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TRAITS RELATED TO DROUGHT TOLERANCE IN TOMATO ACCESSIONS OF DIFFERENT GROWTH TYPE AND FRUIT SIZE

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ABSTRACT

This study was undertaken to investigate the possibilities for breeding drought tolerant tomatoes of different growth type and fruit size. The effects of drought were analyzed and the relationships among the observed traits at optimal irrigation and drought were interpreted using biplot analysis. Greenhouse pot experiment included 40 tomato accessions grown under optimal irrigation and drought (volumetric soil water content 35.0% and 20.9%), designed in complete randomized blocks. Observations were made at the intensive vegetative growth phase. The selection criterion for drought tolerance was plant dry weight. The accessions differed in: the whole plant, shoot and root dry weight, root proportion in plant dry weight (RP), plant height, number of leaves below the first flower branches (NL), number of lateral branches, and the first and second order lateral branches length. Drought resulted in significant decline, with the exceptions of the increased RP and NL. Determinate and indeterminate tomatoes were not significantly different in drought tolerance, implying that both types may be bred for tolerance to the stress; however, the accessions of larger fruit size had comparatively higher water requirements. Results of the biplot analysis indicated that drought tolerance in tomato does not necessarily have to be associated with robust root system and therefore the indirect selection strategy may rely on shoot traits.

Keywords: Biplot, drought, *Lycopersicon esculentum*, vegetative growth.

INTRODUCTION

Tomato (*Lycopersicon esculentum* Mill.) is one of the world's most important vegetable crops. The tomato was grown over area of 4.4 million ha, with annual production of 141.3 million t and accordingly average yields of 32.1 t/ha during the years 2003-2012 (FAO, 2014). There was a steady increase in area and production during this period. While more than a half (54.6%) of the global tomato production is in Asia; Americas, Europe, Africa and Oceania contribute 17.4, 15.5, 12.1 and 0.3 %, respectively. The United States of America, China, India and Turkey cover almost 80% of the world's tomato production, however the highest yields (up to 15 times higher than world average) have been reported for Netherlands, Belgium, United Kingdom, Denmark and Iceland (FAO, 2014). The large differences in yield can be attributed to production system (greenhouse or open field), overall investments in technology of growing tomatoes, yield potential of the cultivars and hybrids (Magán *et al.*, 2008). The green house tomato production, especially, has a major adventage over the open-field situation, due to the ability to cope with specific environmental constraints.

Water deficit is one of the most commonly occurring abiotic stresses, that adversly affects agricultural production, including tomatoes which are generally recognized as drought sensitive at all phases of plant development (Ashraf, 2010; Sun *et al.*, 2014). Drought sensitivity is especially pronounced in modern cultivars and hybrids; therefore broadening the genetic base for breeding by including old cultivars, local populations and wild forms would be of particular importance. Maximizing the water use efficiency is also required in breeding programs, regardless of whether the new variety is attended for greenhouse or open-field growing, fresh consumption or processing, high or low input system (Easlon and Richards, 2009; Foolad, 2007). An effective screening of the starting material is crucial for breeding success. The fact that there is no universal selection criterion for differentiating tolerant and sensitive accessions raises the need for investigating the effects of water shortage on various tomato traits (Foolad, 2007; Hirayama and Shinozaki, 2010).

The objectives of this study were to investigate the effects of drought on tomato accessions differing in growth type and fruit size, and to interpret the relationships among tomato traits observed at optimal irrigation and drought by using biplot analysis. The results should help breeders to develop tomato cultivars and hybrids with enhanced tolerance to drought.

MATERIALS AND METHODS

Forty tomato accessions differing in fruit size (ten very small – up to 50 g, six small – 51 to 80 g, eight medium – 81 to 120 g, eleven large – 121 to 250 g and five extra-large – over 250 g) and growth type (21 indeterminate and 19 determinate) have been included in the study. The accessions are part of the tomato germplasm collection maintained at the Institute for Vegetable Crops, Smederevska Palanka, Serbia, and their classification has been made on the basis of the results of previous long-term field trials.

