The Journal of Animal & Plant Sciences, 29(4): 2019, Page: 998-1009
ISSN: 1018-7081

ASSESSMENT OF DROUGHT TOLERANCE IN SOME COTTON GENOTYPES BASED ON DROUGHT TOLERANCE INDICES

A. Ullah[1,*], A. Shakeel[1], T. A. Malik[1] and M. F. Saleem[2]

[1]Department of Plant Breeding and Genetics, [2]Department of Agronomy, University of Agriculture Faisalabad, Pakistan
[*]Corresponding author's email: azizullahpbg@gmail.com

ABSTRACT

The limited water supply for irrigation is a major constraint to cotton production. Various drought tolerance indices calculated on the basis of yield provide useful information for drought tolerance. The present study was conducted for the evaluation of nine indices related to drought tolerance, such as stress tolerance index (STI), yield index (YI), stress susceptibility index (SSI), mean productivity (MP), yield stability index (YSI), relative drought index (RDI), tolerance index (TOL), sensitive drought index (SDI) and relative decrease in yield index (RDY) in cotton (*Gossypium hirsutum* L.) genotypes. To accomplish this, forty cotton genotypes were evaluated under two moisture regime i.e. normal and drought stress (50% reduced irrigation) in field by using split plot design under RCBD. The calculation of drought tolerance indices were done on the basis of seed cotton yields both under normal and drought stress condition. All the genotypes behaved differently under two moisture levels. The interaction of cotton genotypes with two environments (moisture levels) were studied for various indices related to drought tolerance on the basis of seed cotton yield using Principle Component Analysis (PCA). The drought tolerant and sensitive genotypes were selected on the basis of biplot analysis. Results revealed that for most of the drought tolerance indices under studied; the genotypes VH-144, IUB-212, MNH-886, VH-295, IR-3701, AA-802, NIAB-111, NS-121, FH-113, and FH-142 are either stable or showing positive interaction with drought conditions. These genotypes can be used in further breeding program for developing varieties suitable for cultivation under drought conditions whereas; IR-3, CIM-443, FH-1000, MNH-147, S-12 interacted undesirably with drought stress.

Key words: Breeding program, Drought tolerance indices, *Gossypium hirsutum* L., Seed cotton yield, Stable.

INTRODUCTION

The economy of Pakistan mainly depends upon the agriculture which consists of many allied disciplines in which crop husbandry plays important role. When seed is planted in the soil, the plant development and productivity is subject to numerous biotic and abiotic stresses. It is evidenced that abiotic stresses are the main contributor to yield reduction and the estimated losses due to drought, salinity, high temperature, low temperature, and by other factors are 17%, 20%, 40%, 15% and 8% respectively (Ashraf *et al*., 2008). Drought stress in conjunction with heat stress, amongst the various abiotic stresses is being considered as a great risk for reduction of crop yield and production in the world (Sinclair, 2005; Turner, 1997). Water resources demands for various activities including agriculture is increasing, due to which availability of water is decreases day by day. A higher human demand for water resources also limits its availability for agriculture purpose. On the global basis approximately one third cultivated area suffers from chronically drought stress (Massacci *et al*., 2008). It has also reported that the expectation of future climatic changes will change the temperature and precipitation pattern which will ultimately increase the risks of drought (Rizza *et al*., 2004).

Cotton is the most important textile fiber crop and ranked world's second important oil seed crop after soybean. Its contribution in the agriculture is 5.2% and in the GDP is 1.0% (Anonymous, 2016-17). However cotton crop is being considered as drought tolerant, its sensitivity to drought stress varies greatly in various genotypes (Naidu *et al*., 1998; Gorham, 1996). Cotton is highly affected to drought stress which affects crop growth and development, square formation and retention, boll formation and development, boll shedding and ultimately causing reduction of seed cotton yield and lint quality which suggest the development of drought tolerant genotypes in order to get economic yield in drought hit areas.

As drought is being the major stress related to environment in agriculture on the global basis, developing varieties with improved yield under drought conditions is a most important goal in the plant breeding (Cattivelli *et al*., 2008). Two basic requirements are fundamental for the improvement of cultivars under drought condition. Firstly, variability must be present for drought tolerance in the genotype and secondly this variation must have some genetic basis. In order to develop cotton cultivars for drought tolerance, the screening of germplasm and selection of suitable parents is the basic step in breeding programme.

Breeding for drought tolerance is complicated by the lack of fast, reproducible screening techniques and the inability to routinely create defined and repeatable drought stress conditions where large populations can be evaluated efficiently (Ramirez and Kelly, 1998). The drought tolerance indices provide efficient technique to screen huge germplasm in crop plants. The research work on drought tolerance indices regarding screening huge genotypes in cotton crop is very limited. The various indices related to drought tolerance provide an extent of tolerance to drought based on the yield loss against drought stress and these indices have been used in order to screen many genotypes under drought condition (Mitra, 2001).

In order to classify genotypes against drought tolerance, various indices have been suggested based on yield under both normal and drought condition (Huang, 2000). Stress tolerance (TOL) shows the yield difference under normal and stress condition whereas mean productivity (MP) refers to average of yield under normal (Yp) and stress (Ys) condition (McCaig and Clarke, 1982). Stress susceptibility index (SSI) introduced by Fischer and Maurer (1978) for screening huge germplasm. Guttieri *et al.* (2001) found that value of stress susceptibility index <1 shows drought tolerant genotype, while >1 shows that genotype is sensitive to drought. Stress tolerance index (STI) introduced by Fernandez (1992), which can be useful to identify high yielding genotype under stress and non-stress.

Therefore keeping in mind the present climatic change situation, this study was carried out for the assessment of genotypic variation under drought stress by using various indices in a set of very diverse cotton genotypes and to find drought tolerant and sensitive genotypes.

MATERIALS AND METHODS

Cotton accessions/germplasm was screened by using various drought tolerance indices on the basis of seed cotton yield in field condition. The cotton genotypes were assessed under normal (To) and drought condition (T_1) in the field area (plot size 80 × 120 square feet) of Department of Plant Breeding and Genetics, UAF. For this purpose, 40 genotypes of cotton was grown under normal and drought conditions by using split plot design, with irrigation in main plots and genotypes/cultivars in sub-plots in three replications.. The experiment was planted on 24-05-2013. Ten plants were grown in a single row. The distance between row to row was 75 cm while plant to plant was 30 cm. All the practices including agronomic as well as cultural were the same except irrigations. The rainfall during June-August (vegetative phase) and September-November (reproductive phase) was 199.1 and 12.2 mm respectively. The irrigation to drought stress treatment was given 50 % irrigations as compared to the normal treatment (Kirda *et al.*, 2005). In normal treatment, eight irrigations were applied; one irrigation at the time of sowing, second irrigation 35 days after sowing and six other irrigations with an interval of 15 days up to 125 days after sowing. In drought stress treatment, four irrigations were applied; one irrigation at the time of sowing, second irrigation 35 days after sowing and two other irrigations with an interval of 30 days up to 95 days after sowing. Climatic condition prevailing during present experimentation (April-November) in the year 2013 were given in Fig. 1(Source: Agromet Bulletin, Agriculture Meteorology Cell, Department of Crop Physiology, UAF, Pakistan). During the first week of October, 5 guarded plants per replication for each of the genotypes were tagged for measuring seed cotton yield.

