

## Evaluation of Drought Tolerance Selection Indices Using Grain Yield in Chickpea (*Cicer arietinum* L.)

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### Abstract

Among abiotic stresses, drought is undoubtedly one of the most important ones, that have great impact on crop growth and productivity worldwide. Therefore, identifying of plants' performance against drought stress and estimating drought tolerance become a necessary part of the breeding phase. The main purpose of the present study was to investigate the effect of several indices that combine drought tolerance and high yield potential in chickpea. The trials were conducted under both stressed and no-stressed environments for two growing seasons (2015/2016-2016/2017) in Southeast Anatolia Region of Turkey. Varyans analysis results showed that there were significant differences among genotypes regarding Yp, Ys, MP, MRP, GMP, REI, STI, MISTik 1, MISTik 2, HM, YI, PI, ATI, SNPI and RDY. The genotypes FLIP09-51C, FLIP97-503C and FLIP06-97C had high yield under non-stressed condition, while the genotypes FLIP09-51C, FLIP06-97C and 'Aksu' displayed high amount under stressed condition. Thus, the genotypes FLIP09-51C and FLIP06-97C were found as good candidates for commercial recommendation in both conditions. Spearman rank correlation matrix showed that drought indices were significantly related to each other. The yields in stress and no-stress conditions (Yp and Ys) showed a significant and positive correlation with MP, MRP, GMP, REI, STI, MSTIK1, MSTIK2 and HM and showed a negative correlation with PI and RDY. As a result, it has been found that MISTIK2, DI, HM, STI and YI can be used as optimal indicators for screening drought-tolerant genotypes, while FLIP09-51C, FLIP06-97C, EN934 and 'Aksu' varieties have been the most tolerant genotypes in terms of these indices examined in study.

**Keywords:** chickpea; correlation analysis; drought indices; seed yield

**Abbreviations:** ATI: Abiotic Tolerance Index; DF: Degrees of Freedom; DI: Drought Resistance Index; DTE: Drought Tolerance Efficiency; GM: Golden Mean; GMP: Geometric Mean Productivity; HM: Harmonic Mean of Yield; MISTik2: Modified Stress Tolerance Index 2; MP: Mean Productivity; MRP: Mean Relative Performance; MSTik1: Modified Stress Tolerance Index 1; PI: Superiority Index; R: Rank; RDI: Relative Drought Index; RDY: Relative Decrease in Yield; REI: Relative Efficiency Index; SDI: Sensitivity Drought Index; SNPI: Stress/Non-Stress Production Index; SOV: Source of Variation; SSI: Stress Susceptibility Index; SSPI: Stress Susceptibility Percentage Index; STI: Stress Tolerance Index; TOL: Tolerance; YI: Yield Index; Yp: Potential Yield; Ys: Stress Yield

### Introduction

Chickpea (*Cicer arietinum* L.) is one of the most important edible legumes grown in marginal lands around the world. Its production is about 12.1 million tons from 12.7 million hectares cultivated land, with a mean seed yield of 95 kg ha<sup>-1</sup>. Chickpea is produced on 351.687 hectares in Turkey and ranks fifth in the world after India, Australia, Myanmar and Pakistan (FAO, 2016). Among food legumes, chickpea is rich in nutritional compositions and does not contain significant quantities of any specific major anti-nutritional factors. Due to its high protein content,

chickpea is used as a major protein source in most of developing countries. It is also an important pulses plant in cereal-legume planting rotation in many countries around the world (Zdemur *et al.*, 2003). Biotic and abiotic stresses are important factors limiting the agricultural production in the world. From these abiotic stresses, drought causes severe yield losses in arid and semi-arid regions (Mollasadeghi *et al.*, 2011).

Due to Ascochyta blight disease in chickpea, most of the chickpea production is done in marginal areas and as spring planting in many countries of the world. This situation causes terminal drought stresses during flowering, podding and seed filling period of plants in Turkey. Therefore,

selection for drought tolerant chickpea genotypes is the most important objective for breeding to drought stress. Drought tolerance selection is not easy due to the happening of strong interactions between genotypes and the environment and restricted knowledge about the function and role of tolerance mechanisms. Hence, researchers have used different drought resistance indices to evaluate genetic differences in drought tolerance.

To appraise reaction of plant to drought stress, some selection index (SSI, MP, TOL, YSI, RDI, PI, STI, GMP, HM, YI and KiSTI) based on a mathematical relation between stress and optimal conditions have been recommended (Fischer and Maurer, 1978; Rosielle and Hamblin, 1981; Bouslama and Schapaugh, 1984; Blum, 1988; Lin and Binns, 1988; Fernandez, 1992; Gavuzzi *et al.*, 1997; Farshadfar and Sutka, 2002).

