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Defining Selection Indices for Drought Tolerance in Chickpea under Terminal Drought Stresses

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Abstract

Chickpea improvement for drought tolerance requires reliable assessment of drought tolerance variability among different genotypes. In order to evaluate quantitative drought resistance criteria in some chickpea breeding lines, thirty five genotypes were evaluated both under moisture stress (E1) and non-stress (E2) field environments using a randomized complete block design for each environment. Seven drought tolerance indices including stress susceptibility index, stress tolerance index, tolerance, yield index, yield stability index, mean productivity and geometric mean productivity were used. The significant and positive correlations of Yp and (MP, GMP and STI) and Ys and (MP, GMP and STI) under both the seasons as well as significant negative correlation of SSI and TOL in E1 revealed that selection could be conducted for high MP, GMP and STI under both environments and low SSI and TOL under E1 conditions. The calculated correlation coefficients revealed that STI, MP, and GMP are the superior criteria for selection of high yielding genotypes both under E1 and E2. Results of calculated gain from indirect selection indicated that selection from moisture stress environment would improve grain yield in moisture stress environment better than selection from non-moisture stress environment.

Keywords: Chickpea, drought stress, tolerance index, grain yield

INTRODUCTION

Chickpea is the third most important pulse crop in the world, and it ranks first in the Mediterranean region [1]. It covers 15% of the cultivated area and contributes to 14% (7.9 million ton) of the world's pulse harvest of about 58 million tons [2]. Besides being an important source of human and animal food, chickpea also plays an important role in the maintenance of soil fertility, particularly in the dry, rainfed areas [3,4]. The major chickpea cultivation areas are almost completely in the arid and semi-arid zones of the world. In these areas, chickpea is continuously exposed to increasing drought and high temperatures during flowering and maturity stages [2,5,6,7,] due to insufficient and irregular rainfall. Under mentioned conditions, chickpea faces two types of drought, terminal (soil moisture content is continuously decreased towards the end of the growing season) and intermittent drought (soil moisture depends on precipitation but rainfall is irregular and also insufficient) [7]. Kumar and Abbo (2001) [8] reported that about 90% of the world's chickpea is grown under rainfed conditions where terminal drought is the major stress, accompanying with high temperature stress. Although chickpea is more drought-resistant than other cool-season food legumes, drought is the most important yield reducer in this crop [9,10]. Progress has been made in selecting early-flowering lines for this purpose [11]. Having optimized the crop duration for a particular target terminal-drought environment, the next step should be to genetically enhance the other drought-resistance characteristics, using germplasm base containing large genotypic variation. However, the methods so far developed to identify genotypic differences for drought resistance are cumbersome and generally inappropriate for handling the large number of lines needed for a plant breeding programme, in terms of screening germplasm of both parental material and progenies. And the efficiency of conducting a standard breeding programme in a drought-prone environment can be greatly reduced because of the large seasonal variations in the magnitude of drought stress and possible low yield potential in selected types. These factors have discouraged concerted efforts to breed specifically for drought resistance in chickpea, as well as in most other crops. To differentiate drought resistance genotypes, several selection indices have been suggested on the basis of a mathematical relationship between favorable and stress conditions [12,13]. Tolerance (TOL) [14,15], mean productivity (MP) [14,15], stress susceptibility index (SSI) [16], geometric mean productivity (GMP) and stress tolerance index (STI) [17] have all been employed under various conditions. Fischer and Maurer (1978) [16] explained that genotypes with an SSI of less than a unit are drought resistant, since their yield reduction in drought condition is smaller than the mean yield reduction of all genotypes [18]. Selection of different genotypes under environmental stress conditions is one of the main tasks of plant breeders for exploiting the genetic variations to improve the stress-tolerant cultivars [12]. The present study was undertaken to assess the selection criteria for identifying drought tolerance in chickpea genotypes, so that suitable genotypes can be recommended for cultivation in the drought prone area of Iran.

