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Improvement of Seedling Growth in Cucumber Through External Putrescine Treatments Under Salt Stress

Tuz Stresi Altında Dışsal Putresin Uygulamaları ile Hıyarda Fide Büyümesinin İyileştirilmesi

Beyhan Kibar[1], Cansu Nur Tehmitci[2]

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Abstract: The objective of this research was to investigate the impact of external putrescine (Put) treatments at varying concentrations on the seedling growth of cucumber (*Cucumis sativus* L.) under saline conditions. A total of eight different treatments, including 200 mM NaCl and three different putrescine doses (0.4, 0.8, and 1.2 mM), were used to evaluate their individual and combined impacts. The results indicated that salt stress led to a significant reduction in multiple morphological and physiological traits, such as seedling height, fresh and dry weight of seedlings, stem diameter, number of leaves, chlorophyll content, dry matter ratio, and color quality. However, especially the 0.4 mM Put treatment significantly mitigated the adverse effects of salinity and improved seedling growth under both normal and saline conditions. The highest values for most growth and physiological parameters were observed with 0.4 mM Put treatment. On the other hand, higher putrescine concentrations, particularly in combination with salt stress, did not provide additional benefits and generally reflected the negative effects of salinity alone. It was found that 0.4 Put + 200 NaCl treatment increased seedling height by 10.68%, stem diameter by 25.23%, seedling fresh weight by 41.94%, number of leaves by 26.32%, chlorophyll content by 46.51% and dry matter ratio by 24.97% compared to 200 NaCl treatment. It was concluded that the 0.4 mM Put treatment could be recommended to enhance seedling growth in cucumber under saline conditions. These findings suggest that external putrescine application at optimum doses can serve as a practical strategy to improve seedling growth and salt stress resistance in cucumber cultivation.

Keywords: *Cucumis sativus* L., Salinity, Polyamine, Plant growth

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Öz: Bu araştırmanın amacı, tuzlu koşullarda hıyarın (*Cucumis sativus* L.) fide büyümesi üzerine değişen konsantrasyonlarda dışsal putresin (Put) uygulamalarının etkisini araştırmaktır. Çalışmada 200 mM NaCl ve üç farklı putresin dozu (0.4, 0.8 ve 1.2 mM) dahil olmak üzere toplam sekiz farklı uygulama, bireysel ve birleşik etkilerini değerlendirmek için kullanılmıştır. Sonuçlar, tuz stresinin fide boyu, fidelerin yaş ve kuru ağırlığı, gövde çapı, yaprak sayısı, klorofil içeriği, kuru madde oranı ve renk kalitesi gibi çok sayıda morfolojik ve fizyolojik özellikte önemli azalmaya yol açtığını göstermiştir. Ancak özellikle 0.4 mM Put uygulaması tuzluluğun olumsuz etkilerini önemli ölçüde azaltmış ve hem normal hem de tuzlu koşullar altında fide büyümesini iyileştirmiştir. Çoğu büyüme ve fizyolojik parametre için en yüksek değerler 0.4 mM Put uygulamasıyla gözlenmiştir. Öte yandan, özellikle tuz stresiyle birlikte daha yüksek putresin konsantrasyonları ek fayda sağlamamış ve genellikle tek başına tuzluluğun olumsuz etkilerini yansıtmıştır. 0.4 Put + 200 NaCl uygulamasının, 200 NaCl uygulamasına kıyasla fide boyunu %10.68, gövde çapını %25.23, fide yaş ağırlığını %41.94, yaprak sayısını %26.32, klorofil içeriğini %46.51 ve kuru madde oranını %24.97 oranında artırdığı bulunmuştur. Tuzlu koşullarda hıyarda fide büyümesini artırmak için 0.4 mM Put uygulamasının önerilebileceği sonucuna varılmıştır. Bu bulgular, optimum dozlarda dışsal putresin uygulamasının hıyar yetiştiriciliğinde fide büyümesini ve tuz stresine dayanıklılığı artırmak için pratik bir strateji olarak hizmet edebileceğini göstermektedir.

Anahtar Kelimeler: *Cucumis sativus* L., Tuzluluk, Poliamin, Bitki büyümesi

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[1] Prof. Dr. Beyhan KİBAR, Bolu Abant İzzet Baysal University, Department of Horticulture, beyhan.kibar@ibu.edu.tr (Corresponding author)

[2] M.Sc. Student Cansu Nur TEHMİTCİ, Bolu Abant İzzet Baysal University, Institute of Graduate Education, cansunurtehmitci@gmail.com

INTRODUCTION

Salinity is one of the most significant abiotic stress factors negatively affecting plant growth, development, and yield, often leading to substantial crop losses (Safdar et al., 2019). Soil salinization is increasingly recognized as a significant threat to the sustainability of future agricultural production. Mukhopadhyay et al. (2021) reported that soil salinity currently impacts approximately 33% of irrigated agricultural land and 20% of all cultivated land worldwide, and this proportion is projected to rise significantly by 2050. In Türkiye, around 1.5 million hectares of land are influenced by salinity problems (Okur and Örçen, 2020).