Thus, the present study was conducted to (i) determine drought tolerance indices under stress and non-stress conditions, and (ii) identify some of chickpea genotypes reaction to drought stress.

## Materials and Methods

### *Growth conditions and research materials*

The research was conducted at two locations with different average rainfall amounts, namely Diyarbakır and Kızıltepe, during 2016 and 2017, both of which are located in the Southeast Anatolia Region of Turkey. The favorable site (Diyarbakır) is located at 37° 56' N latitude, 40° 15' E longitude, at an elevation of 670 m above sea level. The soil of the trial area carried out in this locality is a clay loam. The average annual maximum and minimum temperatures are 22.6 °C and 8.8 °C respectively, and average annual precipitation is 485 mm (Anonymous, 2017). Kızıltepe station represents the stressed semi-arid site with 300 mm as mean rainfall. It is located at 37° 19' N latitude, 40° 58' E longitude, at an elevation of 490 m. The soil is deep clay. The yearly average maximum and minimum temperatures are 26.4 °C and 12.1 °C respectively.

The research material consisted of fourteen Kabuli chickpea genotypes (Table 1) which included four check varieties ('Arda', 'Diyar-95', 'Azkan' and 'Aksu') and ten advanced breeding lines.

The field experiments were arranged in a randomized complete block design with three replications at both environments. The plots consisted of 4 rows that were 5 m long and spaced 0.30 m. Seeds were planted with parcel machine at density of 45 seeds per square meter. The sowings were performed on the last week of November in both environments and harvestings were carried out on the

last week of June for stressed fields and in the first week of July for non-stressed experimental site. Di-Ammonium Phosphate (DAP 18-46) fertilizer was used at the rate of 130 kg per hectare as source of N and P before sowing. Weeds were controlled by hand during crop growth and development.

### *Calculation of indices*

The seed yield of each plot was evaluated based on 6 m<sup>2</sup>, and converted to the standard unit at metric kg per hectare. Drought indices were calculated using the consacrated formulas (Annex 1).

### *Statistical analysis*

The correlation coefficients were calculated using the SPSS version 22. The experimental data were statistically analyzed for variance using JMP statistical software (SAS 2007). Differences were compared by Least Significant Difference Test (LSD) at alpha 0.05.

## Results and Discussion

### *Analysis of variance*

Analysis of variance for both potential yield (Y<sub>p</sub>) and stress yield (Y<sub>s</sub>) indicated significant differences among the fourteen chickpea genotypes. Variance analysis of both the potential yield (Y<sub>P</sub>) and the stress yield (Y<sub>S</sub>) indicated significant differences among the genotypes. Also, significant differences were observed for the examined indices MP, MRP, GMP, REI, STI, MIST1k1, MIST1k2, HM, YI, PI, ATI, SNPI and RDY (Table 2).

The ranks of the chickpea according to each one of the drought tolerance indices are given in Table 3. The average seed yield of the varieties under non-stressed conditions ranged from 3,954.4 ('Diyar-95') to 4,825.0 kg (FLIP09-51C), while ranged from 2,384.4 ('Arda') to 3,044 kg in the stressed conditions. Besides, the average grain yield in non-stressed condition (4,370.1 kg) was higher than in stressed condition (2,736.3 kg). When the yields of the varieties were compared in two environments, the largest variation of yield was observed in 'Arda' variety, followed by FLIP97-503C and 'Azkan' respectively. Maximum reductions in grain yield were observed in 'Arda' and FLIP97-503C genotypes, while the least amount of reductions in yields was observed in FLIP03-131C and FLIP06-93C genotypes (Table 3).

