

INFLUENCE OF REDUCED IRRIGATION ON PHENOLOGICAL AND MORPHOLOGICAL CHARACTERS OF DIFFERENT TOMATO GENOTYPES

Stanislava Y. Grozeva, Daniela G. Ganeva, Galina T. Pevicharova

Maritsa Vegetable Crops Research Institute, 32 Brezovsko shosse Str., Plovdiv 4003, Bulgaria

Abstract

Cultivated plants are often exposed to different types of environmental stress which has a negative effect on the vegetative and reproductive development. In the current study the influence of water deficit on phenological and morphological characters of different tomato genotypes was investigated. The experiment was conducted at the Maritsa Vegetable Crops Research Institute in two consecutive years (2016-2017) with 11 indeterminate and 13 determinate tomato accessions grown under optimum and 50% reduced irrigation. The results showed that the plants of indeterminate and determinate tomato types answered the water deficit with a decrease of the fruit number (53.0% and 32.2% respectively), fruit weight (42.9% and 19.2%), plant fresh weight (36.0% and 37.5%), flower number (19.1% and 11.5%), pericarp thickness (19.1% and 10.6%), fruit length (17.9% and 13.5%) and fruit width (15.9% and 8.1%). In the predominant part of the accessions grown in the reduced watering regime the total soluble solids were higher than these of the accessions grown in the optimal one. Strong to very strong positive correlations of plant height, flower number, fruit number and fruit weight in optimal irrigation with the same characters in reduced irrigation were found.

Key words: *Solanum lycopersicum*, watering regime, fresh biomass, correlation analysis

1. INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is a widespread vegetable crop grown in different climatic regions, continental, tropical and sub-tropical where they are often exposed to environmental stress. Among the abiotic stresses water deficit and high temperature are the main limiting factors for the plant growth and productivity. Physiologically water deficit decreases metabolism activities, inhibits cell division and elongation, decreases photosynthesis, transpiration, etc. (Kumar, Solankey & Singh 2012; Yuan et al. 2016). The reproductive stage of the plant development is highly sensitive to drought stress which finally leads to the loss of the tomato yield and quality (Vijitha & Mahendran 2010). The stress response depends on the intensity and duration of exposure, stage of growth and genotype (Nuruddin, Madramootoo & Dodds 2003; Ripoll et al. 2016).

In recent years a great attention has been focused on fundamental studies of tolerance to abiotic stress especially on high temperature and drought (Solankey et al. 2015). For that reason different approaches for evaluation of tolerance to reduced irrigation and elevated temperature as physiological (Patanè et al. 2016; Zhou et al. 2017), morphological (Gotame 2006; Nahar & Ullah 2012), agronomical (Sivakumar & Srividhya 2016), biochemical (Barbagallo, Isabella & Patane, 2013; Klunklin & Savage 2017) and molecular (Sacco et al. 2013; Metwali et al. 2016) have been applied. It has been reported that flowers and flower buds abortions and the reduction in photosynthesis in tomato were higher in susceptible cultivars compared to tolerant ones (Bhatt et al. 2009). Some parameters as fruit size, fruit colour, fruit weight, plant biomass, contents of soluble solids, vitamin C and lycopene can also be included in estimation of the drought tomato tolerance (Nuruddin, Madramootoo & Dodds 2003; Constantinescu et al. 2016; Lovelli et al. 2017).

Selection of drought tolerance in tomato is getting more complicated because of the unstable manifestation of this stress factor and its interaction with high temperature, sunlight, etc. Plants have the ability to cope with the unfavorable environment by a combination of traits at physiological and phenotypic level. This is an additional difficulty to use a single trait for the selection of tolerant tomato genotypes. In order to have an efficient selection the identification of traits suitable for screening of the tomato germplasm under drought conditions is needed (Sivakumar & Srividhya 2016). According to

Foold (2005) the most reliable criteria for the drought tolerance are the agronomic characteristics (yield and yield components) and the absolute and relative plant growth under stress and non-stress environment. Some authors have conducted experiments for establishing the interrelationship of the characters and stress factor (Bozhanova & Dechev 2010; Xu et al. 2016). The results could be used by plant breeders to identify the useful traits as selection criteria to improve the yield under drought condition (Buhroy et al. 2017; Rosmaina et al. 2018).

The aim of this experimental work was on the basis of variation and correlation analysis to determine phenological and morphological characters for screening of tomato genotypes tolerant to drought stress.

