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Evaluation of Some Egyptian cotton (*Gossypium Barbadense* L.) Genotypes to Water Stress by Using Drought Tolerance Indices

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ABSTRACT

The aim of this investigation was the ability of different indices to identifies drought resistant genotypes of cotton under normal and stress conditions. Thirteen drought tolerance indices i.e., stress susceptibility index (SSI), tolerance index (TOL), mean productivity index (MP), geometric mean productivity (GMP), stress tolerance index (STI), yield index (YI), yield stability index (YSI), drought resistance index (DI), yield reduction ratio (YR), a biotic tolerance index (ATI), stress susceptibility percentage index (SSPI), harmonic mean (HM) and golden mean (GOL) were calculated based on seed cotton yield/plant under normal (Yp) and stress (Ys) conditions for 24 cotton genotypes over the two summer seasons (2015 and 2016) at Sakha Agriculture Research Station, Agriculture Research Center, Kafr El-Sheikh, Egypt. The values of mean performances showed that, most studied genotypes were better than the grand mean during Yp and Ys. Drought stress reduced the studied traits while other was tolerant to drought, suggesting genetic variability in 24 cotton genotypes for drought tolerance. According to drought tolerance indices, MP, GMP, STI, YI and HM under Yp and Ys as well as the other studied drought tolerance indices under Ys could properly distinguish drought tolerant cotton genotypes with high yield performance. Therefore, the indices of MP, GMP, STI, YI and HM were considered as a better predictor of Ys and Yp than the other indices. Screening drought tolerant genotypes using mean performances and drought tolerance indices showed cleared that the genotypes G.94, G.86, G.96 and G.89 were the most drought tolerant under Yp and Ys. Thus, they are recommended to be used as parents for improvement of drought tolerance of cotton in breeding and hybridization programs in Egypt to produce and select a new recombination's are more and more tolerant for drought to overcome the water shortage and reduce the water rating of the cotton crop. And the possibility of planting and expansion of those new recombination's under the conditions of new lands that suffer from shortage of water and access to an economic crop. Cluster analysis based on all studied traits of 24 cotton genotypes into five and nine clusters under normal and drought stress conditions, respectively .The results for cluster analysis suggested that these genotypes could be used as a source of germplasm for breeding for drought tolerance and also cleared that the hybridization between clusters may increases variability and expected transgresive segregation to select the new germplasm had more and more drought tolerance.

Introduction

Plants have had to cope with periodic and unpredictable environmental stresses during growth and development because of their early migration from aquatic environments to the land. Surviving such stresses over a long evolutionary scale led them to acquire mechanisms by which they can sensitively perceive incoming stresses and regulate their physiology accordingly (Zhang *et al.*, 2006). In recent years, interest in crop response to environmental stresses has greatly increased because severe losses may result from heat, cold, drought and high concentrations of toxic mineral elements (Blum, 1996).

Drought is one of the most damaging abiotic stresses affecting agriculture. It is an important abiotic factor affecting the yield and yield stability of food cereals and this stress acts simultaneously on many traits leading to a decrease in yield (Boyer, 1982; Ludlow and Muchow, 1990; Teulat *et al.*, 2001; Abebe *et al.*, 2003; Zhang *et al.*, 2006). Despite the lack of understanding of drought tolerance mechanisms, physiological and molecular biological studies have documented several plant responses to drought stress (Schroeder *et al.*, 2001; Luan, 2002). Hence, improved tolerance to drought has been a goal in crop improvement programs since the dawn of agriculture, but unfortunately, success in breeding for tolerance has been limited because (I) it is controlled by many genes, and their simultaneous selection is difficult (Richards, 1996; Yeo, 1998; Flowers et al., 2000) (II) tremendous effort is required to eliminate undesirable genes that are also incorporated during breeding (Richards, 1996) and (III) there is a lack of efficient selection procedures particularly under field conditions (Ribaut *et al.*, 1997; Kirigwi *et al.*, 2004).

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Drought and heat stresses cause declines in: root growth, leaf water potential, cell membrane stability, photosynthetic rate, photochemical efficiency, as well as in carbohydrate accumulation (Howard and Watschke, 1991; Carrow, 1996; Perdomo *et al.,* 1996; Huang *et al.*, 1998; Huang and Gao, 1999; Guttieri *et al.*, 2000; Jiang and Huang, 2000). Wheat grows as a rain-fed crop in semi-arid areas, where large fluctuations occur in the amount and frequency of events from year to year and insufficient water is the primary limitation to wheat production worldwide (Ashraf and Harris, 2005). Generally, different strategies have been proposed for the selection of relative drought tolerance and resistance, so, some researchers have proposed selection under non-stress conditions (Richards, 1996; Rajaram and Van Betran *et al*., 2003), others have suggested selection in the target stress conditions (Ceccarelli and Grando, 1991; Rathjen, 1994) while, several of them have chosen the mid-way and believe in selection under both non-stress and stress conditions (Fischer and Maurer, 1978; Clarke et al., 1992; Fernandez, 1992; Byrne et al., 1995; Rajaram and Van Ginkle, 2001).

In a study on wheat (Sio-Se Mardeh *et al*., 2006), was resulted that grain yield under irrigated conditions was adversely correlated with rain-fed conditions and they stated that, a high potential yield under optimum conditions does not necessarily result in improved yield under stress conditions. Also, Blum (1996) suggested that genotypes with high yield may not be stress resistant, so increasing the yield in these genotypes may be solely due to their high potential yield, and not due to stress resistance mechanism. However, Richard believed that yield selection in the absence of drought is an effective method to improve yield in dry areas (Richard et al., 1990). This paper believe in selection under both nonstress and stress conditions so, the heritability estimates for yield are lower in the stress than nonstress conditions and genotypic variance is limited in stress conditions. In other words, stress limits the expression of genetic maximum potential.

Blum (1988) states that the rate of genetic advance through non-stress selection is usually greater. Therefore, selection based on the performance of genotypes in the stress environment performed well only in the stress conditions but selection base on the performance of genotypes in the non-stress environment may be performed well in both of conditions. Meanwhile, in this paper, “relative tolerance and resistance” phrases are used instead of “tolerance and resistance” because we believe that, generally, there is no complete tolerance and resistance to abiotic-stress. In other words, if a genotype is completely tolerant or resistant, thus, it’s yield should not change in stress and non-stress conditions significantly. In addition, there are several definitions for tolerance and resistance by different researchers (especially in above-mentioned researches). This paper states that: (I) - a genotype with the least yield changes in two conditions (related to other genotypes), is a relatively tolerant genotype, while, (II) - a genotype with a little (or with the least) yield changes (relatively stable related to other genotypes) in two conditions and high and suitable yield in both conditions is a relatively resistant genotype. Therefore, a relatively resistant genotype may be a relatively tolerant genotype while, a relatively tolerant genotype may Ginkle, 2001; or may not be a relatively resistant genotype.

