	<p>Salt stress prevents plant growth and development by disrupting osmotic and ionic balance. In this study; As a result of silicon (Si) application, which can activate tolerance mechanism against salt stress in lettuce seedlings; Changes in antioxidant (SOD, CAT, APX, POD) and physiological parameters (proline, leaf chlorophyll ratio, leaf membrane permeability and relative water content) effective on seedling growth were investigated. Control plants grew better than plants treated with only salt. As a result of Si+100 mM NaCl and Si+50 mM NaCl applications; Increases between 176% and 339% in SOD, CAT, APX, POD levels, increases between 26.9% and 28.1% in leaf chlorophyll and moisture content and decreases between 15.2% and 76.4% in leaf membrane damage were determined. The relationship between proline accumulation and antioxidant enzyme activities was effective with Si application and showed that plants improved their defense against salt stress. Plant development decreased according to the severity of salt as a result of only salt applications. It was determined that 150x100kg.ha-1Si interaction was more effective on plant growth in all plots.</p> <p><b>ÖZET</b></p> <p>Tuz stresi bitkilerin büyümesini ve gelişmesini osmotik ve iyon dengesini bozarak engellemektedir. Bu çalışmada; Marul fidelerinde tuz stresine karşı tolerans mekanizmalarını harekete geçirebilen silikon (Si) uygulaması sonucunda; Fide büyümesinde etkili olan antioksidan (SOD, CAT, APX, POD) ve fizyolojik parametrelerdeki (prolin, yaprak klorofil oranı, yaprak membran geçirgenliği ve bağlı su içeriği) değişimler araştırılmıştır. Kontrol bitkileri, yalnızca tuzla muamele edilen bitkilerden daha iyi büyüdü. Si+100 mM NaCl ve Si+50 mM NaCl uygulamaları sonucunda; SOD, CAT, APX, POD seviyelerinde %176 ile %339 arasında artışlar, yaprak klorofili ve nem içeriğinde %26,9 ile %28,1 arasında artışlar ve yaprak zarı hasarında %15,2 ile %76,4 arasında azalmalar belirlendi. Prolin birikimi ile antioksidan enzim aktiviteleri arasındaki ilişki Si uygulamasıyla etkili olmuş ve bitkilerin tuz stresine karşı savunmayı geliştirdiklerini göstermiştir. Sadece tuz uygulamaları sonucunda tuzun şiddetine göre bitki gelişimi azalmıştır. 150x100kg.ha-1Si etkileşiminin tüm parsellerde bitki büyümesinde daha etkili olduğu belirlendi.</p>
<b>Cite/Atf</b>	Yusuf, Ç. (2025). The effect of silicon applications on seedling growth stress parameters in lettuce ( <i>Lactuca sativa</i> L.) under salt stress conditions. <i>Mustafa Kemal Üniversitesi Tarım Bilimleri Dergisi</i> , 30 (1), 72-82. <a href="https://doi.org/10.37908/mkutbd.1496859">https://doi.org/10.37908/mkutbd.1496859</a>

## INTRODUCTION

The growing world population and the consequent increasing demand for agricultural products continuously contribute to soil degradation (Adejumobi et al., 2016; Temme et al., 2019) and is one of the most critical factors affecting soil salinization. There is a salinity problem in approximately 1.5 million hectares of Turkey's land (Kalefetoğlu; Ekmekçi, 2005). The conditions that affect the growth and development of plants are called stress. Stress factors are divided into abiotic (temperature, drought, salinity, radiation, wind, etc.) and biotic (virus, bacteria and insects, etc.) (Larcher, 1995; Yılmaz et al., 2011). Salinity problem causes many negative effects on agricultural lands. It reduces growth, yield and quality by disrupting the metabolic activities that provide vital events in plants (Alp; Kabay, 2019; Kabay, 2019; Yılmaz et al., 2011).

Lettuce, which is resistant to cold and needs humid weather conditions, is highly sensitive to salt and this sensitivity causes stress in the plant. However, excess salt in the soil affects osmotic stress, ion toxicity, nutrient ion balance, and also affects plant growth and physiological functions (Zhang et al., 2018).

Salinity stress is an abiotic stress factor for plants and has a chemical stress effect. High salt content in the growing medium adversely affects plant life. These negative effects have been determined as disruptions in enzyme regulation, nutrient imbalance, membrane dysfunction, impaired metabolic regulation, osmotic imbalance and problems in water intake, oxidative stress and developmental problems (Orcutt and Nilsen, 1996). The responses of plants exposed to drought and salinity stress are similar (Muns, 2002; Kuşvuran& Kabak, 2012; Osakabe et al., 2014). The water uptake effect of plants grown in salty soils decreases rapidly. Plant development is impaired due to hormonal signals transmitted from the roots in plants (Munns, 2002). Plants first close their stomata to reduce water loss (Kuşvuran& Kabak, 2012, Osakabe et al., 2014). The electrons released as a result of the closure of the stomata and the prevention of the entry of CO<sub>2</sub> gas are absorbed by the chlorophylls and take part in the formation of free oxygen radicals (ROS) together with light energy. ROS damage proteins, membrane lipids, nucleic acids and chlorophyll (Çaylak, 2011; Kuşvuran&Kabak , 2012).

