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SELECTION OF PROMISING CHICKPEA (*CICER ARIETINUM* L.) GENOTYPES USING DROUGHT TOLERANCE INDICES

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ABSTRACT

The unpredictability associated with recent climatic changes like rainfall, drought and heat has affected agricultural crop productions severely, worldwide including Pakistan. Various stresses, particularly drought and specifically "terminal drought" is largely affecting chickpea production in its major growing environments of arid and semi-arid tropics. This demands availability of drought-tolerant chickpea genotypes to mitigate such yield losses. For this purpose, separate experiments under normal and drought-stressed conditions were conducted for three consecutive years (2014-17). The plant material comprised sixty genotypes, laid out in an alpha-lattice design. No irrigation was applied to drought-stressed experiments while normal experiments were irrigated twice at critical growth stages. Twelve drought-tolerance relevant parameters were computed from grain yield under normal (Yp) and drought-stressed (Ys) environments. These included mean productivity (MP), geometric mean productivity (GMP), harmonic mean (HM), tolerance index (TI), drought resistance index (DRI), relative drought index (RDI), stress susceptibility index (SSI), stress tolerance index (STI), modified stress tolerance index for normal (k_1STI), modified stress tolerance index for stressed (k_2STI), yield index (YI) and yield stability index (YSI). Variance analyses suggested significant differences among all the indices computed. High to moderate genotypic and phenotypic variances alongwith GCV, PCV indicated prevalence of additive gene action for TI, Yp, Ys, HM, GMP, MP, SSI, k_2STI, DRI and k_1STI. Estimates of heritability and genetic advance were high for TI, Yp, Ys, HM, GMP and MP. Positive and significant correlation of Yp with Ys, MP, GMP, HM, TI, SSI, STI, k_1STI, k_2STI, YI and Ys with MP, GMP, HM, DRI, RDI, STI, k_1STI, k_2STI, YI, YSI suggested that these are the superior predictors of grain yield under normal and stressed conditions, respectively. Principal component analysis dissected PC1 and PC2 with eigenvalues > 1 and explicated 59.5% and 38.1% of the total variability, respectively and assorted stress-tolerant and susceptible genotypes. Based on the results, genotypes K-01006, K-01101, K-01104, K-01105 and K-01111 were declared as most stable under both stress and non-stressed environments.

Keywords: Chickpea; Drought indices; Genetic components; Association; Principal component analysis

INTRODUCTION

Among the food legumes, chickpea occupies second position after beans. It is cultivated in more than fifty countries worldwide (FAOSTAT, 2013; Naveed *et al.,* 2015). Chickpea grains are nutritious and a leading source of proteins, carbohydrates, vitamins and minerals for the masses in many developing and non-developing nations. World's major chickpea production comes from India, Australia, Pakistan, Turkey, Burma, Ethiopia and Iran where the crop is largely grown on arid and semi-arid tropics, dependent on rainfall as a source for soil moisture (FAOSTAT, 2013). Due to this reason, average production of chickpea in Pakistan is unstable (276-800 kg ha^{-1}) where 85% of the total crop acreage is harvested from rainfed and marginal sand dunes of Thal zone of Punjab province (Shafiq *et al.,* 2011; Anonymous, 2012-13). Under such conditions, drought is the leading cause of yield-instability in all the major field crops (Wang *et al.,* 2003).

Assessment of plant genetic responses under normal and drought-stressed conditions is very important in plant breeding programs and in the development of genotypes possessing desirable features (Khan *et al.,* 2016; Naveed *et al.,* 2016a). The genetic potential of a genotype under contrasting environments is the most reliable criteria in identifying superior accessions for uncertain rainfed-environments (Mohammadi *et al.,* 2010). The selection criteria for developing drought tolerant genotypes for such uncertain conditions greatly vary among the crop scientists as some choose stress conditions, others opt favorable environments while a few prefer both contrasting environments (Rathjen, 1994; Byrne *et al.,* 1995; Betran *et al.,* 2003; Naveed *et al.,* 2016bc).

For the identification of drought-tolerant genotypes, some scientists have proposed drought relevant indices based on yield differences under contrasting environments (Mitra, 2001; Anwar *et al*., 2011; Amiri *et al*., 2014). These parameters are developed keeping in view drought and susceptibility of genetic resources (Fernandez, 1992). Drought-tolerance is the capacity of crop plants to develop and produce under water-deficient environments while drought-susceptibility is measured in terms of yield reduction under drought-stressed conditions (Blum 1988; Khayatnezhad *et al.,* 2010). Mean productivity (MP) is the average performance of the genotypes under normal (Yp) and drought-stressed (Ys) conditions (Rosielle and Hamblin, 1981) while geometric mean productivity (GMP) is based on the relative performance of genotypes due to the varying rainfall intensity over the years (Fernandez, 1992). Other indices such as harmonic mean (HM), tolerance index (TI), yield index (YI) and yield stability index (YSI) are also associated with yield (Kristin *et al.,*1997; Rosielle and Hamblin, 1981; Gavuzzi *et al.,* 1997; Bouslama and Schapaugh, 1984). Lan (1998) introduced drought resistance index (DRI) while Fischer and Maurer (1978) established relative drought index (RDI) as a measure of drought-tolerance in crop plants. Fischer and Maurer (1978), and Fernandez (1992), respectively proposed stress-susceptibility index (SSI) and stress tolerance index. In order to improve the effectiveness of STI, Farshadfar and Sutka (2002) introduced modified stress tolerance index (MSTI) as k_iSTI (k_i is the correction coefficient which adjusts the STI as mass) and further suggested k_1STI for the assortment of genotypes under stressed and k_2STI under normal environments.

Under drought-stressed conditions, exploitation of genetic variability in plant selections for the release of promising genotypes as commercial cultivars is the "major target" of crop breeders (Naveed *et al*., 2019). In this view, the present research work was planned and executed with the objective to find out potential genotypes for water-deficit and irrigated environments. To support the results, various genetic components, correlation coefficients and principal component analyses were also used.

MATERIALS AND METHODS

Experimental site and plant materials: These studies were conducted at the experimental field of Pulses Research Institute, Ayub Agricultural Research Institute, Faisalabad, Pakistan. For three consecutive years (2014-17), sixty chickpea-kabuli genotypes (Table-1) were evaluated under both normal and drought-stressed conditions.

Geographical, soil and meteorological features: The experimental farm is located at an altitude of 184 m, latitude of 31° 21′ 52″ north and longitude of 72° 59′ 40″ east. It has loamy soil texture. To determine soil-composition, pre-sowing soil analysis was done (Table-2). Monthly minimum, maximum temperatures and total precipitation during cropping months were also recorded (Figure-1).

Experimental design and crop husbandry: All the genotypes were laid-out in an alpha-lattice design (ALD) comprising two replications each for drought-stressed and normal field experiments. Two rows, each four meter in length, for every treatment were sown manually using dibbler by maintaining distances of 15 cm and 30 cm plant-plant and row-row, respectively. No irrigation was applied to drought-stressed plot during cropping season except at soaking for the purpose of land preparation. However, normal crop plot was irrigated twice, at the start of the reproductive stage and during grain formation stage. Plant protection measures were adopted according to the crop requirements. At physiological crop maturity, yield data recorded from stressed (Ys) and normal (Yp) plots (g) were converted into kg ha^{-1}.

