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Original scientific paper

EFFECTIVE SELECTION CRITERIA FOR SCREENING DROUGHT TOLERANT RECOMBINANT INBRED LINES OF SUNFLOWER

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In this study, seventy two sunflower recombinant inbred lines were tested for their yielding ability under both water-stressed and well-watered states. The inbred lines were evaluated in a rectangular 8×9 lattice design with two replications in both well-watered and water-stressed conditions, separately. Eight drought tolerance indices including stability tolerance index (STI), mean productivity (MP), geometric mean productivity (GMP), harmonic mean (HM), stress susceptibility index (SSI), tolerance index (TOL), yield index (YI) and yield stability index (YSI) were calculated based on grain yield for every genotype. Results showed the highest values of mean productivity (MP) index, geometric mean productivity (GMP), yield index (YI), harmonic mean (HM) and stress tolerance index (STI) indices for 'C134a' inbred line and least values of stress susceptibility index (SSI) and tolerance (TOL) for 'C61' inbred line. According to correlation of indices with yield performance under both drought stress and non-stress states and principle component analysis, indices including HM, MP, GMP and STI could properly distinguish drought tolerant sunflower inbred lines with high yield performance under both states. Cluster analysis of inbred lines using $Y_{s,}$ Y_p and eight indices, categorized them into four groups including 19, 6, 26 and 19 inbred lines.

Key words: Sunflower, drought tolerance indices, principle component analysis, cluster analysis.

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INTRODUCTION

Drought is the main environmental constraint, which occurs in many parts of the world every year, often having devastating effects on crop productivity. Hence, improving drought tolerant varieties is a major objective in dry land plant breeding programs (LUDLOW and MUCHOW, 1990). Sunflower (*Helianthus annuus* L.) as one of the most important sources of vegetable oil in the world is moderately tolerant to water stress and its production affected by drought conditions (PASDA and DIEPENBROCK, 1990). Drought stress during vegetative phase, flowering and seed filling period causes considerable decrease in yield and oil content of sunflower (RAZI and ASSAD, 1999). Plants can increase their tolerance to water stress through various mechanisms such as leaf area reduction, stomata closing, thicker cuticles, roots enlargment, producing or increasing the rate of some proteins, maintaining photosynthetic rates at high levels, reducing the rate of respiration and regulating the osmotic conditions (POORMOHAMMAD KIANI *et al*., 2007a, b, 2008, 2009).

Drought tolerance is defined as the relative yield of a genotype compared to other genotypes under drought conditions. The relative yield performance of genotypes in drought stressed and non-stressed environments seems to be a common starting point in the identification of desirable genotypes. Selection of suitable genotypes on the basis of relative yield performance has been considered a reliable technique for evaluating a large number of genotypes in drought stressed conditions (VOLTAS *et al.,* 1999; PANTHUWAN *et al.,* 2002).

Several selection indices based on a mathematical relation between yield in drought stressed and non-stressed conditions have been proposed. FISCHER and MAURER (1978) suggested stress susceptibility index (SSI) for yield stability measurement that apprehended the changes in both potential and actual yields in variable environments. ROSIELLE and HAMBLIN (1981) defined stress tolerance (tol) as the differences in yield between stressed (Y_s) and non-stressed (Y_p) environments and mean productivity (MP) as the average of Y_s and Y_p. FERNANDEZ (1992) defined a new advanced index (STI = stress tolerance index), which can be used to identify genotypes that produce high yield under both stressed and non-stressed conditions. FERNANDEZ (1992) classified plants materials according to their performance in different water availabilities to four groups: genotypes with similar good performance in both stressed and non-stressed environments (group A), genotypes with good performance only in non-stressed environments (group B) or stressful environments (group C), and genotypes with weak performance in both environments (group D). Other yield based estimates of drought tolerance are yield stability index (YSI) (BOUSLAMA and SCHAPAUGH, 1984), geometric mean productivity (GMP) (FERNANDEZ, 1992; KRISTIN *et al.,* 1997), yield index (YI) (GAVUZZI *et al.,* 1997), and harmonic mean (HM) (JAFARI *et al.,* 2009). Application of these drought tolerance indices in the selection of drought tolerant genotypes has been reported in several crops (KRISTIN *et al.,* 1997; SIO-SE MARDEH *et al.,* 2006; DARVISHZADEH *et al.,* 2010). The objective of present study was to identify the most suitable indices as well as drought tolerant genotypes in sunflower by using recombinant inbred lines population.