Although silicon is not a basic nutrient element for plants, some studies have shown that it is beneficial for plants. According to these results, silicon reduces water loss in plants; increases leaf chlorophyll content; It has been determined that it increases the endurance of cells and plants respire more. These physiological changes include water deficiency, metal toxicity, salinity, etc. It allows reducing the effects of abiotic stresses such as (Rodrigues et al., 2011; Lima et al., 2011; Rizwan et al., 2015). Exogenous silicon application ameliorated the detrimental effects of salinity stress on stomatal movement of sweet pepper (*Capsicum annum*) plants (Manivannan et al., 2016). It has been determined that silicon application contributes to the protection of photosynthetic pigments and the regulation of the photosynthesis mechanism in plants exposed to salt stress. (Muneer et al., 2014). In general, it has been determined that silicon plays an effective role in the activation of nutrition, growth and antioxidant mechanisms in plants (Boling et al., 2019). Salt tolerance levels of plants are generally at their lowest during the young seedling stage. Considering the problem that salt stress shows its effect more in the seedling period in lettuce, this study aims to further address the modulation of salt stress responses in lettuce seedlings and their relationship with Si, supported by the responses of antioxidant systems of seedlings to stressful salt conditions.

## MATERIALS and METHODS

### *Plant material*

The plant material used in the study was Hazer Lital Lettuce Seed, which belongs to a commercial company. It is a type of lettuce with a belly. It is resistant to heat and it is late to stem. The average head weight is 800 - 1100 gr. Harvest period is 55 - 70 days. The leaf color is light green, resembling light yellow. The leaves are upright, crispy and wide. The leaf edges are wavy and slightly toothed.

**Properties of Powder Potassium Silicate**

Table 1. Content of potassium silicate

*Çizelge 1. Potasyum silikatın içeriği*

items	TR-PS001
Density g/ml(20°C)	0.5-0.8
K <sub>2</sub> O (%)	28.0-32.0
SiO <sub>2</sub> (%)	52.0-58.0
Ratio (M)	2.7-2.9
Degree of fineness (100 Mesh)	5
Dissolution rates ≤	120

**Trial layout and applications were created as follows**

- 1-Control
- 2-50 mM NaCl
- 3-100 mM NaCl
- 4-200 mM NaCl
- 5-50 mM NaCl+Si
- 6-100 mM NaCl+ Si
- 7-200 mM NaCl+ Si

**Electrophoretic separation of superoxide dismutase (SOD; EC 1.15.1.1) isoenzymes**

Leaf extracts containing equal amounts of protein (100 mg/well) were separated by Native-Page according to Laemmli (1970). SOD activity was determined by riboflavin and nitrobluetetrazolium (NBT) staining according to Beauchamp and Fridovich (1971). After the gels were kept in the dye solution for 30 minutes, the densitometric analysis of the SOD isozyme bands was performed with the imaging device in the Bio-1D software program. One unit of SOD activity was determined as the amount of enzyme causing 50% inhibition of the photochemical reduction of NBT, which is the electron acceptor measured in spectrophotometer at 560 nm, and the specific enzyme activity was determined as U/mg protein. Unit indicates the amount of enzyme (SOD) that converts 1 µmol of substrate to product in 1 minute at 25°C.

**Determination of the activity of catalase (CAT; EC 1.11.1.6) isoenzymes**

CAT isozymes Woodbury et al. (1971) according to the method described. After the samples containing 30 g protein were run in 7.5% non-denatured gel, the gels were incubated for 10 minutes in 0.003% H<sub>2</sub>O<sub>2</sub>. Then the gels were stained in a solution containing 1% FeCl<sub>3</sub> and 1% K<sub>3</sub>Fe(CN<sub>6</sub>) for 10 minutes. As soon as the green color started to appear, the gels were also washed with ionized water.

**Determination of the activity of peroxidase (POX; EC 1.11.1.7) isoenzyme(s)**

Electrophoretic separation of POX isozymes Seevers et al. (1971). Samples containing 80 g protein were run on a 10% non-denatured acrylamide gel (PAGE) under constant current (120 mA). Gels were incubated in 200 mM Na-acetate buffer (pH 5.0) containing benzidine and hydrogen peroxide for 30 minutes in the dark to see the bands formed after electrophoresis. The gels were then stored in 7% acetic acid solution.

The determination of APX activity was determined according to Nakano and Asada (1981). As ascorbate oxidizes, the decrease in absorbance at 290 nm from the spectrophotometer was recorded and calculations were made using the extinction coefficient of ascorbate. The oxidation of ascorbate was initiated by the addition of the

enzyme extract and the decrease in absorbance was monitored for 180 sec. One unit of APX activity is expressed as 1 mmol/ml ascorbate oxidized per minute.

### **Membrane permeability (% EC)**

After harvest, 1 cm diameter samples were taken from the leaves of each of the sample plants brought to the laboratory. These samples were washed with distilled water and placed in brown glass bottles, 10 ml of distilled water was added to them and the analysis was repeated in triplicate. The prepared bottles were left in the shaker for 24 hours and at the end of the time, the solutions in the bottles were poured into the tubes and the EC<sub>1</sub> value was measured in the EC meter. Then, the solutions were poured back into the bottles and kept in the autoclave at 120 °C for 20 minutes, then the EC<sub>2</sub> value was measured at room temperature and the EC value was calculated from the formula  $EC_1 / EC_2 \times 100$  (Lutts et al., 1996).

