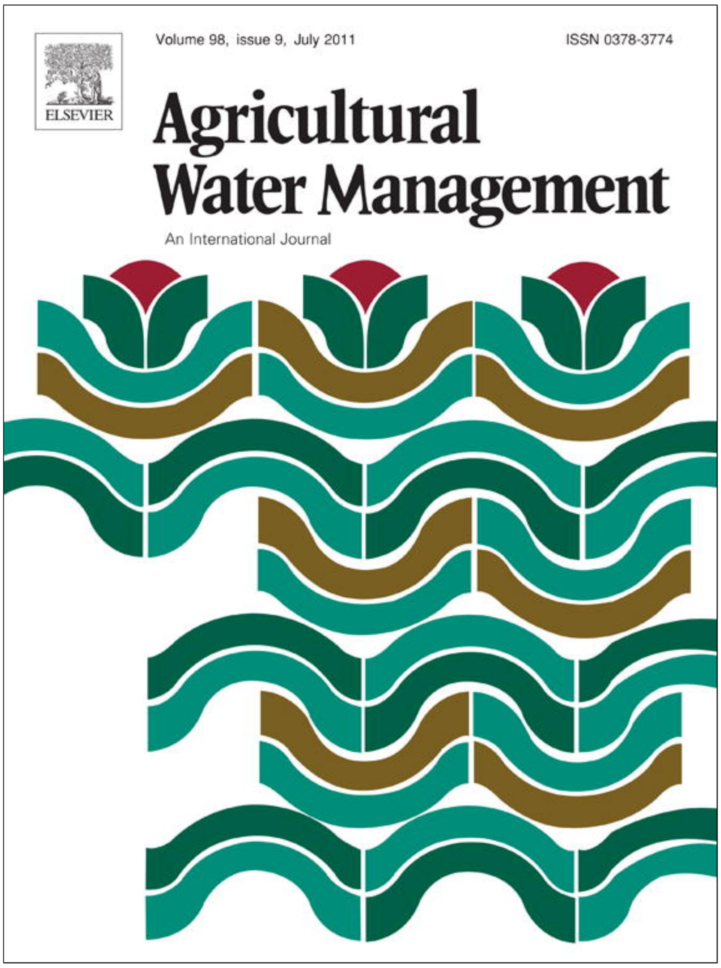
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Assessment of Iranian chickpea (*Cicer arietinum* L.) germplasms for drought tolerance

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ABSTRACT

Iran is one the most important centers of diversity for chickpea in south western Asia. Landraces are well adapted to local environmental conditions, and have evolved a range of morphological, phenological and physiological mechanisms to efficiently utilize the available water in a dry environment. In order to study some of these mechanisms, 150 genotypes of chickpea (Kabuli type) were evaluated using Augmented Designs for Preliminary Yield Trials under stress (Rainfed) and nonstress (Irrigated) conditions in Research Field of Mashhad College of Agriculture, Ferdowsi University of Mashhad, during 2005–2006 growing season. Then, based on the obtained results, four candidate genotypes for drought tolerance and two susceptible ones were evaluated in a pot experiment at open door situation in stressed (25% Field Capacity) and non-stressed (Field Capacity) conditions based on a factorial trial in Randomized Complete Block Design. There were positive and highly significant correlations between quantitative drought resistance indices such as MP, GMP, STI and HM with yield in stress and nonstress conditions. Also, there were positive and high significant correlations for SSI and DRI with yield in nonstress and stress conditions, respectively. Based on drought resistance indices and DRI, MCC544, MCC696 and MCC693 genotypes were superior to others, so they can be viewed as promising genotypes for drought resistance. These results were approved using three dimensional scatter graph and multivariate biplot graph. In stress condition, there were negative and high significant correlations between yield and days to flowering. Drought stress decreased leaf area per plant in all genotypes, significantly. In stressed and non-stressed conditions, leaf area in susceptible genotypes was more than that in tolerant genotypes, thus drought tolerance may be attributed to less transpiration and water loss because of smaller leaf size and reduced leaf area expansion in tolerant genotypes when drought stress develops.

1. Introduction

Chickpea (*Cicer arietinum* L.) is the third most important pulse crop with a total annual global production of 9.7 M tones from 11.5 M ha (FAO, 2007). Chickpea is grown in 52 countries around the world, mainly in South and West Asia, North and East Africa, South Europe and Australia. The major chickpea growing areas are located in the arid and semi arid zones, where the crop is generally planted after the main rainy season and grown on stored soil moisture. In these environments, whether sown in autumn or spring, chickpea is often subjected to terminal drought stress (Turner, 2003). It was reported that water deficit results in nearly 50% of the variation in chickpea production caused by both biotic and abiotic stress factors (Saxena, 1987). Drought stresses are more serious in Iran, because firstly, rainfalls are poorly distributed over the growing season and stop before plant growth completion and secondly, chickpea is traditionally planted towards the end of the rainy season (March or April) and generally grown on progressively declining soil moisture residual and increasing temperature. So, in vegetative and reproductive growth phases, plants are subjected to intermittent and terminal drought stresses, respectively (Ganjeali et al., 2005). Infertile pods, earlier phenology stages, declining seed filling duration and lower harvest index are the results of drought stresses in these regions. The significance of early flowering in reducing duration of crop maturity period has been recognized in semi arid (Kumar and Abbo, 2001) and Mediterranean regions (Rubio et al., 2004). In the mentioned regions, selection for earlier flowering has been highly successful (Thomson and Siddique, 1997; Siddique et al., 1999). There are significant genetic variations in growth duration of chickpea that can be readily selected by observing days to flowering.

