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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Determination of the effects of waterlogging stress on some morphological and physiological parameters in pepper (*Capsicum annuum* L.)

Su baskını stresinin biber bitkisinde (*Capsicum annuum* L.) bazı morfolojik ve fizyolojik parametreler üzerine etkisinin belirlenmesi

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ABSTRACT

This study examined the morphological and physiological responses of the Çermik pepper genotype and the Mazamort pepper variety to waterlogging stress. Conducted in a climate chamber under controlled conditions, the experiment included 0(control), 5, 10, and 15 durations of waterlogging applications, with 3 replications and 10 plants per replication. The Çermik genotype showed the highest plant height (46.90 cm) on 15 day under waterlogging, while the Mazamort variety reached 46.93 cm on the same duration. The root collar diameter was highest in the Çermik genotype (5.63 mm) on 5th day of the control, and in the Mazamort variety (6.17 mm) during the 10th and 15th day control. The highest SPAD values were observed on 15th day of waterlogging for both genotypes, with Çermik at 45.37 SPAD and Mazamort at 45.63 SPAD. Fresh weights peaked at 35.90 g for Çermik and 35.95 g for Mazamort on day 15 of the control. Ion leakage patterns differed between the genotypes, with increased leakage in Çermik on 5th and 10th days of waterlogging, while Mazamort showed decreased leakage on the 10th and 15th day of the control. Overall, the Çermik genotype exhibited higher tolerance to waterlogging stress, making it a recommended choice for agriculture in flood-prone areas.

ÖZET

Bu çalışma, Çermik biber genotipi ile Mazamort biber çeşidinin su baskını stresine karşı morfolojik ve fizyolojik tepkilerini incelemiştir. Kontrollü koşullarda iklim odasında yürütülen deneyde 0(kontrol), 5, 10 ve 15 günlük su baskını uygulamaları yapılmış; her uygulama 3 tekerrürlü ve her tekerrürde 10 bitki olacak şekilde tasarlanmıştır. Çermik genotipi, 15 günlük su baskını uygulamasında 46.90 cm ile en yüksek bitki boyuna ulaşırken, Mazamort çeşidi aynı sürede 46.93 cm'ye ulaşmıştır. Kök boğazı çapı bakımından, Çermik genotipinde en yüksek değer 5. gün kontrol grubunda 5.63 mm olarak ölçülmüş; Mazamort çeşidinde ise 10. ve 15. gün kontrol uygulamalarında 6.17 mm'ye ulaşılmıştır. Yaprak klorofil içeriğini yansıtan SPAD değerleri, her iki genotipte de 15. gün su baskını uygulamasında en yüksek seviyeye ulaşmış; Çermik genotipinde 45.37 SPAD, Mazamort çeşidinde ise 45.63 SPAD olarak belirlenmiştir. Taze ağırlık değerleri, 15. gün kontrol uygulamasında Çermik için 35.90 g, Mazamort için ise 35.95 g ile en yüksek düzeyde kaydedilmiştir. İyon sızıntısı verileri genotipler arasında farklılık göstermiştir. Çermik genotipinde 5. ve 10. gün su baskını uygulamalarında iyon sızıntısında artış gözlenirken, Mazamort çeşidinde 10. ve 15. gün kontrol gruplarında sızıntı azalmıştır. Genel değerlendirme sonucunda, Çermik genotipinin su baskını stresine karşı daha yüksek tolerans gösterdiği belirlenmiş olup, bu özelliği sayesinde su baskını riski yüksek alanlarda tarımsal üretim için önerilen bir durum olarak öne çıkmaktadır.

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INTRODUCTION

Climate change, primarily driven by global warming, is anticipated to exert significant impacts on ecosystems and human health on a global scale, including within our own country. The phenomena of rising sea levels, shifting climatic zones, and the increasing frequency and intensity of extreme weather events—such as floods and droughts—pose both direct and indirect threats to socio-economic sectors and ecological systems (Türkeş, 2001; IPCC, 2021). As sessile organisms, plants are unable to relocate and must therefore develop various adaptive mechanisms to survive in low-oxygen environments induced by heavy rainfall or flooding (Dennis et al., 2000). Turkey is particularly susceptible to the impacts of climate change, given that a significant portion of its territory lies within semi-arid regions where water resources, agriculture, ecosystems, and human livelihoods may be profoundly affected. The anticipated environmental degradation resulting from global warming—including the depletion of water resources, increased incidence of forest fires, and desertification—is likely to heighten the exposure of plants to abiotic stresses, thereby diminishing agricultural productivity. Abiotic stresses such as drought, salinity, extreme temperatures, chemical toxicity, and oxidative stress pose substantial threats to agricultural practices and environmental health, potentially leading to yield losses exceeding 50% in key crops (Wang et al., 2004). Among the various abiotic stresses, waterlogging is a significant factor that negatively impacts global crop production (Bailey-Serres & Voesenek, 2008; Colmer & Voesenek, 2009). Plants require optimal water levels for growth, and both excess water and deficiency can induce environmental stresses such as drought and flooding (Nishiuchi et al., 2012). Waterlogging conditions, characterized by anoxia and hypoxia, can result in root decay, reduced respiration, and ultimately lower yields. Globally, waterlogging affects approximately 16% of irrigated cropland, severely constraining agricultural productivity (Ahsan et al., 2007).

Oxygen deficiency in waterlogged soils negatively affects plant growth and development, leading to reduced productivity (Pradhan & Mohanty, 2013). The diffusion of oxygen in water occurs at a significantly slower rate than in air, resulting in severe hypoxia or anoxia during flooding events (Panozzo et al., 2019). While many plant species are sensitive to flooding, some exhibit adaptive responses, such as the formation of adventitious roots and aerenchyma (Akhtar & Nazir, 2013; Zhou et al., 2012). The capacity of plants to adapt to waterlogged conditions varies among species (Zhou et al., 2012). Pepper (*Capsicum* spp.) is an important vegetable crop consumed globally and throughout Turkey in various forms. Its cultivation occurs across all regions of the country, where peppers are used not only in their fresh state but also as powder, paste, grilled, in sauces, pickles, and as ingredients in main dishes (Sanatombi, 2025). Turkish pepper varieties can be categorized based on shape and intended use into sweet peppers, hot peppers, bell peppers, industrial peppers, and small-fruited hot varieties (Anonymous, 2023).

This study had two primary objectives. The first aim was to determine the physiological effects of waterlogging stress on Çermik and the Mazamort plants. This analysis elucidated the impact of waterlogging on critical physiological parameters, including growth, development, photosynthetic activity, nutrient uptake, and water balance. The second objective was to assess the tolerance of the local Çermik to waterlogging stress and to evaluate its potential as a breeding resource. This involved investigating the resistance of the Çermik pepper genotype to waterlogging, its response under such stress conditions, and its suitability for further development. Ultimately, this study aimed to contribute to the development of waterlogging-resistant and high-yielding pepper varieties, thereby enhancing agricultural resilience in the face of environmental challenges.

MATERIALS and METHODS

Plant material

This study was carried out in the climate chamber of the Faculty of Agriculture, Siirt University in 2023. The climate chamber was kept at 25 °C/20 °C (day/night) with a photoperiod of 16 hours of light and 8 hours of darkness.