### **Relative watercontent (RWC%)**

At the end of the study, the wet weights (YA) (g) of the leaf samples taken from 4 plants selected from each replication for measurements were determined and placed in capped petri dishes, then kept in pure water for 4 hours to make the leaves turgorized, and turgor weights (TA) (g) were measured after 4 hours. Then, they were kept in an oven at 80 °C for 48 hours and their dry weights (KA) (g) were measured. Leaf relative water content was calculated as % according to the following formula (Barr and Weatherley 1962).

YA=Wet Weight, KA=Dry Weight, TA=Turgorous Weight

Relative water content (%):  $[(YA - KA) / (TA - KA)] \times 100$

### **Chlorophyl lamount (SPAD)**

For each application, the middle of the upper leaves of 4 plants selected by chance at each replication. with the SPAD instrument (SPAD-502 Chlorophyll) meters; Konica Minolta, Tokyo, Japan) relative chlorophyll content was measured

### **Proline analysis**

The 0.5 g fresh leaf sample obtained was dissolved with 3% sulfosalicylic acid and filtered. 2 ml of the filtrate was taken and 2 ml of acetic acid and 2 ml of ninhydrin reagent were placed on it. Ninhydrin reagent; It was prepared using ninhydrin, acetic acid and orthophosphoric acid. Then, the samples placed in the tubes were kept in a water bath at 100 °C for 1 hour, and the reaction was terminated on ice. 4 ml of toluene was added to the cooled samples, vortexed and read in a spectrophotometer at 520 nm. Then the calculation was made by comparing it with the proline standards (Bates et al., 1973).

Dry Weight After the harvest, the leaves taken from the sample plants were kept in the oven at 65 °C for 48 hours, and when the last two weighings were equal, they were removed from the oven and the dry weights were calculated (Kacar, 1972).

### **Experimental site design and plant growth conditions**

This study was carried out as a pot trial in the application and research greenhouses of Mersin University, to be implemented in the fall semester of 2023. The experiment was set up according to the random plot design with 4 replications and there were 16 plants in each plot. In the research, rootless height(cm), seedling diameter(cm), number of leaves (plant/piece), seedling fresh and dry weight(g), root fresh and dry weight(g), chlorophyll amount(%), leaf membrane damage(%), relative water content of the leaf(%) and some antioxidant levels in its tissues were measured. In the greenhouse where the experiment was conducted, the ambient temperature was 20-28 °C and the humidity rate was measured as 65%. Pots (1 liter capacity) containing peat: perlite in the ratio

of 2:1 were used as seed planting medium. Before sowing the seeds, the perlites were washed thoroughly with tap water. Lettuce seedlings 177.2 ppm N; 52.70 ppm P; 240.44 ppm K; 53.46Mg; 120.30 ppm Ca; 3.36 ppm Fe; 0.85 ppm Mn; 0.45 ppm B; 0.50 ppm Zn; It was irrigated with 0.10 ppm Cu and 0.05 ppm Mo nutrient solution (Suyum et al., 2012). 25 days after seed sowing (seedlings were 2-3 true leaves in size), the prepared concentration (silicon and NaCl) was applied. Silium was prepared in the form of Potassium silicate ( $K_2SiO_3$ ), 2 mM was prepared and applied as a solution, salt concentrations; It was prepared as 0 (control), 50 mM, 100 mM and 200 mM, and the prepared concentrations were applied with an interval of 2 days. The experiment was terminated after the final concentration was reached (day 16).

### **Statistical analysis**

The data obtained from the experiment were evaluated according to ANOVA analysis of variance using "IBM SPSS statistids 23" statistical programs. Duncan's Multiple Comparison Test was used to compare differences between means.

## **RESULTS and DISCUSSIONS**

The effect of salt, silicon and salt x silicon interaction on plant biomass (plant height and diameter, plant fresh and dry weight, root length, leaf width and number, root fresh and dry weight) was found to be significant. The increase in salt concentration in the solution adversely affected the growth parameters of the seedlings. The biomass values measured in the study, in which silicon and varying concentrations of salt treatments were applied, are presented (Table 2-3). As a result of 200 mM salt application, the effect of stress was determined at the highest level in all biomass measurements. Considering the plant rootless dye effect of the applications; According to the data, the highest growth 50 mM+Si (10.9 cm) treatment gave an increase of 303.7% compared to the 200 mM NaCl (2.7 cm) application, which showed the lowest plant growth. In terms of plant diameter, 50 mM+Si (6.9cm) treatment showed the best improvement, and 200 mM NaCl (2.1cm) treatment showed a 228.7% increase. The best result in the effect of the applications on the number of leaves was obtained from the 50 Mm NaCl+Si (10.5 plant/piece) treatment, and it increased by 219% compared to the 200 mM NaCl (4.8 plant/piece) application, which had the lowest value. When the effect of the applications on the root length of the plant was examined, the highest value was increased by 50 mM+Si (7.9 cm) application, and the lowest value increased by 183.7% compared to the application of 200 Mm NaCl (4.3cm). According to the fresh weight measurements of the plant, the highest value was obtained from the application of Si+50 Mm NaCl (4.6 g), and it increased by 78.9% compared to the application of 200mMNaCl (2.6g), which had the lowest value. According to the leaf dry weight results, 100 mM+Si(0.4g) treatment, which had the highest value, increased 400% compared to 200 mM NaCl(0.1g) application. When the effect of the applications on the plant root wet weight was examined, the highest value was obtained from 50mM+Si (1.2 g) application, and the lowest value was obtained from 200MmNaCl (0.5 g) application, and the difference between applications was found to be 240%. According to the results, root dry weight was obtained from 50 mM+Si (0.3g) Si+ 100 mM NaCl (0.4g) and 200mM+Si applications, which had the highest effect, and the lowest value was obtained from 200 mM NaCl (0.1g) applications, the difference between applications % It was found to be 400. The seedling period is the period when plants are most affected by salt stress. During this period, due to the increasing amount of salt in the soil, the soil osmotic pressure increases and the seedlings are exposed to salt stress. Seedling deaths could be observed under severe conditions of salt stress. It has been reported by some researchers that there are significant decreases in both fresh weight and dry matter in leaves and roots of plants exposed to stress (Irshad et al., 2002; Ghoulam et al., 2002). The results of the reference study are similar to our study. Secco et al. (2010) found a decrease in seedling, root and shoot length as a result of salt stress applied to different melon cultivars. In other studies with similar

