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Original Research

The Impact of High Temperatures on Some Plant Growth Parameters in Some Common Bean Genotypes

Turgay Kabay[1]*, Aytekin Ekincialp[2], Suat Sensoy[3]

[1]Ercis Vocational School, Van Yuzuncu Yil University, 65080 Van, Turkey
[2]Baskale Vocational School, Van Yuzuncu Yil University, 65080 Van, Turkey
[3]Department of Horticulture, Faculty of Agriculture, Van Yuzuncu Yil University 65080 Van, Turkey

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Abstract

Common bean is one of the most cultivated vegetables globally and in Turkey. Especially in areas with a temperate climate, the losses in productivity and quality limit production due to high temperatures. Thus, the present study aimed to determine the bean genotypes tolerant to high temperature stress and to reduce the above-mentioned yield and quality losses to benefit the researchers and producers. In the present study, 46 bean genotypes and 2 bean cultivars, determined to be tolerant and sensitive to high temperatures in previous studies, were used. Variations in 0-5 visual scale value, plant fresh and dry weight, root fresh and dry weight, stem diameter, plant height, leaf number and area, relative leaf water content, membrane damage index and ion (K and Ca) content were determined in bean plants. Bean seeds were sown in 2-liter pots containing 2:1 peat + perlite mixture, 3 plants per pot based on the randomized blocks experimental design. From the seed sowing until the first real leaf appearance, the pots were irrigated with tap water and then, the pots were irrigated with Hoagland nutrient solution. The control plants were grown in a polyethylene greenhouse and the plants subjected to high temperature were grown in an extra polyethylene covered high tunnel in a polyethylene greenhouse to create high temperature stress. There was a daytime temperature difference of 6ºC (optimum: 32.17ºC for high temperature application; optimum: 26.17ºC for control application) between the control and high temperature applications. The analyzes conducted on the plants revealed that the genotypes V21, V28, V32, V82, T65, and V-a1 and cv. Yakutiye were tolerant to high temperature stress, while the genotypes V88, V89, T7, and T72 and cv. Zulbiye were the sensitive ones.

Keywords: high temperature, ion, plant growth, *Phaseolus vulgaris* L.

*e-mail: turgaykabay@gmail.com

Introduction

Increase in temperatures during bean cultivation period leads to necrotic injuries and changes in cellular functions, especially in the stem and the leaves. [1-3]. Nutrient intake of the plants depends on root morphology, soil properties, drought and plant species. Drought, extreme temperatures and mineral nutrition are closely related. Higher temperatures affect nutrient intake negatively and reduce mineral intake [4, 5].

Two of the basic elements required for growth and development are K and Ca ions. Potassium (K) is an essential nutrient for plants and is the most prevalent cation in plants. If the K and Ca contents of a plant are sufficient, transpiration would be under control and the opening and closure of stomata would exhibit a linear correlation with the K content in specialized stoma cells.

In a study where mung beans were exposed to three different temperatures, and it was determined that in high temperatures, the mean shoot biomass (including root) in plants decreased by 9% and 41%, and there were significant differences between the genotypes based on root weight; however, there was a positive correlation between root and shoot weights [6]. It was reported that high temperatures in greenhouse conditions leads to decreases in growth, yield and relative water content in hyacinth bean [7]. In a study where French bean genotypes were exposed to different high temperature regimes; it was found that the plant numbers decreased across the genotypes [8].

It was reported that corn grain yield in high temperatures was reduced by 80-90% when compared to normal temperatures [9]. It was reported in a study conducted with two soybean genotypes (JS 97-52 and EC 538828) under high temperature and arid conditions that there were decreases in several growth traits [10]. In a study where peanut genotypes were analyzed based on pod yield and physiological parameters under heat stress and in environments without stress, it was reported that pod yield, 100-seed weight and pod growth rate could be used as the criteria in selection of heat tolerant genotypes and based on stress tolerance index and pod yield performance; and some genotypes were determined as heat-tolerant ones [11]. In a study investigating the effects of high temperature stress on yield in pepper genotypes, it was reported that high temperatures would negatively affect pepper growth and yield [12].

High temperature stress also leads to drought damages since the water intake of the plants is adversely affected. In a study aiming to determine the tolerance and sensitivity of 46 bean genotypes and 2 bean cultivars to drought stress, it was determined that the genotypes V7, V15, V33, V82, V89, and V-A1, and cv. Yakutiye were tolerant to drought and the genotypes V21, V62, V69, V71, V86, V95, and T7 and cv. Zulbiye were sensitive to drought [13]. It was reported that leaf area and number, plant height and weight, stem diameter and relative leaf water content, and K and Ca content decreased in crop species under drought stress, while the membrane damage index increased [13-16]. It was indicated that the plant weight, leaf number, stem diameter and relative leaf water content decreased and membrane damage index increased in tomato plants exposed to drought stress [17, 18]. In tomato cultivars exposed to drought stress, the fresh and dry weight, leaf area and relative leaf water content significantly decreased in all cultivars when compared to the control group, while in bean plants, water and high temperature stress adversely affected the growth of sensitive bean cultivars [19].

In Turkey, which is the genetic center for various vegetables, the production and consumption of beans is prevalent in every single region for several years. Thus, there are several bean genotypes in each region in Turkey. The objective of the present study was to determine high temperature stress tolerant genotypes among them, would provide benefits for both the producers and researchers.

Material and Methods

In the present study conducted to determine genotypes that are high temperature stress tolerant and sensitive, 46 bean genotypes and two cultivars (cv. Yakutiye determined as abiotic stress tolerant and cv. Zulbiye determined as abiotic stress sensitive in previous studies) were investigated and the study was constructed with a randomized complete block experimental design with 4 replications. The seeds were sown in 2-liter plastic pots containing 2:1 peat: perlite mixture and as 3 seedlings per pot.

The seeds were irrigated with controlled tap water. The plants were irrigated with the standard nutrient solution until harvest after the formation of first true leaves. The irrigation was based on “drained solution/applied solution” [20].

The control plants were grown in a covered greenhouse, while the plants that were exposed to high temperature stress were grown in a high tunnel with a second polyethylene cover in the same greenhouse. There was a daytime temperature difference of 6ºC (optimum: 32.17ºC for high temperature application; optimum: 26.17ºC for control application) between the control and high temperature applications. The nighttime temperature difference between the high temperature stress application and the control application was 2.91ºC (optimum: 14.98ºC for high temperature application; optimum: 12.07ºC for control application). Analyzes were conducted on the samples obtained from the common bean plants after termination of the study on the 37th day.

