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Evaluation of Drought Tolerance Indices and Their Relationship with Grain Yield of Lentil Lines in Drought-stressed and Irrigated Environments

Barat Ali Siahsar, Salehe Ganjali, Maryam Allahdoo

Department of Plant Breeding and Biotechnology, Faculty of Agriculture, University of Zabol, Zabol, Iran.

Abstract: In order to study genetic diversity of lentil lines, screening drought tolerance three indices and lines, eighteen genotypes were evaluated in a randomized complete block design with 3 replications under both stress and non-stress conditions in the Research Farm of Zabol University in 2009. Based on yields of non-stress (Yp) and stress (Ys) conditions, several quantitative drought tolerance indices, such as mean productivity, geometric mean productivity, harmonic mean, tolerance index, yield index, yield stability index, stress susceptibility index and stress tolerance index were used to evaluate the drought responses of these genotypes. GMP, HM and STI were considered as the best indices for selection of lentil lines under drought stress. Based on these indices values, TN1084 could be considered as superlative line, followed by KC210034. TN2464 was the weakest line in respect to drought tolerance. Principal component analysis revealed that the first PCA explained 66.82% of the total variation and named as the yield potential and drought tolerance dimension. The second PCA explained 32.48% of the total variability and named as a stress-tolerant dimension. Distribution of the genotypes in the PCA biplot space indicated the presence of genetic diversity among the lines for drought stress. TN1084 genotype with high PC1 was more suitable for stress and non-stress conditions. KC210034 genotype with high PC2 was more suitable for non-stress than for stress environment. Biplot based on grain yield of lines under stress and non-stress conditions revealed the results of principal component analysis and showed the possibility of diversifying the legume-predominant farming systems in Sistan. Based on cluster analysis TN1084 and KC210034 group had high yield under stress and non-stress conditions and ranked as the best group. TN2464 group had low yield positional under stress and non-stress conditions and ranked as the worst group. All in all, TN1084 and KC210034, respectively, were best line for stress and non-stress conditions and can be recommended for cultivation and parental material for breeding efforts to develop higher yielding varieties.

Key words: Lentil, Drought tolerance indices, Stress, Non-stress

INTRODUCTION

From the initial agriculture activities, always drought has been an important factor, causing famine and fatality. For example, in Sistan and Baluchestan province in south eastern of Iran, total cultivable lands in famine status are about 190000 hectares that equals to 65% of the province area (94% of them belong to Sistan). The latest Sistan famine in 1971, were resulting migration of the large amount of the people to Golestan and Mazandaran provinces in north of Iran. Water shortage damage major agricultural products in most part of the world. Iran, with a mean annual rainfall of 250mm, is considered an arid to semi-arid country (Soltani *et al*., 2001). The limited available water during growing season in some regions, such as Sistan (mean annual rainfall of 50mm), is an important factor limiting crop production and reduces crop yield considerably because of water deficit in Hirmand River. Due to the lack of water resources in Sistan, it is estimated that the total cultivated area depends on Hirmand River. Thus, Sistan agriculture lands are being affected by drought stress conditions or plants may frequently encounter drought stress. Furthermore, developing the drought tolerant varieties of lentil could be the main goal of breeding programs to reach reasonable yield. By developing such tolerant varieties may be help to prevent or overcome water loss especially in Sistan as well as reach to reasonable yield. The use of drought tolerant varieties in Sistan can reduce the likelihood of plant injury due to drought stress.

Corresponding Author: Barat Ali Siahsar, Department of Plant Breeding and Biotechnology, Faculty of Agriculture, University of Zabol, Zabol, Iran.
E-mail: info@siahsar.com or ba_Siahsar@yahoo.com