Saline conditions typically hinder seed germination, slow down plant growth, and reduce yield and quality, all of which lead to major economic losses (Dölarslan and Gül, 2012). The most frequently encountered salt in natural environments is sodium chloride (NaCl). The detrimental impacts of salinity can change depending on plant species and varieties, developmental stages, salt concentration and type, as well as the duration of exposure (Çulha and Çakırlar, 2011). Salt stress adversely influences plant physiology through mechanisms such as osmotic stress, nutritional imbalances and ion toxicity (Arif et al., 2020). Generally, vegetable crops exhibit greater sensitivity to salinity compared to other cultivated plant species such as cereals (Zörb et al., 2019). Therefore, it is highly important to investigate applications that increase resistance to salt stress, especially in vegetable agriculture.

Both saline soil reclamation and the breeding of salt-tolerant cultivars require significant time and financial investment. Accordingly, external treatments of polyamines, as a group of plant growth regulators, are considered as alternative and rapid strategies to mitigate the detrimental impacts of salt stress on agriculturally important plant species.

Polyamines are naturally occurring compounds in plants and function as plant growth regulators (Jangra et al., 2023). They play a crucial role in enhancing plant tolerance to various abiotic stresses, including drought, salinity, extreme temperatures and heavy metal toxicity (Gupta et al., 2013). Among polyamines, putrescine (Put) is usually the most abundant (Kalac and Krausova, 2005). External treatments of polyamines like putrescine can increase stress tolerance in plants by contributing to the improvement of morphological and physiological parameters under salt stress (Xu et al., 2011).

Cucumber (*Cucumis sativus* L.) is a member of the Cucurbitaceae family and is cultivated as an annual vegetable primarily in warm-season climates (Rolnik and Olas, 2020). Cucumber, which is among the vegetables whose fruits are consumed, can be found in markets and supermarkets throughout the year. It is a vegetable that is widely grown in Türkiye and has high economic value. In our country, 1.938.545 tons of cucumber were produced in 2023 (TÜİK, 2024). Türkiye ranks second in the world in cucumber production (Kadakoğlu and Gül, 2023). It is grown both in open fields and under greenhouse conditions in many regions of our country. It is also exported in significant amounts. It is consumed fresh in salads, pickled in the food industry and processed in different ways in the cosmetics industry. Cucumber is one of the low-calorie vegetables and therefore it is at the forefront in diets. Additionally, it is rich in vitamins and minerals (Rolnik and Olas, 2020). However, cucumber is among the vegetable species most sensitive to salinity, which seriously limits plant growth and crop yield (Al-Momany and Abu-Romman, 2023). Therefore, researching effective and applicable strategies to increase cucumber yield and quality in saline conditions is of great importance for sustainable agriculture.

In this study, it was aimed to determine the effects of external putrescine treatments at varying doses under salt stress conditions on the seedling growth of cucumber, which is among the salinity-sensitive vegetable species.

MATERIAL AND METHOD

Material

In the study, the Çengelköy cucumber (*Cucumis sativus* L.) variety was used as the plant material. Among the chemical materials used in the experiment, sodium chloride (NaCl) was obtained from Isolab and putrescine was sourced from Sigma-Aldrich.

Treatments, Experimental Design, Seed Sowing and Growing of Seedlings

The experiment involved eight different treatment combinations, including a fixed salt concentration of 200 mM and three different concentrations of putrescine (0.4, 0.8, and 1.2 mM) (Table 1). The effects of putrescine, both alone and in combination with salt stress, were examined.

Table 1. Experimental treatments, formulations and abbreviations.
Çizelge 1. Deneysel uygulamalar, formülasyonlar ve kısaltmalar.

Treatment No.	Content	Abbreviation
1	Control	Control
2	200 mM NaCl	200 NaCl
3	0.4 mM Putrescine	0.4 Put
4	0.8 mM Putrescine	0.8 Put
5	1.2 mM Putrescine	1.2 Put
6	0.4 mM Putrescine + 200 mM NaCl	0.4 Put + 200 NaCl
7	0.8 mM Putrescine + 200 mM NaCl	0.8 Put + 200 NaCl
8	1.2 mM Putrescine + 200 mM NaCl	1.2 Put + 200 NaCl

Seedlings were grown in a climate-controlled chamber set to 25 ± 1°C, 50–55% relative humidity, and of 14/10 hours light/dark photoperiod. The study was conducted using a completely randomized design (CRD) with three replications. Cucumber seeds were sown in 200 mL plastic cups filled with a substrate composed of peat and perlite at a volume ratio of 3:1 and then irrigated.

Putrescine treatments were applied four times at four-day intervals following the emergence of true leaves. Putrescine solutions were administered by spraying 10 mL per plant, ensuring that both the upper and lower surfaces of the leaves were fully wetted. The solution was supplemented with 0.01% Tween-20 to promote adherence to the leaf surface. In salt treatment, irrigations were made with solutions prepared at the dose discussed in the study to create salt stress. Salt treatments were applied four times at 4-day intervals, at a rate of 30 mL per plant, following the emergence of true leaves. The plants in the control group were watered with distilled water.