The experiment was set in pots and conducted in controlled greenhouse conditions, during the tomato growing season of 2011. It was arranged in complete randomized blocks with three replications and 15 plants per replication. Tomato seedlings grown in optimal conditions were transplanted in plastic pots (one seedling per pot) filled with commercial compost (Biolan C1-B, 600 cm^3 per pot) and irrigated optimally. After ten days, half of the plants were subjected to drought treatment while the other half remained in the optimal irrigation regime (control). The optimal irrigation and drought volumetric soil water contents were 35.0% and 20.9%, respectively, adjusted on the daily basis using time domain refractometer probe (TRASE, Soil Moisture Equipment Corp., USA). The experiment was completed after ten days and the following were measured: plant, shoot and root dry weights (g), plant height (cm), number of leaves below the first flower branches, number of lateral branches, and first and second order lateral branches lengths (cm). Dry weight was determined by drying in oven at 80°C, to constant weight. In addition, root proportion in plant dry weight (%) was calculated.

Basic statistic parameters (mean, standard error of mean, minimum and maximum values) were calculated. The data were processed by analysis of variance and the means were compared using LSD test at the 0.05 level of probability. The accession by treatment interactions of plant dry weight (target trait) and other studied traits (explanatory traits) were studied using a genetic covariate by environment biplot (Yan and Tinker, 2006). Data processing was performed using Statistica 12 software package (StatSoft, USA).

RESULTS AND DISCUSSION

The tomato accessions exhibited significant differences in terms of all investigated traits, in both the optimal irrigation and water deficit (Table 1). Considerably wide intervals of variations that are noted for the traits were expected, because the accessions represent phenotypically heterogeneous material collected over a large territory. The drought treatment exerted a significant influence on all investigated traits, with the exception of number of leaves below the first flower branches, which remained virtually the same at optimal and limited irrigation. As expected, the traits were in most cases reduced by drought treatment; with the values ranging from 87.9 (number of lateral branches) to 27.9% (first order lateral branches length) of the values determined for the control. Negative effects of limited irrigation on the parameters of tomato vegetative growth have been reported by other authors (Foolad, 2007; Chavan *et al.*, 2010; Nahar and Ullah, 2012; George *et al.*, 2013; Ghebremariam *et al.*, 2013; Shamim *et al.*, 2014) and those effects are more pronounced for the treatments imposed at earlier phases of plant development (Nuruddin *et al.*, 2003; Pervez *et al.*, 2009).

Root proportion in plant dry weight was the only trait increased in drought (183.1% with the respect to control), which is probably due to the fact that tomato roots were less affected by drought than the shoots (64.3% and 35.6 of the control, respectively). Alternaely, the root growth of plants is increased to overcome drought, concerned with capturing moist pocket in the rhizosphere (Takeuchi *et al.*, 2016). Similarly, Albacete *et al.* (2008) attributed the increased root/shoot ratio in hydroponically grown tomato to reducing effect of salinity stress on shoots. It is important to note that the discussed values correspond to the average effects of drought on 40 divergent tomatoes. Therefore, the vast intervals of variation noted for root dry weight and root proportion in plant dry weight (23.0 to 165.8 and 73.1 to 345.2 % of the control, respectively) imply the differences among the accessions in terms of root adjustment to drought stress. The significant variability that has been found among the accessions represents a good starting point for breeding tomato characterized by enhanced tolerance to drought.

In order to further investigate the effects of drought on tomato, a genetic covariate by environment biplot (Yan and Tinker, 2006) was constructed. The biplot analysis has become an often used tool for processing data in agronomic research; including those performed on tomatoes (Adalid *et al.*, 2010; Joshi *et al.*, 2011; Panthee *et al.*, 2013; Hernández *et al.*, 2014). In our study, the biplot interprets accession by treatment interaction of plant dry weight using the values of explanatory traits. Plant dry weight was regarded as target trait and all other traits were regarded as explanatory traits (covariates) of the target trait. As depicted in Figure 1, the two moisture conditions (irrigation and drought) differed in terms of the analyzed relations with plant dry weight. Though, the strongest association was observed for shoot dry weight (the longest vector), which correlated positively to plant dry weight at both irrigation and drought (acute angles between trait association and environmental vectors). This was expected, since shoot dry weight at both irrigation regimes represents a great majority of the plant dry weight. The two irrigation regimes were also common in the positive associations of plant dry weight to the plant height, as well as to first and second order lateral branches lengths. However, root proportion in plant dry weight correlated negatively to plant dry weight only at drought and root dry weight correlated positively to plant dry weight only at irrigation, indicating that drought tolerance in tomato does not necessarily have to be associated with robust root system.

