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PERFORMANCE OF ROMANIAN TOMATO LINES UNDER THE AGRO-ENVIRONMENTAL CONDITIONS OF THE REPUBLIC OF MOLDOVA

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ABSTRACT

The paper presents the results of the evaluation of the variability of earliness traits, fruit characteristics, productivity, and heat resistance, as well as the determination of the genetic and breeding value of genotypes of Romanian origin. Cluster analysis (the k-means method) demonstrated that the inter-cluster variance was significantly higher than the intra-cluster variance for traits such as fruit weight, fruit diameter, mesocarp thickness, and the number of locules, indicating that the studied genotypes exhibited distinct and pronounced differences. It was found that the response of tomato plants to temperatures of 25 °C and 43 °C differed depending on the genotype, the growing organ, and the temperature level. Line L 168 exhibited high resistance to 43°C and the highest productivity under the conditions of the central region of the Republic of Moldova, making it of particular interest for breeding programs as a potential genetic source of productivity and heat resistance.

INTRODUCTION

Agriculture is among the sectors most adversely affected by climate change, with its impacts expected to intensify in the coming decades (Akhoundnejad & Daşgan 2020). Under current global warming scenarios, mean temperatures are projected to increase by 2–5 °C by the end of the 21st century (Masson-Delmotte et al. 2021). Such increases in global average surface temperature are anticipated to severely impair plant growth and development, leading to substantial reductions in crop productivity (Iizumi et al. 2018).

The Republic of Moldova is situated in a geographical region where the adverse effects of climate change are unavoidable. Consequently, enhancing crop tolerance to heat stress has become a critical priority. In this context, particular importance is attached to: (i) the development of reliable and applicable methodologies for the identification of tomato genotypes tolerant to high-temperature stress; and (ii) the development and incorporation of resistant parental forms into breeding programs aimed at generating climate-resilient cultivars (Ercolano et al. 2008, Mihnea et al. 2021).

High tomato yields recorded worldwide (exceeding 50 $t \cdot ha^{-1}$) highlight the crop's significant economic value. Combined with the feasibility of mechanized harvesting through modern technologies, tomato cultivation represents an attractive agricultural activity across diverse agroecological zones.

The yield and quality of tomato fruits are determined not only by the optimization of environmental and agronomic conditions, but also by the utilization of genotypes with superior genetic potential. This factor constitutes a key driver of innovation in agriculture and ensures the production of high yields with desirable organoleptic characteristics (Carli et al. 2011, Ercolano et al. 2008, Mihnea 2016, Seymour 2002).

Thermal stress represents a major constraint for the cultivation of Solanum lycopersicum L., leading to significant reductions in productivity (Hazra et al. 2007). The concept of tolerance is broadly defined, while the term resilience refers more specifically to the capacity to maintain productivity under stress conditions (Davies & Ribaut 2017). Yield remains one of the primary selection criteria in breeding programs (Bhandari et al. 2023, Graci & Barone, 2024).

In recent decades, drought and elevated temperatures have become major limiting factors affecting plant growth, reproduction, and yield formation. Temperatures exceeding 35 °C negatively influence seed germination, vegetative growth, flowering, fruit set, and ripening processes (Akhoundnejad & Daşgan 2020). High-temperature stress can result in substantial losses in both fruit yield and quality (Firon et al. 2006, Nahar & Ullah 2012, Wahid et al. 2007). Among the physiological processes affected, pollen viability is particularly critical for successful fertilization and fruit set, directly impacting overall productivity (Peet et al. 2003, Sato et al. 2000).

During the tomato flowering period, air temperatures frequently reach 35–55 °C, which significantly reduces fruit set and yield per unit area. Under these conditions, the selection for heat tolerance has become a priority in the Republic of Moldova. Therefore, the development of tomato genotypes combining resistance to extreme environmental factors with high productivity and superior fruit quality represents a major objective under local agroclimatic conditions (Mihnea et al. 2025).