Nine drought tolerance indices including Stress susceptibility index (SSI), Stress tolerance index (STI), Relative drought index (RDI), Tolerance (TOL), Mean production (MP), Yield stability index (YSI), Yield index (YI), sensitive drought index (SDI) and relative drought index (RDI) were calculated based on seed cotton yield under normal and drought condition using the following relationships. (Fischer and Maurer., 1978; Fernandez, 1992; Fischer *et al.*, 1998; Moosavi *et al.*, 2008; Bouslama & Schapaugh, 1984).

Stress tolerance index (STI) = $(Ys \times Yp)/\bar{Y}p^2$

Stress susceptibility index (SSI) = $1-(Ys/Yp))/(1-(\bar{Y}s/\bar{Y}p))$

Tolerance index (TOL) = $Yp-Ys$

Mean productivity (MP) = $(Ys+Yp)/2$

Yield index (YI) = $Ys/\bar{Y}s$

Yield stability index (YSI) = Ys/Yp

Sensitive drought index (SDI) = $(Yp-Ys)/Yp$

Relative decrease in yield index (RDY) = $100-(Ys/Yp\times100)$

Relative drought index (RDI) = $(Ys/Yp)/(\bar{Y}s/\bar{Y}p)$

Whereas, Yp and Ys, represent yield under non-stress and yield under stress for each genotype while $\bar{Y}s$ and $\bar{Y}p$ denote average yield in stress and non-stress for all genotypes, respectively.

The data which were collected were subjected to analysis of variance using Statistix 8.1. Principle component analysis (PCA) was performed on the mean data using XLSTAT software (Khodadadi *et al*. 2011).

RESULTS AND DISCUSSION

Mean squares showed significant differences for genotypes for all drought tolerance indices (Table. 3). Drought tolerance indices were further analysed by principle component analysis (PCA). Generally, it is agreed that yield and drought tolerance from a breeding viewpoint are a complex traits that shows a high level of genotype × environment interaction (Cooper *at el*. 2006). However, for studies on adaptation of crop plants to complex drought stress situations arising due to climate change, there is a need to exploit the available biodiversity in crop genotypes to understand the mechanisms involved in coping with drought stress (Bhargava and Sawant 2013). For the evaluation of various indices in order to screen cotton genotypes under drought stress, seed cotton yield under normal and drought condition were taken in order to calculate sensitivity and tolerance of various indices. A suitable index must be significantly correlated with yield under stress and non-stress condition (Mitra, 2001).

Comparing genotypes/Mean performance: The genotypes CIM-443, VH-282, IUB-212 and KZ-181 showed higher while MNH-888, CRS-456, VH-283, NS-121 and FH-113 showed lower seed cotton yield under normal condition (Yp). Whereas, genotypes VH-144, IUB-212, NIAB-111, AA-802 and FH-142 recorded higher and S-12, CRS-456, FH-1000, MNH-147 and VH-148 showed lower seed cotton yield under drought condition (Ys) (Table 2). The genotypes IUB-212, NIAB-111, FH-142 and VH-242 were good performer while CRS-456, MNH-888 and CIM-240 were poor performer under both conditions. The variable expressions of 40 cotton genotypes for seed cotton yield under drought stress indicated that there was genotypic variability for drought tolerance. The presence of variability among genotypes for different traits under water stressed conditions has been reported (Mvula *et al*., 2018).

For stress tolerance index, the genotype IUB-212 performed best with highest mean value (3.66) followed by VH-144 (3.64) and NIAB-111 (3.41) depicting that these genotypes were drought tolerant whereas genotype CRS-456 performed poorest with lowest mean value (0.28) followed by S-12 (0.3) and IUB-222 (0.4). Regarding mean productivity, IUB-212 with highest mean value (117.96) followed by VH-144 (117.55) and NIAB-111(116.18) showed good response while CRS-456 with lowest mean value (36.28) followed by MNH-886 and S-12 with mean value of (40.19) and (40.87) respectively showed poor response against drought stress. By comparing genotypes for yield index, VH-144 (3.54) and IUB-212 (3.53) presented highest mean value while S-12 and CRS-456 showed lowest mean value of (0.61) and (0.72) respectively. Under yield stability index, the genotypes VH-295 (0.8) followed by MNH-886 (0.72) and VH-144 (0.71) proved to be drought tolerant with highest mean value while genotypes CIM-443, MNH-147 and FH-1000 with lowest mean value (0.19), (0.2) and (0.19) respectively proved to be drought sensitive. For relative drought index, VH-295 with highest mean value (1.77) followed by MNH-886 (1.59) and VH-144 (1.57) depicting drought tolerance while CIM-443 and MNH-147 with lowest mean value (0.41) and (0.43) respectively showing drought sensitivity.

In normal and drought conditions, the genotype IUB-212 (0.81) showed low drought susceptibility as compared to other genotypes. This genotype has exhibited high drought tolerance because of small yield differences under both conditions. Genotype CRS-456 (1.15) was found more susceptible to drought due to higher SSI value and showed lowest yield among all the genotypes in both normal and drought condition. Rajeswari (1995) evaluated the cotton genotypes under rain-fed conditions and observed some genotypes having high yield potential in drought conditions. Ullah *et al*., (2008) found that seed cotton yield was distinctly affected in all genotypes, except few which proved their superiority over others in drought tolerance. Regarding tolerance index, VH-295 with lowest mean value (11.23) followed by CIM-240 (21.02) and NS-121 (21.64) showed good response while CIM-443 with highest mean value (116.61) followed by IR-3 and KZ-181 with mean value (110.43) and (100.68) respectively showed poor response against drought stress. By comparing genotypes for sensitive drought index, VH-295 (0.2) and MNH-886 (0.28) presented lowest mean value while CIM-443 (0.81) followed by MNH-147 (0.8) and IR-3 (0.76) showed highest mean value.

