The Effects of Potassium Applications on Drought Stress in Sugar Beet

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Abstract Drought is a major environmental stress affecting agricultural productivity around the world. Application of potassium to plants can increase the ability of plants to tolerate drought stress while maintaining turgor pressure at low leaf water potentials. In this research, the effect of potassium applications under drought stress on some physiological parameters of sugar beet, which is a strategic plant, was investigated. In the experiment, irrigation levels were kept at 33%, 66% and 100% of field capacity. Different doses (10–20–40–80 mg kg$^{-1}$) of potassium were applied to the plants. The plants were grown with Hoagland nutrient solution in the growth chamber. Relative water content increased at the 33% irrigation level with potassium applications to 67.39, 68.93, 68.20 and 74.41%, respectively, while membrane damage and MDA content decreased (70.66, 71.10, 65.91, 68.43% and 35.94, 25.38, 21.74, 18.84 nmol g$^{-1}$). In addition, vitamin C and SH compounds decreased at the 33% irrigation level with potassium applications to 252.15, 198.40, 125.06, 134.25 µg g$^{-1}$ and 69.16, 66.94, 55.89, 54.59 µg g$^{-1}$, respectively. According to the results obtained from the experiment, the potassium applied to the plants under drought stress led to an increase in the relative water content and the reduction of membrane damage, and especially to the reduction of non-enzymatic antioxidants produced for defence purposes when faced with plant stress. Therefore, it can be said that potassium may play a critical role in reducing the negative effect of drought stress in sugar beet.

Keywords Drought · Irrigation · Potassium · Sugar beet

Introduction

In order to meet the food needs of the rapidly growing world population, an increase in agricultural production is essential. Abiotic stresses such as drought, salinity, heat and cold are the most harmful factors affecting the growth and productivity of crops worldwide (Gao et al. 2007; Fujita et al. 2014). About 70% of yield losses are considered to be caused by abiotic stresses (Acquaah 2007). Approximately 45% of the world’s agricultural land is constantly exposed to drought stress and approximately 6% of the soil is facing salinity problems (Ashraf and Foolad 2007). With the increase in global warming, the seriousness of the situation has increased and one of the most important factors limiting plant production has been drought stress (Gong et al. 2005; Martinez et al. 2007; Sankar et al. 2008).

Plants undergo significant changes under drought stress. These can result in plants being smaller than the normal size, early maturation, a decrease or increase in root length, an increase in root–shoot ratio, a decrease in the leaf area and weight and leaf curl (Terzi and Kadioglu 2006; Cativelli et al. 2008; Jaleel et al. 2009). The production of highly reactive oxygen species induced by drought increases the content of malondialdehyde (MDA). Malondialdehyde content is thought to be an indicator of oxidative damage (Alkhsabah et al. 2018). It has also been determined that drought stress leads to a decrease in the amount of photosynthetic pigment in plant leaves.
of the leaves in plants (Lawlor and Cornic 2002). Plants have mechanisms that limit the damage caused by long-term drought, called drought tolerance, in order to maintain their metabolism (Courtois et al. 2000). The main effect of stress on plant growth can be explained by osmotic pressure. Osmotic adjustment is considered to be an effective component of abiotic (drought, salinity) resistance in some plants (Gomathi et al. 2010). Plants increase synthesis of osmoprotectants to cope with drought stress (Fayez and Bazaïd 2014). When plants are exposed to stress, they take various ions from the soil solution or synthesize some organic compounds, thereby reducing their osmotic potential (Ashraf 1994; Yordanov et al. 2003). In addition, plants produce enzymatic and non-enzymatic antioxidants to cope with stress. Non-enzymatic antioxidants such as ascorbic acid (vitamin C), carotenoid and phenol have been shown to increase in stress conditions (Hossain et al. 2010).

Potassium (K) is a key element for crop growth and productivity (Munns 2002; Armengaud et al. 2009). It is an essential nutrient for photosynthesis and the transport of assimilates (Wang et al. 2015). Potassium affects the osmotic adjustment of the plant and increases drought resistance by enhancing the translocation of assimilates and maintaining osmotic charge (Eakes et al. 1991; Marschner 1995; Mubarak et al. 2016). The aim of this research is to determine the effect of potassium applications under drought stress on some physiological parameters of sugar beet, which is a strategic plant, and to try to clarify the relationship between drought stress and potassium.