Evaluation with a 0-5 Scale

Bean genotypes were rated for their high temperature tolerance on a 0-5 scale compared to check plants: 0 = healthy plants with no visible symptoms of high temperature stress; 1 = decrease in development; 2 = slight wilting in older leaves; 3 = moderate curling and wilting in upper leaves; 4 = leaves yellow-brown with severe wilting; and 5 = Wilted plants and dried lower leaves [20-22].

Determination of Fresh and Dry Weights

All plants were weighed on a precision scale (±0.1 g). Then, the samples were open air dried one day, and oven dried for 48 hours at 65ºC till reach a constant weight, and the dried samples were weighed on a precision scale (±0.1 g).

Determination of the Plant Height and Diameter

The stem lengths in bean plants were measured with a ruler (±0.1 cm), and their stem diameters were measured with a digital display caliper (±0.1 mm).

Determination of the Number of Leaves and Leaf Area

At the end of the high temperature experiment, the number of leaves was counted and the leaf areas were determined as cm^2 with a planimeter in all bean genotypes.

Determination of the Leaf Relative Water Content (LRWC)

At the end of the high temperature experiment, fresh leaf samples were sampled, weighted (FW) and kept in distilled water for four hours to calculate their turgor weights (TW). Then, the samples were kept in an oven (65ºC) for 48 hours and weighted (DW). The below formula was used in order to calculate the relative water content of the bean genotypes [20, 23, 24].

$$LRWC = \frac{(FW-DW)}{(TW-DW)} \times 100$$

Determination of Relative Growth Rate (g fresh weight day^{-1})

Before and after high temperature stress applications, the plants were weighed and the difference between the two measurements was divided by the number of days [20].

Determination of the Membrane Damages in the Leaf Cells

Membrane Damage Index (MDI) in bean leaves was calculated by measuring the electrolyte out of the cell. The 17 mm diameter discs taken from the bottom 3 leaves were incubated for 5 hours in 10 ml distilled water, and their EC values were measured. The same disc samples were kept at 100 C° for 10 minutes, and their EC values were measured again. Membrane Damage Index (MDI) was calculated by the following formula [20, 25, 26].

$$MDI = \frac{Lt-Lc}{1 - Lc} \times 100$$

Lt: The first EC value of high temperature stressed leaf disk samples / The second EC value of high temperature stressed leaf disc samples kept at 100ºC for 10 minutes.
Lc: The first EC value of control leaf disk samples / The second EC value of control disc samples kept at 100ºC for 10 minutes .

Mineral Element Analysis

At the end of the high temperature experiment, the shoot and root samples from high temperature stressed and control plants were dried in an oven at 65ºC until reach a constant weight. Then the dry samples (200 mg) were ground, pre-lit by ethyl alcohol, and lit till ash formation at 550ºC. The ash samples were dissolved with a 3.3% HCl solution, filtered with a blue-band filter paper, and Na, K, and Ca was determined in an atomic absorption device (Thermo trade brand serial no: ice3000 series aa spectrometer) [20, 22, 27].

Statistical Analysis

Analysis of Variances based on general linear models [28] carried out by SAS 9.4.1 statistical program was used. Duncan's multiple comparison test was used to measure the statistical differences between genotype.

Results and Discussion

High temperatures during bean cultivation reduce the plant yield and quality. Thus, the availability of genotypes and cultivars that are tolerant to high temperatures would have a positive impact on bean production, helping to relieve related problems of producers and researchers. In the present study, it was found that the genotypes V21, V28, V32, V82, T65, V-a1 and cv. Yakutiye on the 0-5 visual scale were statistically tolerant and the genotypes V88, V89, T7, T72 and cv. Zulbiye were statistically sensitive to high temperatures (Table 1). The genotype V21 was the least affected genotype based on the growth rate under high temperature stress, while the growth rate was 0.506% in cv. Yakutiye. It was determined that the lowest growth rates were observed in the genotypes V89 and T72, while the growth rate was 0.124% in cv. Zulbiye (Table 1). The highest relative leaf water content under high temperature stress was observed in the genotype T65 with 80.678% and the lowest relative leaf water content was observed in the genotype T121 with

Table 1. 0-5 scale value, relative plant growth rate (RPGR) (%) and leaf relative water content (LRWC) (%) of the common bean genotypes in the high temperature stress study.