Fernandez (1992) classified plants according to their performance in stressful and stressless conditions to four groups: genotypes with high performance in both conditions (group A), genotypes with good performance

Table 1. List of the 14 chickpea genotypes used for the study

Entry code	Name	Origin	Entry code	Name	Origin
1	EN 934	TURKEY	8	FLIP06-93C	ICARDA
2	FLIP03-112C	ICARDA	9	FLIP06-39C	ICARDA
3	FLIP 03-131C	ICARDA	10	FLIP97-503C	ICARDA
4	FLIP 03-104C	ICARDA	11	'Arda'	TURKEY
5	FLIP09-51C	ICARDA	12	'Diyar-95'	TURKEY
6	FLIP06-133C	ICARDA	13	'Azkan'	TURKEY
7	FLIP06-97C	ICARDA	14	'Aksu'	TURKEY

Annex 1

Index	Formula	References
Mean productivity	: $MP = (Y_{pi} + Y_{si}) / 2$	Rosielle and Hamblin (1981)
Mean relative performance	: $MRP = (Y_{si} / Y_s) + (Y_{pi} / Y_p)$	Hossain <i>et al.</i> (1999)
Stress susceptibility index	: $SSI = (1 - (Y_{si}/Y_{pi})) / (1 - (Y_s/Y_p))$	Fischer and Maurer (1978)
Stress tolerance	: $TOL = Y_{pi} - Y_{si}$	Rosielle and Hamblin (1981)
Geometric mean productivity	: $GMP = \sqrt{(Y_{pi} \times Y_{si})}$	Fernandez (1992)
Relative efficiency index	: $REI = (Y_{si} / Y_s) \times (Y_{pi} / Y_p)$	Hossain <i>et al.</i> (1999)
Stress tolerance index	: $STI = (Y_{si} \times Y_{pi}) / (Y_p)^2$	Fernandez (1992)
Modified stress tolerance index 1	: $MSTIk1 = ((Y_{pi})^2 / (Y_p)^2) \times STI$	Farshadfar and Sutka (2002)
Modified stress tolerance index 2	: $MSTIk2 = ((Y_{si})^2 / (Y_s)^2) \times STI$	Farshadfar and Sutka (2002)
Harmonic mean of yield	: $HM = 2 \times (Y_{pi} \times Y_{si}) / (Y_{pi} + Y_{si})$	Dadbakhsh <i>et al.</i> (2011)
Yield Index	: $YI = Y_{si} / Y_s$	(Gavuzzi <i>et al.</i> , 1997; Lin <i>et al.</i> , 1986)
Superiority index	: $P_i = \sum_{j=1}^n \frac{(x_{ij} - M_j)^2}{2n}$	Lin and Binns (1988)

Where

*n* – the number of environments

*X<sub>ij</sub>* – the seed yield of the *i*th genotype in the *j*th environment

*M* = Yield of the highest yielding genotype in the environment *j*

Sensitivity drought index	: $SDI = (Y_{pi} - Y_{si}) / Y_{pi}$	Farshadfar and Javadinia (2011)
Relative drought index	: $RDI = (Y_{si} / Y_{pi}) / (Y_s / Y_p)$	Fischer and Wood (1979)
Drought resistance index	: $DI = Y_{si} \times (Y_{si} / Y_{pi}) / (Y_s)$	Lan (1998)
Golden mean	: $GM = (Y_{pi} + Y_{si}) / (Y_{pi} - Y_{si})$	Moradi <i>et al.</i> (2012)
Abiotic tolerance index	: $ATI = ((Y_{pi} - Y_{si}) / (Y_p / Y_s)) \times (Y_{pi} \times Y_{si})^{1/2}$	Moosavi <i>et al.</i> (2008)
Stress Susceptibility percentage index	: $SSPI = ((Y_{pi} - Y_{si}) / (2 \times Y_p)) \times 100$	Moosavi <i>et al.</i> (2008)
Stress/non-stress production index	: $SNPI = [(Y_{pi} \times Y_{si}) / (Y_{pi} - Y_{si})] \times (Y_{pi} \times Y_{si} \times Y_{si})^{1/3} / 1/3$	Moosavi <i>et al.</i> (2008)
Relative decrease in yield	: $RDY = 100 - ((Y_{si} / 100) \times Y_{pi})$	Farshadfar and Elyasi (2012)
Drought tolerance efficiency	: $DTE = (Y_{si} / Y_{pi}) \times 100$	Fischer and Wood (1981)

Table 2. Analysis of variance for yield performances of chickpea genotypes in non-stressed and stressed conditions and drought resistance indices