Materials and Methods

**Plant Growth**

In this study, washed sand, with a pH of 8.2 and electrical conductivity of 75 µM cm⁻¹, was used. The plastic sapling production pots, which were 25 × 50 cm in size, were filled with this sand. Resistive soil moisture sensors were placed inside the pots to control the soil moisture level. The soil moisture sensors were calibrated with a device which was designed using an Arduino developer card, and irrigation was carried out according to the data received from that device (Kizil et al. 2018). Irrigation levels were kept at 33%, 66% and 100% according to the field water retention capacity of the medium. Seedlings planted in the pots [Serenada varieties of sugar beet (Beta vulgaris L.)] were grown in a climate room under controlled conditions (day/night 16/8 h, 25/15 °C, 60–70% humidity). Various doses (10–20–40–80 mg kg⁻¹) of potassium were applied to the plants with a potassium phosphate source. Plants were grown with Hoagland solution, using a 1:0.8:1.2, N/P/K ratio (Adiloglu and Guler 2002), with three replicates. Harvesting was completed immediately after sampling the leaves for relative water content and membrane damage at the sugar storage (ripening) phase.

**Relative Water Content**

Four sections with 1 cm diameter were taken from plant leaves, and fresh weights (FW) were determined. Deionized water was added to the sections taken into the tubes, and they were stored in water for 4 h before their turgor weights (TW) were determined. The samples were dried in an oven for 48 h at 65 °C, and their dry weights (DW) were determined. Relative water contents were calculated with the following formula (Barr and Weatherley 1962; Sairam and Srivastava 2002):

\[
\text{RWC}% = \left(\frac{\text{FW} - \text{DW}}{\text{TW} - \text{DW}}\right) \times 100.
\]

**Membrane Damage**

The membrane damage was calculated by measuring the electrolyte released from the cell (Drugokecka and Kacperska-palacz 1978). Four sections with 1 cm diameter were taken from plant leaves. After the samples were kept in deionized water for 5 h, the samples’ electrical conductivity was measured (EC1). After the samples were kept at 100 °C for 10 min, the electrical conductivity of the solution was measured again (EC2). Membrane damage was calculated by the following formula:

\[
\text{Membrane Damage}\% = \left(\frac{\text{EC1} - \text{EC2}}{1 - \text{EC2}}\right) \times 100.
\]

**Chlorophyll Content**

Samples of 500 mg were taken from plant leaves. The samples were extracted with 10 ml of 80% acetone in a porcelain mortar and centrifuged for 20 min at 3000 rpm in a centrifuge. The samples were read in a spectrophotometer (UV/Vis) at 662, 645 and 470 nm wavelengths. The calculations were done according to Lichtenthaler and Wellburn (1985), with the following formulas:

\[
\text{Chlorophyll } a (\text{mg/g}) = \left[12.7(A663) - 2.69(A645)\right] \times V/1000 \times W
\]

\[
\text{Chlorophyll } b (\text{mg/g}) = \left[22.9(A645) - 4.68(A663)\right] \times V/1000 \times W
\]

\[
\text{Total chlorophyll (mg/g)} = \left[20.2(A645) + 8.02(A663)\right] \times V/1000 \times W
\]

\[
\text{Carotenoid (mg/g)} = \left[A480 + \left(0.114 \times A663\right) - \left(0.638 \times A645\right)\right] \times V/1000 \times W.
\]

**Malondialdehyde (MDA) Content**

Samples of 200 mg were taken from plant leaves, and 5 ml of 0.1% trichloroacetic acid (TCA) was added. The mixture was centrifuged at 12,500 rpm for 20 min. Supernatant of 3 ml was taken into the tubes, and 3 ml of 0.1% TBA
prepared in 20% TCA was added. The mixture was incubated in a hot water bath at 95 °C for 30 min and then placed in an ice bath to stop the reaction. The samples were read in a spectrophotometer (UV/Vis) at 532 and 600 nm wavelengths. Malondialdehyde (MDA) content was calculated by the following formula:

\[
MDA = \frac{(A532 - A600)}{155} \times \frac{mmol}{L}\times cm \times Volume (ml) = mM/200 g.
\]

**Proline Content**

Samples of 200 mg were taken from plant leaves and crushed into liquid nitrogen in a porcelain mortar; then, 1 ml of 3% sulfosalicylic acid was added. Samples placed in Eppendorf tubes were centrifuged at 4 °C for 5 min at 14,000 rpm. Then, 0.2 ml of ninhydrin acid (0.3 g ninhydrin, 7.5 ml of acetic acid and 5 ml of 6 M phosphoric acid), 0.2 ml 96% acetic acid, 0.1 ml 3% sulfosalicylic acid and 0.1 ml supernatant sample were added to the tubes. The tubes were kept in a hot water bath at 96 °C for 1 h and then placed in an ice bath to stop the reaction. They were vortexed by adding 1 ml of toluene. Samples were centrifuged again at 14,000 rpm for 5 min, and the upper (red-pink) phase was reached at room temperature. The samples were read in a spectrophotometer (UV/Vis) at 520 nm wavelength. Proline standards were prepared between 5 and 500 μM (Bates et al. 1973).