Bean Genotype	0-5 scale in high temperature stress	RPGR in control (%)	RPGR in high temperature stress (%)	LRWC in control (%)	LRWC in high temperature stress (%)
V5	2.500 gh*	0.279 v*	0.191 w-y*	73.804 m-s*	64.237 h-j*
V6	1.750 hij	0.684 e-i	0.475 a-c	80.879 l-h	71.941 d-f
V7	4.250 abc	0.659 i-k	0.215 t-w	60.857 xyz	45.175 tu
V10	1.500 ij	0.514 s-u	0.331 kl	65.352 vwx	58.731 k-o
V12	2.500 gh	0.686 e-h	0.291 m-o	59.176 z	47.996 st
V14	1.500 ij	0.606 m-o	0.406 f-h	78.731 e-l	71.500 d-f
V15	1.500 ij	0.485 u	0.335 kl	74.627 k-r	69.357 e-g
V21	1.250 j	0.736 b	0.509 a	86.454 ab	78.388 ab
V28	1.250 j	0.537 r-t	0.359 i-k	63.845 v-y	58.728 k-o
V29	1.500 ij	0.553 p-s	0.375 ij	58.557 z	52.579 qr
V30	4.250 abc	0.499 tu	0.210 u-x	60.322 yz	43.344 uv
V32	1.250 j	0.643 i-m	0.442 c-f	84.180 a-d	76.775 bc
V33	1.750 hij	0.590 n-p	0.302 l-n	78.881 e-l	69.293 e-g
V36	2.750 efg	0.612 m-o	0.206 v-x	82.343 b-f	66.209 h-i
V40	1.500 ij	0.519 s-u	0.322 k-m	60.962 xyz	56.320 m-q
V41	4.250 abc	0.538 r-t	0.217 s-w	69.978 stu	53.133 p-r
V43	4.500 ab	0.584 o-q	0.155 yz	68.047 tuv	46.676 tu
V47	3.500 cde	0.638 j-m	0.217 s-u	58.996 z	44.254 t-v
V49	3.500 cde	0.717 b-d	0.288 m-p	65.424 vwx	47.804 st
V57	4.250 abc	0.672 d-k	0.279 n-p	76.799 g-n	55.474 n-q
V62	3.750 bd	0.695 b-g	0.303 l-n	75.749 i-q	57.178 l-p
V63	4.250 abc	0.617 l-o	0.252 o-t	79.792 d-j	58.656 k-o
V64	1.500 ij	0.663 f-k	0.467 bc	83.227 a-e	75.440 b-d
V66	1.500 ij	0.658 g-k	0.447 c-e	66.521 uvw	60.964 j-l
V69	1.750 hij	0.791 a	0.448 c-e	85.224 abc	76.750 abc
V71	2.750 efg	0.575 o-r	0.215 t-w	61.040 xyz	47.449 st
V73	2.750 efg	0.801 a	0.258 o-s	80.196 d-i	59.881 k-m
V77	2.500 gh	0.657 g-l	0.248 p-u	79.037 e-k	60.431 j-m
V79	3.250 def	0.706 b-f	0.251 o-u	81.109 c-g	59.039 k-n
V80	3.250 def	0.712 b-d	0.252 o-t	66.385 uvw	47.572 st
V82	1.250 j	0.598 m-o	0.415 e-g	75.209 jr	69.004 fg
V86	1.750 hij	0.554 p-s	0.386 g-i	74.112 l-s	66.937 hg
V88	4.750 a	0.632 k-n	0.174 x-z	75.096 jr	50.975 rs
V89	4.750 a	0.544 q-s	0.128 z	61.724 xyz	42.704 uv
V90	1.750 h-j	0.599 m-o	0.349 i-k	72.926 n-s	60.054 k-m
V95	1.750 h-j	0.669 e-k	0.339 j-l	76.203 h-p	60.508 j-m
V99	1.500 ij	0.719 bc	0.459 b-d	83.268 a-e	73.284 c-e
T7	4.750 a	0.608 m-o	0.148 yz	71.829 o-t	47.555 st

Table 1. Continued.

T32	3.500 c-e	0.717b-d	0.259 o-r	77.785 g-m	57.009 l-p
T37	2.500 gh	0.593 o-p	0.272 n-q	76.599 g-n	62.509 i-k
T65	1.250 j	0.639 i-m	0.422 d-g	87.330 a	80.678 a
T72	4.750 a	0.691 b-g	0.134 z	62.667 w-z	41.508 v
T121	3.750 bcd	0.705 b-f	0.228 r-w	71.397 q-t	54.817 o-r
V-e1	4.250 abc	0.669 e-k	0.256 o-t	74.755 k-r	54.766 o-r
V-a1	1.250 j	0.681 c-j	0.487 ab	76.399 g-o	71.202 ef
V-g1	3.250 def	0.680 c-j	0.235 r-v	70.779 r-u	52.503 qr
Zulbiye	4.750 a	0.633 k-n	0.124 z	71.544 p-t	47.478 st
Yakutiye	1.250 j	0.705 b-f	0.506 a	77.816 f-m	72.467 de

* There is a significant difference (p<0.05) among the different letters in each column.

41.508% (Table 1). The membrane damage was highest in the genotypes T7, V89 and V88 and cv. Zulbiye, while it was the lowest in the genotypes V-a1, V14, V21, V28, V29, V32, and V99 and cv. Yakutiye. Statistically, plant height loss was the least in the genotype V-a1 under high temperature stress, while the genotype T7 exhibited the highest plant height loss. It can be observed in Table 2 that the leaf number and area loss under high temperature stress were the lowest in the genotypes V-a1 and V15 and the maximum leaf area loss was observed in the genotype T7. It was reported that high temperatures in greenhouse conditions lead to losses in growth, yield and relative leaf water content in hyacinth bean (*Lablab purpureus*. L) plants [7]. It was indicated that when the French bean genotypes were exposed to high temperature stress, the decrease

Table 2. Membrane damage Index (MDI) (%), Shoot height (cm), Leaf area (cm^2) and Leaf number of the bean genotypes in the high temperature stress study.

Bean Genotype	MDI in high temperature stress (%)	Shoot height in control (cm)	Shoot height in high temperature stress (cm)	Leaf area in control (cm^2)	Leaf area in high temperature stress (cm^2)	Leaf number in control	Leaf number in high temperature stress
V5	25.517 k-m*	53.225 j-n*	40.400 g-k*	30.346 a-h*	17.769 f-o*	14.500 a*	11.750 a-d*
V6	22.567 lm	66,025 e-g	52.775 f	29.522 a-h	22.283 a-i	12.500 a-g	9.750 d-h
V7	44.500 c-h	46.875 n-s	38.975 g-k	29.761 a-h	11.311 o-r	11.750 b-g	6.500 l-q
V10	20.764 lm	36.475 uv	29.900 m-o	26.523 c-h	19.396 b-l	12.250 a-g	10.000 c-h
V12	27.645 i-m	39.050 s-v	31.550 mn	36.445 a-d	25.586 a-c	14.250 ab	10.000 c-h
V14	19.873 m	46.750 n-s	29.950 m-o	25.900 e-h	18.337 e-n	12.250 a-g	11.000 b-e
V15	20.240 lm	91.925 a	82.725 a	36.253 a-e	27.506 a	12.250 a-g	9.750 d-h
V21	18.380 m	63.375 g-i	54.625 f	24.822 f-h	17.670 i-o	12.500 a-g	10.500 c-f
V28	19.141 m	60.425 g-j	52.375 f	31.159 a-h	22.417 a-i	14.250 ab	12.500 ab
V29	18.384 m	78.775 cd	70.500 b	26.922 c-h	16.160 i-q	12.000 a-g	10.000 c-h
V30	45.650 c-f	64.375 f-i	42.125 g-i	24.772 f-h	10.975 o-r	10.750 afg	6.750 k-p
V32	18.456 m	59.700 g-k	52.000 f	30.771 a-h	24.826 a-e	13.000 a-f	11.750 a-d
V33	22.426 l-m	50.750 l-q	43.125 gh	37.594 ab	26.088 ab	11.750 b-g	10.250 c-f
V36	29.176 i-m	44.125 o-t	29.950 m-o	36.835 a-c	20.518 b-j	13.250 a-e	8.750 f-k
V40	20.721 lm	51.650 k-p	44.500 gh	29.030 a-h	20.130 b-k	10.500 fg	9.000 e-j
V41	46.190 b-f	56.200 i-m	36.525 i-l	29.521 a-h	9.210 qr	11.250 c-g	8.000 h-n
V43	50.154 a-d	51.500 k-p	25.900 n-p	32.396 a-h	14.187 j-r	11.500 c-g	5.500 opq

Table 2. Continued.

