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Identification of drought tolerance in chickpea (*Cicer arietinum* L.) landraces

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ABSTRACT

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Drought is a major limiting factor for agricultural production in most parts of the world and landraces are important genetic resources for crop improvement in dry areas. During the 2007-2008 cropping season, 23 chickpea (*Cicer arietinum* L.) genotypes consisting of 21 Kabuli chickpea landraces provided by the National Plant Gene Bank of Iran and two known commercial varieties (Hashem and Arman) were evaluated under varying drought stress environments imposed using a line-source sprinkler irrigation system. Most measured traits were significantly decreased by drought stress. The reductions in plant canopy width, seed weight per plant, biomass yield and plant weight were proportional to the severity of stress. For all stress treatments, significant variation was observed for seed yield and yield components, and harvest index. The coefficient of variation for these traits increased with the severity of drought stress. Harvest index, pod and seed number per plant, pod and seed weight per plant, total pod weight, plant weight, biomass and plant canopy width showed the highest positive and significant correlation with seed yield, especially under drought treatments; these traits should therefore be taken into account when selecting genotypes under drought conditions. Variation in drought tolerance and susceptibility indices suggested high genetic variation among the genotypes. Geometric mean productivity (GMP) and stress tolerance index (STI) in combination with stress susceptibility index (SSI) were the best indices for selecting drought tolerant genotypes. Accessions 216066, 216084, 215296 and 215664 were superior genotypes as compared to other accessions under drought conditions.

Keywords: biomass, *Cicer arietinum* L., drought stress, harvest index, tolerance indices

INTRODUCTION

Drought is a major limiting factor for agricultural production in most parts of the world (Yu and Setter, 2003). In semiarid regions such as Iran, where rainfall is erratic and low, water deficit becomes the most important limitation to crop production. Therefore, improvement for drought tolerance has become a major aim for breeders in these areas.

Despite the general definition of drought tolerance in native plant species, it is defined in terms of productivity in crop species (Passioura, 1983). Therefore, grain yield and its components remain as the major selection criteria for improved adaptation to a stress environment. Evaluation of genotypes for either high yield potential or stable performance under different water stress treatments is a starting point in selection for drought tolerance (Ahmad *et al*., 2003). Blum (1979) suggested that for increasing crop performance under water stress, one needs to focus on high yielding genotypes under favorable conditions because the best lines would also perform well under unfavorable conditions. However, Sojka *et al*. (1981) defined drought tolerance as the ability to minimize yield loss in the absence of soil water availability.

Therefore, based on yield loss under drought conditions in comparison to optimal conditions, different drought indices were defined that have been used for screening drought tolerant genotypes (Mitra, 2001). These selection indices were determined based on the mathematical relationship between yields in stress and non-stress conditions to differentiate drought tolerant genotypes from susceptible ones (Clarke *et al*., 1984; Huang, 2000). Indices such as stress tolerance (TOL) and mean productivity (MP) defined by Rosielle and Hamblin (1981), the stress susceptibility index (SSI) proposed by Fischer and Maurer (1978), geometric mean of productivity (GMP) introduced by RamirezVallejio and Kelly (1998) as well as the stress tolerance index (STI) defined by Fernandez (1992) have all been employed to select appropriate genotypes under various harsh conditions. There are many reports in the literature on the utility of these indices for identifying genotypes with more stable yield under moisture-limited conditions (e.g., Kristin *et al*., 1997; Farshadfar and Sutka, 2003; Golabadi *et al*., 2006; Ramirez Vallejio and Kelly, 1998; Najafian, 2009).

Among the stress tolerance indicators, larger values of TOL and SSI represent relatively more sensitivity to stress; thus a smaller values of these indices are favored. Use of these two criteria leads to selection of genotypes with low yield potential under non-stress conditions and high yield under stress conditions (Fernandez, 1992). On the other hand, use of STI and GMP will result in selection of genotypes with higher stress tolerance and yield potential (Fernandez, 1992).

The apparent loss of genetic diversity in many crop plants has triggered widespread interest in niche environments. Landraces are important genetic resources in crop breeding, for they are often pools of novel genes and may provide valuable sources of disease resistance, drought tolerance and other economically desirable attributes (Srivastava and Damania, 1989). Therefore, collecting and characterizing landraces for various traits are primary steps in plant breeding programs (Sadeghzadeh Ahari *et al.*, 2009). West Asian countries, including Iran, are known to be centers of genetic diversity for chickpea (Singh and Ocampo, 1997). The National Plant Gene Bank of Iran (NPGBI) preserves about 5700 accessions of chickpea landraces and wild relatives. Landraces in NPGBI's Kabuli chickpea core collection are valuable sources of novel genes that confer traits such as disease resistance, salt tolerance and drought tolerance, all desirable in chickpea breeding.

The line source sprinkler irrigation system was first developed by Hanks *et al*. (1976) and further standardized at ICRISAT (Nageswara Rao *et al*., 1985). This system creates a gradient of drought stress and allows the evaluation of large numbers of genotypes under varying drought intensity in a given environment. It has proved to be very effective in identifying drought tolerant genotypes in chickpea (Johansen *et al*., 1994).

The objectives of this study were to: (1) evaluate the influence of drought stress on the agronomic characteristics of chickpea landraces; (2) assess the genetic diversity for drought tolerance among those landraces; (3) determine the best selection indices for identifying drought tolerant landraces under a variety of drought conditions; and (4) to identify the range of variability for these indices under drought stress conditions.