Growth parameters of the seedlings were determined 30 days after sowing. Representative photographs illustrating seedling growth responses to different putrescine concentrations under saline and non-saline conditions in cucumber are presented in Figure 1. In this research, seedling height (cm), stem diameter (mm), seedling fresh weight (g), seedling dry weight (g), number of leaves (number plant^{-1}), chlorophyll (spad), color (L*, a*, b*, Chroma and Hue angle), electrical conductivity (EC, μS cm^{-1}), pH and dry matter ratio (%) were determined. The height of seedlings was measured using a ruler. Stem diameter of seedlings was determined with a digital caliper. Seedling fresh weight was determined using a precision balance. To determine the seedling dry weight, the samples were weighed on a precision balance after drying at 65 °C. The number of leaves was determined by counting the leaves formed on the seedlings. The number of leaves per seedling was assessed by counting all fully developed leaves on each seedling. Chlorophyll content of leaves was detected by chlorophyll meter (Apogee Chlorophyll Concentration Meter, MC-100). The color values of leaves were determined using a colorimeter (3NH NR60CP). Electrical conductivity (EC) was determined using an EC meter (Thermo Scientific, Orion Star A212). The pH measurements of the samples were performed with a digital pH meter (Thermo Scientific, Orion Star A111). The dry matter ratio of samples was measured based on the standard protocols outlined by AOAC (1990).

Figure 1. Seedling growth responses to varying putrescine concentrations under saline and non-saline conditions in cucumber.

Şekil 1. Hıyarda tuzlu ve tuzsuz koşullar altında değişen putresin konsantrasyonlarına fide büyüme tepkileri.

Statistical Analysis

All experimental data were statistically evaluated using the JMP 13.2 software. Analysis of variance (ANOVA) was performed to assess the effects of treatments. When the ANOVA indicated significant differences, Tukey's HSD test was employed to compare the group means and identify statistically significant differences.

RESULTS AND DISCUSSION

Figure 2 shows that effects of salt stress and putrescine treatments on seedling growth parameters in cucumber. Significant differences were observed among treatments in terms of seedling height ($P<0.05$), stem diameter ($P<0.01$), fresh weight ($P<0.01$), dry weight ($P<0.01$), and number of leaves ($P<0.01$) in cucumber seedlings. Salt stress (200 mM NaCl) significantly reduced seedling height, stem diameter, seedling fresh weight, seedling dry weight and number of leaves when compared to the control. The highest seedling height (5.90 cm) was observed in 0.4 Put treatment, indicating that exogenous application of putrescine at this concentration promoted shoot elongation under non-stress conditions. This was closely followed by the control (5.86 cm), while other Put doses also maintained comparable values. In contrast, the lowest seedling height (4.68 cm) was recorded under 200 NaCl alone, highlighting the negative impact of salinity on seedling height. The highest stem diameter values were measured in 0.4 Put (4.76 mm), 0.8 Put (4.71 mm), control (4.69 mm), and 1.2 Put (4.56 mm), suggesting that putrescine also contributed to the development of stem girth under normal conditions. In contrast, the lowest stem diameter was determined in 200 NaCl (3.21 mm) and 1.2 Put + 200 NaCl (3.25 mm), indicating that salt stress inhibited cell expansion and vascular tissue development. In terms of seedling fresh weight, the highest values were obtained from 0.4 Put (4.41 g), control (4.29 g) and 0.8 Put (4.22 g) treatments. Conversely, the lowest seedling fresh weight was found in 200 NaCl (2.79 g) and 1.2 Put + 200 NaCl (2.82 g), reflecting significant water loss and biomass reduction due to salt toxicity. For seedling dry weight, the maximum value (0.72 g) was observed in 0.4 Put, while the lowest values were recorded in salt alone and in salt + putrescine combinations. Regarding the number of leaves, the 0.4 Put, 0.8 Put, 1.2 Put and control had the highest values, whereas the lowest number of leaves was detected in 200 NaCl. These results show that salt stress significantly inhibits the growth of cucumber seedlings, while exogenous treatment of putrescine (particularly at 0.4 mM) can alleviate these adverse effects and enhance growth parameters both under normal and saline conditions. Under combined salt stress and Put treatment, 0.4 Put + 200 NaCl was the most effective in mitigating the detrimental effects of salinity, leading to partial recovery in growth parameters. Higher doses (1.2 mM), especially in combination with salt, did not provide additional benefits and often performed similarly to salt stress alone. Exogenous putrescine treatments in the absence of salt stress (0.4-1.2 mM) improved all growth parameters compared to control, with 0.4 Put showing the most consistent positive effects. The 1.2 Put + NaCl treatment was the least effective in mitigating salt stress. This suggests that higher putrescine concentrations may not confer additional benefits under saline conditions and might even contribute to osmotic or metabolic imbalance. Overall, 0.4 mM Put treatment was the most effective dose in promoting seedling growth both under normal and saline conditions, highlighting its potential use as a practical strategy for improving salt tolerance in cucumber (Figure 2).

