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Using Stress Resistance Indices in Sunflower Cultivars Under Mild and Severe Drought Stress Conditions

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Abstract: In order to evaluate the utilization ability of drought resistance indices such as: yield stability index (YSI), stress susceptibility index (SSI), tolerance (TOL), mean productivity (MP), geometric mean productivity (GMP), stress tolerance index (STI) and Harmonic mean (HAM) in sunflower cultivars, an experiments were carried out at Campus of Agriculture and Natural Resources, Razi University, Kermanshah, Iran through 2010 and 2011. The experiment was laid out as split plot based on randomized complete blocks design with three replications. Irrigation regimes were as main-plots and cultivars as sub-plots. Main-plots were control (10 days irrigation regime) (without drought stress), mild drought stress (15 days irrigation regime) and severe drought stress (20 days irrigation regime). Sub-plots were eight sunflower cultivars (Azargol, Iroflor, Armavirovski, Lakumka, Alstar, Master, Sirna and Pumar). The results showed that under mild and severe drought stresses only STI, GMP, HAM and MP having positive and significant correlations with seed yield under non-stress and stress conditions were more effective in identifying the high yielding cultivars. The evaluation of cultivars using drought resistance indices indicated that Azargol hybrid had maximum seed yield under mild and severe drought stress and was superior to others.

Key words: *Helianthus annuus* · Drought stress · Tolerance indices

INTRODUCTION

Drought is one of the most important abiotic stresses that cause a considerable part of plant productions to be destroyed each year in different regions of the world. Approximately, 20,000,000 km^2 of the lands throughout the world are in semi-arid regions [1]. Sunflower (*Helianthus annuus* L.) is one of the most important oil crops with desirable cooking oil due to its high content of unsaturated fatty acids and lack of cholesterol [2]. Drought indices which provide a measure of drought based on loss of yield under drought conditions in comparison to normal conditions have been used for screening drought tolerant genotype [3]. These indices are either based on drought resistance or susceptibility of genotypes [4]. Drought resistance was defined by Hall [5] as the relative yield of a genotype compared to other genotypes subjected to the same drought stress. Drought susceptibility of a genotype is often measured as a function of the reduction in yield under drought stress [6]. The stress susceptibility index (SSI) suggested by Fischer and Maurer [7] for measurement of yield stability that apprehended the changes in both potential and actual yields in variable environments. Guttieri *et al.* [8] suggested that SSI more and less than 1 indicates above and below-average susceptibility to drought stress, respectively. The stress tolerance (TOL) was defined by Rosielle and Hamblin [9] as the differences in yield between the stress and irrigated environments and mean productivity (MP) as the average yield of genotypes under stress and non-stress conditions. The stress tolerance index (STI) was defined by Fernandez [4], which can be used to identify genotypes that produce high yield under both stressed and non-stressed conditions. The geometric mean productivity (GMP) is often used by breeders interested in relative performance,

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since drought stress can vary in severity in field environments over years [10]. The optimal selection criterion should distinguish genotypes that express uniform superiority in both stressed and non-stressed environments from the genotypes that are favorable only in one environment. The yield index (YI) [11] and yield stability index (YSI) [12] are the other yield-based estimates which evaluate the stability of genotypes in the both stress and non-stress conditions.

According to Fernandez [4] theory, genotypes classified into four groups based on their performance in stress and non-stress conditions: A: genotypes producing high yield under both stress and non-stress conditions, B: genotypes with high yield under non-stress condition, C: genotypes with high yield under stress condition, D: genotypes with poor performance under both stress and non-stress conditions. A suitable index must be able to distinguish the genotypes in group A from the other groups. In the present study we evaluated different drought resistance indices for screening of hybrids in sunflower.

MATERIALS AND METHODS

This study was carried out at campus of Agriculture and Natural Resources, Razi University, Kermanshah, Iran through 2010 and 2011. The Campus of Agriculture and Natural Resources Located in the west of Iran (34°20' N latitude, 47°20' E longitude, elevation 1351 m above sea level) in the moderate-cold and semiarid zone. Field experiment was conducted on a clay soil with pH 7.6, N 0.122%, P_2O_5, K_2O, Mn, Fe, Zn and Cu were equal 10.8, 380, 2.6, 6.2, 1.03 and 2.1 $mg.kg^{-1}$, respectively. Weather characteristics through growing seasons in 2010 and 2011 are presented in Table 1.