MATERIALS AND METHODS

Plant materials and experimental design

Seventy two F_9 recombinant inbred lines developed through single seed descent from a cross between the public sunflower parental lines PAC2 and RHA266 were used in this study (FLORES BERRIOS *et al.,* 2000). RHA266 was developed from the across between wild *H. annuus* and peredovik by the United States Department of Agriculture and PAC2 is an INRA-France inbred line developed from the cross between *H. petiolaris* and HA61 (POORMOHAMMAD KIANI *et al*., 2007b). RHA266 is a branched line with higher value in yield and 1000-grain weight compared to PAC2 (RACHID AL-CHAARANI *et al.,* 2004). Seeds of RILs and their two parents kindly provided by INRA-France were evaluated in both well-watered and water-stressed conditions using a rectangular 8×9 lattice design with two replications in each condition. The experiment was conducted in research farm of Urmia University, Iran. The latitude and longitude of region is 37° and 32' north and 45° and 5' east and its elevation is 1313 m above the sea level.

Table 1. Drought tolerance indices used for evaluation of the reaction of sunflower recombinant inbred lines to drought conditions.

Drought tolerance indices	Equation	Reference
stress susceptibility index	$SSI = \dfrac{1-(\dfrac{Y_S}{Y_P})}{1-(\dfrac{\bar{Y}_S}{\bar{Y}_P})}$	Fischer and Maurer (1978)
geometric mean productivity	$GMP = \sqrt{(Y_S)(Y_P)}$	Fernandez (1992) and Kristin et al. (1997)
mean productivity	$MP = \dfrac{Y_S + Y_P}{2}$	Rosielle and Hambling (1981)
harmonic mean	$HM = \dfrac{2(Y_P \, . \, Y_S)}{Y_P + Y_S}$	Jafari et al. (2009)
tolerance index	$TOL = Y_P - Y_S$	Rosielle and Hambling (1981)
stress tolerance index	$STI = \dfrac{(Y_S)(Y_P)}{(\bar{Y}_P)^2}$	Fernandez (1992)
yield index	$YI = \dfrac{Y_S}{\bar{Y}_S}$	Gavuzzi et al. (1997)
yield stability index	$YSI = \dfrac{Y_S}{Y_P}$	Bouslama and Schapaugh (1984)

Y_S and Y_P are stress and optimal (potential) yield of a given genotype, respectively. Y_S and Y_P are average yield of all genotypes under stress and optimal conditions, respectively.

Climate of the region is cold and semidry and the average rainfall and the area temperature according to 16 years statistics are 184 mm and 12°C, respectively. Each plot comprised 1 line with 8 m longs, with a spacing of 75×25 cm between lines and plants, respectively. The distance between well-watered and water-stressed experiments was considered 5 m. The water deficit treatment was applied by changing the irrigation intervals. Irrigations were carried out when an amount of evaporated water (from Class 'A pan' evaporation) reached to 60 (well-watered), and 180 (water-stressed) mm, respectively (POURTAGHI *et al.,* 2011). Amount of irrigation were applied identical for all treatments from planting to complete establishment of sunflower plants (eight-leaf stage (V8)). After this stage, the plots were irrigated according to their prescribed treatments (POURTAGHI *et al.,* 2011). Plants were harvested at maturity, and then the grain yield was recorded for every plot. The drought tolerance indices were calculated for every genotype using the corresponding well-watered and water-stressed plots in each block. The resulting data were analyzed as obtained from a randomized complete block design. Drought tolerance indices were calculated using the equations cited in Table 1.

Statistical analysis

One inbred line out of studied lines had missing data and was omitted from further analysis. The data were analyzed using the general linear model (GLM) procedure in the SAS software (SAS Institute Inc., Cary, NC, USA). Correlations between grain yield per plant in each of the water treatments regimes and drought tolerance indices were determined using SAS PROC CORR (SAS Institute Inc, NC, USA). Multivariate statistical analysis such as principle component analysis, biplot display, three dimensional plots and cluster analysis were performed using the SPSS version 15.0 and StatGraphics version 5.

RESULTS AND DISCUSSION

Genetic variability for grain yield

Analysis of variance revealed significant differences among sunflower inbred lines for all of the studied indices (data not presented). The highest yield value was obtained in C134a followed by C123, C107a, C127a, LR1, LR32, LR16a, C40, C111, LR30-1, LR18b and C34 under stressed condition, and in C134a followed by C55, C86, C123, LR8, C127a, LR1, C107a and LR16a under non-stressed condition (Table 2). The lowest yield value was possessed to LR16b followed by C125b, C78, C148, LR34, C130b, C42, and C100 under stressed condition, and possessed to C125b, LR16b, C100, C129, C137 and C90 under non-stressed condition (Table 2). In addition, C134a followed by LR32, LR1, C134a, C107a, C123, LR16a and C127a had the highest and LR16b, C125b, C148, and C137 had the lowest yield in both stressed and non-stressed environments. Similar to finding of DARVISHZADEH *et al.* (2010), variability of yield in both stressed and non-stressed environments can imply the existence of useful resource for selection of drought tolerant genotypes through classical breeding methods.