Therefore, indirect selection strategy for tomato drought tolerance may rely on shoot traits, such as dry weight, plant height, and first and second order lateral branches length, having in mind their similar associations to the plant dry weight. Nevertheless, it should be noted that these observations refer to pot grown plants. According to Bagiu and Nedelea (2012), field grown tomatoes generally tolerate drought due to deeper and stronger rooting, while the indirectly cultivated require watering due to less developed root system.

Table 1. The effects of drought on 40 tomato accessions, at vegetative growth stage.

Treatment		PDW	SDW	RDW	RP	PH	NL	NLB	LLB1	LLB2
Irrigation	**Mean**	156.3[a]	149.6[a]	6.7[a]	4.4[a]	94.6[a]	6.5[a]	6.2[a]	35.8[a]	31.3[a]
	SE	4.7	4.5	0.3	0.2	2.4	0.1	0.1	1.8	1.6
	Min	32.9	29.1	1.6	1.7	18.8	3.0	3.0	2.1	2.9
	Max	280.9	268.7	16.4	11.6	146.5	9.3	9.9	92.3	76.9
	$LSD_{0.05}$	6.5	6.1	0.3	0.2	6.3	1.5	1.1	6.1	5.8
	$LSD_{0.01}$	8.7	8.1	0.4	0.2	8.4	2.0	1.5	8.1	7.6
Drought	**Mean**	36.6[b]	35.6[b]	64.3[b]	183.1[b]	73.6[b]	95.7[a]	87.9[b]	27.9[b]	31.6[b]
	SE	2.3	2.4	4.5	10.3	1.2	0.6	1.4	2.7	3.6
	Min	15.7	15.2	23.0	73.1	59.3	89.5	69.3	5.1	10.0
	Max	79.7	82.5	165.8	345.2	87.9	102.8	102.4	82.3	129.3
	$LSD_{0.05}$	3.1	3.2	6.9	15.1	4.5	17.3	13.1	6.9	8.5
	$LSD_{0.01}$	4.1	4.2	9.2	20.1	5.9	23.0	17.4	9.1	11.3

PDW–plant dry weight (g), SDW–shoot dry weight (g), RDW–root dry weight (g), RP–root proportion in plant dry weight (%), PH–plant height (cm), NL–number of leaves below the first flower branches, NLB–number of lateral branches, LLB1, LLB2–first and second order lateral branches length (cm)

Values corresponding to drought treatment are % with respect to the irrigated control (100%)

a, b–mean values within the columns followed by the same letter do not differ at the 0.05 level of probability, according to LSD test

