

**Evaluation of different cotton varieties against drought tolerance: A comparative analysis**^aAziz Ullah *, ^bAmir Shakeel, ^cHafiz Ghulam Mihu-Din Ahmed, ^dMuhammad Majid Yar, ^eMuhammad Ali^a Department of Plant Breeding and Genetics, College of Agriculture, University of Sargodha, Pakistan,^b Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad,^c University of Central Punjab, Department of Botany, Punjab Group of Colleges, Bahawalpur 63100, Pakistan,^d Department of Plant Breeding and Genetics, The Islamia University of Bahawalpur^e Department of Agricultural Engineering, Khwaja Fareed University of Engineering & Information Technology, Rahim Yar Khan.

Author's Contribution	Ullah, A. written the original draft. A. Shakeel, supervision, editing and improving final draft. H.G.M.D. Ahmed, analyzed the experimental data. M.M. Yar and M. Ali interpret the results and reviewed the whole manuscript. All authors have read and agreed to the published version of this manuscript.
Article History	*Corresponding email address: azizullahpbg@gmail.com ; ahmedbreeder@gmail.com Received: 10 September 2020, Revised: 15 October 2020, Accepted: 03 November 2020, Published Online: 17 November 2020 ABSTRACT Digital Object Identifier (DOI): https://doi.org/10.33865/IJCRT.002.01.0372

The limited water supply for irrigation is a major constraint to cotton production. Morphological and physiological traits provide useful information for drought tolerance. This research work was carried out for the identification of cotton genotypes having better drought tolerance. For this purpose, forty (40) genotypes of upland cotton were studied under two moisture regime, i.e. normal and drought environment in field conditions. The experiment was conducted using split plot design under RCBD arrangement. All the genotypes behaved differently under two moisture levels. The interaction of cotton genotypes with two moisture levels were studied for various traits, i.e. plant height, sympodial branches, seed cotton yield, boll weight, number of bolls per plant, excised leaf water loss and relative water content by using Principle Component Analysis (PCA). Results showed that 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 for most of the traits under studied. 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 word: *Gossypium hirsutum* L., breeding program, stable, seed cotton yield, water deficit, principle component analysis.

INTRODUCTION: Cotton is a major fiber yielding crop and ranked second as an oilseed crop after soybean (Mammadov *et al.*, 2018). In Pakistan, it is a cash crop and major earnings of foreign exchange. Pakistan ranked at the fourth number in largest cotton production in the whole world. The share of cotton in agriculture is 5.1% and in overall GDP is 1.0% (Ashraf *et al.*, 2018). The total 99% of cotton area in Pakistan and 90% of the world's cotton area is covered with upland cotton. This crop is mostly grown in arid and semiarid regions where a water shortage is often occurring.

The economy of a predominantly agricultural country mainly depends upon the agricultural activities, consisting of many disciplines in which crop husbandry plays an important role. When a seed is planted in the soil, the plant development and productivity are subject to numerous biotic and abiotic stresses. It is evidenced that abiotic stresses are the major contributor to the reduction of crop growth and yield. The losses due to drought, high temperature, salinity, low temperature, and by other factors are 17%, 40%, 20%, 15% and 8% respectively (Ullah *et al.*, 2019; Zaidi *et al.*, 2020). Drought stress has been affecting globally to the agriculture which causes higher yield losses as compared to all other abiotic stresses. Drought along with high temperature is a major constraint to plant growth, survival and productivity on a global basis (Ahmad *et al.*, 2018). It reduces the crop growth and productivity and affects various physiological, biochemical and molecular processes in crop plants. The water deficit along with global climate change makes the condition more severe in major agricultural domains (Khan *et al.*, 2018).

The situations in which it is impossible to modify the environments to suit the crop plants, plant breeders and

geneticists are trying to modify the crop plants for adverse environmental stresses. This alternative strategy is being used to tackle the problem of drought stress (Ahmed *et al.*, 2020). This approach consists of modification of the genetics of crop plants through selection and breeding, to make them suitable for drought declared areas. To develop such material, variability in the crop plant is a basic requirement for drought tolerance and this variability must have some genetic components. Information about these components is necessary for exploitation of these genetic resources through selection and breeding. The variability in a species plays important role in the identification of the target genotypes for the improvement of character under study (Ullah *et al.*, 2017).

The selection and breeding, crop plants against drought may be better if the variation is genetically controlled. Previous studies suggest that drought tolerance is polygenetically controlled. Significant genetic variation has been found in many traits which are associated with drought stress in many crops. The variability in drought stress tolerance in cotton crop is limited as reported by previous work, but a few studies reported that the variation in drought tolerance is available at crop maturity. The information about response of plants to drought stress is essential for improving the drought stress tolerance since morphological traits have been usually used to classify drought tolerant and sensitive genotypes in upland cotton (Jaleel *et al.*, 2009). The main advantages of using these morphological traits in screening include no requirement of any specialized equipment for measuring them. Significant variation has been reported in various morphological traits such as plant height, number of bolls per plant and boll weight (Mahmood *et al.*, 2006). Reduced leaf area is major symptoms of cotton under

drought stressed to reduce transpiration. High leaf water content being genetically controlled and usually used as reliable measures to determine drought tolerant plants (Prasad *et al.*, 2008; Brito *et al.*, 2011).