2. MATERIALS AND METHODS

2.1. Plant material

The experiment was carried out in an open field with 24 tomato accessions from the collection of the Maritsa Vegetable Crops Research Institute (N42° 10' E24° 45') in the period of 2016 and 2017. Thirteen determinate (Marti, Milyana, Solaris, Spectar, BG 252, Kapri, Neven, Pautalia, Venera, BG 160, BG 1527, BG 2086 and BG 985) and eleven indeterminate (Aleno sartse, Ideal, Plovdivska karotina, Rozovo sartse, BG 21β, BG 24/13, BG 720, BG 735, BG 785, BG 822 and BG 2066) accessions were evaluated.

2.2. Field experiment

The seeds of the selected accessions were sown at the beginning of April in an unheated greenhouse. The tomato seedlings were transplanted at the beginning of May at the stage of 2nd-3rd true leaf into the field by a technology of mid-season production of determinate and indeterminate tomatoes. The plants were grown in two watering regimes - optimum and 50% reduced. The reduced irrigation was applied 20 days after transplanting when the plants were well adapted in the field. The experiment was carried out in a randomized complete block design with two replications by 10 plants (area 2,4 m²). A micro-flow drip irrigation method was used with dripping wings and distributors giving 2 L h⁻¹ spaced 20 cm apart and placed along the row.

2.3. Parameter measurements

The following parameters were recorded: maturity earliness (number of days from sowing until 50% of plants have at least one ripened fruit), plant height (cm), fresh plant weight (without fruits and root - kg), flower number (all flowers of the plants from the determinate accessions and flowers from 2 to 5 inflorescences in the indeterminate ones), fruit number (all formed ripened fruits by 31 August of the plants from the determinate accessions and fruits from 2 to 5 inflorescences in the indeterminate ones), fruit weight (average weight of 10 ripened fruits - g). The fruits were scanned by a standard CanoScan 4400F scanner. The length and width of the longitudinal section (cm) and the pericarp thickness (cm) were measured using WinCAM Pro image analysis software. A sample of 10-12 tomato fruits from each replication was analysed for total soluble solids content of the fruits (%).

2.4. Climate parameters

Weather data were collected from June to August in 2016 and 2017 by weather station *Caipos Wave* (Caipos GmbH, Austria). Air temperature – minimum and maximum (°C), air humidity (%), rainfalls (l/m²) and soil moisture at 15 and 30 cm depth (kPa) were recorded.

2.5. Data analysis

The results were presented as mean ($\bar{x}$) and standard deviation (sd). The coefficient of variation (%) and the decrease percentage (D%) were also calculated. The correlation analysis was carried out to evaluate the relationships between the studied parameters in 50% reduced irrigation and optimum irrigation. All calculations were done using SPSS 16.0 software.

3. RESULTS

The daily mean temperature over 25°C was measured in 54% and 51% of the days of the period June-August in 2016 and 2017 respectively (Figure 1). It ranged from 19.78 to 28.80°C in the period of 2016 and from 17.10 to 32.02°C in the period of 2017. The total rainfalls were 134 l/m² and 76.5 l/m² respectively. The rainfalls were distributed as follows: June - 31.5 l/m², July - 38.0 l/m² and August - 64.5 l/m² in 2016 and June - 19.5 l/m², July - 52.5 l/m² and August - 4.5 l/m² in 2017.