MATERIALS AND METHODS

Thirty five kabuli chickpea (*Cicer arietinum* L.) accessions were chosen for the study based on their reputed differences in yield performance under irrigated and non-irrigated conditions (Table 1). Experiments were conducted at the experimental field of Islamic Azad University of Sanandaj, in Kurdistan province (Northwest of Iran) in 2008-2009. Seeds were hand drilled and each genotype was sown in three rows of 2.0 m, with row to row distance of 0.30 m. The experiment was laid out in randomized complete block design (RCBD) with three replications. The trials were hand-weeded twice and irrigated plots were watered once per week. Non-irrigated plots were grown under rain-fed conditions. Sowing was done in February in all experiments. Six plants were randomly chosen from each plot to measure the number of grain per plant (grain/plant), number of pods per plant, plant height and 100-seed weight. Drought resistance indices were calculated using the following relationships:

1. SSI = $\dfrac{1-(y_s/y_p)}{1-(\bar{y}_s/\bar{y}_p)}$ [16]

Where Y_s is the yield of cultivar under stress, Y_p the yield of cultivar under irrigated condition, $\bar{y}_s$ and $\bar{y}_p$ the mean yields of all cultivars under stress and non-stress conditions, respectively, and $1-(\bar{y}_s/\bar{y}_p)$ is the stress intensity. The irrigated experiment was considered to be a non-stress condition in order to have a better estimation of optimum environment.

2. MP= $\dfrac{y_p+y_s}{2}$ [20]
3. TOL= $Y_p - Y_s$ [20]
4. STI= $\dfrac{y_p+y_s}{\bar{y}_p{}^2}$ [17]
5. GMP= $(Y_p\ 5\ Y_s)^{0.5}$ [17]
6. Yield index (YI)= $\dfrac{y_s}{\bar{y}_s}$ [20,21]
7. Yield stability index (YSI)= $\dfrac{y_s}{y_p}$ [22]

Data were analysed using SAS for analysis of variance and Duncan's multiple range test was employed for the mean comparisons.

RESULTS

The results of analyses of variance for grain yield and other related traits in both stress and non-stress environments are given in Table 1. There was a significant difference among stress conditions for grain yield. The genotypes showed significant differences in grain yield and other traits. The main effects of moisture regimes compare with drought stress condition were highly significant for the measured traits. Seed yield of genotypes varied, particularly under stress condition (Table 2). The genotypes number 8, 12, 13 and 26 were the most productive genotypes in irrigated and the least productive ones in irrigated conditions (Table 2). Seed yield under irrigated condition was adversely correlated with non-irrigated condition (Fig 1) suggesting that a high potential yield under irrigated condition does not necessarily result in improved yield under stress condition. Thus, indirect selection for a drought-prone environment based on the results of optimum condition will not be efficient. These results are in agreement with those of Caccarelli and Grando (1991) [23] and Sio-Se Mardeh et al. (2006) [24] who found in barley and wheat. Resistance indices were calculated on the basis of grain yield of genotypes (Table 2). As shown in Table 2, the greater the TOL value, the larger the yield reduction under stress condition and the higher the drought sensitivity. To determine the most desirable drought tolerance criteria, the correlation coefficient between Y_p, Y_s and other quantitative indices of drought tolerance were calculated (Table 3). A positive correlation between TOL and yield under normal condition (Y_p) and a negative correlation between TOL and yield under stress (Y_s) (Table 3) suggest that selection based on TOL will result in reduced yield under well-watered conditions. Similar results were reported in several crops like as wheat [24], durum wheat [25] and barley [26]. The results indicated that there were positive and significant correlations among Y_p and Y_s with MP, GMP and STI were better predictors of Y_p and Y_s than TOL and SSI. The observed results are in consistence with those reported by Fernandez (1992) [17] in mungbean, Farshadfar and Sutka (2002) [27] in maize and Golabadi et al. (2006) [28] in durum wheat. Yield under irrigated condition were 2-3 time higher than yield under stress (Table 2). MP is mean production under both stress and non-stress conditions [29], it will be correlated with yield under both condition. For this reason, MP was able to differentiate cultivars belonging to tolerant group from the others. SSI showed a negative correlation with yield under stress (Table 3). The genotypes number 1, 4, 19 and 30 with high yield under stress produced a lower yield under non-stress condition and showed the lowest SSI value. SSI was adversely correlated with all yield components under stress condition (Table 4), suggesting that this traits can contribute to increase yield under stress and reduce SSI. [17]. There was a positive significant correlation between STI and GMP with non-stress and stress yield (Table 3). We conclude that GMP and STI are able to discriminate tolerant group of genotypes under both environments. YI, proposed by Gavuzzi et al. (2006) [20], was significantly correlated with yield and its components in stress condition (Table 3 and 4). This index ranks genotypes only on the basis of their yield under stress. YSI, evaluates the yield under stress of a genotype relative to its non-stress yield, and should be an indicator for drought tolerant genetic materials. So, the genotypes with high YSI are expected to have high yield under both stress and non-stress environments. In the present study, genotypes with high YSI, showed relatively high yield in both environments (Table 2). Selection based on a combination of indices may provide a more useful criterion for improving drought resistance of chickpea, but study of correlation coefficient are useful in finding out the degree of overall linear association between any two attributes. Thus, a better approach than a correlation analysis such as biplot is needed to identify the superior genotypes for both stress and non-stress environments. Principal component analysis (PCA) revealed that the first PCAs explained 0.65 of the variation with Y_p, Ys, MP, GMP and STI (Fig 2). Thus, the firs dimension can be named as the yield potential and drought tolerance. Considering the high and positive value of this on biplot, genotype that have high value of this indices will be high yielding under stress and