OBJECTIVES: Therefore, the present study was planned for the assessment of genotypic variation under water deficit condition at maturity stage in the field condition in commercial and newly developed elite cotton varieties and to identify drought tolerant and drought sensitive genotypes.

MATERIALS AND METHODS: In this study, forty cotton accessions were screened at maturity stage in the research area of Department of Plant Breeding and Genetics, UAF. These genotypes were evaluated under two moisture regimes, normal (T₀) and drought stress (T₁) in the field conditions. For this purpose, forty genotypes of cotton were grown under normal and drought conditions in split plot design under RCBD arrangement. The main plots contained irrigations while sub-plots contained genotypes in each replication. Ten plants of each genotype were grown in a single row. The distance between rows 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 213.2 and 3.8 mm respectively. Drought stress treatment was given 50% reduced irrigations as compared to the normal treatment (Kirda *et al.*, 2005). Climatic conditions prevailing during present experimentation (April-November) in the year 2013 were provided in the figure 1. (Source: Agromet Bulletin, Agriculture Meteorology Cell, Department of Crop Physiology, UAF, Pakistan). At the maturity stage, when drought symptom appeared, 5 guarded plants for each of the genotypes per replication and treatment were tagged for measuring the data for plant height, number of sympodial branches, number of bolls per plant, boll weight, seed cotton yield per plant, excised leaf water loss and relative water content.

Plant height of the main stem from cotyledonary node to the apex was measured in centimeters. The sympodial branches were counted from each tagged plant on each of the genotype per treatment and replication and then average was calculated. The matured, open bolls were picked from each randomly selected plant from each genotype, per treatment and replication and then average was calculated as number of bolls per plant. For measuring boll weight, five opened bolls having a good opening were picked from each tagged plant for each genotype per treatment and replication. The seed cotton was weighed in grams in electrical balance and then the average boll weight of each entry was calculated by dividing seed cotton weight of five bolls by five. All the opened bolls having a good opening were picked by three picks at maturity and then seed cotton was weighed in grams and then the average weight of seed cotton yield per plant was calculated.

For the measurement of relative water content, three matured leaf samples were obtained from each of the tagged plants from each replication and treatment during the end of September. These leaf samples were kept in polythene bags after they were excised and their fresh weight was taken on the electronic balance. After that the samples were left in the water for one night and by using an electronic balance turgid weight were measured. After keeping these samples at room temperature

for drying for about one hour, these samples were oven dried for 72 h. at 70°C and dry weight of leaf samples were measured. The relative water content was calculated by the formula as under (Barr and Weatherley, 1962).

$$RWC = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Turgid weight} - \text{Dry weight}} \times 100$$

For measuring excised leaf water loss, a sample of three matured leaves was obtained from each of the tagged plants for each of the genotype per replication and treatment during the end of September. These leaf samples were kept in bags soon after they were excised from the plant and their fresh weight was measured on an electronic balance. Then the leaf samples were kept at room temperature on the laboratory bench. The wilted weight of leaves samples were measured after 24 h. and then these samples were oven dried for 72 h. at 70°C for measuring dry weight. The excised leaf water loss was calculated by the formula as under (Clarke and Mccaig, 1982).

$$ELWL = \frac{\text{Fresh weight} - \text{Wilted weight}}{\text{Dry weight}} \times 100$$

Collected data were subjected to analysis of variance using Statistix 8.1. Principle component analysis (PCA) was performed on the mean data using XLSTAT software (Ahmed *et al.*, 2019).

RESULTS: Mean squares showed significant differences for genotypes, treatments and genotype × treatments interaction for all the traits (table 1). Traits showing significant differences for genotypes and treatments were further analysed by principle component analysis (PCA).

Plant height (cm): The biplot analysis for plant height revealed that there was significant variation in forty genotypes of cotton (figure 2). It is obvious that genotypes which are tolerant under drought stress produced taller shoots as compared to sensitive ones. Maximum plant height under normal and drought stress was shown by VH-148. The genotypes such as IUB-212, CRS-2007, NIAB-111, MNH-147 and NS-131 also showed the genetic potential for improving drought tolerance under both conditions. The other genotypes showed specific response against treatment because these genotypes formed positive, but shorter vectors along the vectors of treatment. For example, VH-144, CIM-443, IUB-222 and FH-114 were well under normal treatment whereas FH-170, CIM-707, IR-3 and MNH-886 did better under drought condition. The genotypes i.e. AA 703, FH-171, MG-6, FH-172, VH-293, AA-802, CRS-456, CIM-240, AS-01, S-12, NIAB-820 and VH-282 showed sensitivity against drought stress due to their location on negative side of treatment vectors.