Many criteria have been suggested to increase stress tolerance, particularly drought stress, in crops. However, selection of genotypes based on these criteria has generally been unsuccessful due to their higher relation with survival mechanism of crops (rather than emphasis on stability and high yield in both conditions) and because of drought relationship with many other stress factors of salt, cold, high temperature, acid, alkaline, pathological reactions, senescence, development, cell circle, UV-B damage, wounding, embryogenesis, flowering, signal transduction, etc. Therefore, drought stress is connected with almost all aspects of biology and suggestion of a suitable index for its selection is really complex and difficult.

Fernandez (1992), divided the manifestation of plants into the four groups of (I)– genotypes that express uniform superiority in NIC (group A), (II)- genotypes which perform favorably only in nonstress conditions (group B), (III)- genotypes which yield relatively higher only in stress conditions (group C) and (IV)-genotypes which perform poorly in NIC (group D).Therefore, as Fernandez stated, the best index for stress tolerance selection is one that can be able to separate group A from others .We believe the best index for RT or RR depends on the selection aims(only selection for stability without attention to high yield or selection for commercial aims with attention to stable and high yield) and the conditions of selection (the selection aim is for no irrigated or irrigated conditions). Objectives of the work reported here were: Testing of a new index (ATI) that can select group C with more emphasis on YP than SSI and TOL for identification of relative tolerant genotypes (stable yield in non-irrigated and irrigated conditions), testing of a new index (SSPI) for better understanding of yield changes and identification of relative tolerant genotypes (stable yield in no irrigated and irrigated conditions), testing of a new index for selection of relatively resistant genotypes with relatively stable and high yield in non-irrigated and irrigated conditions and a basic study on the different wheat genotypes according to these indices and a comparison between the new indices and previous ones. In this study we evaluation of some cotton genotypes for drought stress by using this drought tolerance indices to select genotypes from them to improve and use this genotypes in the breeding program to produce new combination has more drought tolerant and then we can decrease the water uses for cotton as well as we can produce economic yield from new cotton combinations.

Materials and Methods

Genetic material and field procedure

The plant materials, used in the present study were 24 genotypes belong to *Gossypium barbadense* L. Thirteen genotypes of them were foreign cotton cultivars and eleven genotypes as Egyptian cultivars. All of these genotypes and have named and origins are presented in Table 1. All genotypes were planted in two experiments conducted at Sakha Agriculture Research Station, Cotton Research Institute, Agriculture Research Center, Egypt to study the effect of water stress (drought) on growth, yield, yield components and physiological traits of Egyptian cotton plants and their performances were used during two successive summer seasons of 2015 and 2016. A randomized complete blocks design with three replications was used with one ridge in each plot. Each replication consisted of 24 plots (genotypes). The ridge was 4 meters long, 70 cm. apart and 40 cm. among hills. The hill was thinned to one plant. The usual cultural practices were followed throughout the growing seasons. Hence, the plants under non- treated plants (control–normal), were irrigated (W1) is take eight irrigates, as well as, the drought stress plants took four irrigations

Table 1. The origin for twenty four genotypes studied

Number	Genotypes	Origins	Country
1	G.89	G.75 x 6022	Egypt
2	Uzbekistan 1	--------------	Uzbekistan
3	G.85	G.67 x C.B. 58	Egypt
4	G.75	G.67 x G. 69	Egypt
5	G.94	10229 x G.86	Egypt
6	Aus.13	--------------	Australia
7	10229	---------------	Australia
8	Uzbekistan 2	--------------	Uzbekistan
9	G.89 x G. 86	G.89 x G.86	Egypt
10	G.45	G.28 x G. 7	Egypt
11	TNB	-------------	Australia
12	G. 93	G.77 x Pima S6	Egypt
13	Suvin	--------------	India
14	G.70	G.59 (A) x G. 51 (b)	Egypt
15	Aus. 12	--------------	Australia
16	BBB	--------------	Greece
17	Kar	--------------	Russia
18	Sea	--------------	Greece
19	G. 96	G.84xG70x G518xPima 62	Egypt
20	G.86	G.75 x G. 81	Egypt
21	G. 95	(G.83 x (G.75 x 5844) x G.80	Egypt
22	PimaS6	---------------	USA
23	Pima S7	---------------	USA
24	C.B. 58	---------------	USA

(W2). The same experimental design was used in the first and second season.

Traits Measurement

Data for growth, yield, yield components and physiological traits were recorded on six plants from every plot, as follows: 1) Growth traits i.e., plant height (ph. cm) and number of fruiting branches (No.F.B/P.); 2) Yield and yield components traits i.e., seed cotton yield/plant (S.C.Y./P. g), lint cotton yield/plant (L.C.Y./P. g), boll weight (B.W. g), number of bolls/plant (No.B./P.), seed index (S.I. g) and lint percentage (L %); and 3) Physiological traits i.e., chlorophyll a (Ch. a), chlorophyll b (Ch. b), carotenoids and proline concentration. The photosynthetic pigments and proline were estimated from method given by Wettestein (1957) and Bates *et al.* (1973), respectively.

Drought indices

All studied traits were calculated as the mean of all the plants across replications in the two years. Drought resistance indices based on studied traits for non-stress (Yp) and drought stress (Ys) conditions for each genotype were calculated using the formulas cited in Table 2 to discriminate genotypes on the basis of drought response in terms for all studied traits.

Results and Discussion

Mean performances

The combined mean performances for the studied traits of cotton genotypes under normal and drought conditions over the two seasons based on each trait showed the response of differed at each condition (Table 3). The studied traits in all studied genotypes had been observed to be affected by drought stress to a considerable extent. These genotypes produced the best values of the studied traits during the normal condition but some genotypes could perform well under drought stress conditions, suggesting genetic variability in these genotypes for drought tolerance. Most studied genotypes were better than the grand means for all studied traits during normal and drought conditions. The results revealed that the 24 cotton genotypes greatly differed in their

Table 2. Drought tolerance indices used for the evaluation of cotton genotypes to drought conditions.

No.	Drought tolerance indices	Equation	Reference
1	Stress susceptibility index (SSI)	$[1-(Y_s/Y_p)]/[1-(\bar{Y}_s/\bar{Y}_p)]$	Fischer and Maurer(1978)
2	Stress tolerance index (TOL)	$Y_p - Y_s$	Rosiellaand Hamblin (1981)
3	Mean productivity index (MP)	$(Y_p + Y_s)/2$	Fischer and Hamblin(1981)
4	Geometric mean productivity (GMP)	$(Y_p x Y_s)^{1/2}$	Fernandez (1993)
5	Stress tolerance index (STI)	$(Y_p x Y_s)/(\bar{Y}_p)^2$	Fernandez (1993)
6	Yield index (YI)	$Y_s/\bar{Y}_s$	Gavuzzi et al (1997)
7	Yield stability index (YSI)	Y_s/Y_p	Bouslama and Schapaugh (1984)
8	Drought resistance Index (DI)	$[Y_s x(Y_s/Y_p)]/\bar{Y}_s$	Blum (1988)
9	Yield reduction ratio (YR)	$1-(Y_S/Y_p)$	Golestani-Araghi and Assad(1998)
10	Abiotic tolerance index (ATI)	$[(Y_p - Y_s)/(\bar{Y}_p - \bar{Y}_s)]x[\sqrt{Y_p x Y_s}]$	Moosavi et al (2007)
11	Stress susceptibility percentage index (SSPI)	$[(Y_p - Y_s)/2(\bar{Y}_p)]x100$	Moosavi et al (2007)
12	Harmonic mean (HM)	$[2(Y_p x Y_s)]/(Y_p + Y_s)$	Hossain et al (1990)
13	Golden mean (GOL)	$(Y_p + Y_s)/(Y_p - Y_s)$	Moradi et al (2012)

Y_p and Y_s: seed cotton yield of each genotype under non-stress and stress conditions, respectively.