Experiment was laid out as split plot based on randomized complete blocks design with three replications. Irrigation regimes were as main plots and cultivars as subplots. Main plots were control (10 days irrigation regime) (without drought stress), mild drought stress (15 days irrigation regime) and severe drought stress (20 days irrigation regime). Sub-plots were eight cultivars (Azargod, Iroflor, Armavirovski, Lakumka, Alstar, Master, sirna and Pumar).

Water treatments performed after 14 leaf stage that synchronised with start of stem elongation. Planting was as furrow method by hand during early June in both years. Each sub-plots contained 5 rows with 55cm distance, 4.5m length and 25cm between two plants. For ensure to attainment of the desired density, three seeds planted in each hole and one of them remained after emerging. Water volume was the same for all treatments and plots. Weed control performed continuously during sunflower vegetative growth period by hand weeding. Based on results of soil testing, 250 kg/ha urea and 150 kg/ha superphosphate triple consumed. Heads covered with paper after pollination to protect against birds atack. Plants harvested in mid october for grain yields (contained 4 m^2 per each plot). The grain yield data were recorded for each genotype at each environment and used to calculate the drought tolerance criteria. The drought tolerance/resistance indices were calculated using the following formulas:

$$SSI = \frac{1-(Y_s/Y_p)}{SI}, SI = 1-\left[\frac{\overline{Y}_s}{\overline{Y}_p}\right] \quad [7]$$

1- $\overline{Y}_s$ / $\overline{Y}_p$ is the stress intensity.

The genotypes with SSI < 1 are more resistant to drought stress conditions.

$$STI = \left(\frac{Y_p}{\overline{Y}_p}\right)\left(\frac{Y_s}{\overline{Y}_s}\right)\left(\frac{\overline{Y}_s}{\overline{Y}_p}\right) = \frac{(Y_p)(Y_s)}{(\overline{Y}_p)^2} \quad [4]$$

The genotypes with high STI values will be tolerant to drought stress.

$$TOL = Y_P - Y_S \quad [9]$$

The genotypes with low values of this index are more stable in two different conditions.

$$MP = \frac{Y_s + Y_p}{2} \quad [9]$$

The genotypes with high value of this index will be more desirable.

$$GMP = (Ys)(Yp) \quad [4]$$

The genotypes with high GMP value will be more desirable.

$$HAM = \frac{2(Y_p \times Y_s)}{(Y_p + Y_s)}$$

The genotypes with high value of this index will be more desirable.

$$YSI = \frac{Y_s}{Y_p} \quad [12]$$

Table 1: Monthly weather parameters of the study area during growth season for 2010 and 2011

Months	Average temperature (°C)	Maximum temperature (°C)	Minimum temperature (°C)	Precipitation (mm)	Evapo-transpiration (mm)	Relative Humidity (%)	Wind speed (m s^{-1})
2010							
June	24.9	40.2	6.4	2.7	284.8	31	5.5
July	28.7	42.6	11.5	0.0	379.2	20	5.5
August	29.5	40.9	14.4	0.0	375.3	19	4.5
September	26.4	39.2	11.4	6.8	302.3	23	3.7
October	20.7	34.9	4.6	0.9	195.6	30	5.6
2011							
June	24.5	40.3	7.2	0.0	304.6	31	4.4
July	28.8	43.6	13.2	0.0	361.2	20	4.0
August	29.8	43.2	14.4	0.0	367.8	17	3.6
September	25.0	38.1	10.2	0.0	284.6	23	3.7
October	18.7	32.4	2.5	0.0	205.3	26	4.1

The genotypes with high YSI values can be regarded as stable genotypes under stress and non-stress conditions.

Ys and Yp are the yields of genotypes evaluated under stress and non-stress conditions and $\overline{Y}_s$ and $\overline{Y}_p$ are the mean yields over all genotypes evaluated under stress and non-stress conditions.