Number of sympodial branches: Genotypes i.e. IUB-212, CIM-707, VH-148, NIAB-111 and IR-901 had shown more sympodial branches and these genotypes were located on the extreme right of treatment vectors (figure 3). The remaining genotypes which performed better under normal and drought conditions were included CRS-2007, FH-170 and VH-144 because these genotypes formed longer vectors which showed their tolerant response under drought stress. The shorter but positive vectors were found in the genotypes such as VH-283, IUB-222, FH-175 and FH-169 which showed a specific response to treatment. The genotypes AA-703, CRS-456, VH-295, FH-113 and IR-3701 were most sensitive to drought stress. In addition the genotypes such as FH-172, FH-941, AS-01, FH-1000, FH-171, MG-6 and IR-3 also showed sensitivity to drought stress because of their vector location on the negative side of vectors of the treatment.

SOV	D.F	PH	SB	BP	BW	SCY	RWC	ELWL
Rep.	2	9.100	11.760	3.990	0.063	98.000	0.001	0.034
Trt.	2	48986.100**	555.774**	6854.430**	54.198**	173834.000**	0.396**	1.221**
Error-I	4	0.300	0.429	0.180	0.042	36.000	0.000	0.010
Gen.	39	955.000**	25.706**	95.210**	2.341**	3265.000**	0.059**	1.577**
Trt*Gen	78	253.400**	7.365**	40.740**	0.423**	1040.000**	0.023**	0.338**
Error-II	234	0.900	0.881	1.850	0.011	27.000	0.000	0.009

Table 1: Mean squares for various traits of screening at maturity stage in the field.

significant, **= highly significant, PH= plant height, SB= number of sympodial branches, BP= number of bolls per plant, BW= boll weight, RWC= relative water content, ELWL= excised leaf water loss.

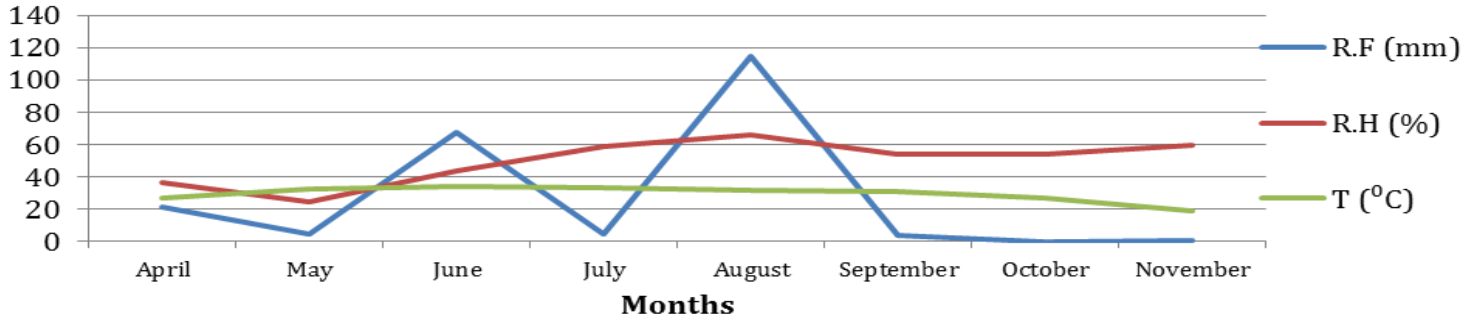


Figure 1: Rainfall, relative humidity and average temperature from April to November during 2013.

Biplot (axes F1 and F2: 100.00 %)

