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EFFECTS OF HIGH TEMPERATURE ON GROWTH CHARACTERISTICS IN TOMATOES

Nadejda MIHNEA, Galina LUPAȘCU

Moldova State University, Institute of Genetics, Physiology and Plant Protection,
20 Padurii Street, MD-2002, Chisinau, Republic of Moldova

Corresponding author email: mihneanadea@yahoo.com

Abstract

The effects of high temperatures continue to be a major problem for food security. Therefore, the creation of high temperature-tolerant varieties is an essential economic measure in the adaptation of plants to climate change. The paper presents the results of screening some tomato prospective lines based on resistance to high temperatures (41, 43°C) in early ontogenesis. Seedlings grown at 25°C served as the control variant. The analysis of the variability of the resistance trait was carried out based on the length of the embryonic radicle, stem, and entire seedling. As a result of the analysis of the percentage of variance in the source of variation of the traits, it was found that the contributions of genotype, temperature, and the genotype x temperature interaction for radicle length were 13.9, 75.7, 5.1%; stem - 9.3, 82.9, 4.3%, and for seedling - 10.2, 80.2, 5%. So, the variability of the lengths of the embryonic radicle, stem, and seedling depends mostly on temperature. By cluster analysis (k-means) in the 43ºC variant, the lines L 504, L 506, L 507 were identified, which formed a separate cluster with the highest values of the evaluated characters. Line 506 exhibited the highest values of growth traits at both levels of stressful temperature, which offers opportunities for its use in breeding programs as a resistance donor.

Key words*: tomato, resistance, temperature, variability*.

INTRODUCTION

Agriculture is one of the sectors negatively affected by climate change, which is expected to be more pronounced in the coming years (Akhoundnejad, 2020). The agricultural sector has a fragile structure, directly dependent on climatic events. Therefore, studies and measures taken to minimize the possible adverse effects of climate change in developed countries are considered "important economic concepts" (Acar, 2010; Akhoundnejad, 2020). The Republic of Moldova is located in the geographical area where the adverse effects of climate change are inevitable. Therefore, it is extremely important to improve the tolerance of crops to thermal stress. In this regard, the following are of major importance: i) the development of reliable and applicable methods and techniques for identifying tomato genotypes tolerant to stress caused by high temperatures; ii) the creation and implementation of resistant parents in breeding programs for the creation of new varieties resilient to climate change (Mihnea, 2022; Mihnea, 2025).

Tomatoes (*Solanum lycopersicum* L.) are the most cultivated vegetable in the world after potatoes (FAOSTAT, 2020) and the most consumed as a fresh culinary additive or as a processed product, mainly due to the nutritional value associated with the pigments present in the ripe fruits (Chaudury et al., 2019).

Temperature stress (TS) is one of the most important abiotic stresses limiting crop productivity worldwide. In both cool and warm seasons, productivity is reduced due to reduced fruit set. Under the current global warming scenario, temperatures are expected to increase by 2-5°C by the end of the 21st century (Masson-Delmotte, 2021). The global average temperature at the soil surface will cause serious damage to plant growth and development, resulting in a strong reduction in the productivity of many crops (Iizumi, 2018). Moreover, tomatoes are one of the main species that are very susceptible to high temperatures. The optimal temperatures for the development of floral organs, pollen, and fruits vary between 15 and 32°C, and temperatures of 35°C and above this level directly affect vegetative and generative development (Daşgan, 2013; Akhoundnejad, 2018; Akhoundnejad, 2020).

Although all plant tissues are severely affected by increased temperatures, reproductive tissues

are the most sensitive, and a temperature increase of a few degrees during the flowering period can cause complete crop loss, as occurs in cereal crops (Hasanuzzaman, 2013). In general, the reproductive period is more sensitive to thermal stress than the vegetative period (Mittler & Blumwald, 2010; Ruan et al., 2010; Zinn et al., 2010). It has been found that under stress conditions, resistant tomato genotypes have the ability to form a much higher number of fruits than sensitive ones (Comlekcioglu et al., 2010).