Statistical analysis: Grain yield data recorded for three years under normal (Yp) and water stress (Ys) conditions were averaged, respectively. Based on Yp and Ys, various drought-tolerance associated indices (Table-3) were computed. Stress intensity was determined using the formula;

$$\text{Stress intensity (SI)} = 1 - \overline{Ys} / \overline{Yp}$$

$\overline{Ys}$ and $\overline{Yp}$ are mean yield of genotypes under stressed and normal conditions.

Variance analysis was performed for each parameter according to Steel and Torrie (1980) procedure. Pearson correlation coefficients and principal component analysis was done in Minitab software. Biplot and Fernandez model diagram were generated in Statistical "R" and "SPSS" software, respectively.

RESULTS

Analysis for significance test: Mean squares of different sources of variations (Table-4) revealed significant differences among the accessions for all the fourteen traits estimated suggesting the legitimacy of further statistical analyses.

Variability studies: Various descriptive statistics for different chickpea plant traits were determined (Table-5). Highest genotypic variance was estimated for tolerance index (TI; 184009.6) followed by yield under normal conditions (Yp; 154757.4), yield under drought-stressed conditions (Ys; 147796.6), harmonic mean (HM; 111168.3), geometric mean productivity (GMP; 107787.7) and mean productivity (MP; 105274.6). Lowest genotypic variance was measured for yield index (YI; 0.078) followed by yield stability index (YSI; 0.085), relative drought index (RDI; 0.111) and stress-tolerance index (STI; 0.159). However, stress-susceptibility index (SSI; 5.087), modified stress-tolerance index for stressed (k_2STI; 1.201), drought-resistance index (DRI; 0.956) and modified stress-tolerance index for normal (k_1STI; 0.885) revealed moderate genotypic variances. Highest and lowest estimates for phenotypic variances were recorded for tolerance index (TI; 191327.8) and yield index (YI; 0.080), respectively. The phenotypic variances for all the indices were slightly higher than genotypic variances. Similarly for environmental variances, highest estimate was revealed for tolerance index (TI; 7318.1) while lowest for yield index (YI; 0.002) and yield-stability index (YSI; 0.002). Genotypic coefficients of variation (GCV %) ranged 22.01 (mean productivity) to 324.06 (stress-susceptibility index). Likewise, GCV, phenotypic coefficients of variation (PCV %) were minimum for mean productivity (22.32) and maximum for stress-susceptibility index (328.99). Heritability (h^2BS) estimates were higher for all the traits studied and ranged 96.2% (TI) to 97.7% (STI). Genetic advance (percent of mean) was highest for TI (271.89%) followed by Yp (249.63%), Ys (245.27%), HM (212.88%), GMP (209.50%) and MP (206.65%). However, it was lowest for YI (0.18%), YSI (0.19%), RDI (0.21%), STI (0.25%), k_1STI (0.60%), DRI (0.62%), k_2STI (0.70%) and SSI (1.44%).

Drought-tolerance studies: Mean values alongwith standard error (SE), coefficients of variation (CV %) and estimates of genotypic least significant difference (LSD) for drought-tolerance related indices were computed (Table-6).

Yield under normal conditions (Yp): Better performing genotypes under normal conditions were viz., 36 (K-01207; 2437.5 kg ha^{-1}), 22 (K-01104; 2254.5 kg ha^{-1}), 10 (K-01006; 2250.0 kg ha^{-1}), 11 (K-01007; 2187.5 kg ha^{-1}) and 23 (K-01105; 2179.5 kg ha^{-1}). Entries such as 17 (K-01018; 729 kg ha^{-1}), 37 (K-01208; 816.5 kg ha^{-1}) and 34 (K-01205; 867.0 kg ha^{-1}) were the poor yielders, respectively. Mean yield for Yp was 1575.9 kg ha^{-1} and 27 out of total 60 genotypes surpassed it. The CV recorded for this parameter was 4.97%.

Yield under drought-stress (Ys): Maximum yield for Ys was revealed by genotype 31 (K-01116; 2208.5 kg ha^{-1}) followed by 23 (K-01105; 2187.5 kg ha^{-1}), 28 (K-01111; 2071.0 kg ha^{-1}), 19 (K-01020; 2062.5 kg ha^{-1}), 5 (CM-1235/08; 2000.0 kg ha^{-1}) and 6 (CM-1238/08; 1945.5 kg ha^{-1}). Minimum values were found for genotypes 49 (K-01230; 625.0 kg ha^{-1}), 51 (K-01240; 687.5 kg ha^{-1}) and 32 (K-01203; 800.0 kg ha^{-1}). Average yield for Ys was 1372.5 kg ha^{-1}. Twenty-four (24) accessions exhibited above average grain yield. The CV estimated was 3.89%.

Mean productivity (MP): Entries 23 (K-01105; 2183.5 kg ha^{-1}), 28 (K-01111; 2093.8 kg ha^{-1}), 22 (K-01104; 2075.3 kg ha^{-1}), 20 (K-01101; 2018.8 kg ha^{-1}), and 10 (K-01006; 2010.5 kg ha^{-1}) exhibited top MP estimates while genotypes 59 (K-01250; 925.0 kg ha^{-1}), 32 (K-01203; 929.3 kg ha^{-1}), 34 (K-01205; 996.0 kg ha^{-1}) indicated lowest MP values, respectively. Mean genotypic estimate for MP was 1474.2 kg ha^{-1} and 29 accessions exhibited greater average values in comparison to mean. The CV was 3.70%.

Geometric mean productivity (GMP): Maximum GMP value was recorded for genotype 23 (K-01105; 2183.5 kg ha^{-1}) followed by 28 (K-01111; 2093.6 kg ha^{-1}), 22 (K-01104; 2067.4 kg ha^{-1}), 20 (K-01101; 2015.7 kg ha^{-1}), and 10 (K-01006; 1996.1 kg ha^{-1}). However, minimum GMP estimate was recorded for genotype 32 (K-01203; 919.8 kg ha^{-1}), 59 (K-01250; 922.7 kg ha^{-1}), and 49 (K-01230; 980.7 kg ha^{-1}). Average value for this trait was 1453.8 kg ha^{-1} and 29 entries exceeded it. Among the analyzed indices, coefficient of variation for GMP (3.63%) was the lowest.

Harmonic mean (HM): HM was highest for the genotype 23 (K-01105; 2183.5 kg ha^{-1}), 28 (K-01111; 2093.5 kg ha^{-1}) and 22 (K-01104; 2059.6 kg ha^{-1}) while it was lowest for 49 (K-01230; 888.2 kg ha^{-1}), 32 (K-01203; 910.4 kg ha^{-1}) and 59 (K-01250; 920.4 kg ha^{-1}). Average value for harmonic mean was 1434.3 kg ha^{-1}. Thirty accessions exhibited above-average values. The CV was 3.65%.

Tolerance index (TI): TI estimates were highest for entries 15 (K-01016; 996.0 kg ha^{-1}), 51 (K-01240; 991.5 kg ha^{-1}), 55 (K-01246; 983.5 kg ha^{-1}), 49 (K-01230; 916.5 kg ha^{-1}) and 36 (K-01207; 908.5 kg ha^{-1}). However, it was lowest for genotypes 31 (K-01116; -750.0 kg ha^{-1}), 17 (K-01018; -708.5 kg ha^{-1}) and 19 (K-01020; -521.0 kg ha^{-1}), respectively. Average genotypic value for TI was 203.4 kg ha^{-1}. Twenty-nine genotypes revealed above average estimates. The CV for TI was 38.34%.