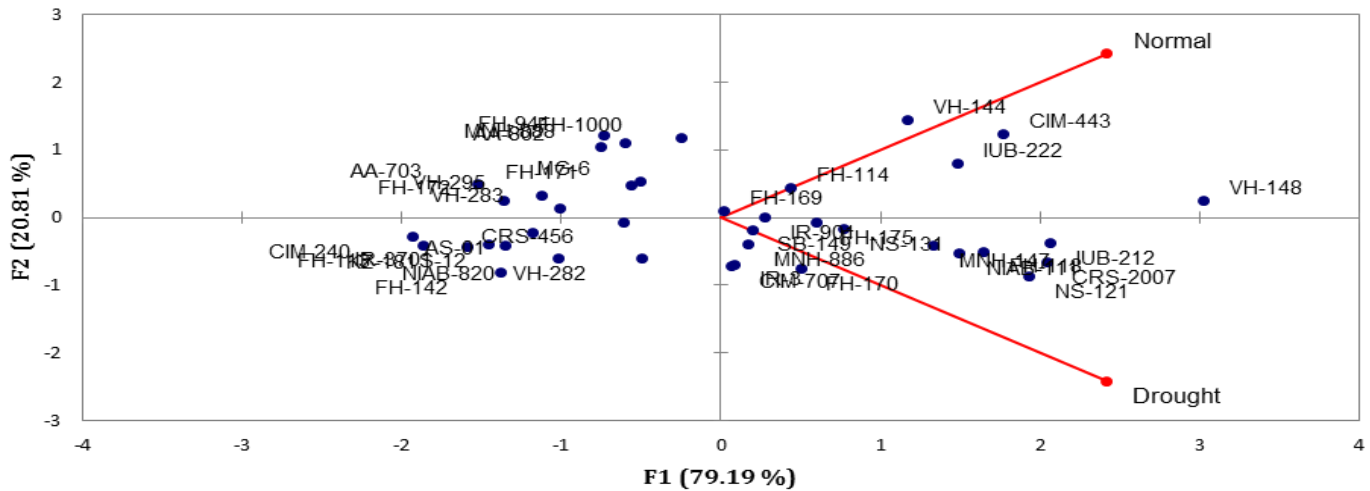


Figure 2: Biplot for plant height of forty cotton genotypes under normal and drought conditions.

Biplot (axes F1 and F2: 100.00 %)

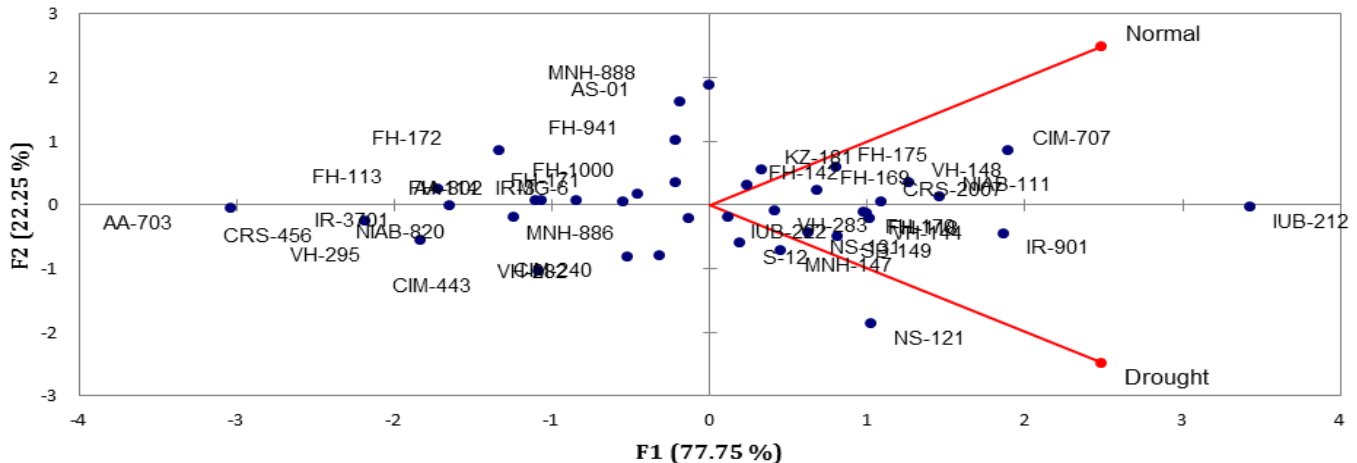


Figure 3: Biplot for sympodial branches of forty cotton genotypes under normal and drought conditions.

Number of bolls per plant: Significant variation was found in 40 genotypes for a number of bolls per plant. The longest stretches with treatment vectors were formed by NIAB-111 and MNH-147 which signified the high number of bolls per plant under normal and drought conditions. The genotypes NS-121, IUB-212, CRS-2007, VH-282 and VH-148 also revealed high genetic potential for drought stress tolerance by retaining more number of bolls per plant and in contrast, genotypes NIAB-820, CRS-456, MNH-886, FH-169 and VH-144 which were located on the opposite to the treatment vectors and ranked as highly drought sensitive genotypes. The remaining genotypes which were located on the negative side of treatment vectors such as IR-3701, AA-703, FH-941, AS-01, FH-113 and S-12 ranked as sensitive genotypes to drought stress (figure 4).

Boll weight (g): In biplot graph for boll weight, the genotypes with maximum boll weight were located right side of treatment vectors which indicated their potential to maintain high boll weight under both treatments (figure 5). This group consisted of highly tolerant genotypes, for example, CIM-707 and FH-170. Other genotypes which also showed some degree of drought tolerance were included IUB-212, NS-121, MNH-147, VH-148 and FH-118. In comparison, the genotypes which were present on left side of treatment vectors showed severe decline in boll weight, therefore the genotypes such as AS-01 and NIAB-111 were found highly sensitive under normal and drought stress. The genotypes such as CRS-456, FH-171, FH-113, FH-175, S-12 and CIM-443 could be clearly categorized as sensitive.