Lentil (*Lens culinaris* L.) is a diploid (2n=2x=14), autogamous species and is one of the oldest crops in the world, which originated in the Near East (Zohary, 1972). Moreover, they are also valuable as feed and fodder for livestock, and play an important role in crop rotations because their nitrogen fixing capability (Durán and Pérez de la Vega, 2004). Nowadays, lentil is still traditionally cultivated in the Mediterranean Basin, Asia and has certain diffusion in the ericas. Although not a major crop, it provides a substantial portion of dietary energy supply on a regional basis (Sonnante and Pignone, 2001). Lentil is a plant that can adapt itself to arid and semi-arid climate. Iran and most other countries of the world to assure their protein needs, use cereals such as pea, bean, vetch and lentil. Cultivation of these crops and gaining lines with maximum operation in shortage of water situation is an important problem in Iran to investigate about it (Soltani *et al*., 2001). So accessing genotypes which can tolerate drought, we can prevent reduction of crops significantly. In this regard selection of lentils that can tolerate drought by means of a suitable index which is able to distinguish these types of genotypes always has been a subject that breeders pay attention to it.

Drought is a serious agronomic problem, being one of the most important factors contributing to crop yield loss in marginal lands and affecting yield stability in temperate areas (Sari-Gorla *et al*., 1999). Breeding for drought tolerance by selecting solely for grain yield is difficult, because the heritability of yield under drought conditions is low, due to small genotypic variance or to large genotype-environment interaction variances (Ludlow and Muchow, 1990). The genetic structure and phenotypic expression of a quantitative trait are highly influenced by environmental factors, thus one barrier for understanding the inheritance of a quantitative trait is genotype-environment interactions (Breese, 1969). The relative yield performance of genotypes in drought stressed and more favorable environments seems to be a common starting point in the selection of genotypes for use in breeding for dry environment (Clarke *et al*., 1992). Drought indices which provide a measure of drought based on yield loss under drought in comparison to normal conditions have been used for screening drought-tolerant genotypes (Mitra, 2001). These indices are either based on drought resistance or susceptibility of genotypes (Fernandez, 1992). Several drought tolerance indices or selection criteria, such as stress tolerance (TOL) and mean productivity (MP) (Rosielle and Hamblin, 1981), geometric mean productivity (GMP) and stress tolerance index (STI) (Fernandez, 1992), harmonic mean (HM) (Kristin *et al*., 1997), yield index (YI) (Gavuzzi *et al*., 1997; Lin *et al*., 1986), yield stability index (YSI) (Bouslama and Schapaugh, 1984), stress susceptibility index (SSI) (Fischer and Maurer, 1978) and regression coefficient of yield of genotype in stress condition (Ys) on environmental indices (Naroui Rad *et al*., 2009; Azizi Chakherchaman *et al*., 2009) have been proposed as ways to identify genotypes with better stress tolerance.

This study was conducted to assess the selection criteria for identifying drought tolerant lentil lines to facilitate its introduction within legume farming system prevailing under drought prone area of Iran, such as Sistan.

MATERIALS AND METHODS

Eighteen lentil lines received from ICARDA were chosen for the evaluation of drought resistance. Experiments were conducted at the Research Farm of Zabol University in 2009. The experiment was carried out in randomized complete block design with three replications. Each genotype was sown in four rows of 3.0m length, and row to row distance of 20cm. Between plots distances were 50cm. Irrigated and non-irrigated plots were watered to flowering stage. Non-irrigated plots were not irrigated after flowering stage. Grain yield of lines measured after elimination of margin of plot. Drought resistance indices were calculated using grain yield of lines and the following relationships:

$$SSI = [1-(Y_S / Y_P)]/[1-(\overline{Y_S} / \overline{Y_P})],$$ (Fischer and Maurer, 1978)

$$MP = (Y_p + Y)/2,$$ (Rosielle and Hamblin, 1981)

$$TOL = Y_p - Y_s,$$ (Rosielle and Hamblin, 1981)

$$STI = (Y_p + Y)/\overline{Y}_p^2,$$ (Fernandez, 1992)

$$GMP = \sqrt{Y_p \times Y_s},$$ (Fernandez, 1992)

$YI = Y_s / \overline{Y}_s$, (Gavuzzi *et al*., 1997)

$YSI = Y_s / Y_p$, (Bouslama and Schapaugh, Jr, 1984)

$HM = 2(Y_P \times Y_S) / Y_P + Y_S$, (Kristin *et al*., 1997)

Where, Ys and Yp are the yield of line under stress and nonstress conditions. $\overline{Y}_s$ and $\overline{Y}_p$ are the mean yields of all lines under stress and non-stress conditions. Correlation coefficient, regression of Ys on Yp and STI, and principle component analysis (PCA) of indices and lines were calculated using SAS software version 9.2 (SAS Inst. Inc., Cary Nc.). Cluster analysis of lines was carried out using Euclidian distance coefficient and between group linkage method by SPSS software version 17.0 (SPSS Inc.).

