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Research Article

The Effects of Low Temperature on Germination Parameters of Some Pepper Cultivars

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Abstract

In this research, the effects of low temperatures on the germination of some pepper cultivars were studied. Six different pepper cultivars (Yalova carliston: long green pepper (YC), Kandil Dolma: bell pepper (KD), Acı kıl: long hot pepper (AK), Sera Demre: long green pepper (SD), Süs biberi: ornamental pepper (SB) and Tatlı Kıl: long sweet pepper (TK)) were germinated in a controlled growth chamber at three different temperatures (15, 20 and 25 °C). The study was carried out by germinating the surface disinfected seeds between blotting papers in petri dishes with 4 replicates. To determine the response of pepper cultivars to temperature changes, germination rate, germination time, root and hypocotyl length, root and hypocotyl fresh and dry weights were studied. The effects of temperature on germination properties were statistically significant, and significant differences were also observed between pepper cultivars. Decreased temperatures resulted in a significant reduction in pepper germination, with the best results at 20 and 25 °C. Lowering the temperature to 15 °C during the germination stage decreased the germination rate, root length, root fresh weight, and root dry weight by 23.50%, 82.87%, 47.83%, and 25.00%, respectively. The cultivars least affected by temperature decrease (15 °C) were SD for germination rate, SB for germination time, AK for root length, SB for root fresh weight, and YC for root dry weight. The results showed that germination decreased with decreasing temperature, but the response of cultivars to this decrease may differ. The consideration of this difference between the cultivars will be beneficial for a healthy production in the pepper cultivation

Keywords: Pepper (*Capsicum annuum* L.), germination, low temperature

Düşük Sıcaklığın Bazı Biber Çeşitlerinin Çimlenme Parametreleri Üzerindeki Etkileri

Öz

Çalışmada, bazı biber çeşitlerinde düşük sıcaklık derecelerinin çimlenme üzerine etkileri araştırılmıştır. Altı farklı biber çeşidinin (YÇ: Yalova Çarliston, KD: Kandil dolma, AK: Menderes Acı kıl biber, SD: Sera Demre, SB: Süs biber, TK: Tatlı kıl) kullanıldığı çalışmada tohumlar 15, 20 ve 25 °C sıcaklıklarının olduğu kontrollü büyütme kabininde çimlenmeye bırakılmıştır. Çalışma, yüzeyi dezenfekte edilen tohumların petri kaplarında kurutma kağıtları arasında 4 tekerrürlü olarak çimlendirilmesiyle gerçekleştirilmiştir. Çalışmada çeşitlerin sıcaklık değişimine karşı gösterdiği tepkilerin belirlenmesi amacıyla çimlenme oranı, çimlenme süresi, kökçük ve hipokotil uzunluğu, kökçük ve hipokotil yaş ve kuru ağırlıkları incelenmiştir. Sıcaklığın çimlenme özellikleri etkileri istatistiksel olarak önemli olup, çeşitler arasında da önemli farklılıklar gözlenmiştir. En iyi sonuçlar 20 ve 25 °C'de olmak üzere, azalan sıcaklıklar biber çeşitlerinin çimlenme parametrelerinde önemli azalmalara neden olmuştur. Çimlenme aşamasında sıcaklığın 15 °C'ye düşürülmesi çimlenme oranı, kökçük uzunluğu, kökçük yaş ağırlığı ve kökçük kuru ağırlığı sırasıyla %23.50, %82.87, %47.83 ve %25.00 oranlarında azaltmıştır. Sıcaklık azalmasından (15 °C) en az etkilenen çeşitler, çimlenme oranı için SD, çimlenme süresi için SB, kökçük uzunluğu için AK, kök yaş ağırlığı için SB ve kökçük kuru ağırlığı için ise YÇ çeşitleri olmuştur. Sonuçlar, azalan sıcaklık ile çimlenmenin azaldığı, bununla birlikte çeşitlerin bu azalmaya gösterdiği tepkilerin farklılık gösterebildiğini göstermiştir. Çeşitler arasında meydana gelen bu farklılığın göz önünde bulundurulması biber yetiştiriciliğinde sağlıklı bir üretimin yapılması için faydalı olacaktır.