Climate chamber conditions included 65-70% relative humidity and 400 µmol $m^{-2} \cdot s^{-1}$ light intensity. The plant materials employed in this study included the "Mazamort"® pepper variety, sourced from Sunagri Seed® in Konya, and the Çermik pepper genotype, a local variety traditionally grown in Diyarbakır. The Çermik genotype is recognized for its distinctive taste, particularly when consumed raw in breakfast and culinary dishes. The soil and climatic conditions in the Çermik district create a specific microenvironment that enhances pepper cultivation, contributing to its unique flavor and aroma profile. It is important to note that the same genotype may not retain these characteristics when grown under different climatic and soil conditions. It was stated in interviews and the results of the research institute's project that these negative outcomes were observed. However, we cannot provide references because the results have not yet been converted into academic publications. Seeds of the local Çermik genotype were obtained from a farmer actively involved in the production of Çermik peppers. In contrast, the Mazamort variety is an economically significant cultivar widely cultivated in Diyarbakır. The Mazamort variety, obtained from Sunagri Seed Company, is suitable for both greenhouse and open-field cultivation. Its fruits are characterized by a length of 10-12 cm, a crisp texture, sweetness, a uniform shape, and a dark green color with three lobes.

Research Area

Cultivation of Plant Genetic Material

Seed sowing and seedling cultivation

A substrate consisting of a 2:1 ratio of peat and perlite was prepared for seed sowing. This substrate was transferred into 45-cell trays with an internal depth of 5 cm and external dimensions of 33 cm x 54 cm, after which sowing was conducted. The substrate used in this study was a peat-based mixture, specifically Klasmann Potground P20®, which was combined with perlite (Agrekal®), an inorganic material. This peat-based substrate primarily consisted of 20% TerrAktiv® compost and 10% GreenFibre® wood fibers, supplemented with frozen black peat to provide structural stability and water retention, as well as white peat to improve water absorption. Perlite, a volcanic mineral with an amorphous structure, mainly comprises silicon dioxide, with smaller amounts of aluminum, sodium, potassium, and iron oxides (Anonymous, 2025a,b).

Application of waterlogging stress to plants

Following germination, seedlings were transplanted once they reached the 3-4 leaf stage. The seedlings were placed in pots with a diameter of 160 mm, height of 140 mm, and a volume of 2 liters. Each pot was filled with a substrate composed of sand, garden soil, peat, and perlite in a 1:2:1:1 (1v:2v:1v:1v) ratio. Once the seedlings acclimatized and overcame transplant stress, the waterlogging stress treatment commenced. This treatment was applied as partial waterlogging (flood) stress, with the plants transferred to deep plastic containers and retained there for the duration of the treatment. The application involved submerging the plants up to the root collar. The duration of the treatment was set at 0 (control), 5, 10, and 15 days, determined based on previous studies (Dere & Daşgan, 2019; Zhen et al., 2021). The waterlogging stress treatments were initiated after the seedlings reached the 3–4 leaf stage, once they had acclimatized and overcome transplant stress. All treatments were started simultaneously; however, the duration of stress exposure varied according to the designated treatment periods of 0 (control), 5, 10, and 15 days. For each duration, plants were maintained under waterlogging conditions for the specified number of days, after which they were harvested for analysis. For example, plants assigned to the 5 day treatment were collected and measured at the end of the fifth day, while plants under the 10 and 15 day treatments continued to be subjected to waterlogging until the end of their respective periods. This approach ensured that each treatment group was exposed to waterlogging stress for the exact intended duration. The experiment was replicated three times, with ten plants per replicate. A visual representation of the treatments and observations for the Çermik genotype and the Mazamort pepper variety is presented in Figure 1.

Throughout the study, nutrient solutions were employed: Stock A containing 1.6% ammonium nitrogen (NH_4), 8.7% nitrate nitrogen (NO_3-N), 7.5% soluble potassium oxide (K_2O), 8.6% calcium (Ca), and 0.3% iron DTPA (Fe); and Stock B containing 2.1% nitrate nitrogen (NO_3-N), 6.4% soluble phosphorus pentoxide (P_2O_5), 11.6% soluble potassium oxide (K_2O), 1.6% magnesium (Mg), 0.1% manganese (Mn), 0.1% zinc (Zn), 0.03% boron (B), 0.003% copper (Cu), and 0.004% molybdenum (Mo) (Yılmaz, 2020). The concentrations of these nutrient solutions were prepared according to the study by Yılmaz (2020) and the application times were adjusted according to daily monitoring. For the control group, the irrigation amount was applied at approximately 25 ± 2% of the drainage rate (Schröder & Lieth, 2002). The electrical conductivity (EC) of the nutrient solution was between 1.8 and 2.4 dS m^{-1}, while the pH levels ranged from 6.0 to 6.5.



Figure 1. Visual representation of the treatments and observations for the Çermik genotype and the Mazamort pepper variety.

Şekil 1. Çermik genotipi ve Mazamort biber çeşidine ait uygulama ve gözlemlerin görsel temsili.

$$\mathrm{DR} = \text{drainage solution (mL)/applied nutrient solution (mL)} \times 100 \quad \text{eq.[1]}$$

Prior to the measurements and analyses, representative plant samples were selected for these purposes. All observations, measurements, and analyses defined in the study were performed on samples collected from at least three plants.

Parameters Investigated

Morphological parameters

The height of the plant (cm), measured in centimeters (±0.5), was defined as the distance from the root collar to the growing tip using a measuring tape. Plant stem and root collar diameter were measured in mm using calipers. the total number of leaves was calculated by counting all leaves on the plant (Dere, 2021). Plant dry weight (g) was determined in grams on a precision scale after the leaf samples were dried in an oven at 65°C for 48 hours (Dasgan et al., 2023). Chlorophyll content in the fourth leaves of the pepper plants was assessed by taking readings with a Minolta SPAD meter (Minolta 502, Osaka, Japan), which indicates variations in green color intensity (Altuntas et al., 2020).

Visual scale evaluation

A visual scale assessment was performed to identify the damage caused by waterlogging stress. Plants were rated on a scale from 0 to 5 based on their damage status (Kuşvuran, 2010; Yang et al., 2020):

0: No damage observed in pepper plants under waterlogging stress.

1: Yellowing and curling of pepper leaves.

2: 25% necrosis and yellowing of pepper leaves.
3: 25-50% necrosis in pepper leaves with visible leaf drop.
4: 50-75% necrosis in pepper leaves, with early signs of plant death.
5: Rapid necrosis of 75-100% in pepper leaves and/or total plant death.

Physiological Parameters

Ion leakage

To assess ion leakage under the experimental conditions, five leaf discs, each with a diameter of 1 cm, were obtained from the second top leaf. The leaf discs were rinsed with distilled water and gently dried using blotting paper. They were then placed in individual test tubes and shaken for 4 hours. Ion leakage for each sample was measured with an EC meter (EC600 model, Extech Instruments A Flir Company), recorded as the initial measurement (EC1). The leaf discs were retained in the same solution and subsequently subjected to autoclaving at 120 °C for 15 minutes, and ion leakage was measured at room temperature, recorded as the final measurement (EC2). The ion leakage was calculated using the following formula (Arora et al., 1998).

$$\text{Ion Leakage } (\%) = (\text{EC1}/\text{EC2}) \times 100 \quad \text{eq.[2]}$$

Leaf relative water content

At the end of the treatments, leaf discs of identical age and size (1 cm in diameter) were collected. The fresh weights (FW) of the discs were measured using a precision balance. The discs were then soaked in distilled water for 4 hours to determine their turgor weight (TW). Following this, the discs were dried in an oven at 70 °C for 24 hours to obtain the dry weight (DW). The leaf relative water content (LRWC) was calculated using the formula (Arefian & Shafaroudi, 2015) :

$$\text{LRWC } (\%) = [((\text{FW} - \text{DW}) / (\text{TW} - \text{DW}))] \times 100 \quad \text{eq.[3]}$$

FW: Fresh Weight, TW: Turgor Weight, DW: Dry Weight

Statistical Analyses

The experiment was conducted in a completely randomized design (CRD) with a factorial arrangement. The factors included pepper genotype (Çermik local genotype and Mazamort variety) and duration of waterlogging stress (0, 5, 10, and 15 days). Each treatment combination was replicated three times, with ten plants per replicate. Data for each pepper genotype were analyzed separately. Analysis of variance (ANOVA) was performed using JUMP 16 software, and means with significant differences were separated using the LSD multiple comparison test (Jump, 2021).