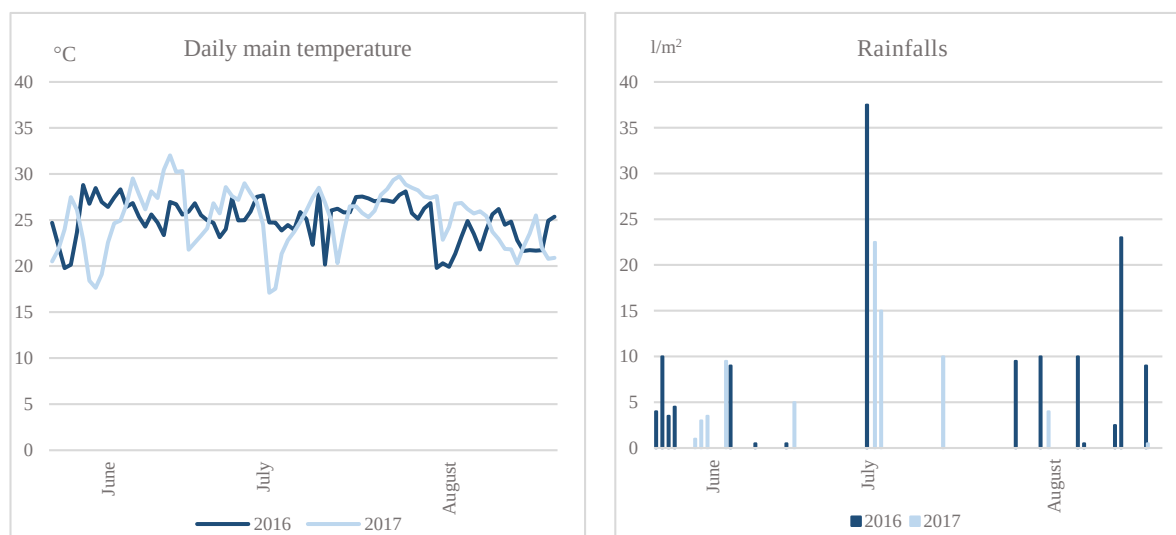


Figure 1. Daily mean temperature and rainfalls for the experimental period of 2016 and 2017

The plants of the indeterminate and determinate tomato types answered the water deficit with a decrease of the fruit number (53.0% and 32.2% respectively), fruit weight (42.9% and 19.2%), fresh plant weight (36.0% and 37.5%), flower number (19.1% and 11.5%), plant height (17.5% and 17.3%), pericarp thickness (19.1% and 10.6%), fruit length (17.9% and 13.5%) and fruit width (15.9% and 8.1%). The plants grown under irrigation at the reduced rate of 50% entered into the ripening stage two days earlier than those grown under optimum irrigation. Furthermore, the control plants of the indeterminate and determinate tomato types had a lower decrease of the total soluble solids (8.9% and 15.7%) than the treated plants (Table 1).

The coefficient of variance for most of the studied traits decreased under conditions of water deficit (Table 1). In both studied tomato types the decrease of the coefficient of variance in reduced irrigation was at the largest extent for the character fresh plant weight. The same coefficient was also lower for the characters flower number, fruit length, fruit width and total soluble solids in the indeterminate tomato accessions and for the maturity earliness, flower number and fruit width in the determinate ones.

Water stress had an impact on the plant growth and development. The studied genotypes showed a significant decrease in plant height and fresh plant weight with the reduced watering regime of 50% (Figure 2). Out of 13 tested determinate accessions genotype Milyana showed the highest decrease of plant height and fresh plant weight (33.3% and 57.3% respectively). In two accessions (BG 252 and BG 1527) the plant height was not changed under conditions of reduced irrigation. In the group of the indeterminate tomato the decrease of plant height in accession BG 24/13 (28.6%) and fresh plant weight in accession BG 785 (60.9%) was the most significant.

Table 1. Morphological characters and total soluble solids of the studied tomato types

	Indeterminate tomato					Determinate tomato				
	Reduced irrigation		Optimum irrigation		D%	Reduced irrigation		Optimum irrigation		D%
	$\bar{X} \pm sd$	CV (%)	$\bar{X} \pm sd$	CV (%)		$\bar{X} \pm sd$	CV (%)	$\bar{X} \pm sd$	CV (%)	
Maturity earliness days	107.5 ± 6.3	5.9	109.8 ± 6.2	5.6	1.8	104.2 ± 3.5	3.4	106.2 ± 4.4	4.1	1.8
Plant height cm	125.4 ± 17.5	14.0	151.8 ± 15.4	10.1	17.5	67.3 ± 13.5	20.1	81.5 ± 13.8	16.9	17.3
Fresh plant weight kg	0.6 ± 0.1	16.7	1.0 ± 0.3	30.0	36.0	0.5 ± 0.1	20.0	0.8 ± 0.3	37.5	37.5
Flower number	14.8 ± 4.9	33.1	18.3 ± 6.9	37.7	19.1	33.9 ± 5.5	16.2	39.1 ± 8.0	20.5	11.5
Fruit number	6.0 ± 4.5	75.0	13.5 ± 7.4	54.8	53.3	21.8 ± 4.5	20.6	32.5 ± 6.4	19.7	32.2
Fruit weight g	126.3 ± 61.0	48.3	231.5 ± 108.6	46.9	42.9	73.1 ± 25.9	35.4	90.4 ± 28.1	31.1	19.2
Fruit length cm	5.8 ± 1.2	20.7	7.2 ± 1.8	25.0	17.9	5.5 ± 0.6	10.9	6.4 ± 0.5	7.8	13.5
Fruit width cm	7.1 ± 1.5	21.1	8.6 ± 2.3	26.7	15.9	5.6 ± 1.1	19.6	6.1 ± 1.3	21.3	8.1
Pericarp thickness cm	0.6 ± 0.1	16.7	0.7 ± 0.1	14.3	19.1	0.8 ± 0.1	12.5	0.9 ± 0.1	11.1	10.6
Total soluble solids %	6.4 ± 0.7	10.9	5.9 ± 0.7	11.9	8.9	6.1 ± 0.8	13.1	5.3 ± 0.6	11.3	15.7

