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SHOOT AND ROOT DRY WEIGHT IN DROUGHT EXPOSED TOMATO POPULATIONS

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This research was conducted with the aim to among forty-one tested tomato (*Lycopersicon esculentum* Mill) populations distinguish those tolerant to limited water supply. Tolerance assessments were performed by using sixteen drought stress selection indices calculated on the basis of tomato shoot and root dry weight yields determined at water stress and non-stress conditions. Populations were differentiated in groups using the method of cluster analysis. The pot experiment was set in controlled greenhouse conditions and comprised optimally irrigated control and drought treatment (35.0 and 20.9% volumetric soil water content, respectively), imposed at the phase of intensive vegetative growth. The experiment was conducted at the Institute for Vegetable Crops in Smederevska Palanka, Serbia. The analyzed tomatoes exhibited significant differences in terms of response to limited irrigation, which had more pronounced effect on shoot dry weight than on the roots (average decrease of 64.4 and 35.7%, respectively). Consequently, root fraction in the total dry weight increased at drought for 68.2% on average. Shoot and root dry weights were positively correlated at optimal irrigation but not in drought, implying genotypic differences in terms of root adjustments to stress conditions. As for the calculated selection indices, substantial variation was found among the populations enabling their ranking in terms of drought tolerance. Since ranking was not the same in all cases, clustering the populations was performed taking into account all sixteen selection indices. The results of this analysis indicate that populations designated with numbers 126, 124, 131, 125, 128, 105, 101, 138, 110, 132 and 109 in Institute for Vegetable Crops germplasm collection

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exhibit satisfactory level of drought tolerance at vegetative phase and therefore may be used as parents in breeding programs.

Key words: drought, stress selection indices, tomato, vegetative growth

INTRODUCTION

Tomatoes (*Lycopersicon esculentum* Mill) are among the world's most important vegetables, occupying approximately 4.8 million ha. There is trend of increase in both tomato harvested area and yield, which is currently about 33.5 t/ha. In Serbia, the vegetable is grown on 20,000 ha with average yields of 9.5 t/ha only. Since cultivars and hybrids of local origin are generally of good yield potential, insufficient investments in technology of growing would be the explanation for such low productivity (TAKAČ *et al.*, 2007; ZDRAVKOVIĆ *et al.*, 2011; STAT. YEARB. SERB., 2012; FAO, 2014).

Water deficit is recognized as one of the major abiotic stress factors limiting agricultural production worldwide, which imposes the need for adequate irrigation in drought prone areas. However, due to limited water availability or because of inability to invest in irrigation systems, many regions have to rely on rainfed farming. Therefore, work on developing cultivars and hybrids that are tolerant to drought remains as solution for increasing crop yields without further increase in water input. Since more or less severe droughts are expected for the region of South East Europe, these studies will increasingly gain in importance (MAKSIMOVIĆ *et al.*, 2012; KRESOVIC *et al.*, 2014). The first step in breeding is to screen the available genotypes in order to distinguish the drought tolerant which will be used as starting material for crossing. However, screening tomato for drought tolerance is not an easy task. Although there are reports that the lack of water affects the number of traits, such as shoot, root and fruit dry weight, plant height, photosynthetic rate etc., there are no established selection criteria for differentiating tolerant and susceptible material (FOOLAD, 2007; WAHB-ALLAH *et al.* 2011; ZDRAVKOVIĆ *et al.*, 2013).

This study was conducted to assess drought tolerance in tomatoes exposed to water deficit at the stage of intensive vegetative growth, by using several drought stress selection indices. The second aim was to analyze the effect of drought on tomato shoots and roots.