Iran is one of the main centers of diversity for chickpea. More than 900 locally and foreign collected genotypes are conserved in Mashhad Chickpea Collection (MCC). Landraces are well adapted to local environmental conditions (Ashraf and Karim, 1991) and so

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there should be a range of morphological, phenological and physiological mechanisms to efficient utilize the available water in a harsh environment.

Most available cultivar and genotypes of chickpea are often susceptible to biotic and abiotic stresses, therefore they have low and unstable yield (Singh and Saxena, 1993). Performance will be usually measured as yield, either biomass or seed yield, but may also be measured as a yield stability in drought-prone environments (Turner, 1996). Blum (1988) reported that screening for drought resistance among cultivars must be conducted based on high performance in stressed and non-stressed conditions, so genotypes that have high yield in both stressed and non-stressed conditions are drought resistant. In bean genotypes, Fernandez (1992) reported that Stress Tolerance Index (STI) is the best criteria for screening drought resistance. Fisher and Maurer (1978) and Rosielle and Hambling (1981) introduced Stress Susceptibility Index (SSI) and Tolerance Index (TOL), respectively. Ganjeali et al. (2005) through the evaluation of 34 chickpea genotypes revealed that Harmonic Mean (HM), Mean Productivity (MP), Geometric Mean Productivity (GMP) and Stress Tolerance Index (STI) are the most suitable indices for screening drought resistance of genotypes.

Despite the identifications of drought resistance mechanisms in large number of crops (Turner, 1996), plant breeders are still largely guided by grain yield and its stability under dry conditions in selecting for drought resistance, so this paper concentrates upon the grain yield results, their adjustment for drought escape and the separation of effects due to the differences in yield potential. Furthermore, it is important to identify the specific morpho-physiological attributes contributing to their adaptation to the water shortage patterns in their native environments. This would assist breeders to combine selectively some of these attributes into high yielding cultivars (Rosielle and Hambling, 1981). Therefore, the objectives of this study were: (1) to assess and identify Iranian chickpea genotypes adaptable to dry environments, (2) to identify the best indices for screening drought tolerance in chickpea genotypes and (3) to identify some morpho-phenological traits important for tolerance to drought stress.

2. Materials and methods

2.1. Field experiment

One hundred and fifty genotypes of chickpea (Kabuli type) that had been collected from different parts of Iran were evaluated in stressed (rainfed) and non-stressed (normal irrigation) conditions as two separate experiments in Mashhad. These experiments were carried out at the Research Field of Faculty of Agriculture, Ferdowsi university of Mashhad located in North Eastern of Iran (Latitude 36°,36′, Longitude 59°,39′ and altitude of 980 m above sea level) in the 2005–2006 season. The climate type in this part of Iran is arid and semi arid with long-term of average annual precipitation of 283 mm falling through winter and early spring. Each experiment (stressed and non-stressed) was laid out in Augmented Designs for Preliminary Yield Traits (Fedrer and Raghava Rao, 1975; Paterson, 1985). Regarding to large number of genotypes, 150 genotypes were arranged in three blocks so that each genotype planted in a single row plot of 4 m length 50 cm apart without repetition. Forty seeds of each genotype were planted by hand over each row (plot) at April 2006. Five genotypes (MCC180, MCC252, MCC283, MCC358 and MCC361) as current and well-known genotypes were repeated as checks in each block. The plots received 70 kg/ha of triple super phosphate before sowing. At the end of growing season, some traits including days from planting to flowering, 100 seeds weight and seed yield were measured for all genotypes. Then genotypes were grouped in 9 classes according to their seed yield at non-stressed conditions and results were presented as brief (Table 1), so detail for each of 150 genotypes not presented individually.

In order to identify drought-tolerant genotypes, 30 top genotypes (approximately 20% of all) that produced seed yield value of 160 g m^{-2} or more (based on yield in irrigated condition) were selected as promising genotypes for drought tolerance.

Some drought resistance and susceptibility indices including Drought Response Index (DRI) were calculated for all genotypes as followed (Fisher and Maurer, 1978; Bidinger et al., 1987; Fernandez, 1992; Ouk et al., 2006; Sio-Se Mardeh et al., 2006):

$$\text{Dry response index (DRI)} = \frac{Y_s - Y}{\text{S.E. of } Y}, \quad Y = a - bF + cY_p \tag{1}$$

$$\text{Mean productivity (MP)} = \frac{Y_s + Y_p}{2} \tag{2}$$

$$\text{Stress tolerance index (STI)} = \frac{Y_s Y_p}{(\bar{Y}_p)^2} \tag{3}$$

$$\text{Geometric mean productivity (GMP)} = (Y_s Y_p)^{1/2} \tag{4}$$

$$\text{Harmonic mean (HM)} = 2\frac{Y_s Y_p}{Y_s + Y_p} \tag{5}$$

$$\text{Stress susceptibility index (SSI)} = \frac{1 - (Y_s/Y_p)}{\text{SI}}, \quad \text{SI} = 1 - \frac{\bar{Y}_s}{\bar{Y}_p} \tag{6}$$

where Y_s: stressed yield, Y: regression estimate of stressed yield, S.E.: standard error of Y, a, b and c: regression coefficients, F: days to flowering, Y_p: non-stressed yield, $\bar{Y}_p$: overall mean of non-stressed yield, SI: stress intensity and $\bar{Y}_s$: overall mean of stressed yield.

In order to screen drought tolerant genotypes, Three Dimensional Scatter Graphs were used. In this method, yield in stressed and non-stressed conditions and drought resistance indices are studied, simultaneously (Fernandez, 1992; Kanoni et al., 2002; Ganjeali et al., 2005). Then we used Principal Components Analysis (PCA) based on the covariance matrix to construct a biplot of genotypes (PC scores) and drought resistance indices including MP, GMP, STI and DRI and yield in stressed and non-stressed conditions (PC factor loading). This analysis is used for abstracting of multivariate data matrix and presenting them, interpretably (Smith, 2002).