Table.1. Mean square for agronomic traits in 35 chickpea genotypes in 2008-2009 under two water regimes

			Mean of square				
		df	No. of Pods/ plant	No. seeds/ Plant	Plant Yield (g/plant)	100-seeds weight	Plant height
Irrigated En							
	Replication	2	217.5	392.75	41.18*	616.2*	325.18
	Genotype	34	567.6**	601.91**	50.85*	937.17**	899.2**
	Error	68	232.5	306.7	21.57	318.02	416.08
Non-Irrigated En							
	Replication	2	63.17	88.16	9.16*	316.2	425.17
	Genotype	34	103.85*	107.83*	8.96**	875.58**	875.76*
	Error	68	57.081	63.01	3.92	418.2	518.5

Table.2. Resistance indices of 35 chickpea genotypes under stress and non-stress environments

	Genotype Name	YSI	YI	Yp	Ys	TOL	MP	SSI	GMP	STI
1	FLIP97-706C	0.49	1.05	5.28	2.58	2.71	3.93	0.69	3.69	0.17
2	FLIP03-17C	0.49	1.26	6.36	3.10	3.26	4.73	0.79	4.44	0.20
3	FLIP03-31C	0.30	0.67	5.53	1.64	3.89	3.58	0.91	3.01	0.15
4	FLIP03-63C	0.66	1.19	4.45	2.92	1.53	3.68	0.47	3.60	0.16
5	FLIP03-74C	0.36	1.18	7.97	2.91	5.07	5.44	1.13	4.81	0.23
6	FLIP03-87C	0.34	1.06	7.76	2.62	5.15	5.19	1.15	4.50	0.22
7	FLIP03-128C	0.43	1.11	6.33	2.72	3.61	4.52	0.86	4.15	0.19
8	FLIP03-134C	0.22	0.78	8.55	1.92	6.63	5.23	1.42	4.05	0.22
9	FLIP03-135C	0.37	0.87	5.74	2.14	3.60	3.94	0.86	3.50	0.17
10	FLIP03-141C	0.46	1.03	5.58	2.55	3.03	4.06	0.75	3.77	0.17
11	FLIP04-2C	0.31	0.88	6.97	2.16	4.81	4.56	1.08	3.87	0.20
12	FLIP04-19C	0.28	1.00	8.73	2.46	6.27	5.60	1.36	4.63	0.24
13	FLIP05-16C	0.25	0.93	9.24	2.29	6.95	5.77	1.48	4.60	0.25
14	FLIP05-18C	0.33	0.95	7.01	2.34	4.68	4.67	1.06	4.05	0.20
15	FLIP05-21C	0.43	0.88	5.07	2.16	2.92	3.61	0.73	3.31	0.16
16	FLIP05-22C	0.43	1.17	6.72	2.88	3.84	4.80	0.90	4.40	0.21
17	FLIP05-26C	0.44	1.36	7.55	3.34	4.21	5.44	0.97	5.02	0.23
18	FLIP05-33C	0.22	0.58	6.33	1.42	4.91	3.87	1.10	3.00	0.17
19	FLIP05-40C	0.49	0.94	4.72	2.31	2.41	3.51	0.64	3.30	0.15
20	FLIP05-44C	0.22	0.97	10.85	2.38	8.47	6.61	1.77	5.08	0.28
21	FLIP05-46C	0.45	1.19	6.48	2.94	3.55	4.71	0.85	4.36	0.20
22	FLIP05-58C	0.31	0.62	4.96	1.53	3.43	3.25	0.83	2.75	0.14
23	FLIP05-59C	0.38	0.89	5.77	2.20	3.58	3.98	0.85	3.56	0.17
24	FLIP05-74C	0.49	1.28	6.42	3.16	3.27	4.79	0.80	4.50	0.21
25	FLIP05-87C	0.36	1.10	7.61	2.71	4.90	5.16	1.10	4.54	0.22
26	FLIP05-110C	0.33	1.18	8.93	2.91	6.02	5.92	1.31	5.10	0.25
27	FLIP05-142C	0.52	1.29	6.08	3.19	2.89	4.63	0.73	4.40	0.20
28	FLIP05-143C	0.33	0.92	6.86	2.26	4.60	4.56	1.04	3.93	0.20
29	FLIP05-150C	0.29	0.85	7.15	2.10	5.06	4.62	1.13	3.87	0.20
30	FLIP05-153C	0.65	1.09	4.16	2.69	1.47	3.43	0.46	3.35	0.15
31	FLIP05-160C	0.39	0.97	6.08	2.38	3.70	4.23	0.88	3.80	0.18
32	FLIP82-150C	0.28	0.98	8.60	2.40	6.20	5.50	1.34	4.54	0.24
33	FLIP88-85C	0.39	1.29	8.07	3.18	4.89	5.62	1.10	5.06	0.24
34	FLIP93-93C	0.44	1.35	7.58	3.32	4.26	5.45	0.98	5.01	0.23
35	ILC482	0.03	0.09	7.29	0.23	7.06	3.76	1.50	1.29	0.16