ST has negative effects on physiological processes in the plant (disruption of photosynthesis, increased respiration), which leads to a decrease in plant productivity (Prasad et al., 2017; Singh et al., 2017). It is accepted that the reduction in the life cycle, associated with the decrease in plant productivity in the case of ST, is caused by its impact on the rate of respiration and photosynthesis (Barnabas, 2008). Another effect of ST is the negative impact on the root system, which provides support for the plant, nutrient absorption, and transport to other organs of the plant (Valdés-López et al., 2016). These phenomena lead to poor root development, disruption of growth stages, pollination, and flowering (Sehgal et al., 2017).

In addition, it has been reported that high temperatures causing floral abortion lead to 80% flower loss in tomato plants, which significantly reduces the number of fruits (Ruan et al., 2010; Rieu et al., 2017). It is worth noting that due to its quantitative nature, resistance depends on a number of factors, including genotypic, environmental, and genotype x environment interactions. High and stable yields of agricultural crops can only be obtained from varieties with high productivity potential and resistance to adverse environmental factors.

The purpose of our research was to evaluate the effect of heat stress on the growth and development traits of tomato plants and identify those with potential use in breeding programs.

MATERIALS AND METHODS

As initial material for the planned research, the following lines were used: L 502, L 503, L 504, L 505, L 506, L 507 L 508; L 601 and L 602 selected from intraspecific hybrid combinations F5, Local form Timisoara x Mary Gratefully, Desteptarea x Florina, Desteptarea x Pontina, Prestij x Pontina, Pontina x Prestij, Mary Gratefully x Florina, Desteptarea x Florina, in comparison with the control variety Mary Gratefully (MG).

For the analysis of ***genetic variability, heritability,*** and ***genetic progress***, the following formulas were applied:

σ^2_g - genotypic variance;

σ^2_{ph} - phenotypic variance;

h^2 - broad heritability coefficient;

PCV - phenotypic coefficient of variation;

GCV - genotypic coefficient of variation;

X - overall mean of the trait;

σ^2_e (variance errors, or VE) = MSE;

GA - genetic advantage;

K - selection differential = 2.06 at 5% selection pressure;

σ_{ph} - overall standard deviation of the trait (Adeniji, 2018; Balkan, 2018).

Cluster analysis of the degree of similarity/ dissimilarity of tomato genotypes based on growth and development characters at different temperatures was performed using the iterative dendrogram construction algorithm and the *k*-means centroid method (Kanavi et al., 2020). The obtained data were statistically processed in the STATISTICA 7 software package.

RESULTS AND DISCUSSIONS

Testing the reaction of perspective lines at different temperature levels on tomato growth traits in early ontogenesis demonstrated that the response of plants to the 3 temperatures (25°C - optimal, 41° and 43°C - heat stress) was differentiated - specific to the genotype and trait analyzed.

In the case of radicle length, it was found that under optimal conditions, it varied within the limits of 36.4-58.0 mm (Figure 1A), and at a temperature of 41°C - 23.6-52.8 mm (Figure 1B). The degree of growth inhibition for the studied forms varied in the range of -1.6...-49.8% (compared with optimal conditions). Strong inhibition was found in the Mary Gratefully variety (49.8%) and L 601 (22.58%). Stimulation was observed in the lines L 504 (2.7%), L 505 (4.4%) and L 602 (2.1%), and relatively low inhibition - in the lines L 503 (1.6%) and L 506 (9%).

Under influence of 43°C temperature, significant inhibition of radicle growth was observed in Mary Gratefully (46.5%) and L 601 (46.9%). Weak sensitivity was observed in the L 504 (-5.4%) and L 507 (-5.4%) lines (Figure 1C).

As for stem, inhibition of growth at a temperature of 41°C was significant only in the Mary Gratefully variety (-8.4%) and relatively low in L 502 (-1%), and in the other genotypes, stimulation was recorded at 9.5...37.3%. Under the influence of a temperature of 43°C, the inhibition varied within the limits of 9.5...49.4%. The most sensitive proved with be Mary Gratefully (-41.0%) and L 602 (-49.4%), and stimulation (by 10.7%) was recorded in L 504. Increased resistance was recorded in L 507, the decrease in stem length compared with the control was 9.5% (figure 1 B).

