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Drought tolerance indices in cotton genotypes as affected by different irrigation regimes

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ABSTRACT

Stress assessment indices use as a suitable method for selecting drought-resistant genotypes. For this purpose, an experiment was done on 30 cotton genotypes. The experimental design was split-plot in a randomized complete blocks design with three replicates in southern Iran, during 2017 and 2018 growing seasons. The main factor was irrigation levels and the sub-factors were 30 cotton cultivars. Drought tolerance indices include stress susceptibility index (SSI), tolerance index (TOL), mean productivity (MP), geometric mean productivity (GMP), stress tolerance index (STI), yield index (YI), yield stability index (YSI), harmonic mean (HAM), sensitivity drought index (SDI), drought response index (DRI), drought resistance index (DI), relative drought index (RDI), stress susceptibility percentage index (SSPI), modified stress tolerance index (MSTI), abiotic tolerant index (ATI) and stress susceptibility percentage (SNPI) index were evaluated. Results showed seed yield under stress and non-stress conditions had a positive and significant correlation with all stress indices except SSI, SDI and DRI indices. The genotypes that are selected based on principal component analysis, have a higher yield in both stress and non-stress conditions and also show higher values for indices with positive correlation. According to three-dimensional plots, Super Elit Arian, Elit Arian, Khandagh, Sepid, Armaghan, Pak, Oltan, Opal and SB-35 genotypes were placed in zone A which had a high yield in stress and non-stress conditions. T-2, Kiza, Varamin, Dr-Omoomi, Termez-14, BK-w30 and Silend genotypes were placed in zone D in which grain yield in both stress and non-stress condition was low. These results are in agreement with results of principal component, biplot and cluster analysis. In general, it can be concluded that these genotypes have high yield under stress conditions and therefore are adapted to areas with drought stress and suitable for cultivation in the climates similar to this study.

Keywords: cluster analysis, modified stress tolerance index, principal component analysis, three-dimensional plots

INTRODUCTION

Cotton is one of the most important and valuable crops which has special economic importance in the world and also in Iran. Cotton seeds are the second largest source of protein after soybeans and the fifth largest source of oil after sunflower (Faryadras *et al.,* 2002). This plant is able to tolerate drought in areas with limited moisture in the vegetative stage and before flowering which leads to improve yield. However, moisture stress early in the season causes the buds to fall, resulting in reduced flower production and fiber yield. One way to deal with drought stress is to breed tolerant and early-maturing plants (Mohammadi *et al.,* 2010).

Because a large part of Iran is located in arid and semi-arid climates, the identification of drought-resistant genotypes is great importance in the face of this limiting factor or reducing the damage caused by it (Samsami *et al.,* 2019; Amiri *et al.,* 2015). (Islam *et al.,* 2021) reported that selection of genotypes according to yield in both stress and non-stress conditions leads to the selection of genotypes with high yield, because the accumulation of favorable alleles in the selected genotypes under drought stress at the same time leads to the selection of genotypes with maximum yield under non-stress condition.

Breeding experts believe that in order to be more efficient in breeding drought tolerant cultivars, it is necessary to identify the indicators that are effective in identifying the stability of cultivars under stress conditions and use them as selection criteria (Chimenti *et al.,* 2002; Rebetzke *et al.,* 2006). (Fernandez, 1992) divided genotypes to four groups according to their reaction to stress and non-stress conditions. Genotypes which have suitable yield on stress and non-stress condition (grope A), genotypes which have suitable yield only under non-stress (group B) and stress (group C) conditions and finally genotypes which have low yield under both stress and non-stress conditions (group D). Tolerance (TOL) has been defined as the difference between grain yield in non-stress and stress conditions and the mean productivity (MP) as the average yield of genotypes under non-stress and stress conditions (Rosielle and Hamblin, 1981). Stress susceptibility index (SSI) has been suggested for measurement of yield stability that calculates the changes in both potential and actual grain yields in variable environments (Fischer and Maurer, 1978 and Nouri *et al.,* 2011). According to Fernandez, the best standard of selection in stress environment is the one which is capable to identify group A among other groups. Also, the best indicators are those that have high correlation with grain yield in both stress and non-stress condition. (Naderi *et al.,* 2013) introduced modified stress tolerance indices (MSTI) for screening genetic material for low and high stress environmental conditions. These indicators include K2STI, K1STI. Due to very limited research on drought tolerance indices in cotton, the objective of the research was to determine the sensitivity of 30 cotton genotypes to drought stress by sixteen drought tolerant indices.

MATERIAL AND METHODS

This experiment was conducted in Haji Abad (28° 36′ N, 54° 41′ E) Fars province in southern Iran, during 2017 and 2018 growing seasons. Seeds of 30 cotton (*Gossypium hirsutum* L.) cultivars including Armaghan, Germany, Opal, Khordad, Tabela-18, Super Elit Golestan, Elit Golestan, Sahel, SB-35, Oltan, Pak, Termez-14, Super Elit Arian, Elit Arian, Kiza, T-3, Super Elit Bakhtegan, Elit Bakhtegan, BK-w30, Mehr, Varamin, Sepid, Super Okra, Barbadens, Silend, Dr-Omoomi, 817-262, T-2, Bley-zoor and Khandagh obtained from Cotton Research Institute of Iran were used in this experiment. The experimental design was split-plot in a randomized complete blocks design with three replicates. The main factor was irrigation levels including normal irrigation at every ten days as control and stopping irrigation for 30 days at the beginning of flowering stage. The sub factor was 30 cotton cultivars. Before planting, N, P_2O_5, K_2O were applied into the field. Another N was applied as top-dressed at 6-leaf stage. All genotypes were planted at the first of July and irrigated. Sampling of all treatments was done seven days after the end of cut-off irrigation. After physiological maturity stage, potential yield (Yp) and stress yield (Ys) were measured from two middle rows in each treatment. Drought indices were calculated using the following equations.