Seed cotton yield (g): This biplot showed significant genetic variation of forty cotton genotypes indicated by their dispersion around biplot origin for seed cotton yield (figure 6). Highest seed cotton yield was recorded in genotypes FH-170, CIM-707 and MNH-147 indicating extreme tolerance to drought stress in these cultivars. The seed cotton yield was also high in NS-121, IUB-212 and VH-148 which were present on the positive side of biplot. Minimum seed cotton yield was observed in genotypes which were located on the left side of treatment vectors such as CRS-456, VH-144, FH-142, MNH-886 and AS-01 which showed more sensitivity to drought stress. In addition, FH-171, NIAB-111, AA-703 and S-12 were also sensitive to drought condition.

Relative water content: This biplot showed that there were significant variations in the genotypes for this trait (figure 7). The genotypes which showed their longest vector length with treatment vectors were CIM-707 and VH-295 which indicated high relative water content under normal and drought conditions. The genotypes for example FH-171, SB-149, IUB-212, FH-172, FH-118, MNH-147, FH-114 and NS-121 also showed the genetic potential for drought tolerance by maintaining high leaf water content. The genotypes FH-113 and CIM-443 which were located on the reverse side of the treatment vectors were ranked as highly drought sensitive. The remaining genotypes which were present on negative sections of biplot included IR-3701, S-12, KZ-181, MNH-886, NIAB-111 and FH-142 and marked as sensitive to drought stress.

Excised leaf water loss: In this biplot (excised leaf water loss) the genotypes showing slightest water loss were located left to the treatment vectors which indicated their capacity to maintain high leaf water content under both conditions (figure 8). This group consisted of highly tolerant genotypes for example KZ-181, VH-283, VH-144 and FH-142. The other genotypes which showed some degree of drought tolerance

were included CRS-456, CIM-240, MNH-886 and IR-3. Whereas, the genotypes which were located on the right side of treatment vectors indicated a maximum water loss, these included FH-1000, CRS-2007 and FH-941 which were marked as sensitive to drought stress.

Correlation study: Correlation studies under normal condition revealed that plant height and sympodial branches are significantly and positively associated with seed cotton yield and number of bolls (table 2). The number of bolls per plant was positively correlated with sympodial branches and seed cotton yield, but negatively correlated with boll weight which is obviously logical. Average boll weight presented significant and positive correlation with seed cotton yield, but negatively associated with number of bolls. Seed cotton yield was significantly and positively associated with plant height, number of sympodial branches, number of bolls and boll weight. Under drought condition, the plant height presented significant positive association with sympodial branches per plant, number of bolls, boll weight and seed cotton yield (table 3). The sympodial branches showed significant positive correlation with plant height, number of bolls, boll weight and seed cotton yield. The number of bolls showed a significant positive association with plant height, sympodial branches and seed cotton yield but negatively associated with boll weight. There were positive association of boll weight with plant height, number of sympodial branches and seed cotton yield and negatively correlated with number of bolls per plant which is logical. Seed cotton yield was significantly positively associated with plant height, sympodial branches, boll weight and bolls per plant. A negative correlation of relative water content and excised leaf water loss with the yield components was observed under both normal and drought the condition but it was statistically non-significant. The study advocated that these traits were not associated with yield related traits on the genetic basis. They did not play any significant role in enhancing seed cotton yield, but they contributed to the plants survival under water deficit condition and can be used as screening techniques in breeding drought tolerance programme.

DISCUSSIONS: The availability of two components is essential for development of drought tolerance through natural or a deliberate selection in *Gossypium hirsutum* L. Firstly, the variability in the plant trait must be present, and secondly, this variability must be controlled by a significant additive component. In the present research work, 40 cotton genotypes were screened at maturity stage in field condition under two moisture regime i.e. normal and drought condition. By comparing different traits such as plant height, number of sympodial branches, number of bolls per plant, boll weight, seed cotton yield, relative water content and excised leaf water loss drought tolerant and sensitive genotypes were selected. Data generated were compared using mean values through biplot analysis. Previous workers for example, (Kar *et al.*, 2005; Shakoore *et al.*, 2010; Iqbal *et al.*, 2011; Ademe *et al.*, 2017) had used screening of drought-tolerant and drought sensitive genotypes for morphological and physiological traits.

By comparing differences and similarities in morphological and physiological traits under two moisture stress conditions (Normal and drought condition), a significant reduction in these characters was observed.

