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Araştırma
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The Effect of Potassium Sulphate Applications on Plant Growth and Nutrient Content of Pepper Plants Grown Under High Temperature Stress*

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Abstract

Objective: Abiotic stresses are one of the most important factors that negatively affect plant growth. Especially in recent years, regression in plant growth and product losses have occurred due to high temperature caused by global climate change. The aim of the study was to reduce the effect of high temperature stress and increase plant tolerance with potassium. One of the ways to increase plant tolerance is proper fertilizer and fertilization techniques.

Material and Methods: Potassium sulfate fertilizer (K_2SO_4), which has a positive effect under abiotic stress conditions, was used as fertilizer in the experiment. The experiment was established according to the randomized plot design with 3 replications and 5 plants in each replication. The effects of foliar (0%, 1%, 2%, 3%) and soil (0-5-10-20 kg da^{-1}) potassium applications on plant growth under high temperature stress were investigated.

Results: As a result of the application of potassium sulfate from the leaves or roots, the effect of the plant green part scale, the membrane injury index, the dry weight ratio of the green parts, the relative moisture content of the leaves, the nitrogen (N), potassium (K) and calcium (Ca) concentrations in the leaves were found to be statistically significant.

Conclusion: The results indicated that potassium applications under high-temperature stress led to increases in nitrogen (N), potassium (K), and chlorophyll concentrations, as well as in the relative moisture content of the leaves. It was found that visual damage to green parts and leaf membrane damage decreased under high-temperature stress. The experiment revealed that potassium sulfate positively influenced plant growth under stressful conditions, reducing damage severity and enhancing plant resistance. The experiment revealed that potassium sulfate positively influenced plant growth under stressful conditions, reducing damage severity and enhancing plant resistance.

Keywords: High-temperature, nutrient element, pepper, potassium sulfate, stress

Yüksek Sıcaklık Stresi Altında Yetiştirilen Biber Bitkilerinde Potasyum Sülfat Uygulamalarının Bitki Gelişimi ve Bitkinin Besin Element İçeriğine Etkisi

Öz

Amaç: Abiyotik stresler bitki gelişimini olumsuz etkileyen en önemli faktörlerden biridir. Özellikle son yıllarda küresel iklim değişikliğinin neden olduğu yüksek sıcaklık nedeniyle bitki gelişiminde gerileme ve ürün kayıpları meydana gelmektedir. Çalışmanın amacı yüksek sıcaklık stresinin etkisini azaltmak ve potasyum ile bitki toleransını artırmaktır. Bitki toleransını artırmanın yollarından biri de uygun gübre ve gübreleme teknikleridir.

Materyal ve Yöntem: Denemede gübre olarak, abiyotik stres şartlarında olumlu etki gösteren potasyum sülfat gübresi (K_2SO_4) kullanılmıştır.

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Deneme, tesadüf parselleri deneme desenine göre 3 tekerrürlü her tekerrürde 5 bitki olacak şekilde kurulmuştur. Kapya biber çeşidine yapraktan (%0, %1, %2, %3) ve topraktan (0-5-10-20 kg da^{-1}) potasyum uygulamalarının yüksek sıcaklık stresi altında bitki gelişimine etkisi incelenmiştir.

Araştırma Bulguları: Yapraklardan veya köklerden potasyum sülfat uygulaması sonucunda, bitki yeşil aksam ölçeği, membran zararlanma indeksi, yeşil aksam kuru ağırlık oranı, yaprakların nispi nem içeriği, yapraklardaki azot (N), potasyum (K) ve kalsiyum (Ca) konsantrasyonların istatistiksel olarak önemli bulunmuştur.

Sonuç: Sonuçlar, yüksek sıcaklık stresi altında potasyum uygulamalarının, yaprakların nispi nem içeriğinin yanı sıra azot (N), potasyum (K) ve klorofil konsantrasyonlarında artışlara yol açtığını göstermiştir. Yüksek sıcaklık stresi altında yeşil kısımlardaki görsel hasarın ve yaprak membran hasarının azaldığı tespit edilmiştir. Deneme, potasyum sülfatın stresli koşullar altında bitki büyümesini olumlu yönde etkilediğini, hasar şiddetini azalttığını ve bitki direncini arttırdığını ortaya çıkarmıştır. Deneme, potasyum sülfatın stresli koşullar altında bitki büyümesini olumlu yönde etkilediğini, hasar şiddetini azalttığını ve bitki direncini arttırdığını ortaya çıkardı.