Table 1. 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)	$\mathrm{Y_p - Y_s}$	Rosielle and Hamblin (1981)
3	Mean productivity index (MP)	$(Y_p+Y_s)/2$	Rosielle and Hamblin (1981)
4	Geometric mean productivity (GMP)	$(\mathrm{Y_p x Y_s})^{1/2}$	Fernandez (1992)
5	Stress tolerance index (STI)	$(Y_p x Y_s)/(\bar{Y}_p)^2$	Fernandez (1992)
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)	$[Y_s x(Y_s/Y_p)]/\bar{Y}_s$	Lan (1998)
9	Sensitivity drought index (SDI)	$(Y_p-Y_s)/\,Y_p$	(Khalili *et al.,* 2012)
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.,* (2008)
11	Stress susceptibility percentage index (SSPI)	$[(Y_p-Y_s)/2(\bar{Y}_p)]x100$	Moosavi *et al.,* (2008)
12	Harmonic mean (HM)	$[2(Y_p x Y_s)]/(Y_p+Y_s)$	Hossain *et al.,* (1990)
13	Drought response index ($\mathrm{DRI_i}$)	$(Y_{act.i}-Y_{est.i})/\mathrm{SE\ of}-Y_{est.i})$	(Abebe *et al.,* 1998)
14	Relative drouth index (RDI)	$(Y_s/Y_p)/\,(\bar{Y}_s/\bar{Y}_p)$	(Fischer and Wood, 1979)
15	Modified stress tolerance index (MSTI)	$(\mathrm{KiSTIK1}=Y_p2/\bar{Y}_p2),\mathrm{K2}=\ (Y_s2/\bar{Y}_s2)$	(Naderi *et al.,* 2013).
16	Stress susceptibility percent index (SSPI)	$[\sqrt{(\mathrm{Yp+Ys})/(\mathrm{Yp-Ys})}]\times[\sqrt{\mathrm{Yp\times Ys\times Ys}}]$	(Moosavi *et al.,* 2008).

Ys is the yield of genotype under stress, **Yp** is the yield of genotype under irrigated conditions, $\bar{Y}_s$ and $\bar{Y}_p$ are the mean yields of all genotypes under stressed and non-stressed conditions, respectively, and $1-Y_s/Y_P$ is the stress intensity. $Y_{act.i}$, $Y_{est.i}$, and ($\mathbf{S.E.}$ of Y_{est}) are representatives of real yield in stress conditions, estimated yield calculated by regression in stress conditions, and the standard error of estimated grain yield of all genotypes, respectively.

For principal component analysis (PCA) and biplot diagram were carried out in MINITAB, three-dimensional plot of the STI with YP and YS traced by STASTICA software and cluster analysis by SPSS software.

RESULTS

Seed yield, boll yield, fibers yield and fiber percentage:

Based on the results, irrigation, genotypes and irrigation × genotypes were significant in seed yield, boll yield, fibers yield and fiber percentage at 1% probability level Table (2). Mean comparisons showed that irrigation cut-off reduced seed and boll yield by 0.83% and 0.82% compared to full irrigation, respectively Table (3). Range of changes between genotypes in seed yield at full irrigation and cut-off, was 1.51 to 3.3 and 0.11 to 0.69 $\mathrm{ton.ha^{-1}}$, respectively Table (3). At full irrigation, the range of changes in boll yield was between 1.92 to 4.58 $\mathrm{ton.ha^{-1}}$ and at irrigation cut-off reached to 0.12 to 1.06 $\mathrm{ton.ha^{-1}}$ Table (3). Changes in fiber yield at full irrigation level between cultivars were 1.09 tons per hectare, but these changes reached up to 0.27 tons per hectare during irrigation cut-off Table (3). At full irrigation, the range of fiber percentage changes was 11.57% and at irrigation cut-off was 21.99%.

Stress Indices:

Yield of cotton genotypes under drought and non-stress conditions with all stress indicators are shown in Tables (4 and 5). Results show that Super Elite Arian, Elite Arian, Armaghan, Khandagh, Opal, Spied, Pak, Oltan, SB-35 genotypes had 4.2 $\mathrm{ton.h^{-1}}$ or more yields under non-stress condition. The yield of genotypes Termez-14, Kisa, Tabela-18, Germany, Varamin, Silend and BK-w30 was less than 2.3 $\mathrm{ton.h^{-1}}$ under non-stress condition. Under drought stress condition, yield of Elite Arian, spied genotypes was higher than 1 $\mathrm{ton.h^{-1}}$ and that of T-2, Termez-14 and Kisa genotypes was less than 250 Kg $\mathrm{h^{-1}}$ Table (4). According to MP,GMP, HMP, STI and YI indices, which high values are indicative of more tolerance to drought stress, Super Elite Arian, Elit Arian, Khandagh, Sepid, Armaghan, Oltan, Opal, SB-35 and Pak were more tolerant and Dr-Omoomi, BK.w30, Termez-14, Silend, Tabela-18 and Varamin genotypes were sensitive to drought stress (Table 4). According to TOL and SSI indices, which low values means more tolerance to drought stress, and YSI index, which show upper tolerance limit, resistant genotypes were detected. According to TOL, Silend, Mehr, Germany, Varamin, Termez-14, and BK-w30 genotypes were more resistant while according to SSI, Germany, Super Elit Bakhteghan, Elit Arian,Khandagh, Varamin, Sahel, Sepid, Armaghan, Pak,Oltan, and 817-262 genotypes showed the best tolerance. According to YSI index, the more resistant genotypes to drought stress were Germany, Elit Golestan, Super Elit Arian, Khandagh, Sepid, Armaghan, Pak, Oltan, Opal and 817-262 Table

(4). Evaluation by TOL and SSI some genotypes such as Arian Super Elite, Elite Arian, Khandagh and Sepid were susceptible to stress condition (Table 4). In contrast, these cultivars were resistant to drought stress using by the MP, GMP, STI, HMP and YI Table (4). TOL index shows the variations due to stress conditions and its numerical value decreases as the variations of a genotype yield under stress becomes less. Therefore, a low value of TOL index is not necessarily an indicative of high yield of the genotypes in normal conditions. Low TOL might be the result of low yield of the genotype in normal conditions and a small variation under stress conditions (Moghadam and Hadizadeh, 2002; Bahrani *et al.,* 2013). It has been reported that MP, GMP and STI index were more successful indices for the selection of genotypes resistant to drought stress (Shafazadeh *et al.,* 2004 and Sadeghzadeh Ahary *et al.,* 2006). According to SDI, SSPI, ATI and SNPI indices, Elite Arian, Super Elite Arian, khandagh, Speid, Armaghan, Pak, Olten, opal, and S-B-35 genotypes had the highest tolerance to drought stress Table (5). According to RDI and DI indices Elite Arian, Super Elite Arian, khandagh, Speid, Armaghan, Pak, Olten, opal, SS-B -35, T-3 and 262-817 genotypes were the most resistant to drought stress Table (5). The DRI index was negative for all cotton genotypes. The value of DRI for Elite Arian, Super Elite Arian, khandagh, Sepid, Armaghan, Pak, Olten and Opal genotypes was more negative compared to others. Difference of yield in genotypes resistant to drought stress was more than 4 ton.h^{-1}. Since the average of yield for these genotypes was large, the DRI index became negative for all genotypes such that more resistant cultivars had more negative values Table (5). The studies of wheat genotypes (Amiri *et al.,* 2014; Cattivelli *et al.,* 2008) showed resistant genotypes had positive DRI index due to their large yield under normal and stress conditions and small averages, which is the inverse condition as we have in this study Table (5). Based on (MSTI P) and (MSTI T) indices, Elite Arian, Super Elite Arian, Khandagh, Sepid, Armaghan, Pak, Oltan, Opal and S-B-35 genotypes had more resistance to drought stress Table (5).