MATERIALS AND METHODS

Forty-one tomato populations originating from various regions of Serbia have been included in a complete randomized block trial placed in controlled greenhouse conditions. The populations are a part of the germplasm collection of the Institute for Vegetable Crops, Smederevska Palanka. The trial was set in three replications, each comprising 15 plants. Young tomato seedlings grown in optimal conditions have been transplanted in pots filled with commercial compost and irrigated to full pot holding capacity. Ten days after, drought treatment was imposed on half of the plants, while for the other half the irrigation remained the same (volumetric soil water content of 20.9 and 35.0%, respectively). The trial was completed ten days after, when the tomatoes were still at the stage of intensive vegetative growth. Soil water content measurements were made using time domain refractometer probe (TRASE, Soil Moisture Equipment Corp., USA). The plants were divided into shoots and roots, dried at 80^{o}C and weighted. Sixteen drought stress selection indices have been calculated for particular populations on the basis of shoot and root dry weights determined at optimal irrigation (DWirr) and drought (DWdr). Means of all populations are designed in formulas as $\overline{DWirr}$ and $\overline{DWdr}$. The indices are:

Stress susceptibility index: $SSI = [1 - (DWdr\ /\ DWirr)]/[1 - (\overline{DWdr}/\overline{DWirr})]$ (FISCHER and MAURER, 1978)

Relative drought index: $RDI = (DWdr/DWirr)/(\overline{DWdr}/\overline{DWirr})$ (FISCHER *and* WOOD, 1979)

Mean productivity: $MP = (DWirr + DWdr)/2$ (ROSIELLE and HAMBLIN, 1981)

Stress tolerance: $TOL = DWirr - DWdr$ (ROSIELLE and HAMBLIN, 1981)

Stability index: $SI = DWdr/DWirr$ (BOUSLAMA and SCHAPAUGH, 1984)

Dry weight yield index: $YI = DWdr/\overline{DWdr}$ (LIN *et al.*, 1986)

Superiority index: $Pi = \sum_{j=1}^{n}(Xij - Mj)^2/2n$, with *n* representing the number of environments, *Xij* grain yield of i^{th} genotype in the j^{th} environment and *Mj* the yield of the genotype with maximum yield at environment *j*. (LIN *and* BINNS, 1988)

Stress tolerance index: $STI = (DWdr \times DWirr)/\overline{DWirr}^2$ (FERNANDEZ, 1992)

Geometric mean productivity: $GMP = \sqrt{(DWirr \times DWdr)}$ (FERNANDEZ, 1992)

Harmonic mean: $HM = (2 \times DWirr \times DWdr)/(DWirr + DWdr)$ (SCHNEIDER *et al.*, 1997)

Drought resistance index: $DI = [DWdr \times (DWdr/DWirr)]/\overline{DWdr}$ (LAN, 1998)

Modified stress tolerance index: $k1STI = DWirr^2/\overline{DWirr}^2$ and $k2STI = DWdr^2/\overline{DWdr}^2$ (FARSHADFAR and SUTKA, 2002)

Abiotic tolerance index: $ATI = [(DWirr - DWdr)/(\overline{DWirr}/\overline{DWdr})] \times [\sqrt{DWirr \times DWdr}]$ (MOOSAVI *et al.*, 2008)

Stress susceptibility percentage index: $SSPI = [(DWirr - DWdr)/2(\overline{DWirr})] \times 100$ (MOOSAVI *et al.*, 2008)

Sensitivity drought index: $SDI = (DWirr - DWdr)/DWirr$ (FARSHADFAR and JAVADINIA, 2011)

Relative decrease: $RD = 100 - [(DWdr \times 100)/DWirr]$

Basic statistic parameters (mean, minimum and maximum, standard error of mean and coefficient of variation), simple Pearson's and Spearman's coefficients of rank correlation have been calculated for the analyzed traits and indices. Differentiating of tomatoes by the means of shoot and root response to limited irrigation was performed using cluster analysis, with Euclidian distance as distance rule. Statistica 12.0 (StatSoft, Tulsa, OK, USA; University of Novi Sad License) software package was used for the calculations and graphing.

RESULTS AND DISCUSSIONS

Significant differences in terms of both shoot and root dry weight yield have been found among the tested tomato populations and between the irrigation regimes (analysis of variance, not shown). In case of shoot dry weight the most important source of variation were the treatments (64.6%); while genotypes and genotype × treatment interaction accounted for 22.7 and 12.4% of total sum of squares, respectively. As for the root dry weight variation, the genotypes contributed approximately the half (49.8%), and the remaining half derived from genotype × treatment interaction (25.6%) and treatments (24.3%). Similar effects of drought on tomato genotypes have been reported by CHAVAN *et al.* (2009) and WAHB-ALLAH *et al.* (2011).