Drought resistance index (DRI): Maximum DRI values were observed for entries viz., 31 (K-01116; 2.437), 17 (K-01018; 2.067), 19 (K-01020; 2.018), 6 (CM-1238/08; 1.830) and 5 (CM-1235/08; 1.637) while minimum for 49 (K-01230; 0.186), 51 (K-01240; 0.206) and 55 (K-01246; 0.305), respectively. Twenty-six genotypes exhibited greater estimates than mean value of 0.953. The CV for drought resistance index was 7.11%.

Relative drought index (RDI): Genotype17 (K-01018; 2.266) followed by 31 (K-01116; 1.738), 37 (K-01208; 1.668), 19 (K-01020; 1.540) and 33 (K-01204; 1.516) exhibited highest RDI value while accessions 49 (K-01230; 0.467), 51 (K-01240; 0.470) and 55 (K-01246; 0.545) revealed lowest estimates. Mean value was 1.045 and 26 entries exceeded it. The CV for relative drought index was 4.77%.

Stress-susceptibility index (SSI): SSI estimates were highest for genotypes 49 (K-01230; 4.598), 51 (K-01240; 4.576) and 55 (K-01246; 4.075) while lowest for 17 (K-

01018; -7.543), 31 (K-01116; -3.983) and 37 (K-01208; -3.510). Thirty-four entries exhibited more values than the mean (0.696). The CV for SSI (48.28%) was the highest among all the indices investigated.

Stress-tolerance index (STI): The highest STI value was recorded for entry 23 (K-01105; 1.920) followed by 28 (K-01111; 1.766), 22 (K-01104; 1.722), 20 (K-01101; 1.636) and 10 (K-01006; 1.605). The lowest estimates were observed for 32 (K-01203; 0.342), 59 (K-01250; 0.343) and 49 (K-01230; 0.387), respectively. Twenty-eight accessions revealed above average estimates than the mean value (0.895). The CV for STI was 6.80%.

Modified stress-tolerance index for normal (k_1STI): Estimates for k_1STI were highest for genotypes 23 (K-01105; 3.673), 36 (K-01207; 3.597) and 22 (K-01104; 3.532) while lowest in 17 (K-01018; 0.091), 37 (K-01208; 0.107) and 34 (K-01205; 0.120). Mean genotypic value for this trait was 1.115 and 24 entries surpassed it. The CV was 14.25%.

Modified stress-tolerance index for stressed (k_2STI): Values of k_2STI were highest for entries viz., 23 (K-01105; 4.878), 28 (K-01111; 4.033) and 31 (K-01116; 3.384). However, it was lowest for 49 (K-01230; 0.081), 51 (K-01240; 0.118) and 32 (K-01203; 0.118). Twenty genotypes indicated higher values than the mean (1.170). The CV for k_2STI was 15.30%.

Yield index (YI): Maximum yield index was revealed for accession 31 (K-01116; 1.609) followed by 23 (K-01105; 1.594) and 28 (K-01111; 1.509) while it was minimum for genotypes 49 (K-01230; 0.456), 51 (K-01240; 0.501) and 32 (K-01203; 0.583), respectively. Average genotypic value for YI was 1.000 and 24 entries surpassed it. The CV for yield index was 3.89%.

Yield stability index (YSI): The highest YSI estimate was revealed for the genotype 17 (K-01018; 1.973) followed by 31 (K-01116; 1.514), 37 (K-01208; 1.453), 19 (K-01020; 1.341) and 33 (K-01204; 1.321). The lowest values were obtained for entries 49 (K-01230; 0.407), 51 (K-01240; 0.410) and 55 (K-01246; 0.475), respectively. Twenty-six entries revealed above average values than the mean (0.910). The CV for YSI was 4.76%.

Association studies: Pearson correlation coefficients among the computed parameters were also determined (Table-7). Yield under normal conditions (Yp) had significant positive association with Ys (0.390), MP (0.838), GMP (0.809), HM (0.778), TI (0.569), SSI (0.532), STI (0.796), k_1STI (0.887), k_2STI (0.561) and YI (0.390) while significant negative relationship with DRI (-0.108), RDI (-0.532) and YSI (-0.532). Yield under drought-stressed (Ys) had significant positive relationship with MP (0.829), GMP (0.853), HM (0.871), DRI (0.850), RDI (0.522), STI (0.855), k_1STI (0.636), k_2STI (0.923), YI (1.000) and YSI (0.522) while significant negative correlation with TI (-0.536) and SSI (-0.522). The association of MP with GMP (0.997), HM (0.988), DRI (0.437), STI (0.990), k_1STI (0.915), k_2STI (0.887) and YI (0.829) was positive and significant. Similarly, correlation coefficients for GMP with HM (0.997), DRI (0.464), STI (0.994), k_1STI (0.905), k_2STI (0.899) and YI (0.853) were positive and significant. HM exhibited significant positive interrelationships with DRI (0.486), STI (0.992), k_1STI (0.891), k_2STI (0.906) and YI (0.871). Significant negative correlation coefficients were revealed for TI with DRI (-0.858), RDI (-0.954), k_2STI (-0.309), YI (-0.536) and YSI (-0.954) while positive with SSI (0.954). Significant positive associations were indicated for DRI with RDI (0.871), STI 0.473), k_2STI (0.679), YI (0.850) and YSI (0.871) while negative with SSI (-0.871). Significant positive correlation coefficients were exhibited for RDI with k_2STI (0.278), YI (0.522) and YSI (1.000) however it was negative with SSI (-1.000). SSI revealed negative significant interrelationships with k_2STI (-0.278), YI (-0.522) and YSI (-1.000). Positive significant relationship was found for STI with k_1STI (0.928), k_2STI (0.928) and YI (0.855). Association between k_1STI and k_2STI (0.794), k_1STI and YI (0.636) and k_2STI with YI (0.923), YSI (0.278) was significant and positive. Significant positive relationship was also observed between YI and YSI (0.522).

Principal component analysis: PC analysis for various drought indices generated 14 components, of which, only first two had eigenvalues greater than 1 while the remaining 12 had eigenvalues less than 1, therefore not discussed/presented (Table-8). Both PC1 and PC2 explained 59.5% and 38.1% of variation existed for the measured traits, respectively. First component was largely influenced by Ys (0.338), YI (0.338), k_2STI (0.333), HM (0.328), STI (0.327), GMP (0.325), MP (0.320), k_1STI (0.273), DRI (0.254) and Yp (0.197). However, major contributions in PC2 were made by SSI (0.401), RDI (-0.401), YSI (-0.401), TI (0.398), Yp (0.350), DRI (-0.287) and k_1STI (0.234).

Table-1. Detail of chickpea experimental plant material.