Table 2. Mean squarer of studied traits

Sources of variations	df	Seed Yield	boll Yield	fibers Yield	Fiber percent
Replication	2	8.542865	0.854516	6.2174422	19277.48208
Drought stress	1	145.0629339	320.8619129	34.43562722	654.90198
Error a	2	4.8678039	0.4088319	5.07563556	295.77328
Genotypes	26	0.8854958	2.0838944	0.2792748	61.12996
Genotypes × Drought stress	26	0.3137626	0.61377727	0.07128584	40.54336
Error b	116	0.035277	0.0017192	0.03656073	21.94806
Total	179	1.17740164	2.24480692	0.43325647	253.049973
CV		14.88	2.15	28.74	13.15

Table 3. Interaction between genotypes and drought in studied traits

Genotypes	Seed Yield		Boll Yield		Fibers Yield		Fiber percent	
	Irrigated	Cut-off Irrigation	Irrigated	Cut-off Irrigation	Irrigated	Cut-off Irrigation	Irrigated	Cut-off Irrigation
Germany	1.47 g	0.21 i	2.22 l	0.38 t-x	0.75 e-q	0.16 o-r	36.6 a-h	43.91 a
Super Elit Golestan	2.23 b-e	0.34 i	3.61 e	0.56q-s	1.28 a-h	0.22 n-r	35.37 a-h	39.3 a-f
Elit Golestan	2.49 a-d	0.38 i	3.34 f	0.6 qr	0.95 c-m	0.22 n-r	37.56 g-i	37.09 a-h
Super Elit Arian	2.79 a-c	0.59 hi	4.4 b-d	0.97op	1.61 a-c	0.38 k-r	36.35 a-h	39.44 a-f
Super Elit Bakhteghan	2.27 c-e	0.4 i	3.43 f	0.59 q-s	1.17 a-i	0.18 n-r	33.84 a-h	31.08 c-h
Elit Bakhteghan	2.49 a-d	0.39 i	3.67 e	0.63 q	1.18 a-h	0.25 m-r	33.07 b-h	39.13 a-f
T2	1.69 e-g	0.13 i	2.52 jk	0.24 x-z	0.83 d-o	0.1 p-r	32.81 a-h	43.43 a
Elit Arian	3.03 a	0.65 hi	4.47 a-c	1.08 no	1.44 a-c	0.43 j-r	32.18 b-h	39.73 a-e
Khandagh	2.28 a-c	0.55 i	4.25 d	0.91 p	1.37 a-f	0.37 k-r	32.15 b-h	40.12 a-e
Varamin	1.39 g	0.17 i	2.26 l	0.28 w-z	0.87 d-n	0.11 p-r	38.07 a-g	39.49 a-f
Tabela 18	1.48 g	0.1 i	2.12 l	0.12 z	0.64 h-r	0.02 r	30.27 e-h	20.92 i
Sahel	2.26 c-e	0.37 i	3.33 fg	0.59 q-s	1.07 a-j	0.22 n-r	31.99 b-h	37.39 a-h
Sepid	3.03 a	0.69 hi	4.4 b-d	1.16 n	1.38 a-f	0.47 i-r	31.18 c-h	40.18 a-e
Mehr	1.68 e-g	0.29 i	2.77 i	0.46 q-u	1.09 a-j	0.17 n-r	39.13 a-f	36 a-h
Silend	1.53 fg	0.18 i	2.15 l	0.31 u-y	0.62 h-r	0.13 o-r	28.97 f-h	42.06 ab
Armagan	2.76 a-c	0.57 hi	4.47 a-c	0.97 op	1.71 a	0.4 k-r	37.98 a-g	40.39 a-e
Pak	2.96 ab	0.5 i	4.36 cd	0.85 p	1.4 a-f	0.35 l-r	32.14 b-h	41.38 a-d
Oltan	2.73a-c	0.51 i	4.43 a-c	0.87 p	1.7 ab	0.37 k-r	38.16 a-g	41.63 a-c
Opal	3.1 a	0.54 i	4.58 a	0.88 p	1.48 a-d	0.34 l-r	32.15 b-h	38.13 a-g
817-262	1.99 de	0.48 i	3 h	0.82 p	1.01 b-l	0.33 l-r	33.69 a-h	40.73 a-e
Super Okra	1.81e-g	0.31 i	2.75 i	0.45 r-v	0.93 c-m	0.14 or	32.82 a-h	30.72 d-h
Khordad	2d-f	0.37 i	3.32 g	0.59 q-s	1.23 a-h	0.23 n-r	37.86 a-h	38.07 a-g
T3	2 d-f	0.43 i	3.04 h	0.63 q	1.04 a-l	0.2 n-r	34.05 a-h	31.96 b-h
Bly-Ayzvar	2 d-f	0.3 i	2.95 h	0.48 q-t	0.95 c-m	0.18 n-r	32 b-h	37.25 a-h
Termez-14	1.19 gh	0.11 i	1.92 m	0.17 yz	0.73g-r	0.07 qr	37.78 a-h	37.38 a-h
Kiza	1.51 fg	0.16 i	2.29 kl	0.25 w-z	0.78 d-p	0.09 p-r	34.01 a-h	36.62 a-h
SB35	3.11 a	0.51 i	4.54 ab	0.86 p	1.42 a-f	0.35 l-r	31.35 c-h	40.39 a-e
Barbadence	1.8 e-g	0.31 i	2.58 j	0.42 s-w	0.79 d-p	0.11 p-r	30.44 e-h	27.4 hi
Bk-w30	1.51 fg	0.2 i	2.22 l	0.3 u-y	0.71 g-r	0.1 p-r	32.18 b-h	32.99 a-h
DR-Omoomi	1.51 fg	0.17 i	2.44 jk	0.29 v-z	0.93 c-m	0.12 o-r	37.91 a-h	42.26 ab

Table 4. Indicators of stress tolerance and yield of cotton cultivars under stress and non-stress condition