Based on these indices and principal components analysis, candidate genotypes for drought tolerance were identified.

Daily precipitation and temperature during cropping season is presented in Fig. 1. The reference evapotranspiration (ETo) for each month within growing season in region as daily mean (mm/day) was as follow: 2.6 at April, 3.8 at May, 5.1 at June, 6.3 at July and 5.5 at August.

2.2. Pot experiment

Based on the results of the field experiment, four candidate genotypes for drought tolerance (MCC544, MCC691, MCC693 and MCC696) and two susceptible genotypes (MCC87 and MCC582) were evaluated. Two plants of each genotype were grown per pot (experimental unit) with 100 cm length and 12 cm diameter in open door condition. The soil was a sandy clay loam from the A-horizon of a field site at Campus of Ferdowsi University of Mashhad, North-eastern of Iran, pH 6.8. The soil was sieved to 5 mm and then mixed 4:1 with sand (soil:sand) to reduce compaction and improve drainage. Treatments were imposed stressed (25% Field Capacity) and non-stressed (Field Capacity) conditions during growing season. Factorial combination of the treatments (genotype and drought stress levels) was laid out in Randomized Complete Block Design (RCBD) with three replications.

At the end of flowering stage (approximately 50 days after sowing) the above and below-ground biomass in all treatments was

Table 1
The frequency of chickpea genotypes based on their seed yield at non-stressed condition, and their mean, standard error and range among each group for some quantitative traits of genotypes at stressed and non-stressed conditions at Mashhad (2006).

Yield group (kg/h)	Genotypes no. in each group	Statistical indices for each group	Days from planting to flowering		100 seeds weight (g)		Seed yield (kg/h)	
			Stress	Non stress	Stress	Non stress	Stress	Non stress
2401–2800	3	Mean	44.7	45.3	24.2	30.9	90.0	2580.1
		S.E.[a]	6.7	7.4	6.3	9.4	100.7	140.0
		Range	12.7	13.3	12.4	18.7	190.3	248.1
2201–2400	6	Mean	42.7	47.2	21.2	26.1	242.2	2290.6
		S.E.	6.3	5.6	6.7	5.1	190.1	64.1
		Range	16.3	15.7	16.8	11.5	498.7	187.1
2001–2200	2	Mean	49.4	48.2	28.9	32.6	114.1	2063.3
		S.E.	9.4	4.8	9.7	10.9	130.2	63.1
		Range	13.3	6.7	13.7	15.4	180.7	90.0
1801–2000	10	Mean	46.3	47.2	28.8	34.7	140.0	1890.1
		S.E.	7.2	5.4	6.4	3.8	141.7	50.3
		Range	19.0	16.0	21.2	11.7	484.5	173.4
1601–1800	17	Mean	48.9	48.0	27.2	33.9	85.6	1690.7
		S.E.	6.7	4.3	6.1	7.3	80.0	70.3
		Range	20.0	12.3	22.5	28.0	260.9	190.2
1401–1600	25	Mean	48.1	50.1	23.1	32.5	125.5	1510.7
		S.E.	7.3	5.1	7.4	6.7	130.5	54.4
		Range	21.3	21.0	35.9	23.6	467.7	189.0
1201–1400	13	Mean	51.6	51.9	24.9	33.9	66.7	1310.3
		S.E.	5.5	2.9	9.1	5.8	60.1	5.2
		Range	16.0	11.7	37.6	19.7	206.7	150.2
1001–1200	20	Mean	53.1	52.1	22.4	34.5	49.1	1104.4
		S.E.	6.8	3.7	11.7	5.4	70.1	6.7
		Range	27.0	13.0	40.4	18.9	249.0	184.0
0–1000	54	Mean	48.7	51.8	16.7	26.6	50.1	510.0
		S.E.	7.8	8.7	12.5	10.6	64.1	36.4
		Range	29.1	28.7	35.9	40.9	290.1	980.4
Total	150	Mean	49.0	50.4	21.7	30.8	84	1187
		S.E.	7.4	6.1	10.8	8.7	105.0	631.0
		Range	29.1	28.7	41.8	46.8	516	2740

[a] Standard error.

measured. Plants in each pot were harvested by cutting the shoots from the roots and then leaf area and root length were recorded before being dried at 70 °C, and finally weighted. Leaf area was measured by leaf area meter. The roots in each pot were recovered from the soil by repeated sieving to produce a clean sample. Roots from each pot were divided into several sections and then placed on the scanner connected to a computer for analysis. Finally, root length from each section of the pot was calculated using ROOTEDGE software computer (Rootedge, 1999). Then, root material was dried and weighted.

2.3. Statistical analysis

Data were analyzed by MSTAT-C and JMP4 software and means comprised based on Least Significant Difference test (LSD). Statistica software was used for principal components analysis.