The aim of this study was to evaluate the variability of traits related to earliness, productivity, and thermal stress tolerance in newly developed tomato lines of Romanian origin, with the objective of identifying valuable genotypes for inclusion in breeding programs.

MATERIAL AND METHODS

Ten promising lines developed at Vegetable Research and Development Station Bacău were used as plant material for the study. The experiments were conducted under both laboratory and field conditions on the experimental plot of the Institute of Genetics, Physiology and Plant Protection.

Tomatoes were cultivated through seedling production in three replicates following a standard methodology, under non-irrigated conditions. Sowing was carried out in the third decade of March. The sowing scheme in the greenhouse was 7 × 10 cm, while the field planting scheme was 70 × 30 cm. Transplanting into the field took place during the second decade of May. Harvesting was performed multiple times (6–8 harvests). Crop management and plant growth were conducted according to the agrotechnical practices accepted in Moldova (Erșova 1978).

Morpho-biological characterization was carried out in accordance with the UPOV descriptors (Test Guidelines for Tomato – UPOV 2011). The lines were

evaluated under two temperature regimes: optimal (25 °C) and stress conditions (43 °C). The assessment of tomato samples for high-temperature tolerance was based on the growth capacity of the embryonic radicle, hypocotyl, and entire seedling over a 7-day period, following exposure on the fourth day to 43 °C for 6 hours (Mihnea 2016). Seedlings grown at 25°C served as the control.

To determine trait variability and the degree of influence of each factor (genotype, temperature, and genotype × temperature interaction), analysis of variance (ANOVA) was employed.

Cluster analysis of the degree of similarity/dissimilarity among tomato genotypes, based on growth and development traits under different temperature conditions, was performed using an iterative dendrogram construction algorithm and the k-means centroid method—approaches widely applied in genetic and breeding research (Kanavi et al. 2020).

The obtained data were statistically processed using the STATISTICA 7 software package.

RESULTS AND DISCUSSIONS

Earliness is a trait of major importance in tomato cultivars, as it enables the staggered scheduling of harvesting over an extended period. This characteristic is closely associated not only with yield potential, but also with several other plant attributes, including cold tolerance, chemical composition, fruit quality, and resistance to major pathogens and pests (Guseva 1989). The development of early-maturing cultivars with uniform ripening and enhanced resistance to both biotic and abiotic stress factors remain a challenging yet highly actual objective in tomato breeding.

Studies conducted on tomato lines of Romanian origin revealed considerable variability in the expression of numerous valuable traits under the environmental conditions of central Republic of Moldova. Data concerning the duration of phenological phases and the total growing season in tomato are presented in Figure 1.

Based on phenological observations carried out throughout the growing season, a relatively high variability was recorded in both the total vegetation period and the interphase intervals, depending on genotype as well as climatic conditions. The duration of the interval from mass seedling emergence to the onset of flowering ranged between 55 and 68 days. Later flowering was observed in lines 104 and 142.

For the second phenological interval, the duration ranged between 39 and 51 days. The shortest period was recorded in line L 182 (39 days), while longer durations were observed in lines L 168 and L 110.