On average, aboveground parts accounted for the whole 95.7 and 93.2% of the total plant biomass (at optimal and limited irrigation, respectively, Table 1); therefore the shoot dry weight yield was further considered as selection criterion for drought tolerance. In addition, both analyzed parameters were reduced by drought treatment, with more pronounced effect on shoot dry weight than on the roots (average decreases of 64.4 and 35.7%, respectively). This resulted in an increase of root fraction in the total dry weight yield determined at drought. An increased root-shoot ratio in tomato grown at unfavorable water supply or high salinity is expected and documented by other authors (e.g. ÅGREN and FRANKLIN, 2003); however, there are different reports about the parameters that contributed to this increase. ALBACETE *et al.* (2008) reported retarded shoot, maintained root growth and thus increased root-shoot ratio in tomato seedlings exposed to salinity stress. Similarly, in an experiment conducted by PROKIĆ *and* STIKIĆ (2011) drought treatment provoked an increase in tomato root length and density. This partial discrepancy with our results could be explained by the differences in number of genotypes included in the analyses, stress intensity and the method of its application. In our study, considerably wide intervals of variation for shoot and root dry weight indicate the possibilities for manipulation aimed to breed tomatoes with enhanced tolerance to drought.

Table 1. Shoot and root dry weight yields (g) and root-shoot ratio (%) in 41 tomato genotypes grown at two irrigation regimes

Treatment	Trait	Mean	Min	Max	SE	CV
Irrigation	Shoot dry weight	149.6	30.1	263.6	7.9	33.7
	Root dry weight	6.7	1.7	16.0	0.6	55.9
	Root-shoot ratio	4.4	1.8	11.5	0.3	48.8
Drought	Shoot dry weight	49.0	18.4	85.6	2.6	33.8
	Root dry weight	3.6	1.5	6.7	0.2	35.2
	Root-shoot ratio	7.4	3.0	13.6	0.5	39.4

SE-standard error of mean, CV-coefficient of variation (%)

Table 2. Pearson's coefficients of correlation among shoot (SDW) and root (RDW) dry weight yields in tomato grown at optimal irrigation (irr) and drought (dr)

	SDWdr	RDWirr	RDWdr
SDWirr	0.50^{**}	0.53^{**}	0.25
SDWdr		0.00	0.11
RDWirr			0.53^{**}

**-significant at 0.01 level of probability

In order to further investigate the effects of limited irrigation on tomato shoot-root ratio, simple correlation coefficients have been calculated among these parameters (Table 2). A positive correlation ($r=0.53^{**}$) was found between shoot and root dry weight implying that the tomato plants with extensive aboveground parts tend to develop stronger roots, when optimally irrigated. However, there was no correlation (r=0.11) between the two parameters at drought, which may be explained by genotypic differences in terms of root adjustments to stress conditions. This assumption may be in accordance to the results of a study (NAHAR *and*

GRETZMACHER, 2011) including only seven tomato genotypes which exhibited highly significant differences concerning root dry weight and length, shoot dry weight and root-shoot ratio when grown at optimal and several variants of limited irrigation.

Table 3. Drought stress selection indices (SSI-RD) and Spearman's coefficients of rank correlation (r) between the indices and tomato seedling's shoot (SDW) and root (RDW) dry weight determined at optimal irrigation (irr) and drought (dr)