The genotypes showed a lower decrease of the number of flowers per plant under condition of 50% reduced irrigation. The variation interval in the determinate tomato type was from 4.8% in BG 1527 to 28.6% in BG 252 while in the indeterminate tomato it ranged from 11.0% in BG 21β to 38.5% in Plovdivska karotina. A slight increase of the number of flowers per plant was recorded in two determinate (Solaris and BG 985) and two indeterminate tomato accessions (Ideal and BG 720) (Figure 3).

The reduced irrigation and the high temperatures had the most pronounced negative effect on the average fruit weight and number of fruits per plant (Figure 3). The decrease of the number of fruits per plant was from 11.5% (BG 985) to 48.3 (Spectar) and 33.6% (BG 21β) to 65.0% (BG 2066) in the determinate and indeterminate tomato types respectively. Moreover, the accessions showed different decrease of fruit weight from optimum to reduced irrigation. It ranged from 10.4% in BG 252 to 43.8% in BG 1527 in the group of determinate tomato. The reduction of fruit weight in the indeterminate tomato was from 20.1% in 2066 to 58.5% in BG 720.

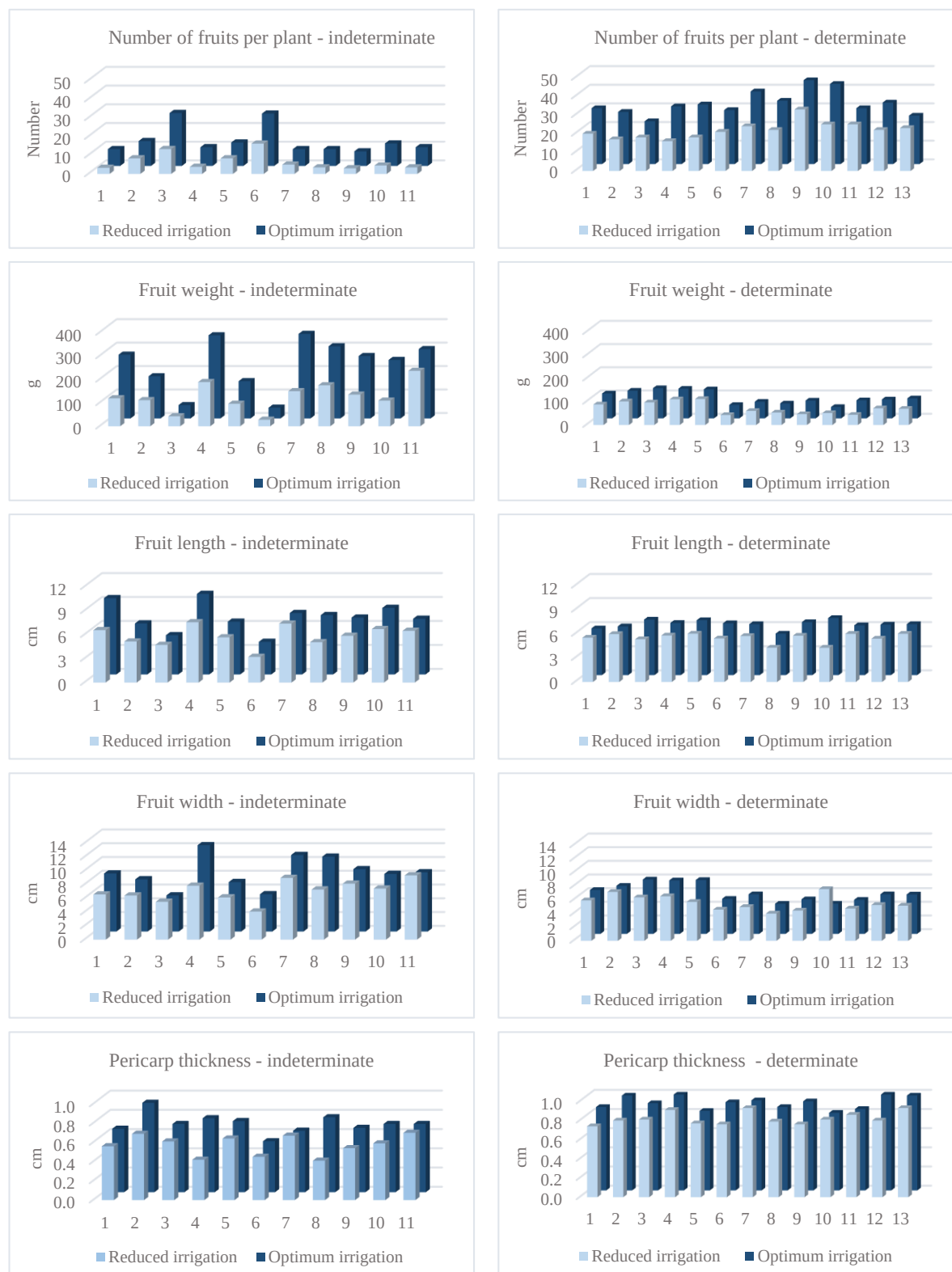


Indeterminate: 1. Aleno sartse; 2. Ideal; 3. Plovdivska karotina; 4. Rozovo sartse; 5. BG 21 β ; 6. BG 24/13; 7. BG 720; 8. BG 735; 9. BG 785; 10. BG 822; 11. BG 2066

Determinate: 1. Marti; 2. Milyana; 3. Solaris; 4. Spectar; 5. BG 252; 6. Kapri; 7. Neven; 8. Pautalia; 9. Venera; 10. BG 160; 11. BG 1527; 12. BG 2086; 13. BG 985