**Ascorbic Acid (Vitamin C) Content**

Samples of 1000 mg were taken from plant leaves and crushed with 5% metaphosphoric acid in a porcelain mortar. The samples were centrifuged at 4 °C for 15 min at 14,000 rpm. A sample of 0.4 ml, 1 ml of 150 mM phosphorus buffer (containing 5 mM EDTA, pH 7.4) and 0.1 ml of 2.5 ml of 150 mM phosphorus buffer (containing 5 mM EDTA, pH 7.4) and 0.1 ml of 2.5 ml of 150 mM phosphorus buffer (containing 5 mM EDTA, pH 7.4) and 0.1 ml of 2.5 ml of 150 mM phosphorus buffer (containing 5 mM EDTA, pH 7.4) were added to the tubes and incubated for 15 min at room temperature. At the end of this period, the homogenates were centrifuged at 4 °C for 15 min at 14,000 rpm. A sample of 0.5 ml, 2.5 ml of 150 mM phosphorus buffer (containing 5 mM EDTA, pH 7.4) and 0.5 ml of 2.5 ml of 150 mM phosphorus buffer (containing 5 mM EDTA, pH 7.4) and 0.5 ml of 2.5 ml of 150 mM phosphorus buffer (containing 5 mM EDTA, pH 7.4) and 0.5 ml of 2.5 ml of 150 mM phosphorus buffer (containing 5 mM EDTA, pH 7.4) were added to the tubes and incubated for 20 min at room temperature. The samples were read in a spectrophotometer (UV/Vis) at 412 nm wavelength. Standards were prepared in the range of 0–100 μg ml⁻¹ reduced glutathione with 5% metaphosphoric acid (Cakmak and Marschner 1992).

**SH Groups Content**

Samples of 200 mg were taken from plant leaves and crushed with 5% metaphosphoric acid in a porcelain mortar. The samples were centrifuged at 4 °C for 15 min at 14,000 rpm. A sample of 0.5 ml, 2.5 ml of 150 mM phosphorus buffer (containing 5 mM EDTA, pH 7.4) and 0.5 ml of 2.5 ml of 150 mM phosphorus buffer (containing 5 mM EDTA, pH 7.4) and 0.5 ml of 2.5 ml of 150 mM phosphorus buffer (containing 5 mM EDTA, pH 7.4) and 0.5 ml of 2.5 ml of 150 mM phosphorus buffer (containing 5 mM EDTA, pH 7.4) were added to the tubes and incubated for 20 min at room temperature. The samples were read in a spectrophotometer (UV/Vis) at 412 nm wavelength. Standards were prepared in the range of 0–100 μg ml⁻¹ reduced glutathione with 5% metaphosphoric acid (Cakmak and Marschner 1992).

**Phenol Content**

Samples of 200 mg were taken from plant leaves and ground in liquid nitrogen. The ground samples were put into glass tubes, 5 ml of 80% methyl alcohol was added, and they were kept in the refrigerator for 48 h. At the end of this period, the homogenates were centrifuged at 4 °C for 20 min at 4000 rpm. Supernatant of 1000 μl, 5 ml of distilled water, 400 μl 50% Folin–Ciocalteu’s reagent (FCR) and 1000 μl 5% sodium carbonate (Na₂CO₃) were put into the tubes, and the reaction mixture was vortexed after being incubated for one hour at room temperature. The samples were read in a spectrophotometer (UV/Vis) at 725 nm wavelength. The total phenol content in the leaf tissues was calculated with standard graphics prepared with gallic acid (Chandler and Dodds 1983).

**Statistical Analysis**

Analysis of variance (ANOVA) was performed using the general linear model (PROC GLM) procedure of the R program. The variance analysis was performed based on the following model:

\[
Yijk = \mu + Gi + Sj + (GS)ij + Mk + eijk,
\]

where the meanings of the symbols are \(Yijk\) observed value, \(\mu\) grand mean, \(Gi\) effect of irrigation \(i (i = 1, 2, 3)\), \(Sj\) effect of potassium \(j (j = 1, 2, 3, 4)\), \((GS)ij\) effect of irrigation \(\times\) effect of potassium, \(Mk\) effect of replication \(k (k = 1, 2, 3)\) and \(eijk\) random error term.