Under relative decrease in yield index, the genotypes VH-295 (19.68) followed by MNH-886 (27.73) and VH-144 (28.89) proved to be drought tolerant with lowest mean value while genotypes CIM-443 (81.16), MNH-147 (80.43) and IR-3 (76.31) with highest mean value proved to be drought sensitive. In this study, overall cotton genotypes mean performance for seed cotton yield in drought conditions was low as compared to normal conditions; nevertheless some genotypes exhibited less mean difference in both moisture regimes, thus showing genotypic variation for drought tolerance. These results agree with those reported by Sezener *et al.* (2015) in cotton.

Among the different genotypes, IUB-212, VH-144 and NIAB-111 showed high yield index (YI), stress tolerance index (STI) and mean productivity (MP) in comparison of other genotypes. Therefore, these genotypes having high scores of stress tolerance index (STI), mean productivity (MP) and yield index (YI) can be designated as tolerant to drought stress. The genotypes such as CRS-456, S-12, IUB-222 and CRS-446 recorded lower value of yield index (YI), stress tolerance index (STI), and mean productivity (MP). Whereas, three genotypes of VH-295, MNH-886 and VH-144, represented high mean value of relative drought index (RDI) and yield stability index (YSI). These genotypes also exhibited higher tolerance as compare to other genotypes with low mean value of relative decrease in yield index (RDY), tolerance index (TOL), stress susceptibility index (SSI) and sensitive drought index (SDI), (as the genotypes would be more tolerant having lower TOL, SSI, RDY, SDI values).

Genotypes showing SSI values less than 1.0 are more tolerant to drought stress while those with values above 1.0 are susceptible to drought stress. The genotypes CIM-443, MNH-147, IR-3 and KZ-181 exhibited susceptibility with high mean value of SSI and TOL. Likewise, Clarke *et al*. (1992) evaluated drought tolerance in wheat genotypes and selected drought tolerant genotypes exhibiting lower SSI and higher STI values. Under stress condition, TOL, STI and SSI were identifying as useful indices discriminating drought tolerance and sensitivity. The efficiency of selection indices based on severity support that various stress levels effects yield under stress condition (Blum 1996).

Principle component analysis: A principle component analysis (PCA) was performed by using the different drought tolerance indices, and in order to get the relationships among various drought tolerance indices, genotypes were exposed to biplot analysis (Table 4). Many researchers have used biplot analysis for comparing genotypes for different criteria. According to Brejda *et al*. (2000), data were considered in each components with EigenF value >1 which determined at least 10% of the variation. The higher Eigen values were considered as best representative of system attributes in principal components. Only two components (PCs) showed more than 1 Eigen value and exhibited about 90.60% cumulative variability, therefore these two PCs were used for further explanation. (Table 4). The contribution of stress tolerance index was 4.75% and 16.70% variability in first and second factors, respectively (Table 5). The percent contribution of mean productivity was very low for first factor but for second factor this had contributed 21.30% variability. Yield index, yield stability index, relative drought index, stress susceptibility index, tolerance index, sensitive drought index and relative decrease in yield index contributed 9.95%, 16.35%, 12.58%, 15.03%, 7.46%, 16.35% and 5.82% variability of F1 and 7.70%, 0.78%, 2.90%, 1.39%, 11.19%, 0.78% and 4.94% variability of F2 respectively (Table 5).

The PC1 which accounted for the highest variability (52.34%) was highly loaded with indices such as sensitive drought index (0.970) (Table 4). The first component representing the significance of this PC for drought related indices i.e., sensitive drought index. The genotypes having low sensitive drought index will be considered in selection criterion under drought condition. The genotypes i.e., VH-295, MNH-886, VH-144, IUB-212, NS-121, FH-113, CIM-240 and IR-3701 were found low sensitive drought index as well as better yield under drought condition. The second principal component accounted for 38.36% of total variability, was highly loaded with mean productivity (0.947) and stress tolerance index (0.839) indicating its importance for altering cotton genotypes with respect to seed cotton yield.

Scree plot (Fig.3) explained the percentage of variation associated with each principal component obtained by drawing a graph between Eigen values and principal component numbers. The PC1 showed 52.34 % variability with Eigen value 5.76 which then declined gradually. Elbow type line is obtained which after 2nd PC tended to straight with little variance observed in each PC. From the graph, it is clear that the maximum variation was observed in PC1.Variables from two component showed 90.60% variability (Fig. 2).

In this study number of drought tolerance indices can be identified with the help of principal component analysis, which are responsible for the observed genotypic variation present within each component. Consequently, drought tolerance indices coming collectively in various principal components and contributing towards elucidation the variability and have the propensity to remain together this may be kept into consideration during utilization of these indices in breeding program. These results concurrence with Maji and Shaibu, 2012; Chakravorty *et al*., 2013; Gana *et al*.,2013; Kumar *et al*. 2015; Mahendran *et al*.,2015.

Biplot graphs were taken by using first and second factors (F1 and F2) of principle component analysis. Vector length and cosine of angle were used for making different groups. These groups showed the similar performance for discrimination of genotypes. Biplot categorized the various drought tolerance indices into three groups. Group 1 had stress susceptibility index, tolerance index, sensitive drought index and relative decrease in yield index. Mean productivity, Stress tolerance index and yield index were present in group 2. Group 3 had relative drought index and yield stability index. The indices had strong positive correlation within the group with each other but among groups these had very weak correlation (Fig. 2). Vector length presented the discrimination power of various drought tolerance indices to differentiate genotypes. The genotypes were also categorized as highly drought tolerant i.e. VH-144, IUB-212, NIAB-111, IR-3701, MNH-886, VH-295, NS-121 and highly drought sensitive i.e. CIM-443, MNH-147, IR-3, FH-1000 and S-12. These findings are in according to Mazid *et al.* (2013) who categorized 41 different rice genotypes using PCA.

Genotypes showed their better performances which were present at some distance from origin in the positive direction of discriminating indices. The genotypes which were present at some distance from the origin in the negative direction of indices exhibited poor performance. Highest estimates of MP, STI and YI were recorded in genotypes FH-142, VH-282, NIAB-111, IUB-212, VH-144 indicating extreme tolerance to drought stress. These estimates were also high in CRS-2007 and FH-118 which were present on positive side of biplot. Minimum estimates of these indices were observed in CRS-456, IUB-222, MNH-888, S-12, VH-283 and VH-148 which were located on left side of treatment vectors and showed more sensitivity to drought stress. In addition, NIAB-820, AS-01, FH-169 and NS-131 were also sensitive to drought condition.

For YSI and RDI the highest estimates was recorded in genotypes VH-295, MNH-886, VH-121, FH-113, FH-172, and IR-3701 indicating extreme tolerance to drought stress. These indices showed minimum estimates with maximum vector length in the negative side of biplot in FH-1000, MNH-147, CIM-443 indicating extreme sensitivity to drought stress. The minimum estimates of SSI, SDI and RDY was recorded in genotypes VH-144 and IUB-212 with maximum vector length in negative side of biplot indicating extreme tolerance to drought stress. The maximum estimates of these indices were observed in genotypes S-12 and FH-1000, which showed more sensitivity to drought stress. In addition, SB-149, CRS-456, VH-148, IUB-222, AS-01 and AA-703 were also sensitive to drought.