$\bar{Y}_p$ and $\bar{Y}_s$: mean seed cotton yield of all genotypes in non-stress and stress conditions, respectively.

Table 3. Mean performance comparison of various traits in cotton genotypes under normal and drought stress environments over the two growing seasons.

Traits / Genotypes	B.W		S.C.Y./P.		L.C.Y./p		L%		S.I.		No.B./P	
	Normal	Drought	Normal	Drought	Normal	Drought	Normal	Drought	Normal	Drought	Normal	Drought
G.89	3.01	2.73	145.66	86.77	57.07	31.50	39.21	36.26	10.87	8.21	48.85	32.30
Uzbekistan 1	3.40	2.89	121.41	75.47	47.27	27.04	38.94	35.83	10.87	7.20	35.80	26.32
G.85	3.07	2.78	127.96	65.34	48.54	21.96	37.90	33.58	10.13	8.13	41.75	23.57
G.75	3.00	2.76	120.13	94.51	44.92	33.07	37.31	34.93	9.79	7.79	39.98	34.26
G.94	3.15	2.21	257.23	103.54	95.86	35.47	37.22	34.23	9.98	7.52	82.38	47.40
Aus.13	3.07	2.85	107.58	85.76	41.41	30.58	38.40	35.66	10.32	8.00	35.09	30.29
10229	3.53	3.29	119.92	66.98	45.18	22.65	37.32	33.77	10.47	8.83	34.03	20.45
Uzbekistan 2	3.34	3.05	112.47	81.83	43.36	29.89	38.48	36.52	10.12	8.68	33.76	26.90
G.89 x G. 86	3.10	2.83	120.70	78.43	45.80	26.54	37.61	33.83	10.44	8.62	38.77	27.81
G.45	3.20	2.52	101.49	66.56	37.76	22.00	36.54	33.05	10.53	8.75	32.19	26.58
TNB	3.13	2.83	107.79	68.10	40.42	22.90	37.29	33.61	10.25	8.37	34.76	24.22
G. 93	3.08	2.79	119.89	48.11	44.83	16.03	36.75	33.29	10.43	8.54	38.43	17.36
Suvin	3.43	3.23	124.37	69.75	47.23	24.90	37.78	35.67	10.39	8.89	36.62	21.80
G.70	3.20	2.98	101.34	73.50	39.35	26.65	38.79	36.22	9.94	8.75	31.77	24.88
Aus. 12	3.12	2.29	137.19	85.40	53.21	31.28	38.62	36.56	10.45	8.77	43.30	37.56
BBB	3.11	2.83	113.44	76.33	42.55	26.09	37.40	34.12	10.37	8.76	36.76	27.25
Kar	3.01	2.36	120.23	88.41	45.72	31.14	37.79	35.15	10.91	8.55	40.19	37.58
Sea	3.26	2.27	136.05	78.40	52.79	28.49	38.37	35.88	10.62	9.01	40.90	34.71
G. 96	3.03	2.43	158.03	112.90	60.06	39.17	37.60	34.65	9.85	8.06	51.82	46.72
G.86	3.11	2.90	162.62	113.15	62.16	40.00	37.94	35.18	9.93	8.43	52.40	38.92
G. 95	2.95	2.23	113.69	84.44	43.39	28.78	37.90	34.06	10.37	8.25	38.68	37.92
PimaS6	3.00	2.27	103.01	63.18	39.60	22.43	38.22	35.47	9.89	8.56	34.45	27.70
Pima S7	2.92	2.38	105.67	58.86	40.24	19.51	37.55	33.11	10.31	8.59	36.17	24.71
C.B. 58	2.95	2.64	116.13	72.36	44.65	25.34	38.42	35.02	10.01	8.53	39.49	27.39
Grand Mean	3.13	2.68	127.25	79.09	48.47	27.64	37.89	34.82	10.30	8.40	40.76	30.19
LSD $_{0.05}$	0.155	0.118	21.48	12.14	8.59	4.33	0.957	0.555	0.391	0.149	7.58	4.93
LSD $_{0.01}$	0.220	0.167	30.59	17.29	12.34	6.165	1.362	0.791	0.557	0.212	10.80	7.02
	Ph.cm		**No.F.B**		**Ch. A**		**Ch.B**		**Carrot.**		**Proline**	
	Normal	Drought	Normal	Drought	Normal	Drought	Normal	Drought	Normal	Drought	Normal	Drought
G.89	182.45	149.81	22.67	16.49	2.62	2.25	2.38	2.06	1.37	1.20	4.35	6.18
Uzbekistan 1	174.91	124.91	18.17	16.11	2.63	2.16	2.81	2.19	1.30	1.17	5.30	7.20
G.85	176.79	123.68	18.75	16.14	2.81	2.26	2.14	1.80	1.93	1.41	5.09	5.80
G.75	172.55	130.15	19.02	14.49	3.33	1.81	2.28	1.68	1.46	1.19	4.26	5.98
G.94	178.76	144.03	19.51	16.49	2.99	2.64	2.80	2.37	1.33	1.13	5.15	6.30
Aus.13	164.91	146.55	17.98	13.49	2.62	2.32	2.51	2.32	1.80	1.21	4.76	6.57
10229	177.55	134.91	19.02	16.65	2.22	1.12	2.34	1.61	1.73	1.51	5.47	6.36
Uzbekistan 2	177.64	149.63	18.02	13.51	2.66	2.39	2.52	1.66	1.53	1.30	5.29	7.19
G.89 x G. 86	164.91	142.29	20.98	18.28	3.37	2.44	2.39	1.81	1.56	1.35	5.20	7.40
G.45	179.81	162.55	18.49	16.55	3.33	2.79	2.53	1.44	1.58	1.28	5.82	7.15
TNB	197.55	170.31	18.49	12.49	3.11	2.17	1.88	1.41	1.61	1.30	5.16	6.18
G. 93	187.10	168.59	19.50	14.51	2.88	2.51	1.93	1.48	1.69	1.06	4.15	6.17
Suvin	161.50	141.17	19.02	15.51	2.58	2.18	2.40	1.41	2.39	1.15	4.84	6.27
G.70	154.04	122.45	14.77	11.47	3.03	2.58	2.81	1.69	1.55	1.30	5.19	6.34
Aus. 12	174.54	156.92	20.32	15.51	2.59	2.09	2.51	1.54	1.71	1.41	4.83	5.58
BBB	177.55	157.45	16.37	14.45	3.24	2.39	2.41	1.33	1.61	1.39	5.16	6.31
Kar	167.55	127.55	16.69	14.49	3.03	2.78	2.20	1.70	1.92	1.15	5.54	6.74
Sea	185.09	141.89	18.49	13.50	2.65	2.41	2.18	1.29	1.42	1.14	5.72	6.69
G. 96	177.55	160.09	17.49	13.51	2.99	2.34	2.22	1.85	1.62	1.39	5.40	6.62
G.86	170.33	125.09	19.51	13.51	3.56	2.42	2.65	2.10	2.01	1.56	5.08	6.28
G. 95	167.36	135.07	16.97	14.26	3.57	2.13	2.44	1.76	1.84	1.25	5.09	6.60
PimaS6	176.00	137.55	20.49	11.98	3.11	2.28	2.51	1.58	2.14	1.13	5.27	6.68
Pima S7	174.91	130.19	18.98	10.51	2.75	2.47	2.46	1.20	1.96	1.35	5.54	6.40
C.B. 58	164.91	145.58	18.09	16.49	2.81	2.66	2.70	1.56	1.47	1.21	5.73	6.52
Grand Mean	174.43	142.85	18.66	14.60	2.94	2.32	2.42	1.70	1.69	1.27	5.14	6.48
LSD $_{0.05}$	3.977	5.689	0.580	0.574	0.180	0.132	0.149	0.176	0.180	0.085	0.249	0.300
LSD $_{0.01}$	5.664	8.102	0.826	0.818	0.256	0.188	0.212	0.250	0.256	0.121	0.355	0.427