Anahtar Kelimeler: Biber (*Capsicum annuum* L.), çimlenme, düşük sıcaklık

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1. Introduction

The term "stress" is used to describe a set of biological, morphological and physiological changes that occur in plants as a result of external factors, which ultimately affect their growth and development [1]. The production of plants is perpetually subjected to stress from a multitude of living organisms and environmental factors, collectively known as biotic and abiotic factors. It is of great importance to consider the impact of abiotic stressors, including salinity, drought, temperature, light and pollution, when planning and executing production processes. The temperature is a significant factor influencing the growth and development of plants. Low and high temperature stress represent a significant abiotic stress factor that can significantly impact the feasibility of agricultural production [2]. Active growth of plants occurs at a relatively limited temperature. Typically, active growth occurs between 0 °C and 45 °C. While the growth and development of some plants is limited at temperatures above 45 °C, some plants have a tolerance to temperatures below 0 °C through visible physiological mechanisms [1,3]. The distribution of plants on Earth is subject to the influence of temperature. Vegetables are additionally classified into two categories, namely hot and cool climate vegetables, based on their temperature requirement [4]. Plants that are adapted to hot climates are sensitive to low temperatures, whereas those that are adapted to cool climates are sensitive to high temperatures [1]. In the majority of cases, plants will continue to grow and develop at optimal temperatures. However, at other temperatures, they will suffer a decrease in production and quality. Optimal temperatures facilitate enhanced plant growth, ensuring equilibrium between photosynthesis, respiration, and other growth processes [3]. Temperature stress is effective in plants both as a high temperature and as a low temperature. At high temperatures, generally above 44 °C, plant death is observed. High temperature causes increased respiration in plants, loss of enzyme activity, changes in cell structure and function, decreased protein synthesis, necrotic spots, decreased physiological activity, and negative effects on plant growth and development by disrupting photosynthetic activity. In the context of plant physiology, low temperatures assume particular significance for species that exhibit high temperature requirements. As temperature declines, there are notable alterations in enzyme activity, particularly in plants. Furthermore, the formation of ice crystals between cells results in the deterioration of the cell structure, ultimately leading to the death of the plant [1,5]. It is stated that optimal seed germination and seedling production in agricultural production is one of the first and most important stages of increasing production and productivity. Low temperature is one of the most important problems, especially in hot climates, plants produced directly by sowing seeds. It has been reported that the cold injury observed in plants exposed to low temperatures between 0-15 °C is a physiological disorder and that plants exposed to this injury respond as "sensitive" and "durable" in terms of sensitivity [6].

It is pointed out that pepper, one of the most important vegetable species in hot climates, is a very sensitive species to temperatures lower than 13-15 °C. Also, good development does not occur at night temperatures below 10 °C [3,4]. It is known that the optimal germination and development of pepper takes place at 20-25 °C, stamen functions can continue up to 5 °C, but at 0°C and below there is plant death. In pepper, temperature requirements may vary at different stages of the plant's development. While seed germination and seedling development are good at 20-25 °C, there is no fruit binding at temperatures below 16 °C and above 32 °C [4,7]. In

greenhouses, during the early growth period of the plant, it is ideal to have a day temperature of 15-21 °C and a night temperature of 14-17 °C. At low temperatures, changes in the flavor and color of pepper fruits may occur [4]. Temperature stress, one of the abiotic stresses in pepper production, has a significant impact on yield. It is therefore important to select varieties that are adapted to regional conditions or to take protective measures during production. The objective of this study was to investigate the effect of low and optimum temperatures on the germination of different pepper cultivars. The aim of the study was to determine the response of selected cultivars to changing ambient temperatures during germination, a critical first stage of vegetative propagation. The study could provide a potential solution to future challenges by elucidating the effects of temperature on germination.

2. Materials and Methods

The study on the effects of different temperatures on seed germination of pepper cultivars was carried out under controlled conditions. Seeds (Yalova carliston: long green pepper (YC), Kandil Dolma: bell pepper (KD), Acı kıl: long hot pepper (AK), Sera Demre: long green pepper (SD), Süs biberi: ornamental pepper (SB) and Tatlı Kıl: long sweet pepper (TK)) of six different pepper (*Capsicum annuum* L.) cultivars were used as plant material in the study.

In order to determine the effect of different pepper cultivars at different temperatures on germination, seeds were germinated under controlled conditions at 15, 20 and 25 °C. Since no germination occurred in seeds at 10 °C, this temperature was excluded from the experiment for the germination stage. The seeds of each cultivar were surface disinfected with 3% sodium hypochlorite. The germination experiment was designed with 4 replicates and 50 seeds in each replicate [8]. The seeds were germinated in sterile, single-use petri dishes (90 mm in diameter and 15 mm in height) that contained two Whatman No. 2 filter papers moistened with 10 ml of distilled water. Germinated seeds were counted after 7 days and the study was terminated after an average of 14 days according to rule of ISTA.

2.1. Germination rate

The germination rate was determined as a percentage by dividing the total number of germinations by the number of seeds sown [9].

Germination rate (%) = (Number of germinated seeds / Total number of seeds) x 100

2.2. Germination time

The average germination time of seeds throughout the study was calculated by counting the germinating seeds each day according to the formula below [9].

Germination time (days) = (t1xg1 + t2xg2+.....+tnxgn) / tnsg

g: Days of observation during germination

t: Number of germinating seeds

tnsg: Total number of seeds germinated during the experiment

2.3. Other parameters

In addition, root and hypocotyl length, root and hypocotyl fresh and dry weights of germinated seeds were measured at the end of the study. Measurements of hypocotyl length, fresh weight and dry weight at 15 ºC could not be made because they did not occur sufficiently during the experiment.

2.4. Statistical analysis

In the seed germination study, each application was set up with 4 replicates, according to ISTA rules, there were 50 seeds per replicate [8]. Statistical analysis of germination rates was performed after arc-sin transformation of the data. After averaging the analyzed parameters, statistical analyses of the data were performed according to the Duncan multiple comparison test in the SPSS program [10].