Code	Genotype	Code	Genotype	Code	Genotype	Code	Genotype
1	09AK055	16	K-01017	31	K-01116	46	K-01217
2	CH45/07	17	K-01018	32	K-01203	47	K-01219
3	CH51/07	18	K-01019	33	K-01204	48	K-01221
4	CH54/07	19	K-01020	34	K-01205	49	K-01230
5	CM-1235/08	20	K-01101	35	K-01206	50	K-01238
6	CM-1238/08	21	K-01103	36	K-01207	51	K-01240
7	CM-2008	22	K-01104	37	K-01208	52	K-01241
8	CM-731/06	23	K-01105	38	K-01209	53	K-01242
9	FLIP-82/150c	24	K-01107	39	K-01210	54	K-01244
10	K-01006	25	K-01108	40	K-01211	55	K-01246
11	K-01007	26	K-01109	41	K-01212	56	K-01247
12	K-01013	27	K-01110	42	K-01213	57	K-01248
13	K-01014	28	K-01111	43	K-01214	58	K-01249
14	K-01015	29	K-01112	44	K-01215	59	K-01250
15	K-01016	30	K-01113	45	K-01216	60	Noor-2009

Table-2. Experimental field soil properties.

Depth (cm)	Texture	EC $mS^{-1}cm$	Ph	Organic Matter (%)	Available P_2O_3 (ppm)	Available K_2O (ppm)	Saturation (%age)
0-30	Loam	1.95	8.83	0.46	12.31	358	34.80

Table-3. Equations followed to compute drought-tolerance indices.

S #	Parameter and equation	Reference
1	Mean productivity (MP) $= \frac{Ys + Yp}{2}$	Fischer and Maurer (1978)
2	Geometric mean productivity (GMP) $= \sqrt{Ys \times Yp}$	Fernandez (1992)
3	Harmonic mean (HM) $= \frac{2(Ys)(Yp)}{(Ys + Yp)}$	Kristin *et al.* (1997)
4	Tolerance index (TI) $= Yp - Ys$	Rosielle and Hamblin (1981)
5	Drought resistance index (DRI) $= Ys \times [\frac{(Ys / Yp)}{\overline{Ys}}]$	Lan (1998)
6	Relative drought index (RDI) $= \frac{(Ys/Yp)}{\overline{Ys}/\overline{Yp}}$	Fischer and Maurer (1978)
7	Stress susceptibility index (SSI) $= \frac{1 - (Ys / Yp)}{1 - (\overline{Ys}/\overline{Yp})}$	Fischer and Maurer (1978)
8	Stress tolerance index (STI) $= \frac{(Ys \times Yp)}{(\overline{Yp})^2}$	Kristin *et al.* (1997)
	Modified stress tolerance index (MSTI) $= kiSTI$	
9	Modified stress tolerance index (k1STI) $= \frac{(Yp^2)}{(\overline{Yp}^2)}$	Farshadfar and Sutka (2002)
10	Modified stress tolerance index (k2STI) $= \frac{(Ys^2)}{(\overline{Ys}^2)}$	
11	Yield index (YI) $= Ys / \overline{Ys}$	Gavuzzi *et al.* (1997)
12	Yield stability index (YSI) $= Ys / Yp$	Bouslama and Schapaugh (1984)

Where Ys and Yp are the genotypic yields under stressed and normal conditions. $\overline{Ys}$ and $\overline{Yp}$ are mean yield of genotypes under stressed and normal conditions.

Table-4. Mean squares of various drought-tolerance indices in chickpea.

S #	Parameters	Replications (df = 1)	Blocks (df = 18)	Genotypes (df = 59)	Error (df = 41)
1	Yield under normal conditions (Yp)	639	5205	277023**	6135
2	Yield under water-stressed conditions (Ys)	11349	5896	260745**	2854
3	Mean productivity (MP)	4344	3019	191304**	2974
4	Geometric mean productivity (GMP)	5074	2841	195614**	2780
5	Harmonic mean (HM)	5704	2869	201481**	2742
6	Tolerance index (TI)	6601	10127	310320**	6085
7	Drought-resistance index (DRI)	0.017	0.010	0.396**	0.005
8	Relative drought index (RDI)	0.003	0.004	0.184**	0.002
9	Stress-susceptibility index (SSI)	0.126	0.189	8.403**	0.113
10	Stress-tolerance index (STI)	0.010	0.004	0.286**	0.004
11	Modified stress-tolerance index for normal (k_1STI)	0.059	0.031	1.587**	0.025
12	Modified stress-tolerance index for stressed (k_2STI)	0.182	0.051	2.138**	0.032
13	Yield index (YI)	0.006	0.003	0.138**	0.002
14	Yield-stability index (YSI)	0.002	0.003	0.140**	0.002

** Significant at 1% level.

Table-5. Genetic parameters for various drought-tolerance indices in chickpea.

S #	Indices	σ^2 g	σ^2 p	σ^2 e	GCV	PCV	ECV	h^2 BS	GAM%
1	Yp	154757.4	160608.8	5851.4	24.96	25.43	4.85	96.4	249.63
2	Ys	147796.6	151578.9	3782.2	28.01	28.37	4.48	97.5	245.27
3	MP	105274.6	108261.9	2987.3	22.01	22.32	3.71	97.2	206.65
4	GMP	107787.7	110586.6	2798.9	22.58	22.87	3.64	97.5	209.50
5	HM	111168.3	113948.9	2780.6	23.25	23.54	3.68	97.6	212.88
6	TI	184009.6	191327.8	7318.1	210.90	215.05	42.06	96.2	271.89
7	DRI	0.956	0.984	0.027	102.60	104.09	17.24	97.2	0.62
8	RDI	0.111	0.114	0.003	31.88	32.31	5.24	97.4	0.21
9	SSI	5.087	5.243	0.156	324.06	328.99	56.75	97.0	1.44
10	STI	0.159	0.162	0.004	44.55	44.97	7.07	97.7	0.25
11	k_1STI	0.885	0.911	0.026	84.37	85.60	14.46	97.1	0.60
12	k_2STI	1.201	1.235	0.034	93.67	94.98	15.76	97.2	0.70
13	YI	0.078	0.080	0.002	27.93	28.28	4.47	97.5	0.18
14	YSI	0.085	0.087	0.002	32.04	32.41	4.91	97.4	0.19

σ^2 g = Genotypic variance, σ^2 p = phenotypic variance, σ^2 e = environmental variance, GCV = genotypic coefficient of variation, PCV = phenotypic coefficient of variation, ECV = environmental coefficient of variation, h^2 BS= heritability broad sense, GAM%= genetic advance as percent of mean.

Table-6. Mean values of various drought tolerance indices in chickpea.