V47	35.053 f-k	67.500 e-g	45.450 g	26.319 d-h	13.590 k-r	11.750 b-g	7.500 i-o
V49	37.700 e-i	87.250 ab	60.700 de	28.226 a-h	13.828 j-r	12.500 a-g	8.000 h-m
V57	43.695 d-h	53.775 j-n	34.025 k-m	27.456 b-h	11.822 m-r	13.000 a-f	8.750 f-k
V62	38.599 e-i	33.125 v	20.550 p	25.107 f-h	11.385 o-r	12.000 a-g	7.500 i-o
V63	46.697 b-e	63.850 f-i	42.150 g-i	29.700 a-h	11.495 n-r	12.250 a-g	7.250 j-o
V64	20.139 lm	78.975 cd	68.200 bc	30.122 a-h	20.541 b-j	11.500 c-g	9.500 e-i
V66	19.506 lm	72.875 de	63.100 cd	37.917 a	24.384 a-g	11.500 c-g	9.500 e-i
V69	20.780 l-m	62.958 g-i	53.675 f	26.349 d-h	14.245 j-r	12.250 a-g	10.500 c-f
V71	34.477 g-k	42.700 q-t	26.025 n-p	22.827 h	9.070 r	11.500 c-g	8.500 f-l
V73	33.964 h-k	84.325 cb	56.925 ef	31.318 a-h	17.293 i--o	12.750 a-g	7.500 i-o
V77	31.873 i-l	60.500 g-j	36.250 i-m	22.747 h	10.947 o-r	12.000 a-g	7.500 i-o
V79	35.754 e-k	53.325 j-n	34,225 j-m	27.568 a-h	13.492 k-r	11.250 c-g	7.250 j-o
V80	37.058 e-j	47.625 n-r	32.175 l-n	32.782 a-h	18.936 c-l	13.000 a-f	8.250 g-m
V82	18.645 m	45.400 n-t	40.375 g-k	29.665 a-h	23.922 a--h	11.250 c-g	10.250 c-g
V86	22.092 lm	50.350 l-q	44.200 gh	22.547 h	16.083 i-q	10.250 g	9.000 e-j
V88	55.196 a-c	49.525 l-q	27.550 no	30.946 a-h	9.529 p-r	11.750 b-g	6.000 n-q
V89	56.879 ab	43.700 p-t	36.400 i-m	28.998 a-h	16.375 i-p	11.000 d-g	6.500 l-q
V90	25.785 k-m	71.900 d-f	51.250 f	31.089 a-h	22.052 a-g	10.250 g	7.250 j-o
V95	26.091 j-m	65.775 e-h	43.625 gh	28.817 a-h	18.484 d-m	13.500 a-d	8.000 h-n
V99	19.417 m	65.400 e-h	57.150 ef	33.735 a-g	24.560 a-f	11.250 c-g	7.500 i-o
T7	58.671 a	63.575 g-i	25.700 n-p	34.681 a-f	11.346 o-r	10.250 g	4.750 q
T32	38.175 e-i	40.900 r-v	27.025 n-p	24.411 f-h	13.020 m-r	11.500 c-g	7.250 j-o
T37	29.177 i-m	53.075 j-n	38.575 h-l	23.667 gh	13.048 m-r	11.000 d-g	7.000 j-o
T65	19.888 m	47.975 m-r	40.775 g-j	29.787 a-h	18.719 d-m	11.250 c-g	9.750 d-h
T72	56.603 ab	57.458 h-l	23.475 op	22.651 h	8.624 r	12.500 a-g	6.250 m-q
T121	37.056 e-j	36.925 u-v	24.575 p-o	26.275 d-h	13.274 k-r	11.500 c-g	8.000 h-n
V-e1	46.664 b-e	52.375 j-o	26.200 n-p	25.162 f-h	9.722 p-r	12.250 a-g	7.000 j-o
V-a1	17.535 m	36.350 uv	31.675 mn	32.972 a-g	24.077 a-h	14.250 ab	13.000 a
V-g1	37.879 e-i	38.175 uv	25.925 n-p	29.169 a-h	14.776 j-r	12.000 a-g	8.750 f-k
Zulbiye	59.642 a	33.950 v	10.375 q	23.899 gh	9.405 p-r	11.500 c-g	5.000 pq
Yakutiye	17.945 m	38.650 s-v	34.675 j-m	32.006 a-h	25.297 a-d	13.750 a-c	12.000 abc

* There is a significant difference ($p<0.05$) among the different letters in each column.

in the plant number increased in these genotypes [8]. It was emphasized that high temperatures reduced corn grain yield by 80-90% compared to normal temperatures [9]. It was reported in a study conducted with two soybean genotypes under high temperature and drought conditions that the decreases in leaf area, seed weight, total biomass, pod, harvest index, seed number per pod and 100-seed weight were observed [10].

There was a significant difference between the fresh and dry shoot and fresh and dry root weights of tolerant and sensitive common bean plants under high temperature stress. The fresh shoot weight loss was the lowest in the genotype V-a1 and the highest in the genotype T7. The dry shoot weight was the lowest in the genotype V-a1 and the highest in the genotype T7. The fresh root weight lost was the lowest in the genotype V-a1 and the highest in the genotype T7. The dry root weight was the lowest in the genotype V-a1 and the highest in the genotype T7 (Table 3). When the fresh and dry shoot/root ratio of bean genotypes under high temperature stress was examined, it was determined that

Table 3. The fresh and dry shoot and root weights (g) of the bean genotypes in high temperature stress study.