RESULTS AND DISCUSSION

To investigate suitable stress resistance indices for screening of cultivars under drought condition, grain yield of cultivars under both non-stress and stress conditions were measured. The best resistance indices were determined from the correlations coefficients between grain yield under both stress and non-stress conditions and drought resistance indices. A suitable index must have a significant correlation with grain yield under both the conditions [3]. Correlation coefficients matrix revealed that GMP, STI, HAM and MP indices could effectively be used for screening of drought resistant cultivars (Tables 12 and 13). Sio-Se Mardeh *et al*. [13] suggested that selection for drought tolerance in wheat under moderate stress could be conducted based on any of the MP, GMP and STI indices under stress and non-stress conditions. Fernandez [4] reported that STI and GMP indices are suitable for selection resistant cultivars of sunflower. Darvishzadeh *et al.* 14] reported GMP, MP and HAM indices to be the best indices screening of resistant cultivar in sunflower. The maximum value for stress susceptibility index (SSI) in mild drought stress was obtained for cultivars Sirna and Master and in severe drought stress was obtained for cultivars Alstar and Master indicating sensitivity of these cultivars to drought stress. As shown, selection based on SSI index identified cultivars with relatively high YP but low YS and this is in agreement those reported by with Sio-se Marde *et al*. [13] on wheat and Darvishzadeh *et al*. [14] on sunflower. Among the stress tolerance indices, a larger value of TOL and SSI represent relatively more sensitivity to stress, thus a smaller value of TOL and SSI are favored [15]. Darvishzadeh *et al*. [14] reported that GMP is more powerful than MP in separating group A cultivars and has a lower susceptibility to different amounts of YS and YP. Therefore, MP, which is based on arithmetic mean, will be biased when the difference between YS and YP is high. YSI index has low correlation with yield in both stress and non-stress conditions so this index could not be suitable for selection of resistant cultivars. In fact, high values of this index belong to cultivars that maintain their performance by changing the environmental conditions. Hence, YSI is an index of stability. The cultivars that have highest values for this index in mild drought stress (Iroflor, Pomar, Azargol and Armavirovski) and in severe drought stress (Azargol) showed lower performance reduction compare with other cultivars. In this experiment calculated correlation coefficient between indices STI and GMP was 0.99. STI index is calculated based on GMP index, high positive correlation between these indices is expectable [13]. High yield value in non-stress and stress environments was exhibited by cultivars Sirna (2010), Iroflor (2011) and Azargol (mean). The maximum value of STI, GMP, HAM and MP in mild drought stress and severe drought stress was observed for cultivars Sirna, Iroflor and Azargol.

Table 2: Yield under non-stress condition (Yp), yield under mild drought stress (Ys) and stress tolerance index (STI) of sunflower cultivars for 2010 and 2011 experiments

	Yp (kg.ha^{-1})			Ys (kg.ha^{-1})			STI		
Cultivars	2010	2011	Mean	2010	2011	Mean	2010	2011	Mean
Azargol	5416.2	4818.9	5117.5	4349.9	3874.8	4112.4	1.22	1.13	1.18
Iroflor	4606.4	5108.9	4857.6	4146.9	4045.2	4096.1	1.22	1.25	1.12
Armavirovski	4020.1	4739.3	4379.7	3626.9	3656.6	3641.7	0.75	1.05	0.90
Lakumka	4308.1	3497.3	3902.7	3715.3	3279.2	3497.3	0.83	0.69	0.76
Alstar	3552.9	3793.8	3673.4	3014.9	2927.6	2971.2	0.55	0.67	0.61
Master	3574.3	3636.3	3605.3	2988.6	2763.6	2876.1	0.55	0.61	0.58
Sirna	5960.1	3860.5	4910.3	4651.0	2935.6	3793.3	1.44	0.68	1.06
Pumar	3632.0	2981.8	3306.9	3243.8	2884.8	3064.3	0.61	0.52	0.56

Table 3: Tolerance index (TOL), mean productivity (MP) and geometric mean productivity (GMP) of sunflower cultivars under mild drought stress and non-stress conditions for 2010 and 2011 experiments.