Variance analysis (ANOVA) was performed by using the statistical package program using the GLM procedure. Differences between applications were determined by the Tukey multiple comparison test \((P < 0.05)\).

**Results**

According to the results of variance analysis, the effect of irrigation \(\times\) potassium interaction on relative water content and membrane damage was statistically significant \((P \leq 0.001)\). In addition, it was determined that the effect of irrigation and potassium applications on relative water
content, membrane damage, leaf width and leaf length was statistically significant (Table 1).

Relative water content showed an irregular change and increased with potassium applications to 65.87, 73.00, 68.52 and 71.94%, respectively. In the same way, irregular changes were observed in irrigation levels and relative water content was determined as 69.73% at 33.3% irrigation, 67.02 at 66% and 72.75 at 100% (Table 2). When the membrane damage was considered, it was observed that membrane damage decreased with increasing irrigation levels and increasing potassium applications (Table 2). Irrigation and potassium applications were found to be statistically significant, although there was no effect of irrigation x potassium interaction on leaf width and leaf length. The lowest leaf width (5.29 cm) was obtained at the 33% irrigation level and 40 mg kg\(^{-1}\) potassium application, the highest leaf width (8.94 cm) at the 100% irrigation level and 80 mg kg\(^{-1}\) potassium application. The leaf length showed similar changes and increased with the irrigation level to 9.58, 13.35 and 14.43 cm, respectively (Table 2).

Variance analysis results of different irrigation levels and doses of potassium on chlorophyll \(a\), chlorophyll \(b\), carotenoid and total chlorophyll are given in Table 3. According to the results of variance analysis, irrigation levels, potassium applications and irrigation x potassium interaction were found to be statistically significant for chlorophyll \(b\), carotenoid and total chlorophyll, but not with chlorophyll \(a\) (\(P \leq 0.01\) and \(P \leq 0.001\)). In parallel, with increasing irrigation levels and increasing doses of potassium, chlorophyll \(a\) content of the leaves increased but this increase was not statistically significant.

Chlorophyll \(a\), chlorophyll \(b\), carotenoid and total chlorophyll contents of leaves are given in Table 4. The chlorophyll \(a\) content of the leaves changed between 11.42 and 12.35 \(\mu g\) g\(^{-1}\). The lowest chlorophyll \(b\) content (4.13 \(\mu g\) g\(^{-1}\)) was obtained at the 33% irrigation level and 40 mg kg\(^{-1}\) potassium application, and the highest chlorophyll \(b\) content (15.41 \(\mu g\) g\(^{-1}\)) at 66% irrigation level and 20 mg kg\(^{-1}\) potassium application. It was determined that the carotenoid content varied between 0.67 and 0.94 \(\mu g\) g\(^{-1}\). The lowest total chlorophyll content (15.79 \(\mu g\) g\(^{-1}\)) was obtained at the 33% irrigation level and 40 mg kg\(^{-1}\) potassium application, and the highest total chlorophyll content (27.42 \(\mu g\) g\(^{-1}\)) at 66% irrigation level and 20 mg kg\(^{-1}\) potassium application.

Variance analysis results of the effects of different irrigation levels and different doses of potassium on vitamin C, SH, proline and MDA content are given in Table 5. According to the results, it was determined that irrigation x potassium interaction was statistically significant (\(P \leq 0.001\)) in terms of all the properties analysed (Table 5). Furthermore, while the irrigation level was statistically effective for all properties, potassium was statistically (\(P \leq 0.001\)) effective for all properties except MDA.

Vitamin C, SH, proline, phenol and MDA contents of leaves are given in Table 6. SH, proline and MDA contents decreased with the increase in irrigation levels. Except for vitamin C, the values were statistically significant (\(P \leq 0.001\)). The lowest vitamin C content (75.55 \(\mu g\) g\(^{-1}\)) was obtained at 100% irrigation level and 10 mg kg\(^{-1}\) potassium application, the highest vitamin C content (255.20 \(\mu g\) g\(^{-1}\)) at 66% irrigation and 40 mg kg\(^{-1}\) potassium application. The application of potassium was found to be statistically significant (\(P \leq 0.001\)) for vitamin C, SH, proline and phenol, but not for the MDA content.