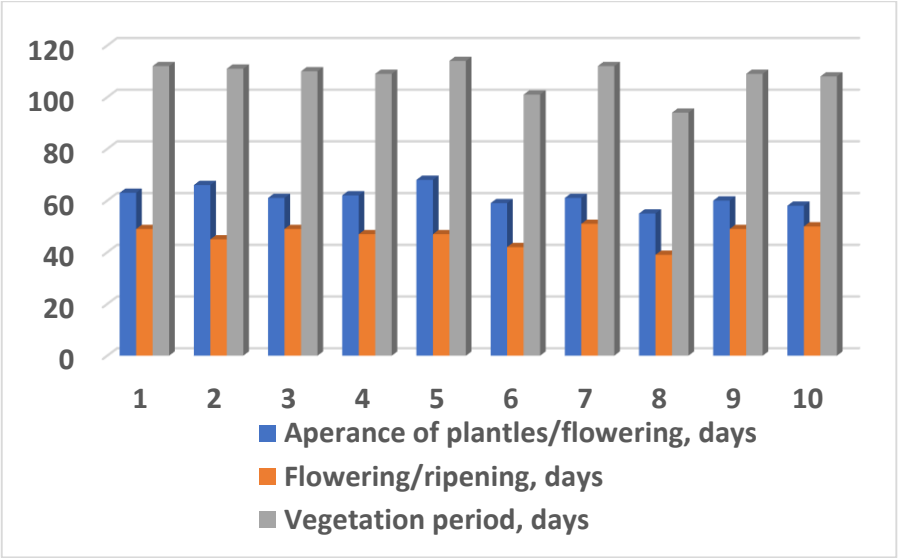


Figure 1. Variability of interphase periods in tomatoes
Horizontally: 1 – L 101, 2 – L 104, 3 – L 125, 4 – L 138, 5– L 142, 6 – L 150, 7 – L 168, 8 – L 181, 9 – L 182, 10 – L 188

The tested forms were grouped into three earliness categories: very early – number of days from mass seedling emergence to the beginning of ripening <105 days (L 181); early – 106–110 days (L 125, L 138, L 150, L 182, L 188); medium-early – 111–115 days (L 101, L 104, L 142 and L 168). No late forms were recorded.

As a result of the evaluation of the lines based on several fruit traits, it was found that the forms exhibit a relatively high variability (Fig 2). Fruit weight is one of the main traits determining the direction of tomato breeding and its economic value. The requirements regarding fruit size differ and are determined by their intended use. The inheritance of fruit weight is a multifactorial trait [26], which must be taken into account when planning experiments. The complexity of this trait is determined by the control of multiple genes which, interacting with environmental factors at different stages of plant development, ensure a high variability of the trait.

According to this trait, the examined lines were classified into two groups: with medium-sized fruits – L 101 (53.7 g), L 104 (58.5 g), L 125 (65.8 g), L 138 (55.8 g), L 142 (88.0 g), L 168 (92.6 g); and with small fruits (<50 g) – L 150, L 181, L 182 and L 188. Although within each population the absolute fruit weight varies, according to the measurements performed, the highest values were recorded in lines L 142 and L 168, and the lowest in L 150 and L 181 (Fig. 2A).

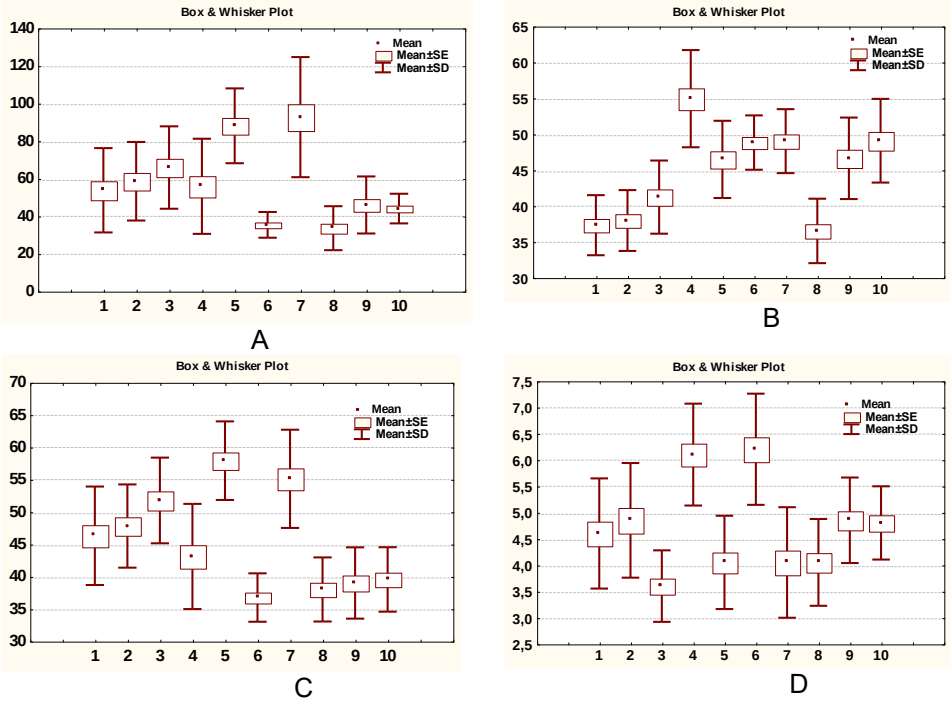
Fruit shape is a morphological trait related to the market quality of tomato yield and meets certain consumer requirements. Fruit shape is derived from the ratio between its length (Fig. 2B) and diameter (Fig. 2C). According to this criterion, the studied lines were classified into four groups: moderately flattened (L/D = 0.7–0.8) – L 101, L 104, L 125, L 142, L 167; medium (L/D = 0.9–1.1) – L 168, L 181; moderately elongated (L/D = 1.2–1.3) – L 138, L 182; strongly elongated (>1.3) – L 150.