results; They concluded that shoot and root dry weights of wheat increased by 15% with Si application in stressful conditions compared to other applications. Ghorbanpour et al. (2020) barley shoots also increased by 27.3%. Ion imbalance caused by the increase in NaCl concentration under salt stress of these decreases; Cell volume and expansion by lowering the water and osmotic potential of the cell, which occurs due to osmotic stress. It is thought to be due to the drying of the shoots and leaves of the plant as a result of osmotic dehydration and increased transpiration, which causes a decrease in the rate of growth. The addition of silicon to the nutrient solution increased plant growth and yield under control or saline conditions (Anderson et al., 1991). According to the results of a study carried out in lettuce, it was seen that increasing NaCl concentrations decreased root and shoot development, but treatment with Si application gave positive results (de Souza Lemos Neto et al. 2018). This behavior was also found in cabbage seedlings by Bernardes et al. (2015), where increasing salt stress reduced seedling development in both high and low vigor groups and reduced the length of shoots and roots at the highest stress levels. Similarly, working with different varieties of 'melon' (Cucumis melo L.), Secco et al. (2010) found a decrease in total seedling length and dry matter under salt stress.

Table 2. The effect of silicon (Si) application on seedling growth parameters on lettuce seedlings exposed to salt stress

*Çizelge 2. Tuz stresine maruz kalan marul fidelerinde silikon (Si) uygulamasının fide büyüme parametrelerine etkisi*

Treatments	Seedling Rootless Length(cm)	Plant diameter (cm)	Number of leaves (plant/piece)	Root length (cm)
Control	5.9 ±0.2cd	5.7 ±0.1b	7 ±0.6b	7.1 ±0.3bc
50mMNaCl	5.5 ±0.3d	4.1 ±0.2c	6.6 ±0.3c	6.6 ±0.3c
100mMNaCl	3.1 ±0.3e	2.9 ±0.2d	6.3 ±0.6c	5.1 ±0.3d
200mMNaCl	2.7 ±0.6ef	2.1 ±0cd	4.8 ±0.3c	4.3 ±0.4e
Si+50mMNaCl	10.9 ±0.4a	6.9 ±0.4a	10.5 ±0.7a	8.3 ±0.5a
Si+100mMNaCl	7 ±0.6c	6.1 ±0.3ab	9.8 ±0.5a	7.9 ±0.6ab
Si+200mMNaCl	6.1 ±0.4cd	5.4 ±0.3b	9.3 ±0.6a	7.4 ±0.4abc
Average	5.89	4.74	7.76	6.67

Table 3. The effect of silicon (Si) application on seedling growth parameters on lettuce seedlings exposed to salt stress

*Çizelge 3. Tuz stresine maruz kalan marul fidelerinde silikon (Si) uygulamasının fide büyüme parametrelerine etkisi*

Treatments	Plant fresh weight (g)	Plant dry weight (g)	Root fresh weight (g)	Root dry weight (g)
Control	3.2 ±0.2cd	0.7 ±0b	1.1 ±0.1a	0.2 ±0c
50mMNaCl	3 ±0.2d	0.6 ±0b	0.9 ±0.1b	0.2 ±0c
100mMNaCl	3.8 ±0.3bc	0.4 ±0c	0.6 ±0.1c	0.3 ±0b
200mMNaCl	2.6 ±0.2d	0.3 ±0c	0.5 ±0c	0.1 ±0a
Si+50mMNaCl	4.6 ±0.2a	1 ±0.1a	1.2 ±0a	0.3 ±0ab
Si+100mMNaCl	4.4 ±0.1ab	1 ±0.1a	1.1 ±0.1a	0.4 ±0a
Si+200mMNaCl	4.4 ±0.3ab	1 ±0.1a	1 ±0.1b	0.2 ±0c
Average	3.71	0.71	0.91	0.24

In the study carried out, the main effect of silicon was observed in salty conditions, and it was observed that silicon reduced the negative effect of salt stress (Öztekin et al.2017,2018; Zhu et al.2004; Aranda et al., 2005). Stress-resistant plants have good levels of antioxidants. In order to cope with the oxidative damage caused by excessive ROS production due to excessive concentrations of salt, Si has been reported to reduce the harmful

effects of ROS and maintain membrane stability (Ghorbanpour et al., 2020). Defense products SOD, POX, CAT and APX data measured in lettuce seedlings exposed to stress are presented (Table 4). In this study; The use of Si against the negative effects of salt stress increased the activity of SOD, POX, CAT and APX enzymes. In a study showing results consistent with our study; seedling growth slowed down as a result of oxidative damage in tomato seedlings exposed to salt stress, but silicon addition to the salt solution partially compensated the negative effects of NaCl stress by increasing the tolerance of tomato plants to NaCl salinity by increasing the activities of SOD, APX, POX, CAT, soluble protein content, chlorophyll content and photochemical efficiency of PSII. Thus, silicon can alleviate salt toxicity and improve the growth of tomato plants (Al-aghabary et al. 2005).