responses under stress condition for all studied traits, compared with normal irrigation. These results are in good agreement with those reported by Tauqae *et al.* (2013); Iqbal *et al.* (2011) and Golestain and Assad (1998).

For boll weight (BW) among 24 genotypes, the 10229 cultivar had recorded the highest mean performance in normal and drought conditions with mean values of 3.53 and 3.29 g, respectively, while, Pima S7 and G.94 cultivars was recorded the lowest mean performance values (2.92 and 2.21g) during the normal and drought conditions, respectively. The highest values of seed cotton yield per plant (S.C.Y./P.), lint cotton yield per plant (L.C.Y./P.) and lint percentage (L.%) were observed for G.94 cultivar under the normal condition with the mean values of 257.95 g, 95.86 g and 39.21%, respectively, beside the G.86 cultivar for S.C.Y./P. (113.15 g) and L.C.Y./P (40.00 g) and the Aust. 12

cultivar for L% (36.56%) were registered the highest mean values under drought condition. Whilst, the genotypes G. 70 and G. 93 cultivars for S.C.Y./P (101.34 and 48.11 g, respectively), the genotypes G.45 and G.93 for L.C.Y./P (37.76 and 16.03 g, respectively) and the G. 45 genotype for L% (36.54 and 33.05%) gave the lowest means in normal and drought conditions. These results are agreement with those of Tauqur *et al.* (2013) and Iqbal *et al.* (2011).

For seed index (S.I), the highest mean performances for Kar. and Sea cultivars with values of 10.91 and 9.01g, however the lowest mean performances for G.75 and Uzbekistan 1 cultivars with values 9.79 and 7.20g were found under normal and drought conditions, respectively. In respect to number of bolls/plant, the genotype G.94 gave the highest mean performances with values of 82.38 and 47.40, however, the genotypes G.70 and G.93 gave the lowest mean performance with values of 31.77 and 17.36 at normal and drought conditions, respectively. Regarding to plant height (Ph.), the highest mean value by TNB genotype (197.55 and 170.31 cm) and the lowest mean values by Suvin and G.70 genotypes (161.50 and 122.45 cm) were found during non-stress and stress conditions, respectively. Highest mean performances for fruiting branches/plant were recorded by TNB genotype at normal condition and by G.89 x G.86 genotype at stress condition with values of 22.67 and 18.28, respectively. In contrast, the lowest mean performances for fruiting branches/plant were recorded by G.70 and Pima S7 cultivars with 14.77 and 10.51 under non- stress and stress conditions, respectively.

The genotypes G.95 and G.45 for chlorophyll a (Ch. a) content (3.57 and 2.79 mg/g dwt), the genotypes Uzbekistan 1 and G.94 for chlorophyll b (Ch. b) content (2.81 and 2.37 mg/g dwt), the genotypes Suvin and G. 86 (2.39 and 1.56 mg/g dwt) for carotenoids content as well as the genotypes G.45 and G.89 x G.86 (5.82 and 7.40 mg/gfwt) for proline concentration were displayed the maximum mean at normal and drought conditions, respectively. The genotypes Sea and 10229 for Ch. A content (2.65 and 1.12 mg/g dwt), the genotypes TNB and Pima S_7 for Ch. b content (1.88 and 1.20 mg/g dwt), the genotypes Uzbekistan 1 and G.94 (1.30 and 1.13 mg/g dwt) for carotenoids content as well as the G.93 and Aust.12 (4.15 and 5.58 mg/gfwt) for proline concentration were displayed the minimum mean at normal and drought conditions, respectively. These findings were in accordance with those of Nazari and Pakniyat (2010); Iqbal *et al*. (2011)and Singh *et al.* (2015).

The ranking of genotypes according to seed cotton yield and other studied traits in each year was different indicating different responses of genotypes to different levels of drought. This finding justified the utilization of stress tolerance index to describe the behavior of genotypes under stress and normal conditions (Benmahammed *et al.,* 2010). Selection based on just yield cannot be effective but selection through yield and its components has more efficiency (El-Hashash *et al.,* 2018).

Drought Tolerance indices

Drought tolerance indices i.e., SSI , TOL, MP, GMP, STI, YI, YSI , DI, YR, ATI, SSPI, HM and GO were calculated on the basis of seed cotton yield/plant for understanding 24 cotton genotypes response under normal (Yp) and stress (Ys) conditions and are presented in Table 4. Seed cotton yield/plant of 24 cotton genotypes under Yp condition had an increasing value of 37.72% than Seed cotton yield under Ys condition over the two growing summer seasons. Drought stress in this study could be considered moderate stress, therefore this results provides a good indication of a genotypic differences under random drought stress. According to Fernandez (1993) the best measure for selection under drought condition could separate genotypes which have desirable and similar yield under stress and normal conditions from other groups and also the best indices are those which have high correlation with seed cotton yield under both conditions. Selection based on a combination of indices may provide a more useful criterion for improving drought resistance of cotton. Genotypes with low tolerance indices i.e., SSI, TOL, YR, ATI and SSPI and genotypes with high tolerance indices i.e., MP, GMP, STI, YI, YSI, DI, HARM and GOL would be more tolerant.