SE–standard error of mean

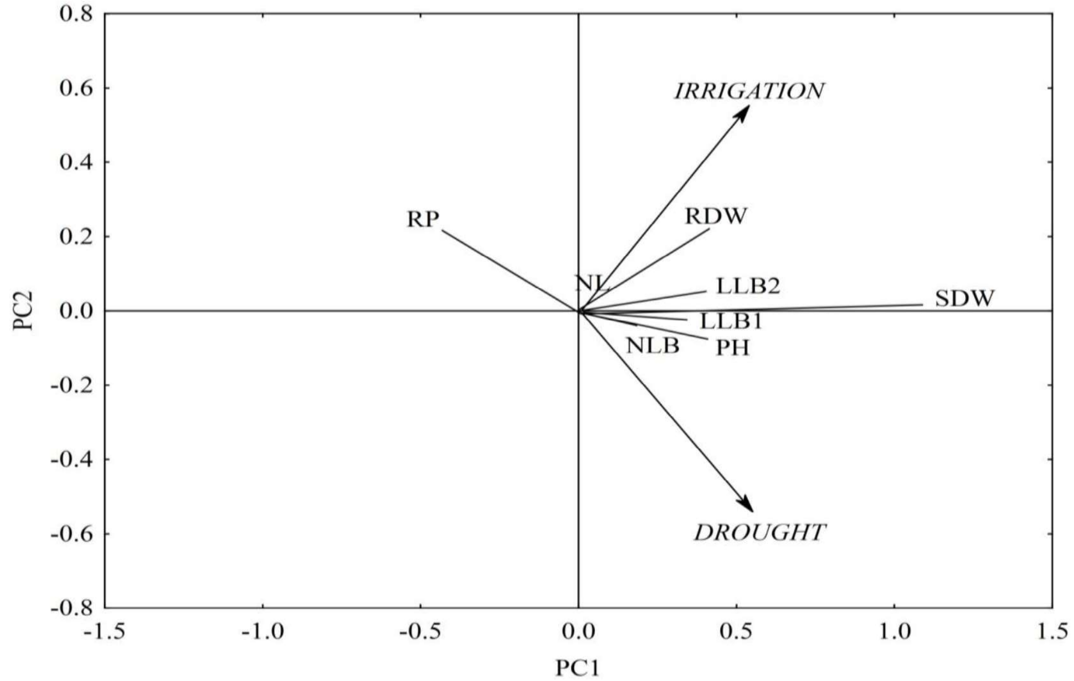


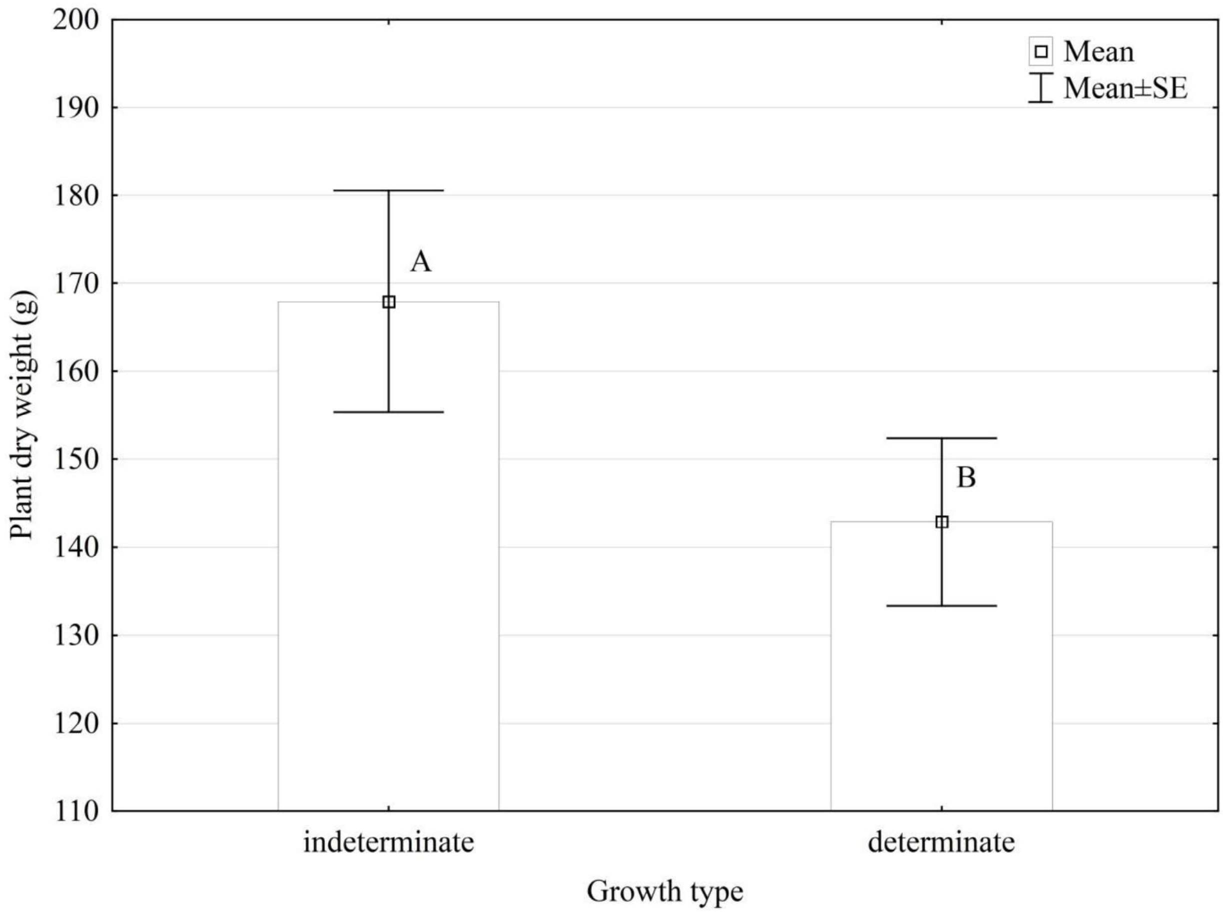
Figure 1: Genetic covariate by environment (irrigation, drought) biplot interpreting accession by environment interaction of tomato plant dry weight and explanatory traits