MATERIALS AND METHODS

A field experiment was conducted during the 2007-2008 cropping season at the research station of NPGBI, Seed and Plant Improvement Institute, Karaj, Iran. A total of 23 genotypes, including 21 Kabuli chickpea landraces originating from Iran, were provided by NPGBI (Table 6) to be used in this study, and two known cultivars (Hashem and Arman) were evaluated for their performance under varying drought treatments imposed by a line source sprinkler irrigation system.

The experiment was a strip plot design with three replications. Irrigation levels were arranged systematically in each replication in strips parallel to the sprinkler line, and genotypes were randomized within each replication (Hanks *et al*., 1976; Moinuddin and Khanna-Chopra, 2004). Each plot was 1.5 m wide and 1.5 m long, consisting of three rows of a single genotype. The inter-row and inter-plant spacing were 50 and 7 cm, respectively. Seed beds were laid out on either side of the line source and parallel to it; they were divided lengthwise into four irrigation levels (T1, T2, T3 and T4) based on distance from the sprinkler line: T1 was between 1.5 and 3 m away from the sprinkler line, T2 between 6 and 7.5 m, T3 between 10.5 and 12 m, and T4 between 15 and 16.5 m. A line source sprinkler system with one main pipe operated by the "Nelson F-33" sprinkler model with a spraying diameter of 28 m was used for irrigation, and sprinkler heads were placed at 6-m intervals. The line source imposed the water stress as follows: the treatment plot nearest to the line source (T1) received the most water, and the water deficit increased progressively as the distance from the sprinkler line increased.

From sowing to flowering, all plots (under stress or non-stress treatments) were irrigated with the same amount of water to maintain the soil water content close to field capacity. Deficit irrigation treatments were applied from flowering to plant maturity. After flowering, non-stress conditions were maintained by irrigating the plots throughout the crop season. Stressed plots were irrigated at the same time but the amount of water received depended on the distance from the sprinkler line. The amount of irrigation applied to the nearest rows (T1) was adjusted to bring the top 60 cm of the soil to field capacity when available soil water at such depths dropped below 50% of total available water (Zhang *et al.*, 2000). The amount of water applied to each treatment was measured by using catch cans placed in different plots; efforts were made to sprinkle only when wind was low.

Table 1. Analysis of variance for different characteristics of chickpea genotypes under various drought s

S.O.V	df	Mean square									
		Days to flowering	Days to maturity	Plant canopy height	Plant canopy width	Plant weight	Pod number per plant	Pod weight per plant	Seed number per plant	Seed weight per plant	Seed number per pod
Replication	2	29.320*	90.242**	18.950	354.264**	10.020*	135.699**	2.565	1.609	0.7920	0.0108
Drought treatment (A)	3	41.090**	406.984**	1027.555**	5887.115**	3175.270**	17308.180**	1919.562**	19191.700**	990.6440**	0.0132
Error (a)	6	7.030	34.610**	7.830	70.872	1.392	29.549	0.626	13.357	0.1650	0.0060
Genotype (B)	22	103.860**	60.550**	123.435**	84.418**	44.150**	467.456**	22.442**	407.878**	11.0681**	0.0326
Error (b)	44	5.830	6.484	9.757	43.250	2.910	28.483	1.830	16.652	0.3580	0.0108
A × B	66	5.785	9.170*	19.758**	91.413**	49.160**	326.923 **	20.854**	297.411**	11.6840**	0.0132
Error (c)	132	4.603	5.870	8.950	33.820	2.300	26.910	1.566	18.466	0.2800	0.0060
Total	275										
CV%		3.940	2.84	10.6	13.05	15.1	27.04	23.32	25.51	14.24	7.69

***, ** Significant at the 5% and 1% probability levels.**

Table 2. Statistical parameters of Kabuli chickpea genotypes in different drought stress treat

Traits	Mean				Std deviation				Range			
	T1	T2	T3	T4	T1	T2	T3	T4	T1	T2	T3	
Days to flowering	54.35ab	55.43a	53.70b	53.80b	3.05	3.51	3.11	3.31	13.33	14.00	12.00	
Days to maturity	88.16a	85.61b	82.69c	83.28bc	1.62	3.01	2.78	4.15	6.00	10.00	12.67	
Plant canopy height (cm)	31.19a	31.62a	26.30b	23.68c	5.28	4.22	2.35	3.11	21.54	20.42	9.31	
Plant canopy width(cm)	54.12a	49.56b	41.38c	33.18d	5.07	4.03	4.96	7.28	21.83	17.91	19.69	
Plant weight (g)	18.19a	13.09b	4.91c	4.03d	6.24	4.05	1.70	2.36	27.02	15.36	7.20	
Seed number per plant	37.51a	23.22b	4.00c	2.64c	17.45	9.57	4.17	4.44	76.67	37.67	13.75	
Pod number per plant	38.29a	26.13b	6.58c	5.75c	18.59	8.59	5.28	5.95	86.67	27.67	18.33	
Seed weight per plant (g)	8.41a	5.18b	0.74c	0.54d	3.14	1.96	0.75	1.07	14.02	8.34	2.21	
Pod weight per plant (g)	11.80a	7.55b	1.08c	1.02c	4.29	2.55	1.10	1.49	18.85	9.12	4.14	
Total pod weight (g m^{-2})	193.68a	130.29b	19.88c	16.05c	74.15	45.65	21.23	25.18	311.97	158.16	73.83	
Biomass yield (g m^{-2})	300.34a	220.53b	78.84c	63.64d	98.90	57.06	32.79	42.11	356.86	189.26	128.72	1
Grain yield (g m^{-2})	139.83a	86.87b	12.62c	9.61c	47.47	30.09	13.34	16.00	168.10	109.70	44.58	
Harvest index	0.44a	0.41a	0.14b	0.10b	0.05	0.07	0.11	0.11	0.17	0.32	0.40	
100-seed weight (g)	23.70a	24.03a	17.87b	16.14c	5.91	5.81	6.49	5.15	19.30	19.29	32.64	
Single seed pod (%)	93.62a	94.06ab	97.54b	98.84b	11.93	12.75	4.41	2.38	43.33	53.33	13.33	