SOV	DF	Yp	Ys	MP	MRP	SSI	TOL
Genotype	13	7491107**	5219226**	5122273.7**	1.758**	1.173 <sup>ns</sup>	4931572 <sup>ns</sup>
Replication	3	566794	601329	462032.4	0.181	0.264	488116
Error	95	13608602	12204302	3631305	1.325	8.441	37100589
CV		8.65	13.1	5.49	6.0	3.06	13.80
SOV	DF	GMP	REI	STI	MSTIk1	MSTIk2	HM
Genotype	13	5491024**	1.781**	0.733**	2.734**	3.328*	5976366**
Replication	3	534937	0.171	0.069	0.212	0.365	612815
Error	95	4616955	1.318	1.228	3.259	3.733	6495562
CV		6.39	12.0	14.50	13.42	15.23	7.82
SOV	DF	YI	PI	SDI	RDI	DI	GM
Genotype	13	0.710**	2.05x10 <sup>12</sup> **	0.161 <sup>ns</sup>	0.451 <sup>ns</sup>	0.607 <sup>ns</sup>	107.21 <sup>ns</sup>
Replication	3	0.086	1.98x10 <sup>11</sup>	0.028	0.074	0.094	7.93
Error	95	1.011	275x10 <sup>12</sup>	1.583	2.178	2.631	539.37
CV		10.01	15.32	11.25	14.01	15.20	10.20
SOV	DF	ATI	SSPI	SNPI	RDY	DTE	
Genotype	13	2.94 x10 <sup>13</sup> *	634.21 <sup>ns</sup>	842.12*	2.55 10 <sup>10</sup> **	1607.56 <sup>ns</sup>	
Replication	3	2.26 x10 <sup>12</sup>	64.79	107.42	2.45 x 10 <sup>9</sup>	284.56	
Error	95	9.73 x10 <sup>13</sup>	4141.31	3482.78	2.09 x10 <sup>10</sup>	15830.28	
CV		3.26	13.5	1.21	13.42	12.80	

SOV: source of variation; DF: degrees of freedom; ns: non-significant; \*\* significant on 0.01 level. \*significant on 0.05 level

only in stressless conditions (group B) or stressful stressless conditions (group D), and genotypes with low performance in both conditions (group C).

According to this classification, the FLIP09-51C, FLIP97-503C and FLIP06-97C, FLIP03-104C, EN934 and 'Aksu' genotypes had higher yield performances than the mean yields of the genotypes in both stressed and non-stressed conditions, and were located on the group A. Whereas 'Diyar 95', FLIP03-112C, FLIP06-39C, 'Azkan' and FLIP06-133C genotypes had lower yields than the average yields of the genotypes for both environments and were located on the group C. On the other hand, FLIP03-131C and FLIP06-93C genotypes had higher yield performance than average yield for only stressed environments and were included in group D. However, the 'Arda' variety had higher yields than the average yield for stress-free environments and was included in group B. It was noteworthy that the FLIP 09-51 C and FLIP 06-97C genotypes performed well both under stressed and stressed conditions (Fig. 1).

Based on stress tolerance indices MP, MRP, GMP, REI, STI, MSTIk1, MSTIk2, HM and ranking method genotypes, FLIP09-51C, FLIP06-97C and 'Aksu' all with highly grain yield under stressed and non-stressed conditions were identified as drought tolerance genotypes. Other chickpea genotypes were identified as semi-tolerance or semi-sensitive to drought stress (Table 3). Genotypes 'Diyar 95', FLIP06-39C and FLIP03-112C displayed the lowest values for these indices and were noted as the most susceptible genotypes under both conditions. Farshadfar and Sutka (2002) and Gholiouri *et al.* (2009) considered it the best possible selection criteria where a genotype should be distinguished from the other genotypes.

The indices SSI, SDI, TOL, ATI and SSPI were highly correlated with yield under non-stressed condition. Thus, these indices can be used to identify cultivars in the tolerant group for non-stressed conditions. Therefore, the genotypes FLIP09-51C and FLIP97-503C for TOL, ATI and SSPI, and FLIP97-503C for SSI and SDI were found as the most drought tolerant genotypes under non-stressed condition when genotype was based on the ranking method. The genotypes FLIP06-93C and FLIP03-131C displayed the lower amount of SSI, SDI, TOL, ATI and SSPI and were as the most susceptible genotypes under non-stressed condition. The index SSI has been widely used by researchers to identify sensitive and resistant genotypes (Golabadi *et al.*, 2006; Sio-Se Mardeh *et al.*, 2006; Shirani Rad and Abbasian, 2011). The greater value of SSI indicated the larger drought tolerance under stress and the cultivars with greater SSI were higher drought sensitivity. Yp showed positive correlation with SSI, MP, TOL, STI, GMP, HM, PI and K1STI, while the Ys indicated positive correlation with the HM, YI, YSI, RR and K2STI indices (Sabaghnia *et al.*, 2014).