3. Results and discussions

3.1. Field experiment

Substantial diversity was found among genotypes for different quantitative traits. The overall mean for days to flowering in stressed and non-stressed conditions was not significant, but considerable variations for time to flowering were observed among genotypes (Table 1). It seems that time to flowering was affected by genotype, but not by soil moisture regime. The existence of wide genetic variations for flowering time was documented by Pundir et al. (1984), who evaluated the world chickpea germplasm main-

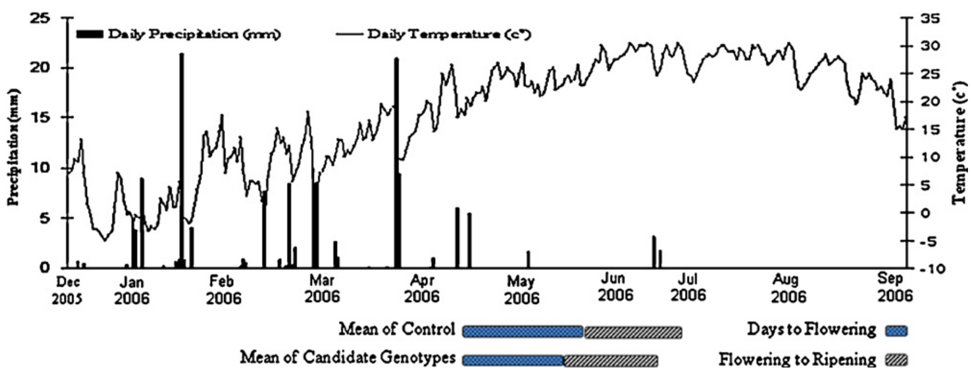

Fig. 1. Daily precipitation and temperature and phenological period for control and candidate chickpea genotypes for drought tolerance during cropping season at Mashhad (2005–06).

tained from ICRISAT and listed 43 accessions that flowered in less than 39 days at Patancheru.

In this experiment, days to flowering ranged from 37 days in MCC748 (as an early flowering) to 65 days in MCC526 (as a late flowering) genotypes. In environments in which terminal drought is likely, selection for early flowering genotypes is important, because drought is a serious limiting factor for yield production (Subbarao et al., 1995; Thomson and Siddique, 1997; Siddique et al., 1999). However, selection for early flowering may not always increase yields in climates with unpredictable and intermittent drought (Siddique and Sedgley, 1986; Siddique et al., 1994).

Drought stress had significant effect on 100 seed weights. The overall mean across 150 genotypes for 100 seed weights ranged from 21.7 g in drought stress to 30.8 g in irrigated condition (Table 1). Under stressed conditions, reduction in 100 seed weights is likely the result of limiting effects of drought stress on assimilate production and partitioning to seeds. Furthermore, short duration of reproductive phase in stressed environments must not be neglected. Turner (1996) and Singh et al. (2005) showed that drought stress through earlier phenology and shorter seed filling duration caused reduction in seed size, harvest index and finally grain yield.

There were large differences for seed yield in stressed (rainfed) and non-stressed (irrigated) conditions. Under irrigated conditions, seed yield ranged from 2740 kg/ha in MCC759 to 43 kg/ha in MCC529, while under rainfed conditions it ranged from 516 kg/ha in MCC537 to 10 kg/ha in MCC525. Seed yield differences among genotypes in their reaction to drought stress is related to the fact that agro-climatic conditions in Iran vary considerably even within short distance, and genotypic differences are the results of adaptive response to the different environments (Ganjeali et al., 2005). In stressed environments, seed yield decreased significantly and the main reasons can be the inadequate and poorly distributed rainfall over the growing season (less than 60 mm), declining residual soil moisture and increasing temperature through reproductive growth stage.

Since yield in non-stressed environments (potential yield) is an important component for screening drought tolerance (Blum, 1988; Singh and Saxena, 1993), 30 genotypes that produced seed yields more than 160 g m^{-2} (based on grain yield in non-stressed condition) were selected as promising genotypes and were compared. Based on the results of seed yield in stressed and non-stressed conditions (Table 2), the genotypes that produced superior yield in non-stressed conditions did not have necessarily high yields under stressed conditions. These results approved lack or inefficiency of drought tolerance mechanisms in some of these genotypes. Blum (1988) suggested that screening for drought resistance must be conducted based on genetic materials for high yields in non-stressed conditions, probably genotypes/cultivars that have high performance and stable yields in stressed and non-stressed environments are tolerant to drought. These genotypes would have economic yields in dry years and high performance in rainy. In this experiment, yield in stressed and non-stressed conditions was high for MCC696, but MCC674 had high performance only in non-stressed and poor yield in stressed condition.

Quantitative drought tolerance and susceptibility indices for 30 promising genotypes are presented in Table 2. Genotypic differences among Iranians chickpeas for these indices were reported by other scientists (Farshadfar et al., 2001; Jamshid Moghadam et al., 2002; Kanoni et al., 2002; Ganjeali et al., 2005). Since STI, HM, MP and GMP indices showed positive and high significant correlation with yield in stressed and non-stressed conditions (Table 3), so these indices are the best criteria for identifying drought resistant genotypes/cultivars. Meanwhile, SSI had only significant correlation with yield in non-stressed condition.

Drought response index (DRI) had positive and highly significant correlation with yield only in stressed conditions. Since DRI evaluates genotypes independently from the escape mechanisms, genotypes with DRI values of 1.3 or more were identified as drought tolerant genotypes (Bidinger et al., 1987), but these genotypes may not have high potential yield.

Since our hypothesis is drought tolerant genotypes should produce high yield in years with low rainfall and be responsive to moisture supply in rainy years, identifying high performance genotypes in stressed and non-stressed conditions is an objective. According to drought resistance indices (STI, HM, MP and GMP), MCC544, MCC696, MCC693, MCC537 and MCC521 genotypes were identified as candidate genotypes for drought tolerance. They had DRI values of 1.3 or more (except MCC521). Thus, these genotypes can be considered as drought tolerant (high yield under stressed and non-stressed conditions).