According to Fischer and Maurer index (SSI) (1978), the inbred lines C78, LR8, RHA266, C130b, C77, LR30, LR34, LR5, C148 and C55 with high SSI values were found to be the most susceptible genotypes whereas inbred lines C61, LR25a, LR53, LR57, C104, C143, C40, C106, LR19, LR51, LR32 and C124 with low value were found to be tolerant to drought stress (Table 2). The less numerical rate of SSI indicates less stress susceptibility and more water stress tolerance of a genotype. YADAV and BHATNAGAR (2001) suggested the use of SSI in combination with yield value under stressed condition for identifying drought tolerant/susceptible genotypes.

Considering TOL index, a genotype would be more tolerant if it has less TOL value. Based on TOL, the inbred lines C61, LR25a, LR53, LR57, C107a, C111, C104, C129, C150, C143, C106, LR51, C40, LR54 and C124 with low values were considered as tolerant genotypes, whereas the inbred lines C55, C86, LR30, C71, LR5 and C134a with the high TOL values were considered as susceptible (Table 2). FERNÁNDEZ (1992) has been manifested that TOL index was efficient in improving yield under stressed condition and the selected genotypes performed poorly under non-stressed condition. Yield stability index (YSI) also was calculated for a given inbred lines using grain yield under stressed and non-stressed conditions. The genotypes with high YSI is expected to have high yield under stressed and low yield under non-stressed conditions. The lowest YSI was observed for C78, LR8, C130b, C77 and RHA266 and the highest YSI was observed for C61, LR25a, LR53, C107a, C111, LR57, C150, C40, C129, C106 and LR32 inbred lines (Table 2).

Table 2. Average yield under optimal and stress conditions and drought tolerance indices values of the studied sunflower recombinant inbred lines.

No.	RIL	YS	YP	SSI	GMP	MP	HM	TOL	STI	YI	YSI
1	RHA266	5.99	16.23	2.33	9.86	11.11	8.75	10.24	0.29	0.46	0.37
2	PAC	11.27	13.76	0.67	12.45	12.52	12.39	2.49	0.46	0.87	0.82
3	C55	16.53	42.92	2.28	26.64	29.73	23.87	26.39	2.13	1.28	0.39
4	LR16b	2.31	5.47	2.14	3.55	3.89	3.25	3.16	0.04	0.18	0.42
5	C59	13.30	14.50	0.31	13.89	13.90	13.87	1.2	0.58	1.03	0.92
6	C104	16.62	16.94	0.07	16.78	16.78	16.78	0.32	0.84	1.28	0.98
7	C127a	25.64	30.20	0.56	27.83	27.92	27.73	4.56	2.32	1.98	0.85
8	C126	9.56	17.25	1.65	12.84	13.41	12.30	7.69	0.49	0.74	0.55
9	LR7	7.96	11.49	1.14	9.56	9.73	9.40	3.53	0.27	0.61	0.69
10	LR25a	12.45	12.60	0.04	12.52	12.53	12.52	0.15	0.47	0.96	0.99
11	C138	9.95	17.56	1.60	13.22	13.76	12.70	7.61	0.52	0.77	0.57
12	C71	9.12	20.81	2.08	13.78	14.97	12.68	11.69	0.57	0.70	0.44
13	C70	11.16	15.22	0.99	13.03	13.19	12.88	4.06	0.51	0.86	0.73
14	LR53	7.56	10.52	1.04	8.92	9.04	8.80	2.96	0.24	0.58	0.72
15	C137	6.81	10.35	1.27	8.40	8.58	8.21	3.54	0.21	0.53	0.66
16	LR53	12.48	12.64	0.05	12.56	12.56	12.56	0.155	0.47	0.96	0.99
17	LR54	10.23	11.02	0.27	10.62	10.63	10.61	0.79	0.34	0.79	0.93
18	C40	21.19	21.96	0.13	21.57	21.58	21.57	0.77	1.40	1.64	0.96
19	C100	5.83	7.73	0.91	6.71	6.78	6.65	1.9	0.14	0.45	0.75
20	C90	8.14	10.48	0.83	9.24	9.31	9.16	2.34	0.26	0.63	0.78
21	LR16a	23.29	26.60	0.46	24.89	24.95	24.84	3.31	1.86	1.80	0.88
22	LR35	10.84	14.40	0.91	12.49	12.62	12.37	3.56	0.47	0.84	0.75
23	C86	18.78	35.71	1.75	25.90	27.25	24.61	16.93	2.01	1.45	0.53
24	LR8	10.57	31.07	2.44	18.12	20.82	15.77	20.5	0.98	0.82	0.34
25	C129	9.54	9.97	0.16	9.75	9.76	9.75	0.43	0.29	0.74	0.96
26	C123	28.51	34.37	0.63	31.30	31.44	31.17	5.86	2.94	2.20	0.83
27	C98a	11.52	20.28	1.60	15.28	15.90	14.69	8.76	0.70	0.89	0.57
28	C42	5.59	13.18	2.13	8.58	9.39	7.85	7.59	0.22	0.43	0.42
29	C143	17.35	17.99	0.13	17.67	17.67	17.66	0.64	0.94	1.34	0.96