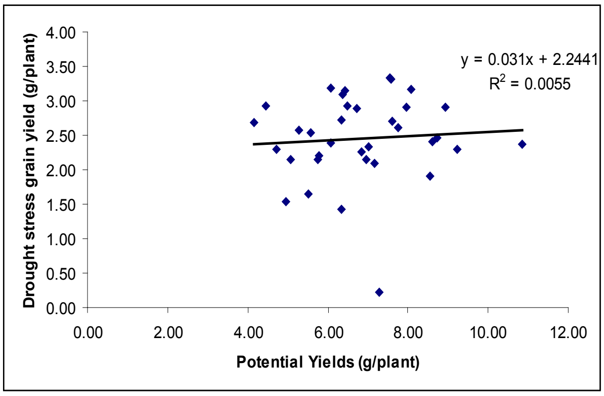

Fig.1. Association between grain yield of irrigated and non-irrigated chickpea genotypes.

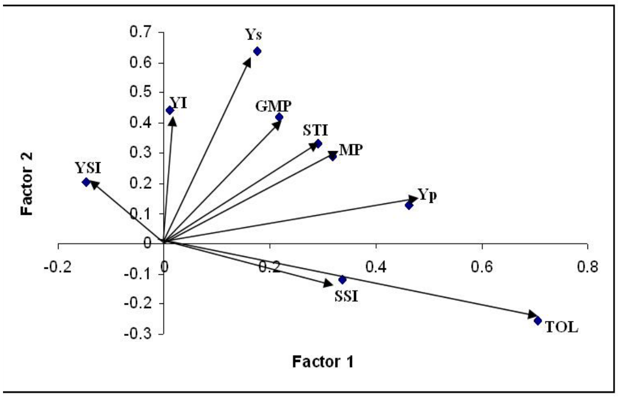

Fig.2. Principal component analysis of drought resistance indices.

Table.3. Correlation coefficients between Yp, Ys and drought tolerance indices

	YSI	YI	TOL	MP	SSI	GMP	STI	YP	YS
YSI	1.000								
YI	0.709**	1.000							
TOL	-0.857**	-0.325	1.000						
MP	-0.281	0.442*	0.704**	1.000					
SSI	-0.856**	-0.323	1.000**	0.706**	1.000				
GMP	0.217	0.826**	0.236	0.844**	0.238	1.000			
STI	-0.277	0.441*	0.702**	0.997**	0.703**	0.843**	1.000		
YP	-0.608**	0.075	0.919**	0.927**	0.919**	0.594**	0.924**	1.000	
YS	0.709**	1.00**	-0.325	0.442*	-0.323	0.826**	0.441*	0.075	1.000

Table.4. Simple correlation coefficients between resistance indices and spike length, grains/spike, grain yield/plant and dry weight of 24 durum wheat cultivars in irrigated (IR) and non-irrigated (NIR) conditions.