The indices YI, DI, GM, SNPI, RDI and DTE showed significant and positive correlation with grain yield (Ys) under stress conditions. Based on these indices and ranking method, the genotypes FLIP03-131C, FLIP09-51C, FLIP06-97C and 'Aksu' for YI and DI, FLIP03-131C for GM, FLIP03-131C and FLIP06-97C for SNPI, RDI and DTE were as the most drought tolerant genotypes. The yields of these genotypes under stress conditions have also been high (Table 3). Shiranirad and Abbasian (2011)

reported that STI, GMP and YI were able to identify rapeseed cultivars producing high yield under both stress and non-stressed conditions.

In the present study, the GM, RDI, DI and DTE showed significant and positive correlation with yield under stress when stress is too severe (Table 4). FLIP03-131C genotype with high yield under stress produced a lower yield under stressless condition and showed the highest RDI, DI and DTE (Table 3). Positive correlations among the MP, GMP and Yp indices (Toorchi *et al.*, 2012) and positive correlations among the GMP, MP and STI indices (Dehghani *et al.*, 2009) were reported in canola.

#### Correlation analysis

A correlation analysis between grain yield and drought tolerance indices is a good criterion for screening the best genotypes. An appropriate index should have a significant correlation with grain yield under both conditions (Mitra, 2001). Correlation coefficients between Yp, Ys, and other quantitative indices of drought tolerance, were calculated to identify the most desirable drought tolerant criteria (Table 4). The results indicated that there were positive and significant correlations among Yp and Ys with MP, MRP, GMP, REI, STI, MSTIk1, MSTIk2 and HM under stressed and non-stressed conditions. However, the indices Pi and RDY showed negative and significant correlation with both Yp and Ys. Therefore, these indices can be used to select genotypes that are better adapted to both conditions.

The results concerning MRP, REI, GMP and STI are in agreement with Bennani *et al.* (2017). Naghavi *et al.* (2013) reported that yield in stress and non-stress conditions were significantly and positively correlated with STI, GMP, MP, MSTIk1 and MSTIk2 in corn cultivars. Toorchi *et al.* (2012) showed that correlation between MP, GMP, Ys and Yp was positive in spring canola. Moreover, significant repeatable correlations were found between yield (Ys) under stress conditions and the drought indices (YI, RDI, DI, GM, DTE, SSI, TOL, SDI, ATI and SSPI). Yield in stress condition (Ys) indicated significantly and positive correlation with the YI, RDI, DI, GM and DTE, while showed significantly and negative correlation with the indices SSI, TOL, SDI, ATI and SSPI.

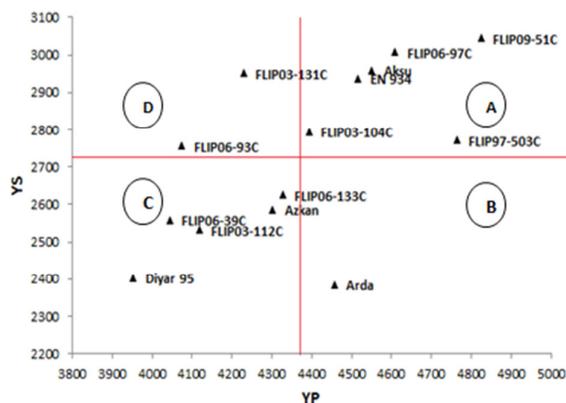


Fig. 1. The relationship between seed yield produced under no-stress and drought stress environments

The yield ( $Y_p$ ) under non-stress condition had strong positive correlation with SSI, TOL, SDI, ATI and SSPI, where as it had significant and negative correlation with YI, RDI,DI, GM and DTE. These relationships were affected by the drought density and pointed that genotypes chosen based on these indices are characterized by drought tolerance criteria and will enhance yield for stress conditions. Significant and positive relationships were found between  $Y_s$  and widely used drought indices MP, GMP, STI, SSI, TOL in many studies (Golabadi *et al.*, 2006; Mohammadi *et al.*, 2010; Farshadfar *et al.*, 2012a; Rahmani *et al.*, 2013). Also, Jafari *et al.* (2009) and Farshadfar *et al.* (2014) reported positive significant correlations between  $Y_s$  and HM, YI, DI, MSTIk1 and MSTIk2 in their drought studies. Strong repeatable significant correlations were

found between MP, MRP, GMP, REI and MSTIk1, and these indices have had greater correlation coefficient with grain yield ( $Y_p$  and  $Y_s$ ) under both conditions. Similar findings were reported Golabadi *et al.* (2006), Mevlut and Sait (2011), Drikvand *et al.* (2012), Moradi *et al.* (2012), Rahmani *et al.* (2013), Naghavi *et al.* (2013) and Farshadfar *et al.* (2014).