30	C61	16.02	16.08	0.01	16.05	16.05	16.05	0.06	0.77	1.24	1.00
31	C92	16.55	26.48	1.39	20.93	21.52	20.37	9.93	1.31	1.28	0.63
32	LR30-1	20.52	22.91	0.39	21.68	21.72	21.65	2.39	1.41	1.58	0.90
33	C107a	26.98	27.22	0.03	27.10	27.10	27.10	0.24	2.20	2.08	0.99
34	C142	9.20	12.02	0.87	10.52	10.61	10.42	2.82	0.33	0.71	0.77
35	C76	10.41	16.41	1.35	13.07	13.41	12.74	6	0.51	0.80	0.63
36	LR51	10.85	11.52	0.22	11.18	11.19	11.17	0.67	0.37	0.84	0.94
37	LR5	8.90	20.52	2.10	13.51	14.71	12.42	11.62	0.55	0.69	0.43
38	C108	10.94	15.99	1.17	13.23	13.47	12.99	5.05	0.52	0.84	0.68
39	C150	17.68	18.15	0.09	17.91	17.91	17.91	0.465	0.96	1.36	0.97
40	C34	19.24	21.94	0.46	20.55	20.59	20.50	2.7	1.27	1.49	0.88
41	C131	13.14	15.63	0.59	14.33	14.39	14.28	2.49	0.62	1.01	0.84
42	C134a	39.98	51.17	0.81	45.23	45.58	44.89	11.19	6.13	3.09	0.78
43	C125b	2.56	4.63	1.65	3.44	3.60	3.30	2.07	0.04	0.20	0.55
44	LR19	18.69	19.85	0.22	19.26	19.27	19.25	1.16	1.11	1.44	0.94
45	C77	6.50	17.61	2.33	10.70	12.06	9.50	11.11	0.34	0.50	0.37
46	C139	10.61	16.01	1.25	13.03	13.31	12.76	5.4	0.51	0.82	0.66
47	LR44	18.53	23.22	0.75	20.74	20.88	20.61	4.69	1.29	1.43	0.80
48	LR4	10.14	14.37	1.09	12.07	12.26	11.89	4.23	0.44	0.78	0.71
49	LR18b	19.48	22.60	0.51	20.98	21.04	20.92	3.12	1.32	1.50	0.86
50	C111	20.59	20.84	0.04	20.71	20.72	20.71	0.25	1.29	1.59	0.99
51	C62	10.64	12.17	0.47	11.38	11.41	11.35	1.53	0.39	0.82	0.87
52	LR34	5.18	12.96	2.22	8.19	9.07	7.40	7.78	0.20	0.40	0.40
53	LR67	9.14	11.82	0.84	10.39	10.48	10.31	2.68	0.32	0.71	0.77
54	LR57	14.62	14.85	0.06	14.73	14.74	14.73	0.23	0.65	1.13	0.98
55	LR59	9.72	16.07	1.46	12.50	12.90	12.11	6.35	0.47	0.75	0.60
56	LR1	24.41	27.45	0.41	25.89	25.93	25.84	3.04	2.01	1.88	0.89
57	C54	9.06	17.78	1.81	12.69	13.42	12.00	8.72	0.48	0.70	0.51
58	C148	4.40	10.86	2.20	6.91	7.63	6.26	6.46	0.14	0.34	0.41
59	C106	8.25	15.49	1.73	11.30	11.87	10.77	7.24	0.38	0.64	0.53
60	LR32	23.94	25.59	0.24	24.75	24.77	24.74	1.65	1.84	1.85	0.94
61	LR29	17.19	21.30	0.71	19.13	19.24	19.02	4.115	1.10	1.33	0.81
62	C124	9.67	10.58	0.32	10.11	10.13	10.10	0.91	0.31	0.75	0.91
63	C89	8.96	16.54	1.70	12.17	12.75	11.62	7.58	0.44	0.69	0.54
64	C121	8.32	18.73	2.06	12.48	13.53	11.52	10.41	0.47	0.64	0.44
65	C79	8.47	14.72	1.57	11.17	11.60	10.75	6.25	0.37	0.65	0.58
66	C130b	5.53	15.22	2.36	9.17	10.38	8.11	9.69	0.25	0.43	0.36
67	LR30	9.39	24.94	2.31	15.30	17.17	13.64	15.55	0.70	0.72	0.38
68	C101	16.49	24.91	1.25	20.27	20.70	19.84	8.42	1.23	1.27	0.66
69	C78	3.63	12.56	2.63	6.75	8.10	5.63	8.93	0.14	0.28	0.29
70	C106	12.84	13.50	0.18	13.17	13.17	13.16	0.66	0.52	0.99	0.95
71	LR46	12.37	20.84	1.50	16.06	16.61	15.52	8.47	0.77	0.95	0.59