RESULTS and DISCUSSION

Effects of treatments on 0-5 scale values of Çermik genotype and Mazamort pepper variety

The effects of treatments on scale values and the significance of differences among groups were assessed using LSD (Least Significant Difference) values, as presented in Figure 2. The treatments had a statistically significant impact on the 0-5 scale value for both the Çermik pepper genotype (Figure 2a, $p \leq 0.0001$) and the Mazamort pepper variety (Figure 2b, $p \leq 0.0001$), with significant differences observed among the resulting groups.

Results indicated that the visual scale values for Çermik pepper genotype plants ranged from 0.00 to 3.25, with the lowest values observed in initial seedlings and the control group at 10 days, and the highest in the 15 day waterlogging treatment (Figure 2a). Following waterlogging stress, moderate necrosis and chlorosis (approximately

25%) were noted on leaves at 5 and 10 days. By the 15 day mark, a moderate level (25-50%) of necrosis was observed, along with minimal leaf drop.

For the Mazamort pepper variety, visual scale values ranged from 0.00 to 4.25, again with the lowest in initial seedlings and the highest at the 15 day waterlogging treatment (Figure 2b). Similar to the Çermik genotype, plants under waterlogging stress exhibited moderate necrosis (25-50%) and leaf drop at 5 and 10 days. However, by 15 days, necrosis increased to 50-75%, accompanied by a gradual onset of plant mortality.

These findings highlight the detrimental effects of waterlogging stress on both pepper varieties, with increasing severity of leaf damage and plant health deterioration over time. Such results underscore the need for effective water management strategies in the cultivation of these pepper varieties to mitigate stress-related impacts.

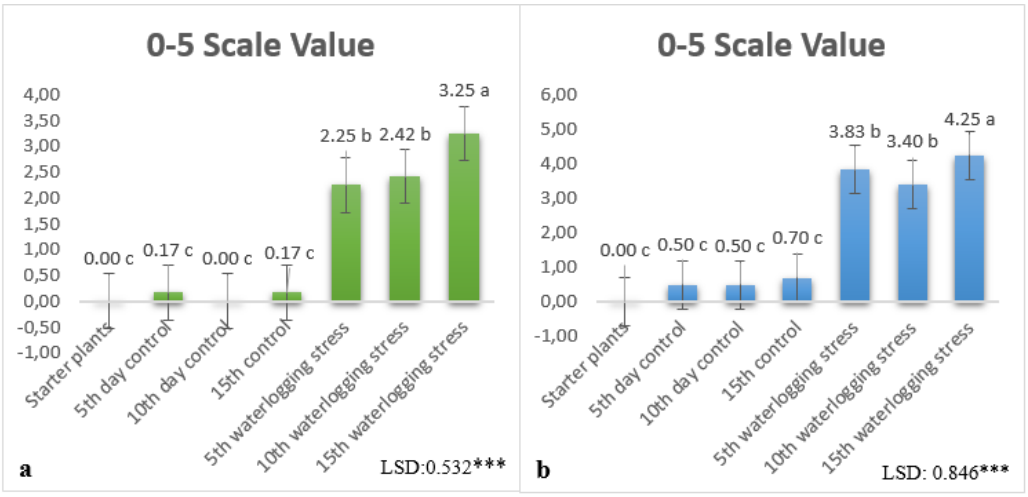


Figure 2. Effects of applications on 0-5 value of Çermik genotype(a) and Mazamort pepper variety(b)

Şekil 2. Çermik genotipi(a) ve Mazamort biber çeşidinin(b) 0-5 değerine uygulamaların etkileri

Effects of treatments on plant height (cm) of Çermik pepper genotype and Mazamort pepper variety

The effects of treatments on plant heights and the significance of differences between groups were determined using LSD values, as illustrated in Figure 3. The plant height of the Çermik pepper genotype was found to be statistically significant ($p \leq 0.0090$). In contrast, the Mazamort pepper variety showed no statistically significant differences among groups following the treatments ($p \leq 0.4123$).

The average plant heights of the initial seedlings, control groups (5th, 10th, and 15th day), and those subjected to waterlogging treatments (5th, 10th, and 15th day) are presented in Figure 3. For the Çermik pepper genotype, plant heights ranged from 28.63 cm to 46.90 cm, with the lowest heights observed in the initial seedlings and the highest recorded after 15 days of waterlogging treatment. A height increase of approximately 64% was noted in the 15 day waterlogged plants compared to the initial seedlings (Figure 3a).

In the Mazamort pepper variety, plant heights varied from 41.83 cm to 46.93 cm, again showing the lowest heights in the initial seedlings and the highest after 15 days of waterlogging treatment. An increase of 12.2% in height was observed in the 15 day waterlogged plants relative to the initial seedlings (Figure 3b).

Overall, waterlogging treatments resulted in height increases for both pepper varieties compared to the initial seedlings. When comparing the control groups (5th, 10th, and 15th day) with the waterlogging treatments (5th, 10th, and 15th day), a notable increase in plant heights was evident (Figure 3).

Flooding is a significant environmental stress factor in agriculture, exerting pronounced negative effects on plant growth. The responses of plants to flooding can vary markedly among species, making this a critical issue for agricultural productivity. The literature indicates that flooding adversely impacts numerous morphological and physiological parameters, including plant growth, root development, leaf count, and chlorophyll content. Various

studies have documented these detrimental effects, highlighting the importance of understanding species-specific responses to enhance resilience in agricultural systems. For example, research by Samad et al. (2001) indicated that moderate levels of waterlogging often resulted in stunting of plant growth. Mensah et al. (2006) reported decreased plant heights in *Sesamum indicum* as the duration of waterlogging increased. Similarly, Collaku & Harrison (2002) observed reductions in plant heights for various wheat cultivars exposed to waterlogging for durations of 10, 20, and 30 days under greenhouse conditions. These findings underscore the diversity of plant responses to waterlogging, suggesting that while some species may exhibit enhanced growth under certain conditions, prolonged waterlogging typically has adverse effects on growth across most plant species. This information is critical for developing effective water management strategies in agricultural production and understanding the impacts of water stress on plant growth.