	TOL			MP			GMP		
Cultivars	2010	2011	Mean	2010	2011	Mean	2010	2011	Mean
Azargol	1066.3	944.0	1005.1	4883.0	4346.8	4614.9	4853.8	4321.1	4587.5
Iroflor	459.4	1063.6	761.5	4376.6	4577.1	4476.9	4370.6	4546.1	4458.3
Armavirovski	393.2	1082.7	737.9	3823.5	4197.9	4010.7	3818.4	4162.9	3990.6
Lakumka	592.8	218.1	405.4	4011.7	3388.3	3700.0	4000.7	3386.5	3693.6
Alstar	538.0	866.2	702.1	3283.9	3360.7	3322.3	3272.9	3332.7	3302.8
Master	585.6	872.7	729.2	3281.4	3200.0	3240.7	3272.9	3170.1	3219.2
Sirna	1309.0	924.8	1116.9	5305.5	3398.0	4351.8	5265.0	3366.4	4315.7
Pumar	388.1	96.9	242.5	3437.9	3398.0	3417.9	3432.4	2932.9	3182.7

Table 4: Susceptibility stress index (SSI), yield stability index (YSI) and harmonic mean (HAM) of sunflower cultivars under mild drought stress and non-stress conditions for 2010 and 2011 experiments

	SSI			YSI			HAM		
Cultivars	2010	2011	Mean	2010	2011	Mean	2010	2011	Mean
Azargol	1.29	1.04	1.17	0.80	0.74	0.77	4824.8	4295.6	4560.2
Iroflor	0.65	1.11	0.88	0.90	0.73	0.81	4364.6	4515.3	4439.9
Armavirovski	0.64	1.22	0.93	0.90	0.70	0.80	3813.4	4128.1	3970.7
Lakumka	0.90	0.33	0.61	0.86	0.66	0.76	3989.8	3384.8	3687.3
Alstar	0.99	1.22	1.10	0.84	0.55	0.70	3261.8	3304.9	3283.4
Master	1.07	1.28	1.18	0.83	0.52	0.68	3255.3	3140.4	3197.9
Sirna	1.44	1.28	1.36	0.78	0.65	0.71	5224.8	3335.1	4279.9
Pumar	0.70	0.17	0.43	0.89	0.73	0.81	3427.0	2932.5	3179.7

Table 5: Yield under non-stress condition (Yp), yield under severe drought stress (Ys) and stress tolerance index (STI) of sunflower cultivars for 2010 and 2011 experiments

	Yp (kgha^{-1})			Ys (kgha^{-1})			STI		
Cultivars	2010	2011	Mean	2010	2011	Mean	2010	2011	Mean
Azargol	5416.2	4818.9	5117.5	4084.8	3576.8	3830.8	1.15	1.04	1.09
Iroflor	4606.4	5108.9	4857.6	3202.1	3773.3	3487.7	0.76	1.17	0.97
Armavirovski	4020.1	4739.3	4379.7	2534.5	3362.5	2948.5	0.53	0.96	0.74
Lakumka	4308.1	3497.3	3902.7	2851.1	2339.4	2595.3	0.63	0.49	0.56
Alstar	3552.9	3793.8	3673.4	1961.2	2112.9	2037.0	0.36	0.49	0.43
Master	3574.3	3636.3	3605.3	2261.8	1915.1	2088.4	0.42	0.42	0.42
Sirna	5960.1	3860.5	4910.3	4129.8	2538.8	3334.3	1.28	0.59	0.93
Pumar	3632.0	2981.8	3306.9	2275.4	2188.2	2231.8	0.43	0.39	0.41

Table 6: Tolerance index (TOL), mean productivity (MP) and geometric mean productivity (GMP) of sunflower cultivars under severe drought stress and non-stress conditions for 2010 and 2011 experiments

	TOL			MP			GMP		
Cultivars	2010	2011	Mean	2010	2011	Mean	2010	2011	Mean
Azargol	331.3	1242.1	1286.7	4750.5	4197.8	4474.2	4703.6	4151.6	4427.6
Iroflor	1404.2	1335.5	1369.9	3904.3	4441.1	4172.7	3840.6	4390.6	4115.6
Armavirovski	1485.5	1376.7	1431.1	3277.3	4050.9	3664.1	3192.0	3992.0	3592.0
Lakumka	1457.0	1157.9	1307.4	3579.6	2918.4	3249.0	3504.7	2860.4	3182.5
Alstar	1591.7	1680.9	1636.3	2757.0	2953.4	2855.2	2639.7	2831.2	2735.5
Master	1312.4	1721.2	1516.8	2918.0	2775.7	2846.9	2843.3	2638.9	2741.1
Sirna	1830.2	1321.6	1575.9	5045.0	3199.6	4122.3	4961.3	3130.6	4045.9
Pumar	1356.6	793.5	1075.0	2953.7	2585.0	2769.3	2874.8	2554.3	2714.6