Salinity significantly affects seedling and plant growth. Salinity prevents the plant from easily taking in water from the environment, causing the plant to spend too much energy to take water, and thus plant growth slows down and stops (Ekmekçi et al., 2005). Additionally, it has been reported that plant growth is negatively affected by decreasing photosynthetic efficiency at high salt concentrations (Aranda and Syvertsen, 1996). Cucumber is among the vegetable species most sensitive to salinity (Al-Momany and Abu-Romman, 2023). Consistent with our study, previous studies have found that salt stress has negative effects on seedling development in cucumber (Zhang et al., 2009), melon (Kuşvuran, 2010), pepper (Rastgeldi, 2010), okra (Kuşvuran, 2011) and bean (Mena et al., 2015; Seymen and Önder, 2015). It has been determined that putrescine application positively affects seedling development in bean (Abdel-Azem et al., 2015), onion (Amin et al., 2011) and pepper (Khan et al., 2012) under stress-free conditions.

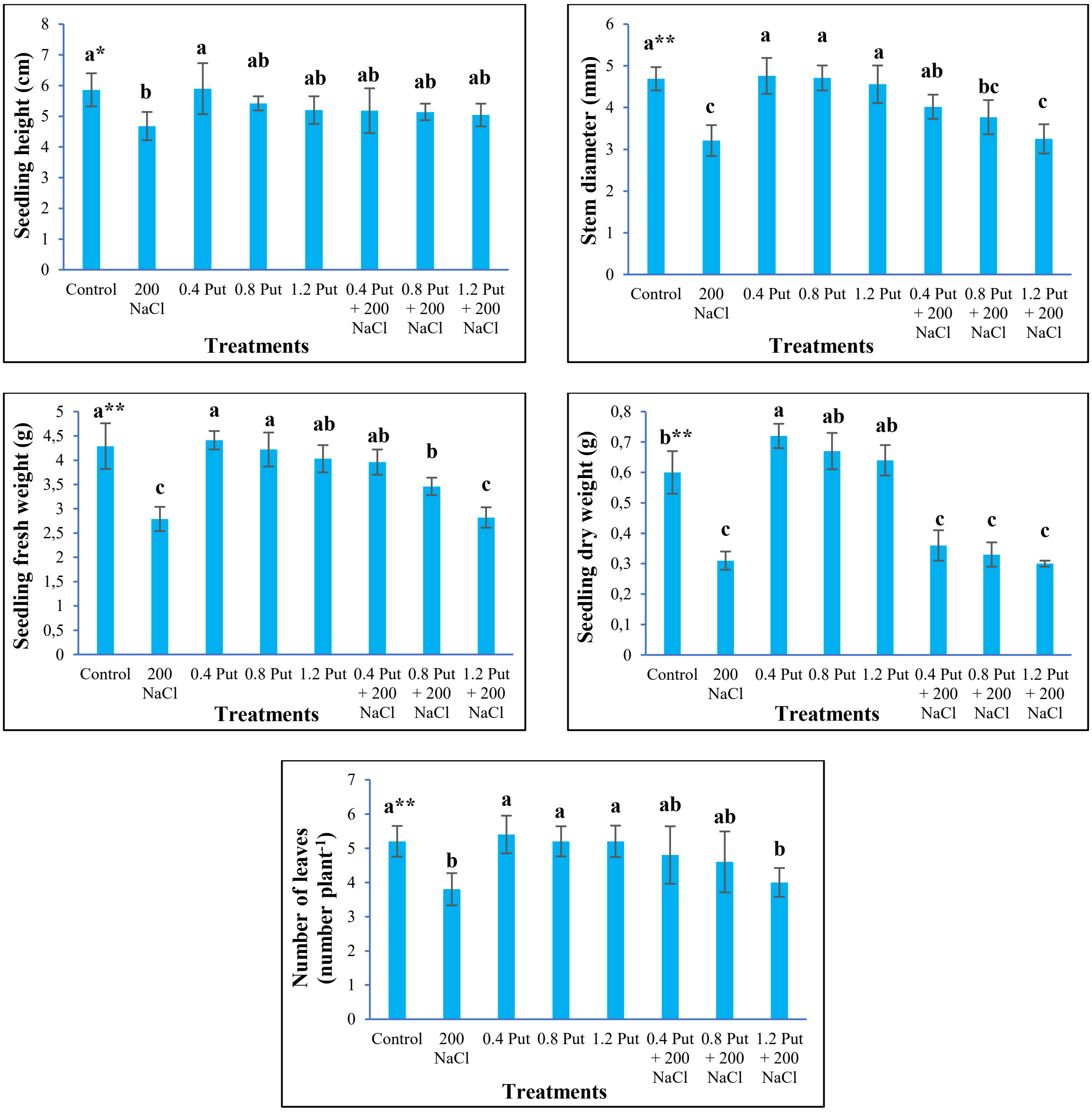

Figure 2. Effects of salt stress and putrescine treatments on seedling height, stem diameter, seedling fresh weight, seedling dry weight and number of leaves in cucumber (**: Significant at P<0.01 level, *: Significant at P<0.05 level).
*Şekil 2. Hıyarda tuz stresi ve putresin uygulamalarının fide boyu, gövde çapı, fide yaş ağırlığı, fide kuru ağırlığı ve yaprak sayısı üzerine etkileri (**: P<0.01 düzeyinde önemli, *: P<0.05 düzeyinde önemli).*