Genotype	Yield P	Yield S	TOL	SSI	MP	GMP	STI	YI	YSI	HM
Germany	2.2200	0.3767	1.6300	1.0137	1.4050	1.1445	0.1231	0.6384	0.2658	0.9322
Super Elit Golestan	3.6067	0.5600	3.0500	1.0313	2.0833	1.4212	0.1898	0.9492	0.1553	0.9695
Elit Golestan	3.4433	0.6033	2.8400	1.0069	2.0233	1.4413	0.1952	1.0226	0.1752	1.0268
Super Elit Arian	4.4033	0.9700	3.4300	0.9519	2.6867	2.0667	0.4014	1.6441	0.2203	1.5898
Super Elit Bakhteghan	3.4333	0.5933	2.8400	1.0098	2.0133	1.4273	0.1914	1.0056	0.1728	1.0118
Elit Bakhteghan	3.6733	0.6333	3.0400	1.0103	2.1533	1.5253	0.2186	1.0734	0.1724	1.0804
T2	2.5200	0.2367	2.2800	1.1062	1.3783	0.7723	0.0560	0.4011	0.0939	0.4327
Elit Arian	4.4700	1.0767	3.3900	0.9268	2.7733	2.1938	0.4523	1.8249	0.2409	1.7353
Khandagh	4.2500	0.9133	3.3400	0.9585	2.5817	1.9702	0.3648	1.5480	0.2149	1.5036
Varamin	2.2600	0.2800	1.9800	1.0696	1.2700	0.7955	0.0595	0.4746	0.1239	0.4983
Tabela 18	2.1233	0.1233	2.0000	1.1499	1.1233	0.5117	0.0246	0.2090	0.0581	0.2331
Sahel	3.3267	0.5933	2.7300	1.0031	1.9600	1.4049	0.1855	1.0056	0.1784	1.0071
Sepid	4.4033	1.1633	3.2400	0.8983	2.7833	2.2633	0.4814	1.9718	0.2642	1.8404
Mehr	2.7667	0.4633	2.3000	1.0164	1.6150	1.1322	0.1205	0.7853	0.1675	0.7937
Silend	2.1533	0.3100	1.8400	1.0451	1.2317	0.8170	0.0627	0.5254	0.1440	0.5420
Armagan	4.4700	0.9700	3.5000	0.9559	2.7200	2.0823	0.4075	1.6441	0.2170	1.5941
Pak	4.3633	0.8500	3.5100	0.9830	2.6067	1.9258	0.3486	1.4407	0.1948	1.4228
Oltan	4.4333	0.8733	3.5600	0.9803	2.6533	1.9677	0.3639	1.4802	0.1970	1.4592
Opal	4.5767	0.8833	3.6900	0.9852	2.7300	2.0107	0.3799	1.4972	0.1930	1.4809
817-262	3.0033	0.8167	2.1900	0.8888	1.9100	1.5661	0.2305	1.3842	0.2719	1.2841
Super Okra	2.7467	0.4533	2.2900	1.0193	1.6000	1.1159	0.1170	0.7684	0.1650	0.7782
Khordad	3.2300	0.5933	2.6400	0.9966	1.9117	1.3844	0.1801	1.0056	0.1837	1.0025
T3	3.0367	0.6333	2.4000	0.9662	1.8350	1.3868	0.1807	1.0734	0.2086	1.0481
Bly-Ayzvar	2.9500	0.4833	2.4700	1.0208	1.7167	1.1941	0.1340	0.8192	0.1638	0.8306
Termez-14	1.9167	0.1733	1.7400	1.1104	1.0450	0.5764	0.0312	0.2938	0.0904	0.3179
Kiza	2.2933	0.2500	2.0400	1.0877	1.2717	0.7572	0.0539	0.4237	0.1090	0.4509
SB35	4.5377	0.8633	3.6700	0.9885	2.7005	1.9793	0.3682	1.4633	0.1903	1.4507
Barbadence	2.5833	0.4200	2.1600	1.0223	1.5017	1.0416	0.1020	0.7119	0.1626	0.7225
Bk-w30	2.2200	0.3000	1.9200	1.0558	1.2600	0.8161	0.0626	0.5085	0.1351	0.5286
DR-Omoomi	2.4433	0.2900	2.1500	1.0759	1.3667	0.8418	0.0666	0.4915	0.1187	0.5185

Ys= Stress yield, Yp= Potential yield, TOL= Stress tolerance index, SSI= Stress susceptibility index, MP= Mean productivity index, GMP= Geometric mean productivity, STI= Stress tolerance index, YI= Yield index, YSI= Yield stability index, HM= Harmonic mean.

Table 5. Indicators of stress tolerance and yield of cotton cultivars under stress and non-stress condition

Genotypes	SDI	DI	RDI	SSPI	MSTI P	MSTI S	ATI	SSPI	DRI
Germany	0.7342	0.0481	0.9381	24.9847	0.0570	0.0502	0.3049	1.4409	-0.6689
Super Elit Golestan	0.8447	0.0267	0.8584	46.6994	0.2320	0.1710	0.7831	2.9946	-0.9320
Elit Golestan	0.8248	0.0324	0.9687	43.5316	0.2175	0.2042	0.7404	3.0810	-0.8637
Super Elit Arian	0.7797	0.0655	1.2179	52.6262	0.7314	1.0850	1.2834	5.7207	-1.0394
Super Elit Bakhteghan	0.8272	0.0314	0.9555	43.5316	0.2121	0.1936	0.7332	3.0288	-0.9020
Elit Bakhteghan	0.8276	0.0335	0.9532	46.5972	0.2773	0.2519	0.8387	3.3829	-0.9356
T2	0.9061	0.0068	0.5192	34.9990	0.0335	0.0090	0.3189	1.0900	-0.7856
Elit Arian	0.7591	0.0795	1.3317	52.0131	0.8493	1.5062	1.3464	6.3872	-1.0940
Khandagh	0.7851	0.0602	1.1882	51.1445	0.6192	0.8742	1.1890	5.2688	-1.0071
Varamin	0.8761	0.0106	0.6850	30.3495	0.0285	0.0134	0.2849	1.1361	-0.6248
Tabela 18	0.9419	0.0022	0.3211	30.6560	0.0104	0.0011	0.1851	0.5679	-0.6413
Sahel	0.8216	0.0324	0.9861	41.8966	0.1929	0.1876	0.6946	2.9552	-0.9161
Sepid	0.7358	0.0942	1.4607	49.6628	0.8772	1.8716	1.3263	6.8204	-1.0514
Mehr	0.8325	0.0238	0.9259	35.3055	0.0867	0.0743	0.4717	2.0559	-0.7857
Silend	0.8560	0.0137	0.7959	28.2546	0.0273	0.0173	0.2724	1.1883	-0.6689
Armagan	0.7830	0.0645	1.1998	53.6481	0.7652	1.1014	1.3182	5.7835	-1.1291