Figure 2. Impact of water deficit on plant characteristics in 11 indeterminate and 13 determinate tomato accessions

The reduced irrigation and the high temperatures also affect fruit length, fruit width and pericarp thickness. Among the indeterminate accessions the negative effect of water deficit on the measured components of the fruit size and pericarp thickness was highest in accessions Rozovo sartse and BG 735. The accessions Plovdivska karotina and BG 720 distinguished with a slight reduction of fruit morphology traits. In the group of determinate accessions the most significant decrease was recorded in fruit length in BG 160, fruit width in Solaris and pericarp thickness in BG 2086. The lowest decrease of fruit size was established in Milyana.

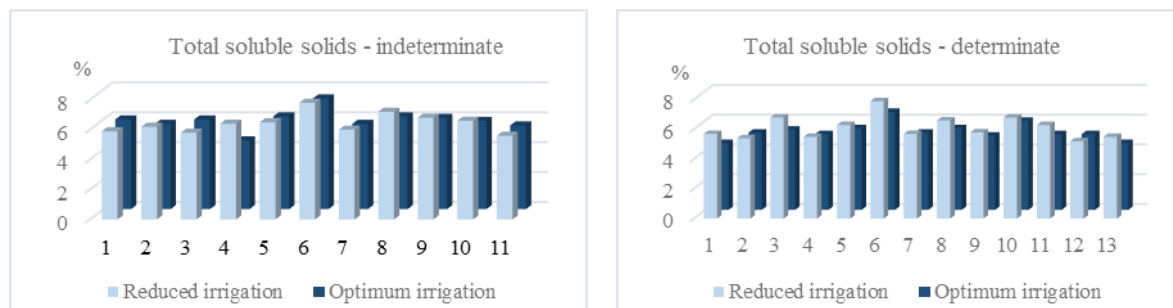


Indeterminate: 1. Aleno sartse; 2. Ideal; 3. Plovdivska karotina; 4. Rozovo sartse; 5. BG 21β; 6. BG 24/13; 7. BG 720; 8. BG 735; 9. BG 785; 10. BG 822; 11. BG 2066

Determinate: 1. Marti; 2. Milyana; 3. Solaris; 4. Spectar; 5. BG 252; 6. Kapri; 7. Neven; 8. Pautalia; 9. Venera; 10. BG 160; 11. BG 1527; 12. BG 2086; 13. BG 985

Figure 3. Fruit characteristics of 11 indeterminate and 13 determinate tomato accessions grown under optimum and 50% reduced irrigation

The content of total soluble solids was higher in all tomato accessions grown in 50% reduced irrigation except variety Aleno sartse (Figure 4). Accessions Rozovo sartse and Marti was characterized by the highest increase of total soluble solids under drought stress (39.1% and 26.7% respectively).