Shoot dry weight							
Index	Mean	Min	Max	SE	CV	$r_{(SDWirr)}$	$r_{(SDWdr)}$
SSI	0.957	0.260	1.260	0.036	23.7	0.49**	-0.48**
RDI	1.088	0.463	2.520	0.073	42.8	-0.49**	0.48**
MP	99.3	27.5	173.4	4.7	30.4	0.96**	0.64**
TOL	100.6	5.3	196.0	7.0	44.4	0.94**	0.16
SI	0.356	0.152	0.830	0.024	42.8	-0.49**	0.48**
YI	1.000	0.375	1.750	0.053	33.8	0.44**	1.00**
Pi	4271.6	1.6	14553.7	469.8	70.4	-0.99**	-0.53**
STI	0.346	0.033	1.000	0.032	59.7	0.80**	0.86**
GMP	84.3	27.3	149.5	4.0	30.0	0.80**	0.86**
HM	72.1	27.2	129.0	3.5	31.5	0.62**	0.97**
DI	0.373	0.073	1.170	0.036	61.0	-0.07	0.82**
k_1STI	0.511	0.001	3.040	0.102	127.2	0.96**	0.64**
k_2STI	0.508	0.009	3.050	0.096	121.0	0.63**	0.96**
ATI	3020.0	47.2	8597.9	315.6	66.9	0.99**	0.43**
SSPI	33.6	1.8	65.5	2.3	44.4	0.94**	0.16
SDI	0.644	0.175	0.850	0.024	23.7	0.49**	-0.48**
RD	64.4	17.5	84.8	2.4	23.7	0.49**	-0.48**
Root dry weight							
Index	Mean	Min	Max	SE	CV	$r_{(RDWirr)}$	$r_{(RDWdr)}$
SSI	0.765	-1.407	1.649	0.097	81.5	0.76**	-0.10
RDI	1.206	0.431	3.111	0.085	45.3	-0.76**	0.10
MP	5.2	1.6	10.8	0.4	44.2	0.97**	0.69**
TOL	3.2	-1.6	11.6	0.5	103.8	0.90**	0.17
SI	0.643	0.230	1.658	0.045	45.3	-0.76**	0.10
YI	1.000	0.427	1.874	0.055	35.2	0.53**	1.00**
Pi	27.7	0.3	57.8	2.4	56.7	-0.99**	-0.59**
STI	0.587	0.057	1.959	0.074	81.0	0.93**	0.78**
GMP	4.8	1.6	9.4	0.3	40.4	0.93**	0.78**
HM	4.5	1.6	8.5	0.3	38.0	0.86**	0.86**
DI	0.648	0.166	1.861	0.060	58.9	-0.24	0.66**
k_1STI	1.358	0.004	11.029	0.366	172.5	0.99**	0.64**
k_2STI	0.960	0.010	5.777	0.217	145.0	0.80**	0.92**
ATI	10.5	-2.7	52.5	2.1	130.4	0.97**	0.37*
SSPI	23.4	-11.9	86.3	3.8	103.8	0.90**	0.17
SDI	0.357	-0.657	0.770	0.045	81.5	0.76**	-0.10
RD	35.7	-65.8	77.0	4.5	81.5	0.76**	-0.10

SE-standard error of mean, CV-coefficient of variation (%)