Contioued Table 5									
Pak	0.8052	0.0508	1.0770	53.8524	0.6236	0.7234	1.2238	5.0284	-1.1273
Oltan	0.8030	0.0527	1.0891	54.5677	0.6721	0.7973	1.2670	5.2164	-1.1348
Opal	0.8070	0.0523	1.0671	56.6115	0.7479	0.8516	1.3431	5.3991	-1.1828
817-262	0.7281	0.0681	1.5034	33.5173	0.1954	0.4416	0.6194	3.7099	-0.6877
Super Okra	0.8350	0.0229	0.9125	35.1523	0.0830	0.0691	0.4629	2.0054	-0.7282
Khordad	0.8163	0.0334	1.0156	40.4149	0.1766	0.1821	0.6602	2.8886	-0.8838
T3	0.7914	0.0405	1.1531	36.8383	0.1566	0.2083	0.6028	2.9261	-0.7533
Bly-Ayzvar	0.8362	0.0243	0.9059	37.8091	0.1096	0.0899	0.5327	2.2445	-0.7654
Termez-14	0.9096	0.0048	0.5000	26.7218	0.0108	0.0027	0.1817	0.6706	-0.5371
Kiza	0.8910	0.0084	0.6027	31.3203	0.0266	0.0097	0.2798	1.0489	-0.6150
SB35	0.8097	0.0504	1.0519	56.3203	0.7124	0.7883	1.3154	5.2539	-1.1611
Barbadence	0.8374	0.0209	0.8989	33.1596	0.0640	0.0517	0.4076	1.7870	-0.6538
Bk-w30	0.8649	0.0124	0.7471	29.4298	0.0290	0.0162	0.2834	1.1853	-0.5698
DR-Omoomi	0.8813	0.0106	0.6562	33.0063	0.0374	0.0161	0.3278	1.2491	-0.6237

SDI= Sensitivity drought index, DI= Drought resistance Index, RDI= Relative drouth index, SSPI= Stress susceptibility percentage index, MSTI= Modified stress tolerance index, ATI= Abiotic tolerance index, SSPI= Stress susceptibility percent index, DRI= Drought response index.

Correlation Coefficient

The researchers believe that the best indicator of drought tolerance is the indices which has high correlation with grain yield under both stress and non-stress conditions (Fernandez, 1992). The results of the correlations among drought tolerance indices are shown in Table (6). The correlation between yield under stress and non-stress conditions was significant at 1 percent probability level with value of 0.94 (Table 6). (Haghjoo and Bahrani, 2015) and (Tabib Loghmani *et al.,* 2019), reported seed yield had positive and significant correlation under stress and non-stress condition. Seed yield under stress and non-stress condition had positive and significant correlation with all stress indices expect SSI, SDI and DRI indices Table (6). (Sadeghzadeh Ahari, 2006) found that grain yield had positive and significantly correlation under drought stress and non-stress conditions with STI, GMP and MP index. (Amiri *et al.,* 2014) also reported that grain yield had positive and significant correlation with STI, GMP, MP, SSI, TOL, YI, YSI, SDI, SSPI, KSTI P and KSTI S indices.

Table 6. The correlation coefficients between traits

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Yield P	1	1																		
Yield S	2	0.94**	1																	
TOL	3	0.98**	0.87**	1																
SSI	4	-0.73**	-0.91**	-0.61**	1															
MP	5	1**	0.96**	0.96**	-0.79**	1														
GMP	6	0.97**	0.99**	0.91**	-0.87**	0.99**	1													
STI	7	0.96**	0.98**	0.91**	-0.82**	0.98**	0.99**	1												
YI	8	0.94**	1**	0.87**	-0.91**	0.97**	0.99**	0.98**	1											
YSI	9	0.62**	0.81**	0.48**	-0.94**	0.69**	0.79**	0.74**	0.81**	1										
HAM	10	0.94**	0.99**	0.86**	-0.91**	0.97**	0.99**	0.98**	0.99**	0.84**	1									
SDI	11	-0.62**	-0.81	-0.48**	0.94**	-0.69**	-0.79**	-0.74**	-0.81**	-1**	-0.84**	1								
DI	12	0.81**	0.95**	0.7**	-0.93**	0.86**	0.93**	0.93**	0.95**	0.91**	0.96**	-0.91**	1							
RDI	13	0.73**	0.91**	0.61**	-1**	0.79**	0.87**	0.82**	0.91**	0.94**	0.91**	-0.94**	0.93**	1						
SSPI	14	0.98**	0.87**	1**	-0.61**	0.96**	0.91**	0.9**	0.87**	0.48**	0.86**	-0.48**	0.7**	0.61**	1					
MSTI P	15	0.95**	0.93**	0.91**	-0.71**	0.96**	0.94**	0.98**	0.93**	0.62**	0.93**	-0.62**	0.86**	0.71**	0.91**	1				
MSTIS	16	0.84**	0.91**	0.77**	-0.75**	0.87**	0.89**	0.94**	0.91**	0.66**	0.9**	-0.66**	0.9**	0.75**	0.77**	0.95**	1			
ATI	17	0.99**	0.95**	0.97**	-0.75**	0.99**	0.98**	0.98**	0.95**	0.65**	0.95**	-0.65**	0.85**	0.75**	0.97**	0.98**	0.89**	1		
SNPI	18	0.97**	0.99**	0.91**	-0.84**	0.98**	0.99**	1**	0.99**	0.73**	0.98**	-0.73**	0.92**	0.84**	0.91**	0.97**	0.94**	0.98**	1	
DRI	19	-0.97**	-0.87**	-0.98**	0.63**	-0.96**	-0.92**	-0.91**	-0.87**	-0.54**	-0.88**	0.54**	-0.73**	-0.63**	-0.98**	-0.91**	-0.78**	-0.96**	-0.91**	1

Ys= Stress yield, Yp= Potential yield, TOL= Stress tolerance index, SSI= Stress susceptibility index, MP= Mean productivity index, GMP= Geometric mean productivity, STI= Stress tolerance index, YI= Yield index, YSI= Yield stability index, HM= Harmonic mean, SDI= Sensitivity drought index, DI= Drought resistance Index, RDI= Relative drouth index, SSPI= Stress susceptibility percentage index, MSTI= Modified stress tolerance index, ATI= Abiotic tolerance index, SSPI= Stress susceptibility percent index, DRI= Drought response index.