According to the measurements made on salt-treated lettuce seedlings, the proline level, which was 341.5  $\mu\text{g g}^{-1}$  in Si+50 mM NaCl application, decreased to 101.2  $\mu\text{g g}^{-1}$  in 200 mM NaCl application. While the proline level was measured as 334.9  $\mu\text{g g}^{-1}$  in Si+100 mM NaCl application, it was measured as 114.2  $\mu\text{g g}^{-1}$  in 100 mM NaCl application. When these results were examined, the amount of proline decreased due to the increase in the NaCl concentration applied to the lettuce seedlings, and the Si fertilizers added in addition to the salt content increased the proline level and reduced the effect of salt stress. It has been reported that the decrease in the amount of proline and the decrease in membrane permeability are directly proportional to the increases in the relative water content of the leaves. This can be expressed as the plant's development of tolerance to stress (Bokhari and Trent, 1985). Proline, which has an important place under stress in recent years, has become one of the most effective observations in plants' weight and management defense systems during salt and water stress periods. (Shannon, 1997). Proline accumulation under silicon treatment was 11.5 and 14.4  $\mu\text{g g}^{-1}$  Fw in salt-stressed plants at 1500 and 3000 ppm. (Abdelaal et al., 2020)

Data on chlorophyll amounts of lettuce seedlings exposed to different concentrations of salt stress are given in Table (5). According to the measurements made on the samples obtained, Si+200 mM treatment increased the leaf chlorophyll rate by 28.1% compared to the 200 mM application. It was determined that the chlorophyll ratio measured in Si+100 Mm salt application increased by 26.9% compared to 100 Mm salt application. In the effect of applications on leaf chlorophyll contents, while high salt concentration decreased chlorophyll ratio, the highest chlorophyll contents were determined in Si+50Mm treatment. Chlorophyll content in leaves increased as a result of silicon added salt applications. The chlorophyll index value increased with the addition of silicon to the nutrient solution and varied between 200mMNaCl (36.7SPAD) and 50mMNaCl (52.6SPAD). According to the measurements made in lettuce seedlings treated with salt, the leaf membrane damage rate in Si +50 Mm NaCl treatment decreased by 15.2% compared to 200 Mm NaCl application. While the leaf membrane damage rate was 72.4% in 100 Mm NaCl application, it was 62.9% in Si+100 Mm NaCl application. According to these findings, membrane damage increased as the salt concentration increased. As a result of Si applications, the effects of salt on membrane damage were reduced. Recently, measuring the amount of water in the leaves gives the most reliable information about the general water status of the plants. According to the measurements made on lettuce seedlings treated with salt, the relative humidity of the leaf measured in Si+50 mM NaCl application increased by 68.5% compared to 50 mM NaCl application. While the relative humidity of the leaves was 70.7% in Si+100 mM NaCl application, it was 60.9% in 100 mM NaCl application. According to these findings, the relative moisture content of the leaves decreased as the salt concentration increased. Romero-Aranda et al. (2000) stated that the water consumption of plants decreases under salt stress and this decrease is due to the decrease in stomatal density, stomatal conductivity and root hydraulic transmission of plants under salt stress, and thus the decrease in transpiration rate. Fernandez-Garcia et al. (2003) also stated that root hydraulic transmission decreases with salinity, and this decrease is closely related to the decrease in the activity and concentration of channel proteins (aquaporins), which provide the transport of water and natural compounds in root plasma membranes through spaces. It was determined that plant water consumption increased with the application of silicon to the nutrient solution, albeit at low rates (Öztekin et al., 2014), Gong et al. (2005) stated that silicon has a

positive effect against the decrease in water uptake by plants. It is known that silicon promotes the functioning of the antioxidant defense mechanism in plants exposed to abiotic stress factors such as salinity, strengthens the plant body, has positive effects on photosynthesis and water use efficiency, and increases resistance to stress factors by reducing lipid peroxidation and membrane permeability in plants under stress (Gong et al. et al., 2005).

Table 4. The effect of silicon (Si) application on some antioxidant activities in lettuce seedlings exposed to salt stress

*Çizelge 4. Tuz stresine maruz kalan marul fidelerinde silikon (Si) uygulamasının bazı antioksidan aktivitelere etkisi*