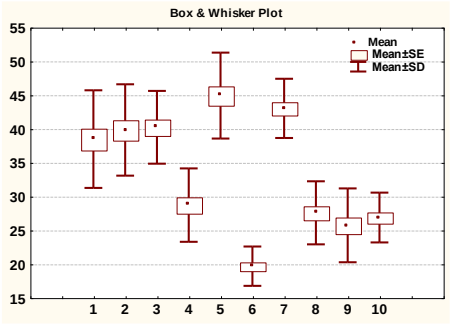
Pericarp thickness is an important index that largely determines the proportion of marketable fruits. Its magnitude and variability must be taken into

account when developing tomato genotypes for mechanized cultivation. Data from the literature [3,14,18] indicate a considerable genotypic variability of this trait. According to existing standards for the evaluation of tomato morphological traits, the pericarp may be classified as: thin (<3 mm), medium (3–6 mm), or thick (>6 mm). Comparative analysis of the obtained results showed that, in most lines, pericarp thickness was medium (3.6–4.8 mm), with the exception of two lines, L 138 and L 150, where it was thick (6.1–6.2 mm) (Fig. 2D). Therefore, all studied lines, along with other valuable traits, also possess fruit transportability.

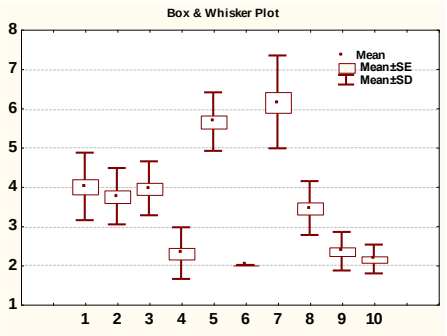
Mesocarp thickness constitutes the content of the locules, the fruit center, and the partitions between locules. The size of the pulp determines the intended use of the fruits (fresh consumption, juice, or paste). According to existing standards, tomato fruits are divided into five groups based on this trait: very small core (2 cm), small (2.1–3 cm), medium (3.1–4 cm), large (4.1–5 cm), and very large (>5 cm). The data obtained from measurements showed that the 10 investigated lines fall into four groups: very small core (L 150); small core (L 138, L 181, L 182, L 188); medium core (L 101, L 104, L 125); and large core (L 142, L 168) (Fig. 2E). The evaluation results indicate that the analyzed lines can be used not only for fresh consumption but are also of interest for the food industry as raw material for processing into various products.

The number of seed locules represents an internal morphological trait of the syncarpous fruit, used to determine the number of fused carpels forming the pistil and the type of placentation. In tomatoes, the number of locules usually varies from 2–3 to 5–9 and differs between cultivars. Based on this trait, the following fruit types were identified: with two locules (L 150); two or three locules (L 138, L 182); three or four locules (L 104, L 125, L 181); four, five or six locules (L 101, L 125); and more than six locules (L 142 and L 168) (Fig. 2F).