Entries	Yp	Ys	MP	GMP	HM	TI	DRI	RDI	SSI	STI	k_1STI	k_2STI	YI	YSI
1	1508.0	1041.5	1274.8	1252.9	1231.4	466.5	0.525	0.794	2.390	0.632	0.580	0.364	0.759	0.692
2	1787.5	1104.5	1446.0	1404.1	1363.4	683.0	0.500	0.711	2.955	0.794	1.021	0.518	0.805	0.619
3	1541.5	1029.0	1285.3	1259.2	1233.7	512.5	0.501	0.767	2.572	0.639	0.612	0.359	0.750	0.668
4	1791.5	1708.5	1750.0	1749.5	1749.0	83.0	1.188	1.096	0.356	1.234	1.604	1.919	1.245	0.954
5	1783.0	2000.0	1891.5	1888.1	1884.6	-217.0	1.637	1.289	-0.949	1.436	1.838	3.052	1.458	1.123
6	1508.5	1945.5	1727.0	1713.0	1699.1	-437.0	1.830	1.481	-2.244	1.182	1.084	2.383	1.418	1.290
7	1237.5	1133.5	1185.5	1184.2	1182.8	104.0	0.758	1.050	0.663	0.567	0.354	0.397	0.826	0.915
8	1600.0	1271.0	1435.5	1424.8	1414.2	329.0	0.741	0.917	1.561	0.818	0.850	0.700	0.926	0.799
9	1816.5	1387.5	1602.0	1587.3	1572.8	429.0	0.774	0.877	1.830	1.015	1.348	1.040	1.011	0.764
10	2250.0	1771.0	2010.5	1996.1	1981.7	479.0	1.016	0.904	1.651	1.605	3.274	2.681	1.291	0.787
11	2187.5	1283.5	1735.5	1675.5	1617.6	904.0	0.549	0.674	3.203	1.130	2.178	0.989	0.935	0.587
12	1354.0	1458.5	1406.3	1405.1	1403.8	-104.5	1.147	1.238	-0.604	0.795	0.587	0.899	1.063	1.078
13	1366.5	1304.0	1335.3	1334.7	1334.3	62.5	0.908	1.096	0.356	0.718	0.540	0.651	0.951	0.954
14	1408.0	1720.5	1564.3	1556.4	1548.7	-312.5	1.532	1.403	-1.721	0.977	0.785	1.545	1.254	1.222
15	1912.5	916.5	1414.5	1323.8	1238.9	996.0	0.321	0.551	4.032	0.706	1.046	0.315	0.668	0.480
16	1771.0	1208.5	1489.8	1462.0	1434.9	562.5	0.604	0.787	2.440	0.861	1.097	0.667	0.881	0.686
17	729.0	1437.5	1083.3	1023.6	967.3	-708.5	2.067	2.266	-7.543	0.422	0.091	0.464	1.047	1.973
18	1733.5	1812.5	1773.0	1772.6	1772.1	-79.0	1.381	1.201	-0.354	1.266	1.531	2.207	1.321	1.046
19	1541.5	2062.5	1802.0	1782.3	1762.8	-521.0	2.018	1.540	-2.644	1.279	1.227	2.888	1.503	1.341
20	2121.0	1916.5	2018.8	2015.7	2012.7	204.5	1.264	1.038	0.741	1.636	2.965	3.192	1.397	0.905
21	2058.5	1500.0	1779.3	1757.2	1735.4	558.5	0.797	0.837	2.103	1.244	2.126	1.488	1.093	0.729
22	2254.5	1896.0	2075.3	2067.4	2059.6	358.5	1.163	0.965	1.235	1.722	3.532	3.305	1.382	0.841
23	2179.5	2187.5	2183.5	2183.5	2183.5	-8.0	1.600	1.153	-0.029	1.920	3.673	4.878	1.594	1.004
24	1521.0	1021.0	1271.0	1244.6	1218.9	500.0	0.505	0.777	2.507	0.624	0.591	0.345	0.744	0.677
25	1320.5	1146.0	1233.3	1230.1	1226.9	174.5	0.726	0.995	1.036	0.613	0.442	0.443	0.835	0.867
26	2125.0	1291.5	1708.3	1655.8	1605.0	833.5	0.574	0.699	3.035	1.104	2.006	0.982	0.941	0.609
27	1891.5	1208.5	1550.0	1511.8	1474.5	683.0	0.563	0.735	2.791	0.922	1.346	0.719	0.881	0.640
28	2116.5	2071.0	2093.8	2093.6	2093.5	45.5	1.477	1.124	0.168	1.766	3.192	4.033	1.509	0.979
29	2037.5	1291.5	1664.5	1622.0	1580.6	746.0	0.597	0.728	2.835	1.060	1.773	0.938	0.941	0.635
30	1008.5	1104.5	1056.5	1055.4	1054.3	-96.0	0.882	1.259	-0.748	0.450	0.188	0.296	0.805	1.097
31	1458.5	2208.5	1833.5	1794.8	1756.8	-750.0	2.437	1.738	-3.983	1.298	1.117	3.384	1.609	1.514
32	1058.5	800.0	929.3	919.8	910.4	258.5	0.443	0.867	1.896	0.342	0.154	0.118	0.583	0.756
33	1000.0	1312.5	1156.3	1145.2	1134.2	-312.5	1.260	1.516	-2.483	0.531	0.222	0.492	0.957	1.321
34	867.0	1125.0	996.0	987.6	979.3	-258.0	1.064	1.490	-2.305	0.393	0.120	0.266	0.820	1.297
35	1345.5	1312.5	1329.0	1328.9	1328.8	33.0	0.933	1.120	0.191	0.711	0.519	0.652	0.956	0.976
36	2437.5	1529.0	1983.3	1930.0	1878.3	908.5	0.700	0.722	2.882	1.500	3.597	1.861	1.114	0.628
37	816.5	1187.5	1002.0	984.6	967.5	-371.0	1.259	1.668	-3.510	0.392	0.107	0.301	0.865	1.453
38	1241.5	1104.5	1173.0	1170.8	1168.6	137.0	0.718	1.022	0.854	0.552	0.343	0.359	0.805	0.890
39	1604.0	1721.0	1662.5	1661.3	1660.1	-117.0	1.347	1.232	-0.569	1.111	1.152	1.749	1.254	1.073
40	1558.5	1333.5	1446.0	1441.4	1436.8	225.0	0.833	0.983	1.117	0.837	0.818	0.791	0.972	0.856
41	1354.0	979.5	1166.8	1151.6	1136.6	374.5	0.517	0.831	2.144	0.534	0.395	0.272	0.714	0.724
42	1377.0	1708.5	1542.8	1533.7	1524.6	-331.5	1.546	1.427	-1.881	0.948	0.731	1.474	1.245	1.243
43	1450.0	1000.0	1225.0	1204.0	1183.4	450.0	0.503	0.793	2.404	0.584	0.495	0.310	0.729	0.690

44	1854.0	1312.5	1583.3	1559.9	1537.0	541.5	0.677	0.813	2.264	0.981	1.361	0.899	0.957	0.708
45	1145.5	1371.0	1258.3	1253.2	1248.2	-225.5	1.196	1.374	-1.526	0.633	0.336	0.635	0.999	1.197
46	1750.0	1416.5	1583.3	1574.5	1565.7	333.5	0.836	0.930	1.477	0.999	1.239	1.069	1.032	0.810
47	1879.0	1271.0	1575.0	1545.2	1516.0	608.0	0.627	0.777	2.507	0.962	1.367	0.826	0.926	0.677
48	1529.0	1604.0	1566.5	1565.9	1565.2	-75.0	1.228	1.207	-0.398	0.990	0.946	1.359	1.169	1.051
49	1541.5	625.0	1083.3	980.7	888.2	916.5	0.186	0.467	4.598	0.387	0.371	0.081	0.456	0.407
50	1237.5	1229.0	1233.3	1233.3	1233.3	8.5	0.889	1.140	0.053	0.613	0.378	0.491	0.896	0.993
51	1679.0	687.5	1183.3	1074.4	975.5	991.5	0.206	0.470	4.576	0.466	0.533	0.118	0.501	0.410
52	1200.0	992.0	1096.0	1091.1	1086.2	208.0	0.598	0.949	1.346	0.480	0.281	0.254	0.723	0.827
53	1879.0	1783.5	1831.3	1830.6	1830.0	95.5	1.234	1.090	0.396	1.351	1.929	2.296	1.300	0.949
54	1567.0	1846.0	1706.5	1700.8	1695.1	-279.0	1.585	1.353	-1.381	1.165	1.152	2.108	1.345	1.178
55	1858.5	875.0	1366.8	1273.0	1186.1	983.5	0.305	0.545	4.075	0.653	0.912	0.266	0.638	0.475
56	1275.0	1146.0	1210.5	1208.3	1206.0	129.0	0.753	1.033	0.777	0.588	0.385	0.412	0.835	0.900
57	1042.0	1262.5	1152.3	1146.9	1141.5	-220.5	1.116	1.392	-1.647	0.530	0.232	0.448	0.920	1.213
58	1212.5	812.5	1012.5	992.4	972.7	400.0	0.398	0.770	2.552	0.397	0.236	0.139	0.592	0.671
59	983.5	866.5	925.0	922.7	920.4	117.0	0.559	1.013	0.915	0.343	0.134	0.138	0.632	0.882
60	1891.5	1696.0	1793.8	1791.1	1788.4	195.5	1.108	1.030	0.801	1.292	1.862	1.973	1.236	0.897
Mean	1575.9	1372.5	1474.2	1453.8	1434.3	203.4	0.953	1.045	0.696	0.895	1.115	1.170	1.000	0.910
SE	36.4	35.4	29.9	30.2	30.7	39.8	0.045	0.031	0.208	0.037	0.087	0.101	0.026	0.027
CV%	4.97	3.89	3.70	3.63	3.65	38.34	7.11	4.77	48.28	6.80	14.25	15.30	3.89	4.76
LSD (0.05)	158.2	107.9	110.1	106.5	105.8	157.5	0.137	0.101	0.679	0.123	0.321	0.361	0.079	0.088