In the case of seedling length, it was found that its reduction relative to the control ranged between 2.8-45.7% at 41ºC and 6.7-44.7% at 43ºC. At the same time, the temperature of 41ºC most strongly influenced the Mary Gratefully variety (-45.7) and the L 601 line (-12.0%), and stimulation was recorded in the L 503, L 504, L 505 and L 602 lines at 2.8; 14.3; 7.7; 17.9%, respectively. Significant inhibition at 43ºC was demonstrated by the varieties Mary Gratefully (44.7%), L 502 (31.0%), L 505 (33.6%), L 506 (32.6%), L 601 (33.5%) (Figure 1C).

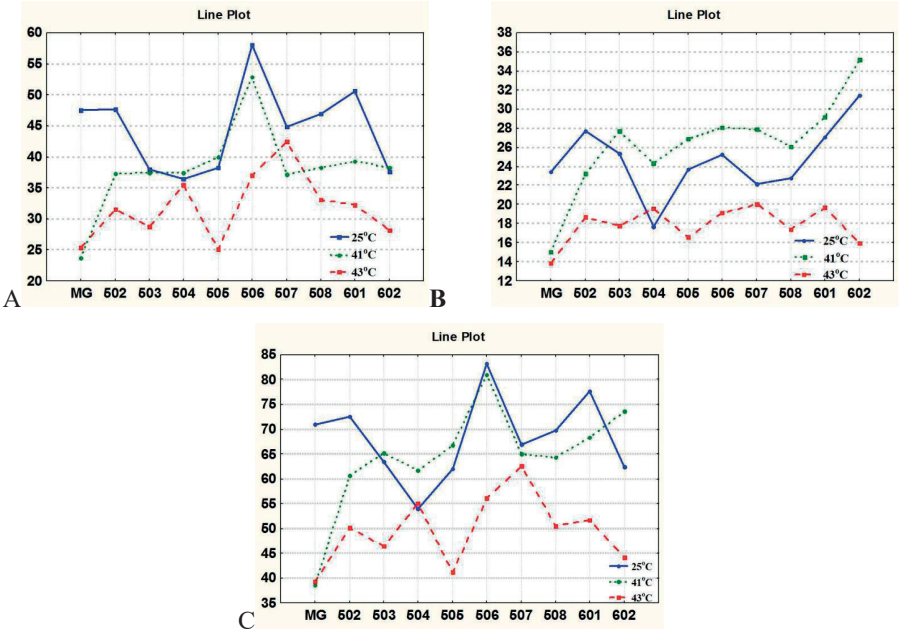

Figure 1. Variability of growth characters: A - radicle length; B - stem length; C - seedling length at different temperature levels

The distribution dendrogram of the perspective lines based on the reaction of the embryonic radicle, the stem, and the seedling demonstrates the existence of similarities, but also differences between the tomato genotypes both in optimal and stress conditions.

The distribution based on Euclidean distances highlighted the formation of distunderct clusters within the evaluated genotype set: 2 - under optimal conditions (Figure 2 A) and 3 - heat stress conditions (Figure 2 B, C).

The degree of similarity between tomato genotypes according to the reaction of growth organs to different temperature levels was different. For example, under optimal conditions, the Mary Gratefully variety and lines L 508, L 502; L 503 and L 505, recorded the highest similarity, confirmed by the smallest Euclidean distance for all evaluated characters. The differences between these genotypes were accentuated in the case of stress temperatures, which led to their localization in different clusters.