Indeterminate: 1. Aleno sartse; 2. Ideal; 3. Plovdivska karotina; 4. Rozovo sartse; 5. BG 21β; 6. BG 24/13; 7. BG 720; 8. BG 735; 9. BG 785; 10. BG 822; 11. BG 2066

Determinate: 1. Marti; 2. Milyana; 3. Solaris; 4. Spectar; 5. BG 252; 6. Kapri; 7. Neven; 8. Pautalia; 9. Venera; 10. BG 160; 11. BG 1527; 12. BG 2086; 13. BG 985

Figure 4. Total soluble solids content of 11 indeterminate and 13 determinate tomato accessions

4. DISCUSSION

Change in the climatic conditions during the last decades has forced a continuous expansion of the research in the field of abiotic stress. New genes resistant to high temperatures and drought have been searched for (Solankey et al. 2015).

In order to have an effective and efficient selection breeders are needed to identify traits that are suitable for screening of tomato germplasm under heat and drought conditions (Sivakumar & Srividhya 2016). Correlations between the most affected characters by stress have been investigated. The attention has been directed to the yield, the productivity characters and to the relationship between them (Buhroy et al. 2017).

The experimental results of our study revealed that the drought and the elevated temperature affected negatively the studied phenological and morphological characters. Significant variation among the studied tomato accessions was observed. The plants of indeterminate and determinate tomato types answered the water deficit at the highest degree with a decrease of the fruit number, fruit weight and plant fresh weight. In contrast, the flower number and fruit morphological traits (length, width and pericarp thickness) were influenced weakly. Similar results were obtained by Alsamir et al. (2017) who established that in high temperature the number of fruits per plant was severely impacted while the number of flowers showed little change. Srivastava et al. (2012) reported that the period of flowering phase was the most sensitive to water scarcity. According to Falcetti et al. (1995) water deficit during the flowering stage could cause abortion of the flowers due to a decrease of pollen fertility, pistil damage and decrease the amount of fruits. In addition, the measured high temperature in the period of flowering leads to increase of the flower abortion (Sato, Peet & Gardner 2001). The authors confirmed that the fruit set was the limiting factor under drought stress. In our experiment the decrease of the fruit weight was higher in the accessions with fruits of bigger size. The results confirmed those obtained by Wahb-Allah, Alsadon & Ibrahim (2011) and Sivakumar & Srividhya (2016).

In correspondence with our data Khan et al. (2015) and Zhou et al. (2017) reported about a decrease of plant height and fresh plant weight in response to water stress. The reduction in plant height under water deficit in tomato may be due to the damage in cell division, cell enlargement and differentiation (Taiz & Zeiger 2006; Litvin, van Iersel & Malladi 2016) as well as to the lower intensity of photosynthesis (Stoeva et al. 2010).

According to Ali et al. (2009) the success of selection depends on the choice of selection criteria for improving fruit yield in which studies on correlation will provide information regarding the association among various traits and offers an opportunity for selecting genotypes that have desirable traits simultaneously.

A very strong positive correlations of plant height, number of flowers per plant and fruit number per plant in optimal irrigation with the same characters in reduced irrigation were found in our experiment (Table 2). Strong correlations were registered for fruit weight, fruit width, pericarp thickness and total soluble solids. These correlations indicate the constant genetic reaction toward the above mentioned traits of each tomato accession grown in optimum irrigation and water deficit.