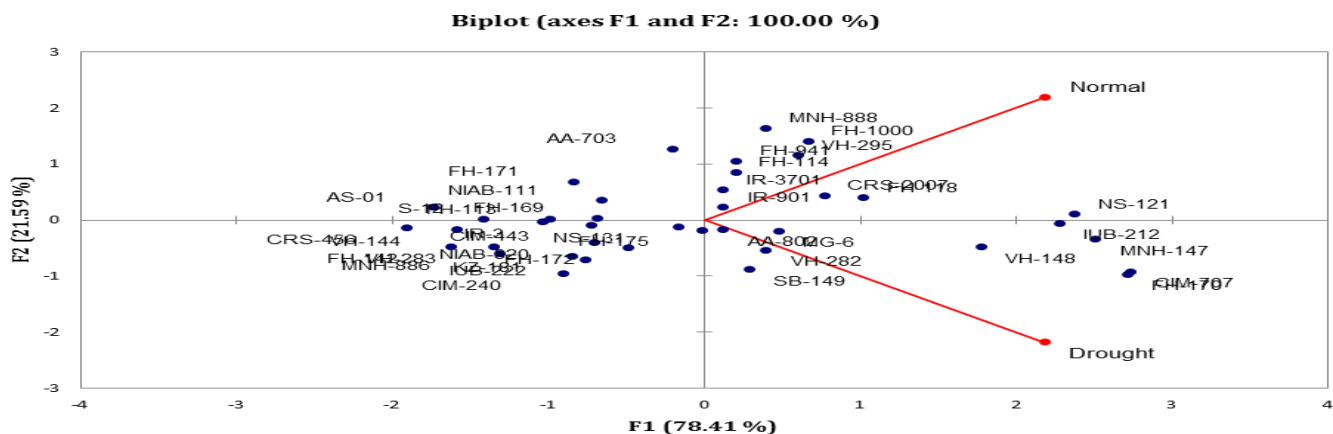


Figure 6: Biplot for seed cotton yield of forty cotton genotypes under normal and drought conditions.

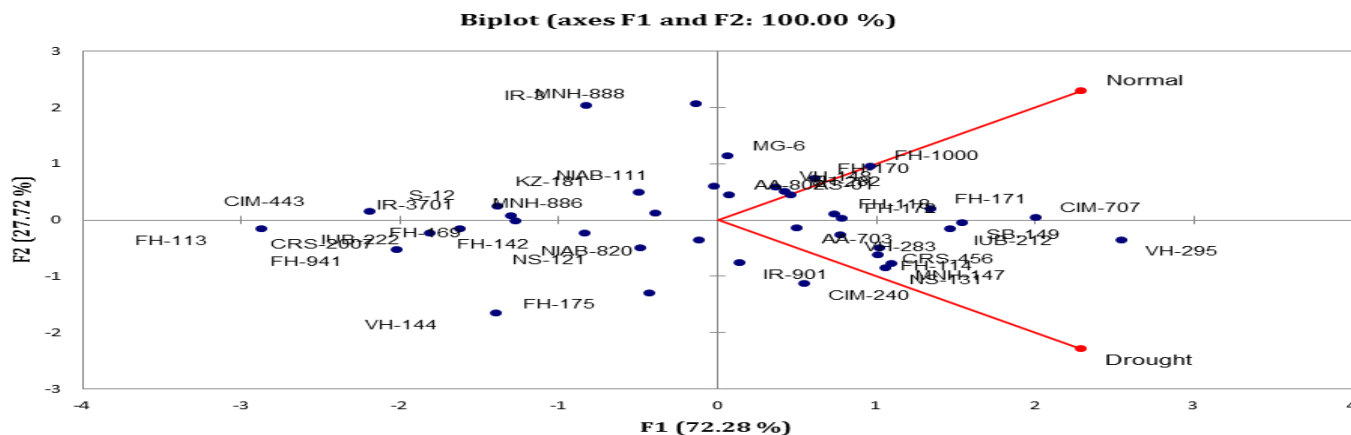


Figure 7: Biplot for relative water content of forty cotton genotypes under normal and drought conditions.

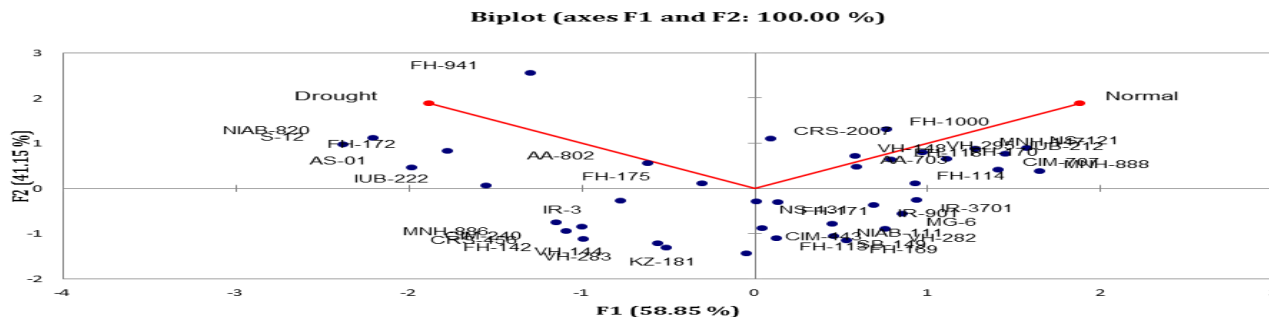


Figure 8: Biplot for excised leaf water loss of forty cotton genotypes under normal and drought conditions.