Table 7: Susceptibility stress index (SSI), yield stability index (YSI) and harmonic mean (HAM) of sunflower cultivars under severe drought stress and non-stress conditions for 2010 and 2011 experiments

	SSI			YSI			HAM		
Cultivars	2010	2011	Mean	2010	2011	Mean	2010	2011	Mean
Azargol	0.73	0.78	0.75	0.75	0.74	0.74	4657.2	4105.9	4381.6
Iroflor	0.90	0.79	0.85	0.69	0.73	0.71	3778.0	4340.7	4059.3
Armavirovski	1.10	0.88	0.99	0.63	0.70	0.66	3108.9	3934.0	3521.4
Lakumka	1.00	1.01	1.00	0.66	0.66	0.66	3431.4	2803.5	3117.4
Alstar	1.33	1.35	1.34	0.55	0.55	0.55	2527.3	2714.2	2620.7
Master	1.09	1.44	1.26	0.63	0.52	0.57	2770.4	2508.9	2639.7
Sirna	0.91	1.04	0.97	0.69	0.65	0.67	4879.0	3063.1	3971.0
Pumar	1.11	0.81	0.96	0.62	0.73	0.68	2797.9	2524.1	2661.0

Table 8: Correlation coefficients among different drought tolerance indices and grain yield under normal and mild drought stress conditions in 2010 experiment

	YP	YS	SSI	STI	GMP	HAM	MP	TOL	YSI
YP	1								
YS	0.966**	1							
SSI	0.654ns	0.440ns	1						
STI	0.997**	0.979**	0.606ns	1					
GMP	0.993**	0.989**	0.564ns	0.997**	1				
HAM	0.991**	0.991**	0.554ns	0.997**	0.999**	1			
MP	0.994**	0.988**	0.571ns	0.998**	0.999**	0.999**	1		
TOL	0.879**	0.727*	0.931**	0.849**	0.818*	0.812*	0.824*	1	
YSI	-0.654ns	-0.440ns	-1.000**	-0.606ns	-0.564ns	-0.554ns	-0.571ns	-0.931**	1

ns, * and **: non- Significant at 5% and 1% level of probability, respectively. Ys: yield under mild stress; Yp: yield under non-stress; STI: stress tolerance index; YSI: yield stability index; HAM: harmonic mean; TOL: tolerance index; SSI: susceptibility stress index; MP: mean productivity; GMP: geometric mean productivity

Table 9: Correlation coefficients among different drought tolerance indices and grain yield under normal and mild drought stress conditions in 2011 experiment

	YP	YS	SSI	STI	GMP	HAM	MP	TOL	YSI
YP	1								
YS	0.887**	1							
SSI	0.573ns	0.134ns	1						
STI	0.973**	0.967**	0.372ns	1					
GMP	0.973**	0.964**	0.391ns	0.998**	1				
HAM	0.973**	0.969**	0.373ns	0.999**	0.999**	1			
MP	0.918**	0.968**	0.240ns	0.976**	0.967**	0.969**	1		
TOL	0.797*	0.431ns	0.948**	0.640ns	0.654ns	0.639ns	0.533ns	1	
YSI	0.408ns	0.696ns	-0.392ns	0.567ns	0.550ns	0.561ns	0.697ns	-0.112ns	1

ns, * and **: non- Significant at 5% and 1% level of probability, respectively. Ys: yield under mild stress; Yp: yield under non-stress; STI: stress tolerance index; YSI: yield stability index; HAM: harmonic mean; TOL: tolerance index; SSI: susceptibility stress index; MP: mean productivity; GMP: geometric mean productivity

Table 10: Correlation coefficients among different drought tolerance indices and grain yield under normal and severe drought stress conditions in 2010 experiment