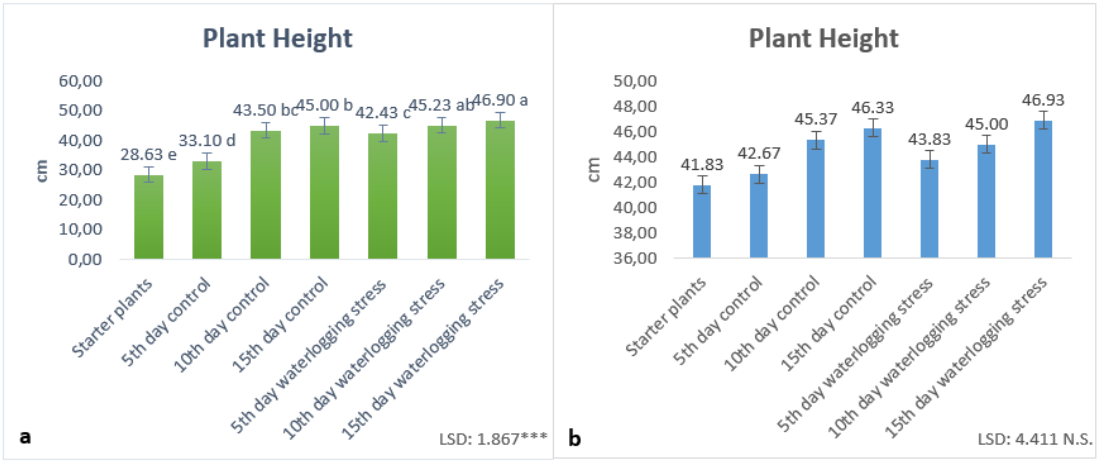


Figure 3. Effects of applications on plant height (cm) of Çermik genotype (a) and Mazamort pepper variety (b)
Şekil 3. Çermik genotipi (a) ve Mazamort biber çeşidinin (a) bitki boyuna (cm) uygulamaların etkileri

Effects of treatments on stem diameter (mm) of Çermik pepper genotype and Mazamort pepper variety

The effects of treatments on stem diameters and the significance of differences among various groups were evaluated using LSD values, as presented in Figure 4. The differences in stem diameter among treatments for the Çermik pepper genotype were found to be statistically significant ($p<0.05$), while those for the Mazamort pepper variety were even more pronounced ($p\leq0.0005$).

The average stem diameters of the initial seedlings, control groups (5th, 10th, and 15th day), and those subjected to waterlogging treatments (5th, 10th, and 15th day) are illustrated in Figure 4. In the Çermik pepper genotype, stem diameters varied between 3.33 mm and 5.63 mm, with the lowest values observed in the initial seedlings and the highest recorded in the control group on the 15th day. Compared to the initial seedlings, a 69.0% increase in stem diameter was noted in the 15 day control group, while a 37.0% increase was observed in the 15 day waterlogged plants (Figure 4a).

For the Mazamort pepper variety, stem diameters ranged from 3.67 mm to 6.03 mm, with the lowest measurements in the initial seedlings and the highest in the control group on the 10th day. The highest stem diameter was recorded in the 10 day control group, showing a 64.3% increase compared to the initial seedlings, while a 19.9% increase was noted in the 15 day waterlogged plants (Figure 4b).

Tsukahara & Kozlowski (1986) reported that waterlogging reduced stem diameter growth in *Betula platyphylla* var. japonica seedlings. In contrast, Xiao et al. (2009) found that in mangrove seedlings, as the duration of waterlogging increased, both stem and pith diameters also increased. The present study indicates that while waterlogging duration generally enhances stem diameter, it can lead to reductions compared to control groups. Other studies highlight that the effects of waterlogging vary by plant species; for instance, while it reduces stem diameter in

Betula platyphylla var. japonica, it appears to enhance growth in mangrove species. This discrepancy suggests that different plant species develop unique adaptation mechanisms to cope with water stress, emphasizing the complexity of waterlogging's effects on plant growth. The ability of various species to tolerate waterlogging in different ways underlines the importance of considering these variances when formulating water management strategies in agricultural production.

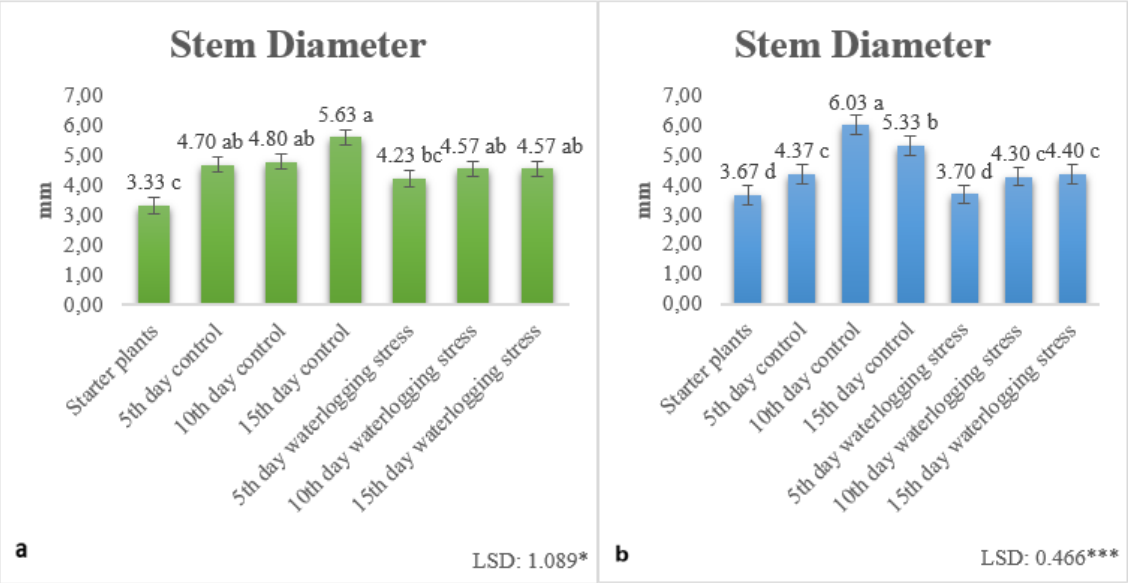


Figure 4. Effects of applications on stem diameter (mm) of Çermik genotype (a) and Mazamort pepper variety (b)
Şekil 4. Çermik genotipi (a) ve Mazamort biber çeşidinin (b) gövde çapına (mm) uygulamaların etkileri

Effects of treatments on root collar diameter (mm) of Çermik pepper genotype and Mazamort pepper variety

The effects of treatments on collar diameter and the significance of differences among various groups were analyzed using LSD values, as illustrated in Figure 5. The impact of treatments on collar diameter in the Çermik pepper genotype was found to be statistically significant ($p \leq 0.0080$), as was the case for the Mazamort pepper variety ($p \leq 0.0001$).

In the Çermik pepper genotype, collar diameters ranged from 3.47 mm to 5.63 mm, with the lowest values in the initial seedlings and the highest recorded in the control group on the 5th day (5.63 mm). Compared to the initial seedlings, there was a 62.2% increase in collar diameter in the 5 day control group, and a 40.3% increase in the 15 day waterlogged plants (Figure 5a).

For the Mazamort pepper variety, collar diameters varied between 3.93 mm and 6.17 mm, with the lowest measurements in the initial seedlings and the highest in both the control group on the 10th day and the 15th day (6.17 mm). Relative to the initial seedlings, collar diameters increased by 56.9% in both the 10th and 15th day control groups, and by 13.7% in the 15 day waterlogged plants (Figure 5b).

Overall, waterlogging treatments resulted in increased collar diameter compared to the initial seedlings for both pepper varieties. However, when comparing the control groups (5th, 10th, and 15th days) with the waterlogging treatments (5th, 10th, and 15th days), a decrease in collar diameter was noted (Figure 5).