Anahtar Kelimeler: Yüksek sıcaklık, besin elementi, biber, potasyum sülfat, stres

Introduction

The sustainable and healthy development of plants within environmental constraints has long been a significant challenge in achieving high crop yields and product quality. The main factors affecting agricultural production and threatening global food security are global warming, climate change, weather uncertainty, drought, and high temperatures. These factors are exacerbated by increasing temperatures and unpredictable patterns of precipitation (Hasan et al., 2021; IPCC, 2019; Phurailatpam and Mishra, 2020; Singh Malhi et al., 2021; Teuling, 2018; Zandalinas et al., 2020; Zhang et al., 2019). The combined effect of prolonged and frequent occurrences of drought and high temperatures in the future has the potential to exert more substantial effects on agricultural production compared to isolated episodes. Abiotic challenges, such as high temperatures and heat stress, are frequently encountered limitations that effect on both plant growth and productivity. The primary consequences experienced by plants in response to high temperatures include premature maturation, wilting, abscission of leaves and flowers, and reduced yields (Porter, 2005; Akhoundnejad et al., 2020). Hence, it is vital to understand the present and future impacts of drought and increased temperatures on agricultural yield, both individually and in combination (Pullens et al., 2021). The occurrence of prolonged drought and increased temperatures has the potential to exert more significant effects on agricultural production in the future compared to isolated occurrences (Potopová et al., 2020). Abiotic stresses, such as high temperatures and heat stresses cause widespread constraints that have adverse effects on both plant growth and productivity. The primary consequences observed in plants in response to increased temperatures include premature maturation, wilting, abscission of leaves and flowers, and reduced crop productivity (Porter, 2005). Therefore, it is vital to know the current and future impacts of drought and increased temperature on crop production (Pullens et al., 2021). Recently, high temperatures in agricultural yield both alone and in combination. The high temperatures might impede the ability of seed germination and plant growth (Ahammed et al., 2018; Yamori et al., 2014). Furthermore, the impact of high temperature stress on plants encompasses significant changes in photosynthetic processes, respiration activities, transpiration rates, and cell structure (Ben-Asher et al., 2008). Another prominent consequence of high temperatures is the substantial impact on enzymatic activity in photosynthesis. This thermal impact can induce physiological and metabolic disorders, as well as compromise the cellular structure. Consequently, the occurrence of membrane lipid peroxidation finally results in disruption of the cell membrane integrity (Kotak et al., 2007; Huang et al., 2017). Moreover, Turkey is located in a geographical zone that is inherently susceptible to the adverse consequences of climate change. Furthermore, due to its geographical location, Turkey is inherently prone to the adverse effects of climate change. Hence, nations like Turkey must tackle climate change, minimize uncertainties, mitigate potential negative impacts, and devise policies to achieve these objectives (Daşgan et al., 2021). One strategy to bolster plant resistance involves developing resistant varieties or employing effective fertilization techniques.

The management of plant nutrition has recently attracted significant attention context of managing various abiotic stresses, including high temperature stress (Waraich et al., 2012). Potassium (K) is an essential macronutrient that plays significant roles in various plants functions, including osmoregulation, regulation of membrane potential, transport of sugars within plants, adaptation to stress, and facilitation of growth (Sardans and Penuelas 2021; Sanyal et al., 2020). According to Perelman et al. (2022), the application of potassium fertilizer promotes the tolerance to abiotic stress in plant. Potassium ions (K^+) are involved in the regulation of various biochemical processes related to protein synthesis, carbohydrate metabolism and enzyme activation (Hasanuzzaman et al., 2018). Potassium is an essential mineral for plants, playing a crucial role from the early growth stage to the vegetative growth phase, as well as in challenging environmental conditions. Furthermore, the presence of high K concentration in chemical mitigates the adverse impacts of various stressors, such as high temperatures, salinity, water stress, and metal toxicity (Johnson et al., 2022). Abiotic stressors, such as salinity, drought, and extreme temperatures, induce the production of reactive oxygen species (ROS). A mounting body of evidence suggests that enhancing the K+ nutritional status of plants could enhance their ability to withstand abiotic stress by decreasing ROS levels (Pandey and Mahiwal, 2020). Various physiological processes, including photosynthesis and stomatal control, rely on the regulation of K+ ions. Additionally, the K confers tolerance to abiotic stress maintains K^+ ion homeostasis under salinity conditions and controls the osmotic balance (Assaha et al., 2017; Kumar et al., 2020). The primary functions of K^+ in plants under heat stress include the activation of various metabolic and physiological processes, such as photosystem activity, respiration, nutrient homeostasis, and improvement of tissue water potential to mitigate the effects of high temperatures. Additionally, the K ion functions as an osmolyte and plays a role in the maintenance and regulation of stomatal conductivity, hence mitigating potential cell damage (Azedo-Silva et al.,2004). The beneficial impact of K in mitigating the adverse effects of high temperature stress has been documented in various plant species, including cotton and wheat (Shahid et al., 2019), palm trees (Elsayd et al., 2018), and wheat (Dias and Lidon, 2010; Sarwar et al., 2019). Vegetables contain a significant amount of essential nutrients, such as vitamins, minerals, and dietary fiber, as well as a variety of antioxidant compounds that are necessary for maintaining human health (Zhou et al., 2020). Pepper, belonging to the (*Capsicum* spp). *Solanaceae* family is one of the most important vegetable crops in the world. The cultivation of pepper is widespread, mostly for its fruit, which is consumed either fresh, dried, or utilized in the production of spicy seasonings (Baenas et al., 2019). Pepper is widely grown in different climatic conditions both under open-fields and protected environments. The international trade of fresh pepper fruits and processed products is widespread. Therefore, pepper cultivation plays a significant role in providing employment opportunities, particularly for small farmers around the world (Adeoye et al., 2014). Therefore, increasing pepper fruit yield is important. The fresh fruit yield in pepper cultivation is influenced by environmental conditions, which can impose stress on the crop, resulting in less fruit yield and a decline in quality (Parisi et al., 2020). Despite pepper being a vegetable that grows in hot climates, it is imperative to investigate novel approaches for mitigating the adverse effects of high temperatures. This is because high temperatures can lead to many detrimental consequences for both pepper plants and their fruits.