Table 1 Comparison of the effect of four levels of potassium on RWC, membrane damage, leaf width and leaf length of sugar beet, grown under drought-stressed and non-drought-stressed conditions

| Source of variation | df | RWC       | Membrane damage | Leaf width | Leaf length |
|---------------------|----|-----------|-----------------|------------|-------------|
| Irrigation          | 2  | 92.571*** | 822.151***      | 16.471***  | 68.224***   |
| Potassium (K)       | 3  | 84.473*** | 81.701***       | 1.200*     | 4.020**     |
| Irrigation x K      | 6  | 16.128*** | 40.440***       | .504       | .939        |
| Error               | 22 | 1.048     | 1.078           | .286       | .655        |

\(df\) degrees of freedom

*, ** and ***Significant difference at \(P \leq 0.05\), \(P \leq 0.01\) and \(P \leq 0.001\), respectively

Discussion

Determination of RWC of the plants can provide the most appropriate measure of the plant water condition under stress. Relative water content is a major indicator of hydration and a more efficient signaler of drought than the water content (Tomar and Kumar 2004; Silva et al. 2007). Relative water content decreases under drought conditions (Molnar et al. 2002). In different plant varieties, the RWC of the plants changed from between 88 and 95% in turgid to about 30–40% in seriously dehydrated plants. Plant
RWC during wilting is at about 60–70% in most plants (Jungklang et al. 2017). According to the results of this study, relative water content increased with increasing irrigation amounts. Relative water content is lower in stressed plants than in plants grown under normal conditions. It is clear evidence that water stress adversely affected RWC through the dehydration of tissues in sugar beet under drought stress. Our results show similar results to Asgharipour and Heidari’s (2011) study with sorghum mustard and groundnut plants. Umar (2006) stated in his study that potassium applications increase the relative water content of the plant under normal conditions, as well as water stress conditions. The results obtained were in parallel with this study, and the applied potassium ensured preservation of the RWC of the plant. There is 8.43% difference between the lowest potassium dose and the highest potassium dose in terms of relative water content (Table 2).

Many studies show that membrane integrity and stability are important for plants under drought stress (Bajji et al. 2002). Wang and Huang (2004) reported that membrane stability was reduced under drought conditions. When Table 2 is examined, it is seen that membrane damage decreases with increasing irrigation levels and drought stress increases membrane damage, which is in parallel with previous studies. Potassium plays a significant role in balancing membrane integrity and regulating stomata movement and osmotic pressure (Fayez et al. 2014). In addition, a sufficient potassium source increases drought resistance by increasing root prolongation and protecting cell membrane stability (Premachandra et al. 1991). According to our results, membrane damage decreased

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**Table 2** Effect of four levels of potassium on RWC, membrane damage, leaf width and leaf length of sugar beet, grown under drought-stressed and non-drought-stressed conditions

| K (mg kg⁻¹) | Irrigation (field capacity) | Irrigation (field capacity) |
|-------------|-----------------------------|-----------------------------|
|             | 33%                         | 66%                         | 100%                        | Mean |
|             | RWC (%)                     | 100%                        | Mean                        |
| 10          | 67.39 e                     | 61.40 f                     | 68.83 de                    | 65.87 C |
| 20          | 68.93 dc                    | 72.93 bc                    | 77.13 a                     | 73.00 A |
| 40          | 68.20 e                     | 66.03 e                     | 71.34 cd                    | 68.52 B |
| 80          | 74.41 ab                    | 67.71 e                     | 73.71 bc                    | 71.94 A |
| Mean        | 69.73 C                     | 67.02 B                     | 72.75 A                     | 69.03 A |

- **Leaf width (cm)**
- **Leaf length (cm)**

The differences between the interaction of potassium and irrigation means having different lower case letters in a column are statistically significant at 0.05 alpha level. The differences between the potassium means having different capital letters in a column are statistically significant at 0.05 alpha level. The differences between the irrigation means having different capital letters in a line are statistically significant at 0.05 alpha level

**Table 3** Comparison of the effect of four levels of potassium on chlorophyll a, chlorophyll b, carotenoid, total chlorophyll of sugar beet, grown under drought-stressed and non-drought-stressed conditions

| Source of variation | df | Chlorophyll a | Chlorophyll b | Carotenoid | Total chlorophyll |
|---------------------|----|---------------|---------------|------------|-------------------|
| Irrigation          | 2  | .154          | 68.991**      | .029**     | 69.377**          |
| Potassium (K)       | 3  | .480          | 21.662**      | .007*      | 19.676**          |
| Irrigation × K      | 6  | .201          | 26.380**      | .032**     | 25.991**          |
| Error               | 22 | .178          | .305          | .001       | .255              |

* and **Significant difference at $P < 0.01$ and $P < 0.001$, respectively
with increasing potassium applications. When the irrigation level and potassium interaction is examined, it is seen that the potassium applications did not have any effect on the membrane damage in the plants without drought stress but decreased the membrane damage in the plants under stress. According to the results, potassium plays a significant role in reducing membrane damage under drought stress.