FERNANDEZ (1992) proposed STI index which discriminates genotypes with high yield and stress tolerance potentials. A high STI demonstrates a high tolerance and the best advantage of STI is its ability to separate group A genotypes from other genotypes. Based on the STI index, the inbred lines including C134a C123, C127a, C107a, C55, C86 and LR1 had the high values and considered as tolerant lines with high yield stability in the both conditions (Table 2). In this study, the results of GMP, MP, HM and YI indices in selection of genotypes were similar to STI index. This result is not unexpected regarding to reported significant relation between STI with GMP, MP, HM and YI indices in sunflower (DARVISHZADEH *et al.,* 2010).

Correlation between grain yield and drought tolerance indices

Correlation coefficients were used to identify the best criterion for selecting drought-tolerant genotypes. According to literature (FARSHADFAR and SUTKA, 2002; DARVISHZADEH *et al.,* 2010), a suitable index must to have a significant relation with yield in both stressed and non-stressed states. As shown in Table 3, indices including GMP, MP, HM, YI and STI were highly correlated with each other as well as with Y_s and Y_p. The observed relations were consistent with those reported by FERNANDEZ (1992) in mungbean, FARSHADFAR and SUTKA (2002) in maize, GOLABADI *et al.* (2006) in durum wheat and Darvishzadeh et al. (2010) in sunflower. However, TOL and SSI were not strongly correlated with the above mentioned indices. On the other hand, TOL and SSI show rankings different from the other indices. The positive correlation between TOL and Y_p and the negative correlation between TOL and Y_s was found (Table 3) which suggesting selection based on TOL will lead to reduction of yield under well-watered conditions. Similar results were reported by CLARK *et al.* (1992) and SIO-SE MARDEH *et al.* (2006). SSI showed a negative correlation with Y_s. Any significant correlation was not found between Y_P and SSI.

Table 3. Correlation between different drought tolerance indices and mean yield of sunflower recombinant inbred lines under optimal and stress conditions.

	YS	YP	SSI	GMP	MP	HM	TOL	STI	YI
YP	0.78^{***}								
SSI	-0.56^{***}	0.02^{ns}							
GMP	0.96^{***}	0.92^{***}	-0.33^{**}						
MP	0.93^{***}	0.95^{***}	-0.26^{*}	0.99^{***}					
HM	0.98^{***}	0.89^{***}	-0.39^{***}	0.99^{***}	0.99^{***}				
TOL	-0.12^{*}	0.54^{***}	0.79^{**}	0.17^{ns}	0.26^{*}	0.1^{ns}			
STI	0.91^{***}	0.88^{***}	-0.24^{*}	0.95^{***}	0.95^{***}	0.95^{***}	0.19^{ns}		
YI	0.99^{***}	0.78^{***}	-0.56^{***}	0.96^{***}	0.93^{***}	0.97^{***}	-0.1^{ns}	0.91^{***}	
YSI	0.56^{***}	-0.02^{**}	-0.99^{***}	0.33^{**}	0.26^{*}	0.39^{***}	-0.79^{***}	0.25^{*}	0.56^{***}

^{ns}: non significant. *, ** and *** significant at 5, 1 and 0.1% probobility level, respectively.