Among 24 studied genotypes, the genotypes G.94, G.86, G.96 had highly seed cotton yield/plant under YP and YS. While, the genotypes G.45 and G.70 under Yp and the genotypes Pima S7 and G.93 under Ys were recorded the lowest seed cotton yield/plant. Other studied genotypes were moderate of seed cotton yield/plant. The genotypes Aus.13, G.75, G.95, Kar., Uzbekistan 2 and G.70 were recorded the lowest values by SSI, TOL, YR, ATI and SSPI and the highest values by YSI, indicating these genotypes were recognized as the most drought tolerant and desirable under Ys. As well as, this index had succeeded in selection of genotypes with moderate to high yield under YS. On the other hand, the highest values by SSI, TOL, YR, ATI and SSPI as well as the lowest values by YSI were found for the genotypes G.94, G.93 and G.85. These indices indicate that the genotype G. 94 had a greater seed cotton yield under Yp and Ys conditions and possible select of this genotype under to these indices to improve drought tolerant in cotton. While, the genotypes G.93 and G.85 had a greater grain yield reduction under drought stress condition and the least relative drought tolerant. According to these the drought tolerance indices, the other genotypes were identified as semi-tolerance or semi-sensitive to drought stress.

In respect to drought tolerance indices i.e., MP, GMP, STI, YI and HM, the three genotypes G.94, G.86 and G.96 had the high values of seed cotton yield/plant and considered as drought tolerance with high yield stability under the Yp and Ys conditions, thus, the selection should be done based on high rate of these drought tolerance indices. And quite the opposite, the genotypes G.93, Pima S6 and Pima S7 with the lowest values of these drought tolerance indices were considered as susceptible. By these indices, the other genotypes were identified as semi-tolerance or semi-sensitive to drought stress.

As for other indices, the two genotypes G.96 and G.86 by DI and the genotypes Aus.13, G.75, Kar. and G.95 by DI and GOL indices were found as drought tolerance with highest values of these indices and seed cotton yield under stress condition and these results also cleared that under stress conditions and the selection should be done based on high rate of these indices. While, the genotype Pima S7 by DI and the genotype G.94 by GOL and the two genotypes G.93 and G.85 by the two indices were recorded the lowest values of these indices, thus, the least relative drought tolerant.

Similar ranks for the genotypes were observed between MP, GMP, STI, YI and HM indices and between SSI, TOL, YR, ATI and SSPI and YSI indices, which suggests that these indices are equal for selecting genotypes that highly yielding under normal and drought stress conditions, and it seems that these indices had succeeded in selection genotypes with high yield under Yp and Ys conditions, these results were agreement with Koleva and Dimitrova 2018, Kardemir *et al*

Table 4. Comparison of different drought tolerance indices for cotton genotypes based on seed cotton yield per plant under normal (Yp) and drought (Ys) conditions (averaged over tow years).

Drought indices / Genotypes	Yp	Ys	SSI	TOL	MP	GMP	STI	YI	YSI	DI	YR	ATI	SSPI	HM	GOL
G.89	145.66	86.77	1.07	58.89	116.22	112.40	0.78	1.10	0.60	0.65	0.40	137.45	23.14	108.76	3.95
Uzbekistan 1	121.41	75.47	1.00	45.94	98.44	95.70	0.57	0.95	0.62	0.59	0.38	91.30	18.05	93.08	4.29
G.85	127.96	65.34	1.29	62.61	96.65	91.40	0.52	0.83	0.51	0.42	0.49	118.87	24.61	86.51	3.09
G.75	120.13	94.51	0.56	25.62	107.32	106.60	0.70	1.20	0.79	0.94	0.21	56.69	10.07	105.79	8.38
G.94	257.23	103.54	1.58	153.69	180.39	163.20	1.64	1.31	0.40	0.53	0.60	520.75	60.39	147.65	2.35
Aus.13	107.58	85.76	0.54	21.82	96.67	96.10	0.57	1.08	0.80	0.86	0.20	43.51	8.57	95.44	8.86
10229	119.92	66.98	1.17	52.95	93.45	89.60	0.50	0.85	0.56	0.47	0.44	98.52	20.80	85.95	3.53
Uzbekistan 2	112.47	81.83	0.72	30.64	97.15	95.90	0.57	1.04	0.73	0.75	0.27	61.03	12.04	94.73	6.34
G.89 x G. 86	120.70	78.43	0.93	42.27	99.57	97.30	0.58	0.99	0.65	0.64	0.35	85.39	16.61	95.08	4.71
G.45	101.49	66.56	0.91	34.93	84.02	82.20	0.42	0.84	0.66	0.55	0.34	59.60	13.72	80.39	4.81
TNB	107.79	68.10	0.97	39.69	87.94	85.70	0.45	0.86	0.63	0.54	0.37	70.59	15.60	83.46	4.43
G. 93	119.89	48.11	1.58	71.78	84.00	76.00	0.36	0.61	0.40	0.24	0.60	113.18	28.20	68.67	2.34
Suvin	124.37	69.75	1.16	54.62	97.06	93.10	0.54	0.88	0.56	0.50	0.44	105.63	21.46	89.37	3.55
G.70	101.34	73.50	0.73	27.84	87.42	86.30	0.46	0.93	0.73	0.67	0.28	49.89	10.94	85.20	6.28
Aus. 12	137.19	85.40	1.00	51.80	111.30	108.20	0.72	1.08	0.62	0.67	0.38	116.41	20.35	105.27	4.30
BBB	113.44	76.33	0.86	37.11	94.88	93.00	0.53	0.97	0.67	0.65	0.33	71.69	14.58	91.25	5.11
Kar	120.23	88.41	0.70	31.82	104.32	103.10	0.66	1.12	0.74	0.82	0.27	68.12	12.50	101.89	6.56
Sea	136.05	78.40	1.12	57.65	107.23	103.30	0.66	0.99	0.58	0.57	0.42	123.63	22.65	99.48	3.72
G. 96	158.03	112.90	0.75	45.13	135.46	133.60	1.10	1.43	0.71	1.02	0.29	125.16	17.73	131.70	6.00
G.86	162.62	113.15	0.80	49.48	137.88	135.60	1.14	1.43	0.70	1.00	0.30	139.34	19.44	133.45	5.57
G. 95	113.69	84.44	0.68	29.25	99.07	98.00	0.59	1.07	0.74	0.79	0.26	59.51	11.49	96.91	6.77
PimaS6	103.01	63.18	1.02	39.83	83.10	80.70	0.40	0.80	0.61	0.49	0.39	66.72	15.65	78.32	4.17
Pima S7	105.67	58.86	1.17	46.81	82.26	78.90	0.38	0.74	0.56	0.42	0.44	76.65	18.39	75.60	3.51
C.B. 58	116.13	72.36	1.00	43.77	94.24	91.70	0.52	0.92	0.62	0.57	0.38	83.30	17.20	89.16	4.31
Max	257.23	113.15	1.58	153.69	180.39	163.20	1.64	1.43	0.80	1.02	0.60	520.75	60.39	147.65	8.86
Min	101.34	48.11	0.54	21.82	82.26	76.00	0.36	0.61	0.40	0.24	0.20	43.51	8.57	68.67	2.34
Mean	126.45	78.75	0.97	47.70	102.60	99.36	0.63	1.00	0.63	0.64	0.37	104.59	18.74	96.28	4.91