On the basis of TOL, the minimum estimates was recorded in genotypes NS-131, FH-175, NIAB-820, FH-172, NS-121 and CIM-240 indicating tolerance to drought stress. The maximum estimates of these indices were observed in genotypes VH-282, CRS-2007, FH-118 and IR-901 which are located in the negative side of biplot indicating drought sensitive. In this study, MNH-888 had lowest TOL value (11.07), but the cultivar had low (28.66 g plant-1) instead of having higher seed cotton yield under drought condition. On the other hand, CIM-443 had highest TOL value (116.61), however the cultivar had high seed cotton yield (57.08 g plant-1) under drought condition. These results show that drought tolerance is a complex trait that can involve various growth-related traits and genes, corresponding to different ways. Also, drought tolerance cannot be attributed to a genotype, because of its superiority for a single trait; therefore different parameters would be used to determine tolerant genotypes for drought stress as suggested by Al-Hamdani and Barger (2003).

The results (PCA) exhibited that the first two components showed 52.34 and 38.26% of the total variability. Further it indicated that the second component (PC2) showed 38.26% of the variation (total yield variation) and associated positively with Ys, Yp, YI, STI and MP. This component of PCA was related to drought tolerance (yield potential). The genotypes having high value of PC2 were expected to be high yielder under normal and drought condition. Similar type of findings was found by Golabadi *et al*. (2006) in wheat (durum). The PC1 showed 52.34% of variation and was correlated with TOL, RDY, SDI and SSI. PC1 was associated with stress susceptibility. Keeping in view the tolerance and susceptibility, PC1 and PC2 were known as “stress susceptibility and yield potential” respectively. The results of a biplot showed the genotypes IUB-212, VH-144, NIAB-111, AA-802, VH-282 and FH-142 were located close to the best indices with high PC2 values as compare to PC1 values (Fig. 2). The most of genotypes with low values of PC2 as compare to PC1 were selected as sensitive genotypes such as CIM-443, MNH-147, IR-3, KZ-181, CRS-2007, FH-114 and CIM-707. Our findings are supported by Kaya *et al*. (2002) who identify those genotypes which have high PC2 and low PC1 scores indicating higher yield and genotypes with lower PC2 and higher PC1 value indicating lower yield.

Correlation study: The calculations of certain indices related to drought were taken on the basis of quantitative traits in normal and drought condition which can be utilized as indicators of tolerance to drought. For the assessment of most desirable drought tolerance measures, the correlation among seed cotton yield under normal condition (Yp), seed cotton yield under drought condition (Ys) and different drought tolerance indices were carried out (Table 6). Usually, indices which are strongly correlated with yield in normal and stress environment are considered the useful ones as separating the genotypes with high yield in normal and stress conditions. There were significant positive correlation among Ys, Yp, yield index (YI), stress tolerance index (STI) and mean productivity (MP), showing that these criteria differentiated tolerant genotypes which have high yield under normal and drought stress condition. Similar type of findings were reported by Dehghani *et al*. (2009), Toorchi *et al*. (2011) and Khalili *et al*. (2012) that mean productivity and stress tolerance index had significant positive correlation with stress yield. Jafari *et al*. (2009) identify that since stress tolerance index strongly correlated with yield under normal and stress, this index might be used as suitable index for selection and developing drought tolerant hybrids.

Tolerance (TOL), sensitive drought index (SDI) and relative decrease in yield index (RDY) showed positive association with yield under non-stress (Yp) while negatively associated with yield under stress (Ys). Relative drought index (RDI), yield stability index (YSI) showed significant positive correlation with yield under stress (Ys). Stress susceptibility index (SSI) showed significant negative correlation with yield under stress (Ys). The genotypes with high SSI and TOL values revealed higher seed cotton yield under normal stress and on the other hand, there was a trend with low SSI and TOL scores to be related with high yield under drought stress. Similar type of trend was found by Clark *et al*. (1992), Talebi *et al*. (2009), Sio-Se Mardeh *et al*. (2006), and Karimizadeh *et al*. (2011).

In the present work, PCA was used to describe the correlation between seed cotton yield and different drought tolerance indices. According to Kim *et al*. (2013), among multivariate methods, PCA is a frequently used method to classify samples. Analysis revealed strong correlation between seed cotton yield and different drought tolerance indices using PC1 and PC2. Chunthaburee *et al*. (2016) also reported correlation explained by first and second PC, as other PCs cover only little information of data sets. PCA clearly separated drought sensitive genotypes from drought tolerant genotypes.

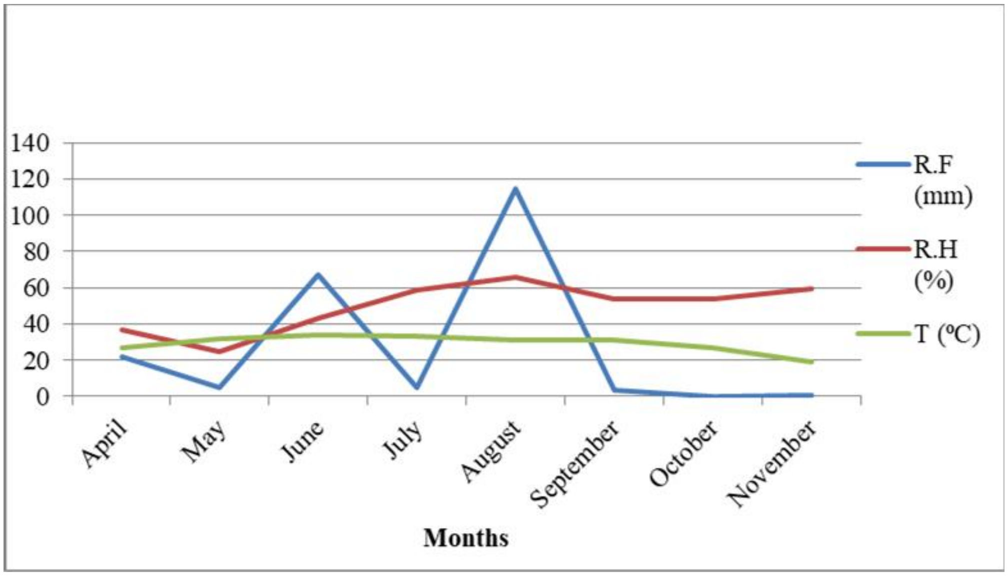

Fig. 1. Rainfall, relative humidity and average temperature from April to November during 2013