3. Results and Discussion

Temperature, cultivar and the two-way interaction of these parameters had a significant effect ($p < 0.01$) on germination (Table 1, Figure 1a). In the present study, when the temperature was reduced to 15 °C, the germination rate decreased to 54.50%. There was no significant difference ($p > 0.05$) between 25 °C and 20 °C. Among the pepper cultivars used in the experiment, the highest seed germination rate (80.00%) was determined in the SB at 25 °C, and the lowest rate (38.00%) in the YC at 15 °C. According to the mean values, the highest (78.66%) and lowest (50.66%) germination rates were observed in the SD and YC cultivars, respectively. Considering the germination rates at 15 °C, the highest rate (74.00%) was found in SD, the greatest decrease compared to the results at 25 °C was found in SB (Table 1, Figure 1a).

As shown in Table 1, germination time was also significantly affected by temperature ($p < 0.001$), cultivar ($p < 0.001$) and the interaction of cultivar x temperature ($p < 0.05$). The germination time of pepper was longest at 15 °C (9.41 days), and there was no significant difference ($p > 0.05$) between the germination times at 20 and 25 °C. According to the cultivar averages, KD had the longest germination time (7.35 days) while SD had the shortest (4.72 days). The cultivars with the shortest (8.54 days) and longest (10.56 days) germination times at 15 °C were identified as SB and KD, respectively (Table 1, Figure 1b).

Table 1. Effect of different temperatures on seed germination rate and germination time in some pepper cultivars

Parameter	Cultivars (C)	Temperature (T)						*Mean*	Significance		
		25 °C		20 °C		15 °C			*C*	*T*	*CxT*
			CR (%)		CR (%)		CR (%)				
Germination rate (%)	YC	59.00 a	100	55.00 a	-6.78	38.00 b	-35.59	**50.66 D**			
	KD	77.25 b	100	88.00 a	13.91	49.00 c	-36.56	**71.41 B**			
	AK	70.00 a	100	66.50 a	-5.00	60.00 a	-14.29	**65.50 C**			
	SD	76.00 b	100	86.00 a	13.16	74.00 b	-2.63	**78.66 A**	***	***	***
	SB	80.00 a	100	72.00 a	-10.00	42.00 b	-47.50	**64.66 C**			
	TK	70.00 a	100	69.00 a	-1.43	64.00 a	-8.57	**67.66 BC**			
	Mean	**72.04 A**	**100**	**72.75 A**	**1.46**	**54.50 B**	**-23.53**				
Germination time (days)	YC	5.35 b	100	5.54 b	3.55	10.08 a	88.41	**6.99 A**			
	KD	5.57 b	100	5.92 b	6.28	10.56 a	89.59	**7.35 A**			
	AK	4.45 b	100	3.25 c	-26.97	9.09 a	104.27	**5.59 B**			
	SD	3.03 b	100	2.52 b	-16.83	8.64 a	185.15	**4.72 C**	***	***	*
	SB	5.16 c	100	6.58 b	27.52	8.54 a	65.50	**6.76 A**			
	TK	5.70 b	100	5.41 b	-5.09	9.55 a	67.54	**6.88 A**			
	Mean	**4.88 B**	**100**	**4.87 B**	**-0.20**	**9.41 A**	**92.83**				

*: $p<0.05$; ***:$p<0.001$

There is no significant difference ($p>0.05$) between the means shown with the same lowercase or uppercase letter in the same row or column.

CR expresses the rate of change compared to 25 °C.