E



F

Figure 2. Phenotypic variability of some fruit characters in tomato forms (A – fruit mass; B -fruit length; C – fruit diametert; D – pericarp thickness; E – mesocarp thickness; F – number of lodges)
Horizontally: 1 – L 101, 2 – L 104, 3 – L 125, 4 – L 138, 5– L 142, 6 – L 150, 7 – L 168, 8 – L 181, 9 – L 182, 10 – L 188

By constructing dendrograms of form distribution, using fruit weight, fruit length and width, pericarp thickness, mesocarp thickness, and number of seed locules as classification indices, the genotypes were separated into three well-defined branches. The highest degree of similarity was recorded among lines L 101, L 104, L 105, as well as L 142 and L 168 (Fig. 3).

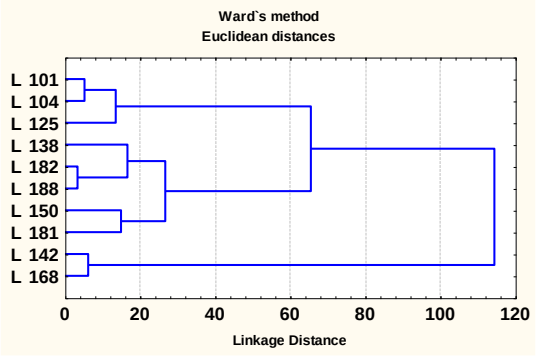


Figure 3. Cluster analysis of tomato varieties based on some fruit characters.

Cluster analysis (k-means method) showed that intercluster variance was much higher than intracluster variance for the traits fruit weight, fruit diameter, mesocarp thickness, and number of locules (Table 1), indicating that the genotypes under study exhibited clearly pronounced differences. In contrast, for fruit length and pericarp thickness, intercluster variance was lower than intracluster variance, suggesting that the differences among genotypes based on these traits were not significant.

Table 1.

Analysis of the inter- and intracluster variance of the fruit characters

Variant	Intercluster variance	df	Intraclusterian variance	df	F	p
Fruit mass	3422.326	2	207.6898	7	57.67322	0.000045
Fruit length	37.,454	2	287.8350	7	0.45543	0.651718
Fruit diametert	458.724	2	47.5600	7	33.75807	0.000254
Pericarp thickness	1.104	2	5.4800	7	0.70511	0.526039
Mesocarp thickness	552.668	2	129.8125	7	14.90100	0.003001
Number of lodges	15.689	2	3.5000	7	15.68900	0.002592

By classifying the genotypes based on the six traits, it was found that the genotype groups, separated into three clusters, differed in both the level and variability of the studied traits (Table 2). Thus, cluster 1 included four genotypes with medium values – L 101, L 104, L 125, L 138; cluster 2 comprised genotypes with the highest values – L 142, L 168; and cluster 3 included genotypes with the lowest values – L 150, L 181, L 182, L 188.

Table 2.

Descriptive analysis of clusters

Cluster	Character	x	Genotype
1	Fruit mass, g	58.450	L 101, L 104, L 125, L 138
	Fruit length, mm	42.600	
	Fruit diametert, mm	47.250	
	Pericarp thickness, mm	4.800	
	Mesocarp thickness, mm	36.800	
	Number of lodges	3.525	
2	Fruit mass, g	90.300	L 142, L 168
	Fruit length, mm	47.750	
	Fruit diametert, mm	56.500	
	Pericarp thickness, mm	4.100	
	Mesocarp thickness, mm	43.950	
	Number of lodges	5,950	
3	Fruit mass, g	39,700	L 150, L 181, L 182, L 188
	Fruit length, mm	45,250	
	Fruit diametert, mm	38,350	
	Pericarp thickness, mm	5,000	
	Mesocarp thickness, mm	24,975	
	Number of lodges	2,525	

One of the main directions in breeding is the development of high-yielding cultivars. The biological yield potential in tomato is closely dependent on environmental conditions. The climatic conditions of 2025 were extremely unfavorable. Drought and high temperatures (35–45 °C), which persisted throughout the entire growing season, led to a considerable reduction in yield. The results of the evaluation of productivity parameters are presented in Figure 3.