The genotypes VH-144, IUB-212, MNH-886, VH-295, IR-3701, AA-802, NIAB-111, NS-121, FH-113 and FH-142 were found as tolerant, whilst IR-3, CIM-443, FH-1000, MNH-147 and S-12 were sensitive to drought stress. It was further observed that effect of drought stress on number of bolls, boll weight and seed cotton yield was greater than that on other traits. Previously, similar responses in these traits were studied in water stressed plants of *Pennisetum glaucum* and cotton (Shakoor *et al.*, 2010; Ulloa *et al.*, 2020). Like morphological parameters, excised leaf water loss and relative water content, differentiated drought stress tolerant and sensitive genotypes. The genotypes NIAB-820, AA-703, FH-175, IUB-222 and NIAB-111 showed tolerance to drought stress which maintained high relative water content, whilst IR-3, MG-6, FH-172 and SB-149 proved to be poor retainers regarding leaf water content. Similar decrease in relative water content in wheat plants under drought stress had been reported (Matin *et al.*, 1989; Geravandi *et al.*, 2011),

Therefore, high leaf water content during water deficit conditions revealed effective screening criteria to identify drought tolerant genotypes in barley and *Triticum aestivum* (Tavakol and Pakniyat, 2007; Dabbert *et al.*, 2017). For excised leaf water loss, genotypes showing lowest values were desirable due to exhibiting minimum loss of leaf water content under drought stress. Comparison of forty cotton genotypes shown valuable information about potential of the material to withstand water deficit tolerance and allowed the identification of some drought tolerant and sensitive genotypes. Comparison of genotypes based on morpho-physiological traits suggests that they might be important source of genes for enhancing drought tolerance. In previous research related to drought tolerance in cotton, Ullah *et al.* (2019) showed great variations in material tested under normal and water deficit condition which is in according to the present study.