Table-7. Correlation coefficients among various drought tolerance indices in chickpea.

Indices	Ys	MP	GMP	HM	TI	DRI	RDI	SSI	STI	k_1STI	k_2STI	YI	YSI
Yp	0.390**	0.838**	0.809**	0.778**	0.569**	-0.108	-0.532**	0.532**	0.796**	0.887**	0.561**	0.390**	-0.532**
Ys		0.829**	0.853**	0.871**	-0.536**	0.850**	0.522**	-0.522**	0.855**	0.636**	0.923**	1.000**	0.522**
MP			0.997**	0.988**	0.028	0.437**	-0.014	0.014	0.990**	0.915**	0.887**	0.829**	-0.014
GMP				0.997**	-0.020	0.464**	0.021	-0.021	0.994**	0.905**	0.899**	0.853**	0.021
HM					-0.064	0.486**	0.053	-0.053	0.992**	0.891**	0.906**	0.871**	0.053
TI						-0.858**	-0.954**	0.954**	-0.034	0.245	-0.309*	-0.536**	-0.954**
DRI							0.871**	-0.871**	0.473**	0.201	0.679**	0.850**	0.871**
RDI								-1.000**	0.036	-0.194	0.278*	0.522**	1.000**
SSI									-0.036	0.194	-0.278*	-0.522**	-1.000**
STI										0.928**	0.928**	0.855**	0.036
k_1STI											0.794**	0.636**	-0.194
k_2STI												0.923**	0.278*
YI													0.522**

** Significant at 1% level

Table-8. Principal Component analysis for various drought tolerance indices in chickpea.

	PC1	PC2
Eigenvalue	8.331	5.330
Cumulative percentage	59.50	38.10
Loadings by different indices		
Ys	0.338	-0.087
Yp	0.197	0.350
MP	0.320	0.161
GMP	0.325	0.145
HM	0.328	0.130
TI	-0.121	0.398
DRI	0.254	-0.287
RDI	0.123	-0.401
SSI	-0.123	0.401
STI	0.327	0.141
k_1STI	0.273	0.234
k_2STI	0.333	0.021
YI	0.338	-0.087
YSI	0.123	-0.401

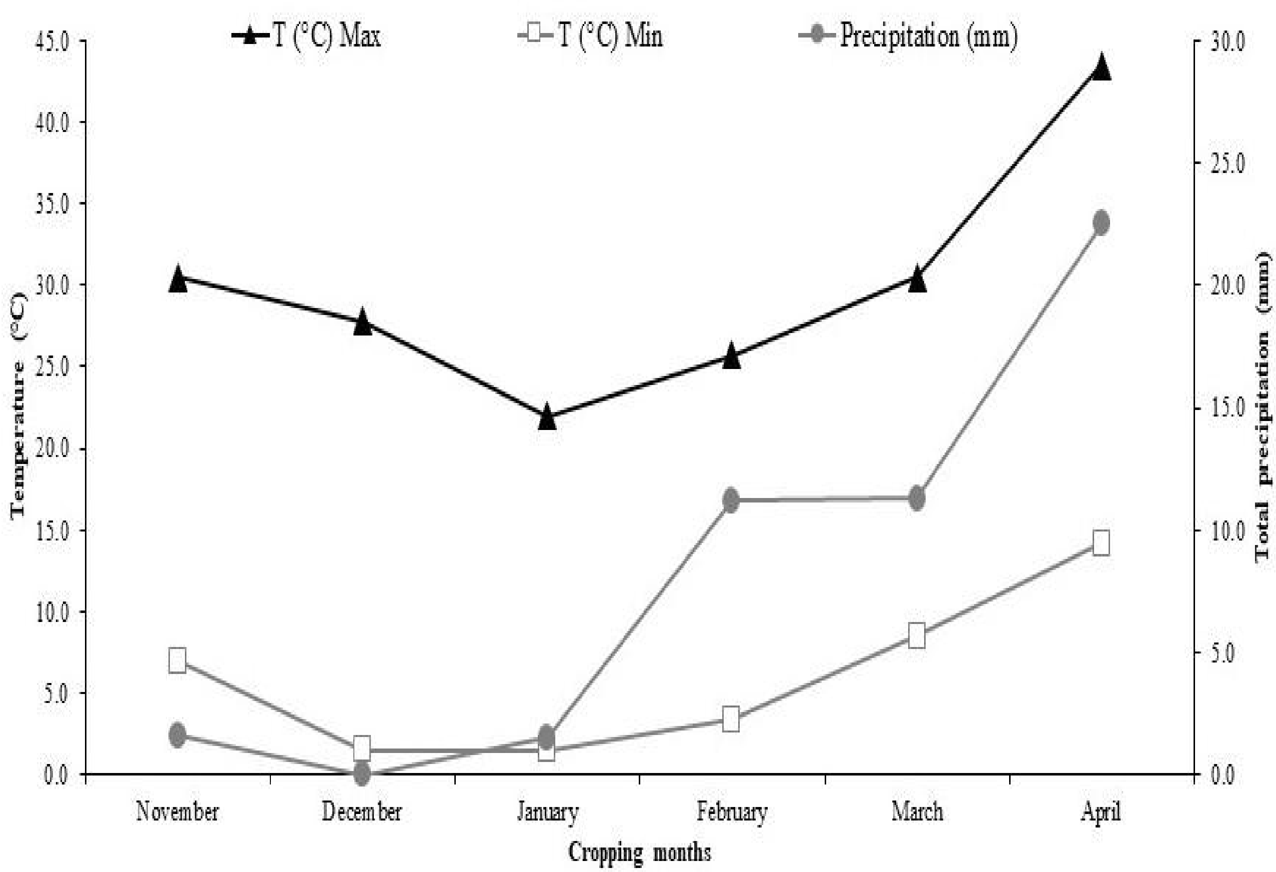

Figure-1. Monthly minimum, maximum temperature and total precipitation during cropping season 2014-17.