Means in each column followed by similar letter(s) are not significant at the 5% probability level, using Duncan's Multiple Range Tes

Because of low precipitation during the period between sowing and flowering, 52 mm of uniform irrigation was applied to all treatments. After that, eight irrigations were applied using the line source sprinkler irrigation system. Total rainfall during the 2007-2008 cropping season (March-June) was 18.1 mm. The line source irrigation system cumulatively supplied 184, 130, 31 and 3.5 mm of water to T1, T2, T3 and T4 treatments, respectively, with the total water available being 254.1**,** 200.1, 101.1 and 73.6 mm, respectively. Standard agricultural practices were maintained throughout the crop cycle.

Several traits including days to flowering, days to maturity, plant height, number of seeds and pods per plant, number of seeds per pod, 100-seed weight, biological yield, seed yield and harvest index (HI) were recorded during the growing season and after crop harvest. In addition, five quantitative selection criteria including stress susceptibility index (SSI; Fischer and Maurer, 1978), stress tolerance index (STI; Fernandez, 1992), tolerance (TOL; Rosielle and Hamblin, 1981), mean productivity (MP; Rosielle and Hamblin, 1981) and geometric mean productivity (GMP; Fernandez, 1992) were estimated using grain yield under different drought stress conditions. The drought tolerance of chickpea landraces was evaluated based on these criteria.

An analysis of variance appropriate to the strip plot design was carried out using SAS (version 9.1). Differences between treatment means were compared using Duncan's multiple range tests at a 0.05 probability level. A principal component analysis was performed using Statgraphics plus-win 2.1 software and a biplot display of the first two components was used for grouping landraces under different stress conditions and illustrating the relationship between the genotypes and stress tolerance attributes. To identify the most desirable drought tolerance criteria, correlation coefficients between Ys (grain yield under different drought treatments), Yp (grain yield under controlled conditions, T1) and other quantitative indices of drought tolerance were determined by the cosine of the angle between their vectors (Yan and Rajcan, 2002). In addition, trends of some traits in chickpea genotypes contrasting with drought tolerance were investigated.

RESULTS

The results of the analysis of variance for different traits under drought conditions (Table 1) show that despite the number of seeds per pod, drought stress had significant effects on other measured traits. The studied genotypes showed significant differences in all traits. The genotype × treatment interaction was significant for all traits except for days to flowering (Table 1). Values for plant canopy width, seed weight per plant, biomass yield and plant weight decreased in all three drought stress treatments; these reductions were proportional to the severity of stress (Table 2).

Based on the results of descriptive statistics (Table 2), excluding days to flowering, days to maturity and plant canopy height, there were high variations in other measured traits under different drought treatments, and coefficients of variation increased with severity of drought stress (Table 2). Coefficients of variation for HI ranged from 10.48% in T1 to 110.57% in T4; mean values were 0.44 for well-watered plots and 0.10 for water stressed plots.

Simple correlations between traits and grain yield under different drought treatments are shown in Table 3. Seed yield was found to have positive and significant correlations with yield components, biomass and canopy width in all treatments, and also showed a positive correlation with harvest index.

Table 3. Coefficients of correlation between plant characteristics and grain yield for chickpea genotypes in different drought treatments.

	Grain yield			
	T1	T2	T3	T4
Days to flowering	-0.085	-0.087	-0.193	-0.377
Days to maturity	-0.067	-0.025	0.142	-0.472*
Plant canopy height	0.176	0.122	0.018	0.286
Plant canopy width	0.499*	0.066	0.598**	0.739**
Plant weight	0.787**	0.501*	0.593**	0.938**
Pod number per plant	0.643**	0.435*	0.864**	0.899**
Pod weight per plant	0.854**	0.540**	0.894**	0.916**
Seed number per plant	0.702**	0.321	0.956**	0.921**
Seed weight per plant	0.773**	0.538**	0.955**	0.961**
Biomass yield	0.868**	0.623**	0.753**	0.893**
Total pod weight	0.904**	0.662**	0.950**	0.935**
Harvest index	0.307	0.425*	0.905**	0.853**
100-seed weight	0.183	0.384	0.007	0.483*
Seed size	0.222	0.367	0.132	0.483*
Single seed pod percentage	0.019	0.083	-0.110	0.085