	YP	YS	SSI	STI	GMP	HAM	MP	TOL	YSI
YP	1								
YS	0.983**	1							
SSI	-0.803*	-0.895**	1						
STI	0.995**	0.991**	-0.832**	1					
GMP	0.994**	0.997**	-0.860**	0.996**	1				
HAM	0.992**	0.998**	-0.869**	0.995**	0.999**	1			
MP	0.996**	0.995**	-0.850**	0.997**	0.999**	0.999**	1		
TOL	0.479ns	0.311ns	0.124ns	0.417ns	0.383ns	0.367ns	0.400ns	1	
YSI	0.803*	0.895**	-1.00**	0.832**	0.860**	0.869**	0.850**	-0.124ns	1

ns, * and **: non- Significant at 5% and 1% level of probability, respectively. Ys: yield under severe stress; Yp: yield under non-stress; STI: stress tolerance index; YSI: yield stability index; HAM: harmonic mean; TOL: tolerance index; SSI: susceptibility stress index; MP: mean productivity; GMP: geometric mean productivity

Table 11: Correlation coefficients among different drought tolerance indices and grain yield under normal and severe drought stress conditions in 2011 experiment

	YP	YS	SSI	STI	GMP	HAM	MP	TOL	YSI
YP	1								
YS	0.921**	1							
SSI	-0.408ns	-0.730*	1						
STI	0.967**	0.987**	-0.619ns	1					
GMP	0.970**	0.987**	-0.616ns	0.998**	1				
HAM	0.959**	0.993**	-0.649ns	0.997**	0.999**	1			
MP	0.980**	0.979**	-0.570ns	0.997**	0.998**	0.996**	1		
TOL	0.253ns	-0.143ns	0.778*	0.005ns	0.011ns	-0.030ns	0.058ns	1	
YSI	0.408ns	0.730*	-1.000**	0.619ns	0.616ns	0.649ns	0.579ns	-0.778*	1

ns,* and **: non- Significant at 5% and 1% level of probability, respectively. Ys: yield under severe stress; Yp: yield under non-stress; STI: stress tolerance index; YSI: yield stability index; HAM: harmonic mean; TOL: tolerance index; SSI: susceptibility stress index; MP: mean productivity; GMP: geometric mean productivity

Table 12: Correlation coefficients among different drought tolerance indices and grain yield under normal and mild drought stress conditions over two years

	YP	YS	SSI	STI	GMP	HAM	MP	TOL	YSI
YP	1								
YS	0.937**	1							
SSI	0.523ns	0.197ns	1						
STI	0.989**	0.977**	0.395ns	1					
GMP	0.986**	0.981**	0.380ns	0.999**	1				
HAM	0.984**	0.984**	0.366ns	0.998**	0.999**	1			
MP	0.989**	0.978**	0.393ns	0.999**	0.999**	0.999**	1		
TOL	0.799*	0.541ns	0.926**	0.705*	0.692*	0.681ns	0.703*	1	
YSI	0.225ns	0.513ns	-0.650ns	0.352ns	0.362ns	0.374ns	0.350ns	-0.341ns	1

ns, * and **: non- Significant at 5% and 1% level of probability, respectively. Ys: yield under severe stress; Yp: yield under non-stress; STI: stress tolerance index; YSI: yield stability index; HAM: harmonic mean; TOL: tolerance index; SSI: susceptibility stress index; MP: mean productivity; GMP: geometric mean productivity

Table 13: Correlation coefficients among different drought tolerance indices and grain yield under normal and severe drought stress conditions over two years

	YP	YS	SSI	STI	GMP	HAM	MP	TOL	YSI
YP	1								
YS	0.965**	1							
SSI	-0.684ns	-0.849**	1						
STI	0.987**	0.992**	0.783*	1					
GMP	0.987**	0.994**	-0.791*	0.999**	1				
HAM	0.982**	0.997**	-0.807*	0.998**	0.999**	1			
MP	0.991**	0.991**	-0.773*	0.998**	0.999**	0.998**	1		
TOL	0.149ns	-0.113ns	0.612ns	-0.001ns	-0.010ns	-0.037ns	0.018ns	1	
YSI	0.686ns	0.850**	-0.999**	0.785*	0.793*	0.809*	0.775*	-0.610ns	1

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