Material and Methods

The experiment was conducted during the 2020 growing season, the experimental field situated at 41° 43' 32.65" latitude and 37° 10' 17.63" longitude in the Şırnak province, Türkiye. The experiment was carried out using a randomized plot design, consisting of 3 replications, with each replication containing 5 plants. In this study, Slonovo, one of the capia pepper varieties, was used as plant material. Two separate trials were conducted, referred to as “control” and “high temperature” trials, during two different periods, with planting time, with modifications made to the planting schedule in the spring-summer growing period. The control trial was conducted in accordance with the regional planting schedule, while the second trial (High Temperature) was conducted after a period of 40 days. Fertilizers were applied based on the results of soil analysis (Figure 1) as recommended by Akhoundnejad et al. (2012). Specifically, 15 kg of nitrogen (N), 5.5 kg of phosphorus pentoxide (P_2O_5), 21.9 kg of potassium oxide (K_2O), 11.5 kg of calcium oxide (CaO) and 12 kg of magnesium oxide (MgO) were applied as plant nutrients. The highest temperatures recorded, during the stress test were 36.8 °C, 39.02 °C, 43.06 °C and 41.15 °C in the months of April, May, June, July, and August, respectively (Figure 2). Despite being adapted to hot climates, the growth and development of pepper plants decline when exposed to temperatures over 35°C.

The climatic conditions of the region indicate that the temperatures occurring during the plant development period can have a negative impact on plant growth, yield, and overall quality. Potassium sulphate was used as fertilizer in the experiment, with the specific application method and doses outlined in Table 1.

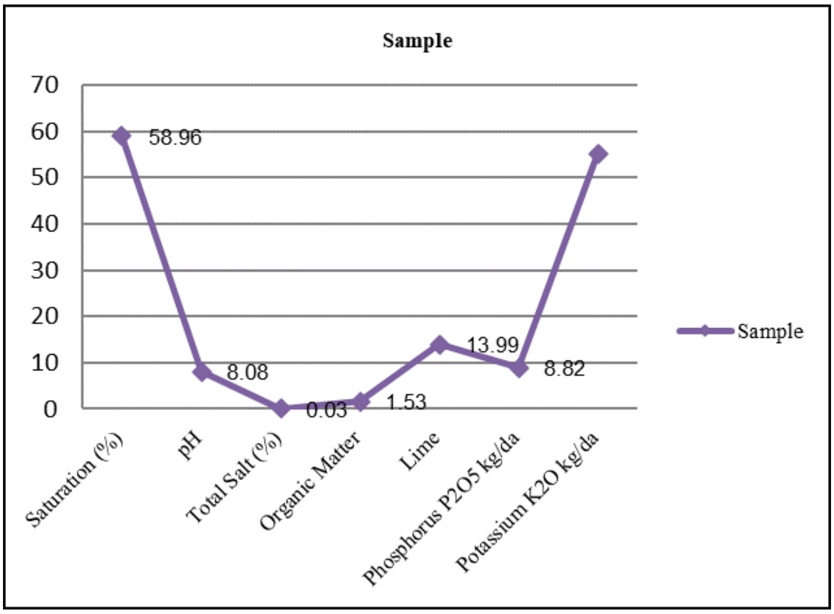

Figure 1. Soil analysis of the experimental area (2020)

Table 1. Fertilizer type and doses made in the experiment

Method of Application	Control	High temperature
Foliar	Control (%0)	Control (%0)
	% 1 K_2SO_4	%1 K_2SO_4
	%2 K_2SO_4	%2 K_2SO_4
	%3 K_2SO_4	%3 K_2SO_4
Soil	5 kg $da^{-1}K_2SO_4$	5 kg $da^{-1}K_2SO_4$
	10 kg $da^{-1}K_2SO_4$	10 kg $da^{-1}K_2SO_4$
	20 kg $da^{-1}K_2SO_4$	20 kg $da^{-1}K_2SO_4$