Genotype	Shoot fresh weights in control (g)	Shoot fresh weights in high temperature stress (g)	Shoot dry weights in control (g)	Shoot dry weights in high temperature stress (g)	Root fresh weights in control (g)	Root fresh weights in high temperature stress (g)	Root dry weights in control (g)	Root dry weights in drought stress (g)
V5	26.838 a-g*	13.187 e-m*	3.859 p-s*	2.823 h-j*	6.665 gh*	3.580 h-k*	0.901 ab*	0.571 e*
V6	24.394 c-I	16.738 b-i	3.523 suu	2.844 g-j	5.005 n	2.250 q-u	0.909 ab	0.462 gh
V7	25.076 c-I	10.219 l-p	5.305 efg	2.743 h-k	6.040 ijk	4.881 f	0.840 cd	0.701 d
V10	23.808 c-I	16.560 b-i	3.636 r-t	3.131 f-i	4.649 nop	4.0 88 h	0.549 i-m	0.393 jk
V12	33.560 a	12.073 i-o	4.911 hi	4.246 b-d	3.767 qrs	3.311 jkl	0.479 nop	0.417 ijk
V14	25.532 b-I	16.309 b-i	3.194 uv	2.591 i-k	4.702 no	4.104 h	0.523 k-n	0.472 fg
V15	20.443 hi	13.420 e-m	2.844 xyz	2.367 j-l	3.381 st	3.111 k-n	0.417 qrs	0.387 k
V21	25.071 c-I	17.024 b-i	4.618 jil	3.796 c-e	8.228 c	7.306 d	0.903 ab	0.796 b
V28	27.298 a-h	16.576 b-i	3.996 opq	2.496 j-l	5.180 ln	4.661 g	0.599 ghi	0.496 f
V29	26.394 b-I	18.263 a-e	6.736 bc	5.247 a	9.331 b	8.607 b	0.871 bc	0.775 bc
V30	19.491 I	7.449 op	2.603 z	1.626 m-o	4.076 pqr	1.925 s-v	0.496 m-p	0.191 rst
V32	32.569 ab	20.473 ab	4.371 l-o	3.684 d-f	10.236 a	9.580 a	0.940 a	0.873 a
V33	24.384 c-I	11.066 j-p	6.100 d	4.324 cb	6.829 fgh	5.788 e	0.766 e	0.703 d
V36	27.016 a-h	12.282 h-o	4.051 n-q	2.646 i-k	5.724 jkl	2.998 l-o	0.664 f	0.422 ij
V40	25.051 c-I	16.821 b-i	5.045 g-i	4.439 b	5.020 n	4.673 g	0.508 l-o	0.462 gh
V41	24.579 c-I	10.056 l-p	3.243 u-w	2.335 j-k	4.542 nop	2.316 q-u	0.403 rs	0.205 r
V43	22.583 f-I	9.102 m-p	3.276 t-v	1.238 o	7.221 efg	2.890 l-p	0.821 d	0.238 pq
V47	24.173c-I	10.295 l-p	2.806 y-z	1.144 o	4.252 opq	2.354 p-t	0.302 tu	0.144 u-x
V49	27.466 a-h	17.366 a-h	4.219 m-p	2.277 j-k	5.689 klm	2.894 l-p	0.617 g	0.277 no
V57	28.332 a-g	15.151 c-l	3.573 s-u	2.167 k-m	3.733 qrs	1.803 uvw	0.289 tuv	0.167 tuv
V62	25.970 b-I	13.581 d-m	4.104 n-p	2.433 j-l	6.304 hij	3.669 hij	0.734 e	0.433 hi
V63	25.808 b-I	11.177 j-p	2.892 w-z	1.001 o	5.015 n	2.614 n-q	0.516 lmn	0.301 mn
V64	25.321 c-I	18.732 a-d	4.667 i-l	3.421 e-g.	6.547 hi	5.778 e	0.596 ghi	0.421 ij
V66	28.573 a-f	17.425 a-h	4.247 m-o	3.432 e-g	4.799 no	2.780 m-q	0.571 g-k	0.407 ijk
V69	30.306 a-d	17.240 b-i	5.451 ef	3.756 de	8.921 b	7.992 c	0.884 bc	0.756 c
V71	26.045 b-I	13.775 c-m	2.989 v-y	2.259 j-k	7.808 cd	3.681 hij	0.681 f	0.259 op
V73	28.620 a-g	16.445 b-i	4.797 i-j	2.259 j-k	4.653 nop	1.936 r-v	0.535 j-m	0.260 op
V77	27.936 a-g	16.837 b-i	6.805 bc	4.247 b-d	6.476 hi	3.530 ijk	0.582 g-j	0.247 op
V79	25.572 c-I	13.262 e-m	3.283 v-u	1.974 l-n	4.959 n	2.292 q-u	0.255 uv	0.149 uvw
V80	27.045 a-h	12.444 h-o	4.223 m-p	2.130 k-m	4.871 no	2.476 o-r	0.262 uv	0.130 wx
V82	22.238 g-I	15.827 b-k	6.927 b	5.727 a	6.463 hi	6.091 e	0.742 e	0.679 d
V86	23.826 c-I	18.153 a-f	4.793 i-k	3.646 ef	3.524 rst	3.263 j-m	0.316 t	0.296 mn
V88	26.975 a-h	9.134 m-p	5.203 f-h	1.198 o	4.783 no	3.694 hij	0.509 l-o	0.198 rs
V89	25.761 e-I	8.012 n-p	5.601 e	1.937 l-n	4.740 no	1.402 w	0.556 h-l	0.137 vwx
V90	25.164 c-I	17.804 a-f	4.912 i-j	3.114 f-i	3.736 qrs	2.314 q-u	0.237 v	0.114 x
V95	28.852 a-g	20.513 ab	7.412 a	5.438 a	5.110 mn	3.583 h-k	0.471 nop	0.438 hi
V99	29.847 a-e	18.806 a-c	4.407 l-n	3.428 e-g	3.119 t	2.774 m-q	0.451 pqr	0.428 i
T7	22.844 e-I	6.179 p	4.522 k-m	1.139 o	4.925 n	1.381 w	0.382 s	0.139 vwx

Table 3. Continued.