It has been affirmed that drought stress reduces the growth of plants (Swapna and Shylaraj 2017). Results of vegetative growth parameters (leaf width and leaf length) as affected by irrigation levels and potassium applications are presented in Table 2. As discussed earlier, drought stress negatively impacts the yield. The leaf width and leaf length showed an important reduction in response to the decreasing levels of irrigation. Plants acclimatize to a decrease in soil moisture by a reduction in leaf area production (Higgs and Jones 1990). Potassium applications increase plant growth because of the positive influence of potassium on the metabolic mechanisms of the plant (Quintero et al. 1998). In addition, it has been reported in previous studies that potassium applications can reduce the damage caused by drought stress (Raza et al. 2013). According to the results obtained from this study, leaf width and leaf length showed a significant increase parallel to potassium applications (Table 2). When the irrigation level and potassium interaction was examined, it was determined that there was no effect on leaf width and leaf length.

A significant reduction in chlorophyll and water content of the plant due to drought has been emphasized by various researchers (Yang et al. 2006; Ahmad et al. 2017). According to Zahoor et al. (2017), chlorophyll is reduced

### Table 4

| K (mg kg\(^{-1}\)) | Irrigation (field capacity) | Chlorophyll \(a\) (\(\mu g\ g^{-1}\)) | Chlorophyll \(b\) (\(\mu g\ g^{-1}\)) |
|--------------------|--------------------------|----------------------------------|----------------------------------|
| 10                 | 33%                      | 11.77                            | 14.98 a                          |
|                    | 66%                      | 11.68                            | 12.70 bcd                        |
|                    | 100%                     | 12.05                            | 12.69 cd                         |
|                    | Mean                     | 11.83                            | 13.46 A                          |
| 20                 | 33%                      | 11.85                            | 11.80 d                          |
|                    | 66%                      | 12.01                            | 15.41 a                          |
|                    | 100%                     | 11.52                            | 15.25 a                          |
|                    | Mean                     | 11.79                            | 14.16 A                          |
| 40                 | 33%                      | 11.66                            | 11.80 d                          |
|                    | 66%                      | 12.21                            | 13.84 abc                         |
|                    | 100%                     | 11.42                            | 14.61 ab                         |
|                    | Mean                     | 11.76                            | 10.86 B                          |
| 80                 | 33%                      | 12.35                            | 7.20 e                           |
|                    | 66%                      | 12.22                            | 14.03 abc                         |
|                    | 100%                     | 12.21                            | 12.64 cd                         |
|                    | Mean                     | 12.26                            | 11.29 B                          |
| Mean               |                          | 11.90                            | 9.52 B                           |
|                   |                          | 12.03                            | 14.00 A                           |
|                   |                          | 11.80                            | 13.80 A                           |

### Table 5

| Source of variation | df | Vitamin C | SH | Proline | Phenol | MDA |
|---------------------|----|-----------|----|---------|--------|-----|
| Irrigation          | 2  | 33,019.636* | 1700.922* | 37,707.477* | 26,759.027* | 114,009* |
| Potassium (K)       | 3  | 4742.173*  | 204.166* | 6105.840* | 1978.725* | .883 |
| Irrigation \(\times\) K | 6  | 5537.148*  | 377.936* | 17,246.463* | 4380.301* | 132,916* |
| Error               | 22 | 37,980     | 2.517 | 26.568 | 127,862 | .315 |

*Indicates significant difference at \(P \leq 0.001\)
in leaves of drought-stressed plants as compared to non-drought-stressed plants, which could affect carbon flux in stressed plants. Potassium treatments improve such physiological characteristics, which can improve the plant water condition under drought stress (Umar et al. 1990). Asgharipour and Heidari (2011) found that chlorophyll content increased significantly with increasing levels of irrigation and potassium. The results obtained from our study are partly compatible with this study. Although an increase in total chlorophyll content was observed with increasing levels of irrigation, total chlorophyll content decreased with increasing potassium applications. Table 4 shows that chlorophyll $a$ content did not change with the level of irrigation, but chlorophyll $b$ content decreased with a decreasing level of irrigation. In another study, the content of chlorophyll was higher in plants with sufficient $K$ application under drought, and it was pronounced in low-$K$-sensitive cultivars (Zahoor et al. 2017). In our study, total chlorophyll content decreased to 40 mg kg$^{-1}$ of potassium under drought. Chlorophyll $b$ content increased 42.63% with the application of 80 mg kg$^{-1}$ of potassium at the same irrigation level. Carotenoids (Farooq et al. 2009), which are known to support the resistance of plants to drought stress, decreased by about 24% with the 40 and 80 mg kg$^{-1}$ potassium applications at the 33% irrigation level, when compared to 10 and 20 mg kg$^{-1}$ potassium applications. Potassium applications did not have an effect on carotenoids when the irrigation level increased and drought stress was alleviated.