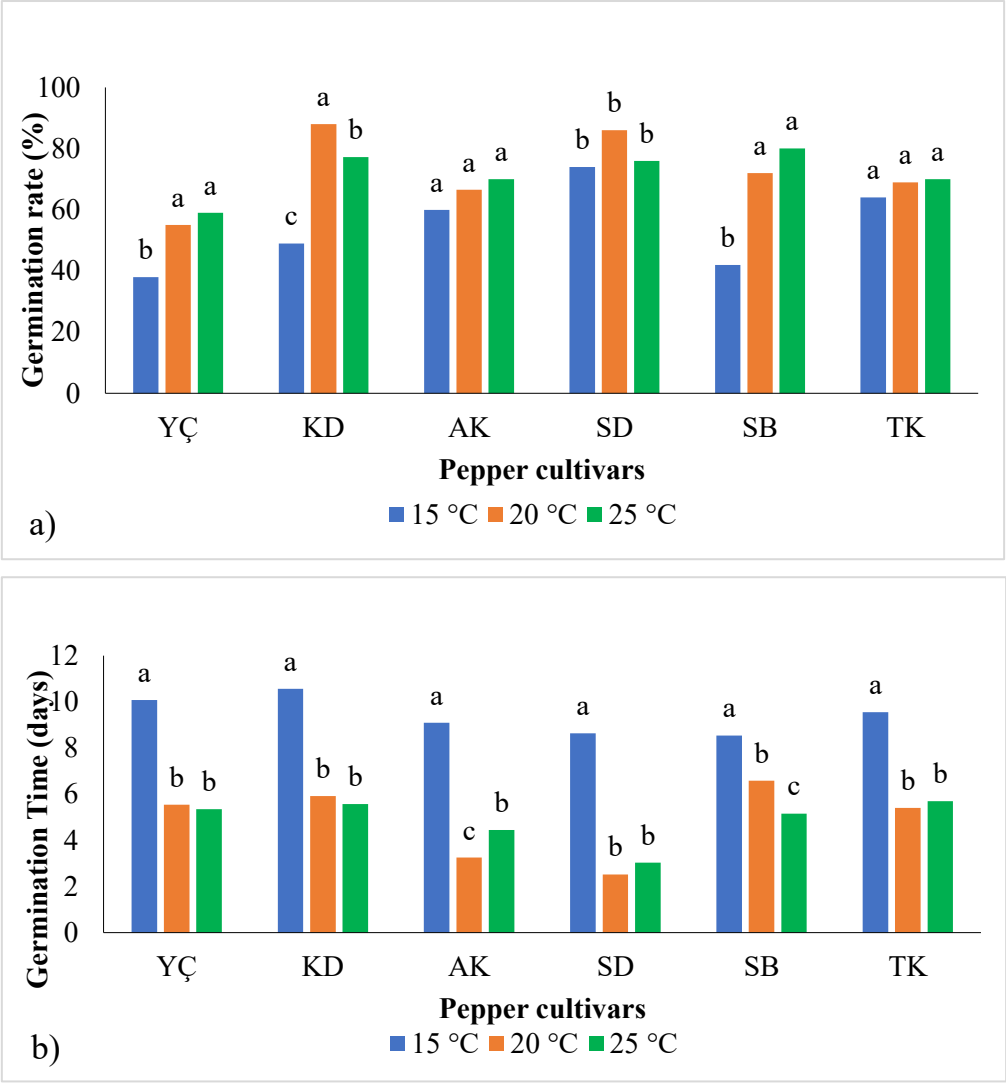

Figure 1. Effect of temperature x cultivar interaction on seed germination rate (a) and germination time (b) parameters.

According to the results of the analysis of variance showing the effect of different temperatures on seed hypocotyl length in different pepper cultivars, it was determined that the effects of temperature and cultivars were statistically significant ($p < 0.001$) and the interaction temperatures with cultivar was insignificant. Hypocotyl data at 15 °C are not available as the hypocotyl did not appear until the time of measurement. Nevertheless, the seed hypocotyl length of pepper YC was the shortest (1.77 cm) and the hypocotyl length of SD was the longest (2.63 cm) according to the average of the cultivars. At 20 °C, 63.38% - 77.85% reduction in hypocotyl length occurred, with the greatest reduction in cultivar YC (Table 2, Figure 2a).

In the study, the effect of different temperatures and cultivars on pepper root length was found to be statistically significant, and the interaction between temperature and cultivar was also significant ($p < 0.001$). It was observed that as the temperature value decreased, the length of the roots also decreased. The mean root length, which was 3.56 cm at 25 °C, was measured to be 0.61 cm at 15 °C. The highest value for root length between cultivars was found in cultivar KD (5.62 cm) at 25 °C, AK (2.65 cm and 1.06 cm) at 20 °C and 15 °C. At 15 °C, root length

was measured at least in cultivar SB (0.36 cm). According to the average results, while the root length is mostly KD (2.69 cm), the shortest root length is determined in cultivar YC (1.12 cm) (Table 2, Figure 2b).

Table 2. Effect of different temperatures on hypocotyl and root lengths in some pepper cultivars

Parameter	Cultivars (C)	Temperature (T)						Mean	Significance		
		25 °C		20 °C		15 °C		*C*		*T*	*CxT*
			CR (%)		CR (%)		CR (%)				
Hypocotyl length (cm)	YC	2,89 a	100	0,64 b	-77,85	-	-	**1,77 B**			
	KD	3,03 a	100	0,86 b	-71,62	-	-	**1,95 B**			
	AK	3,67 a	100	1,27 b	-65,40	-	-	**2,47 A**			
	SD	3,85 a	100	1,41 b	-63,38	-	-	**2,63 A**	***	***	NS
	SB	2,95 a	100	0,73 b	-75,25	-	-	**1,84 B**			
	TK	3,09 a	100	0,77 b	-75,08	-	-	**1,93 B**			
	Mean	**3,25 A**	**100**	**0,94 B**	**-71,08**	**-**	**-**				
Root length (cm)	YC	1,95 a	100	1,01 b	-48,21	0,39 c	-80,00	**1,12 E**			
	KD	5,62 a	100	2,02 b	-64,06	0,42 c	-92,53	**2,69 A**			
	AK	2,89 a	100	2,65 a	-8,30	1,06 b	-63,32	**2,20 BC**			
	SD	3,79 a	100	2,36 b	-37,73	0,94 c	-75,20	**2,36 B**	***	***	***
	SB	3,87 a	100	1,27 b	-67,18	0,36 c	-90,70	**1,83 D**			
	TK	3,26 a	100	2,06 b	-36,81	0,52 c	-84,05	**1,95 CD**			
	Mean	**3,56 A**	**100**	**1,90 B**	**-46,63**	**0,61 C**	**-82,87**				

NS: $p>0.05$; ***:$p<0.001$

There is no significant difference ($p>0.05$) between the means shown with the same lowercase or uppercase letter in the same row or column.

CR expresses the rate of change compared to 25°C.