SDW–shoot dry weight, RDW–root dry weight, RP–root proportion in plant dry weight, PH–plant height, NL–number of leaves below the first flower branches, NLB–number of lateral branches, LLB1, LLB2–first and second order lateral branches length

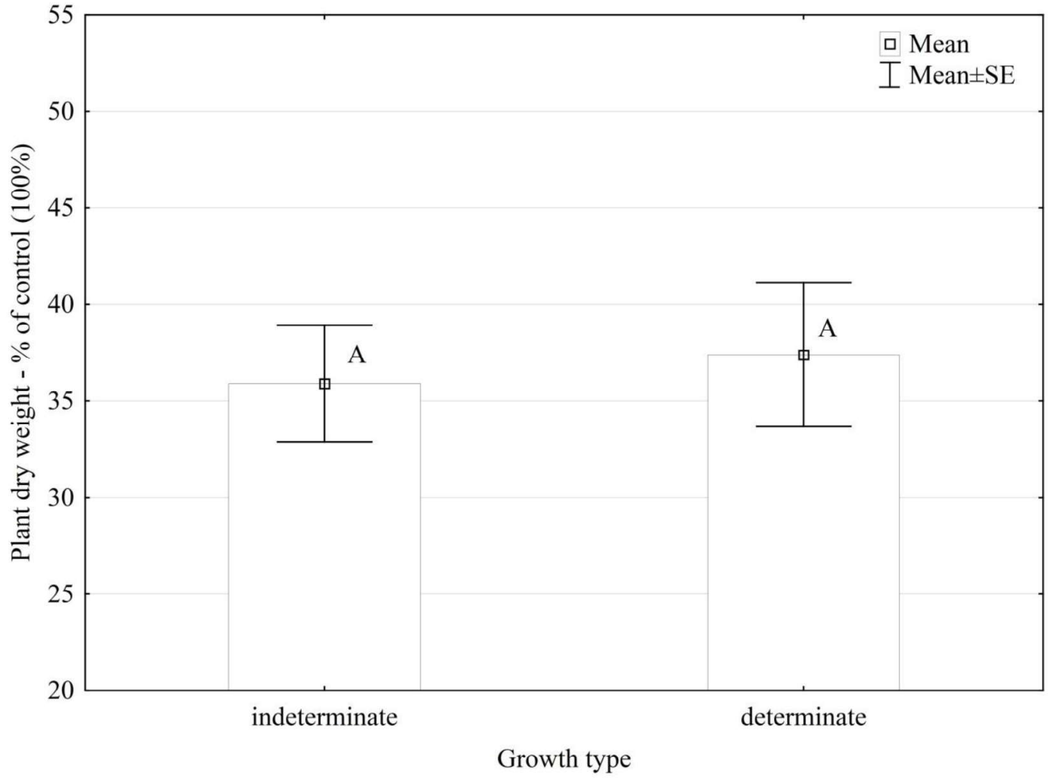
An important feature of tomato as an agricultural plant is a great diversity among the cultivars and hybrids, which partly results from adaptation to different cropping systems required for tomatoes produced for different purposes. According to their use, tomato varieties may be divided into those for fresh consumption and those for processing. Varieties attended for processing are usually of determinant growth type, uniform ripening and homogenous fruit shape and size (Díez and Nuez, 2008). Varieties for fresh consumption often have long harvesting period (indeterminate growth type), with fruit size ranging from very small (cherry type, up to 30 g) to extra-large (250 g and more), depending on the preferences of the specific consumers (Solanke and Kumar, 2013). In order to investigate the possibilities for breeding drought tolerant tomatoes attended for different purposes, we compared the effects of drought treatment on tomato accessions differing in growth type and fruit size. Plant dry weight was used as selection criterion for drought tolerance.