Principal Component Analysis

To investigate the relationship between genotypes and stress tolerance indices, principal component analysis was conducted using data for stress index and yield Tables (7 and 8). About 97 percent of the total variation of data can be explained by first two main components. Therefore, biplot were drawn based on these two components. The first principal component which justified 87.4 percent of total variance, had high positive and significant correlation with yield under both stress and non-stress conditions, and all stress indices except for SDI, SSI and the DRI Tables (7 and 8). This component is therefore named as yield potential and drought tolerance. The genotypes that are selected based on this component, have higher yield in both stress and non-stress conditions and also show higher values for indices with positive correlation. The second component expressed 12.6 percent of total data variation and had negative correlation with yield under drought stress (YS), indices such as YSI, DRI, DI, YI and HAM Tables (7 and 8) and positive correlation with others. Genotypes selected based on this component, had low yield under stress and non-stress conditions; i.e. sensitive genotypes. According to the first and the second main components Figure (1, 2 and 3) genotypes were divided into different groups based on their yield and drought tolerance. Genotypes including Elit Arian, Super Elit Arian, Khandagh, Sepid, Armaghan, Oltan, Opal and SB-35 were placed in high potential, low sensitivity to drought stress zone and near the important drought tolerance indices. It can be concluded that these genotypes have high yield under stress condition and therefore are adapted to areas with drought stress. Genotypes T-2, Kiza,Varamin, Dr-Omoomi, Termez-14, BK-w30 and Silend were placed in low potential zone under drought stress and near the sensitive drought indices such as SSI. These genotypes have low yield under stress and non-stress condition Figure (1, 2 and 3).

Table 7. Principal component (PC) analysis based on grain yield and stress tolerance indicators

PC	EV	Variance%	Yield P	Yield S	TOL	SSI	MP	GMP	STI	YI	YSI	HAM
1	16.61	87.4	0.25	0.24	0.22	-0.22	0.24	0.25	0.24	0.24	0.2	0.24
2	1.86	12.6	0.2	-0.04	0.31	0.31	0.13	0.02	0.06	-0.4	-0.42	-0.06

Table 8. continue- Principal component (PC) analysis based on grain yield and stress tolerance indicators

PC	EV	Variance%	SDI	DI	RDI	SSPI	MSTI P	MSTIS	ATI	SNPI	DRI
1	16.61	87.4	-0.2	0.23	0.22	0.22	0.23	0.22	0.24	0.24	-0.22
2	1.86	12.6	0.42	-0.21	0.32	0.31	0.15	0.3	0.17	0.06	-0.27

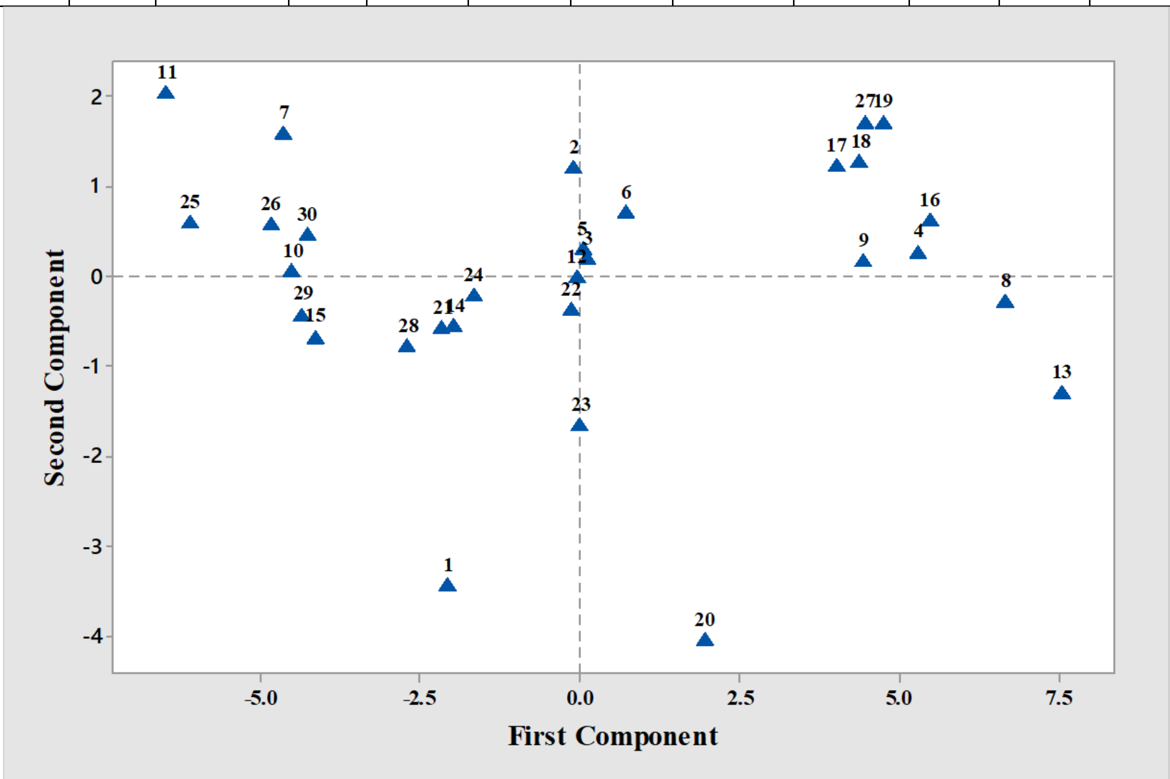

Fig. 1. Biplot of first and second components of thirty cotton genotypes

1=Germany, 2- Super Elit Golestan, 3= Elit Golestan, 4= Super Elit Arian, 5= Super Elit Bakhteghan, 6= Elit Bakhteghan, 7= T2, 8= Elit Arian, 9= Khandagh, 10= Varamin, 11= Tabela-18, 12= Sahel, 13= Sepid, 14= Mehr, 15= Silend, 16= Armagan, 17= Pak, 18= Oltan, 19= Opal, 20=817-262, 21= Super Okra, 22= Khordad, 23= T3, 24= Bly-Ayzvar, 25= Termez-14, 26= Kiza, 27= SB35, 28= Barbadence, 29= Bk-w30, 30= DR-Omoomi