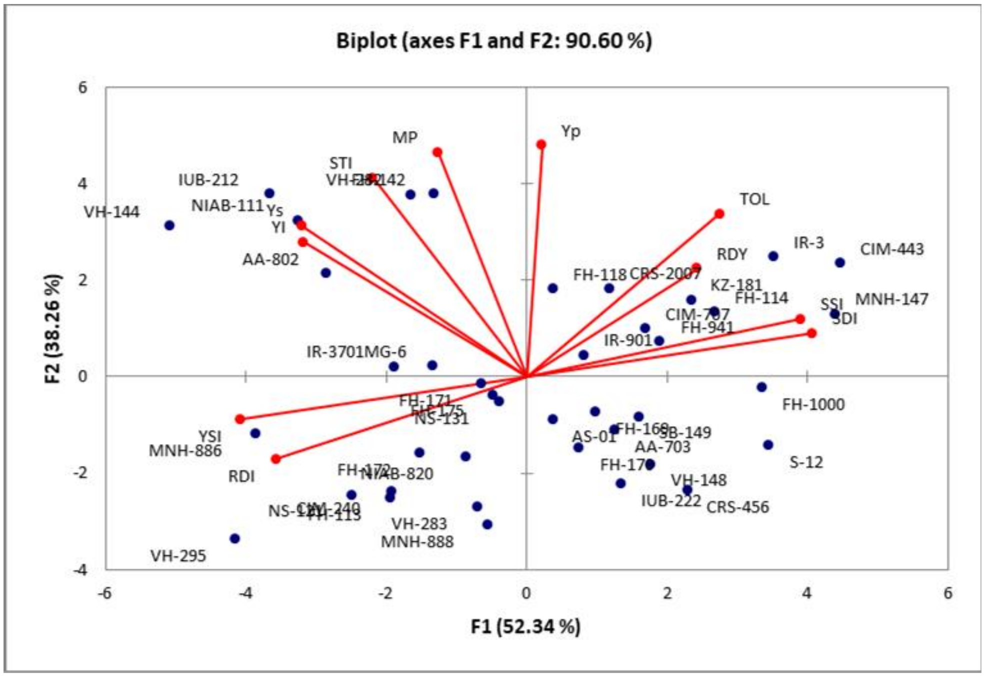

Fig. 2. Biplot for drought tolerance indices in 40 cotton genotypes based on first two components. Ys: Yield in stress condition; Yp: Yield in non-stress condition; SSI: Stress Susceptibility Index; STI: Stress Tolerance Index; TOL: Tolerance Index; MP: Mean Productivity; YSI: Yield Stability Index; YI: Yield index; RDI: Relative drought index; RDY: Relative decrease in yield index; SDI: Sensitive drought index

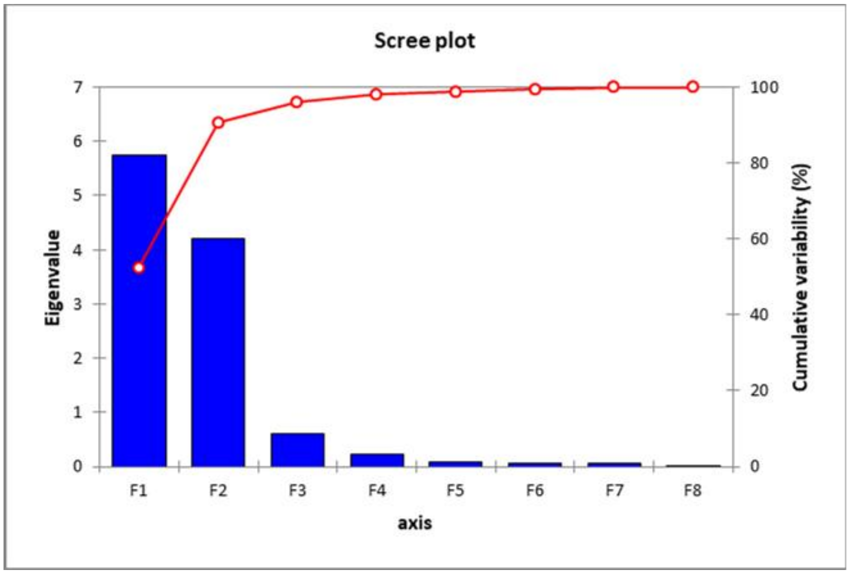

Fig. 3. Scree plot representing eigenvalue and cumulative variability percentage of different factors based on Principle component analysis

Table 1. List of 40 cotton genotypes/lines used in the current study.

Sr. No	Cultivar/Lines	Origin	Sr. No	Cultivar/Lines	Origin
1	AA-703	Ali Akbar Seeds	21	IR-3	NIBGE, Faisalabad
2	AA-802	Ali Akbar Seeds	22	IR-3701	NIBGE, Faisalabad
3	AS-01	Exotic	23	IR-901	NIBGE, Faisalabad
4	CRS-2007	CRS, Multan	24	IUB-212	IUB, Bahawalpur
5	CRS-456	CRS, Multan	25	IUB-222	IUB, Bahawalpur
6	FH-113	CRI, Faisalabad	26	KZ-181	Kanzo Seeds
7	FH-114	CRI, Faisalabad	27	MG-6	Exotic
8	FH-118	CRI, Faisalabad	28	NIAB-111	NIAB, Faisalabad
9	FH-142	CRI, Faisalabad	29	NIAB-820	NIAB, Faisalabad
10	FH-1000	CRI, Faisalabad	30	MNH-888	CRS, Multan
11	FH-169	CRI, Faisalabad	31	MNH-886	CRS, Multan
12	FH-170	CRI, Faisalabad	32	NS-121	Neelam Seeds
13	FH-171	CRI, Faisalabad	33	NS-131	Neelam Seeds
14	FH-172	CRI, Faisalabad	34	S-12	Sitara Seeds
15	FH-175	CRI, Faisalabad	35	SB-149	Exotic
16	CIM-707	CCRI, Multan	36	VH-148	CRS, Vehari
17	CIM-443	CCRI, Multan	37	VH-144	CRS, Vehari
18	CIM-240	CCRI, Multan	38	VH-282	CRS, Vehari
19	MNH-147	CRS, Multan	39	VH-283	CRS, Vehari
20	FH-941	CRI, Faisalabad	40	VH-295	CRS, Vehari

CRI = Cotton Research Institute (Faisalabad), CCRI = Central Cotton Research Institute (Multan), CRS = Cotton Research Station, NIBGE = National Institute of Biotechnology and Genetic Engineering, IUB = Islamia University Bahawalpur

Table 2. Mean value of forty cotton genotypes for seed cotton yield and various indices.