T32	27.580 a-g	16.019 b-j	3.682 r-s	1.213 o	5.020 n	2.436 p-s	0.459 opq	0.213 qr
T37	27.112 a-h	17.411 a-h	2.990 v-y	1.518 no	3.815 qrs	1.848 t-w	0.372 s	0.174 stu
T65	23.404 d-I	17.019 b-i	3.531 s-u	2.874 h-j	3.849 qrs	3.542 ijk	0.297 tu	0.264 op
T72	25.076 c-I	7.533 op	4.923 i-j	1.322 o	3.708 qrs	1.675 vw	0.279 tuv	0.122 wx
T121	26.857 a-h	10.911 k-p	5.187 f-g	3.318 e-h	6.623 hi	3.358 i-l	0.590 ghi	0.318 m
V-e1	30.771 a-c	13.025 f-n	6.481 c	2.259 j-k	5.796 jk	2.649 n-q	0.457 opq	0.259 op
V-a1	29.642 a-f	22.312 a	3.729 r-s	3.252 e-h	5.634 klm	5.316 f	0.502 l-p	0.477 fg
V-g1	26.636 a-h	12.749 g-n	4.689 i-k	2.352 j-k	7.303 def	3.860 hi	0.745 e	0.352 l
Zulbiye	26.081 b-I	7.409 op	6.055 d	2.327 j-k	5.175 lmn	1.500 vw	0.516 l-n	0.127 wx
Yakutiye	28.565 a-g	20.700 ab	4.136 n-p	3.598 ef	7.631 de	7.141 d	0.606 gh	0.573 e

* There is a significant difference (p<0.05) among the different letters in each column.

Table 4. The fresh and dry shoot and root ratio and Stem diameter (mm) of the bean genotypes in high temperature stress study.

Genotype	Fresh shoot/root ratio in control	Fresh shoot/root ratio in high temperature stress	Dry shoot/root ratio in control	Dry shoot/root ratio in high temperature stress	Stem diameter in control (mm)	Stem diameter in high temperature stress (mm)
V5	0.250 e-i*	0.277 e-l*	0.236 bc*	0.203 c*	5.738 a-d*	4.588 c-h*
V6	0.207 i-m	0.136 p-t	0.259 a	0.163 g-h	5.508 a-g	4.398 c-l
V7	0.247 e-j	0.491 a	0.159 ef	0.256 a	5.793 a-c	4.023 g-o
V10	0.196 k-q	0.249 f-o	0.151 fg	0.126 ij	4.995 e-l	4.543 c-j
V12	0.121 st	0.278 e-l	0.098 n-p	0.099 k-n	5.350 b-i	4.513 c-j
V14	0.186 l-q	0.254 f-n	0.164 ef	0.182 d-f	5.238 b-k	4.603 c-g
V15	0.165 n-s	0.241 g-o	0.147 f-i	0.162 g-h	4.540 l	4.160 f-n
V21	0.332 ab	0.433 abc	0.196 d	0.209 c	5.143 c-l	4.770 cde
V28	0.191 l-q	0.282 e-k	0.149 f-h	0.198 cd	4.600 kl	4.105 f-n
V29	0.363 a	0.481 a	0.129 i-l	0.148 h	5.335 b-i	4.838 c
V30	0.210 i-n	0.268 e-m	0.191 d	0.118 i-k	4.648 jkl	3.953 k-q
V32	0.330 abc	0.470 ab	0.221 c	0.243 a	5.598 a-e	4.883 bc
V33	0.283 c-f	0.224 g-r	0.126 j-m	0.163 g-h	5.003 e-l	4.398 c-l
V36	0.216 h-m	0.244 g-o	0.165 ef	0.162 g-h	5.590 a-e	4.563 c-i
V40	0.202 i-o	0.283 e-j	0.101no	0.104 j-m	4.738 h-l	4.175 f-n
V41	0.186 l-q	0.239 g-o	0.124 k-m	0.088 m-p	5.218 b-k	4.413 c-k
V43	0.325 abc	0.356 cde	0.251 ab	0.192 c-e	4.708 i-l	3.535 o-r
V47	0.178 m-r	0.235 g-p	0.107 mn	0.126 i	5.298 b-j	4.430 c-k
V49	0.208 i-n	0.167 m-t	0.146 f-j	0.121 ij	5.083 d-l	3.998 j-p
V57	0.133 rst	0.124 st	0.081 o-r	0.077 o-r	5.020 e-l	4.060 g-o
V62	0.245 f-k	0.306 d-i	0.179 de	0.178 d-g	5.390 b-h	4.610 c-g
V63	0.195 l-q	0.254 f-n	0.178 de	0.231 b	5.320 b-i	4.405 c-k
V64	0.259 d-h	0.312 d-g	0.128 i-m	0.119 i-k	4.805 h-l	4.160 f-n
V66	0.170 m-r	0.160 n-t	0.135 f-j	0.119 i-k	5.480 a-g	4.623 c-f
V69	0.298 bcd	0.505 a	0.162 ef	0.159 gh	5.763 abc	4.888 bc

Table 4. Continued.

V71	0.300 bcd	0.271 e-l	0.229 c	0.115 i-l	5.578 a-f	4.368 c-l
V73	0.163 n-s	0.120 st	0.112 l-n	0.115 i-l	5.038 e-l	4.145 f-n
V77	0.233 g-l	0.203 j-t	0.085 o-q	0.058 r	5.323 b-i	4.273 d-m
V79	0.198 k-p	0.180 l-t	0.077 p-r	0.076 o-r	4.790 h-l	3.728 n-r
V80	0.185 l-q	0.208 h-t	0.063 t-r	0.062 qr	5.088 d-l	4.220 e-n
V82	0.295 b-e	0.387 bcd	0.107 mn	0.119 i-k	5.020 e-l	4.543 c-j
V86	0.151 o-t	0.180 k-t	0.066 r-t	0.081 n-q	4.968 e-l	4.475 c-k
V88	0.181 m-r	0.414 abc	0.097 n-p	0.169 f-h	5.345 b-i	3.493 pqr
V89	0.190 l-q	0.193 j-t	0.099 no	0.071 o-r	4.908 g-l	3.353 r
V90	0.149 p-t	0.133 q-t	0.048 t	0.037 s	5.268 b-k	4.350 c-l
V95	0.177 m-r	0.174 l-t	0.057 st	0.081 n-q	5.385 b-h	4.620 c-f
V99	0.104 t	0.148 o-t	0.102 no	0.125 ij	5.410 b-h	4.780 cd
T7	0.217 h-m	0.227 g-q	0.085 o-q	0.122 ij	5.180 c-l	3.398 r
T32	0.183 l-q	0.168 m-t	0.125 l-m	0.176 e-g	4.910 g-l	4.203 f-n
T37	0.146 rst	0.111 t	0.125 l-m	0.115 i-l	5.193 b-l	4.135 f-n
T65	0.168 m-s	0.220 g-r	0.084 o-q	0.092 m-o	4.843 g-l	4.380 c-l
T72	0.149 p-t	0.247 f-o	0.057 st	0.092 l-o	5.225 b-k	3.543 o-r
T121	0.249 e-i	0.309 d-h	0.114 k-n	0.096 l-o	5.025 e-l	4.043 g-o
V-e1	0.191 l-q	0.212 g-s	0.071 q-s	0.115 i-l	5.250 b-k	3.853 l-r
V-a1	0.190 l-q	0.239 g-o	0.135 g-k	0.147 h	5.853 ab	5.333 ab
V-g1	0.288 b-f	0.307 d-i	0.159 ef	0.149 h	5.140 c-l	3.743 m-r
Zulbiye	0.200 l-p	0.207 i-t	0.085 o-q	0.067 qr	5.283 b-j	3.448 qr
Yakutiye	0.267 d-g	0.346 c-f	0.147 g-i	0.160 gh	6.078 a	5.625 a