Thus SSI index is suitable factor to identification of genotypes with low yield and olerant to drought stress. SSI has been widely used by researchers for discriminating drought tolerant/susceptible genotypes (FISCHER and MAURER, 1978; CLARKE *et al.,* 1984, 1992; WINTER *et al.,* 1988). TOL and SSI indices were employed by GAVUZZI *et al.* (1993) to identify genotypes with superior drought adaptation in trials conducted in several locations of southern

Italy. The correlation coefficients of YSI with Y_p were negative while it had positive correlation with Y_s. These results are disagreed with BOUSLAMA and SCHAPAUGH (1984) who stated that cultivars with a high YSI were expected to have high yield under both stressed and non-stressed conditions. However, SIO-SE MARDEH *et al.* (2006) found that cultivars with the highest YSI exhibit the low yield under non-stressed and the high yield under stressed conditions. In this research, there was significant positive correlation among TOL and SSI while there was significant negative correlation between YI and YSI.

Interrelationship among selected indices and grain yield

Regarding to correlation coefficient, GMP, MP, HM, YI and STI are better predictors of Y_p and Y_s. To identify the relationship among Y_P, Y_S and these suitable drought tolerance indices, three-dimensional plots were employed (Figure 1). These plots show the ability of drought tolerance indices in detecting FERNANDEZ (1992) groups. By using drought tolerance indices and Y_p and Y_s, three dimensional diagrams could partition the inbred lines in four groups: (1) genotypes producing high yield under both water stressed and non-stressed environments (group A), (2) genotypes with high yield under either non-stress (group B) or (3) stress (group C) environments and (4) genotypes with poor performance under both stressed and non-stressed environments (group D). A suitable index must be able to distinguish group A genotypes from the other groups. Three dimensional plots corresponding to GMP, MP, HM, YI and STI indices were illustrated that inbred lines 'C127a, C40, LR16a, C86, C123, LR30-1, C107a, C34, C134a, LR44, C111, LR1 and LR32 are drought toelrant because they express uniform superiority in both stressed and non-stressed conditions (Group A) (Figure 1). Considering to lower susceptibility of GMP to different amounts of Y_S and Y_P, it is more powerful than MP in separating group A genotypes, where the difference between Y_S and Y_P is high (FERNANDEZ, 1992). Based on results, YI index is a suitable criterion for selection of drought tolerant genotypes and can distinguish group A genotypes. However, in contrast to our results, Sio-Se Marde et al. (2006) reported that YI indiex did not discriminate genotypes belonging to group A in wheat. Paralleled with the results of FERNANDEZ (1992), KRISTIN et al. (1997), FARSHADFAR and SUTKA (2002) and DARVISHZADEH *et al.* (2010), the STI could identified group A genotypes, properly.

Multivariate analysis

Correlation coefficients are useful in finding the degree of overall linear association between any two attributes but selection based on a combination of indices may be provided a more useful criterion for improving sunflower tolerance to drought stress. Principal Component Analysis (PCA) is one way to compress data sets of high dimensional vectors into lower dimensional ones.

Principal component analysis (PCA) revealed that the first PCA (PC1) explained 69.35% of the variation and had positive correlation with Y_s, Y_p, MP, GMP, HM, TOL, YI, YSI and STI (Table 4). Thus, the first dimension can be named as the yield potential and drought tolerance. Genotypes possessed high values of PC1, could be high yielding under stressed and non-stressed environments. The second PCA (PC2) explained 28.55% of the total variability and correlated positively with TOL and SSI (Table 4).