T1, T2, T3 and T4: non stress to severe water stress treatments, respectively.
*** and **: Significant at the 0.05 and 0.01 levels, respectively.**

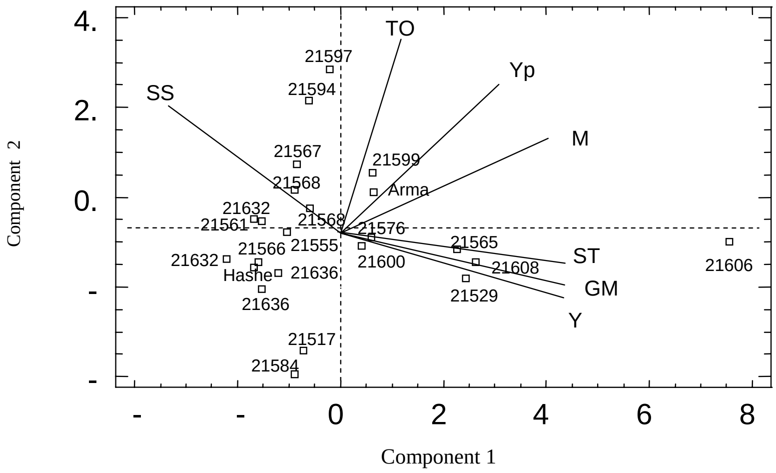

Fig. 1. Biplot display of two principal components of drought tolerance indices in chickpea genotypes under T3 drought stress treatment.

The coefficient of correlation increased with severity of drought and became more significant for T3 (r = 0.90**) and T4 (r = 0.85**).

Drought tolerance indices including TOL, SSI, MP, GMP and STI were calculated for all genotypes under three different drought conditions (Table 4). The STI means varied from 0.66 under the T2 treatment to 0.07 under T4, while SSI means ranged from 0.88 under T2 to 0.98 under T4. Means of MP varied from 107 under T2 to 71.8 under T4, while TOL means ranged from 49 under T2 to 122 under the T4 treatment. GMP means fluctuated from 103 under treatment T2 to 26 under T4.

Stress intensity calculation based on equation $(SI) = 1 - (\bar{Y}s / \bar{Y}p)$ suggested that drought treatments T2, T3 and T4 were subjected to drought stress intensities (SI) of 0.26, 0.87 and 0.95, respectively. To better differentiate among genotypes, more moderate SI should be considered (Porch, 2006). Due to the high SI of treatment T4 and very low SI of T2, these treatments may be less informative for screening and selecting drought tolerant genotypes. Therefore, landraces were grouped based only on T3 data.

Based on the results of estimated indices for treatment T3 (Table 4), genotypes 216066 and 215618 had maximum and minimum STI and GMP values, respectively, while genotypes 215979 and 215171 showed maximum and minimum TOL and SSI values. The highest MP value was observed for genotype 216066 and the lowest value for was observed for 215843.

Principal component analysis across different indices under T3 resulted in a number of linear combinations of these indices that account for most of the variability in the data. Considering eigen values greater than or equal to 1.0 (Lezzoni and Prits, 1991), the two first components together accounted for 97.8% of the variability (Table 5). The first component contributed most of the variability (65.09%) and was explained by variation in Yp, Ys, STI, GMP and MP. The contribution of the second component to total variation was also very high (32.74%), which was explained by the diversity among genotypes for TOL and SSI (Table 6). Higher PCA1 and lower PCA2 scores produced high yielding genotypes. Genotypes 216066, 216084, 215296 and 215654 had maximum amount of component I (Table 7). On the other hand, genotypes 215843, 215171, 216368 and 215296 had minimum amount of component II and the best rank based on it (Table 7).

The most prominent relations revealed by these bi-plots are: (1) a strong negative association between SSI and indices Ys, GMP and STI, as indicated by the large obtuse angles between their vectors; (2) near zero correlation between SSI and Yp and also between TOL and indices GMP and STI, as indicated by the near perpendicular angles of their vectors; and (3) a positive association between Ys and indices GMP and STI, as indicated by the acute angles between their vectors in the T3 treatment (Fig. 1). The results obtained from the bi-plot graph confirmed the correlation analysis (data not shown).

According to the bi-plot display of the first two components, genotypes were distributed among four main groups (Fig. 1). Group I, with higher values for components I and II, includes genotypes Arman and 215995. Group II, with a higher value for component I and a lower value for component II, includes genotypes 215654, 216066, 215296 and 216084. Group III, with a higher value for component II and a lower value for component I,

Table 4. Values of drought tolerance indices for chickpea genotypes under different drought treatments (T2, T3 and T