Given these results, the results of the hereby study showed that the indices MP, MRP, GMP, REI and MSTIk1 could be used as suitable indicators for screening drought tolerant chickpea genotypes. Farshadfar *et al.* (2001) stated that the most suitable indices for selection of drought-tolerant varieties are indicators showing a relatively high correlation with grain yield under both stressful and stress free environments.

Table 3. Mean comparison for yield performances of chickpea genotypes in non-stressed and stressed conditions and twenty-three drought resistance indices

Genotype	$Y_p$	R	$Y_s$	R	MP	R	MRP	R	SSI	R	TOL	R
EN 934	4517.4	5	2937.6	5	3727.5	5	2.11	4	0.95	10	1579.8	10
FLIP03-112C	4119.6	11	2531.9	12	3325.8	12	1.86	12	0.98	6	1587.7	9
FLIP03-131C	4231.9	10	2950.9	4	3591.4	7	2.05	6	0.80	14	1281.0	14
FLIP03-104C	4395.5	7	2793.6	6	3594.5	6	2.02	7	0.93	12	1601.9	7
FLIP09-51C	4825.0	1	3044.6	1	3934.8	1	2.22	1	1.00	5	1780.4	3
FLIP06-133C	4330.1	8	2624.6	9	3477.3	8	1.95	8	1.05	4	1705.5	5
FLIP06-97C	4609.8	3	3007.2	2	3808.5	2	2.16	2	0.95	9	1602.6	6
FLIP06-93C	4075.6	12	2755.8	8	3415.7	11	1.94	9	0.88	13	1319.8	13
FLIP06-39C	4045.1	13	2558.8	11	3302.0	13	1.86	13	0.94	11	1486.2	12
FLIP97-503C	4765.3	2	2771.2	7	3768.2	3	2.09	5	1.06	2	1994.1	2
'Arda'	4457.4	6	2384.4	14	3420.9	10	1.89	11	1.26	1	2072.9	1
'Diyar-95'	3954.4	14	2402.8	13	3178.6	14	1.79	14	0.96	8	1551.6	11
'Azkan'	4303.0	9	2586.4	10	3444.7	9	1.93	10	1.05	3	1716.6	4
'Aksu'	4551.1	4	2958.3	3	3754.7	4	2.13	3	0.97	7	1592.8	8
Genotype	GMP	R	REI	R	STI	R	MSTIk1	R	MSTIk2	R	HM	R
EN 934	3635.6	4	1.11	4	0.70	4	0.77	5	0.83	4	3546.6	4
FLIP03-112C	3204.7	12	0.87	12	0.55	12	0.50	12	0.49	11	3091.7	12
FLIP03-131C	3529.1	6	1.05	6	0.65	6	0.61	8	0.77	5	3468.2	5
FLIP03-104C	3488.2	7	1.02	7	0.64	7	0.65	6	0.68	7	3386.7	7
FLIP09-51C	3826.7	1	1.23	1	0.78	1	0.99	1	0.98	1	3722.1	1
FLIP06-133C	3352.9	8	0.95	8	0.60	8	0.59	9	0.58	9	3235.2	9
FLIP06-97C	3719.5	2	1.16	2	0.73	2	0.81	2	0.89	2	3633.0	2
FLIP06-93C	3345.5	9	0.94	9	0.59	9	0.52	11	0.62	8	3277.2	8
FLIP06-39C	3199.5	13	0.86	13	0.55	13	0.47	13	0.49	12	3101.9	11
FLIP97-503C	3603.7	5	1.09	5	0.69	5	0.81	3	0.73	6	3450.8	6
'Arda'	3247.5	11	0.89	11	0.57	11	0.61	7	0.46	13	3085.3	13
'Diyar-95'	3049.9	14	0.79	14	0.49	14	0.41	14	0.41	14	2928.7	14
'Azkan'	3324.6	10	0.93	10	0.59	10	0.57	10	0.53	10	3210.3	10
'Aksu'	3666.2	3	1.13	3	0.71	3	0.80	4	0.84	3	3580.0	3
Genotype	YI	R	PI	R	SDI	R	RDI	R	DI	R	GM	R
EN 934	1.07	5	98431.8	10	0.35	11	1.04	5	0.70	5	5.06	6
FLIP03-112C	0.92	12	343672.3	3	0.37	5	0.98	10	0.59	11	5.46	4
FLIP03-131C	1.08	4	173264.0	8	0.30	14	1.12	1	0.76	1	6.19	1
FLIP03-104C	1.02	6	154448.7	9	0.35	9	1.02	7	0.66	7	5.42	5
FLIP09-51C	1.11	1	50483.0	14	0.37	6	1.01	8	0.71	4	4.74	10
FLIP06-133C	0.96	9	228527.9	7	0.39	4	0.97	11	0.60	10	4.82	9
FLIP06-97C	1.10	2	57402.0	13	0.35	12	1.05	3	0.72	2	4.95	7
FLIP06-93C	1.01	7	295910.9	4	0.32	13	1.09	2	0.69	6	5.71	2
FLIP06-39C	0.93	11	343984.9	2	0.36	7	1.01	9	0.61	9	5.67	3
FLIP97-503C	1.01	8	88289.6	12	0.40	2	0.93	13	0.61	8	4.74	11
'Arda'	0.87	14	272602.1	5	0.46	1	0.85	14	0.48	14	3.56	13
'Diyar-95'	0.89	13	548729.9	1	0.35	8	1.02	6	0.59	12	2.09	14
'Azkan'	0.95	10	230253.5	6	0.39	3	0.96	12	0.58	13	4.45	12
'Aksu'	1.08	3	92168.3	11	0.35	10	1.04	4	0.71	3	4.89	8
Genotype	ATI	R	SSPI	R	SNPI	R	RDY	R	DTE	R		
EN 934	3513636.9	6	18.0	9	25.6	4	-132577.3	11	65.1	4		