*, **-significant at 0.05 and 0.01 levels of probability, respectively

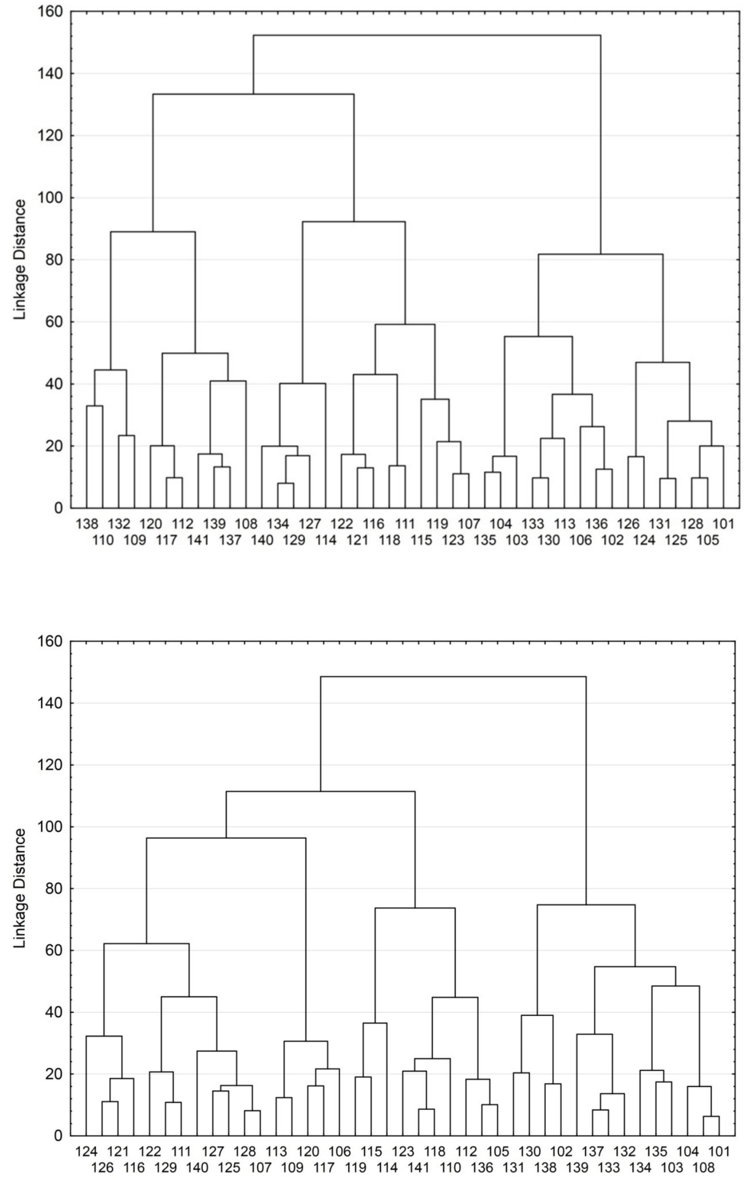

Figure 1. Dendogram of the tomato populations based on drought stress selection indices calculated for shoot (a) and root (b) dry weight yield

Nevertheless, shoot dry weight yield was in our study considered as selection criterion for drought tolerance in vegetative stage of tomato development; however, it is essential for plant breeders to decide on the method for differentiating the level of the tolerance among the genotypes. Numerous drought stress selection indices taking into account the relations between plant performance at stress and non-stress conditions have been proposed for this purpose (e.g. FISCHER and MAURER, 1978; FERNANDEZ, 1992; MOOSAVI *et al.*, 2008) and employed in several field and vegetable crops, such as wheat, maize, oat, rye, tomato and mung bean (ANWAR *et al.*, 2011; FARSHADFAR *et al.*, 2013; ZDRAVKOVIĆ *et al.*, 2013). In our study, sixteen commonly used selection indices have been calculated for both shoot and root dry weights (Table 3). Substantial variation was noted among the populations for all the indices, providing a good basis for their ranking in terms of drought tolerance. However, the ranking was not the same for all indices (not shown) which notably complicate the selection. In an attempt to determine the indices that are the most suitable for differentiating the populations, Spearman's coefficients of rank correlation have been calculated between the indices and dry weights measured at stress and non-stress conditions. However, all the indices correlated to stress and/or non-stress dry weights and those not correlating to dry weight determined at particular irrigation regime were not the same for shoots and roots. This was somewhat expected; since considerably different relationships among the indices and parameters related to drought tolerance have been reported by other authors (e.g. ANWAR *et al.*, 2011; ILKER *et al.*, 2011), even for the same material tested in different seasons (FARSHADFAR *et al.*, 2012). Therefore, differentiating the populations in terms of drought tolerance was performed taking into account their ranking on the basis of all sixteen calculated selection indices and using the method of cluster analysis (Figure 1).

The classification of populations in terms of shoot and root response to limited irrigation is depicted in Figure 1. Two main clusters are clearly noticeable in both dendograms. As for shoot dry weight, the two clusters separate populations with good or medium (subcluster 126-101 and 135-102, respectively) performance at both irrigation regimes from other populations. Amongst the remaining populations, attention should be paid on subcluster with populations 138-109 which are drought tolerant but with inherently low shoot dry weights. Comparatively low shoot dry weights are not necessarily undesirable; tomato varieties differ dramatically in terms of morphological characters such as plant height, number and length of lateral branches, fruit size etc. (GLOGOVAC *et al.*, 2010; ZDRAVKOVIĆ *et al.*, 2010), implying the variation in weight of plant vegetative parts. Thus, populations 126, 124, 131, 125, 128, 105, 101, 138, 110, 132 and 109 may be considered as starting material in selection for tomato drought tolerance. As seen in Figure 1b, those populations differed significantly in terms of root dry weight response to drought; e.g. 101, 131, 132 and 138 belong to the cluster which separates populations with low root dry weight at both optimal and limited irrigation (101-131) from other populations. On average, populations classified in this cluster exhibited moderate decrease (101, 131), and in one third of the cases the weight of their roots was even increased (132, 138) at drought treatments when compared to optimally irrigated control. On the other hand, drought caused significant root dry weight reduction in populations 124, 126, 125 and 128. Thus, the results of this study indicate that drought tolerant tomato genotypes differ in root adjustments to limited water supply, at least in vegetative stage of plant development.