	MP			TOL			GMP			SS	
KC.No	**T2**	**T3**	**T4**	**T2**	**T3**	**T4**	**T2**	**T3**	**T4**	**T2**	**T**
215171	51.986	57.020	60.210	59.9640	49.90	43.520	42.469	51.270	56.140	1.98	0.6
215296	97.339	92.600	76.450	100.2900	109.76	142.060	83.431	74.590	28.280	1.84	0.8
215551	76.580	44.210	69.010	3.5382	68.28	18.670	76.560	28.090	68.380	0.12	0.9
215618	67.064	34.210	33.950	0.5783	66.28	66.800	67.064	8.510	6.110	0.02	1.0
215654	111.750	82.450	78.520	90.1490	148.74	156.610	102.260	35.600	5.720	1.55	1.0
215664	101.720	57.410	51.250	0.7912	89.41	101.720	101.720	36.020	6.310	0.02	0.9
215671	134.300	79.880	77.220	39.2970	148.14	153.460	132.850	29.910	8.680	0.69	1.0
215685	119.540	73.810	69.250	37.0640	128.53	137.650	118.100	36.310	7.630	0.73	1.0
215686	107.490	71.510	72.180	68.8880	140.84	139.510	101.820	12.450	18.570	1.31	1.1
215767	122.350	71.290	76.190	37.3690	139.48	129.690	120.910	14.810	39.990	0.72	1.1
215843	64.930	43.800	41.230	8.5181	50.79	55.910	64.790	35.680	30.310	0.33	0.8
215944	157.750	117.370	112.410	133.5900	214.35	224.280	142.910	47.860	7.790	1.61	1.0
215979	162.930	102.570	102.420	83.6550	204.37	204.660	157.470	8.840	4.350	1.10	1.1
215995	125.610	84.580	93.660	84.6670	166.72	148.570	118.260	14.320	57.030	1.36	1.1
216001	113.250	65.600	65.800	6.9116	102.21	101.820	113.190	41.120	41.680	0.16	0.9
216066	172.830	145.790	128.650	147.2300	201.33	235.590	156.370	105.460	51.720	1.61	0.9
216084	133.870	96.000	78.290	44.2810	120.02	155.430	132.020	74.930	9.470	0.77	0.8
216324	97.643	61.380	60.220	43.1570	115.67	117.990	95.228	20.560	12.100	0.98	1.0
216325	76.924	40.030	40.370	2.5301	76.32	75.630	76.913	12.080	14.140	0.09	1.0
216364	76.145	56.770	51.730	53.5340	92.28	102.370	71.285	33.080	7.470	1.41	1.0
216368	91.402	48.800	50.600	0.9880	86.20	82.590	91.400	22.880	29.240	0.03	1.0
Arman	137.270	95.820	105.580	69.0680	151.96	132.450	132.850	58.390	82.230	1.09	0.9
Hashem	77.600	48.650	44.680	19.9800	77.87	85.810	76.955	29.180	12.480	0.62	0.9
Mean	107.750	72.677	71.299	49.3930	119.54	122.296	103.340	36.171	26.341	0.88	1.0

includes genotypes 215686, 215671, 215944 and 215979. The other genotypes were placed in group IV, on the lower end of both components. Group II genotypes, with higher GMP and STI values and lower TOL and SSI values, were among the more tolerant genotypes. On the other hand, group III genotypes with higher TOL and SSI values and lower GMP and STI values were among the more susceptible genotypes. Hence, genotypes 216066, 215979, and 215843 from groups II, III and IV, respectively, which were located at the maximum distance from the center of graph and also showed different drought susceptibility, were selected. Grain yield trends and traits that have significant correlations with grain yield were compared with each other in these contrasting genotypes (Fig. 2).

There was a significant difference among genotypes for harvest index, biological yield, number of seeds and pods per plant (Fig. 2). All of these traits were significantly affected by drought stress and were reduced under stress conditions, as expected. Except for genotype 215843, drought immediately reduced all traits in other genotypes, even in very mild-drought stress (T2). This implies that genotype 215843 adapted to mild-drought conditions; therefore, the drought stress threshold at which different traits start to decline is higher in this genotype. Despite this difference, the reactions to severe drought treatments (T3 and T4) were similar for all three landraces.

Mean comparisons of some traits (Fig. 2) showed that genotype 216066 produced the highest yields under severe drought (T4). This accession also possessed higher values in plant canopy width, harvest index, biological yield, pod number and seed weight per plant. On the other hand, reduction of these traits due to moisture stress was more obvious in genotype 215979, and the slope and intercept of

Table 5. Eigen value, percent of variance and cumulative percentage of component extracted from PCA analysis of drought tolerance indices in Kabuli chickpea genotypes under T3 drought treatment.

	Component numbers					
	Component 1	Component 2	Component 3	Component 4	Component 5	Component 6
Eigen value	4.56	2.3	0.116	0.033	0.0019	0.0003
Percent of variance	65.1	32.74	1.66	0.47	0.027	0.004
Cumulative percentage	65.1	97.83	99.5	99.97	99.99	100

Table 6. Weight of the first two components extracted from PCA analysis under the T3 treatment.

Traits	Component1	Component2
Yp	0.315	0.489
Ys	0.443	-0.213
MP	0.413	0.312
GMP	0.446	-0.170
STI	0.453	-0.102
TOL	0.121	0.640
SSI	-0.341	0.417

Table 7. Values of the principal components and ranking based on them of each Kabuli chickpea genotype.