	YSI	YI	TOL	MP	SSI	GMP	STI
No. of Pods/Plant (IR)	-0.597**	-0.095	0.783**	0.671**	0.784**	0.327*	0.660**
No. of Pods/Plant (NIR)	0.363*	0.724**	-0.509**	0.478**	-0.057	0.679**	0.475**
No. of Seeds/Plant (IR)	-0.592**	-0.55**	0.804**	0.721**	0.805**	0.379*	0.715**
No. of Seeds/Plant (NIR)	0.364*	0.745**	-0.072	0.491**	-0.070	0.729*	0.478**
Plant Yield (IR)	-0.572**	0.012	0.80**	0.769**	0.801**	0.448**	0.760**
Plant Yield (NIR)	0.567**	0.861**	-0.260	0.40*	-0.257	0.732**	0.369*
100-Seeds Weight (IR)	0.153	0.114	-0.126	-0.034	-0.126	0.055	-0.038
100-Seeds Weight (NIR)	0.456**	0.421*	0.357*	-0.022	-0.354*	0.265	-0.009
Plant Height (IR)	-0.604**	-0.066	0.811**	0.720**	0.812**	0.372*	0.711**
Plant Height (NIR)	0.325	0.492**	-0.036	0.336*	-0.035	0.462**	0.352*

non-stress environments. The second PCA explained 0.47 of the total variability and had positive correlation with TOL, SSI and YSI. Therefore, the second component can be named as a stress-tolerant dimension and it separates the stress-tolerance genotypes from non-stress tolerance ones. Thus, selection of genotypes that have high PCA1 and low PCA2 are suitable for both stress and non-stress environments. Therefore, genotypes belonging to numbers 2, 4, 5, 6, 20, 26 and 34 are superior genotypes for both environments with high PC1 and low PC2. Genotypes belonging to numbers 8, 12, 13, 21, 32 and 33 with high PC2 are more suitable for non-moisture stress than moisture-stress environment

DISCUSSION

Yield (and yield-related traits) under stress were independent of yield (and yield-related traits) under non-stress condition, but this was not the case in less severe stress condition. It is feasible to classify the studied genotypes base on their seed yields under stress and non-stress conditions into four classes, A (with yields higher than average under both conditions), B (with yields higher than average under non-stress conditions), C (with yields higher than average under stress conditions), D (with yields lower than average both conditions). According to Fernandez (1992), the best criterion is the one that is capable to distinguish the class A from other classes. With an eye to above mentioned results and also to the positive significant correlation between SSI and TOL indices, it can be concluded that these two indices are of equal potentials in discriminating of genotype classes. The mathematical basis of TOL index is so that if the differences between two rates averaged are high, the geometrical mean (GMP) will approach toward a smaller figure. Hence, this index is of high efficiency in the selection of stress tolerant genotypes. As STI, GMP and MP were able to identify cultivars producing high yield in both conditions. When the stress was severe, TOL, YSI and SSI were found to be more useful indices discriminating resistant cultivars, although none of the indicators could clearly identify cultivars with high yield under both stress and non-stress conditions (tolerant group of genotypes). Several researchers have concluded that selection will be most effective when the experiments are done under both favorable and stress conditions [30,31,32]. Trethowan et al. (2002) [33] showed that selection in alternating drought and non-drought environments at the International Maize and Wheat Improvement Center (CIMMYT) has resulted in a significant progress in the development of wheat germplasm adapted to dry areas globally. Over all, drought stress reduced significantly the yield of some genotypes and some of them revealed tolerance to drought, which suggested the genetic variability for drought tolerance in this material. Therefore, based on this limited sample and environments, testing and selection under non-stress and stress conditions alone may not be the most effective for increasing yield under drought stress. The results of calculated gain from indirect selection in moisture stress environment would improve yield in moisture stress environment better than selection from non-moisture stress environment. Chickpea breeders should, therefore, take into account the stress severity of the environment when choosing an index. The findings of this study showed that the breeders should choose the indices on the basis of stress severity in the target environment. SSI, GMP, TOL are suggested as useful indicators for chickpea breeding, where the stress is severe (northwest of Iran at the present study).

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