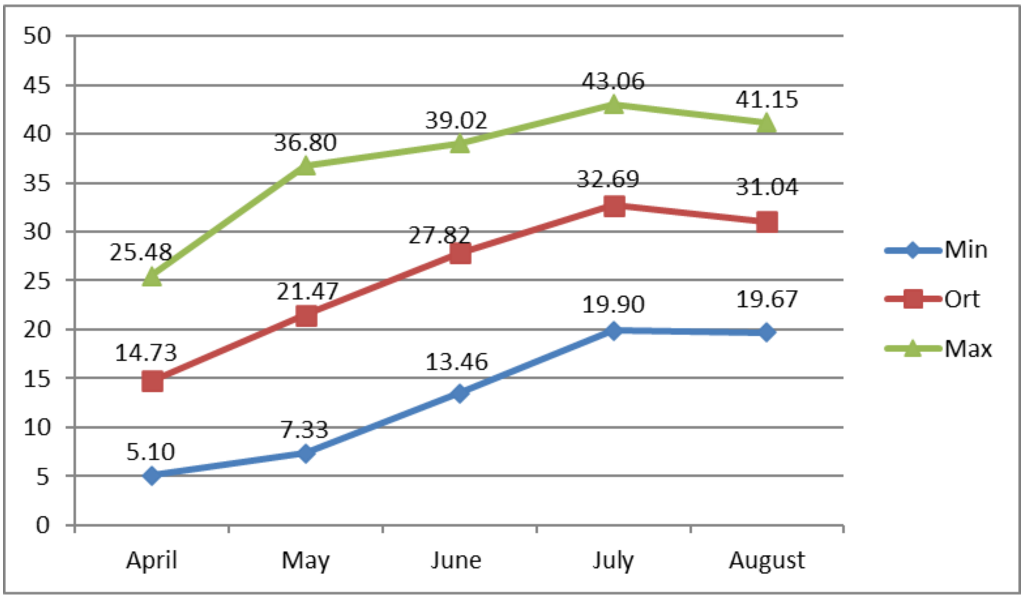

Figure 2. Temperature data of the trial area (2020)

Measurements related to plant growth

Green Parts Scale Evaluation

A scoring system ranging from 0 to 5 was used to assess the extent of plant damage resulting from high temperature stress (Daşgan et al., 2010).

0: Control plants

1: The occurrence of yellowing and wilting in lower leaves.

2: Leaf curling, closing, wilting and yellowing.

3: The plant is damaged between 51-70%.

4: The damage in plants ranges between 71 and 90%.

5: The plant is completely dried.

Dry Weight Ratio of Plant Green Parts (g plant^{-1})

In the experiment, 3 plants were collected from each replication, and their fresh weights were measured prior to drying. The dry weights of the dried plants were weighted and the average weights were recorded. Then, the dry weight ratio was determined by the ratio of dry weight to the fresh weight (Lahai and Ekanayake, 2009).

Dry weight ratio of green parts = (Dry weight/Fresh weight)x100

Chlorophyll Content (SPAD)

The chlorophyll content of the pepper plants was measured using a Minolta brand chlorophyll meter. Measurements were taken on the fourth and fifth leaves from the apex of the pepper plants.

Water Use Efficiency (g L^{-1})

The amount of water used during the experiment was recorded, and the data pertaining to the quantity of precipitation was obtained from the Meteorology Directorate of the Region. The total amount of overall water and the specific amount of water per plant were determined. Consequently, the total amount of water per plant during the production season was determined. The weights of pepper fruits were recorded during each harvest and afterwards, the total yield per plant was calculated. The efficiency of water use was calculated by the ratio of crop yield to the amount of water supplied (Akhoundnejad, 2011).

Water Use Efficiency (g L^{-1}) = Yield (g plant^{-1}) / Water Delivered (L plant^{-1})

Relative Water Content of Leaves (RWC)

The fresh weights of the fourth and fifth leaves from the apex of the pepper plants were weighed. The leaves were then placed in half-filled plastic cups and left for 4 hours. Afterwards, the leaves were removed from the water, and Turgor weights were recorded. The leaves were dried in an oven at 65 ºC for 48 hours. The relative water content (%) of the leaves was calculated using the equation explained by Dasgan and Temtek, (2022), Sanchez et al. (2019) and Türkan et al. (2005).

Proportional Water Content (%) = [(LFW-LDW)/(LTW-LDW)]x100

In the equation; LFW is the leaf fresh weight, LDW is the leaf dry weight, and LTW is the leaf turgor weight

Leaf Membrane Injury Index

The membrane injury index was determined through the quantification of electrolyte leakage from the cells of the leaves collected from 3 plants in each replication. The plant parts (17 mm diameter) from both stress-induced and control plants, were immersed in deionized water for 4 hours. Subsequently, the electrical conductivity (EC) of these discs was measured. The EC values of the solutions were afterwards measured following the exposure of the same discs to a temperature of 100°C for 10 minutes. The calculation of membrane injury index (%) in leaf cells was performed using the following equation (Fan and Blake, 1994).

Leaf Membrane Injury Index (%) =(Lt-Lc/1-Lc)x100

In the equation, Lt is the ratio of the EC value of leaf exposed to drought before autoclaving to the EC value recorded after autoclaving, Lc is the ratio of the EC value of control leaf before autoclaving to the EC value recorded after autoclaving.