Genotype	Component 1	Rank	Component 2	Rank
215171	-0.714	12	-2.604	2
215296	2.440	3	-1.018	4
215551	-1.040	16	0.0326	14
215618	-1.530	18	0.259	15
215654	2.260	4	-0.366	10
215664	-1.580	20	-0.653	8
215671	-0.850	13	1.540	21
215685	-0.587	10	0.559	17
215686	-0.880	15	0.954	19
215767	0.595	7	-0.089	13
215843	-0.879	14	-3.140	1
215944	-0.610	11	2.940	22
215979	-0.210	9	3.640	23
215995	0.625	6	1.340	20
216001	0.410	8	-0.283	11
216066	7.560	1	-0.193	12
216084	2.630	2	-0.654	7
216324	-1.670	21	0.307	16
216325	-2.200	23	-0.587	9
216364	-1.220	17	-0.884	5
216368	-1.530	19	-1.255	3
Arman	0.640	5	0.910	18
Hashem	-1.670	22	-0.760	6

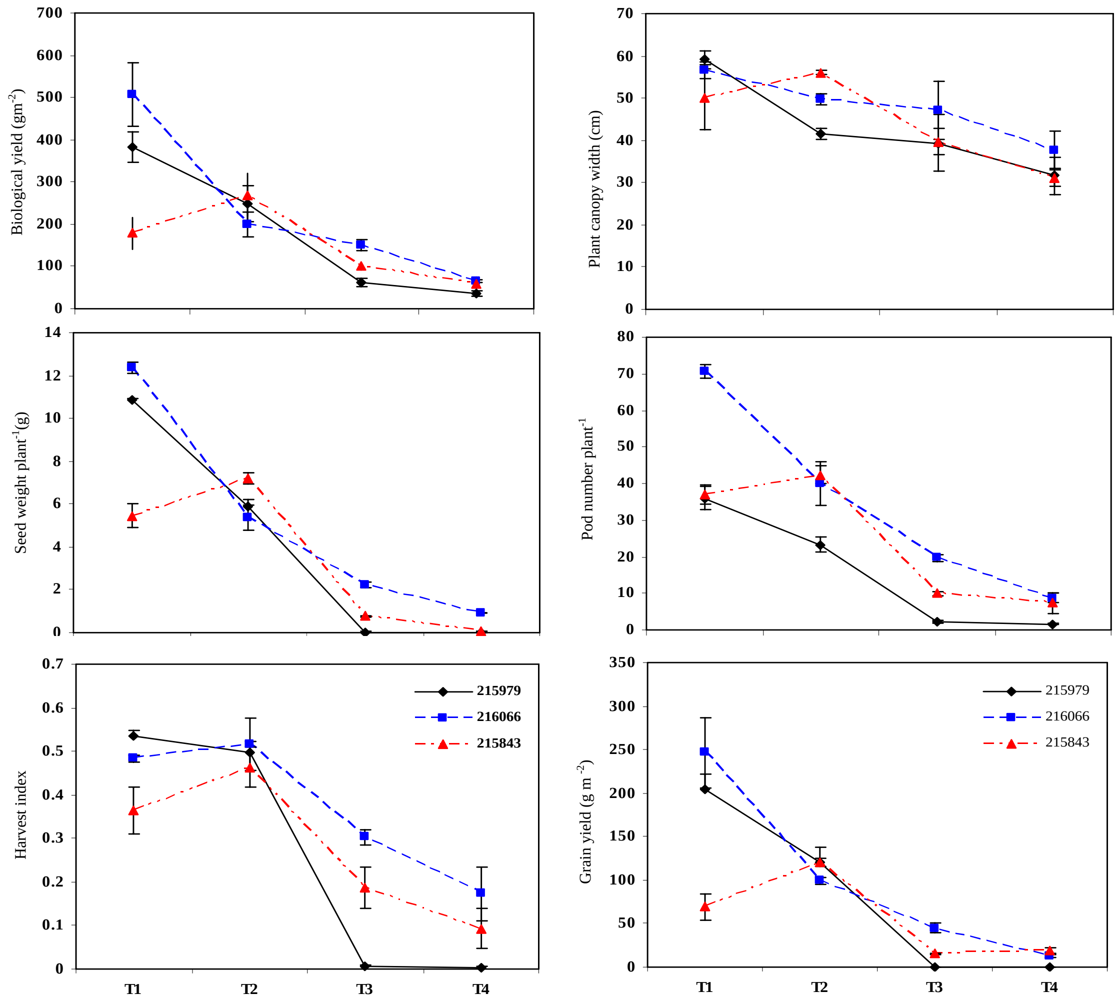

Fig. 2. Trends of some agronomic traits in three contrasting chickpea landraces in a drought treatment gradient. Each data point represents the average of three replications. Error bars indicate standard error of the means (SE).

this reduction were higher between the T2 and T3 treatments (Fig. 2).

DISCUSSION

To improve drought tolerance in crop plants, the genetic variation of the crop for traits related to drought tolerance must be investigated (Ali *et al*., 2009; Dhanda *et al*., 2004). In this study, the effect of drought treatments and their interaction with genotypes were significant for all studied traits except seed number per pod; it can therefore be concluded that landraces responded differently to the different drought treatments supplied by line source irrigation.

Of the studied traits, yield components, seed and pod number and weight, and harvest index had the highest coefficients of variation, especially under T3 and T4 drought treatments. Harvest index, pod number, biomass and plant canopy width showed the highest positive and significant correlation with seed yield, especially under drought treatments. Studies of the trends of these traits in contrasting genotypes (Fig. 2) showed that they could easily distinguish genotypes in different drought tolerance groups. Therefore, these traits should be taken into account when selecting genotypes under drought conditions.