S.No	Genotype	Yp	Ys	STI	MP	YI	YSI
1	MNH-147	122.16	23.90	0.79	73.03	0.87	0.20
2	FH-171	97.30	49.22	1.30	73.26	1.79	0.51
3	S-12	64.91	16.82	0.30	40.87	0.98	0.26
4	CRS-2007	125.45	49.71	1.69	87.58	1.80	0.40
5	CRS-456	52.82	19.73	0.28	36.28	0.72	0.37
6	AA-703	76.94	30.65	0.64	53.79	1.45	0.40

7	FH-114	122.00	35.59	1.18	78.80	1.29	0.29
8	FH-118	130.07	53.94	1.91	92.00	1.96	0.41
9	MNH-888	39.73	28.66	0.40	40.19	1.04	0.55
10	IR-3	144.72	34.28	1.35	89.50	1.24	0.24
11	FH-169	84.18	34.66	0.79	59.42	1.53	0.41
12	VH-144	137.39	97.70	3.64	117.55	3.54	0.71
13	FH-1000	94.98	23.22	0.60	59.10	0.84	0.24
14	FH-172	76.69	45.16	0.94	60.93	1.64	0.59
15	FH-175	94.35	47.36	1.21	70.86	1.62	0.50
16	IUB-212	138.73	97.19	3.66	117.96	3.53	0.70
17	AS-01	80.55	35.93	0.79	58.24	1.86	0.45
18	VH-295	57.06	45.83	0.71	51.44	1.66	0.80
19	NIAB-111	146.61	85.74	3.41	116.18	3.11	0.58
20	FH-941	126.51	32.82	1.13	79.66	1.19	0.26
21	FH-170	74.75	30.72	0.62	52.73	1.33	0.41
22	CIM-707	113.14	38.93	1.20	76.03	1.78	0.34
23	IR-901	106.30	43.48	1.25	74.89	1.58	0.41
24	FH-142	147.84	78.43	3.15	113.14	2.85	0.53
25	NS-121	65.79	44.15	0.79	54.97	1.60	0.67
26	FH-113	65.42	42.05	0.75	53.73	1.23	0.64
27	MG-6	104.71	54.60	1.55	79.65	1.98	0.52
28	SB-149	91.69	30.59	0.76	61.14	1.11	0.33
29	NIAB-820	73.94	40.63	0.82	57.28	1.47	0.55
30	CIM-443	173.69	57.08	1.06	85.38	0.98	0.19
31	CIM-240	55.96	34.95	0.53	45.46	2.57	0.62
32	VH-282	153.65	77.48	3.23	115.56	2.81	0.50
33	NS-131	92.14	44.30	1.11	68.22	1.61	0.48
34	VH-148	67.49	24.39	0.45	45.94	0.88	0.36
35	MNH-886	85.39	61.71	1.43	73.55	2.24	0.72
36	AA-802	127.27	77.33	2.67	102.30	2.81	0.61
37	IUB-222	59.38	24.77	0.40	42.07	0.90	0.42
38	IR-3701	95.43	58.35	1.51	76.89	2.78	0.61
39	VH-283	57.74	32.45	0.51	45.10	1.18	0.56
40	KZ-181	137.71	37.02	1.38	87.36	1.34	0.27

Table 2: Cont.

S.No	Genotype	RDI	SSI	TOL	SDI	RDY
1	MNH-147	0.43	1.47	98.26	0.80	80.43
2	FH-171	1.11	0.91	48.08	0.49	49.41
3	S-12	0.57	1.36	48.09	0.74	74.08
4	CRS-2007	0.87	1.29	75.74	0.60	71.73
5	CRS-456	0.61	1.15	33.09	0.63	62.64
6	AA-703	0.88	1.10	46.29	0.60	60.17
7	FH-114	0.64	1.30	86.41	0.71	70.83
8	FH-118	0.91	1.21	76.13	0.59	49.53
9	MNH-888	1.29	0.82	11.07	0.45	44.60
10	IR-3	0.52	1.40	110.43	0.76	76.31
11	FH-169	0.91	1.08	49.52	0.59	58.83
12	VH-144	1.57	0.41	39.69	0.29	58.36
13	FH-1000	0.84	1.38	71.76	0.76	75.55
14	FH-172	1.30	0.75	31.53	0.41	41.11
15	FH-175	1.11	0.91	46.99	0.50	49.80
16	IUB-212	0.96	0.81	41.53	0.30	67.36
17	AS-01	0.98	1.01	44.62	0.55	55.39
18	VH-295	1.77	0.36	11.23	0.20	19.68

19	NIAB-111	1.29	0.76	60.87	0.42	41.52
20	FH-941	0.57	0.89	93.68	0.74	29.46
21	FH-170	1.27	1.08	44.03	0.59	58.91
22	CIM-707	0.76	1.20	74.21	0.66	65.59
23	IR-901	0.90	1.08	62.82	0.59	59.10
24	FH-142	0.82	0.99	69.42	0.47	69.47
25	NS-121	1.48	0.60	21.64	0.33	32.89
26	FH-113	1.42	0.65	23.37	0.36	35.72
27	MG-6	1.15	0.67	50.11	0.48	47.86
28	SB-149	0.93	1.22	61.10	0.67	38.56
29	NIAB-820	1.21	0.83	33.31	0.45	45.05
30	CIM-443	0.41	1.49	116.61	0.81	81.16
31	CIM-240	1.19	0.69	21.02	0.38	37.56
32	VH-282	1.11	0.91	76.17	0.50	62.67
33	NS-131	1.06	0.76	47.84	0.52	51.92
34	VH-148	1.08	1.17	43.10	0.64	63.86
35	MNH-886	1.59	0.51	23.68	0.28	27.73
36	AA-802	1.34	0.72	49.94	0.39	58.24
37	IUB-222	0.92	1.07	34.61	0.58	58.28
38	IR-3701	0.81	0.83	37.08	0.39	38.86
39	VH-283	1.24	0.80	25.29	0.44	43.79
40	KZ-181	0.59	1.34	100.68	0.73	33.67

Yp= seed cotton yield under normal, Ys= seed cotton yield under drought, STI= stress tolerance index, YI= yield index, MP= mean productivity, YSI= yield stability index, RDI= relative drought index, SSI= stress susceptibility index, TOL= tolerance index, SDI= sensitive drought index, RDY= relative decrease in yield index

Table 3. Mean squares of various drought tolerance indices for screening cotton genotypes in field.