Collecting Leaf Samples and Leaf Analysis

Leaf Potassium (K) and Calcium (Ca) Contents

Following the removing the pepper leaves, the leaves were washed using distilled water and dried in an oven at 65 °C for 48 hours. Subsequently, the samples were ground for analysis. A total of 200 mg ground samples was burned in a muffle furnace at 550 °C for 5 hours. The resulting ash obtained after the incineration process was dissolved using a 33% hydrochloric acid (HCl) acid, and the solution was then filtered using a filter paper. The filtered samples subjected to a dilution of 1/10 using a 3.3% HCl acid solution. The concentrations of potassium (K) and calcium (Ca) were determined using the Varian brand FS220 model Atomic Absorption Spectrophotometer device on the diluted samples (Akhoundnejad and Daşgan, 2018).

Leaf Total Nitrogen (N) Content

One gram of dry ground leaf samples were weighed and placed into Kjeldahl tubes. Then, a volume of 5 mL of concentrated H_2SO_4 and a selenium tablet were added to the tubes. The resulting mixture was subjected to combustion in the Kjeldahl apparatus at 400 °C for 1 hour until the color of the mixture became pale. Then, the distillation process was carried out using a Kjeldahl tube distillation system, employing a solution containing 28% NaOH. Boric acid and indicator solution were added to the ammonia released during process of distillation, and titration was carried out with 0.01 N HCl solution. The total nitrogen content of leaf samples was calculated by measuring the volume of HCl acid consumed in the titration process (Dasgan et al., 2023).

Statistical Analysis

The data obtained from the study using the JMP 13 statistical software program. The study was carried out using a randomized plot design with 3 replications. The data obtained were compared using the least significant difference (LSD) test at a 5% significance level.

Results and Discussion

The study aimed to examine the effect of potassium treatments on plant leaf injury under high temperature conditions. The results are presented in Table 2. A statistically significant difference was observed between the fertilizer treatments. The use of foliar potassium sulfate fertilizer at concentrations of 1%, 2%, and 3%, as well as soil applications of 5, 10, and 20 kg da^{-1} resulted in reduced injury to the plant's leaves in comparison to the control plot. The application of 20 kg da^{-1}+soil K_2SO_4 resulted in the least impact when compared to the control group. However, it caused the most significant injury in comparison to other applications. The findings of the study revealed that all foliar and soil potassium sulfate applications exhibited the ability to mitigate the negative impacts of high temperature stress compared to the control plot. In abiotic stress studies the assessment of scale is deemed significant in several crops such as tomato (Daşgan et al., 2002), pepper (Aktaş et al., 2006), beans (Daşgan and Koç, 2009) and, melon (Kuşvuran, 2010) in addition to the examination of morphological and physiological characteristics.

The application having the greatest membrane injury was 5 kg da^{-1}+soil (9.5%), while the application with the lowest membrane injury was 20 kg da^{-1}+soil (5.35%). There is an approximate difference of 43% between the control group (9.10) and the presence of 4%.

Leaf membrane injury under high temperature stress conditions was significantly different between the applications (Table 2). While the lowest leaf membrane injury under stress conditions was recorded in 20 kg da^{-1}+soil (5.35%), 10 kg da^{-1}+soil (5.93%), 3% + leaf (5.95%) and 2% + leaf (6.50%) treatments; the highest leaf injury was determined in 5 kg da^{-1}+soil (9.50%), control (9.10%) and 1%+leaf (8.23%) treatments, respectively. The application with the highest membrane injury was 5 kg da^{-1}+soil (9.5%) and the application with the lowest membrane injury was 20 kg da^{-1}+soil (5.35%) with an approximate 43% difference. The difference in membrane injury between 5 kg da^{-1}+soil, and the control group (9.10%) was only 4%. Previous studies have revealed that membrane injury increases under stress conditions (Katarzania et al.,2010; Kuşvuran, 2010). The observed damage to tomatoes under high temperature stress can be attributed to a reduction in stomatal conductivity when compared to the control group (Zhou et al., 2015). This reduction in stomatal conductivity is primarily caused by a decrease in transpiration, and a lack of CO_2 accumulation. Akhoundnejad and Daşgan (2018) conducted a study on tomatoes to investigate the impact of high temperature stress on membrane injury in leaves. The results indicated that the leaves subjected to high temperature stress exhibited a higher level of membrane injury compared to the control (Akhoundnejad and Daşgan, 2018). According to the findings of Saidi et al. (2010), both short-term, and long-term heat exposure critically affect membrane transport and increase injury to membrane leakage and permeability of cells.

The dry weight ratios of green parts were significantly different between the fertilizer application treatments (Table 2). The average dry weight ratio of green parts (31.41%), except for 10 kg da-1+soil (35.71%) treatment was higher than that recorded in control, and other potassium applications. The dry weight ratio of green parts in 10 kg da-1 + soil application increased by approximately 12.85% compared to control plants. The difference in the lowest (20 kg da-1+soil 28.99%) and highest (10 kg da-1+soil 35.71%) dry weight ratio of green parts was 18%. Taiz et al. (2015) reported that K+ deficiency decreased plant growth in plants.