In candidate genotypes, days to flowering both in stressed and non-stressed conditions were less than that of average promising genotypes (Table 2) and overall mean of genotypes (Table 1). Early phenology (drought escape) and short times subjected to drought and high temperature stresses (that usually happen in reproductive stage) are probably the strategic approaches related to drought tolerance about candidate genotypes in this experiment. These results have been reported by other researchers (Turner et al., 2001; Kumar and Abbo, 2001).

Three dimensional scatter graph was used where yield in stress (Y_s), yield in non-stress (Y_p) and drought resistance indices were placed in *X*, *Y* and *Z* axis. In this graph, *X* and *Y* surfaces have been separately fractioned to four equal parts as follow:

Group (A): High yield in stressed and non-stressed environments.
Group (B): High yield in non-stressed but low yield in stressed environments.
Group (C): High yield in stressed and low yield in non-stressed environments.
Group (D): Low yield in stressed and non-stressed environments.

Fernandez (1992) recommended that the indices which are able to separate group A from the other groups are the best for screening drought tolerant genotypes.

Evaluation of three dimensional scatter graphs (Fig. 2(1)) showed that genotype numbers 4, 5 and 6 (MCC544, MCC693 and MCC696) are placed on group A. These genotypes are firstly superior for yield in stressed and non-stressed conditions and are secondly superior for quantitative tolerance indices than others, so they were recommended as candidate genotypes for tolerance to drought. Despite genotype numbers 19 and 30 (MCC537 and MCC521) having high yield in stressed conditions their yield potential (yield in irrigated condition) were low, so were placed on group C. Conversely, yield potential in genotype numbers 1, 2, 3, 7, 8 and 9 (MCC759, MCC674, MCC550, MCC546, MCC508 and MCC562, respectively) were high but their yields in stressed conditions were poor, so these genotypes were classified as drought susceptible genotypes and they are only recommended for humid environments or regions with adequate water.

Principal Components Analysis was conducted retaining the first two components (90%) (data not presented) and omitting others with no significant effect (Fig. 3). Results demonstrated that the first component had positive and high significant correlations with yield in stressed conditions and with some indices such as HM, STI, GMP and MP, but this component had negative correlation with DRI ($R^2 = -0.85$). Drought tolerant and susceptible genotypes were classified by high and low values of this component, respectively.

The second component had positive and significant correlation with yield potential ($R^2 = 0.84$). Based on this component, well adapted genotypes to availability of water (humid environments)

Table 2
The mean of seed yield, days to flowering and resistance, susceptibility and response to drought indices for 30 superior chickpea genotypes at Mashhad (2006).

Row no.	Genotype name (MCC)	Seed (yield kg/h)		Days from planting to flowering		Resistance, susceptibility and response to drought indices					
		Stress	Non stress	Stress	Non stress	GMP	HM	STI	MP	SSI	DRI
1	759	37.7	2743.0	50.0	54.0	321.6	74.4	0.1	938.2	1.1	−1.5
2	674	20.1	2505.0	47.0	41.6	224.6	40.0	0.0	1390.4	1.1	−1.9
3	550	213.0	2495.0	37.0	40.6	729.1	393.0	0.4	1262.6	1.0	−0.4
4	544	342.6	2392.0	38.0	43.6	905.3	599.0	0.6	1354.0	0.9	1.5
5	696	516.2	2340.0	37.0	41.8	1099.0	846.0	0.9	1367.5	0.8	3.8
6	693	355.2	2290.0	38.0	44.8	901.8	615.0	0.6	1428.0	0.9	1.7
7	546	129.7	2280.0	45.0	43.6	544.0	245.4	0.2	1324.0	1.0	−0.5
8	508	19.3	2270.0	53.0	57.6	209.5	38.3	0.0	1205.0	1.1	−1.1
9	562	91.7	2206.0	45.0	47.6	450.0	176.1	0.1	1145.0	1.0	−1.0
10	807	20.4	2108.0	56.0	51.6	207.5	40.4	0.0	1064.0	1.1	−0.6
11	732	207.0	2019.0	43.0	44.8	646.3	375.4	0.3	1112.8	1.0	0.5
12	569	64.0	1992.0	47.0	47.6	356.7	124.0	0.1	1028.0	1.0	−1.0
13	805	5.0	1930.0	56.0	51.6	13.9	0.2	0.0	965.0	1.1	−1.0
14	551	145.0	1921.0	37.0	41.6	527.5	269.4	0.2	1033.0	1.0	−0.2
15	791	47.2	1921.0	55.0	51.6	301.0	92.1	0.1	984.0	1.1	−0.7
16	815	5.6	1906.0	56.0	51.6	103.5	11.2	0.0	956.0	1.1	0.4
17	552	221.0	1870.0	40.0	40.6	643.0	395.4	0.3	1046.0	1.0	0.0
18	644	151.0	1864.0	45.0	56.6	950.0	279.5	0.2	1007.0	1.0	4.0
19	537	484.7	1854.0	40.0	43.6	948.0	768.5	0.6	1169.0	0.8	1.4
20	774	47.1	1832.0	45.0	42.6	294.0	91.9	0.1	940.0	1.1	0.7
21	692	233.5	1818.0	41.0	44.8	651.6	41.4	0.3	1026.0	0.9	−1.6
22	543	72.3	1804.0	40.0	41.6	361.2	139.1	0.1	938.2	1.0	0.4
23	777	82.0	1785.0	56.0	44.6	382.6	157.0	0.1	933.6	1.0	1.6
24	770	259.0	1785.0	45.0	51.6	679.6	452.0	0.3	1021.7	0.9	−0.9
25	641	75.1	1764.0	45.0	43.6	364.0	144.0	0.1	919.6	1.0	1.6
26	722	166.0	1761.0	56.0	44.8	540.6	303.2	0.2	963.6	1.0	1.2
27	575	228.0	1755.0	45.0	47.6	634.0	404.6	0.3	992.0	0.9	−1.4
28	775	2.9	1740.0	56.0	51.6	71.2	5.8	0.0	871.4	1.1	−0.7
29	766	14.8	1723.0	54.0	51.6	159.8	29.4	0.0	869.0	1.1	−0.3
30	521	321.4	1602.0	37.0	54.0	717.5	535.3	0.4	962.0	0.9	1.0
Mean	152.6	2009.2	46.2	47.2	497.9	256.2	0.2	1073.9	1.0	0.2	
Standard error	139.7	280.4	6.9	5.0	284.8	232.7	0.2	161.4	0.1	1.4	