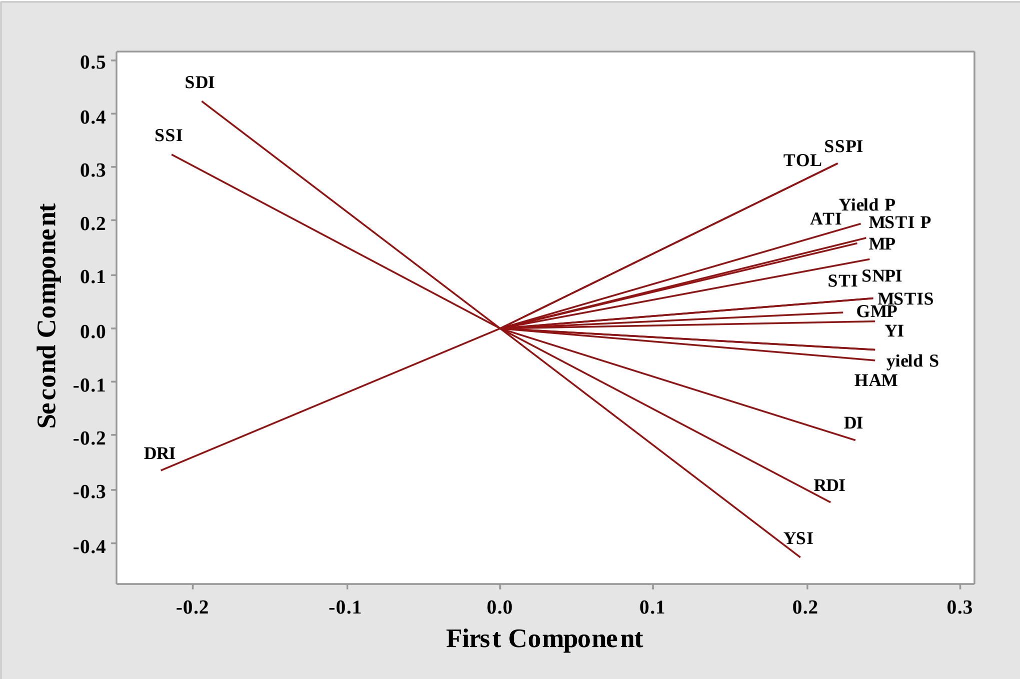

Fig. 2. Biplot of first and second components of drought stress tolerance indicators

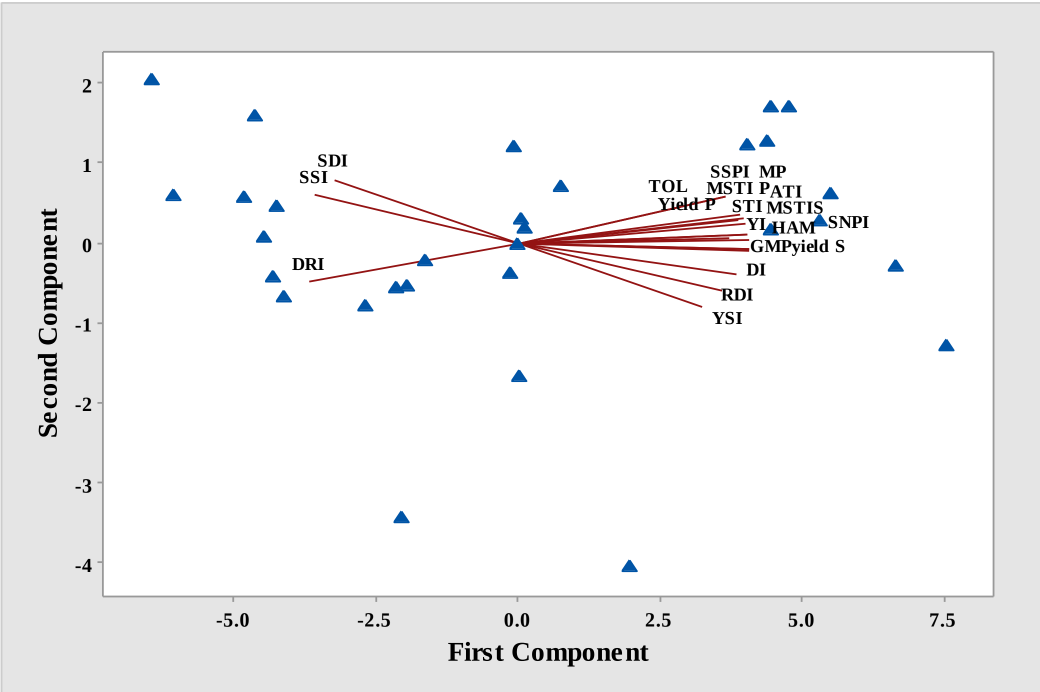

Fig. 3. Biplot of first and second components of thirty cotton genotypes and drought stress tolerance indicators

Three-Dimensional Plots

According to high correlation between indices such as MP, GMP, HMP and STI the three-dimensional plots of the STI with YP and YS were studied Figure (4). Super Elit Arian, Elit Arian, Khandagh, Sepid, Armaghan, Pak, Oltan, Opal and SB-35 genotypes were placed in zone A which had high yield in stress and non-stress conditions. T-2, Kiza, Varamin, Dr-Omoomi, Termez-14, BK-w30 and Silend genotypes were placed in zone D in which grain yield in both stress and non-stress condition was low Figure (4). These results are in agreement with results of principal component and biplot.

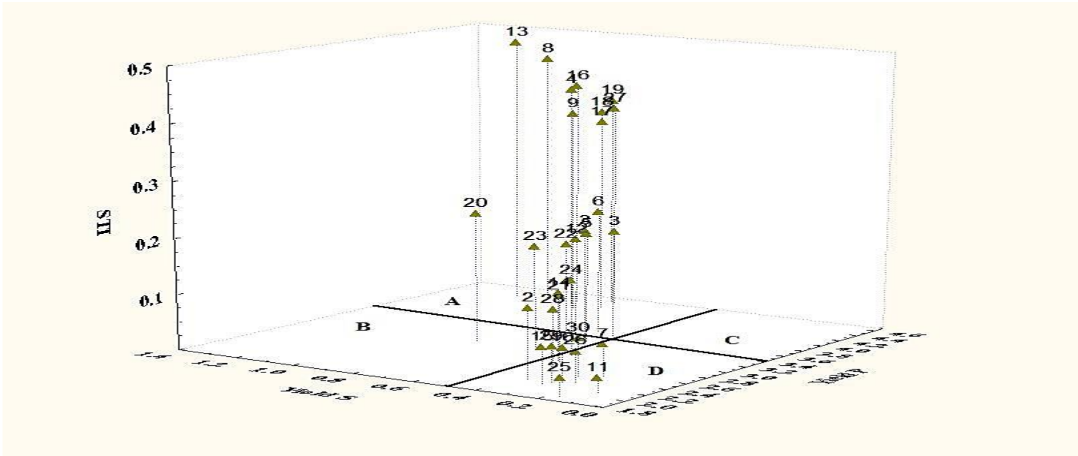

Fig. 4. Three-dimensional plot between Yp, Ys and STI

Cluster Analysis

Cluster analysis was done based on drought tolerance index and genotypes yield in both stress and non-stress condition Figure (5). Cluster analysis divided genotypes into two groups. The first group itself had two subgroups. Super Elit Arian, Elit Arian, Khandagh, Sepid, Armaghan, Pak, Oltan, Opal and SB-35 genotypes were placed in first subgroup with high resistance to drought stress. Super Elit Golestan, Elit Golestan, Sahel, Khordad and Super Elit Bakhtegan genotypes were placed in the second subgroup which was less resistant to drought stress. The second group was also divided into two subgroups with T-3, Bley-zoor,Barbadens, Dr-Omoomi, Mehr,Super Okra, T-2 and 817-262 genotypes in subgroup 1 and Varamin, Tabela-18, Kiza, Silend, BK-w30, Germany and Termez-14 genotypes in subgroup 2 which was sensitive to drought stress Figure (5).