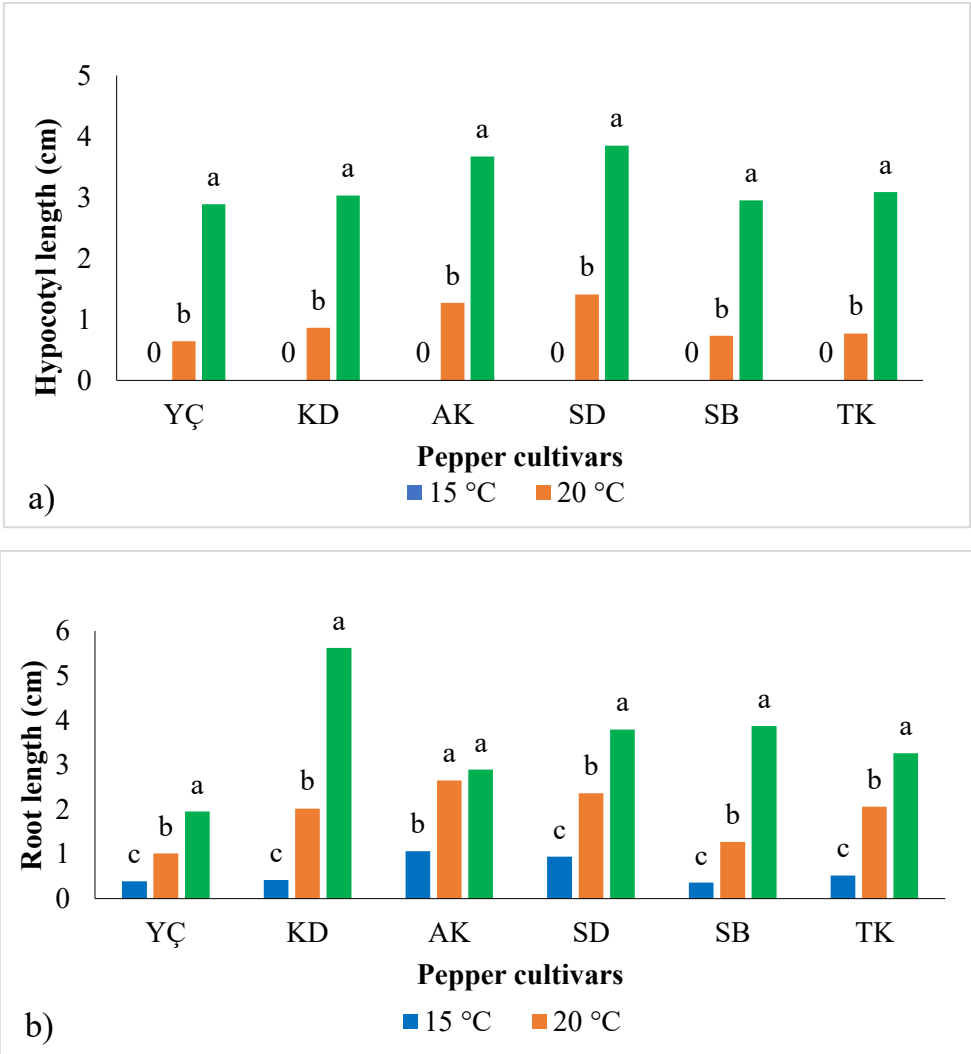

Figure 2. Effect of temperature x cultivar interaction on hypocotyl length (a) and root length (b) parameters.

According to the results of the statistical analysis, it was found that the effects of temperature and cultivar on hypocotyl fresh weight were important and the interaction between cultivar and temperature was insignificant. The fresh hypocotyl weight decreased significantly with decreasing temperature, SD cultivars at 20 °C (0.014 g) had the highest fresh hypocotyl weight among the cultivars and was the least decreasing compared to 25 °C. In the data of the averages, the highest fresh weight of the hypocotyl was found in the SD (0.021 g), while the lowest was found in the SB (0.011 g). For fresh hypocotyl weight at 15 °C (Table 3, Figure 3a) no results were obtained.

In the study, it was found that the effect of temperature and cultivar, the interaction between cultivar and temperature was significant ($p < 0.001$) on the root weight of pepper. The decrease in temperature caused a decrease in the weight of the roots in pepper, with the lowest root weight recorded at 15 °C being 0.0024 g. Following the means, it was measured as the highest (0.0048 g) root weight in the SD and the lowest (0.0023 g) in the SB. At 15 °C, the cultivar with the lowest decrease in fresh root weight was SB and the highest fresh root weight was in SD (Table 3, Figure 3b).

It was found that the effect of cultivar on hypocotyl dry weight was important, the effect of temperature on hypocotyl dry weight and the interaction between temperature and cultivar was insignificant. Among the cultivars, the highest value was found in KD (0.0020 g), while the lowest value was found in SB (0.0011 g). No results were obtained for hypocotyl dry weight at 15 °C. The minimum decrease in the dry weight of the hypocotyl at 20 °C occurred in the SD and the maximum decrease was observed in the YC (Table 3, Figure 3c).

In the analysis of variances showing the effect of different temperatures on the root dry weight of pepper, it was found that temperature, the effects of cultivar and the interaction between temperature and cultivar were important. Root dry weight was the same at 20 °C and 25 °C and decreased at 15 °C. The mean root dry weight was highest in KD and close to the other cultivars (Table 3, Figure 3d).