SOV	D.F	STI	MP	YI	YSI	RDI	SSI	TOL	SDI	RDY
Rep	2	0.005	48.540	0.000	0.007	0.001	0.001	70.380	0.007	61.278
Gen.	39	2.703^{**}	1635.990^{**}	1.675^{**}	0.074^{**}	0.359^{**}	0.248^{**}	1908.740^{**}	0.074^{**}	738.94^{**}
Error	78	0.036	15.410	0.026	0.003	0.013	0.009	47.520	0.003	27.001

*= significant, **= highly significant, NSCY= seed cotton yield under normal, DSCY= seed cotton yield under drought, STI= stress tolerance index, YI= yield index, MP= mean productivity, YSI= yield stability index, RDI= relative drought index, SSI= stress susceptibility index, TOL= tolerance index, SDI= sensitive drought index, RDY= relative decrease in yield index.

Table 4. Correlations between variables and factors; Eigenvalue, Variability and Cumulative variability of different factors based on Principle component analysis.

Variables	Factor 1	Factor 2
Yp	0.051	0.977
Ys	-0.762	0.637
STI	-0.523	0.839
MP	-0.300	0.947
YI	-0.757	0.569
YSI	-0.970	-0.182
RDI	-0.851	-0.349
SSI	0.930	0.242
TOL	0.656	0.686
SDI	0.970	0.182
RDY	0.579	0.456
Eigenvalue	5.76	4.21
Variability (%)	52.34	38.26
Cumulative Percentage	52.34	90.60

Yp = seed cotton yield under normal, Ys = seed cotton yield under drought, STI= stress tolerance index, YI= yield index, MP= mean productivity, YSI= yield stability index, RDI= relative drought index, SSI= stress susceptibility index, TOL= tolerance index, SDI= sensitive drought index, RDY= relative decrease in yield index.

Table 5. Contribution of the variables (%) in variability of different factors having eigenvalue greater than 1.

Variables	Factor 1	Factor 2
Yp	0.046	22.675
Ys	10.094	9.639
STI	4.746	16.705
MP	1.561	21.301
YI	9.952	7.697
YSI	16.352	0.783
RDI	12.583	2.900
SSI	15.033	1.390
TOL	7.465	11.193
SDI	16.352	0.783
RDY	5.817	4.935

Yp = seed cotton yield under normal, Ys = seed cotton yield under drought, STI= stress tolerance index, YI= yield index, MP= mean productivity, YSI= yield stability index, RDI= relative drought index, SSI= stress susceptibility index, TOL= tolerance index, SDI= sensitive drought index, RDY= relative decrease in yield index.

Table 6. Correlation coefficients between seed cotton yield (g plant-1) under normal (Yp) and stress (Ys) condition with various drought tolerance indices.

	Yp	Ys	STI	MP	YI	YSI	RDI	SSI	TOL	SDI
Ys	0.568**									
STI	0.776**	0.944**								
MP	0.932**	0.827**	0.945**							
YI	0.475**	0.938**	0.867**	0.737**						
YSI	-0.235	0.627**	0.351*	0.115	0.635**					
RDI	-0.361*	0.422**	0.153	-0.061	0.385**	0.871**				
SSI	0.259	-0.542**	-0.272	-0.061	-0.539**	-0.930**	-0.870**			
TOL	0.768**	-0.091	0.204	0.484**	-0.155	-0.773**	-0.765**	0.735**		
SDI	0.235	-0.627**	-0.351*	-0.115	-0.635**	-1.000**	-0.871**	0.930**	0.773**	
RDY	0.368	-0.113	0.112	0.202	-0.128	-0.590	-0.611**	0.698**	0.533	0.590

*= significant, **= highly significant, Yp= seed cotton yield under normal, Ys= seed cotton yield under drought, STI= stress tolerance index, YI= yield index, MP= mean productivity, YSI= yield stability index, RDI= relative drought index, SSI= stress susceptibility index, TOL= tolerance index, SDI= sensitive drought index, RDY= relative decrease in yield index

Conclusion: It is concluded from the present study that MP, TOL, SSI, STI and YI are the suitable indices for screening genotypes that produce higher yields in both normal and drought conditions (drought tolerant genotypes). It is further concluded that the genotypes IUB-212, MNH-886, VH-144, VH-295, AA-802, NIAB-111, NS-121, FH-113, IR-3701 and FH-142 are either stable or show positive interaction with drought conditions for most of the drought tolerance indices. These genotypes can be used in further breeding program for developing varieties suitable for cultivation under drought hit areas of Pakistan whereas; CIM-443, FH-1000, IR-3, S-12 and MNH-147 show undesirable interaction with drought stress.

REFERENCES

Al-Hamdani, S.H. and T.W. Barger (2003). Influence of water stress on selected physiological responses of three sorghum genotypes. Italy J. Agronomy. 7: 15–22.

Anonymous. (2016-17). Economic survey of Pakistan. Ministry of food, agriculture and livestock, economic advisor wing, Islamabad, Pakistan.

Ashraf, M., H. Athar, P. Harris and T. Kwon. (2008). Some prospective strategies for improving crop salt tolerance. Adv. Agron. 97: 45-110.

Bhargava, S., Sawant K. (2013). Drought stress adaptation: metabolic adjustment and regulation of gene expression. Plant Breed. 132: 21-32.

Blum, A. (1996). Crop responses to drought and the interpretation of adaptation. Plant Growth Regul. 20: 135-148.

Bouslama, M., Schapaugh W.T. (1984). Stress tolerance in soybean. Part 1: evaluation of three screening techniques for heat and drought tolerance. Crop Sci. 24: 933-937.

Brejda, J.J., Moorman T.B, Karlen D.L, Dao T.H. (2000). Identification of regional soil quality factors and indicators. I. Central and Southern High- Plains. Soil Sci. Soc. Am. J. 64: 2115-2124.

Cattivelli, L., F. Rizza, F.W. Badeck, E. Mazzucotelli, A.M. Mastrangelo, E. Francia, C. Marè, A. Tondelli and A.M. Stanca (2008). Drought tolerance improvement in crop plants: An integrated view from breeding to genomics. Field Crop RES. 105: 1-14.

Chakravorty, A., Ghosh P.D, Sahu P.K. (2013). Multivariate analysis of landraces of rice of West Bengal. American J. Experimental Agriculture. 3(1): 110-123.

Cooper, M., van Eeuwijk F, Chapman S.C, Podlich D.W, Loeffler C. (2006). Genotype-by environment interactions under water-limited conditions. In JM Ribaut, ed, Drought Adaptation in Cereals, Haworth (NY). 51-96p

Chunthaburee, S., A. Dongsansuk, J. Sanitchon, W. Pattanagul, and P. Theerakulpisut (2016). Physiological and biochemical parameters for evaluation and clustering of rice cultivars differing in salt tolerance at seedling stage. Saudi J BiolSci. 23: 467–477.

Clarke, J.M, De Pauw R.M, Townley-Smith T.M. (1992). Evaluation of methods for quantification of drought tolerance in wheat. Crop Sci. 32: 728-732.