These improvements of putrescine on growth may be attributed to the role of putrescine in promoting cell division and elongation as well as stabilizing cellular structures under non-stress conditions (Xu et al., 2011; Jangra et al., 2023). It has been determined that seedling growth was inhibited by salinity in cucumber, and putrescine application reduced the negative effect of salt on seedling growth (Yuan et al., 2019). It has been reported that external treatment of polyamines significantly improves plant growth and development under different stress conditions by ensuring the maintenance of cell ion balance and cell membrane stability in plants, preventing chlorophyll loss, and increasing the synthesis of proteins, nucleic acids and protective alkaloids (Xu et al., 2011; Shi et al., 2013). Shu et al. (2012) stated that salt stress significantly reduces photosynthetic activity in cucumber, however, putrescine applied to the plant from the leaves prevented the negative effect of salt stress on photosynthesis. In another study, salinity significantly reduced seedling growth in bean, and putrescine treatments under salt stress conditions enhanced seedling growth parameters (Kibar et al., 2020). Zeid (2004) reported that putrescine application increased seedling growth in bean both under salty and normal conditions, and that putrescine reduced the harmful effect of salt. It was determined that traits such as seedling fresh weight, seedling height, seedling dry weight, stem diameter, root fresh weight, number of leaves and root dry weight in different vegetables exhibited a significant reduction due to salinity, and putrescine treatments under saline conditions improved the mentioned plant growth parameters (Biçer, 2016; Ekinci et al., 2019; Mohamedsrajaden, 2019). The results of this research align with those reported in earlier studies.

The effects of the treatments discussed in the study on chlorophyll, electrical conductivity, pH and dry matter content of cucumber seedlings were found to be significant ($P<0.01$). The results demonstrate significant physiological responses to both salt stress and putrescine treatments. The highest chlorophyll content (45.76 spad) was observed in 0.4 Put treatment, indicating a stimulating effect of putrescine on chlorophyll synthesis or protection of photosynthetic pigments under normal conditions. In contrast, the lowest chlorophyll content was recorded in 200 NaCl and 1.2 Put + 200 NaCl treatments, revealing the detrimental effect of salt stress on the photosynthetic mechanism. Among the salt + putrescine treatments, 0.4 Put + NaCl exhibited improved chlorophyll content compared to the NaCl alone, suggesting that putrescine had a partial protective effect under salt stress. Electrical conductivity (EC), which reflects the ion concentration in the medium, was significantly affected by salt treatments. EC increased significantly under salt stress. The highest EC (771 µS cm^{-1}) was observed in 1.2 Put + 200 NaCl treatment, indicating elevated ion accumulation under salt stress, especially when higher putrescine concentrations were used. On the other hand, the lowest EC values were found in 0.4 Put (182 µS cm^{-1}), control (187 µS cm^{-1}), and 0.8 Put (188 µS cm^{-1}) and 1.2 Put (205 µS cm^{-1}) treatments. EC values also increased as the putrescine dose increased under both saline and normal conditions. The pH values showed minor but statistically significant variations across treatments, ranging from 7.35 to 8.10. The highest pH values were recorded in control, 0.4 Put and 1.2 Put treatments, while the lowest pH was observed in 0.8 PUT + 200 NaCl treatment. The highest value for dry matter content (15.14%) was found at 0.4 Put, indicating that putrescine increased dry matter accumulation under non-stress conditions. In contrast, the lowest dry matter content was detected in 200 NaCl (9.05%) and 1.2 Put + 200 NaCl (9.11%). These results suggest that severe salt stress, especially when combined with higher putrescine doses, reduces dry matter production, probably due to growth inhibition. In summary, these findings demonstrate that salt stress significantly impairs physiological traits such as chlorophyll content and dry matter accumulation in cucumber seedlings. However, 0.4 Put emerged as the most effective dose in improving chlorophyll content, increasing dry matter accumulation and minimizing salt-induced physiological deterioration under both normal and saline conditions (Figure 3).