The assessment of fruit weight, number of fruits per plant, and productivity per plant in the studied material revealed a relatively high variability (Figure 4). Fruit weight ranged from 24.5 g (L 105) to 91.6 g (L 168) (Figure 4A). The number of fruits

per plant varied between 10 and 22 fruits. A higher number, exceeding 15 fruits, was recorded in lines L 150 and L 182 (Figure 4B).

As shown in Figure 4C, productivity in the studied forms was relatively low, indicating that the pedoclimatic conditions of that year were quite severe for tomato cultivation in the absence of an irrigation system.

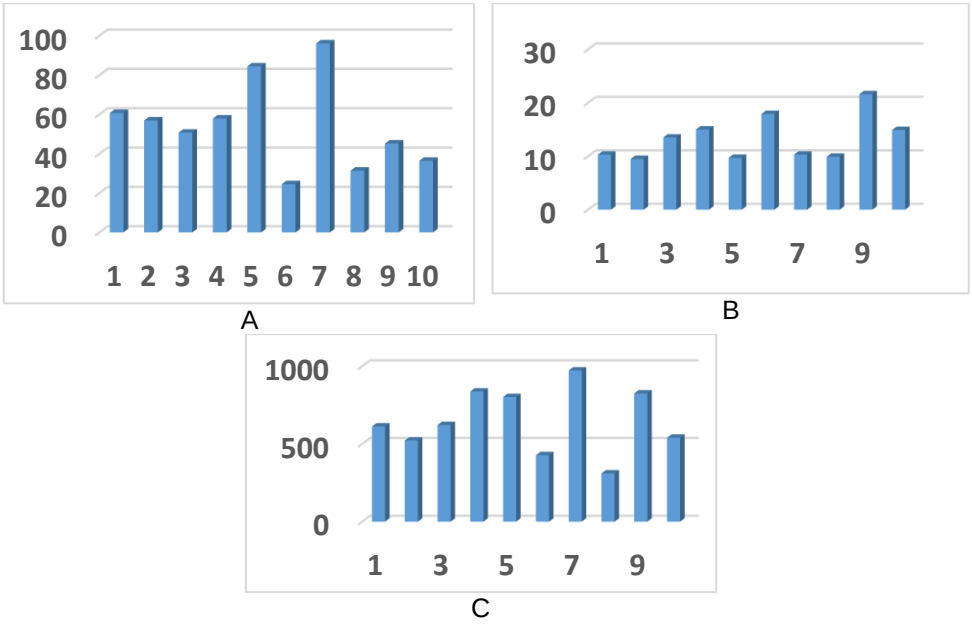


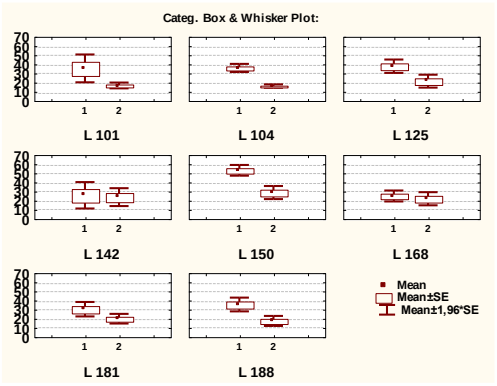
Figure 4. Variability of productivity traits in tomatoes A – fruit mass (g), B – number of fruits per plant, C – productivity per plant (g)
1- L 101, 2 - L 104, 3- L 125, 4 - L 138, 5 - L 142, 6 - L 150, 7 - L 168, 8 - L 181, 9 - L 182, 10- L 188

The evaluation of the response of several tomato lines to different temperature levels, with respect to growth traits during early ontogenesis, demonstrated that plant response to the two temperature regimes (25 °C – optimal and 43 °C – stress) was differentiated, being specific to genotype, growth organ, and temperature level.