Table 3. Effect of different temperatures on hypocotyl fresh weight, root fresh weight, hypocotyl dry weight and root dry weight in some pepper cultivars

Parameter	Cultivars (C)	Temperature (T)						*Mean*	Significance		
		25 °C		20 °C		15 °C			*C*	*T*	*CxT*
			CR (%)		CR (%)		CR (%)				
Hypocotyl fresh weight (g)	**YC**	0,019 a	100	0,005 b	-73,68	-	-	**0,012 C**	***	***	NS
	KD	0,025 a	100	0,008 b	-68,00	-	-	**0,016 B**			
	AK	0,023 a	100	0,011 b	-52,17	-	-	**0,017 B**			
	SD	0,028 a	100	0,014 b	-50,00	-	-	**0,021 A**			
	SB	0,017 a	100	0,005 b	-70,59	-	-	**0,011 C**			
	TK	0,017 a	100	0,008 b	-52,94	-	-	**0,012 C**			
	Mean	**0,021 A**	**100**	**0,008 B**	**-61,90**	**-**	**-**				
Root fresh weight (g)	**YC**	0,0044 a	100	0,0033 ab	-25,00	0,0025 b	-43,18	**0,0034 CB**	***	***	***
	KD	0,0059 a	100	0,0018 b	-69,49	0,0016 b	-72,88	**0,0031 DC**			
	AK	0,0034 a	100	0,0027 a	-20,59	0,0026 a	-23,53	**0,0029 DC**			
	SD	0,0066 a	100	0,0049 b	-25,76	0,0028 c	-57,58	**0,0048 A**			
	SB	0,0024 a	100	0,0024 a	-	0,0020 a	-16,67	**0,0023 D**			
	TK	0,0050 a	100	0,0049 a	-2,00	0,0027 b	-46,00	**0,0042 BA**			
	Mean	**0,0046 A**	**100**	**0,0033 B**	**-28,26**	**0,0024 C**	**-47,83**				
Hypocotyl dry weight (g)	**YC**	0,0014 a	100	0,0011 b	-21,43	-	-	**0,0013 CD**	NS	***	NS
	KD	0,0021 a	100	0,0019 b	-9,52	-	-	**0,0020 A**			
	AK	0,0016 a	100	0,0015 b	-6,25	-	-	**0,0016 BC**			
	SD	0,0018 a	100	0,0017 b	-5,56	-	-	**0,0018 AB**			
	SB	0,0012 a	100	0,0011 b	-8,33	-	-	**0,0011 D**			
	TK	0,0014 b	100	0,0015 a	7,14	-	-	**0,0015 BC**			
	Mean	**0,0016**	**-**	**0,0015**	**-6,25**	**-**	**-**				

	YC	0,0003 b	100	0,0004 a	33.33	0,0003 ab	-	**0,0003 C**			
	KD	0,0007 a	100	0,0006 b	-14.29	0,0003 c	-57,14	**0,0005 A**			
	AK	0,0004 a	100	0,0003 b	-25.00	0,0002 b	-50,00	**0,0003 C**			
Root dry weight (g)	**SD**	0,0005 a	100	0,0005 a	-	0,0003 b	-40,00	**0,0004 B**	**	***	***
	SB	0,0004 a	100	0,0002 b	-50.00	0,0002 b	-50,00	**0,0003 C**			
	TK	0,0002 b	100	0,0003 a	50.00	0,0003 a	50,00	**0,0003 C**			
	Mean	**0,0004 A**	**100**	**0,0004 A**	**-**	**0,0003 b**	**-25,00**				

NS: p>0.05; ***:p<0.001, **:p<0.01,

There is no significant difference (p>0.05) between the means shown with the same lowercase or uppercase letter in the same row or column.

CR expresses the rate of change compared to 25 °C.