Salt stress significantly influences the physiological and biochemical properties of vegetable seedlings. Salt stress generally causes a reduction in chlorophyll content due to the disruption of chlorophyll biosynthesis and the promotion of oxidative stress. In the present study, salt stress markedly reduced chlorophyll content, consistent with chloroplast damage and impaired pigment biosynthesis under saline conditions. In studies involving cucumber, radish, and lettuce, conducted by Yıldırım et al. (2008), Bukhat et al. (2020), and Salem (2021) respectively, increasing salinity was shown to reduce chlorophyll content. Previous studies on cucumber (Yıldırım et al., 2008), lettuce (Salem, 2021) and radish (Bukhat et al., 2020) have shown that chlorophyll content decreases as salinity levels increase. It has been stated that at high salt concentrations, there is a decrease in the total chlorophyll amount due to ion accumulation and irregularities in the opening and closing of stomata, and as a result, photosynthetic efficiency decreases and plant development is negatively affected (Aranda and Syvertsen, 1996). In the studies conducted on cucumber (Shu et al., 2012), bean (Zeid, 2004; Kibar et al., 2020) and tomato (Mohamedsrajaden, 2019), it was found that chlorophyll content decreased significantly with salinity and an enhancement in chlorophyll content under saline conditions through external putrescine application was observed, which supports our current findings. Exogenous application of putrescine, either alone or in combination with salt stress, can positively modulate several physiological and biochemical parameters in vegetable seedlings. Putrescine is known to enhance chlorophyll biosynthesis and protect chloroplast structure by mitigating oxidative stress, thus helping to maintain or even increase chlorophyll content under both normal and salt-stressed conditions (Yuan et al., 2018). In previous studies, it was reported that EC values in the plant significantly increased under salt stress in lettuce (Eraslan et al., 2007), tomato (Mohamedsrajaden, 2019) and bean (Kibar et al., 2020). Additionally, Mohamedsrajaden (2019) determined that putrescine applications in tomato under both salty and unsalted conditions reduced EC content compared to control. Electrical conductivity in plant tissues typically increases due to the accumulation of salt ions (e.g., Na^+ and Cl^-), reflecting higher osmotic stress. Putrescine may help alleviate the increase in tissue electrical conductivity typically observed under salt stress by reducing the adverse effects of salt-induced ionic imbalance. According to Kibar et al. (2020), increased salinity levels caused a decline in both dry matter content and pH in bean. They further reported that external putrescine applications under saline conditions improved dry matter accumulation. These outcomes are consistent with the results of the current study.

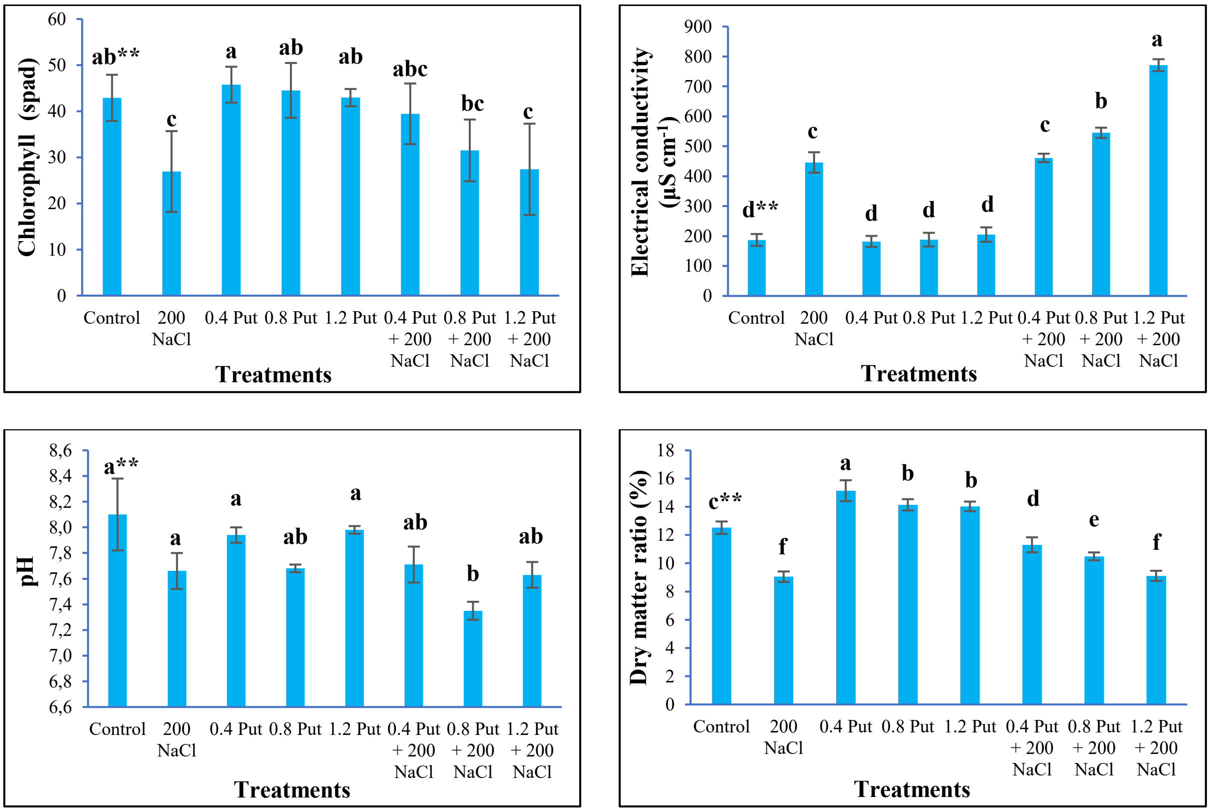

Figure 3. Effects of salt stress and putrescine treatments on chlorophyll, electrical conductivity, pH and dry matter content in cucumber (**: Significant at P<0.01 level).