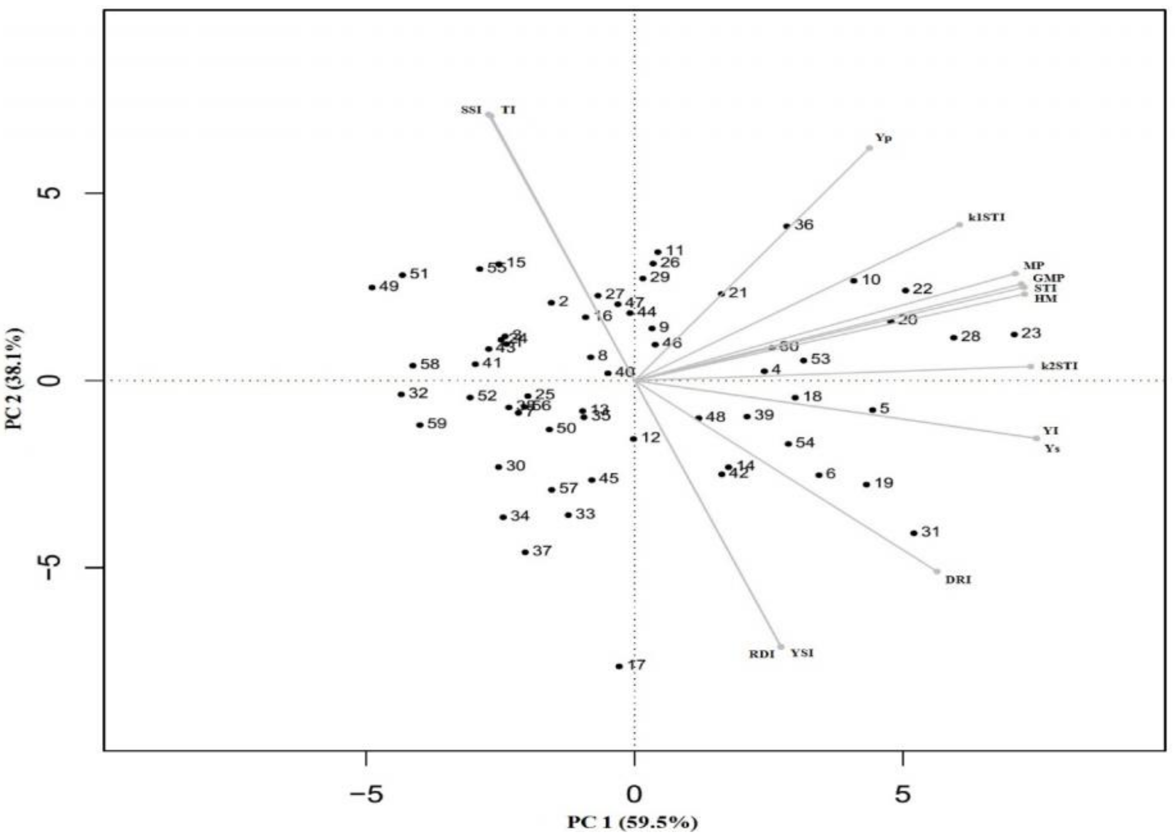

Figure-2. Biplot based on first two principal components for various drought response measurements and genotypes.

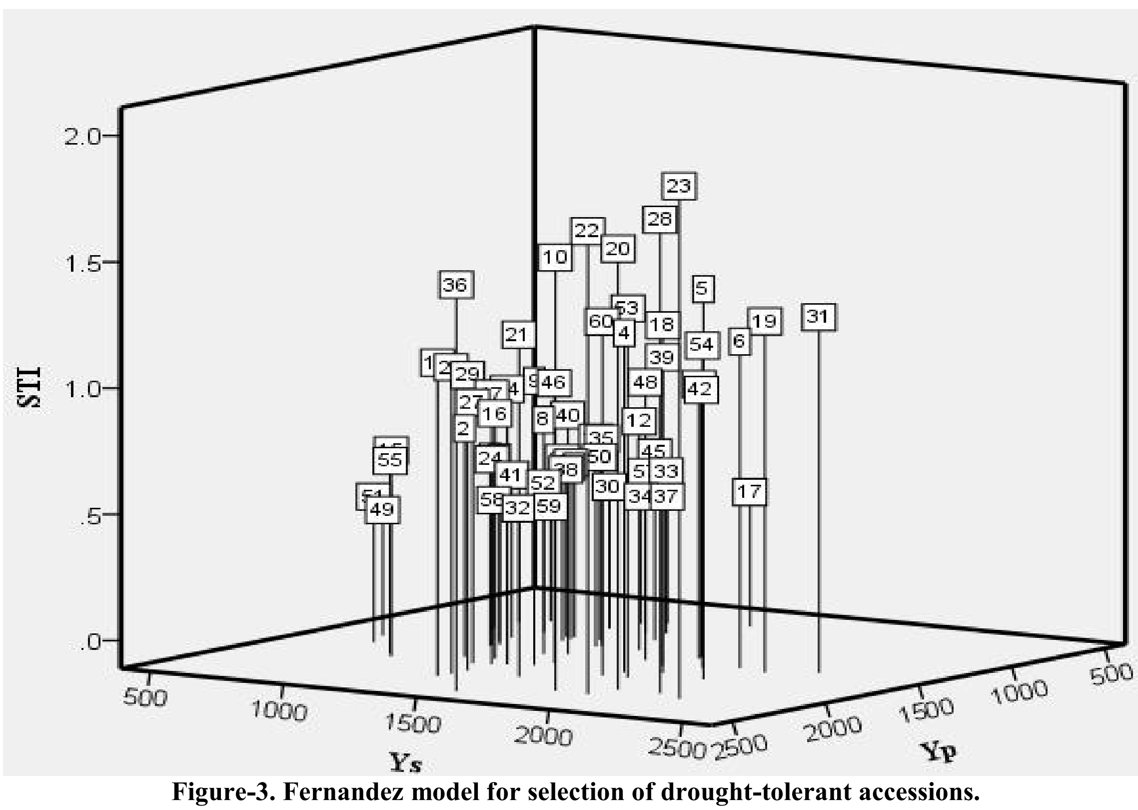

Figure-3. Fernandez model for selection of drought-tolerant accessions.

DISCUSSION

Any crop improvement program depends largely upon the availability and utilization of variation present in the genepool. In the current study, analysis of variance confirmed the diversity of chickpea genotypes for genes controlling yield and associated drought-tolerance indices (Yagdi and Sozen, 2009; Anwar *et al.,* 2011). As yield and its contributing traits are quantitative and under the environmental influence, therefore partitioning them into genetic components is necessary for determining the additive or heritable fraction of variation. High to moderate genotypic and phenotypic variances and their coefficients of variations indicated predominance of additive gene action and scope for the improvement of indices such as TI, Yp, Ys, HM, GMP, MP,SSI, k_2STI, DRI and k_1STI. PCV estimates were slightly higher than GCV for all the parameters suggesting the involvement of environmental component in the phenotypic expression of the indices (Mishra *et al.,* 2015). Variability alone is not adequate to find out the transmissible segments of variation. Shukla *et al.,* (2006) suggested considering of genetic gain and heritability for cogent plant selections in breeding schemes. High heritability and low genetic advance limits the scope of selection for crop improvement due to the presence of non-additive gene action, however, high heritability alongwith high genetic advance would broaden the scope for improvement through selection due to existence of additive gene action. Indices such as TI, Yp, Ys, HM, GMP and MP in the current studies had higher estimates for broad-sense heritability and genetic advance (% of mean), hence, were under the control of additive gene action.