Treatments	SOD	CAT	POX	APX	PROLIN
Control	130.2 ±10.3c	317.8 ±10.3c	57.5 ±0.7c	7.9 ±0.6d	169.7 ±6.3C
50mMNaCl	109.5 ±6.8cd	311.1 ±12.3c	55.1 ±1.3c	7 ±0.2de	155.2 ±8.7c
100mMNaCl	100.2 ±7.3d	268.6 ±26.6de	54 ±1.2c	5.9±-0.2d	114.2 ±6.7d
200mMNaCl	97.8 ±2.3d	226.9 ±16.6e	51.8 ±1.8c	4.6 ±0.2f	101.2 ±2.2d
Si+50mMNaCl	249.1 ±6.2a	560.1 ±6.3a	110 ±5.6a	15.6 ±0.5a	341.5 ±6.1a
Si+100mMNaCl	237.8 ±6.4a	514.7 ±14ab	98.7 ±4.8b	13.4 ±0.4b	334.9 ±7.6a
Si+200mMNaCl	194.2 ±9b	491.3 ±9b	91.7 ±4.3b	10.2 ±0.5c	275.5 ±5.8b
Average	160	384.36	74.11	9.23	213.17

Table 5. The effect of silicon (Si) application on some physiological parameters on lettuce seedlings exposed to salt stress

*Çizelge 5. Tuz stresine maruz kalan marul fidelerinde silisyum (Si) uygulamasının bazı fizyolojik parametrelere etkisi*

Treatments	Membran edamage(%)	Chlorophyllratio(%)	RelativeHumidity(%)
Control	59.5 ±2.4b	51.3 ±0.3a	72.7 ±0.9ab
50mMNaCl	48.8 ±2.4b	43.2 ±0.4c	70.4 ±1.3ab
100mMNaCl	33.7 ±1.2c	38.9 ±0.9de	65.8 ±0.4c
200mMNaCl	31.9±-1c	36.7 ±1f	53.7 ±1.4d
Si+50mMNaCl	62.5 ±3.5a	52.6 ±2a	75.3 ±0.3a
Si+100mMNaCl	57.4 ±2.1b	45.6 ±0.4b	70.7 ±1.9b
Si+200mMNaCl	54.5 ±2.1b	40.6 ±0.6cd	60.8 ±2c
Average	49.75	44.12	67.05

In conclusion, lettuce seedlings exposed to salt stress are adversely affected, but the effects of this stress can be reduced by 100 mM and 200 mM silicon applications. Silicon supplementation was beneficial and plays an important role in reducing the adverse effects of salinity on the growth, physiological and biochemical characteristics of lettuce seedlings. Silicon application caused an increase in relative water content, chlorophyll concentrations, antioxidant enzyme activity, root-free height, seedling diameter, leaf number, seedling fresh and dry weight, root fresh and dry weight. The results of this study may help to clarify the regulatory effects of exogenous Si on important functions of lettuce seedlings grown under salinity stress.

#### ACKNOWLEDGEMENTS

This study is a Master's thesis and granted by Erciyes University Scientific Research Projects Coordination Unit (Grant no: FYL-2022-11632).

## STATEMENT OF CONFLICT OF INTEREST

The author(s) declare no conflict of interest for this study.

## AUTHOR'S CONTRIBUTIONS

The contribution of the authors is equal.

## STATEMENT OF ETHICS CONSENT

Ethical approval is not applicable, because this article does not contain any studies with human or animal subjects.

## REFERENCES

- Abdelaal, K.A., Mazrou, Y.S., & Hafez, Y.M. (2020). Silicon foliar application mitigates salt stress in sweet pepper plants by enhancing water status, photosynthesis, antioxidant enzyme activity and fruit yield. *Plants*, 9 (6), 733. <https://doi.org/10.3390/plants9060733>
- Alp, Y., & Kabay, T. (2019). The effect of drought stress on antioxidative enzyme and nutrient exchange in some tomato genotypes. *Turkish Journal of Agricultural and Natural Sciences*, 6 (1), 71-77. <https://doi.org/10.30910/turkjans.515352>
- Al-aghabary, K., Zhu, Z., & Shi, Q. (2005). Influence of silicon supply on chlorophyll content, chlorophyll fluorescence, and antioxidative enzyme activities in tomato plants under salt stress. *Journal of Plant Nutrition*, 27 (12), 2101-2115. <https://doi.org/10.1081/PLN-200034641>
- Anderson, D.L., Snyder, G.H., & Martin, F.G. (1991). Multi-year response of sugarcane to calcium silicate slag on Everglades histosols. *Agronomy Journal*, 83 (5), 870-874. <https://doi.org/10.2134/agronj1991.00021962008300050019x>
- Adejumobi, M.A., Alonge, T.A., & Ojo, O.I. (2016). A review of the techniques for monitoring soil salinity in irrigated fields. *AIMS*, 2, 167-170.
- Barr, H.D., & Weatherley, P.E. (1962). A re-examination of the relative turgidity technique for estimating water deficits in leaves. *Australian Journal of Biological Sciences*, 15 (3), 413-428. <https://doi.org/10.1071/BI9620413>
- Bates, L.S., Waldren, R.P.A., & Teare, I.D. (1973). Rapid determination of free proline for water-stress studies. *Plant and Soil*, 39, 205-207. <https://doi.org/10.1007/BF00018060>
- Beauchamp, C., & Fridovich, I. (1971). Superoxide dismutase: improved assays and an assay applicable to acrylamide gels. *Analytical Biochemistry*, 44 (1), 276-287. [https://doi.org/10.1016/0003-2697\(71\)90370-8](https://doi.org/10.1016/0003-2697(71)90370-8)
- Bernardes, P.M., Mengarda, L.H.G., Lopes, J.C., Nogueira, M.U., & Rodrigues, L.L. (2015). Qualidade fisiológica de sementes de repolho de alta e baixa viabilidade sob estresse salino. *Nucleus*, 12 (1), 77-86. <https://doi.org/10.37378/1982.2278.1105>
- Boling, L., Prabhakaran, S., & Abinaya, M. (2019). Mechanisms of silicon-mediated amelioration of salt stress in plants. *Plants*, 8, 307. <https://doi.org/10.3390/plants8090307>
- Bokhari, U.G., & Trent, J. D. (1985). Proline concentrations in water stressed grasses. *Rangeland Ecology & Management/Journal of Range Management Archives*, 38 (1), 37-38. <https://doi.org/10.2307/3899329>
- Çaylak, E. (2011). Oxidative stress and antioxidants in animals and plants. *Journal of Medical Research*, 9 (1), 73-83. [https://doi.org/10.3168/jds.S0022-0302\(93\)77620-1](https://doi.org/10.3168/jds.S0022-0302(93)77620-1)
- Fernandez-Garcia, N., Cerda, A., & Carvajal, M. (2003). Grafting, a useful technique for improving salinity tolerance of tomato?. In *International Symposium on Managing Greenhouse Crops in Saline Environment*, (pp. 251-256). <https://doi.org/10.17660/ActaHortic.2003.609.37>