Villarreal-Navarrete et al. (2014) reported that in their study on waterlogging stress, root growth parameters in *Physalis peruviana* L. diminished significantly, with a marked reduction in collar diameter. These findings indicate that while waterlogging can enhance collar diameter, prolonged exposure can lead to a reduction in size. In contrast, the study on *Physalis peruviana* emphasizes the detrimental effects of waterlogging on collar diameter. The physiological responses of plants to stress are complex, and such varied outcomes are often influenced by plant species, the nature and severity of the applied stress, growth conditions, and methodological differences. Previous

studies have reported similar reductions in leaf number due to waterlogging stress in various crops, including soybean (Nakayama & Komatsu, 2008), wheat (Samad et al., 2001), maize (Rao et al., 2002), tomato (Else et al., 2009), watermelon (Yetisir et al., 2006), and pigeon pea (Çelik, 2010; Çelik & Turhan, 2011).

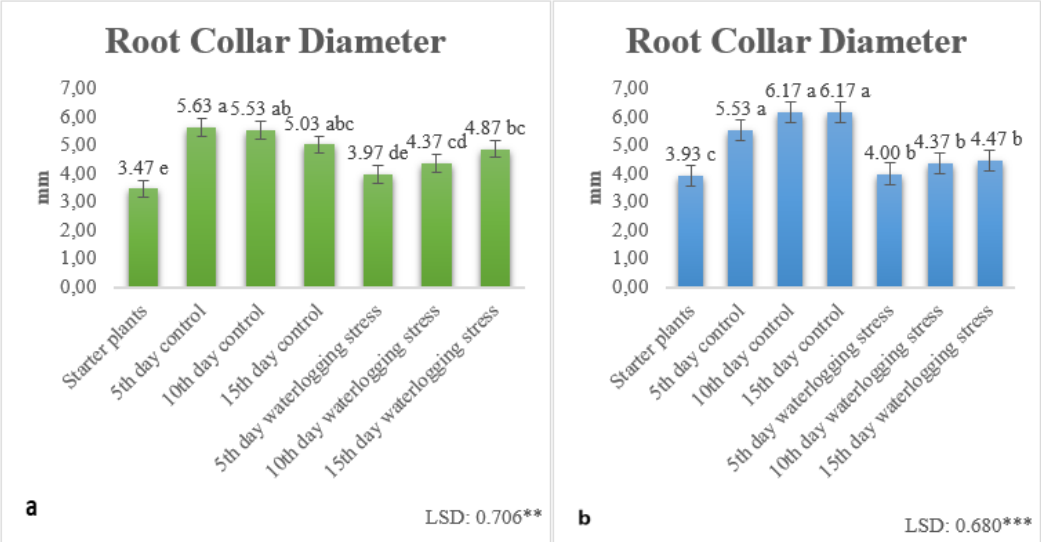


Figure 5. Effects of applications on root collar diameter (mm) of Çermik genotype (a) and Mazamort pepper variety (b)

Şekil 5. Çermik genotipi (a) ve Mazamort biber çeşidinin (b) kök boğazı çapına (mm) uygulamaların etkileri

Effects of treatments on leaf number of Çermik pepper genotype and Mazamort pepper variety (number/plant)

The effects of treatments on leaf number and the significance of differences among groups were analyzed using LSD values, as shown in Figure 6. In the Çermik pepper genotype, differences among treatments were statistically significant ($p \leq 0.0013$). Leaf numbers in Çermik pepper plants ranged from 40.00 to 57.00 leaves/plant, with the lowest observed in initial seedlings and the highest recorded in the control group on the 15th day. Compared to initial seedlings, leaf number increased by 42.5% in the 15 day control group and by 15.0% in the 15 day waterlogged group (Figure 6a).

Conversely, the effects of treatments on leaf number in the Mazamort pepper variety were statistically significant ($p \leq 0.01$). Leaf numbers in Mazamort pepper plants varied between 22.33 and 42.33 leaves/plant, with the lowest values in initial seedlings and the highest in the control group on the 5th day (42.33 leaves/plant). Relative to initial seedlings, leaf number increased by 89.5% in the 5 day control group and by 32.9% in the 15 day waterlogged group (Figure 6b).

When comparing waterlogging stress treatments (5th, 10th, and 15th days) with control treatments (5th, 10th, and 15th days), a decrease in leaf numbers was observed (Figure 6).

Kumutha et al. (2009) noted a reduction in leaf area due to waterlogging, and Pociecha et al. (2008) reported decreases in leaf numbers following similar treatments. Overall, our findings align with the existing literature, demonstrating that waterlogging has a detrimental effect on leaf number across different plant species. This study confirms that water stress is a widespread phenomenon affecting leaf number in pepper plants, consistent with the observed trends in other crops.

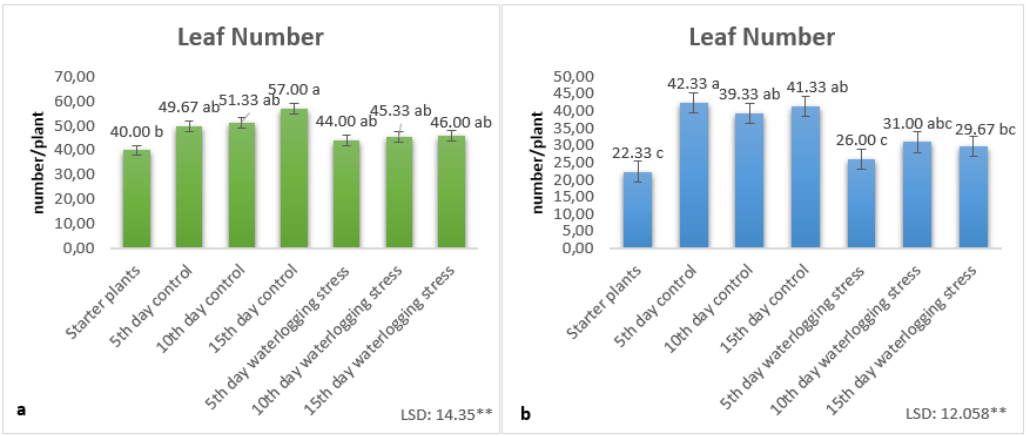


Figure 6. Effects of applications on leaf number (number/plant) of Çermik genotype (a) and Mazamort pepper variety (b)

Şekil 6. Çermik genotipi (a) ve Mazamort biber çeşidinin (b) yaprak sayısına (adet/bitki) uygulamaların etkileri

Effects of treatments on fresh weights (g) of Çermik genotype and Mazamort pepper variety

The effects of treatments on fresh weights and the significance of differences among groups were evaluated using LSD values, as shown in Figure 7. The treatments significantly affected the fresh weight of the Çermik pepper genotype (Figure 7a, $p \leq 0.01$) and the Mazamort pepper variety (Figure 7b, $p \leq 0.0001$), with notable differences observed among the groups.