*Şekil 3. Hıyarda tuz stresi ve putresin uygulamalarının klorofil, elektriksel iletkenlik, pH ve kuru madde içeriği üzerine etkileri (**: P<0.01 düzeyinde önemli).*

The pH of plant tissues may slightly decrease under salt stress because of ionic imbalance and increased organic acid production. As a matter of fact, in our study, the pH value under salt stress decreased compared to the control. In terms of pH, putrescine may contribute to pH homeostasis by regulating ion uptake and organic acid metabolism. Regarding dry matter content, salt stress can lead to either an increase or decrease depending on the severity and duration of the stress. In some cases, moderate salt stress causes a relative increase in dry matter due to reduced water content, while severe stress can impair growth and biomass accumulation, resulting in a decline in dry matter. Putrescine may promote biomass accumulation and osmotic adjustment, leading to an increase in dry matter, especially under stress conditions where growth would be inhibited.

According to Figure 4, the differences among treatments in terms of a*, b*, Chroma and Hue angle color values were statistically significant (P<0.01). On the other hand, the effect of treatments on L* color value was found to be insignificant. The L* values, which represents lightness, varied between 42.10 and 45.12 depending on the treatments. Regarding a* values, which indicate the green-red axis (positive values indicate red; negative values indicate green), the most negative a* values were found in 0.8 Put (-11.30), 1.2 Put (-11.28) and control (-11.25), reflecting strong green pigmentation (more negative = more green). In contrast, the least negative a* value (-5.59) was observed in 1.2 Put + 200 NaCl, indicating a significant reduction in greenness due to salt stress, especially when combined with high putrescine concentration. The b* color value represents the yellow-blue coordinate (positive values indicate yellow; negative values indicate blue). The highest b* values were recorded in control, 0.4 Put, 0.8 Put and 1.2 Put treatments, indicating enhanced yellow pigmentation. However, the lowest b* value was observed in 1.2 Put + 200 NaCl. Chroma value indicates color intensity or saturation. In terms of Chroma, the highest value (22.39) was observed in 1.2 Put, while the lowest value (13.24) was found in 1.2 Put + 200 NaCl treatment. This suggests that while 1.2 Put enhances color intensity under normal conditions, it loses effectiveness or may even contribute to color degradation under salt stress. Hue angle represents the actual color tone (in degrees). Hue angle values ranged from 114.26 to 121.94. For Hue angle, the highest values were recorded in 200 NaCl, control, 0.4 Put, 0.8 Put and 1.2 Put treatments. Conversely, the lowest Hue angle was detected in 1.2 Put + 200 NaCl, suggesting a shift in perceived color tone under salt stress combined with high putrescine levels. The most favorable color characteristics were generally observed in treatments where putrescine was used alone under non-stress conditions. In conclusion, exogenous putrescine treatment (especially at 0.8-1.2 mM under non-saline conditions) appears to improve or maintain favorable leaf color characteristics. However, the combination of salt stress with high putrescine concentration negatively affected most color parameters, likely due to cumulative stress impacts on pigment metabolism. The most severe color degradation was seen in 1.2 Put + 200 NaCl, which had the lowest b*, Chroma, and Hue angle values and the least negative a* value, suggesting possible chlorosis or pigment loss due to excessive stress (Figure 4).

Salt stress and putrescine treatments, either individually or in combination, can significantly influence the color characteristics of vegetable seedlings. Salt stress adversely affects the color properties of vegetable seedlings by inducing physiological and biochemical changes. Salt stress often leads to a reduction in L* (lightness) values due to chlorophyll degradation and oxidative damage, resulting in darker and more discolored tissues. It can also cause fluctuations in a* (red-green) and b* (yellow-blue) values due to stress-induced accumulation of anthocyanins or carotenoids. Overall, salt stress tends to impair visual quality by altering pigmentation and diminishing color uniformity in seedlings. Conversely, external putrescine application to seedlings can mitigate these negative effects by enhancing antioxidant capacity, stabilizing chlorophyll content, and maintaining membrane integrity, thereby helping to preserve or even improve color quality. Putrescine treatment under salt stress may alleviate the color-degrading effects of salinity and lead to more stable L*, a*, b*, Chroma and Hue angle values in the seedlings. Kibar et al. (2020) reported that salt, putrescine, and salt + putrescine treatments caused significant differences in a*, b*, and Chroma color parameters of fresh bean seedlings, whereas no significant differences were observed among treatments for L* and Hue angle color values. In another study, Kiemde and Kibar (2023) found that the difference among salt, putrescine and salt + putrescine treatments in terms of Hue angle color value of lettuce plants was statistically significant, while the effect of the treatments on L*, a*, b* and Chroma color values was insignificant.