- De Souza Lemos Neto, H., de Almeida Guimarães, M., Sampaio, I.M.G., de Araújo Hendges, A.R.A., de Oliveira, A.B., & Filho, S.M. (2018). Silicon (Si) reduces the effects of salt stress on germination and initial growth of lettuce (*Lactuca sativa* L.). *Australian Journal of Crop Science*, 12 (9), 1410-1418. <https://doi.org/10.21475/ajcs.18.12.09.PNE1074>
- Ghorbanpour, M., Mohammadi, H., & Kariman, K. (2020). Nanosilicon-based recovery of barley (*Hordeum vulgare*) plants subjected to drought stress. *Environmental Science: Nano*, 7 (2), 443-461. <https://doi.org/10.1039/C9EN00973F>
- Ghoulam, C., Foursy, A., & Fares, K. (2002). Effects of salt stress on growth, inorganic ions and proline accumulation in relation to osmotic adjustment in five sugar beet cultivars. *Environmental and Experimental Botany*, 47(1), 39-50. [https://doi.org/10.1016/S0098-8472\(01\)00109-5](https://doi.org/10.1016/S0098-8472(01)00109-5)
- Gong, H., Zhu, X., Chen, K., Wang, S., & Zhang, C. (2005). Silicon alleviates oxidative damage of wheat plants in pots under drought. *Plant Science*, 169 (2), 313-321. <https://doi.org/10.1016/j.plantsci.2005.02.023>
- Gottardi, S., Iacuzzo, F., Tomasi, N., Cortella, G., Manzocco, L., Pinton, R., Römheld, V., Mimmo, T., Scampicchio, M., Dalla Costa, L., & Cesco, S. (2012). Beneficial effects of silicon on hydroponically grown corn salad (*Valerianella locusta* (L.) Laterr) plants. *Plant Physiology and Biochemistry*, 56, 14-23. <https://doi.org/10.1016/j.plaphy.2012.04.002>
- Irshad, M., Yamamoto, S., Eneji, A.E., Endo, T., & Honna, T. (2002). Urea and manure effect on growth and mineral contents of maize under saline conditions. *Journal of Plant Nutrition*, 25 (1), 189-200. <https://doi.org/10.1081/PLN-100108790>
- Kacar, B. (1972). *Chemical analysis of soil and plant*. Ankara University. Faculty of Agriculture Publication No: 53, A.U. Press, Ankara.
- Kabay, T. (2019). Effects of different potassium doses on development of high temperature-sensitive bean plants. *Fresenius Environmental Bulletin*, 28 (1), 320-325. <https://doi.org/10.24326/asphc.2020.4.6>
- Kalefetoğlu, T., & Ekmekci, Y. (2005). The effects of drought on plant salt tolerance mechanisms. *Gazi University Journal of Science*, 18 (4), 723-740.
- Kuşvuran, S., & Abak, K. (2012). Response of melon genotypes to drought stress. *Çukurova University Journal of Science and Engineering*, 28 (5).
- Larcher, W. (1995). *Physiological plant ecology*. Published by Springer, ISBN 0-387-09795-3, New York, 506 p.
- Lima, M.D.A., Castro, V.F.D., Vidal, J.B., & Enéas-Filho, J. (2011). Aplicação de silício em milho e feijão-de-corda sob estresse salino. *Revista Ciência Agronômica*, 42, 398-403. <https://doi.org/10.1590/S1806-66902011000200019>
- Laemmli, U.K. (1970). Cleavage of structural proteins during the assembly of the head of bacteriophage T4. *Nature*, 227 (5259), 680-685. <https://doi.org/10.1038/227680a0>
- Lutts, S., Kinet, J.M., & Bouharmont, J. (1996). NaCl-induced senescence in leaves of rice (*Oryza sativa* L.) cultivars differing in salinity resistance. *Annals of Botany*, 78 (3), 389-398. <https://doi.org/10.1006/anbo.1996.0134>
- Manivannan, A., Soundararajan, P., Muneer, S., Ko, C.H., & Jeong, B.R. (2016). Silicon mitigates salinity stress by regulating the physiology, antioxidant enzyme activities, and protein expression in *Capsicum annuum* 'Bugwang'. *BioMed Research International*, 2016. <https://doi.org/10.1155/2016/3076357>
- Muneer, S., Park, Y.G., Manivannan, A., Soundararajan, P., & Jeong, B.R. (2014). Physiological and proteomic analysis in chloroplasts of *Solanum lycopersicum* L. under silicon efficiency and salinity stress. *International Journal of Molecular Sciences*, 15 (12), 21803-21824. <https://doi.org/10.3390/ijms151221803>
- Munns, R. (2002). Comparative physiology of salt and water stress. *Plant, Cell & Environment*, 25 (2), 239-250. <https://doi.org/10.1046/j.0016-8025.2001.00808.x>
- Nakano, Y., & Asada, K. (1981). Hydrogen peroxide is scavenged by ascorbate-specific peroxidase in spinach chloroplasts. *Plant and Cell Physiology*, 22 (5), 867-880. <https://doi.org/10.1093/oxfordjournals.pcp.a076232>