would be classified (C region on biplot graph). Since the first component had positive and high significant correlation with yield in stressed condition and drought tolerance indices, and also the second component had positive and high significant correlation with yield potential, genotypes placed on upper space of both these components (genotype numbers of 4, 5 and 6) were identified as high yielding and tolerant genotypes.

Genotype numbers 27, 30, 19 and 24 were placed near to the DRI vector with fairly high yield in drought conditions but because of their low yield potential, they only can be used in breeding programs for drought tolerance as parental materials.

Time to flowering had significant negative and positive correlation with seed yield in stressed and non-stressed conditions, respectively. These correlations were not significant for time to maturity. Earliness is an important factor for yield improvement in stressed environments, but influences negatively on yield in non-stressed environments (Kumar, 2005). Flowering and seed setting in early flowering genotypes take places before becoming critical moisture and temperature stress (drought escape), thus as a result, time to flowering has negative correlation with seed yield. These results were suggested by Leport et al. (1999) and Turner et al. (2001). Earliness (shorter time to flowering) and avoidance from terminal drought may be the main reason for superiority of MCC544, MCC693 and MCC696 genotypes.

Stress susceptibility index (SSI) was positively associated with time to flowering in nonstressed conditions. Probably, extending reproductive period may result in high susceptibility to drought stress for genotypes (Thomson and Siddique, 1997; Siddique et al., 1999). The association of 100 seed weights with seed yield was positive and significant in non-stressed conditions but this associ-

Table 3
The correlation between seed yield in stressed and non-stressed conditions with resistance, susceptibility and response to drought indices for chickpea genotypes at Mashhad (2006).

	Y_s	Y_p	STI	SSI	HM	MP	GMP	DRI
Y_s	1.00							
Y_p	0.12^{**}	1.00						
STI	0.88^{**}	0.26^{**}	1.00					
SSI	0.00	0.24^{**}	0.03^{*}	1.00				
HM	0.97^{**}	0.20^{**}	0.91^{**}	0.04^{*}	1.00			
MP	0.23^{**}	0.98^{**}	0.39^{**}	0.22^{**}	0.32^{**}	1.00		
GMP	0.84^{**}	0.37^{**}	0.86^{**}	0.07^{**}	0.92^{**}	0.51^{**}	1.00	
DRI	0.53^{**}	0.00	0.42^{**}	0.00	0.47^{**}	0.01	0.31^{**}	1.00

Y_s and Y_p: seed yield in stressed and non-stressed conditions, respectively.
* Significant at $p \leq 0.05$.
** Significant at $p \leq 0.01$.