Of the different indices, STI and GMP showed maximum variation. The considerable amount of variability for these two indices may indicate their high selection gains under the applied treatments. Highly significant correlations were found between grain yield under stress (Ys) and indices MP, GMP and STI, especially under T3. Hence they are better predictors of Ys and will produce similar results. The observed relationship among these indices is in line with those reported by Fernandez (1992) in mungbean, Farshadfar and Sutka (2003) in maize, Kristin *et al.* (1997) in common bean and Golabadi *et al.* (2006) in durum wheat. Jafari *et al.* (2009), Azizi-Chakherchaman *et al.* (2009) and Sio-Se Mardeh *et al.* (2006) also reported that GMP and STI are reliable indices for identifying high yielding, drought tolerant genotypes. Likewise, Ramirez Vallejio and Kelly (1998) observed positive and significant correlations between some yield components and GMP in common bean.

On the other hand, the strong negative association between SSI and Ys is indicated by the large obtuse angles between their vectors. Therefore, genotypes that have high STI and GMP and also low SSI can be considered drought tolerant (Najafian, 2009). Hence, a combination of different indices is thought to provide a more useful criterion for identifying superior genotypes in both stress and non-stress environments.

Bi-plot analysis has been used by many researchers for comparing different genotypes based on different criteria and in different plant species (e.g., Thomas *et al*., 1996; Kaya *et al*., 2002; Yan and Rajcan, 2002; Farshadfar and Sutka, 2002). Principal component analysis (PCA) revealed that the first component explained 65% of the variation in the T3 treatment and correlated with Ys, STI and GMP. Thus the first component can be a good indicator of yield potential and drought tolerance. Considering the high positive value of this component, in the bi-plot it can point out genotypes that produce higher yield in stress environments. Unfortunately, these indices cannot always perfectly identify drought tolerant genotypes, when used as unique indices. This is because when the yield of a particular genotype in one environment is high, the value of these indices is increased (Najafian, 2009).

The second component explained 32.7% of the total variability in T3 and had positive correlations with SSI and TOL. Low values of SSI and TOL indicate tolerant genotypes. Therefore, the second component can be a good indicator of drought susceptibility. Consequently, genotypes with low values of this component are suitable for stress environments. However, low TOL and SSI values may not necessarily be a good indication of a genotype's drought tolerance.

Why are genotypes with low TOL and SSI values (e.g., 215843 and 215171) not considered drought tolerant? As previously stated, when used as unique indices, SSI and TOL can identify only genotypes that exhibit smaller yield reductions under water stress compared with well-watered conditions (Najafian, 2009). However, low TOL and SSI values of a variety could be due to lack of yield production under well-watered conditions rather than its ability to tolerate water stress (Fig. 2). Therefore selection of tolerant genotypes cannot be based solely on the second component. By comparing two dimensions of the bi-plot, it can be concluded that landraces 216066, 216084, 215296, and 215654 are the best genotypes for drought conditions, given that they showed a lower SSI (component II) value and higher values for yield potential, STI and GMP indices (component I) under drought.

In conclusion**,** results of this study indicate that STI and GMP indices had a similar ability to differentiate between drought sensitive and drought tolerant chickpea genotypes. These indices had highly significant positive correlations with grain yield in stress environments. A combination of SSI with STI and GMP is a better predictor of Ys and can be recommended for future screening of chickpea genotypes for drought tolerance. Illustrating the usefulness of more moderate stress intensity, in this study, T3 treatment (in which 100 mm total water was available to the crop) was the treatment that best differentiated drought tolerant chickpea genotypes. Landraces 216066, 216084, 215296 and 215654 were the best genotypes under drought conditions, as they showed a lower SSI value and higher values for yield potential, STI and GMP indices under drought. Therefore they should be further tested for their drought confirming characteristics.

REFERENCES

Ahmad, R., S. Qadir, N. Ahmad, and K. Hussain-Shah. 2003. Yield potential and stability of nine wheat varieties under water stress conditions. Int. J. Agri. Biol. 5: 7-9.

Ali, M. A., A. Abbas, S. H. Niaz, M. Zulkiffal, and S. H. Ali. 2009. Morpho-physiological criteria for drought tolerance in sorghum (*Sorghum bicolor*) at seedling and post-anthesis stages. Int. J. Agri. Biol. 11: 674-680.

Azizi-Chakherchaman, S., H. Mostafaei, L. Imanparast, and M. R. Eivazian. 2009. Evaluation of drought tolerance in advanced lentil genotypes in Ardabil region, Iran. J. Food Agric. Environ. 7: 283-288.

Blum, A. 1979. Genetic improvement of drought resistance in crop plants. A case for sorghum. Pp 495-545. *In* Hussell, H., and R. C. Staples (eds.). Stress physiology in crop plants. Wiley Interscience, New York.

Clarke, J. M., T. F. Townley-Smith, T. N. McCaig, and D. G. Green. 1984. Growth analysis of spring wheat cultivars of varying drought resistance. Crop Sci. 24: 537-541.

Dhanda, S. S., G. S. Sethi, and R. K. Behl. 2004. Indices of drought tolerance in wheat genotypes at early stages of plant growth. J. Agron. Crop Sci. 190: 6-12.

Farshadfar, E., and J. Sutka. 2003. Screening drought tolerance criteria in maize. Acta Agron. Hung. 50: 411-416.

Farshadfar, E., and J. Sutka. 2002. Multivariate analysis of drought tolerance in wheat substitution lines. Cereal Res. Commun. 31: 33-39.