When optimally irrigated, accessions of indeterminate growth type had greater plant dry weight from the determinant ones; while no significant difference in plant dry weight reduction due to limited irrigation was found between the two varietal types (Figure 2 a, b). Therefore; although the indeterminate tomatoes are more robust than the determinant ones even at the phase of vegetative growth, both types may be bred for drought tolerance. At optimal irrigation, the accessions with smaller fruits generally had lower plant dry weight yields and vice versa (Figure 2 c), implying the positive association between the weight of vegetative parts of plants and future fruit weight. In addition, strong positive linear relationship was found between fruit size and plant dry weight reduction due to the imposed drought treatment (Figure 2 d). It implies that tomato varieties with extra-large and large fruits have more water requirements that begin earlier in plant development, at least at the phase of intensive vegetative growth. However, further research comprising the observations made at both vegetative and reproductive phases of tomato development and including both fruit weight and number of fruits per plant would be required to confirm the hypothesis.

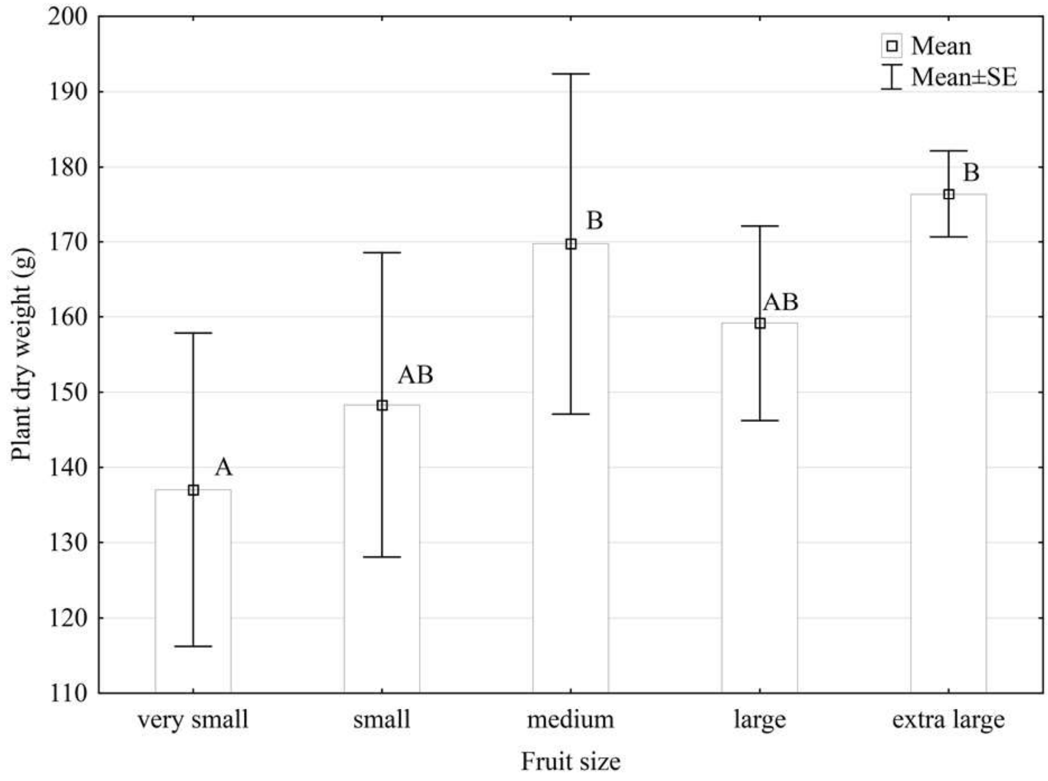
a)



b)