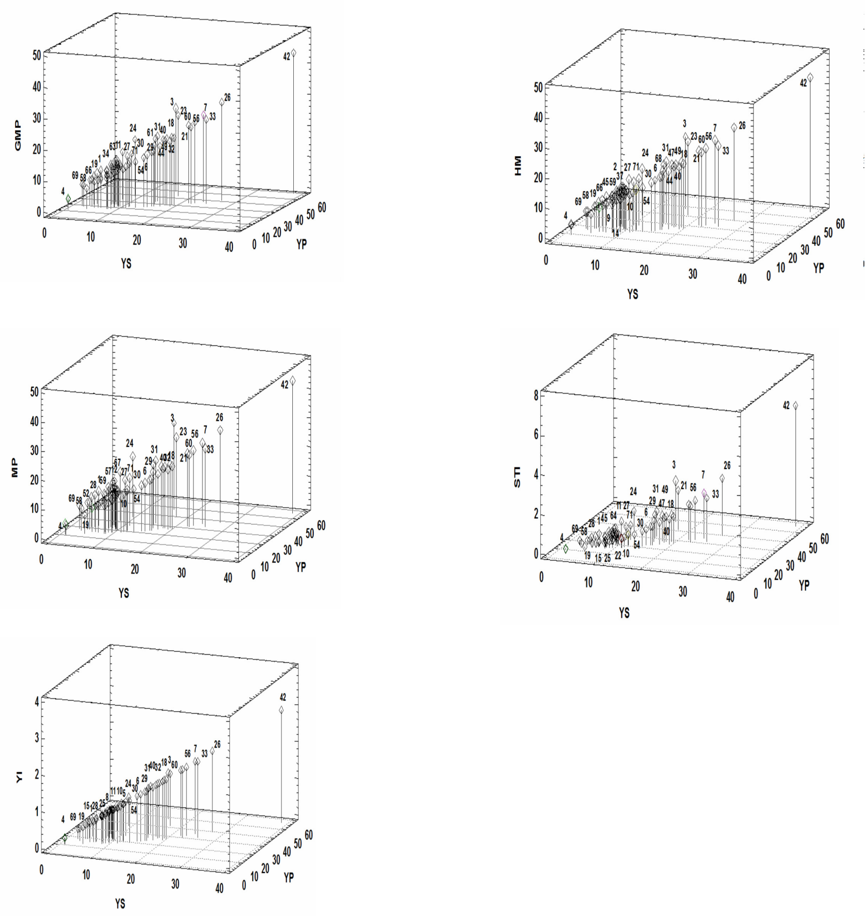

Figure 1. Tree dimension scheme of potential yield (Y_P), stress yield (Y_S) and geometric mean productivity (GMP), harmonic mean (HM), mean productivity (MP), stress tolerance index (STI) and yield index (YI) for sunflower inbred lines. Genotype codes: see Table 1.

Therefore, the second component can be named as a stress-tolerant dimension and it separates the stress-tolerant genotypes from non-stress tolerant ones. Selection of genotypes that have high PC1 and low PC2 are suitable for both stressed and non-stressed environments. Considering high value of PC1 and low value of PC2, inbred lines with code number of 7, 18, 21, 26, 32, 33, 40, 42, 47, 49 50, 56 and 60 were superior genotypes for both stressed and non-stressed environments. Inbred lines belonging to numbers 1, 3, 12, 23, 24, 37, 42, 45, 67 and 69 with high values of PC2 were more suitable for non-moisture stress than for moisture-stress environment. Moreover, in agreement with DARVISHZADEH *et al*. (2010), the proximity of genotypes to important drought tolerant indices in the biplot presentation (Figure 2) could depict drought tolerant genotypes. Considering to Figure 2, there was high genetic variability for drought tolerant among studied inbred lines. FARSHADFAR and SUTKA (2002), SIO-SE MARDEH *et al.* (2006) and GOLABADI *et al.* (2006) were also obtained similar results in multivariate analysis of drought tolerance in different crops.

Table 4. Eigen value and vectors of principal component analysis for potential yield (YP), stress yield (YS) and drought tolerance indices[1]

Principal component	1	2
Eigen value	6.93	2.85
Percentage of variance	69.35	28.55
Cumulative percentage	69.35	97.90
YP	0.33	0.29
YS	0.37	- 0.08
SSI	-0.17	0.52
TOL	0.02	0.57
MP	0.37	0.13
GMP	0.37	0.08
STI	0.36	0.11
HM	0.37	0.04
YI	0.37	-0.08
YSI	0.17	-0.52

[1] Indices: see Table 1.

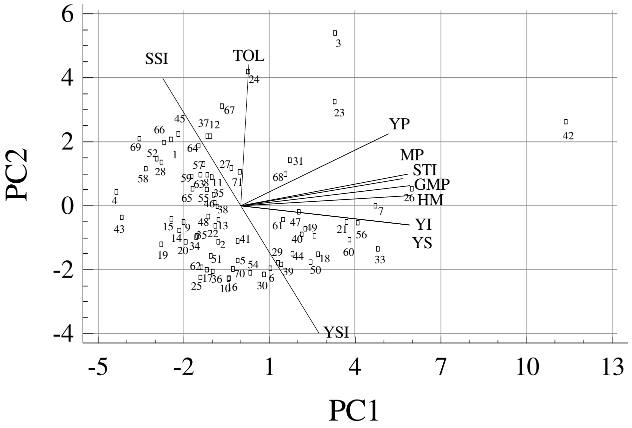

Figure 2. The genotype by trait biplot of sunflower breeding for resistance to drought stress trial. The indices are abbreviated in uppercase letters (see Table 1), and each inbred lines is represented by numbers (see Table 2.).

The cluster analysis was done to study the variation between genotypes based on drought tolerance indices. Cluster analysis based on drought tolerance indices and using UPGMA clustering method (Figure 3), grouped the studied inbred lines into four separate groups which involved 19, 6, 26 and 19 of inbred lines, respectively.