Fernandez, G. C. J. 1992. Effective selection criteria for assessing stress tolerance. *In* Kuo, C.G. (ed.). Proceedings of the International Symposium on Adaptation of Vegetables and Other Food Crops in Temperature and Water Stress. AVRDC Publication, Tainan, Taiwan.

Fischer, R. A., and R. Maurer. 1978. Drought resistance in spring wheat cultivars. I. Grain yield responses. Aus. J. Agric. Res. 29: 897-912.

Golabadi, M., A. Arzani, and S. A. M. Mirmohammadi Maibody. 2006. Assessment of drought tolerance in segregating populations in durum wheat**.** African J. Agric. Res.1: 162-171**.**

Hanks, R. J., J. Keller, V. P. Rasmussen, and G. D. Vilson. 1976. Line source sprinkler for continuous variable studies crop production. Soil Sci. Soc. Am. J. 40: 426-429.

Huang, B. 2000. Role of root morphological and physiological characteristics in drought resistance of plants. Pp. 39-64. *In* Wilkinson, R. E. (ed.). Plant–environment interactions. Marcel Dekker Inc., New York.

Jafari, A., F. Paknejad, and M. Jami Al-Ahmadi. 2009. Evaluation of selection indices for drought tolerance of corn (*Zea mays* L.) hybrids. Int. J. Plant Prod. 3: 33-38.

Johansen, C., L. Krishnamurthy, N. P. Saxena, and S. C. Sethi. 1994. Genotypic variation in moisture response of chickpea grown under line source sprinklers in a semi arid tropical environment. Field Crop Res. 37: 103-112.

Kaya, Y., C. Palta, and S. Taner. 2002. Additive main effects and multiplicative interactions analysis of yield performances in bread wheat genotypes across environments. Turk. J. Agric. For. 26: 275-279.

Kristin, A. S., R. R. Serna, F. I. Perez, B. C. Enriquez, J. A. A. Gallegos, R. R. Vallejo, N. Wassimi, and J. D. Kelley. 1997. Improving common bean performance under drought stress. Crop Sci. 37: 43-56.

Lezzoni A. F., and M. P. Prits. 1991. Applications of principal component analysis to horticulture research. Hortic. Sci. 26: 334-338.

Mitra, J. 2001. Genetics and genetic improvement of drought resistance in crop plants. Curr. Sci. 80: 758-762.

Moinuddin and R. Khanna-Chopra. 2004. Osmotic adjustment in chickpea in relation to seed yield and yield parameters. Crop Sci. 44: 449-455.

Nageswara Rao, R. C., S. Singh, M. V. K. Sivakumar, K. L. Srivastava, and J. H. Williams. 1985. Effect of water deficit at different growth phases of peanut. 1. Yield responses. Agron. J. 77: 782-786.

Najafaian, G. 2009. Drought tolerance indices, their relationships and manner of application to wheat breeding programs. Middle Eastern & Russian J. Plant Sci. Biotech. 3: 25-34.

Passioura, J. B. 1983. Roots and drought resistance. Agric. Water Manag. 7: 265-280.

Porch, T. G. 2006. Application of stress indices for heat tolerance screening of common bean. J. Agron Crop Sci. 192: 390-394.

Ramirez Vallejio, P., and J. D. Kelly. 1998. Traits related to drought resistance in common bean. Euphytica. 99: 127-136.

Rosielle, A. A., and J. Hamblin. 1981. Theoretical aspect of selection for yield in stress and non-stress environments. Crop Sci. 21: 943-946.

Sadeghzadeh Ahari, D., A. K. Kashi, M. R. Hassandokht, A. Amri, and K. Alizadeh. 2009. Assessment of drought tolerance in Iranian fenugreek landraces. J. Food Agric. Environ. 7: 414-419.

Singh K. B., and B. Ocampo. 1997. Exploitation of wild cicer species for yield improvement in chickpea. Theor. Appl. Genet. 95: 418-423.

Sio-Se Mardeh, A., A. Ahmadi, K. Poustini, and V. Mohammadi. 2006. Evaluation of drought resistance indices under various environmental conditions. Field Crop Res. 98: 222-229.

Sojka, R. E., L. H. Stolzy, and R. A. Fischer. 1981. Seasonal drought response of selected wheat cultivars. Agron. J. 73: 838-845.

Srivastava, J. P., and A. B. Damania.1989. Use of collections in cereal improvement in semi-arid areas. Pp. 88-104. *In* Brown, A. H. D., O. H. Frankel, D. R. Marshall, and J. T. Williams. (eds.). The use of plant genetic resources. Cambridge University Press, Cambridge.

Thomas, H., S. J. Dalton, C. Evans, K. H. Chorlton, and I. D. Thomas. 1996. Evaluating drought resistance in germplasm of meadow fescue. Euphytica. 92: 401-411.

Yan, W., and I. Rajcan. 2002. Biplot analysis of test sites and trait relations of soybean in Ontario. Crop Sci. 42: 11-20.

Yu, L. X., and T. L. Setter. 2003. Comparative transcriptional profiling of placenta and endosperm in developing maize kernels in response to water deficit. Plant Physiol. 131: 568-582.

Zhang, H., M. Pala, and T. Oweis. 2000. Water use and water use efficiency of chickpea and lentil in a Mediterranean environment. Aust. J. Agric. Sci. 51: 295-304