55
50
45
40
35
30
25
20
Plant dry weight - % of control (100%)
Mean
Mean±SE
A
A
indeterminate
determinate
Growth type

c)


200
190
180
170
160
150
140
130
120
110
Plant dry weight (g)
Mean
Mean±SE
A
AB
B
AB
B
very small
small
medium
large
extra large
Fruit size

d)

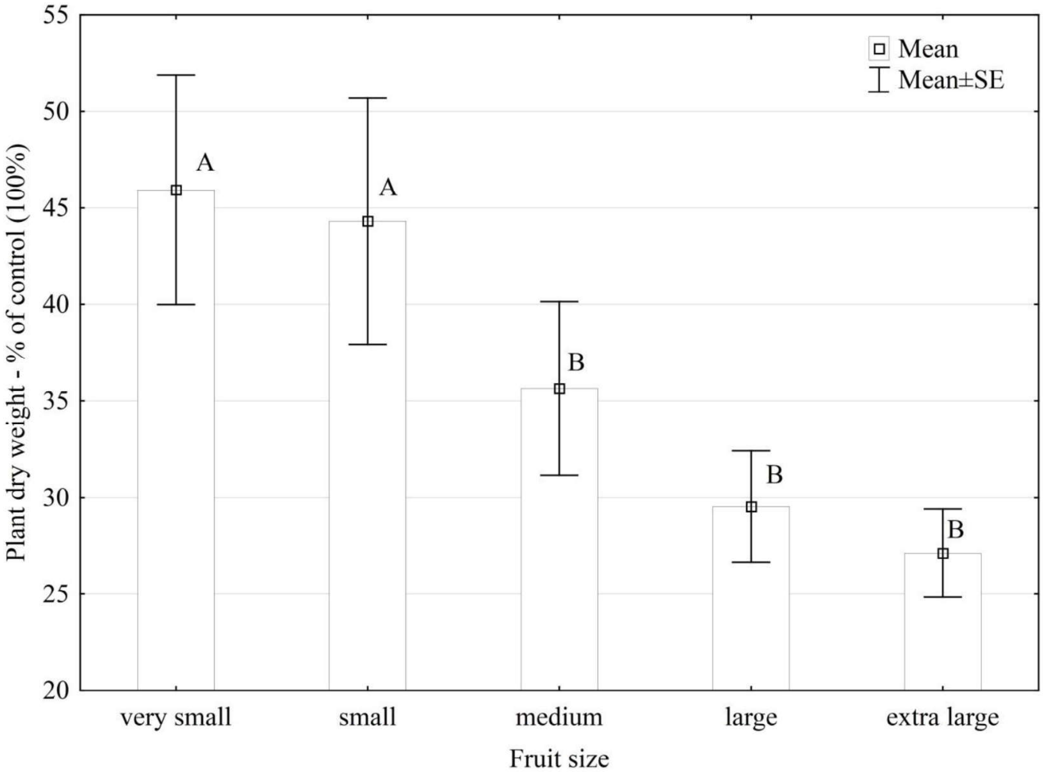


Figure 2: The effects of drought on plant dry weight in 40 tomato accessions differing in growth type and fruit size (a, c–optimal irrigation, b, d–drought)

Regarding other investigated traits, the comparisons of the drought effects on tomatoes of different growth type and fruit size are given in Table 2. At optimal irrigation, the indeterminate accessions were more robust than the determinate types and therefore were characterized by higher values for the majority of the analyzed traits; the exceptions were those related to root system. However, the two groups of accessions were affected by limited irrigation to the similar extent, confirming once again the possibility for breeding drought tolerant tomato regardless of growth type. Concerning the groups of accessions of different fruit sizes and optimal irrigation, significant variability was found in terms of all observed traits. However, the variation was probably in most cases due to genotypic differences that are not related to fruit size, since only shoot dry weights tended to have higher values in groups of accessions characterized by larger fruits and vice versa. Similar to the plant dry weight, the shoot dry weights of the accessions of larger fruits were more affected by drought than those of the accessions of smaller fruits. Number of leaves below the first flower branches and first order lateral branches length were affected to the similar extent in all groups, while the accessions of larger fruits had larger reduction in second order lateral branches length and higher increase in root proportion in plant dry weight. Therefore, limited irrigation affects both determinate and indeterminate tomatoes to the similar extent and both types may be bred for drought tolerance. Generally, tomato accessions of larger fruits have comparatively high water requirements, even still at the phase of intensive vegetative growth.