Results indicated that the fresh weights of Çermik pepper genotype plants ranged from 17.82 to 35.90 g, with the lowest fresh weight recorded in the 15 day waterlogging treatment and the highest in the control group at 15 days. In the case of the Mazamort pepper variety, fresh weights varied between 11.80 and 39.85 g, again showing the lowest values under the 15 day waterlogging treatment and the highest in the control group at 15 days. Compared to initial seedlings, the control group at 15 days demonstrated a 14.3% increase, while the 15 day waterlogging stress resulted in a significant reduction of approximately 66.2% in fresh weight.Dn watermelon, Else et al. (2009) on tomato, and Pociecha et al. (2008) on pea, have reported significant reductions in fresh weight due to waterlogging stress. These findings across various plant species consistently highlight the negative impacts of waterlogging stress on plant growth and yield. The effects of waterlogging stress on plant metabolism are generally mediated through its influence on essential physiological processes, such as water uptake, photosynthetic activity, and nutrient absorption, ultimately leading to a decrease in fresh weight. These results underscore the importance of effective water management practices in agricultural production to mitigate the adverse effects of water stress on crop health and yield.

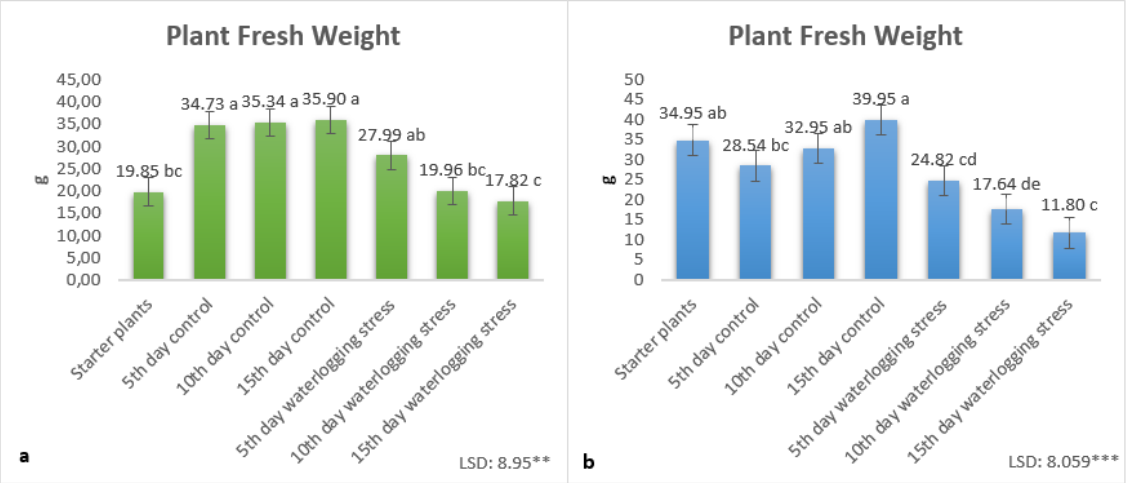


Figure 7. Effects of applications on plant fresh weight (gr) of Çermik genotype (a) and Mazamort pepper variety (b

Şekil 7. Çermik genotipi ve Mazamort biber çeşidinin bitki taze ağırlığına (gr) uygulamaların etkileri

Effects of treatments on dry weights (g) of Çermik genotype and Mazamort pepper variety

The effects of treatments on plant dry weights and the significance of differences among groups were assessed using LSD values, as depicted in Figure 8. The impact of treatments on the dry weight of the Çermik pepper genotype was statistically significant ($p \leq 0.0010$), while the effects on the Mazamort pepper variety were also significant ($P \leq 0.0001$).

Results showed that the dry weights of Çermik pepper genotype plants ranged from 1.31 to 3.36 g, with the lowest values recorded in initial seedlings and the highest observed in the 15 day waterlogging stress treatment (Figure 8a).

In the Mazamort pepper variety, dry weights varied from 1.29 to 3.19 g, with the lowest values found under the 5 day waterlogging stress and the highest in the control group at 15 days. Relative to initial seedlings, the control group at 15 days exhibited a 39.8% increase, while the 15 day waterlogging stress treatment resulted in a 25.1% decrease in dry weight (Figure 8b).

Comparative analysis between control (5th, 10th, and 15th days) and waterlogging stress treatments (5th, 10th, and 15th days) revealed an increase in dry weight for the Çermik genotype, whereas a decrease was noted for the Mazamort variety (Figure 8).

Previous studies by Çelik & Turhan (2011) and Çelik (2010) indicated reductions in root dry weights of various bean plants subjected to waterlogging stress. Else et al. (2009) reported decreases in both fresh and dry weights in tomato plants under similar conditions. Additionally, Yetişir et al. (2006) observed reductions in dry weights of watermelon plants exposed to waterlogging stress. Conversely, Luo et al. (2011) documented increased dry weights in Alternanthera philoxeroides and Hemarthria altissima species following a 20 day waterlogging treatment and subsequent recovery efforts. The findings of the present study are consistent with existing literature, contributing to our understanding of the complex effects of waterlogging stress on plant growth. These results underscore the necessity for tailored water management strategies in agricultural practices to mitigate the adverse impacts of waterlogging on crop productivity.

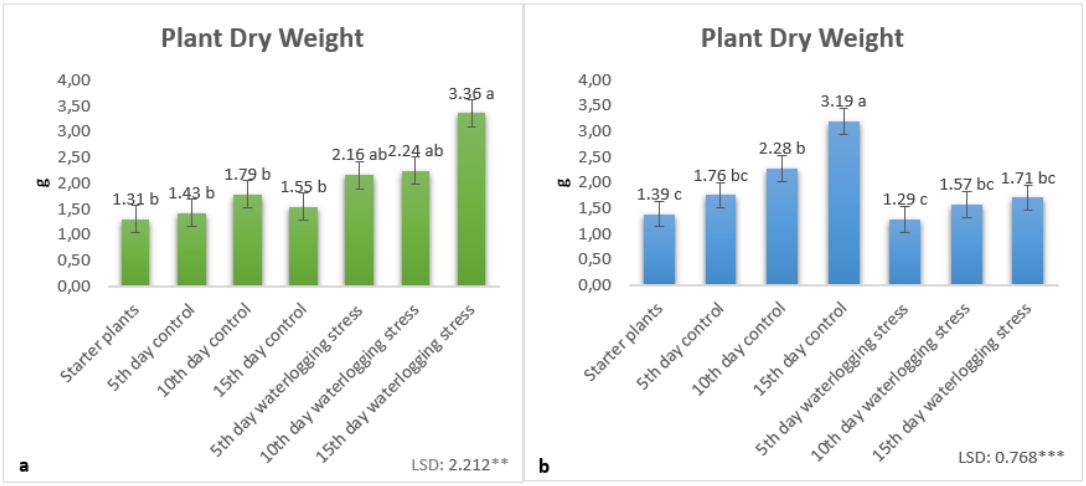


Figure 8. Effects of applications on plant dry weight (g) of Çermik genotype (a) and Mazamort pepper variety (b)

Şekil 8. Çermik genotipi (a) ve Mazamort biber çeşidinin (b) bitki kuru ağırlığına (g) uygulamaların etkileri

Effects of treatments on SPAD values of Çermik genotype and Mazamort pepper variety

The effects of treatments on SPAD values and the significance of differences among groups were analyzed using LSD values, as shown in Figure 9. The treatments had a statistically significant effect on the SPAD value of the Çermik pepper genotype ($p \leq 0.0001$) as well as the Mazamort pepper variety ($p \leq 0.0001$).

Following the treatments, SPAD values in Çermik pepper plants ranged from 30.67 to 45.37, with the lowest recorded in initial seedlings and the highest in the 15 day waterlogging treatment. Compared to initial seedlings, there was an approximately 47.9% increase in SPAD content in the 15 day waterlogging treatment (Figure 9a).