RESULTS AND DISCUSSION

Analysis of variance and mean comparisons of Ys, Yp and drought tolerance indices showed that, there were high significant differences ($p<0.01$) between lentil lines (Table 1), indicating presence of high genetic diversity among them. Moments of Ys, Yp and drought tolerance indices revealed the variation between lines. Highest and the lowest phenotypic coefficient of variation belong to STI and YSI indices, respectively (Table 2).

The highest Ys, MP, GMP, HM, YI and STI were recorded in TN1084 line, followed by KC210034, but the difference of them was significant. Maximum Yp belong to KC210034 line that had significant difference with TN1084 line. Among all lines, TN1084 and KC210034 had the highest yields in stress and optimal conditions, respectively. The least MP, GMP, HM, YI and STI belong to TN2464 line. Moreover, this line produced the lowest yields in both conditions (Table 1). MP, GMP, HM, YI and STI were used for screening drought tolerant high yielding genotypes in the both conditions (Fernandez, 1992; Mohammadi *et al*., 2003). These indices, as were reported by Fernandez (1992), was able to differentiate genotypes belong to A-group, including genotypes with high yield performance in both conditions, from the others (B, C or D groups). In these cases, genotypes with a high MP, GMP, HM, YI and STI would belong to A-group. Furthermore, these indices are related to yield under drought stress if it is not too severe and the difference between Ys and Yp is not too large. A higher MP, GMP, HM, YI and STI value is indicating more tolerance to drought stress (Fernandez, 1992; Gavuzzi *et al*., 1997; Bouslama and Schapaugh, Jr, 1984; Hossain *et al*., 1990). Therefore, Based on these indices values, TN1084 would belong to A-group and could be considered as superlative line, followed by KC210034. TN2464 would belong to D-group and could be as the weakest line in respect to drought tolerance.

TN2437 line had the lowest TOL and SSI (Table 1). Thus, from the stress tolerance point of view (TOL and SSI), this line was more tolerant genotype, which their low quantity is indicating tolerant genotype (Table 1). It seems TOL had succeeded in selecting genotypes with high yield under stress, but had failed to select genotypes with proper yield under both environments. Obviously, this index only pointed out the genotypes with the lowest yield in normal conditions. TN2437 line had highest TOL and SSI (Table 1). The greater the TOL and SSI value, the larger yield reduction under stress conditions and the higher the drought sensitivity. Therefore, based on TOL and SSI, this line was selected as sensitive one. It seems if a given line has high yields under both stress and normal conditions, but there is much variation in its yields between these two situations, it would not be detected as tolerant by TOL and SSI (e. g., KC210034). The greatest and the lowest YSI index belong to TN2022 and TN2437 lines, respectively. Formerly, stated that these lines, respectively, had the lowest and greatest TOL and SSI. Therefore, based on YSI, TOL and STI indices, TN2022 and TN2437 lines could be considered relatively drought tolerant and sensitive, respectively. TOL, SSI and YSI were found to be more useful indices in discriminating drought resistant/susceptible genotypes. SSI has been widely used by other researchers for this purpose (Clarke, *et al*., 1992; Fischer and Maurer, 1978; Winter *et al*., 1988). SSI does not differentiate between potentially drought-tolerant genotypes and those that possessed low overall yield potential. Although low TOL has been used as a basis for selecting cultivars with resistance to water stress, the likelihood of selecting low yielding cultivars with a small yield differential can be anticipated (Ramirez Vallejio and Kelly, 1998). To decrease the influence of yield reduction from stressed to non-stressed conditions, Yadav and Bhatnagar (2001) suggested the use of SSI in combination with yield under stress. These two parameters were employed previously by Gavuzzi *et al*. (1993) to identify genotypes with superior drought adaptation in trials conducted in several locations of western Iran. In the case of this combination, TN1084 was the best genotype whereas the TN2022 with the lowest yield in both conditions showed the lowest SSI. Furthermore, the low amount of TOL for TN1084 line emphasizing the tolerance of it (Table 1). Ramirez Vallejo and Kelly (1998) reported that selection based on a combination of both GM and SSI may provide a more desirable criterion for improving drought resistance in common bean. In the case of this combination, once more, TN1084 was the best genotype.