* There is a significant difference ($p<0.05$) among the different letters in each column.

the fresh shoot/root ratio varied between 0.111 and 0.505, while the dry shoot/root ratio varied between 0.058 and 0.243 (Table 4). The stem diameter of the genotype V-a1 was the least affected by high temperature stress, while the most affected genotype was T7 (Table 4). It was reported that the direct exposure of the mung bean genotypes to high temperatures (45ºC/30ºC) led to about 9% to 41% decreases in the mean shoot biomass (including root), and there were significant differences between the genotypes based on root weight; however, there was also a positive correlation between root and shoot weight [6]. In a study where peanut genotypes were analyzed based on pod yield and physiological parameters under heat stress and in environments without stress, it was reported that pod yield, 100-seed weight and pod growth rate could be used as the criteria in selection of heat tolerant genotypes and based on stress tolerance index and pod yield performance, ICGVs 07246, 07012, 06039, 06040, 03042, 07038 and 06424 were described as heat-tolerant genotypes [11]. In a study investigating the effects of high temperature stress on yield in pepper genotypes, it was reported that the optimum temperature for flowering and fruiting of pepper was between 20.70ºC and 30,74ºC, and temperatures between 24.22ºC and 32.17ºC would significantly affect pepper growth and yield [12].

Analysis of the variations in shoot potassium content in bean genotypes exposed to high temperature stress demonstrated that the lowest changes were observed in the genotype V99 and the changes were also significant in the genotypes V29 and V-a1. The least affected one was cv. Yakutiye (Table 5). Among the sensitive cultivars, high K losses were observed in the genotypes V80, V88, and T7 and cv. Zulbiye. Analysis of the variations in root K content in bean genotypes exposed to high-temperature stress demonstrated that the lowest changes were observed in the genotypes V82, V95, V-a1 and V79. The maximum reduction in K content was determined in the genotypes V89 and T7 (Table 5).

The genotypes with the lowest loss in shoot Ca content were V14, V-a1, V82, and V15 when exposed to high temperature stress. It was observed that Ca content in cv. Yakutiye's shoots was 2.938% in the control group and 2.572% in the high temperature stress

Table 5. The fresh and dry shoot and root K and Ca (%) of the bean genotypes in the high temperature stress study.

Genotype	Shoot K content in control (%)	Shoot K content in high temperature stress (%)	Root K content in control (%)	Root K content in high temperature stress (%)	Shoot Ca content in control (%)	Shoot Ca content in high temperature stress (%)	Root Ca content in control (%)	Root Ca content in high temperature stress (%)
V5	2.399 de*	1.942 ef*	1.805 e*	1.449 g*	3.299 c*	2.325 ij*	2.163 g*	1.621 i*
V6	1.787 z	1.510 op	1.233 v	1.028 v	3.042 j-k	2.291 j	1.467 u	1.195 u
V7	2.018 wx	1.197 t	1.657 kl	1.443 g	2.682 r	2.029 q	1.819 n	1.138 w
V10	2.375 ef	2.059 ab	1.755 f-h	1.122 q	2.714 qr	2.235 k	2.031 i	1.780 g
V12	2.386 e	1.865 gh	1.591 n	1.248 m	3.229 de	2.408 h	1.218 w	0.936 yz
V14	2.208 o-t	1.765 ji	1.656 kl	1.075 t	3.384 ab	3.034 a	1.693 r	1.465 m
V15	1.758 z	1.498 op	1.382 r	1.085 st	2.683 r	2.362 i	2.388 c	2.112 b
V21	2.447bc	1.992 c-e	1.758 fg	1.395 h	2.727 p-r	2.298 j	1.913 l	1.597 j
V28	2.264 j-l	1.957 ef	1.848 d	1.369 ij	3.157 f-g	2.545 fg	1.343 v	0.907 yz
V29	2.196 q-t	1.939 ef	1.733 ij	1.268 l	3.148 g-i	2.755 b	1.688 r	1.358 n
V30	1.798 z	1.373 rs	1.659 k	0.880 z	3.190 e-g	1.968 r	1.474 u	0.831 z
V32	2.392 de	2.114 a	1.840 d	1.573 c	3.217 ef	2.708 c	2.164 g	1.919 d
V33	2.203 p-t	1.866 gh	1.543 o	1.173 o	2.785 p	2.346 i	2.389 c	1.931 d
V36	2.111 v	1.367 rs	1.735 h-j	1.108 qr	3.332 bc	2.538 fg	2.557 b	1.847 f
V40	2.478 ab	2.068 ab	1.641 kl	1.456 fg	3.083 i-k	2.752 b	2.339 e	2.114 b
V41	2.489 a	1.647 lm	1.798 e	1.093 rs	3.172 e-g	2.093 o	1.489 u	1.234 s
V43	2.283 ij	1.689 kl	1.205 w	0.975 w	2.718 qr	1.245 y	1.601 s	0.842 z
V47	2.244 k-o	1.679 kl	1.408 q	1.118 q	2.697 qr	2.053 pq	1.995 j	1.577 k
V49	2.185 r-u	1.528 no	1.739 g-i	1.248 m	2.763 pq	2.207 kl	1.999 j	1.512 l
V57	2.222 n-r	1.939 ef	1.358 s	1.089 st	2.724 p-r	2.164 mn	2.007 j	1.339 o
V62	2.289 ij	1.947 ef	1.842 d	1.327 k	3.136 g-i	1.606 u	2.093 h	1.173v
V63	1.807 z	1.408 qr	1.324 t	1.059 u	2.713 qr	1.730 t	1.595 s	1.197 u
V64	2.035 w	1.516 op	1.235 v	1.019 v	2.747 p-r	2.359 i	1.718 q	1.265 r
V66	2.259 j-m	1.941 ef	1.801 e	1.505 e	3.285 cd	2.678 c	1.699 qr	1.309 pq
V69	2.443 bc	1.890 fg	1.601 mn	1.355 j	3.227 de	2.560 e-g	1.467 u	1.149 w
V71	2.346 fg	1.954 ef	1.859 d	1.267 l	2.686 r	2.028 q	1.334 v	1.056 l
V73	2.093 v	1.723 jk	1.859 d	1.373 i	2..849 o	2.185 lm	1.474 u	1.217 t
V77	2.234 l-p	1.666 kl	1.741 g-i	1.225 n	2.978 l-n	1.979 r	2.260 f	1.712 h
V79	2.171 tu	1.588 mn	1.473 p	1.326 k	2.858 o	2.222 kl	1.521 t	1.294 q
V80	2.422 cd	1.501 op	1.949 a	1.338 k	2.861 o	2.101 o	1.759 p	1.471 m
V82	2.279 i-k	1.934 ef	1.812 e	1.698 b	2.531 s	2.235 k	1.696 qr	1.509 l
V86	2.366 ef	1.837 gh	1.773 f	1.243 m	3.038 j-l	2.597 e	1.969 k	1.499 l
V88	2.211 n-s	1.385 r	1.912 b	0.949 x	3.144 g-i	1.514 v	1.686 r	0.840 z
V89	1.985 y	1.315 s	1.638 l	0.719 z	3.028 kl	2.673 cd	1.139 y	0.893 yz
V90	1.985 xy	1.651 l	1.360 s	0.925 y	2.942 n	2.142 n	1.171 x	0.838 z
V95	2.449 bc	1.970 de	1.949 a	1.803 a	3.008 lm	2.343 i	1.595 s	1.308 pq
V99	2.308 hi	2.048 bc	1.891 c	1.698 b	2.983 l-n	2.443 h	2.262 f	2.122 b
T7	2.177 s-u	1.406 qr	1.856 d	0.885 z	2.959 mn	1.474 w	1.529 t	0.809 z