Yp: yield under non-stress; Ys: yield under stress; SSI: susceptibility stress index; TOL: tolerance index; MP: mean productivity; GMP: geometric mean productivity; STI: stress tolerance index; YI: yield index; YSI: yield stability index; DI: drought resistance index; YR: yield reduction ratio; ATI: abiotic tolerance index; SSPI: stress susceptibility percentage index; HM: harmonic mean; GOL: golden mean.

2011 Uallah and Zafar 2006 , Mohammadi *et al* 2011, Khalili *et al* 2012 and Jafari et al 2009.

The genotypes G.94, G.86, G.96 and G.89 using MP, GMP, STI, YI and HM under Yp and Ys as well as the genotypes Aus.13, G.75, G.95 and Kar. Using the other drought tolerance indices under Ys as the most drought tolerance genotypes.

Cluster analysis

Data obtained from biochemical and yield and its components traits of twenty four cotton genotypes in both water treatments were analyzed by multivariate method using cluster analysis. Only traits that showed statistically significant G × E interactions were used, indicating that the genotypes responded differently to water treatments. Cluster analysis seemed to be an efficient method for extracting the structured relationships among genotypes and provides a hierarchical classification of these genotypes and presented in a dendrogram. Hierarchical cluster analysis for the 24 cotton genotypes under both treatments (control and drought) based on average linkage (within groups). The results from dendrogram showed that the 24 cotton genotypes classified to five and nine clusters under normal and drought stress conditions, respectively as illustrated in Table 5, Table 6 and Figures 1 and 2.

Table 6 showed the cluster mean performance of the twenty four cotton genotypes under both control and drought stress. The three clusters VI, VII and VIII comprise only one genotype Giza 94, Giza 86 and Giza 96 which represents the most important commercial varieties in Egypt showed high seed cotton / plant over the overall mean and the clusters means. Also, cluster V which had three genotypes Giza 75, Kar and Giza 95 had the same trend for higher seed cotton yield / plant over both clusters mean and overall mean. These results indicated that these new genotypes more tolerant to drought stress

Table 5. Clusters number and genotypes classification under normal and drought stress conditions for 24 cotton genotypes.

Cluster No.	Genotypes No.	Genotypes Names
Under control conditions		
I	4	PimaS6, Pima S7, Giza 45 and TNB
II	14	Uzbekistan 2, BBB, Uzbekistan 1, 10229, Giza 75, Giza 93, Giza 85, Giza 95, C.B. 58, Giza 89 x Giza 86, Kar, Suvin, Giza 70 and Aus.13
III	2	Giza 96 and Giza 86
IV	3	Aus. 12, Sea and Giza 89
V	1	Giza 94
Under drought stress		
I	8	Giza 89, Aus.13, Uzbekistan 2, Sea, Giza 89 x Giza 86, C.B. 58, BBB and Aus. 12
II	2	Giza 45 and TNB
III	1	Giza 93
IV	7	Uzbekistan 1, Giza 70, Giza 85, 10229, Suvin, Pima S6 and Pima S7
V	3	Giza 75, Kar and Giza 95
VI	1	Giza 94
VII	1	Giza 86
VIII	1	Giza 96

Table 6. Mean performance for the clusters under normal and drought stress conditions for 24 cotton genotypes

Clusters No.	BW	SCY	LY	L%	SI	NBP	Ph.	NFB	Ch A	Ch B	Carrot	Proline
Under control conditions												
I	3.06	104.49	39.51	37.40	10.25	34.39	182.07	19.11	3.08	2.35	1.82	5.45
II	3.16	117.09	44.59	37.91	10.33	37.22	170.66	18.10	2.91	2.42	1.70	5.08
III	3.07	160.33	61.11	37.77	9.89	52.11	173.94	18.50	3.28	2.44	1.82	5.24
IV	3.13	139.63	54.36	38.73	10.65	44.35	180.69	20.49	2.62	2.36	1.50	4.97
V	3.15	257.23	95.86	37.22	9.98	82.38	178.76	19.51	2.99	2.80	1.33	5.15
Clusters mean	3.11	155.75	59.08	37.81	10.22	50.09	177.22	19.14	2.97	2.47	1.63	5.18
Overall mean	3.13	127.25	48.47	37.89	10.30	40.76	174.43	18.66	2.94	2.42	1.69	5.14
Under drought stress												
I	2.69	80.66	28.71	35.48	8.57	30.53	148.77	15.22	2.37	1.70	1.28	6.56
II	2.68	67.33	22.45	33.33	8.56	25.40	166.43	14.52	2.48	1.43	1.29	6.67
III	2.88	71.44	25.22	35.21	8.03	24.92	123.68	14.57	2.33	1.89	1.29	6.45
IV	2.79	64.69	22.37	34.51	8.72	23.67	135.96	13.66	2.01	1.45	1.29	6.43
V	2.45	89.12	31.00	34.71	8.20	36.59	130.92	14.41	2.24	1.71	1.20	6.44
VI	2.21	103.54	35.47	34.23	7.52	47.40	144.03	16.49	2.64	2.37	1.13	6.30
VII	2.9	113.15	40.00	35.18	8.43	38.92	125.09	13.51	2.42	2.10	1.56	6.28
VIII	2.43	112.9	39.17	34.65	8.06	46.72	160.09	13.51	2.34	1.85	1.39	6.62
Clusters mean	2.62	85.30	29.55	34.46	8.29	33.39	146.83	14.53	2.39	1.78	1.27	6.43
Overall mean	2.68	79.09	27.64	34.82	8.41	30.19	142.85	14.60	2.32	1.70	1.27	6.48

The results for cluster analysis suggested that there is variation among the genotypes for different studied traits. Genotypes with greater similarity for biochemical and yield and its components traits were placed in the same cluster. These genotypes could be used as a source of germplasm for breeding for drought tolerance. The genetic diversity in cotton found in this study showed that these genotypes had sufficient scope for genotypic improvement through hybridization between genotypes within clusters El-Mansy, 2005, Mohammadi and Prasanna, 2003 and Abd El-Moghny et al., 2015. These divergent clusters, which are closer to each other, would not be expected to transgresive sergeant or display heterosis. Crossing between these distinct clusters may increases variability and expected transgresive sergeants.