For the Mazamort pepper variety, SPAD content ranged from 34.20 to 45.63, again with the lowest in initial seedlings and the highest in the 15 day waterlogging treatment. Relative to initial seedlings, the 15 day waterlogging treatment resulted in a 33.4% increase in SPAD content (Figure 9b).

Research on wheat has indicated that there is no significant change in leaf chlorophyll content immediately following waterlogging; however, as waterlogging persists, notable changes become evident. This suggests that wheat exhibits an initial rapid response to water stress, with significant changes emerging only during prolonged stress (Olgun et al., 2008; Zheng et al., 2009; Li et al., 2011). Parelle et al. (2006) reported that the negative effects of waterlogging on chlorophyll in oak trees began to manifest after one week and worsened over time. Similar reductions in total chlorophyll content due to waterlogging have been observed in studies involving tomato (Else et al., 2009), onion (Yiu et al., 2008), and maize (Rao et al., 2002). Singer et al. (1996) noted decreases in total chlorophyll in Giza 3 and Bronco fresh bean varieties following waterlogging treatments. Pociecha et al. (2008) found significant reductions in chlorophyll content in broad beans due to waterlogging. Else et al. (2009) observed that water potential decreased in tomatoes under waterlogging, leading to stomatal closure and a significant reduction in photosynthesis. Ahmed et al. (2002) reported rapid declines in photosynthetic rates during both vegetative and generative stages of mung bean subjected to waterlogging. Huang et al. (1994) found that Bayles and Savannah wheat varieties experienced reduced photosynthesis and chlorophyll content after 17 days of waterlogging. In contrast to the general findings of reduced chlorophyll content in other studies, our research found that both the Çermik genotype and the Mazamort variety exhibited increased chlorophyll content in response to waterlogging. These results suggest that pepper genotypes and varieties may possess resilience to waterlogging stress, potentially enhancing chlorophyll production as a coping mechanism. This indicates that further investigation into the adaptive strategies of these pepper varieties under stress conditions may provide insights for improving water management practices in agricultural production.

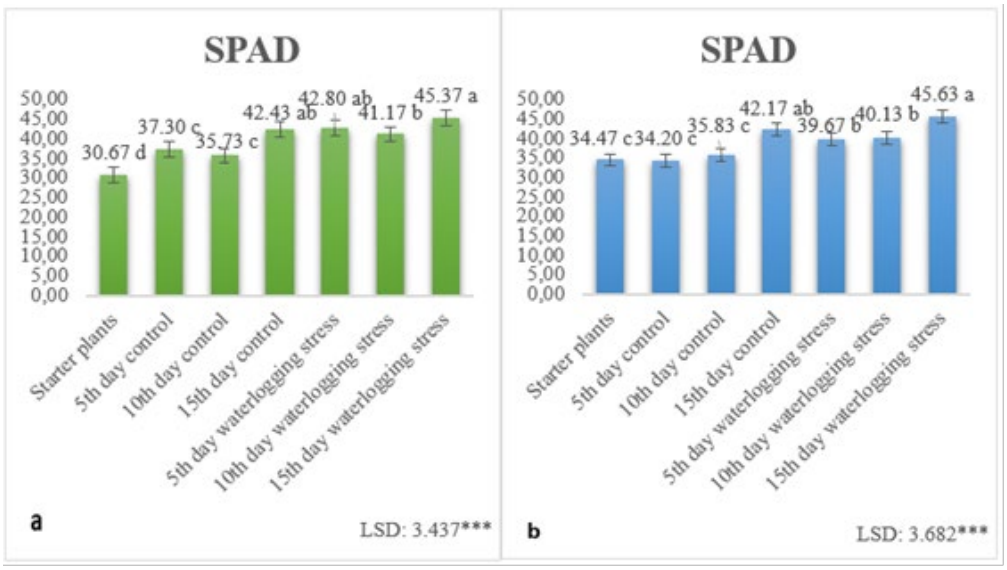


Figure 9. Effect of applications on SPAD values of Çermik genotype (a) and Mazamort pepper variety (b)
Şekil 9. Çermik genotipi (a) ve Mazamort biber çeşidinin (a) SPAD içeriğine uygulamaların etkisi

Effects of treatments on leaf relative water content (%) of Çermik genotype and Mazamort pepper variety

The effects of treatments on leaf relative water content (RWC) and the significance of differences among groups were assessed using LSD values, as shown in Figure 10. The impact of treatments on leaf RWC in the Çermik pepper genotype was found to be statistically significant ($p \leq 0.0006$). Similarly, treatments also had a significant effect on the leaf RWC of the Mazamort pepper variety ($p \leq 0.0001$). The differences among the groups resulting from these applications were significant.

For the Çermik pepper genotype, leaf RWC varied between 68.74% and 97.54%, with the lowest value recorded under the 15 day waterlogging stress treatment and the highest observed in the control group at the 15th day. Compared to the initial seedlings, the control group at the 15th day showed an increase of 4.71% in leaf RWC, while a decrease of 26.2% was noted when compared to the 15 day waterlogging stress treatment (Figure 10a).

In the Mazamort pepper variety, leaf RWC ranged from 44.25% to 91.52%, with the lowest values found under the 15 day waterlogging stress and the highest in the control group at the 5th day. Compared to initial seedlings, the control group at the 5th day exhibited a 4.93% increase in leaf RWC, whereas a decrease of 49.3% was observed in comparison to the 15 day waterlogging stress treatment (Figure 10b).

A comparison of the control (5th, 10th, and 15th days) and waterlogging stress treatments (5th, 10th, and 15th days) revealed a decline in leaf RWC for both the Çermik genotype and the Mazamort variety (excluding the control group at the 5th day) (Figure 10).

Previous studies, such as those conducted on *Eucalyptus camaldulensis, E. globulus, Ulmus Americana, Salix nigra,* and *Quercus macrocarpa* seedlings, reported that waterlogging led to stomatal closure, resulting in lower leaf water potential and turgor ratios in control plants (Kozlowski, 1984). Ashraf & Rehman (1999) also noted that waterlogging reduced leaf turgor potential. In research involving mung beans, it was found that the leaf water potential of control plants did not differ significantly after eight days of waterlogging treatment (Ahmed et al., 2002). These findings indicate that while the effects of waterlogging stress on different plant species may exhibit similar characteristics, they can also vary significantly between species. For instance, in some plant types, water stress leads to stomatal closure, resulting in decreased water potential and turgor ratios, while in others, these effects may be less pronounced or differ altogether. This underscores the complexity of plant responses to waterlogging stress and the need for species-specific management strategies in agricultural practices.