Table 5. Continued.

T32	2.246 k-n	1.819 hi	1.792 e	1.470 f	3.395 a	2.525 g	1.469 u	1.094 x
T37	2.282 ij	1.809 hi	1.224 v	0.922 y	3.334 bc	2.644 d	2.718 a	1.989 c
T65	2.223 m-q	1.826 g-i	1.255 u	1.108 qr	3.318 c	2.527 g	2.362 d	2.217 a
T72	2.156 u	1.663 kl	1.455 p	0.694 b	3.126 g-i	1.337 x	2.282 f	1.091 y
T121	2.005 x-y	1.450 pq	1.546 o	1.138 p	3.008 lm	1.852 s	1.864 m	1.306 pq
V-e1	2.195 q-t	1.548 no	1.618 m	1.278 l	3.144 g-i	2.442 x	1.923 l	1.321 p
V-a1	2.311 hi	2.030 b-d	1.744 g-i	1.578 c	2.993 l-n	2.646 d	2. 044 i	1.859 f
V-g1	2.328 gh	1.847 gh	1.891 c	1.536 d	3.098 h-j	2.083 op	1.341 v	1.018 y
Zulbiye	2.290 ij	1.366 rs	1.719 j	0.948 x	3.139g-i	1.495 vw	1.783 o	0.921 z
Yakutiye	2.173 s-u	1.942 ef	1.849 d	1.701 b	2.938 n	2.572 ef	2.043 i	1.904 e

* There is a significant difference ($p<0.05$) among the different letters in each column.

exposure group (Table 5). The genotypes V41, T7 and T72 genotypes and cv. Zulbiye variety demonstrated the highest Ca content.

The lowest Ca losses in plant roots were determined in the genotypes T65, V99, V-a1 and cv. Yakutiye. The highest changes in Ca content were observed in the genotypes V88, V43 and T7. Increase in temperatures during bean cultivation leads to necrotic injury and alterations in cellular functions, especially in the plant stem and leaves [1-3]. Nutrient intake of the plants depends on root morphology, soil properties, drought and plant species. Drought, extreme temperatures and mineral nutrition are closely related. Higher temperatures affect nutrient intake negatively and reduce mineral intake [4]. If the plant K and Ca content is sufficient, transpiration would be under control and the opening and closure of stomata would exhibit a linear correlation with the K content in specialized stoma cells.

High temperature stress also leads to drought damages since the water intake of the plants is adversely affected. In a study aiming to determine the tolerance and sensitivity of 46 bean genotypes and 2 bean cultivars to drought stress, it was determined that the genotypes V7, V15, V33, V82, V89, and V-A1 and cv. Yakutiye were tolerant and the genotypes V21, V62, V69, V71, V86, V95, and T7 and cv. Zulbiye were sensitive to drought [13]. It was reported that leaf area and number, plant height and weight, stem diameter and relative leaf water content, and K and Ca content decreased in the bean genotypes under drought stress, while the membrane damage index increased [13, 15]. It was indicated that the plant weight, leaf number, stem diameter and relative leaf water content decreased and membrane damage index increased in tomato plants exposed to drought stress [17, 18]. In tomato cultivars exposed to drought stress, the fresh and dry weight, leaf area and relative leaf water content significantly decreased in all cultivars when compared to the control group, while in bean plants, water and high temperature stress adversely affected the growth of sensitive bean cultivars [19]. It has been reported in another study that organic and chemical fertilizers increase the growth and development and nutrient content of vegetable plants under abiotic stress [29-32].

Conclusions

In the present study conducted to determine high temperature sensitive and tolerant bean genotypes, the changes in 0-5 visual scale scores, fresh and dry weight, growth rate, fresh and dry shoot/root weight ratios, stem diameter, plant height, leaf number and area, relative leaf water content, membrane damage index, shoot and root ion (K and Ca) content in 46 genotypes and 2 cultivars were examined. It was determined that the genotypes V21, V62, V69, V71, V86, V95, and T7 and cv. Zulbiye were sensitive to high temperature stress, while the genotypes V7, V15, V33, V82, and V89 and V-A1 and cv. Yakutiye were tolerant ones.

In conclusion, the present study once more evidenced that the parameters applied to determine the effects of high temperature stress on bean genotypes were suitable methods in selecting genotypes tolerant to high temperature stress.

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Conflict of Interest

The authors declare no conflict of interest.

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