FLIP03-112C	3019900.2	10	17.9	10	24.6	9	-103362.2	3	62.6	10
FLIP03-131C	2759397.9	13	14.5	14	27.1	1	-124537.2	9	70.3	1
FLIP03-104C	3343104.8	9	18.0	8	25.5	5	-121900.3	8	64.5	6
FLIP09-51C	4227996.7	2	20.3	3	25.4	7	-146916.8	14	63.3	9
FLIP06-133C	3445068.5	8	19.4	5	24.2	11	-112813.8	7	61.2	11
FLIP06-97C	3680962.9	4	18.3	6	25.7	3	-138282.6	13	65.5	3
FLIP06-93C	2719917.9	14	15.0	13	25.9	2	-112231.2	6	68.0	2
FLIP06-39C	2819012.8	12	16.7	12	24.9	8	-102629.2	2	64.1	8
FLIP97-503C	4231237.5	1	22.4	2	24.5	10	-130037.3	10	59.5	13
'Arda'	4154098.1	3	23.6	1	21.6	13	-106410.4	4	53.8	14
'Diyar-95'	2935822.9	11	17.6	11	15.4	14	-93877.3	1	64.5	7
'Azkan'	3490273.4	7	19.5	4	23.6	12	-110746.4	5	60.8	12
'Aksu'	3653654.4	5	18.2	7	25.5	6	-134590.2	12	65.1	5

Yp: Potential Yield, Ys: Stress Yield, MP: Mean Productivity, MRP: Mean relative performance, SSI: Stress Susceptibility Index, TOL: Tolerance, GMP: Geometric Mean Productivity, RI: Relative efficiency index, STI: Stress Tolerance Index, MSTIk1: Modified stress tolerance index 1, MSTIk2: Modified stress tolerance index 2, HM: Harmonic mean of yield, YI: Yield Index, PI: Superiority Index, SDI: Sensitivity drought index, RDI: Relative Drought Index, DI: Drought Resistance Index, GM: Golden mean, ATI: Abiotic Tolerance Index, SSPI: Stress Susceptibility Percentage Index, SNPI: Stress/non-stress production index, RDY: Relative decrease in yield, DTE: Drought tolerance efficiency, R: Ranks.