The effect of potassium applications on water use efficiency (WUE) was statistically insignificant differences between treatments. The results showed that WUE in control and stress plots increased with potassium treatments. While the 3%+leaf treatment increased WUE in the control plot, a significant increase of 24.18% was observed, especially in the 2%+leaf treatment compared to the control. Notably, even in the stress plot, this treatment led to a significant positive change of 11.53% compared to the same treatment in the control plot. The most significant difference was observed in the control (36.05%) and 3%+leaf (36.02%) treatments compared to the control. Water use efficiency increased with potassium application except for 20 kg da-1+soil (9.08 b) and 3%+leaf (10.45 ab) treatments in the stress plot.

Table 2. Evaluation of 0-5 scale in green parts, dry weight ratio of green parts (g/plant) and membrane injury index

	Application	Stress plot		
		0-5 Scale	**Leaf membrane injury index (%)**	**Dry weight ratio of plant green parts (g/plant)**
Foliar	**Control**	2.30 a	9.10 f	31.12 c
	%1	1.25 bc	8.23 e	30.62 d
	%2	1.00 c	6.50 d	30.32 e
	%3	1.00 c	5.95 c	29.88 f
Soil	**5 kg da^{-1}**	1.50 b	9.50 g	33.23 b
	10 kg da^{-1}	1.17 c	5.93 b	35.71 a
	20 kg da^{-1}	2.00 ab	5.35 a	28.99 g
	Mean	1.45	7.22	31.41
	LSD	0.795	0.018	3.238
	P	0.0033*	<0001*	<0001*

The 20 kg da-1+soil treatment resulted in the lowest WUE value in the stress plot compared to the control. The results revealed a 3.09% decrease in WUE with 20 kg da-1+soil treatment compared to the control (Table 3).

The relative water content (RWC) serves as a significant indication for assessing the physiological condition of water within plants, expressing the equilibrium between water uptake and loss by transpiration (Hassanzadeh et al. 2009; Tanentzap et al.,2015; Lugojan and Ciulca, 2011). The effect of potassium treatments on leaf RWC in the control and stress experiment is given in Table 3. The control experiment revealed that the application of 1%+ leaf potassium or more resulted in a 5.35% increase in leaf RWC compared to the control application. The lowest RWC value in control experiment was recorded in 10 kg da^{-1}+soil application, resulting in a decrease of 9.44% compared to the control treatment. Saeed et al. (2023) reported that exposure to the heat stress caused a decrease in RWC in three pepper varieties (Moro, Tilhari and Ren-02). All applications in the stress experiment resulted in a decrease in RWC of the leaves when compared to the control experiment. However, all potassium sulfate fertilizer applications in the stress experiment led to an increase in RWC compared to the control application (potassium was not applied) (Table 3). The highest RWC in the stress experiment was obtained in the application of 20 kg da^{-1}+ soil (66.41%). The experimental treatment resulted in a 30.48% increase in the RWC compared to the control application.

Table 3. Mean values of the relative water content of the leaves and the effect of water use efficiency of potassium, and the measurements of the % change of the stress trial compared to the control trial

	Application	Water use efficiency (WUE) (kg ha mm^{-1})			The relative water content (RWC) (%)		
		Control	**Stress**	**% change relative to control**	**Control**	**Stress**	**% change relative to control**
Foliar	**Control**	7.97bc	10.84 ab	36.05	89.47 a	46.17 bc	48.40
	%1	10.09 abc	11.26 ab	11.53	94.53 a	56.14 ab	40.61
	%2	10.51 ab	12.40 a	17.98	83.41 a	64.89 a	22.20
	%3	7.68 c	10.45 ab	36.02	88.41 a	66.24 a	25.08
Soil	**5 kg da^{-1}**	10.61 a	11.48 a	8.20	84.95 a	57.12 ab	32.76
	10 kg da^{-1}	9.86 abc	11.53 a	16.93	81.75 a	61.94 a	24.23
	20 kg da^{-1}	9.37 abc	9.08 b	3.09	93.34 a	66.41 a	28.85
	Mean	6.69	8.06	20.41	87.98	59.84	31.73
	LSD	2.554	2.354	-	21.672	11.241	-
	P	0.1394	0.1717	-	0.871	0.004*	-

The chlorophyll content of leaves in potassium applications was not statistically different between the control and stress experiments (Figure 3). The chlorophyll content in the stress group decreased compared to the control group, except for the 5 kg da^{-1}+soil application. The chlorophyll content in the control group increased with an increase in potassium sulphate applications, except for 1%+leaf and 3%+leaf treatments. The control group had the lowest chlorophyll content in 2%+leaf (68.17) application. Although there was no statistical difference observed in the chlorophyll content of plants in the stress group, there was a notable changes in the chlorophyll content with the applications. The application of 20 kg da^{-1}+soil potassium sulfate resulted in a 3% reduction in chlorophyll content compared to the control group. The highest chlorophyll content in the stress group was recorded in the application of 5 kg da^{-1}+soil (76.87), that corresponded to 14% increase compared to the control plot. The chlorophyll content decreases as a consequence of the high temperature stress. Many researchers have underscored the adverse impact of stress on chlorophyll content (Amira and Qados, 2011; Barnabas et al., 2008; Güneri Bağcı, 2010; Georgieva et al., 2007; Kabay and Şensoy, 2017; Zengin, 2007). The chlorophyll content significantly increased in comparison to the control. Several previous research have stated that the application of potassium fertilizer to plants subjected to abiotic stress conditions leads to an increase in plant weight, ion concentration and chlorophyll content (Ahmed et al. 2020; Arslan, 2018; Kıran et al., 2014; Yıldırım ad Güneş, 2021; Georgieva et al., 2007; Barnabás et al., 2008; Demirel, 2008). The results revealed that all treatments, except for the 5 kg da^{-1}+soil treatment (4.40%), caused a decrease in the chlorophyll content.