Group I and Group II were comprised genotypes that had low yield in stressed state. Hence, genotypes possessed to these groups could stable in non-stressed state and considered as group B. Clustering results revealed that the group III genotypes locate in group D (low Y_s and Y_p) because in the most cases, have high TOL and SSI values among all studied genotypes. Group IV was included genotypes that had highest value of STI, HM and GMP indices accompany with higher grain yield (Table 2) and located in group A of Fernandez's classification. In consistent with findings of DARVISHZADEH *et al.* (2010), the classification based on cluster analysis was paralleled with biplot analysis.

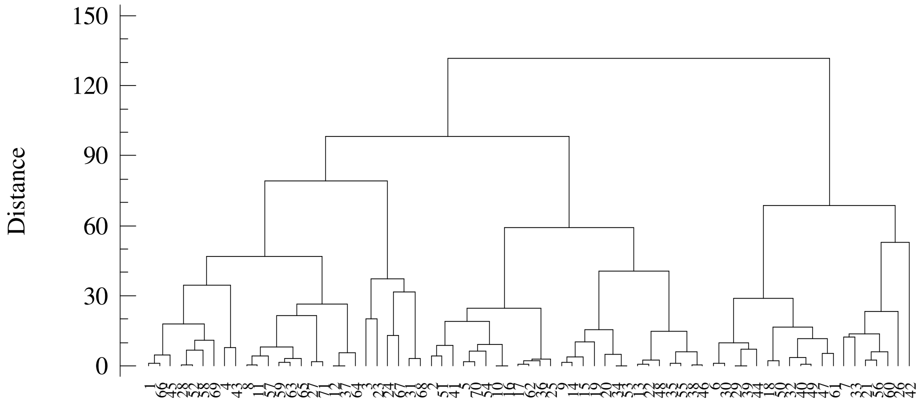

Figure 3. Dendrogram from cluster analysis based on drought tolerance indices and grain yield of sunflower recombinant inbred lines in both normal and stress environment. Genotype codes: see Table 2.

CONCLUSIONS

To sum up, drought tolerance indices including HM, MP, GMP and STI were suggested for selection of drought tolerant sunflower genotypes with high yield performance under both drought stressed and non-stressed states (group A genotypes). In addition, the genotype selection can be done based on PCA results (using several indices information instead of only one index). Clustering of genotypes based on drought tolerance indices as independent variables could identify Fernandez's classification. For hybrid breeding programmes and construction of mapping population for QTL analysis of drought tolerance, we suggest making a first selection of parents according to MP, GMP, HM and STI indices.

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EFEKTIVNI KRITERIJUMI SELEKCIJE U TESTIRANJU REKOMBINOVANIH LINIJA SUNCOKRETA TOLERANTNIH NA SUŠU

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Izvod

U radu su prikazani rezultati testiranja 72 rekombinantne samooplodne linije suncokreta na prinos u uslovima suše i uslovima navonjavanja. Linije su ocenjivane u rectangular 8×9 dizajnu u dva ponavljanja kako u uslovima suše tako i u uslovima navodnjavanja. Korišćeno je osam indikatora tolerantnosti na sušu uključujući indeks stabilnosti tolerantnosti (STI), prosečnu produktivnost (MP), geometrijski prosečnu produktivnost (GMP), harmonični prosek (HM), indeks osetljivosti na stress suše (SSI), indeks tolerantnosti (TOL). Indeks prinosa (YI) i indeks stabilnosti prinosa (YIS) izračunatih na osnovu prinosa za svaki genotip. Rezultati su pokazali najveće vrednosti indeksa prosečne produktivnosti (MP), geometrijske prosečne produktivnosti (GMP), indeksa prinosa (YI), harmoničnog prinosa (HM) i indeksa tolerantnosti na stress suše (STI) za 'C134a' samooplodnu liniju i najnižu vrednost indeksa osetljivosti na sušu (SSI) i tolerantnosti (TOL) za C61 samooplodnu liniju. Prema korelaciji pokazatelja za osobinu prinosa u uslovima stresa suše i u nestresnim uslovima i analize osnovnih komponenata, pokazatelji, uključujući HM, MP, GMP i STI mogu na pravi način razdvojiti samooplone linije suncokreta tolerantnih na sušu sa visokim osobinama prinosa u normalnim i stresnim uslovima suše.

Analizom grupisanja samooplodnih linija korišćenjem Y_s i Y_p i osam pokazatelja dobijene su četiri grupe, uključujući 19, 6, 26, i 19 samooplodnih linija

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