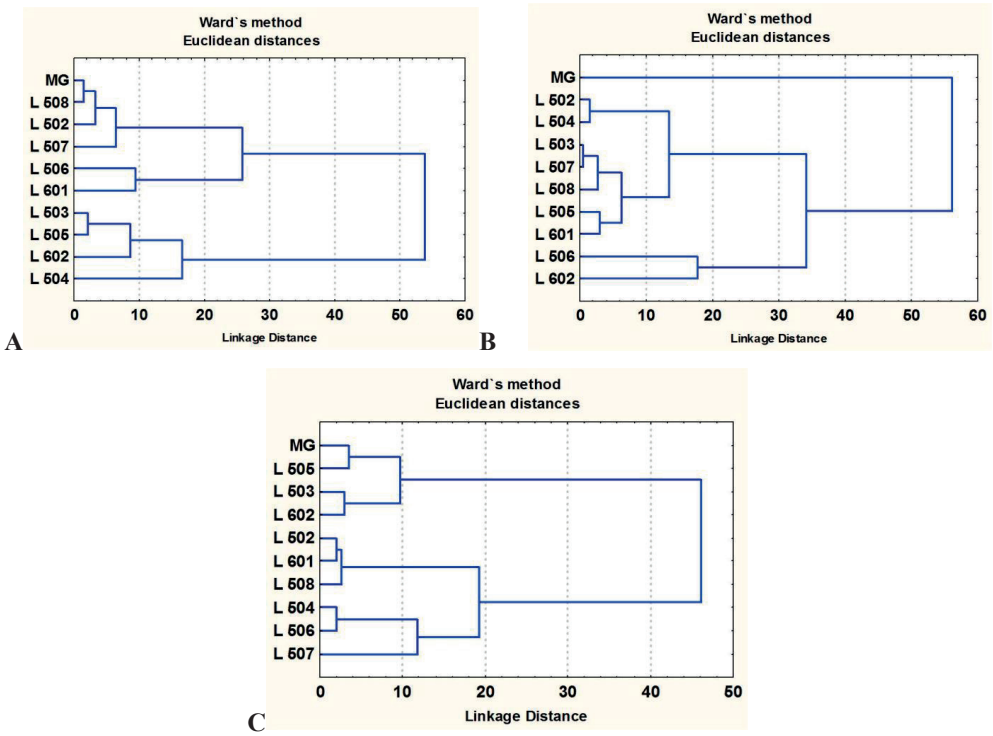

Figure 2. Dendrogram of distribution of tomato genotypes based on growth traits under optimal conditions: A - 25°C and heat stress; B - 41°C, C - 43°C

The calculation of inter- and intracluster distances by the centroid clustering method (k-means) demonstrated that, except for stem length under optimal conditions, the distance between clusters was much greater than within it at all 3 temperatures, which indicates that the tomato lines were successfully distributed into clusters based on the 3 characters under study. The ratio of intercluster to intracluster distance demonstrated that the highest capacity for differentiating genotypes occurred at 41°C, and stem length exhibited a diminished discriminatory capacity compared to the other 2 characters (Table 1).

Table 1. Analysis of inter- and intracluster variance in the interaction of tomato genotypes with temperature

Variant	Intercluster variance	df	Intracluster variance	df	Report Intercluster variance/ Intracluster variance	F	p
25^0C							
Legth of the radicle	405.4760***	2	34.3600	7	11.79	41.30283	0.000133
Legth of the stem	11.4415	2	100.5825	7	0.11	0.39813	0.685867
The seedling length	553.9840***	2	88.2850	7	6.28	21.96233	0.000963
41^0C							
Legth of the radicle	426.3322***	2	7.4888	7	56.84	199.2538	0.000001
Legth of the stem	143.6452*	2	93.3988	7	1.54	5.3829	0.038397
The seedling length	956.4800***	2	115.6200	7	8.27	28.9541	0.000412
43^0C							
Legth of the radicle	220.3148**	2	44.41417	7	4.96	17.,36162	0.001934
Legth of the stem	27.5707**	2	7.79333	7	3.5	12.38203	0.005024
The seedling length	401.8058***	2	60.59418	7	6.63	23.20883	0.000815

*, **, *** - significant differences for p<0.05, 0.01, 0.001.

By classifying the genotypes based on the evaluated characters, it was found that in the 41°C variant, L 506 formed a separate cluster with the highest values of growth characters, and at 43ºC the highest values of the characters radicle, stem, and seedling length were recorded by lines L 504, L 506 and L 507 (Table 2).

Table 2. Descriptive cluster analysis

Cluster	Caracter	x	Genotype	x	Genotype	x	Genotype
		25°C		41°C		43°C	
1	The length of the radicle, mm	37.5	L 503, L 504, L 505, L 602	38.1	L 502, L 503, L 504, L 505, L 507, L 508, L 601, L 602	31.4	L 502, L 503, L 508, L 601
	The length of the stem, mm	24.5		27.6		18.4	
	The length of the seedlings, mm	60.4		65.7		49.7	
2	The length of the radicle, mm	46.7	Mary Gratefully, L 502, L 507, L 508	52.8	L 506	26.2	Mary Gratefully, L 505, L 602
	The length of the stem, mm	23.2		28.1		15.4	
	The length of the seedlings, mm	70.0		80.9		41.5	
3	The length of the radicle, mm	54.3	L 506, L 601	23.6	Mary Gratefully	38.3	L 504, L 506, L 507
	The length of the stem, mm	26.1		15.0		19.6	
	The length of the seedlings, mm	80.4		38.5		57.9	

They are of interest in the breeding process as possible sources of resistance to stress temperatures.