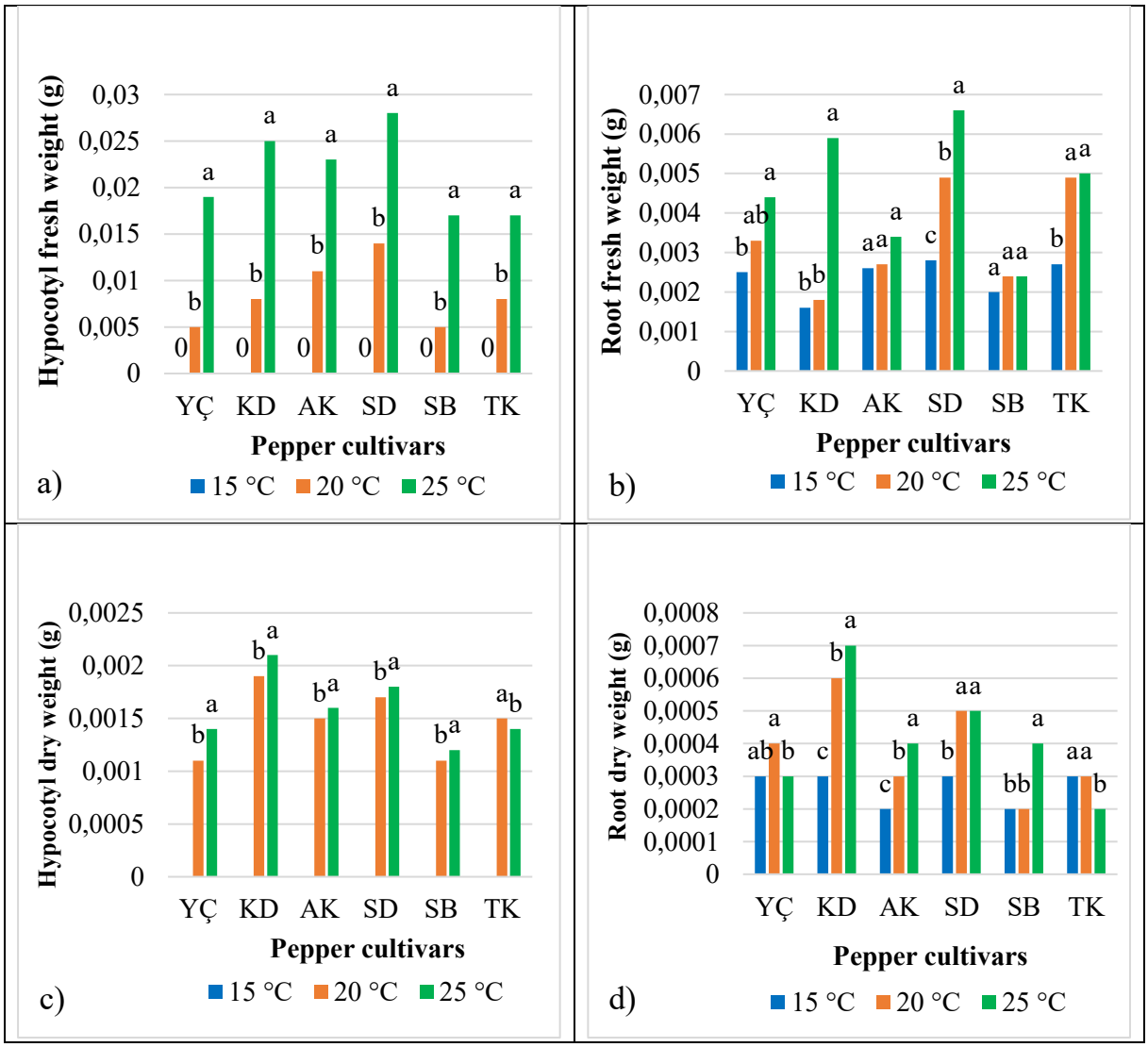

Figure 3. Effect of temperature x cultivar interaction on hypocotyl fresh weight (a), root fresh weight (b), hypocotyl dry weight (c) and root dry weight (d) parameters.

In the present study, parameters related to seed germination properties at different temperatures were investigated in six different pepper cultivars. The germination parameters (except the germination time) of all the pepper cultivars used in the study decreased with decreasing temperature during the germination phase. As the temperature dropped to 15 °C, the germination rate decreased by 23.50%, the root length was 82.87%, the root age was 47.83% and the root dry weight was decreased by 25.00% (hypocotyl measurements could not be made at this temperature). Cultivars that are least affected by the drop in temperature (15 °C); SD for germination rate, SB for germination time, AK for root length, SB for root fresh weight, and YC for root dry weight.

Temperature is one of the most important factors influencing where and when crops are grown, and this needs to be taken into account when producing plants. Vegetables are divided into cool and hot climate vegetables in terms of temperature requirements, which directly affect the life of the plant from sowing to harvest [7,11]. Low temperature stress is one of the most restrictive environmental factors for agricultural crops, especially vegetables, and this causes significant crop losses. Summer vegetables are sensitive to cold temperature (0-15°C) during their developmental periods, such as seed germination, vegetative growth and reproduction [2]. In the case of peppers, one of the hot climate vegetables, the fact that the temperature is below or above the optimum (20-25 °C) has a negative effect on growth and development. It is known that pepper does not grow in cold conditions when the night temperature falls below 10 °C, that color formation and flavor are reduced at low temperatures, and that the effects of cold damage on plants and fruit are observed. It is important to keep temperatures at optimum levels, especially during the early growth period of pepper [4].

The effects of low temperature are particularly noticeable during germination and early seedling development, with growth and development being arrested and top buds of very sensitive species being damaged. However, it is noted that seedlings in the vegetative stage are more sensitive to cold than advanced plants [12]. In our study, there was a decrease in the germination of the seeds of the pepper cultivars when the temperature was lower than 20 °C. In their study, researchers found that temperatures in a constant temperature growth cabinet at 13, 16 and 18 °C and in a greenhouse at 15-27 °C affected the seed production index of 105 pepper cultivars [13]. Furthermore, a study demonstrated that beans, corn, cucumber, eggplant, peas, pepper, radish, spinach and watermelon exhibited altered germination patterns in response to fluctuations in soil temperature. Notably, a decline in germination was observed in peas, radishes and spinach when the soil temperature reached or declined below 10 °C. It was observed that the growth of maize was limited to a temperature range of 2.3–14.5 °C, while the growth of beans, cucumber, eggplant, pepper and watermelon ceased when the soil temperature reached 16.7–18.9 °C [14].