Table 2. Correlation coefficients among phenological and morphological characters in tomato fruits grown in optimum and reduced irrigation

	PH (R)	PH (O)	PW (R)	PW (O)	FN (R)	FN (O)	FrN (R)	FrN (O)	FW (R)	FW (O)	FL (R)	FL (O)	FrW (R)	FrW (O)	PT (R)	PT (O)	DM (R)	DM (O)	ME (R)	ME (O)
PH (R)	◆																			
PH (O)	0.961**	◆																		
PW (R)	0.319	0.369	◆																	
PW (O)	0.189	0.259	0.636**	◆																
FN (R)	-0.867**	-0.879**	-0.457*	-0.430*	◆															
FN (O)	-0.809**	-0.803**	-0.455*	-0.411*	0.942**	◆														
FrN (R)	-0.877**	-0.877**	-0.475*	-0.432*	0.958**	0.925**	◆													
FrN (O)	-0.822**	-0.804**	-0.449*	-0.441*	0.929**	0.980**	0.948**	◆												
FW (R)	0.663**	0.589**	0.347	0.320	-0.713**	-0.714**	-0.769**	-0.747**	◆											
FW (O)	0.800**	0.758**	0.484*	0.418*	-0.831**	-0.835**	-0.862**	-0.870**	0.890**	◆										
FL (R)	0.241	0.226	0.322	0.395	-0.362	-0.408	-0.409*	-0.481*	0.611**	0.685**	◆									
FL (O)	0.418*	0.406*	0.301	0.374	-0.489*	-0.488	-0.531**	-0.547**	0.620**	0.755**	0.759**	◆								
FrW (R)	0.639**	0.581**	0.411*	0.325	-0.674**	-0.660**	-0.725**	-0.663**	0.835**	0.808**	0.553**	0.594**	◆							
FrW (O)	0.681**	0.629**	0.473*	0.442*	-0.762**	-0.767**	-0.804**	-0.795**	0.864**	0.936**	0.654**	0.717**	0.745**	◆						
PT (R)	-0.782**	-0.816**	-0.280	-0.302	0.801**	0.662**	0.715**	0.654**	-0.411	-0.595**	-0.027	-0.336	-0.333	-0.571**	◆					
PT (O)	-0.743**	-0.764**	-0.219	-0.137	0.689**	0.552**	0.607**	0.536**	-0.253	-0.460	0.002	-0.169	-0.339	-0.336	0.756**	◆				
DM (R)	0.248	0.205	-0.188	-0.093	-0.205	-0.181	-0.129	-0.142	-0.156	-0.013	-0.416*	-0.056	-0.140	0.007	-0.470*	-0.436*	◆			
DM (O)	0.365	0.402	0.024	-0.073	-0.382	-0.276	-0.314	-0.229	-0.133	0.001	-0.486*	-0.201	-0.020	-0.067	-0.510**	-0.636**	0.733**	◆		
ME (R)	0.420*	0.403	0.357	0.221	-0.422*	-0.370	-0.467*	-0.393	0.333	0.483*	0.400*	0.400*	0.358	0.613**	-0.402	-0.284	0.054	-0.127	◆	
ME (O)	0.462*	0.401	0.235	-0.031	-0.445*	-0.382	-0.482*	-0.371	0.390	0.415*	0.107	0.159	0.444	0.448*	-0.228	-0.322	-0.100	0.161	0.402*	◆

R – reduced irrigation; O – optimum irrigation

PH - Plant height; PW - Plant weight; FN - Flower number; FrN - Fruit number; FW - Fruit weight;
FL - Fruit length; FrW - Fruit width;

PT - Pericarp thickness; TSS – Total soluble solids; ME - Maturity earliness

The correlation analyses on the morphological characters in both watering regimes separately showed that the change in the environment did not change the relations between the studied characters. The number of fruits per plant manifested a very strong to strong positive correlations with flower number per plant and average fruit weight. The average fruit weight also displayed a strong positive correlation with fruit width as reported by other authors (El-Shaieny 2017; Buhroy et al. 2017). In contrast, the plant height showed strong negative significant association with the number of flowers and number of fruits

per plant. A negative strong significant correlation between the number of flowers per plant and the average fruit weight was observed.

The constant expression of the correlations illustrate that the productivity characters which are leading during the tomato breeding in optimum irrigation could also be leading characters during the breeding in reduced irrigation. Therefore, the tomato varieties resistant to water deficit could be bred in analogical way as in optimum irrigation.

5. CONCLUSIONS

The results indicate that the water stress significantly reduced the phenological and morphological characters of the investigated tomato accessions. On the basis of variation and correlation analysis the leading morphological characters for screening of tomato genotypes in water deficit were determined. The number of flowers per plant and number of fruits per plant were relevant characters and can be indirectly used for the successful breeding of tomato genotypes tolerant to drought stress.

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