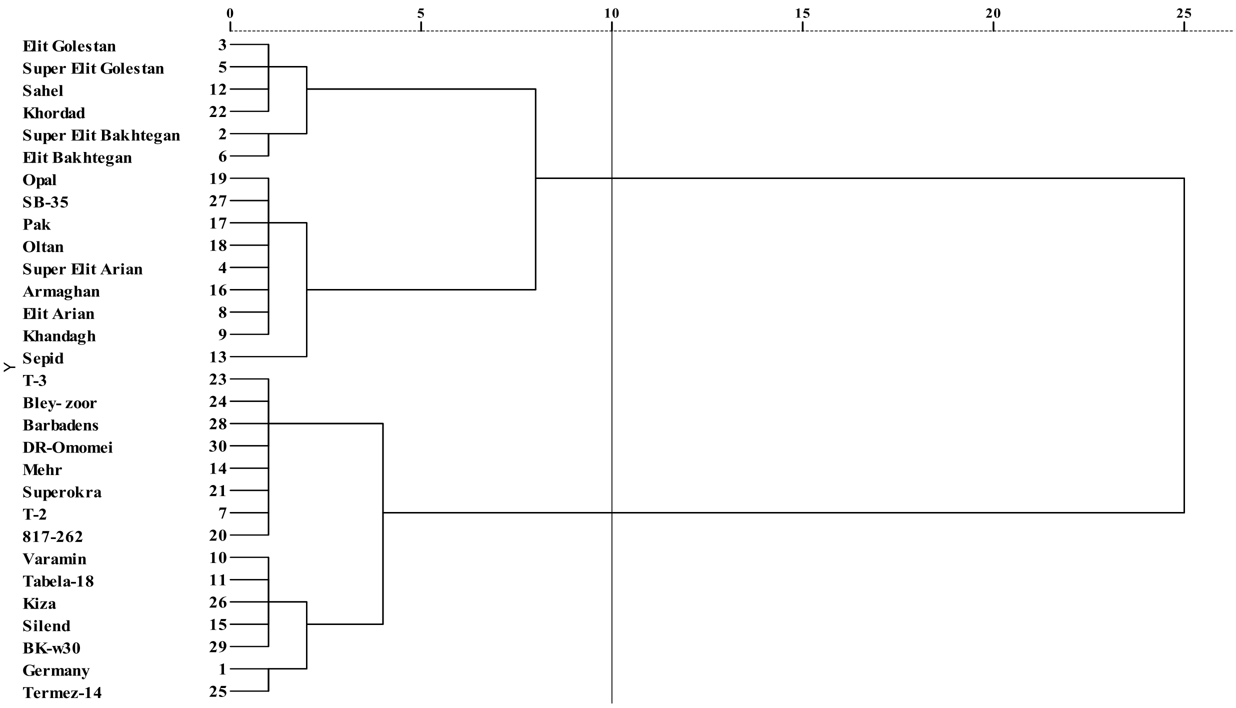

Fig. 5. Cluster analysis of cotton genotypes

DISCUSSION

High values of MP, GMP, HMP, STI and YI indices, were indicative of more tolerance to drought stress. TOL index shows the variations due to stress conditions and its numerical value decreases as the variations of a genotype yield under stress becomes less. Therefore, a low value of TOL index is not necessarily an indicator of high yield of the genotypes in normal conditions. Low TOL might be the result of low yield of the genotype in normal conditions and a small variation under stress conditions (Bahrani *et al.,* 2013). It has been reported that MP, GMP and STI index were more successful indices for the selection of genotypes resistant to drought stress (Sadeghzadeh Ahary *et al.,* 2006). The studies of wheat genotypes (Amiri *et al.,* 2014; Cattivelli *et al.,* 2008) showed resistant genotypes had positive DRI index due to their large yield under normal and stress conditions and small averages, which is the inverse condition as found in this study Table (4). Based on (MSTI P)

and (MSTI T) indices, Elite Arian, Super Elite Arian, Khandagh, Sepid, Armaghan, Pak, Oltan, Opal and S-B-35 genotypes had more resistance to drought stress. Difference of yield in genotypes resistant to drought stress was more than 4 ton.h^{-1}. Since the average of yield for these genotypes was large, the DRI index became negative for all genotypes such that more resistant cultivars had more negative values. The researchers believe that the best indicator of drought tolerance is the indices which has high correlation with grain yield under both stress and non-stress conditions (Fernandez, 1992). (Haghjoo and Bahrani 2015) and (Tabib Loghmani *et al.,* 2019), reported seed yield had positive and significant correlation under stress and non-stress condition. Seed yield under stress and non-stress condition had positive and significant correlation with all stress indices expect SSI, SDI and DRI index. (Sadeghzadeh Ahari, 2006) found that grain yield had positive and significantly correlation under drought stress and non-stress conditions with STI, GMP and MP index. (Amiri, 2014) also reported that grain yield had positive and significant correlation with STI, GMP, MP, SSI, TOL, YI, YSI, SDI, SSPI, KSTI P and KSTI S indices. (Mohammadi *et al.,* 2011) reported that about 99.5 percent of the total variation explained by two main components. The results of cluster analysis were similar to the results of principal component analysis and biplot. (Mohammadi *et al.,* 2011; Sadat Sayyah *et al.,* 2012; and Dorostkar *et al.,* 2015) also use cluster analysis based on drought tolerance index.
In general, it can be stated that drought stress had significant effect on cotton yield. According to the results of this research Elite Arian, Super Elite Arian,S-B -35, Oltan, opal, Pak, Khandagh, Sepid and Armaghan genotypes were resistant to drought stress and suitable for cultivation in the similar climate regions.

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