It is possible that there are discrepancies between species with regard to germination at low temperatures, in addition to differences between cultivars of the same species. The cultivars employed in our study exhibited disparate responses to the temperature alteration with regard to germination characteristics. Similarly, researchers investigated the effect of priming on the controlled germination of pepper seeds (Corbacı, Sera Demre and Yalova oil cultivars) at temperatures of 15 °C and 35 °C. They found that the highest increase in germination occurred in the Corbacı cultivar at both temperatures [15]. The impact of varying temperature regimes

on the germination characteristics of diverse wheat (*Triticum aestivum*) varieties was examined. The germination and associated traits of seeds from five wheat varieties (Moomal 2000, T J-83, Imdad-2005, Abadgar-93 and Mehran 89) were analyzed at three distinct temperatures (10, 20 and 30 °C). It was observed that as the temperature increased, there was a corresponding increase in germination parameters, with the varieties exhibiting disparate responses. Furthermore, the germination time of seven tomato genotypes was evaluated at 10 °C or below. The analysis yielded the conclusion that the genotype designated as Lch-14, derived from *Lycopersicum chilense*, exhibited the shortest germination time [17]. In a separate study, the impact of cold stress (13 °C) on germination in seven distinct hybrid salad varieties was examined. The findings revealed that three cultivars demonstrated tolerance, with only one cultivar exhibiting the highest level of tolerance [18]. In the study by Borowski and Michałek [19], eight different soybeans were used to examine the effects of low temperature stress on germination and the early growth period. The results demonstrated a decrease in germination characteristics with a reduction in temperature. Similarly, this study demonstrated that temperature has a significant impact on seed germination percentage and germination speed, with notable differences observed among species. In a study conducted on rice, it was stated that 13 °C cold application caused a decrease in coleoptile length [20]. The study conducted by Liu et al. [21] showed that temperature significantly affects seed germination percentage and germination speed, which differs among species. Temperature also plays a major role in the healthy development of seedlings after germination. In this study, it was observed that hypocotyl and root development were affected by temperature. Similarly, it was stated that in tomato, there was a decrease of 56.7% and 65.3% in plant fresh weight with high and low temperature stress, and root fresh weight decreased by 64.6%, especially with low temperature stress, and that heat stress affected growth and photosynthetic properties more [22]

Temperature is important for seed germination as well as pollination and fertilization of vegetables. Pollen viability is among the most important criteria during the reproduction phase under cold stress. Pollen damage occurs in plants exposed to low temperatures [23] Studies have shown that low temperature stress negatively affects pollen viability in vegetables [24, 25, 26, 27]. Plants have evolved a range of physiological, biochemical and molecular mechanisms to detect and respond to low temperature stress [28]. Also, these mechanisms include modifications to the cell membrane and rearrangement of the cytoskeleton. On the other hand, decreased seedling growth of cucumber with low temperature stress was associated with decrease in chlorophyll content, photosynthetic capacity, and increased reactive oxygen species and malondialdehyde content [29]. The process of cold tolerance in plants is a complex one, whereby low or freezing temperatures result in the formation of ice within tissues, which in turn causes cellular dehydration. The mechanism of cold stress has been demonstrated to be regulated by the ICE-CBF-COR genes, although other factors such as various hormones, circadian clocks and light also play a role [30]. The findings of our study were examined in terms of germination and post-germination development in pepper, and the changes that occur with temperature are consistent with the findings of previous studies conducted by other researchers in this field.

4. Conclusion

The cultivation of pepper, which has significant production potential on a global and national scale, is characterized by its diversity of cultivars. A reduction in temperature, which is typical of pepper cultivation in hot climates, has a detrimental impact on plant development and, most importantly, on fruit yield. Furthermore, the responses of the diverse pepper cultivars currently available in the Turkish market to temperature stress may also vary. The present study evaluated the effects of low temperature stress during seed germination on pepper cultivars representing different groups. The majority of the cultivars under discussion, in conjunction with the reduction in temperature, exhibited discernible or quantifiable damage to their physiological and morphological characteristics. However, the cultivars employed in the study exhibited disparate responses to low-temperature stress. With regard to the Menderes Acı Kıl and Süs Biberi cultivars employed in the study, their response to low temperature was less pronounced. Additionally, the Sera Demre cultivar possesses mechanisms that enable it to withstand the detrimental effects of low temperature. It can be postulated that the general characteristics of these cultivars will have a significant effect on low-temperature stress, particularly given the bitter nature of the plants in question. It is important to note that this observation should not be taken as a definitive conclusion in itself. Furthermore, it would be beneficial to investigate the reactions of these cultivars to low temperature stress during the period of fruit formation.

The present study examined the effects of low temperature during the seed germination stage, which represents the initial and most crucial phase of vegetative production. Based on the findings, this research will serve as a valuable reference point in elucidating the impact of low temperature stress on the yield stage of pepper.

Ethics in Publishing

There are no ethical issues regarding the publication of this study

Author Contributions

ME and EY designed the experiment, OA, ME and EY conducted the experiment, ME and EY analyzed the results. The manuscript was written by Oguzhan Araz and all author approved the final manuscript.

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