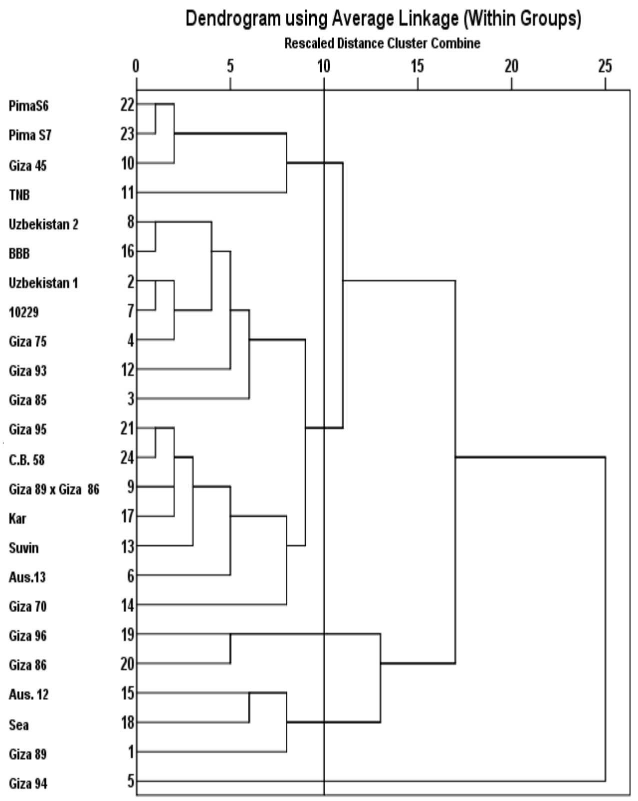

Figure 1. Dendrogram of 24 cotton genotypes resulting from cluster analysis under normal conditions

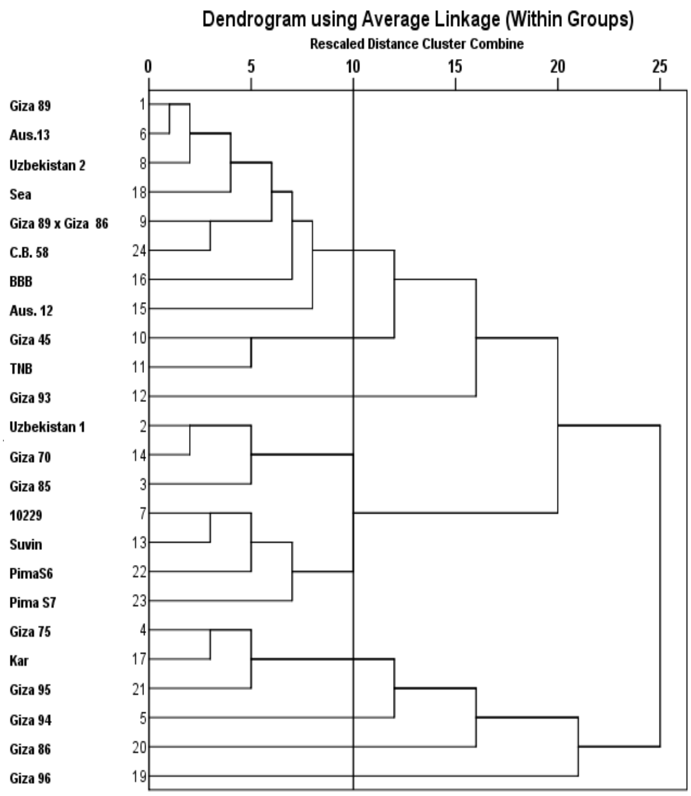

Figure 2. Dendrogram of 24 cotton genotypes resulting from cluster analysis under drought stress conditions

Conclusions

Based on drought tolerance indices it can be concluded that MP, GMP, STI, YI and HARM under Yp and Ys as well as the other studied drought tolerance indices under Ys were the best indicators of discriminate drought tolerant genotypes. During screening drought tolerant genotypes using mean performances and drought tolerance indices, the genotypes G.94, G.86, G.96 and G.89 were the most drought tolerant genotypes. Therefore they are recommended to be used as parents for improvement of drought tolerance for other cultivars cotton in Egypt.

References

Abd El-Moghny, A. M., S. Max Mariz, and H. A. Gibely Reham. (2015). Nature of Genetic Divergence among Some Cotton Genotypes. The Journal of Cotton Science 19:368–374.

Abebe, T., C. G. Arron, M. Bjorn and C.C., John. (2003). Tolerance of Mannitol-accumulating transgenic wheat to water stress and salinity. Plant Physiol.131, 1748-1755.

Araghi .S.G and M.T. Assad. (1998). Evaluation of four screening techniques for drought resistance and their relationship to yield reduction ratio in wheat. Euphytica. 103(3):293-299.

Ashraf M. and P.J.C. Harris (2005). Abiotic stresses Plant resistance through breeding and molecular Approaches, Haworth Press Inc., New York.

Bates, L. S., R. P. Waldem and I. D. Teare (1973). Rapid determination of free proline under water stress studies. Plants and Soil 39: 205- 207.

Benmahammed A., M. Kribaa, H. Bouzerzour, and A. Djekoun (2010). Assessment of stress tolerance in barley (Hordeum vulgare L.) advanced breeding lines under semi-arid conditions of the eastern high plateaus of Algeria. Euphytica.172: 383-394.

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

Blum A. (1988) .Plant breeding for stress environments. CRC Press, Boca Raton, FL. 1988; 38-78.

Boyer, J.S., (1982). Plant productivity and environments. Science 218, 443-448.

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

Byrne P.F., J. Bolanos, G.O. Edmeades, and D.L. Eaton. (1995). Gains from selection under drought versus multilocation testing in related tropical maize populations, Crop Sci. 35, 63-69.

Carrow, R.N., (1996). Drought avoidance characteristics of diverse tall fescue cultivars. Crop Sci. 36, 371–377.

Ceccarelli S. and S. Grando, (2000). Selection environment and environmental sensitivity in barley, Euphytica 57, 157-167.

Clarke, J.M., R.M. DePauw and T.F. Townley Smith, (1992). Evaluation of methods for quantification of drought tolerance in wheat. Crop Sci. 32, 723–728.

El-Hashash, E.F., R. Y.A. EL-Agoury, K.M. El-Absy and S.M.I. Sakr (2018). Genetic Parameters, Multivariate Analysis and Tolerance Indices of Rice Genotypes under Normal and Drought Stress Environments. Asian Journal of Research in Crop Science, 1(3): 1-18.

El-Mansy, Y.M. (2005). Using genetic components for predicting new combination in some cotton cresses (Gossypium barbadense L.,). Ph.D. Thesis, Fac., Agric., Mansoura Univ., Egypt.

Fernandez, G.C.J., (1992). Effective selection criteria for assessing plant stress tolerance. In: Kuo CG, ed. Adaptation of Food Crops to Temperature and Water Stress. Shanhua: Asian Vegetable Research and Development Center, Taiwan, Publ. No. 93-410, 257–270.