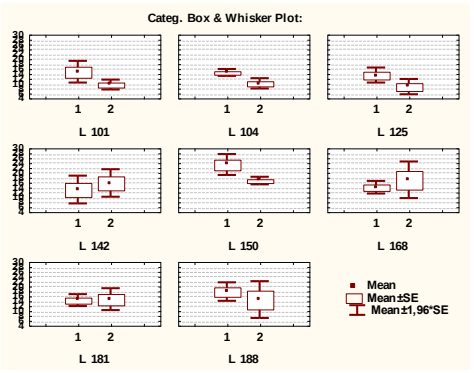
In the case of radicle length, it was found that under optimal conditions, root length ranged between 24.8 and 52.8 mm, while at 43 °C it ranged between 15.8 and 28.5 mm (Figure 1B). The degree of growth inhibition for the studied forms varied between −7.8 % and −55.4 % (compared to optimal conditions). A strong inhibition was observed in lines L 101 (−53.1 %), L 104 (−55.4 %), and L 188 (−50.9 %). Lines L 142 and L 168 showed the highest tolerance, with radicle length reduced by only 7.8 % and 12.1 %, respectively, compared to the optimal temperature (Figure 4A).

Regarding hypocotyl length, growth inhibition at 43 °C was significant only in lines L 101 and L 125 (−35.4 % and −35.1 %, respectively). In three cases (L 142, L 168, and L 181), stimulation was recorded, ranging from 2.8 % to 21.4 % compared to the control. In the remaining cases, inhibition ranged between 18 % and 30.6 %.

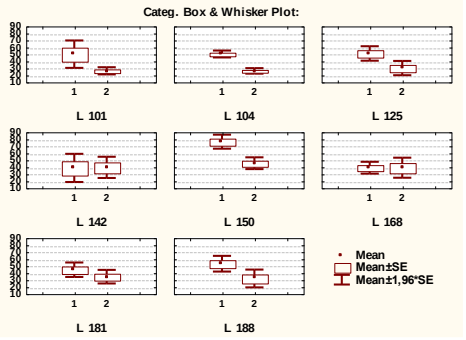
In terms of seedling length, it was observed that exposure to 43 °C resulted in a slight stimulation of 1.8 % in line L 142. In all other variants, a reduction compared to the control was recorded, ranging between 0.3 % and 48.4 %. At the same time, the temperature of 43 °C had the strongest negative effect on lines L 101 (−47.8 %), L 104 (−48.4 %), and L 125 (−41.4 %).



A



B



C

Figure 5. Influence of temperature on the length of the root (A), stem (B) and seedling (C) of tomato
Horizontal 1 – Control (H_2O), 2 – t 43 ^{0}C.

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	7	186,75*	6,9	48,35*	33,3	351,35*	9,1
Temperature	1	2360,41*	87,6	61,43*	42,3	3180,14*	82,6
Genotype x temperature	7	98,13	3,6	21,09	14,5	207,68	5,4
Random effects	32	49,85	1,93	14,27	9,8	109,08	2,8

*- p<0,05.

By calculating the percentage contribution to the sources of variation of the traits, it was found that the contribution of genotype, temperature, and genotype × temperature interaction to radicle length was 6.9 %, 87.6 %, and 3.6 %, respectively; for hypocotyl length – 33.3 %, 42.3 %, and 14.5 %; and for seedling length – 9.1 %, 82.6 %, and 5.4 %.

Thus, factorial analysis showed that the contribution of temperature to the source of variation in radicle, hypocotyl, and seedling length was the highest, indicating that temperature is the decisive factor for the evaluated traits. It should be noted that genotype played a relatively important role in hypocotyl length, where its contribution to the source of variation reached 33.3%, suggesting a relatively distinct phenotypic plasticity of tomato hypocotyl length under limiting temperature conditions.

CONCLUSIONS

By calculating the percentage contribution to the sources of variation of the traits, it was found that the contribution of genotype, temperature, and genotype × temperature interaction to radicle length was 6.9 %, 87.6 %, and 3.6 %, respectively; for hypocotyl length – 33.3 %, 42.3 %, and 14.5 %; and for seedling length – 9.1 %, 82.6 %, and 5.4 %.

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