- R**EFERENCES: Ademe, M. S., S. He, Z. Pan, J. Sun, Q. Wang, H. Qin, J. Liu, H. Liu, J. Yang and D. Xu, 2017. Association mapping analysis of fiber yield and quality traits in upland cotton (*Gossypium hirsutum* L.). *Molecular genetics and genomics*, 292(6): 1267-1280.
- Ahmad, S., M. Iqbal, T. Muhammad, A. Mehmood, S. Ahmad and M. Hasanuzzaman, 2018. Cotton productivity enhanced through transplanting and early sowing. *Acta scientiarum. Biological sciences*, 40: e34610-e34610.
- Ahmed, H. G. M.-D., M. Sajjad, M. Li, M. A. Azmat, M. Rizwan, R. H. Maqsood and S. H. Khan, 2019. Selection criteria for drought-tolerant bread wheat genotypes at seedling stage. *Sustainability*, 11(9): 2584.
- Ahmed, H. G. M.-D., Y. Zeng, X. Yang, H. A. Anwaar, M. Z. Mansha, C. M. S. Hanif, K. Ikram, A. Ullah and S. M. S. Alghanem, 2020. Conferring drought-tolerant wheat genotypes through morpho-physiological and chlorophyll indices at seedling stage. *Saudi journal of biological sciences*, 27(8): 2116-2123.
- Ashraf, S., A. H. Sangi, Z. Y. Hassan and M. Luqman, 2018. Future of cotton sector in Pakistan: A 2025 outlook. *Pakistan journal of agricultural research*, 31(2).
- Barr, H. and P. Weatherley, 1962. A re-examination of the relative turgidity technique for estimating water deficit in leaves. *Australian journal of biological sciences*, 15(3): 413-428.
- Brito, G. G. d., V. Sofiatti, M. M. d. A. Lima, L. P. d. Carvalho and J. L. d. Silva Filho, 2011. Physiological traits for drought phenotyping in cotton. *Acta scientiarum. Agronomy*, 33(1): 117-125.
- Clarke, J. M. and T. N. Mcaig, 1982. Excised-leaf water retention capability as an indicator of drought resistance of *Triticum* genotypes. *Canadian journal of plant science*, 62(3): 571-578.
- Dabbert, T. A., D. Pauli, R. Sheetz and M. A. Gore, 2017. Influences of the combination of high temperature and water deficit on the heritabilities and correlations of agronomic and fiber quality traits in upland cotton. *Euphytica*, 213(1): 6.
- Geravandi, M., E. Farshadfar and D. Kahrizi, 2011. Evaluation of some physiological traits as indicators of drought tolerance in bread wheat genotypes. *Russian journal of plant physiology*, 58(1): 69-75.
- Iqbal, K., F. M. Azhar and I. A. Khan, 2011. Variability for drought tolerance in cotton (*Gossypium hirsutum*) and its genetic basis. *International journal of agriculture and biology*, 13(1).
- Jaleel, C. A., P. Manivannan, A. Wahid, M. Farooq, H. J. Al-Juburi, R. Somasundaram and R. Panneerselvam, 2009. Drought stress in plants: A review on morphological characteristics and pigments composition. *International journal of agriculture and biology*, 11(1): 100-105.
- Kar, M., B. Patro, C. Sahoo and B. Hota, 2005. Traits related to drought resistance in cotton hybrids. *Indian journal of plant physiology*, 10(4): 377-380.
- Khan, A., X. Pan, U. Najeeb, D. K. Y. Tan, S. Fahad, R. Zahoor and H. Luo, 2018. Coping with drought: Stress and adaptive mechanisms, and management through cultural and molecular alternatives in cotton as vital constituents for plant stress resilience and fitness. *Biological research*, 51(1): 47.
- Kirda, C., S. Topeu, H. Kaman, A. Ulger, A. Yazici, C. M and M. Derici, 2005. Grain yield response and nitrogen fertilizer recovery of corn under deficit irrigation. *Photosynthetica*, 19: 312-319.
- Mahmood, S., M. Irfan, F. Raheel and A. Hussain, 2006. Characterization of cotton (*Gossypium hirsutum* L.) varieties for growth and productivity traits under water deficit conditions. *International journal of agriculture and biology*, 17(1):11-15.
- Mammadov, J., R. Buyyarapu, S. K. Guttikonda, K. Parliament, I. Y. Abdurakhmonov and S. P. Kumpatla, 2018. Wild relatives of maize, rice, cotton, and soybean: Treasure troves for tolerance to biotic and abiotic stresses. *Frontiers in plant science*, 9: 886.
- Matin, M., J. H. Brown and H. Ferguson, 1989. Leaf water potential, relative water content, and diffusive resistance as screening techniques for drought resistance in barley. *Agronomy journal*, 81(1): 100-105.
- Prasad, P., S. Staggenborg and Z. Ristic, 2008. Impacts of drought and/or heat stress on physiological, developmental, growth, and yield processes of crop plants. Response of crops to limited water: Understanding and modeling water stress effects on plant growth processes, 1: 301-355.
- Saeed, F., J. Farooq, A. Mahmood, M. Riaz, T. Hussain and A. Majeed, 2014. Assessment of genetic diversity for cotton leaf curl virus (CLCUD), fiber quality and some morphological traits using different statistical procedures in '*Gossypium hirsutum*'L. *Australian journal of crop science*, 8(3): 442.
- Shakoor, M. S., T. A. Malik, F. M. Azhar and M. F. Saleem, 2010. Genetics of agronomic and fiber traits in upland cotton under drought stress. *International journal of agriculture and biology*, 12(4): 495-500.
- Tavakol, E. and H. Pakniyat, 2007. Evaluation of some drought resistance criteria at seedling stage in wheat (*Triticum aestivum* L.) cultivars. *Pakistan journal of biological sciences*, 10(7): 1113-1117.
- Ullah, A., H. Sun, X. Yang and X. Zhang, 2017. Drought coping strategies in cotton: Increased crop per drop. *Plant biotechnology journal*, 15(3): 271-284.
- Ullah, A., A. Shakeel, T. Malik and M. Saleem, 2019. Assessment of drought tolerance in some cotton genotypes based on drought tolerance indices. *Journal of animal and plant sciences*, 29(4): 1-9.
- Ullah, A., A. Shakeel, T.A. Malik and M.F. Saleem (2019b). Combining ability analysis of various fibre quality traits under normal and water deficit condition in cotton. *Pakistan journal of agriculture sciences*. 56(2): 359-366.
- Ulloa, M., L. M. De Santiago, A. M. Hulse-Kemp, D. M. Stelly and J. J. Burke, 2020. Enhancing upland cotton for drought resilience, productivity, and fiber quality: Comparative evaluation and genetic dissection. *Molecular genetics and genomics*, 295(1): 155-176.
- Zaidi, S. S. e. A., R. Z. Naqvi, M. Asif, S. Strickler, S. Shakir, M. Shafiq, A. M. Khan, I. Amin, B. Mishra and M. S. Mukhtar, 2020. Molecular insight into cotton leaf curl geminivirus disease resistance in cultivated cotton (*Gossypium hirsutum*). *Plant biotechnology journal*, 18(3): 691-706.