Fernandez, G.C. (1993). Effective selection criteria for assessing plant stress tolerance. Adaptation of food crops to temperature and water stress. 13-81992257270

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

Flowers, T.J., M.L. Koyama, S.A. Flowers, C. Sudhakar, K.P. Singh and A.R. Yeo. (2000). QTL: their place in engineering tolerance of rice to salinity. J. Exp. Bot. 51, 99-106.

Gavuzzi P,F. Rizza; M, Palumbo; R.G, Campanile; G.L, Ricciardi; and B. Borghi. (1997). Evaluation of field and laboratory predictors of drought and heat tolerance in winter cereals. Canadian Journal of Plant Science. 77(4):523-531.

Guttieri, M.J., R. Ahmad, J.C. Stark and E. Souza, (2000). End- use quality of six hard red spring wheat cultivars at different irrigation levels. Crop Sci. 40, 631–635.

Howard, H. and T.L. Watschke, (1991). Variable high-temperature among Kentucky bluegrass cultivars. Agron. J. 83, 689–693.

Huang, B., J.D. Fry and B. Wang, (1998). Water relations and canopy characteristic of tall fescue cultivars during and after drought stress. Hurt Science 33,837–840.

Huang, B. and H. GAO, (1999). Physiological responses of diverse tall fescue cultivars to drought stress. HortScience 34,897–901.

Hossain AB, Sears RG, Cox TS, Paulsen GM.(1990). Desiccation tolerance and its relationship to assimilate partitioning in winter wheat. Crop Science. 30(3):622-627.

Iqbal, K., F.M. Azhhar, I. A. Khan and Ehasan – Uallah. (2011). Variability for drought tolerance in cotton (Gossypium hirsutum) and its genetic basis. Int. J. Agric. Biol. 13: 61-66.

Jiang, Y. and B. Huang, (2000). Effects of drought or heat stress alone and in combination on Kentucky bluegrass. Crop Sci. 40, 1358–1362.

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

Kirigwi F.M., M. van Ginkel, R. Trethowan, R.G. Sears, S. Rajaram and G.M. Paulsen, (2004). Evaluation of selection strategies for wheat adaptation across water regimes, Euphytica 135, 361-371

Koleva M and V.Dimitrova (2018) .Evaluation of Drought Tolerance in New Cotton Cultivars Using Stress Tolerance Indices. AGROFOR. 3(1).11-17.

Karademir. C; K .Emine, R. Ekinci and K Berekatoğlu, (2011). Yield and fiber quality properties of cotton (Gossypium hirsutum L.) under water stress and non-stress conditions. African Journal of Biotechnology 10(59), pp. 12575-12583.

Khalili M, Naghavi MR, Pour AR, 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

Luan, S., (2002). Signaling drought in guard cells. Plant Cell Environ 25, 229–237.

Ludlow, M.M and R.C.Muchow, (1990). A critical evaluation of traits for improving crop yields in water-limited environments. Adv. Agron. 43, 107- 153.

Moradi H, Akbari GA, Khorasani SK, Ramshini HA.(2012). Evaluation of drought tolerance in corn (Zea mays L.) new hybrids with using stress tolerance indices. European Journal of Sustainable Development. 1(3):543-560.

Moosavi S.S; B. Yazdi MR, Samadi, AA, Naghavi; H, Dashti; and A. Pourshahbazi. (2007).Introduction of new indices to identify relative drought tolerance and resistance in wheat genotypes. Desert. 12(2):165-178.

Mohammadi M., R, Karimizadeh and M. Abdipour. (2011). Evaluation of drought tolerance in bread wheat genotypes under dryland and supplemental irrigation conditions. Aust. J. Crop. Sci. 5: 487–493

Mohammadi, S.A., and B.M. Prasanna. (2003). Analysis of genetic diversity in crop plants—salient statistical tools and considerations. J. Crop Sci. 43:1235–1248.

Nazari, L., and H. Pakniyat. (2010). Assessment of drought tolerance in barley genotypes. Journal of Applied Sci. 10: 151-156.

Perdomo, P., J.A. Murphy and G.A. Berkowitz. (1996). Physiological changes associated with performance of Kentucky bluegrass cultivars during summer stress. HortScience 31, 1182–1186.

Rajaram S. and M. Van Ginkle, (2001). Mexico, 50 years of international wheat breeding, Bonjean A.P., Angus W.J., (Eds.), The World Wheat Book: A History of Wheat Breeding. Lavoisier Publishing, Paris, France. 579-604.

Rathjen A.J., (1994). The biological basis of genotype × environment interaction: its definition and management. Proceedings of the Seventh Assembly of the Wheat Breeding Society of Australia, Adelaide, Australia.

Ribaut, J.M., C. Jiang, D. Gonzalez-de-leon, G.O. Edmeades and D.A Hoisington., (1997). Identification of quantitative trait loci under drought conditions in tropical maize: 2. Yield components and marker-assisted selection strategies. Theor. Appl. Genet. 94,887-896

Richard, J.S., P. Patterson and T.E. Carter. (1990). Field drought tolerance of soybean plant introduction. Crop Sci. 30, 118- 123.

Richards, R.A., (1996). Defining selection criteria to improve yield under drought. Plant Growth Regul. 20, 157-166

Rosielle .A.A and J. Hamblin. (1981). Theoretical Aspects of Selection for Yield in Stress and Non-Stress Environment 1. Crop science. 21(6):943-946.

Schroeder, J.I., J.M. Kwak and G.J. Allen,, (2001). Guard cell abscisic acid signaling and engineering drought hardiness in plants. Nature 410, 327–330.

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

Singh. C., V. I. Kumar, V. Prasad, R. Patil and B. K. Rajkumar. (2015). Response of upland cotton (G. hirsutum L.) genotypes, to drought stress using drought tolerance indices. J. Crop. Sci. Biotech. 19(1): 53-59.

Teulat, B., C. Borries and D. This. (2001). New QTLs identified for plant water status, water-soluble carbohydrate and osmotic adjustment in a barley population grown in a growth-chamber under two water regimes. Theor. Appl. Genet. 103,161-170.

Ullah I, and Y. Zafar (2006). Genotypic variation for drought tolerancein cotton (Gossypium hirsutum L.): seed cotton yield responses. Pak. J. Bot. 38:1679–1687.

Wettestein, D. V. (1957). Chlorophyll lethal under submikro shopische formweshel der plastiden. Experimental Cell. Res. 12: 527- 533.

Yue, B., L. Xiong, W. Xue, Y. Xing,L. Lijun and C. Xu. (2005). Genetic analysis for drought resistance of rice at reproductive stage in field with different types of soil. Theor. Appl. Genet. 111, 1127–1136.

Zhang, J., J. Wensuo, Y. Jianchang and M. I. Abdelbagi. (2006). Role of ABA in integrating plant responses to drought and salt stresses. Field Crops Res. 97, 111–119.