Mean yield comparison under contrasting environments indicated substantial yield loss in the yield potential of some of the genotypes duly confirmed by the moderate value (0.13) of stress intensity. Under drought-stressed conditions, accessions 31 (K-01116), 23 (K-01105), 28 (K-01111), 19 (K-01020), 5 (CM-1235/08) and 6 (CM-1238/08) had the greatest grain yield while genotypes 49 (K-01230), 51 (K-01240) and 32 (K-01203) exhibited lowest grain yield. Under normal conditions, genotypes 36 (K-01207), 22 (K-01104), 10 (K-01006), 11 (K-01007) and 23 (K-01105) had the highest grain yield while entries 17 (K-01018), 37 (K-01208) and 34 (K-01205) had the lowest grain yield. Larger yield reduction under drought-stressed conditions indicated greater TI value and higher drought sensitivity. Smaller estimate for TI and SSI of the genotypes 31 (K-01116), 17 (K-01018), 19 (K-01020), 6 (CM-1238/08), 37 (K-01208), 42 (K-01213), 14 (K-01015), 33 (K-01204), 54 (K-01244) and 34 (K-01205) indicated their tolerance while higher values for 15 (K-01016), 51 (K-01240), 55 (K-01246), 49 (K-01230), 11 (K-01007), 26 (K-01109) and 36 (K-01207) suggested their susceptibility. Indices such as MP, GMP, HM, STI ranked the genotypes similarly and identified accessions 23 (K-01105), 28 (K-01111), 20 (K-01101) and 22 (K-01104) as drought tolerant while entries 59 (K-01250), 32 (K-01203), 49 (K-01230) and 37 (K-01208) as drought susceptible (Saba *et al.,* 2001; Anwar *et al.,* 2011). Genotypes 49 (K-01230), 51 (K-01240), 55 (K-01246), 15 (K-01016) and 11 (K-01007) had highest YSI values while genotypes 17 (K-01018), 31 (K-01116), 37 (K-01208), 19 (K-01020) and 33 (K-01204) had lowest. For DRI and RDI, genotypes 31 (K-01116), 17 (K-01018) and 19 (K-01020) had higher values while entries 49 (K-01230), 51 (K-01240), 55 (K-01246) and 15 (K-01016) had lowest values, respectively. For modified stress-tolerance index (k_1STI and k_2STI), higher estimates were recorded for genotypes 23 (K-01105), 28 (K-01111), 22 (K-01104) and 10 (K-01006) and lower for genotypes 32 (K-01203), 59 (K-01250), 17 (K-01018), 49 (K-01230) and 37 (K-01208).

Simultaneous consideration of all the indices suggested that entries viz., 17 (K-01018), 19 (K-01020), 22 (K-01104), 23 (K-01105), 28 (K-01111), 31 (K-01116), 33 (K-01204), 37 (K-01208) were drought-tolerant while entries 11 (K-01007), 15 (K-01016), 32 (K-01203), 37 (K-01208), 49 (K-01230), 51 (K-01240), 55 (K-01246), 59 (K-01250) were drought-susceptible.

Correlation analysis is valuable in devising the stress-tolerance criteria in crop plants. Results indicated significant ($P \leq 0.01$) positive association between Yp and Ys, specifying the occurrence of reasonable stress-intensity. This moderate drought-stress intensity suggested that the indirect selection will be effective depending on the performance of genotypes under stressed conditions (Amiri *et al.,* 2014). Except DRI for normal conditions, all other parameters revealed significant ($P \leq 0.01$) correlations with grain yield (Yp). In drought-stressed conditions, associations among all the studied indices were significant ($P \leq 0.01$) with grain yield (Ys). Complete associations were observed for RDI with SSI (-ve), YSI (+ve) and between SSI and YSI (+ve). Similarly, relationship between Ys and YI (+ve) was strong, complete and in accordance to the findings of Farshadfar and Elyasi (2012).

In contrast to association studies, biplot analysis has been regarded more useful in identifying the better performing genotypes under contrasting environments as genotypes are evaluated for all the traits, concurrently (Riaz *et al*., 2013). First and second component of biplot, cumulatively, explained 97.6% of overall variation (Figure-2). PC1 contributed 59.5% of total variability with Ys, YI, k_2STI, HM, STI, GMP, MP, k_1STI, DRI and Yp. PC2 explained 38.1% with SSI, RDI, YSI, TI, Yp, DRI and k_1STI as major constituents. Higher PC1 and lower PC2 estimates are helpful in the selection of genotypes for stressed as well as normal environments (Shahryari and Mollasadeghi, 2011). In a selection model, Fernandez (1992) classified the genotypes into four groups based on performance under contrasting environments (Figure-3). According to this model, genotypes 23 (2183.5 kg ha^{-1}), 28 (2093.8 kg ha^{-1}), 22 (2075.3 kg ha^{-1}), 20 (2018.8 kg ha^{-1}) and 10 (2010.5 kg ha^{-1}) had high grain yield stability under both the contrasting (normal and drought) environments i.e. (group A). Accessions 36 (K-01207), 22 (K-01104), 10 (K-01006), 11 (K-01007) and 23 (K-01105) exhibited high grain yield under normal environments (group B). Entries 31 (K-01116), 23 (K-01105), 28 (K-01111), 19 (K-01020), 5 (CM-1235/08) and 6 (CM-1238/08) had maximum grain yield under drought-stressed environments (group C). Genotypes 59 (K-01250), 32 (K-01203), 34 (K-01205), 37 (K-01208) and 58 (K-01249) performed poorly in respect of grain yield under stressed and normal conditions (group D). Differentiation of stable genotypes (Group A) from the other three groups had been regarded as the best selection criteria for stress-tolerance in crop plants (Gholiouri *et al.,* 2009; Amiri *et al.,* 2014).

Conclusions: Significant positive association of Yp with Ys, MP, GMP, HM, TI, SSI, STI, k_1STI, k_2STI, YI and Ys with MP, GMP, HM, DRI, RDI, STI, k_1STI, k_2STI, YI, YSI were concluded as the best indicators of grain yield in contrast to negative significant correlation of Yp with RDI, YSI and Ys with TI and SSI. Moreover, genotypes 10 (K-01006), 20 (K-01101), 22 (K-01104), 23 (K-01105) and 28 (K-01111) were identified most stable under both normal and drought-stressed conditions. Entries 36 (K-01207), 22 (K-01104), 10 (K-01006), 11 (K-01007) and 23 (K-01105) exhibited suitability to only normal field conditions while 31 (K-01116), 23 (K-01105), 28 (K-01111), 19 (K-01020), 5 (CM-1235/08) and 6 (CM-1238/08) revealed adaptation to drought-stressed environments. Genotypes 59 (K-01250), 32 (K-01203), 34 (K-01205), 37 (K-01208) and 58 (K-01249) adapted poorly to both stressed and normal conditions.

Author's Contributions: M. Naveed designed and conducted experiments and done write-up. M. Nadeem performed statistical analyses and literature reviewed. M. A. Zahid collected and compiled the data. M. Shafiq and C. M. Rafiq supervised all the activities.

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