Ascorbic acid (vitamin C) is a strong antioxidant protecting plants against damage when exposed to abiotic stresses, and it is one of the most studied antioxidants (Mittler 2002; Eltayeba et al. 2006; Bao et al. 2016). When vitamin C content was compared, the lowest vitamin C content was found at the 100% irrigation level. When the irrigation level was reduced and the plant was exposed to drought, an increase in plant vitamin C content occurred (Table 6). In Lester’s study (2005), treatments of

### Table 6: Effect of four levels of potassium on vitamin C, SH, proline, phenol, MDA of sugar beet, grown under drought-stressed and non-drought-stressed conditions

| K (mg kg$^{-1}$) | 33% | 66% | 100% | Mean | 33% | 66% | 100% | Mean |
|-----------------|-----|-----|------|------|-----|-----|------|------|
| Vitamin C (µg g$^{-1}$) |     |     |      |      |     |     |      |      |
| 10              | 252.15 a | 207.30 c | 75.55 h | 178.33 B | 69.16 a | 59.69 cd | 30.77 f | 53.21 A |
| 20              | 198.40 c | 232.38 b | 138.81 e | 186.87 A | 66.94 ab | 61.50 bc | 34.50 f | 54.31 A |
| 40              | 125.06 ef | 255.20 a | 109.92 fg | 163.40 C | 55.89 d | 69.08 a | 40.75 e | 55.24 A |
| 80              | 134.25 e | 159.76 d | 103.87 g | 132.62 D | 54.59 d | 37.22 f | 45.58 e | 44.63 B |
| Mean            | 175.21 B | 213.66 A | 107.04 C |      | 61.64 A | 55.60 B | 37.90 C |      |
| Proline (µM g$^{-1}$) |     |     |      |      |     |     |      |      |
| 10              | 297.61 bc | 308.09 b | 204.14 e | 269.95 A | 284.50 a | 178.56 cd | 206.60 bc | 223.22 A |
| 20              | 154.60 fg | 289.41 c | 200.99 e | 215.00 C | 212.08 bc | 218.35 b | 148.46 d | 192.97 B |
| 40              | 371.12 a | 145.52 g | 152.66 g | 223.10 B | 269.49 a | 259.31 a | 140.32 d | 223.22 A |
| 80              | 378.88 a | 239.60 d | 170.82 f | 263.10 A | 283.60 a | 162.54 d | 154.01 d | 200.05 B |
| Mean            | 300.55 A | 245.65 B | 182.15 C |      | 262.42 A | 204.70 B | 162.35 C |      |
| Phenol (µg g$^{-1}$) |     |     |      |      |     |     |      |      |
| 10              |       |       |       |       |       |       |       |       |
| 20              |       |       |       |       |       |       |       |       |
| 40              |       |       |       |       |       |       |       |       |
| 80              |       |       |       |       |       |       |       |       |
| Mean            |       |       |       |       |       |       |       |       |

The differences between the interaction of potassium and irrigation means having different lower case letters in a column are statistically significant at 0.05 alpha level. The differences between the potassium means having different capital letters in a column are statistically significant at 0.05 alpha level. The differences between the irrigation means having different capital letters in a line are statistically significant at 0.05 alpha level.
potassium increased the fruit firmness, vitamin C, sugar and carotene contents in muskmelon. In contrast to this study, potassium applications decreased the vitamin C content of the plant in our study. When the interaction between irrigation level and potassium was examined, the vitamin content decreased with increasing potassium applications, especially at the 33% irrigation level.

Oxidation of SH compounds from non-enzymatic antioxidants is a sign of oxidative stress, and a decrease in the content of SH compounds depends on reactive oxygen species (Sharma and Dubey 2005). It has been suggested that drought can launch generation of the superoxide radicals and hydrogen peroxide, which may attack membrane lipids and inactivate SH containing enzymes (Sade et al. 2011). Although not a general rule, oxidative stress factors increase the level of SH compounds in plant tissues (Uysal 2012). According to our results, SH content decreased with an increasing irrigation level and decreasing drought stress. These results were similar to previous studies. It has been emphasized in previous studies that the decrease in the level of SH compounds may be an indicator that potassium plays an important role in defense against oxidative stress when the potassium is applied adequately (Uysal 2012). When the irrigation level and potassium interaction was examined, SH content decreased with increasing potassium under stress conditions but increased with increasing potassium at the 100% irrigation level.