- Orcutt, D.M., & Nilsen, E.T. (1996). The physiology of plants under stress. Soil and Biotic Factors, pp:177-237, John Wiley&Sons, inc. NY. <https://doi.org/10.3389/fpls.2014.00086>
- Osakabe, Y., Osakabe, K., Shinozaki, K., & Tran, L.S.P. (2014). Response of plants to water stress. *Frontiers in Plant Science*, 5, 76566. <https://doi.org/10.3389/fpls.2014.00086>
- Öztekin, G.B., Tüzel, Y., & Tüzel, İ.H. (2017). Serada topraksız domates yetiştiriciliğinde silisyumun tuz stresine etkisi. *Akademik Ziraat Dergisi*, 6, 243-256.
- Oztekin, G.B., Tuzel, Y., Tuzel, I.H., & Tepecik, M. (2018). Effects of silicon on tomato grown in substrate culture under salinity stress. *Fresenius Environmental Bulletin*, 27 (8), 5520-5530.
- Rodrigues, F.D.A., Oliveira, L.D., Korndörfer, A.P., & Korndörfer, G.H. (2011). Silício: um elemento benéfico e importante para as plantas. *Informações Agronomicas*, 134 (1), 14-20.
- Romero-Aranda, R., Yeo, A.R., Flowers, T.J., & Cuartero, J. (2000). Variability for some physiological characters affecting salt tolerance in tomato. In *International Symposium on Techniques to Control Salination for Horticultural Productivity*, (pp. 435-441). <https://doi.org/10.17660/ActaHortic.2002.573.52>
- Rizwan, M., Ali, S., Ibrahim, M., Farid, M., Adrees, M., Bharwana, S.A., Zia-Ur-Rehman, M., Qayyum, M.F. & Abbas, F. (2015). Mechanisms of silicon-mediated alleviation of drought and salt stress in plants: A review. *Environmental Science and Pollution Research*, 22, 15416-15431. <https://doi.org/10.1007/s11356-015-5305-x>
- Shannon, M.C., & Grieve, C.M. (1998). Tolerance of vegetable crops to salinity. *Scientia Horticulturae*, 78 (1-4), 5-38. [https://doi.org/10.1016/S0304-4238\(98\)00189-7](https://doi.org/10.1016/S0304-4238(98)00189-7)
- Suyum, K., Dasgan, H.Y., Sari, N., Kusvuran, S., Aydoner, G., Akyol, M., Akhoundnejad, Y., Solmaz, I., & Bol, A. (2012). Genotypic variation in the response of water melon genotypes to alinity and drought stresses. <https://cabidigitallibrary.org/terms-and-conditions>
- Secco, L.B., Queiroz, S.O., Dantas, B.F., de Souza, Y.A., & da Silva, P.P. (2010). Qualidade de sementes de acessos de melão, *Cucumis melo* L., em condições de estresse salino. *Revista Verde de Agroecologia e Desenvolvimento Sustentável*, 5 (2), 5. <http://revista.gvaa.com.br>
- SeEVERS, P.M., DALY, J.M., & CATEDRAL, F.F. (1971). The role of peroxidase isozymes in resistance to wheat stem rust disease. *Plant Physiology*, 48 (3), 353-360. <https://doi.org/10.1104/pp.48.3.353>
- Temme, A.A., Kerr, K.L., & Donovan, L.A. (2019). Vigour/tolerancetrade-off in cultivated sunflower (*Helianthus annuus*) response to salinity stress is linked to leaf elemental composition. *Journal of Agronomy and Crop Science*, 205 (5), 508-518. <https://doi.org/10.1111/jac.12352>
- Yılmaz, E., Tuna, M., & Burun, B. (2011). Tolerance strategies of plants against salt stress effects. *CBÜ Journal of Science*, 7 (1), 47-66.
- Zhu, Z., Wei, G., Li, J., Qian, Q., & Yu, J. (2004). Silicon alleviates salt stress and increases antioxidant enzymes activity in leaves of salt-stressed cucumber (*Cucumis sativus* L.). *Plant Science*, 167 (3), 527-533. <https://doi.org/10.1016/j.plantsci.2004.04.020>
- Woodbury, W., Spencer, A.K., & Stahmann, M.A. (1971). An improved procedure using ferricyanide for detecting catalase isozymes. *Analytical Biochemistry*, 44 (1), 301-305. [https://doi.org/10.1016/0003-2697\(71\)90375-7](https://doi.org/10.1016/0003-2697(71)90375-7)