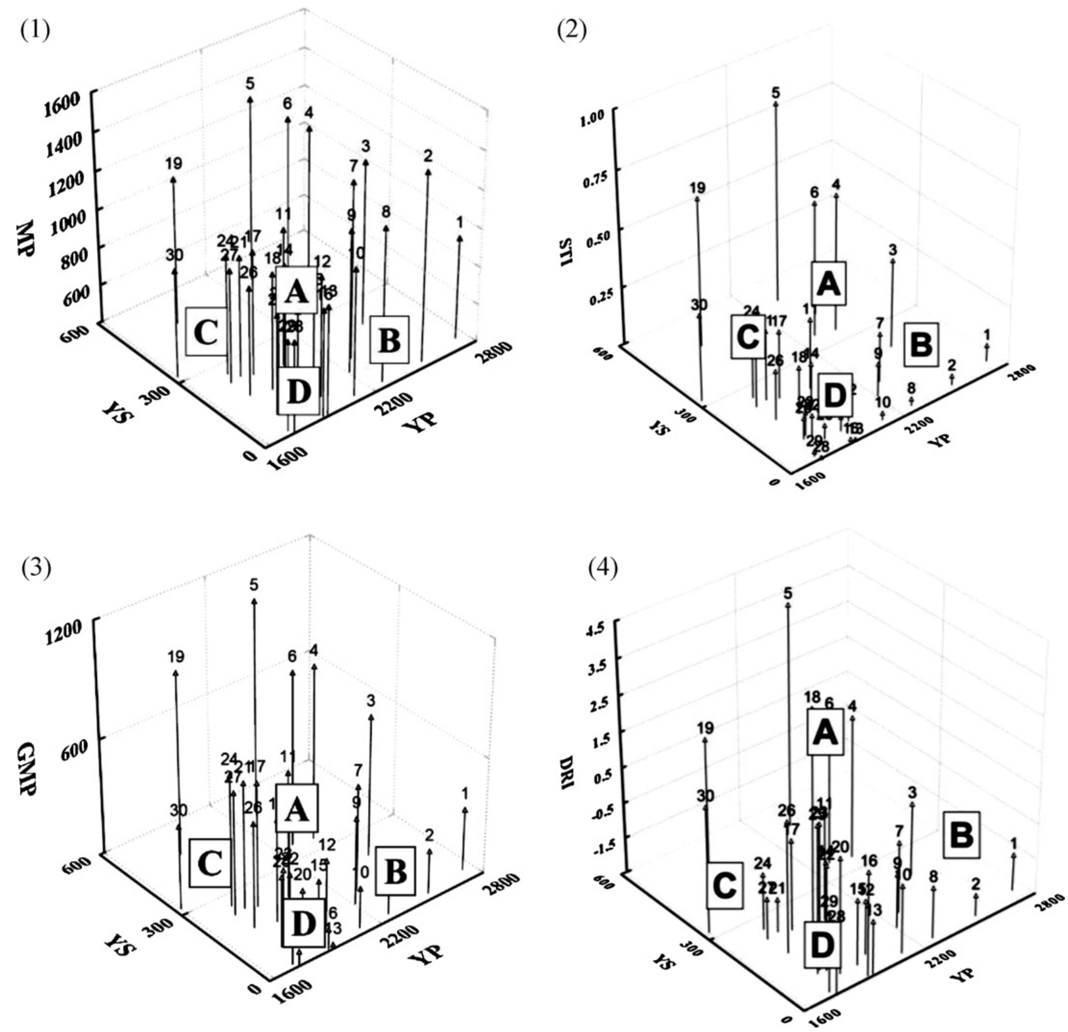

Fig. 2. Three dimensional scatter graph for showing the relationship between yield in stress (Y_s), yield in non-stress (Y_p) and drought resistance indices (1: MP, 2: STI, 3: GMP and 4: DRI) for 30 top genotypes as promising genotypes for drought tolerance at Mashhad (2005–06).

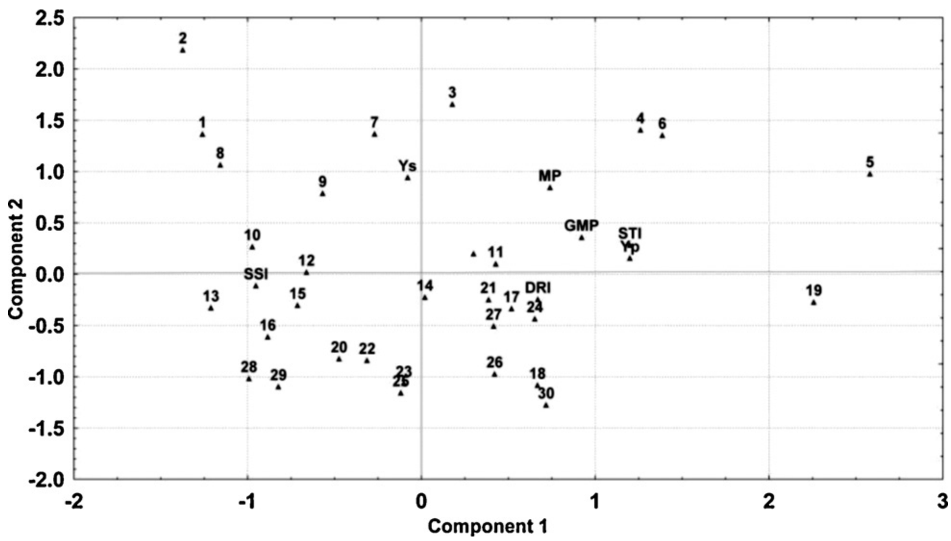

Fig. 3. Principal Components Analysis (PCA) based on the covariance matrix of genotypes (PC scores) and drought resistance indices including MP, GMP, STI and DRI and yield in stressed and non-stressed conditions (PC factor loading). The first and second components have positive and high significant correlations with yield in stressed and non-stressed conditions, respectively.

Table 4
The correlation between seed yield and some agronomic traits with resistance, susceptibility and response to drought indices for chickpea genotypes at Mashhad (2006).

Phenotypic traits		Seed yield		Resistance, susceptibility and response to drought indices					
		Y_s[a]	Y_p[a]	STI	GMP	MP	HM	SSI	DRI
Days to flowering	a	−**	**	−**	−**	−**	−**	ns	ns
	b	ns	**	ns	ns	**	ns	**	ns
Days to ripening	a	ns	ns	ns	ns	ns	ns	ns	ns
	b	ns	ns	ns	ns	ns	ns	**	ns
100 seed weight	a	ns	**	ns	**	**	ns	**	ns
	b	ns	**	ns	ns	**	ns	**	ns

a and b: correlations in stressed and non stressed conditions, respectively.
**: Significant at $p \leq 0.01$.
[a] Y_s and Y_p: seed yield in stressed and non-stressed conditions, respectively.

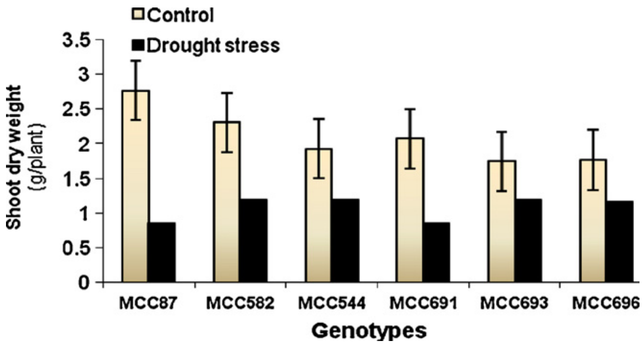

Fig. 4. Shoot dry weight of four tolerant Iranian chickpea genotypes and two susceptible genotypes (MCC87 and MCC582) under drought stress and non-stressed (control) moisture regimes ($LSD_{0.05}$ bar has been shown).