Proline is a low molecular mass compound which regulates osmotic pressure and diminishes osmotic damage (Jungklang et al. 2017). Proline accumulates in plants in response to abiotic stresses (Fiasconaroa et al. 2019). The accumulation of proline during drought stress is probably associated with mechanisms that adjust osmotic pressure (Santos et al. 2015). When Table 6 is examined, it is seen that proline content has increased significantly with a decreasing level of irrigation. Similar results were obtained in previous studies and the proline content of some plants (wheat, rice, sunflower) increased under drought stress (Cechin et al. 2006; Simova-Stoilova et al. 2008). Other studies have reported a positive correlation between potassium content and proline (Marques et al. 2011; Fiasconaroa et al. 2019). When Table 6 is examined in terms of the interaction between irrigation levels and potassium, it shows that proline content decreased with potassium applications up until the 80 mg kg\(^{-1}\) potassium application, except for the 33% irrigation level. However, proline content increased at all irrigation levels at the 80 mg kg\(^{-1}\) potassium application. It is thought that this increase may be due to the salt level resulting from the applied potassium dose. Previous studies have also reported increased proline content due to increased salt concentrations (Gomathi et al. 2010; Fayez and Bazaid 2014).

Phenols can act as antioxidants to reduce free radicals and defend plants against the negative effects of ROS due to abiotic stress (Fayez et al. 2014). Higher levels of phenols in plants are related to the mechanisms necessary in order to survive under stress (Fiasconoraoa et al. 2019). According to our results, the phenol content increased with increasing drought stress. Similar results were obtained in previous studies in some plants (cucumber, wheat, potato) (Daneshmand et al. 2010; Tiwari et al. 1998; Fayez and Bazaid 2014). It has been emphasized by various researchers that adequate potassium increases the concentration of phenol, which plays an important role in plant resistance (Prasad et al. 2010; Fiasconaraoa et al. 2019). In plants that were not exposed to drought stress, phenol content was high at low-potassium applications and phenol content decreased as potassium doses increased.

Membrane lipid peroxidation produces malondialdehyde (MDA), and it is related to the membrane permeability of leaves (Chen and Yu 1994). Research has shown that malondialdehyde can improve membrane permeability (Zou et al. 2018). According to other researchers, membrane damage increased with drought stress (Hamed et al. 2011; Fayez and Bazaid 2014). Our results are in parallel with these studies; MDA content decreased due to an increase in the irrigation level. Potassium improves membrane permeability (Hakerlerker et al. 1997). Drought and salt stress caused malondialdehyde to be produced in barley leaves, and malondialdehyde content was decreased by KNO\(_3\) applications (Fayez and Bazaid 2014). In contrast to previous studies, the MDA content averages in our study did not change as a result of potassium applications. When the interaction between irrigation level and potassium was examined, MDA content decreased at the 33% irrigation level with increasing potassium doses while increasing at the 66% and 100% irrigation levels.

**Conclusion**

According to the results, plant relative water content increased with K applications under drought conditions. The membrane damage due to drought stress decreased with the increase in K applications. This demonstrates the role of potassium in reducing the damage of drought-dependent cell membranes. The total chlorophyll content under drought stress decreased with increasing potassium concentrations, while it increased in non-stressed plants. In conditions where the potassium supply of the plants is sufficient, decreased levels of vitamin C indicate that ascorbic acid is used to protect against oxidative stress. A similar situation was observed for SH compounds. The proline content of the plants decreased with potassium applications, while it increased at the 80 mg kg\(^{-1}\)
potassium dose. It is thought that this increase may be due to the salt level resulting from the applied potassium dose. The malondialdehyde (MDA) content decreased under drought stress with increasing potassium concentrations, while it increased in non-stressed plants.

In summary, applying potassium to the plants under drought stress led to an increase in the relative water content and the reduction of membrane damage, and in particular to the reduction of non-enzymatic antioxidants produced for defence purposes when plants are faced with plant stress. Thus, it can be said that potassium may play a critical role in reducing the negative effects of drought stress in sugar beet. Therefore, it is thought that keeping the K nutrition at a sufficient level for the plants grown in the regions where irrigation may be a problem can be beneficial in reducing the damage of drought stress.

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Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

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