Dehghani, G.H., Malekshhi F, Alizadeh B. (2009). A study of drought tolerance indices in canola (*Brassica napus* L.) genotypes. J. Sci.Technol. Agri. Natural Reso. 13: 77-90.

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

Fischer, R.A., D. Rees, K.D. Sayre, Z.M. Lu, A.G. Condon and A.L. Saavedra (1998). Wheat yield progress associated with higher stomatal conductance and photosynthetic rate and cooler canopies. Crop Sci. 38: 1467-1475.

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

Gana, A.S., Shaba S.Z, Tsado E.K. (2013). Principal component analysis of morphological traits in thirty-nine accessions of rice (*Oryza sativa* L.) grown in a rainfed lowland ecology of Nigeria. J. of Pl. Breed. and Crop Sci. 5(10): 120-126.

Golabadi, M., A. Arzani and S.A.M. Mirmohammadi Meibody (2006). Assessment of drought tolerance in segregating Populations in Durum Wheat. Afr. J. Agric. Res. 5: 162-171.

Gorham, J. (1996). Glycine betain is a major nitrogen containing solute in the Malvaceae. Phytichum. 43: 367–369.

Guttieri, M.J., J.C. Stark, K. Brien and E. Souza (2001). Relative sensitivity of spring wheat grain yield and quality parameters to moisture deficit. Crop Sci. 41: 327-335.

Huang, B., Gao H. (2000). Root physiological characteristics associated with drought resistance in tall fescue cultivars. Crop Sci. 40: 196-203.

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

Karimizadeh, R., Mohammadi M, Ghaffaripour S, Karimpour F, Shefazadeh M.K. (2011). Evaluation of physiological screening techniques for drought-resistant breeding of durum wheat genotypes in Iran. Afr. J. Biotechnol. 10: 12107-12117.

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

Khalili, M., Naghavi M.R, Pour A.R, Talebzadeh J. (2012). Evaluating of drought stress tolerance based on selection indices in spring canola cultivars (*Brassica napus*L.). J. Agri. Sci. 4: 78-85.

Khodarahmpour, Z. (2011). Effect of drought stress induced by polyethylene glycol (PEG) on germination indices in corn (*Zea mays* L.) hybrids, Afr. J. Biotechnol. 10: 1816-1822.

Kim, J.K., S.Y. Park, S.H. Lim, Y. Yeo, H.S. Cho and S.H. Ha (2013). Comparative metabolic profiling of pigmented rice (Oryza sativa L.) cultivars reveals primary metabolites are correlated with secondary metabolites. J. Cereal Sci. 57: 14–20.

Kirda, C., S. Topeu, H. Kaman, A.C. Ulger, A. Yazici, M. Cetin and M.R. Derici. (2005). Grain yield response and nitrogen fertilizer recovery of maize under deficit irrigation. Photosynthetica. 19: 312-319.

Kumar, P., Sao A, Gupta A.K, Kumar M. (2015). Principal component analysis for assessment of genetic diversity in upland paddy for Bastar plateau. Electronic J. of Pl. Breed. 6(4): 1052-1059.

Mahendran, R., Veerabadhiran P, Robin S, Raveendran M. (2015). Principal Component Analysis of Rice Germplasm Accessions under High Temperature Stress. Int. J. of Agril. Sci. and Res. 5(3): 355-360.

Maji, A.T., Shaibu A.A. (2012). Application of principal component analysis for rice germplasm characterization and evaluation. J. Plant Breed. Crop Sci. 4: 87-93.

Massaci, A., S.M. Nabiev, L. Petrosanti, S.K. Nematov, T.N. Chernikova, K. Thor and J. Leipner. (2008). Response of the photosynthetic apparatus of cotton (Gossypium hirsutum L.) to the onset of drought stress under field conditions studied by gas-exchange analysis and chlorophyll fluorescence imaging. Plant Physiol. Biochem. 46: 189-195.

Mazid, M.S., M.Y. Rafii, M.M. Hanafi, H.A. Rahim, and M.A. Latif (2013). Genetic variation, heritability, divergence and biomass accumulation of rice genotypes resistant to bacterial blight revealed by quantitative traits and ISSR markers. Physiol Plant. 149: 432–447.

McCaig, T.N., Clarke J.M. (1982). Seasonal changes in nonstructural carbohydrate levels of wheat and oats grown in semiarid environment. Crop Sci. 22: 963–970.

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

Moosavi, S.S., B. YazdiSamadi, M.R. Naghavi, A.A. Zali, H. Dashti and A. Pourshahbazi (2008). Introduction of new indices to identify relative drought tolerance and resistance in wheat genotypes. Desert. 12: 165-178.

Mvula, J., J.M. Bokosi, V. Kabambe and M.H.P. Banda (2018).Screening cotton (*Gossypium hirsutum* L.) genotypes for drought tolerance under screen house conditions in Malawi. J. Plant Breed. Crop Sci. 10(2): 48-57.

Naidu, B.P., D.E. Cameron and S.V. Konduri (1998). Improving drought tolerance of cotton by glycine betain application and selection. In: Proc. 9th Australian Agronomy Conference, Wagga Wagga.

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

Rajamani, A. (1994). Screening *Gossypium hirsutum* genotypes for drought tolerance. Madras Agric. J. 8: 465-468.

Rajeswari, V.R. (1995). Evaluation of cotton genotypes for drought tolerance under rain fed conditions. Ann. Plant Physiol. 9: 109-112.

Rizza, F., F.W. Badeck, L. Cattivelli, L. Destri, O. D Fonzo and N. Stanca. (2004). Use of a water stress index to identify barley genotypes adapted to rainfed and irrigated conditions. Crop Sci. 44: 2127-2137.

Sezener, V., H. Basal, C. Peynircioglu, T. Gurbuz, K. Kizilkaya (2015). Screening of cotton cultivars for drought tolerance under field conditions. Turk J Field Crops. 20(2): 223-232.

Sinclair, T.R. (2005). Theoretical analysis of soil and plant traits influencing daily plant water flux on drying soils. Agron J. 97: 1148-1152.

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

Talebi, R., Fayaz F, Naji N. (2009). Effective selection criteria for assessing drought stress tolerance in durum wheat (*Triticum durum* Desf.). Gen. Appl. Plant Physiol. 35:64- 74

Toorchi, M., Naderi R, Kanbar A, Shakiba MR. (2011). Response of spring canola cultivars to sodium chloride stress. Ann. Bio. Res. 2: 312-322.

Turner N.C. (1997). Further progress in crop water relations. Advance Agronomy. 58: 293-338.

Ullah, I., M. Rahman, M. Ashraf and Y. Zafar (2008). Genotypic variation for drought tolerance in cotton (*G. hirsutum* L.): Leaf gas exchange and productivity. Flora. 2: 105-115.