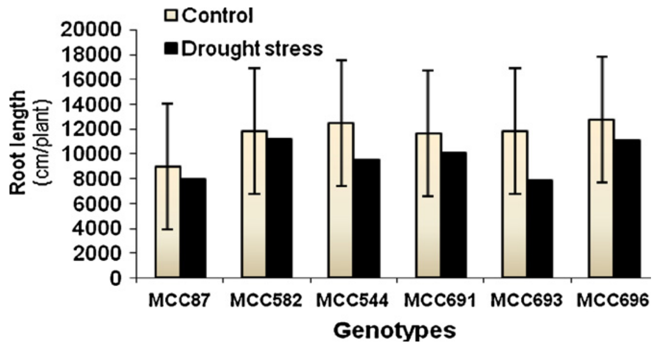

Fig. 6. Root length of four tolerant Iranian chickpea genotypes and two susceptible genotypes (MCC87 and MCC582) under drought stress and non-stressed (control) moisture regimes ($LSD_{0.05}$ bar has been shown).

ation in stressed conditions was not significant. Long duration of grain filling cannot be fulfilled under short reproductive period in stressed conditions particularly in regions with terminal drought stress (Turner et al., 2001; Anbessa and Bejiga, 2002). Since DRI evaluates genotypes for drought resistance independently from drought escape and earliness (Bidinger et al., 1987), there were no significant correlations between DRI and times to flowering and time to maturity. Stress susceptibility index and potential yield were positively associated with 100 seed weights (Table 4).

3.2. Pot experiment

Based on the results, shoot weight (stem + leaves) were affected by drought stress in all genotypes, but the decrease was significant only in MCC87, MCC582 and MCC691 genotypes (Fig. 4). This must have happened as a result of decrease in net photosynthesis under drought stress (Berry, 1975). In all genotypes root dry weight decreased by drought stress and there were no significant differences among genotypes (Fig. 5). Results about root length were the same (Fig. 6). High and significant correlation between root length and root dry weight have been suggested by some researchers (Ganjeali et al., 2005; Fageria et al., 2006). Deep and dense root system is important for water absorption where the soil surface is dried rapidly, but sufficient soil moisture may be available in the deeper zone. This is typical for chickpea production regions in Iran.

Drought stress significantly decreased leaf area per plant in all genotypes. Leaf area in susceptible genotypes (MCC87 and MCC582) was more than that in tolerant genotypes in stressed and non-stressed conditions (Fig. 7). According to Hsiao and Acevedo (1974) for production environments relying on stored soil moisture, crops need to adjust their transpiring surface through reducing leaf growth (as a mechanism for reducing water loss). Developments for drought tolerant genotypes through decreasing in leaf area were reported by scientists (Singh and Saxena, 1993; Ganjeali and Nezami, 2008). Thus, drought tolerance in this study may be attributed to reduced transpiration and then water loss by having smaller leaf size and reducing leaf area expansion of genotypes when drought stress develops.

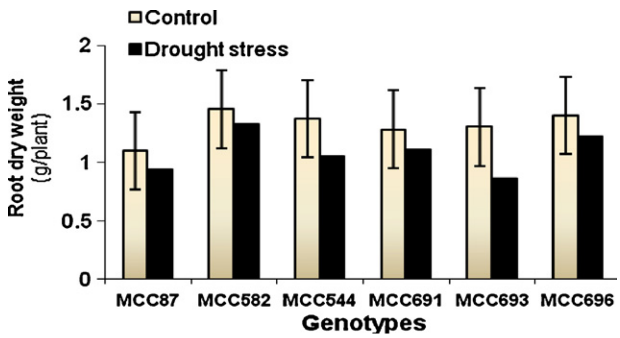

Fig. 5. Root dry weight of four tolerant Iranian chickpea genotypes and two susceptible genotypes (MCC87 and MCC582) under drought stress and non-stressed (control) moisture regimes ($LSD_{0.05}$ bar has been shown).

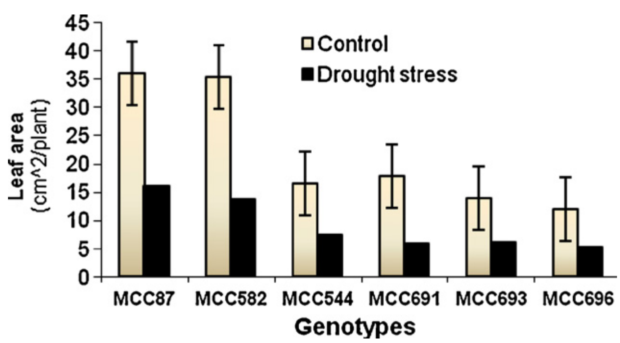

Fig. 7. Leaf area of four tolerant Iranian chickpea genotypes and two susceptible genotypes (MCC87 and MCC582) under drought stress and non-stressed (control) moisture regimes ($LSD_{0.05}$ bar has been shown).

4. Conclusion

Chickpea is grown in spring as a rainfed crop in west and north eastern parts of Iran where the rainfall amount and its distribution are highly variable. Our hypothesis was that drought resistant genotypes should produce high yields in years with low rainfall and be responsive to moisture supply in years with high rainfall. The variations observed for drought resistance indices, grain yield and days to flowering among genotypes were considerable. In candidate genotypes for drought resistance, days to flowering both in stressed and non-stressed conditions were less than that of average promising genotypes and overall mean of genotypes. In stress condition, there were negative and high significant correlations between yield and days to flowering. Based on drought resistance indices and DRI, MCC544, MCC696 and MCC693 genotypes were superior to others, so they can be recommended as candidate genotypes for drought resistance. In this study, leaf area in susceptible genotypes was more than that in tolerant genotypes that may be related to less transpiration and water loss because of smaller leaf size and area expansion in tolerant genotypes when drought stress develops.

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