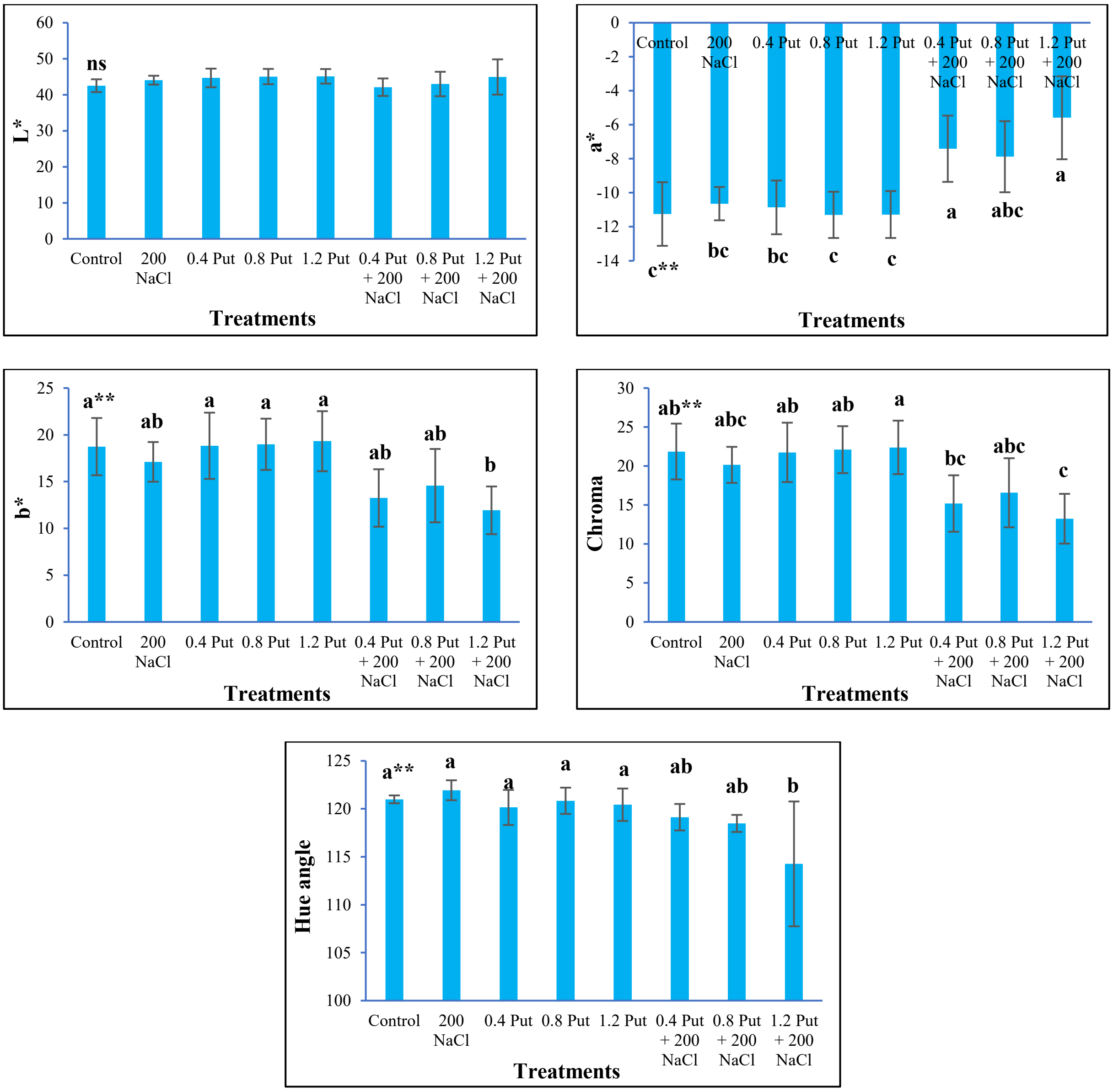

Figure 4. Effects of salt stress and putrescine treatments on color characteristics (L*, a*, b*, Chroma and Hue angle) in cucumber (**: Significant at P<0.01 level, ns: non-significant).

Şekil 4. Hıyarda tuz stresi ve putresin uygulamalarının renk özellikleri (L, a*, b*, Kroma ve Hue açısı) üzerine etkileri (**: P<0.01 düzeyinde önemli, ns: önemli değil).*

CONCLUSION

The results clearly demonstrated that salinity (200 mM NaCl) negatively affected seedling growth in cucumber and salt stress significantly impaired the morphological and physiological development of seedlings. The damage caused by salt stress reached its peak level at the dose of 200 mM NaCl, where salt was applied alone. External application of putrescine was effective in alleviating these negative effects. In general, it was detected that putrescine treatments under saline conditions increased seedling growth parameters and markedly decreased the detrimental impacts of salinity. When three different doses of putrescine (0.4, 0.8 and 1.2 mM) were evaluated, it was determined that the 0.4 mM dose was more effective on seedling growth than the other doses both under saline conditions and under normal conditions without salt stress. This low-dose putrescine treatment significantly improved seedling growth, enhanced chlorophyll content, stabilized physiological traits such as electrical conductivity and pH, and preserved favorable leaf color characteristics. The findings highlight that low-dose external putrescine treatment, particularly at 0.4 mM, can serve as a practical and effective approach to improve salt tolerance and promote healthy seedling development in cucumber. In conclusion, 0.4 mM Put treatment can be recommended as an effective strategy to promote the growth of cucumber seedlings under salt stress. This strategy could be especially valuable in regions affected by soil salinization and contribute to sustainable vegetable production under saline conditions.

CONFLICT OF INTEREST

The authors report that there are no conflicts of interest related to this study

DECLARATION OF AUTHOR CONTRIBUTION

BK: Study design, data analysis and manuscript preparation. CNT: Conducting experimental procedures and carrying out laboratory analyses.

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