Research on tomato drought tolerance has been mostly done on wild relatives and possibilities for introducing desirable alleles from exotic germplasm. When it comes to commercial cultivars and hybrids that are generally considered sensitive to abiotic stresses, few reports are available in the literature (FOOLAD *et al.*, 2003; FOOLAD, 2007; CHAVAN *et al.*, 2010). Tomatoes require adequate irrigation throughout the whole life cycle, with drought tolerance at one stage of development not necessarily correlating to tolerance at other stages. Therefore, a comprehensive research, preferably including all major plant developmental stages as well as fruit yield and quality as final selection criteria for tolerance would be useful contribution for solving the problem.

CONCLUSIONS

The results of this study indicate that genotypes designated with numbers 126, 124, 131, 125, 128, 105, 101, 138, 110, 132 and 109 in Smederevska Palanka tomato germplasm collection exhibit satisfactory level of drought tolerance, at least at the stage of intensive vegetative growth.

Root dry weight of the drought tolerant genotypes responded differently to limited water supply, in the range from increase of 65.8 (138) to decrease of 76.2% (126). Therefore, at vegetative stage of development, tomato genotypes differ in root adjustments to limited water supply.

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SUVA MASA NADZEMNOG DELA BILJKE I KORENA POPULACIJA PARADAJZA IZLOŽENIH SUŠI

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Izvod

Istraživanje je sprovedeno sa ciljem da se od četrdeset jedne testirane populacije paradajza (*Lycopersicon esculentum* Mill) izdvoje tolerantne na sušu. Procena tolerantnosti je izvršena pomoću šesnaest selekcionih indeksa računatih na osnovu prinosa suve materije nadzemnog dela biljke i korena merenih u uslovima optimalne i nedovoljne obezbeđenosti vodom. Klaster analiza je primenjena radi grupisanja proučavanih populacija prema tolerantnosti. Ogled je postavljen u saksijama smeštenim u staklenik, podrazumevao je optimalno zalivanu kontrolu i sušni tretman (zapreminski procenat sadržaja vlage u zemljištu 35,0 i 20,9%), primenjeno u fazi intenzivnog vegetativnog porasta. Eksperiment je izvršen u Institutu za povrtarstvo u Smederevskoj Palanci, Srbija. Između populacija su utvrđene razlike u pogledu reakcije na sušu, koja je u većoj meri uticala na suvu masu nadzemnog dela nego na korenove (prosečna redukcija 64,4 i 35,7%), što je uzrokovalo veću frakciju korenova u suvoj masi biljke u odnosu na kontrolu, prosečno 68,2%. Suve mase nadzemnog dela biljke i korenova su u pozitivnoj korelaciji kod kontrole ali ne i kod sušnog tretmana, što upućuje na razlike među populacijama u smislu prilagođavanja korenovog sistema na sušni stres. Varijabilnost utvrđena među populacijama u pogledu selekcionih indeksa omogućava rangiranje u smislu tolerantnosti. Pošto rangiranje genotipova nije bilo jednako u svim slučajevima, grupisanje je izvršeno uzevši u obzir svih šesnaest selekcionih indeksa. Genotipovi koji su u kolekciji Instituta označeni brojevima 126, 124, 131, 125, 128, 105, 101, 138, 110, 132 i 109 su izdvojeni kao tolerantni na sušu u vegetativnoj fazi životnog ciklusa i stoga mogu biti korišćeni kao roditelji u oplemenjivačkim programima.

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