Table 4. Simple correlation coefficients of stress indices with seed yield of 14 chickpea genotypes

	YP	YS	MP	MRP	SSI	TOL	GMP	REI
YS	-0.072							
MP	0.717**	0.644**						
MRP	0.611**	0.730**	0.979**					
SSI	0.530**	-0.530**	0.036	-0.129				
TOL	0.760**	-0.702**	0.092	-0.039	0.724**			
GMP	0.523**	0.810**	0.967**	0.982**	-0.126	-0.154		
REI	0.607**	0.734**	0.979**	0.999**	-0.127	-0.044	0.983**	
STI	0.272**	0.877**	0.822**	0.815**	-0.099	-0.377**	0.906**	0.823**
MSTIk1	0.577**	0.635**	0.886**	0.819**	0.182	-0.001	0.873**	0.830**
MSTIk2	0.264**	0.923**	0.848**	0.903**	-0.346**	-0.412**	0.938**	0.910**
HM	0.350**	0.903**	0.900**	0.940**	-0.244**	-0.338**	0.981**	0.943**
YI	0.168	0.853**	0.725**	0.847**	-0.593**	-0.436**	0.830**	0.844**
Pi	-0.744**	-0.432**	-0.873**	-0.831**	-0.263**	-0.250**	-0.823**	-0.825**
SDI	0.661**	-0.768**	-0.030	-0.157	0.793**	0.972**	-0.259**	-0.160
RDI	-0.486**	0.609**	0.054	0.242**	-0.0954**	-0.743**	0.232**	0.237**
DI	-0.394**	0.905**	0.331**	0.471**	-0.811**	-0.870**	0.533**	0.471**
GM	-0.225**	0.579**	0.233**	0.281**	-0.165	-0.538**	0.377**	0.277**
ATI	0.899**	-0.370**	0.431**	0.277**	0.792**	0.883**	0.212	0.277**
SSPI	0.770**	-0.684**	0.112	-0.031	0.784**	0.995**	-0.133	-0.035
SNPI	0.103	0.494**	0.424**	0.438**	0.116	-0.248**	0.508**	0.436**
RDY	-0.523**	-0.810**	-0.967**	-0.979**	0.123	0.154	-0.998**	-0.983**
DTE	-0.661**	0.768**	0.030	0.157	-0.793**	-0.972**	.259**	.160
	STI	MSTIk1	MSTIk2	HM	YI	Pi	SDI	
MSTIk1	0.912**							
MSTIk2	0.910**	0.787**						
HM	0.932**	0.825**	0.967**					
YI	0.670**	0.496**	0.889**	0.873**				
Pi	-0.645**	-0.699**	-0.617**	-0.747**	-0.538**			
SDI	-0.453**	-0.110	-0.501**	-0.424**	-0.527**	-0.208*		
RDI	0.171	-0.124	0.445**	0.357**	0.710**	0.168	-0.793**	
DI	0.607**	0.291**	0.745**	0.665**	0.795**	-0.070	-0.929**	
GM	0.490	0.215	0.469**	0.473**	0.389**	-0.332**	-0.442**	
ATI	0.061	0.436**	0.074	0.034	-0.235**	-0.507**	0.818**	
SSPI	-0.325**	0.056	-0.396**	-0.315**	-0.460**	-0.269**	0.970**	
SNPI	0.534**	0.361**	0.497**	0.552**	0.391**	-0.606**	-0.146	
RDY	-0.914**	-0.890**	-0.946**	-0.977**	-0.821**	0.799**	0.262**	
DTE	.453**	.110	.501**	.424**	.527**	.208	-1.000**	
	RDI	DI	GM	ATI	SSPI	SNPI	RDY	
DI	0.858**							
GM	0.230*	0.491**						
ATI	-0.768**	-0.684**	-0.405**					
SSPI	-0.797**	-0.879**	-0.516**	0.914**				
SNPI	0.001	0.275**	0.917**	-0.076	-0.218*			
RDY	-0.0225*	-0.534**	-0.357**	-0.218*	0.131	-0.485**		
DTE	.793**	.929**	.442**	-.818**	-.970**	.146	-.262**	

## Conclusions

The variance and correlation analysis results used in the research showed that there are statistical differences between genotypes for MP, MRP, GMP, REI, STI, MSTIK1, MSTIK2 and HM indices and these indices showed strong correlations with yields of both environments. The results of the study especially indicated that indices MP, MRP, GMP, REI and MSTIK1 can be used as the most suitable indicators for selecting drought tolerant chickpea genotypes under both stressed and non-stressed environments. The indices PI and RDY showed negative and significant correlation with yields under both conditions. However, GM, RDI, DI and DTE indices show significant and positive correlation with yield under stress only when stress is too severe. These indices can also be considered as suitable criteria for selecting drought-tolerant and highly efficient genotypes in environments where drought is predominant. In consideration to all indices, FLIP09-51C, FLIP06-97C and 'Aksu' cultivar exhibited the best rank, and hence they were defined as the most tolerant genotypes, while 'Diyar 95', FLIP06-39C and FLIP03-112C genotypes were the most sensitive for drought.

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