The nitrogen content of green parts of the pepper plants grown under high temperature stress was significantly different in potassium sulfate applications between the controland stress experiments (Figure 4). The application of 2%+foliar application in the control and stress groups decreased the nitrogen content of green parts compared to the control plots. The nitrogen content of leaves in control and stress groups increased with increasing doses of K_2SO_4 application. Consistent with our findings, Colpan et al. (2013) observed that the application of increasing doses of potassium (K_2O) fertilizer to tomato plants resulted in increased amounts of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) in the leaves. In a separate investigation, Zengin et al. (2009) documented that the majority of macronutrients found in sugar beet leaves increased as potassium (K) doses were increased.

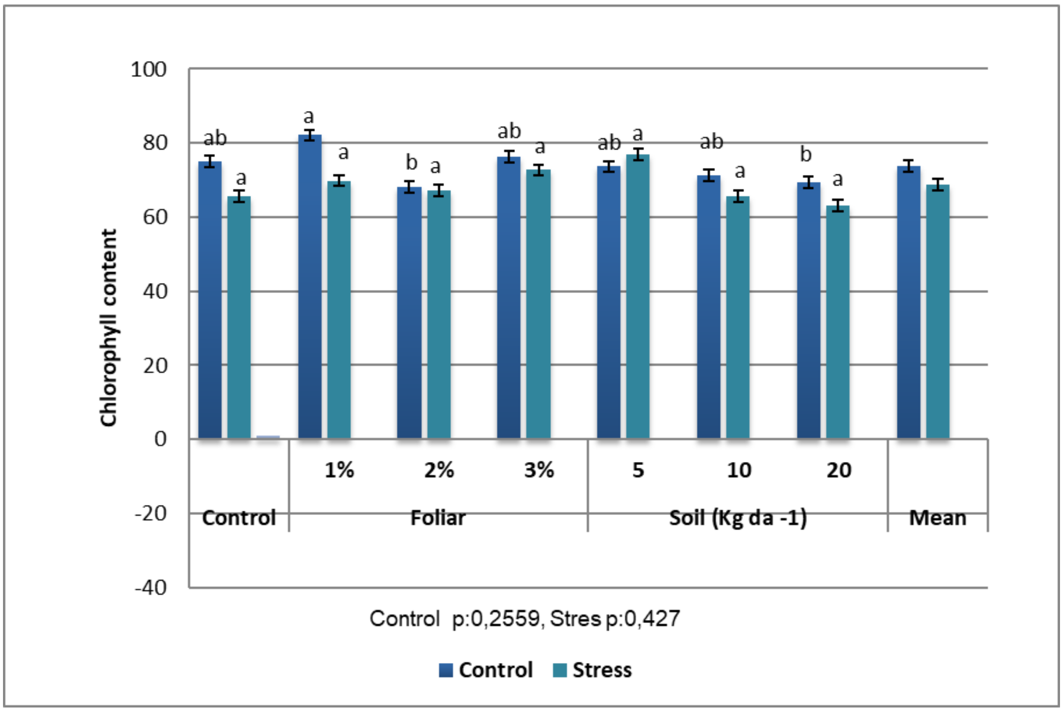

Figure 3. Chlorophyll ratio in leaves (SPAD)