Statistical processing of experimental data for all genotypes studied through factor analysis allowed the determination of the variability of characters and the degree of influence of each factor (genotype, temperature), as well as their interaction on the variability of the studied traits (Table 3).

By calculating the percentage contribution to the source of variation of characters, it was found that the contribution of genotype, temperature, and the genotype x temperature interaction in radicle length was 13.9; 75.7; 5.1%; stem - 9.3; 82.9; 4.3% and seedling - 10.2; 80.2; 5.0%.

Table 3. The contribution of genotype and temperature to the growth capacity of tomatoes

Source of variation	Freedom degree	The length of the radicle		The length of the stem		Length of the seedling	
		Mean sum of squares	WSV, %	Mean sum of squares	WSV, %	Mean sum of squares	WSV, %
Genotype	9	219.8*	13.9	66.4*	9.3	368.0*	10.2
Temperature	2	1200.9*	75.7	591.4*	82.9	2892.8*	80.2
Genotype x temperature	18	80.1	5.1	30.8	4.3	179.0	5.0
Random effects	60	84.6	5.3	25.1	3.5	168.3	4.7

*- $p<0.05$.

Thus, through factor analysis, it was found that the weight of temperature in the source of variation of the length of the radicle, stem, and seedling was the highest, which denotes that the temperature factor is decisive for the evaluated characters. From the data presented, it is observed that in general the role of genotype (9.3-13.9%) and genotype x temperature interactions (4.3-5.1%) were less relevant for the growth of tomato seedlings. However, based on one of the integral indices - seedling length, we can observe at L 504, L 507, relatively small differences between the 25°C, 41°C, 43°C variants, which denotes their advanced adaptability to limiting temperatures (Figure 1C).

The genotypic (σ^2_g) and phenotypic (σ^2_{ph}) variances were much higher for radicle length and seedling length than for the stem (Table 4).

Table 4. Genetic variability and heritability of tomato growth traits under heat stress at early stages of plant development

Parameter	The length of the radicle	The length of the stem	Length of the seedling
σ^2_g	45.07	13.79	66.57
σ^2_{ph}	129.67	38.85	235.06
h^2	0.35	0.35	0.28
GCV, %	17.54	16.23	13.30
PCV, %	29.82	27.25	25.26
PCV – GCV, %	12.28	11.02	11.96
GAM, %	20.93	20.72	15.05

The difference between PCV and GCV was 11.02-12.28% and reflects the effect of stress temperatures on the response of growth organs.
The broad-sense heritability coefficient (h^2=0.28-0.35) indicates a weak-medium capacity for the hereditary transmission of the characters under study under high-temperature conditions. However, its association with medium-high values of genetic progress leads to the idea of the involvement of additive factors in the control of growth characters.

CONCLUSIONS

The analysis of tomato growth traits – radicle, stem, and seedling in tomato perspective lines at different temperature levels highlighted the differentiated nature of their reaction to limiting temperatures. In some cases, stress temperatures produced significant inhibition of growth organs.
Through cluster analysis (k-means), 3 lines were identified - L 504, L 506, L 507, which recorded the highest values of radicle, stem, and seedling length at 43°C, which offers opportunities for their use in breeding programs as resistance donors.
Factorial analysis of the genotype x temperature interaction based on testing the reaction of the embryonic radicle, stem, and tomato seedling at three temperature levels demonstrated that, in the source of variation in the characters, the main role belongs to the temperature factor (75.7-82.9%), followed by the genotype (9.3-13.9%) and the tomato x temperature interaction factors (4.3-5.1%). The data indicate that the temperature factor is the most important for the growth and development of tomato plants. However, genotypes were identified - L 504, L 507, in which relatively small differences were recorded in the whole plant between the optimal variant (25°C) and the variants with thermal stress, which denotes their adaptability to high temperatures.
High temperatures reduce not only the normal biological parameters of growth and development characters but also their hereditary transmission capacity. However, the association of h^2 values of 0.28-0.35 with relatively high indices of genetic progress (15.1-20.9%) reveals real opportunities to create resistant tomato genotypes through individual selection.

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