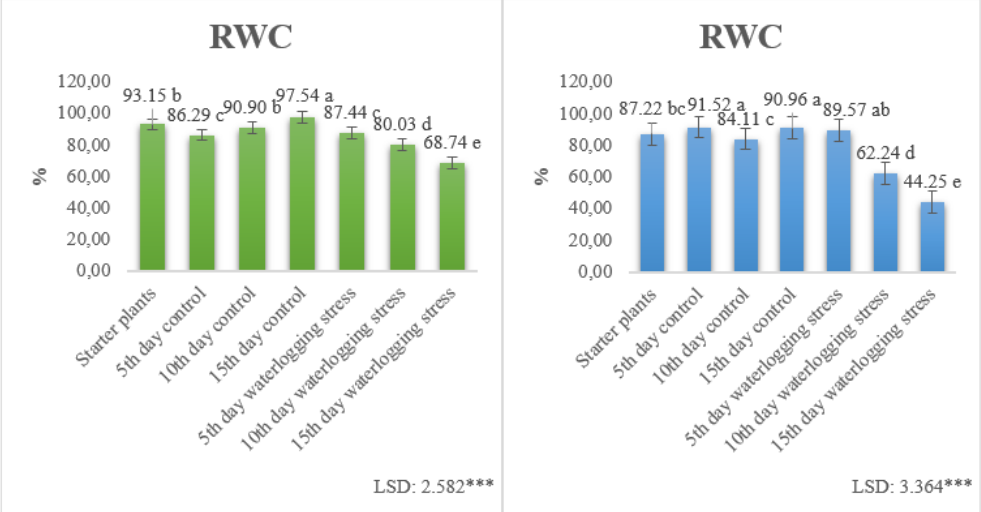


Figure 10. Effect of applications on RWC(%) of Çermik genotype (a) and Mazamort pepper variety (b)

Şekil 10. Çermik genotipi (a) ve Mazamort biber çeşidinin (b) yaprak bağıl su içeriği(%) üzerine uygulamaların etkisi

Effects of waterlogging treatments on ion leakage (%) in Çermik genotype and Mazamort pepper variety

The effects of treatments on ion leakage and the significance of differences among groups were evaluated using LSD values, as shown in Figure 10. The impact of treatments on ion leakage in the Çermik pepper genotype was statistically significant ($p \leq 0.0442$). Similarly, the effects on ion leakage in the Mazamort pepper variety were also statistically significant ($p \leq 0.0027$). The differences among the groups resulting from these applications were noteworthy.

For the Çermik pepper genotype, ion leakage varied between 18.23% and 22.34%, with the lowest value observed in the control group at the 10th day and the highest in the waterlogging treatment at the same time point. Compared to the initial seedlings, there was a 7.9% increase in ion leakage under the 10 day waterlogging stress treatment, while a decrease of 1.17% was noted under the 15 day waterlogging stress (Figure 11a).

In the Mazamort pepper variety, ion leakage ranged from 15.48% to 21.91%, with the lowest values recorded in the control group at the 10th day and the highest under the 15 day waterlogging stress treatment. Compared to the initial seedlings, a 23.7% increase in ion leakage was observed in the 15 day waterlogging treatment (Figure 11b).

When comparing the control groups (5th, 10th, and 15th days) with the waterlogging treatments (5th, 10th, and 15th days), both the Çermik genotype and Mazamort variety showed an increase in ion leakage (excluding the 5th day waterlogging treatment) (Figure 11). Aydoğan & Turhan (2012) investigated the tolerance and recovery capacities of 15 fresh bean (*Phaseolus vulgaris* L.) genotypes under waterlogging stress from morphological and physiological perspectives. They reported an increase in ion leakage percentages for all genotypes following waterlogging treatment, which was found to be higher than the values obtained during recovery applications. This suggests that waterlogging stress tends to increase ion leakage in plant cells. However, certain plant genotypes may develop specific tolerance mechanisms against waterlogging stress, potentially reducing ion leakage or mitigating stress effects through recovery capabilities. Such studies contribute to our understanding of how plants respond to water stress and can aid in the development of more resilient varieties for agricultural production.

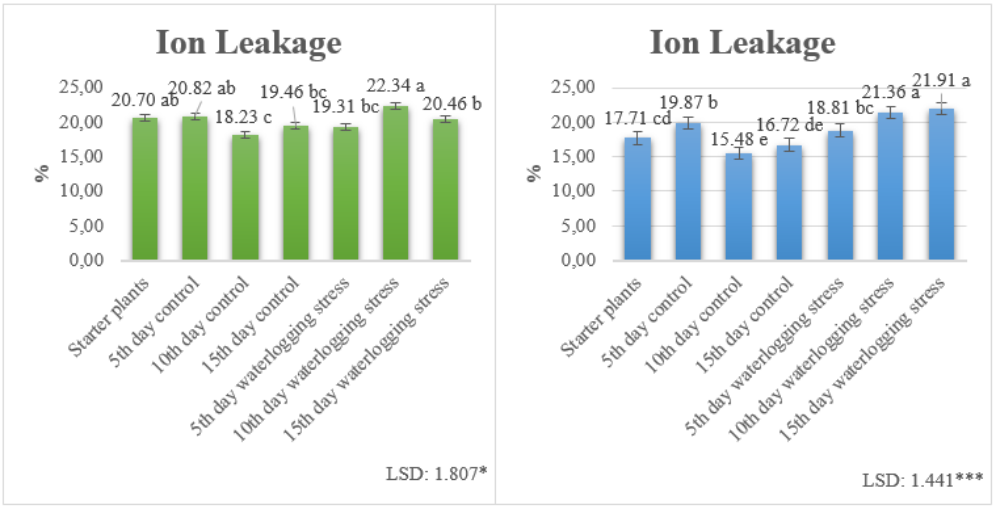


Figure 11. Effect of applications on ion leakage (%) of Çermik genotype (a) and Mazamort pepper variety (b)
Şekil 11. Çermik genotipi (a) ve Mazamort biber çeşidinin (b) iyon sızıntısı (%) üzerine uygulamaların etkisi

CONCLUSION and RECOMMENDATIONS

This study demonstrated that the Çermik pepper genotype exhibits a higher tolerance to waterlogging stress compared to the Mazamort pepper variety, as evidenced by its superior morphological and physiological performance under prolonged waterlogging conditions. Waterlogging treatments significantly affected various parameters, including plant height, stem and collar diameters, leaf number, SPAD value, fresh and dry weights, leaf relative water content, and ion leakage. The Çermik genotype maintained better physiological stability throughout the treatments, showing higher chlorophyll content, relative water content, and dry matter accumulation, along with lower ion leakage levels. These responses indicate that the genotype possesses effective adaptive mechanisms that mitigate the detrimental effects of temporary hypoxia in the root zone. In particular, the highest values for plant height and other growth parameters were observed in the Çermik genotype on the 15th day of waterlogging, suggesting that it can sustain growth even under stress conditions. Conversely, the Mazamort pepper variety displayed lower tolerance, as reflected by more severe visual symptoms such as chlorosis, necrosis, and partial mortality after 15 days of waterlogging. Moreover, significant reductions in dry weight, relative water content, and increased ion leakage confirmed its higher sensitivity to oxygen deficiency in the rhizosphere. Overall, while Mazamort performed better under non-stressed conditions, it lacked effective morphological or physiological adjustment mechanisms under waterlogging stress. The findings of this research provide valuable insights into the species-specific tolerance mechanisms of pepper under waterlogging stress and emphasize the potential use of tolerant genotypes in breeding programs. The Çermik pepper, a local genotype naturally adapted to highland environments, demonstrated resilience to temporary waterlogging, indicating resistance to short-term root zone oxygen deficiency. Owing to these adaptive characteristics, the Çermik genotype represents a promising candidate for cultivation in highland regions prone to sudden rainfall or surface water accumulation. Furthermore, its stress tolerance under high-altitude conditions suggests that it could serve as an important genetic resource in breeding programs aimed at developing new varieties suitable for highland agriculture and resistant to environmental stresses. Nevertheless, further comprehensive studies are recommended to better elucidate its tolerance mechanisms and to validate its potential under diverse environmental conditions.

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STATEMENT OF CONFLICT OF INTEREST

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

AUTHOR'S CONTRIBUTIONS

The contribution of the authors is equal.

STATEMENT OF ETHICS CONSENT

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

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