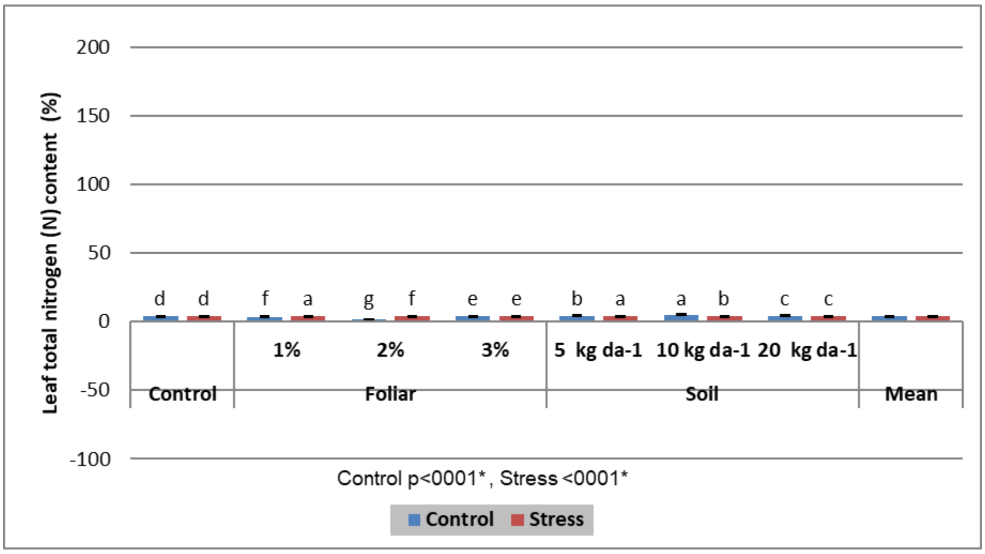

Figure 4. Leaf total nitrogen (N) content (%)

Calcium concentration in green parts under high temperature stress decreased in potassium applications at the control plot compared to the control plants (Table 4). The study revealed a decrease in calcium concentration in plants subjected to high temperature stress in comparison to the control group. The application of the 3%+leaf treatment resulted in a significant reduction of calcium concentrations by 46.64% as compared to the control plot. In contrast to the findings presented in our study, Temur et al. (2023) reported that the use of potassium fertilizers, specifically K_2SO_4 and KNO_3, on tomato plants resulted in an increase in calcium concentrations in the leaves. Furthermore, the extended exposure to high temperatures may result in a more pronounced detrimental effect on the uptake of essential nutrients. One potential consequence of extended exposure to high temperatures is a reduction in the availability of oxygen, ultimately resulting in the reddening of roots (Wells and Eissenstat, 2002; Zhou ve ark., 2019). The discoloration of root segments might lead to reduced nutrient uptake by the plant, potentially resulting in a decline in crop productivity (Park et al., 2023).

The effect of foliar and soil potassium sulfate application at different doses on potassium concentration in the leaves is shown in Table 4. The application of potassium in the control plot resulted in a significant increase in the concentration of potassium in the leaves compared to the control. The potassium content of leaves increased by the application of 3%+leaf and 20 kg da^{-1}+soil compared to the control (0% K_2SO_4). Specifically, the K content in the leaves increased by roughly 16% and 9.53% for the two corresponding treatments. The application of potassium in the stress plot resulted in an increase in the concentration of potassium. Furthermore, the applications of 3%+leaf and 20 kg da^{-1}+soil in the stress plot exhibited the highest levels of growth. The findings demonstrate similarities to the findings reported by Izsaki (2006) and Szulc (2010), indicating that the application of nitrogen and potassium leads to an increase in the concentration of nitrogen, phosphorus, and potassium in the plant.

Table 4. Calcium (Ca) and Potassium (K) concentration in leaves (%)

	Application	Calcium (Ca)			Potassium (K)		
		Control	Stress	% change relative to control	Control	Stress	% change relative to control
Foliar	**Control**	3.21 a	1.80 c	-43.93	3.70 f	3.39 f	-8.38
	%1	2.55 f	1.50 g	-41.18	3.63 g	3.38 g	-6.89
	%2	2.62 e	1.68 e	-35.88	3.91 d	4.02 c	2.81
	%3	2.83 b	1.51 f	-46.64	4.41 a	4.08 b	-7.48
Soil	**5 kg da^{-1}**	2.73 c	1.75 d	-35.90	3.97 c	3.56 e	-10.33
	10 kg da^{-1}	2.55 f	1.83 b	-28.24	3.77 e	3.91 d	3.71
	20 kg da^{-1}	2.63 d	2.10 a	-20.15	4.09 b	4.09 a	0.00
	Mean	2.73	1.74	-36.26	3.93	3.78	-3.82
	LSD	5.495	3.774	-	4.539	2.794	-
	P	<,0001*	<,0001*	-	<,0001*	<,0001*	-

Conclusion

This study aimed to investigate the impact of different concentrations of foliar application (1%, 2%, 3%) or soil application (5 kg da^{-1},10 kg da^{-1}, 20 kg da^{-1}) of potassium sulfate on plant growth. The findings indicated that the use of potassium sulfate fertilizer, either by foliar or soil application, had a positive effect on plant growth under stress conditions The examination of potassium sulfate using the green component scale revealed that the degree of exposure to stress and applications had a mitigating effect on membrane injury. The application of potassium applications resulted in an increase in the nitrogen, potassium and chlorophyll concentrations in the green parts, as well as increased relative water content of the leaves, in comparison to the control group of plants that did not get potassium treatment under stress conditions. The utilization of potassium additionally improved the water use efficiency during stress period. the efficiency of water use under stress conditions. Based on the aforementioned analyses, it is widely believed that potassium has the potential to exert a beneficial impact on plant growth under high temperature stress conditions.

Conflicts of Interest

The authors declare no conflicts of interest.

Authors Contribution

YA&HYD: Planning the trial, contributing to the execution of the laboratory and the trial. LE&BT: Contributing to the setup and execution of the trial, evaluation of the data, and writing of the article.

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