Table 2. The effects of drought on 40 tomato accessions differing in growth type and fruit size, at vegetative growth stage.

Treatment	Accession	Group	SDW	RDW	RP	PH	NL	NLB	LLB1	LLB2
Irrigation	Growth type	Determinate	136.7[a]	6.2[a]	4.8[a]	74.6[a]	5.9[a]	5.7[a]	26.3[a]	23.1[a]
		Indeterminate	160.7[b]	7.2[a]	4.1[a]	111.9[b]	7.0[b]	6.7[b]	43.9[b]	38.4[b]
	Fruit size	Very small	131.4[a]	5.6[a]	4.6[ab]	101.5[ab]	6.7[ab]	6.8[a]	35.6[ab]	39.4[a]
		Small	143.0[ab]	5.3[a]	3.8[a]	87.1[ac]	6.2[a]	6.2[ab]	24.4[c]	20.3[b]
		Medium	161.7[b]	8.1[b]	4.4[ab]	97.4[abc]	6.3[a]	6.0[b]	43.5[a]	34.6[ac]
		Large	151.3[ab]	7.9[b]	5.2[b]	85.5[c]	6.3[a]	5.9[b]	32.6[bc]	27.4[bc]
		Extra large	170.6[b]	5.8[ab]	3.3[a]	107.1[b]	7.2[b]	6.3[ab]	44.9[a]	32.4[ac]
Drought	Growth type	Determinate	36.5[a]	59.4[a]	173.4[a]	74.6[a]	95.8[a]	87.5[a]	30.0[a]	29.7[a]
		Indeterminate	34.8[a]	68.5[a]	191.6[a]	72.8[a]	97.0[a]	89.1[a]	26.2[a]	33.7[a]
	Fruit size	Very small	45.5[a]	66.5[ab]	157.8[a]	78.0[a]	95.0[a]	90.2[ab]	28.9[a]	40.5[a]
		Small	42.8[ab]	84.6[c]	187.5[a]	75.6[ab]	97.6[a]	86.1[ab]	29.7[a]	39.1[ab]
		Medium	34.9[bc]	53.4[a]	156.0[a]	72.0[bc]	97.2[a]	88.2[ab]	24.6[a]	24.9[b]
		Large	28.4[cd]	54.5[a]	184.0[a]	70.4[c]	95.9[a]	86.0[a]	30.7[a]	28.6[b]
		Extra large	25.9[d]	76.4[bc]	270.1[b]	72.8[bc]	98.0[a]	93.3[b]	22.8[a]	25.0[b]

SDW–shoot dry weight (g), RDW–root dry weight (g), RP–root proportion in plant dry weight (%), PH–plant height (cm), NL–number of leaves below the first flower branches, NLB–number of lateral branches, LLB1, LLB2–first and second order lateral branches length (cm)

Values corresponding to drought treatment are % with respect to the irrigated control (100%)

a, b, c, d–mean values within the columns followed by the same letter do not differ at the 0.05 level of probability, according to LSD test

Conclusions: The tomatoes differed in terms of all the analyzed traits, at both optimal and limited irrigation. The traits were reduced by drought, except of the increased root proportion in plant dry weight and unchanged number of leaves below the first flower branches. Since no significant difference in the response to limited irrigation was found between determinate and indeterminate tomatoes, both may be bred for drought tolerance. The accessions of larger fruit size generally have higher water requirements when compared to those of smaller fruits. The results of the biplot analysis indicated that drought tolerance in tomato does not necessarily have to be associated with robust root system. Therefore, indirect selection strategy may rely on shoot traits, with the note that these observations refer to pot grown plants examined at the vegetative stage of growth. The observed variability is a good starting point for breeding drought tolerant tomato.

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