To determine the most desirable drought tolerance criteria, the correlation coefficient between Yp, Ys and other quantitative indices of drought tolerance were calculated (Table 3). There was positive and high significant correlation between Ys and Yp ($r=0.86^{**}$), suggesting that a high potential yield under optimum condition does necessarily result in improved yield under stress condition. Correlation of Ys and Yp with MP, GMP, HM, YI and STI indices were very strong and high significant (Table 3). These results were agreed to finding of Azizi Chakherchaman *et al*. (2009) in lentil that showed correlation coefficient of yield to MP, HM, GMP and STI indices was positive and significant under stress and non-stress conditions and to SSI index was negative and significant. Moreover, these results were agreed to finding of Narouie Rad *et al*. (2009) in lentil lines of Iran gene bank and Khaghani (2008) in faba bean. The significant and positive correlation of Yp and MP, GMP, HM, YI and STI indices showed that these criteria were more effective in identifying high yielding cultivars under different moisture conditions. Correlation coefficients of Ys and Yp with TOL ($-0.04^{n.s}$ and $0.47^{n.s}$, respectively), SSI (-0.52^{*} and $-0.03^{n.s}$, respectively) and YSI (0.52^{*} and $0.03^{n.s}$, respectively) showed that MP, GMP, HM, YI and STI indices were better predictor of Yp and Ys than TOL, SSI and YSI. These results were agreed to founding of Talebi *et al*. (2009) in durum wheat, Farshadfar and Sutka (2003) in maize and Golabadi *et al*. (2006) in durum wheat. Stress tolerance (TOL) was moderately correlated with yield in optimum condition and had less negatively correlation with yield under stress condition, having in mined the fact that a small value of TOL is desirable. These results were agreed to results of Narouie Rad *et al*. (2009) in lentil lines of Iran gen bank, that TOL was strongly correlated with yield under non-stress condition and had negative and non significant correlation with yield under stress condition. Selection for this parameter would tend to favor low yielding genotypes. Similar results were reported by Clarke *et al*. (1992) and Rosielle and Hamblin (1981). These researchers showed that a selection based on TOL, failed to identify the best genotypes. The stress susceptibility index (SSI) introduced by Fisher and Maurer (1978), had significant slight negatively correlation with yield under stress and a lower negative correlation with yield in normal condition. Thus, a small value of SSI is desirable and selection for this parameter would also tend to favor low yielding genotypes, but to a much smaller extent than selection for TOL index. SSI has been widely used by researchers to identify sensitive and tolerant genotypes (Clark *et al*., 1992; Golabadi *et al*., 2006).

Table 1: F Value and mean comparisons of Ys, Yp and drought tolerance indices.

Genotype	Ys	Yp	TOL	MP	GMP	HM	YI	YSI	SSI	STI
TN1084	615.15a**	690.67b	75.52l	652.91a	651.81a	650.72a	2.1093a	0.8907a	0.3526l	2.3779a
KC210034	490.77b	698.33a	207.57b	594.55b	585.42b	576.43b	1.6828b	0.7028e	0.9587h	1.9181b
TN2463	221.75l	411.33i	189.58c	316.54j	302.01j	288.14l	0.7604l	0.5392k	1.4863b	0.5105j
TN1087	226.15lk	322.67n	96.52j	274.41m	270.13k	265.92m	0.7754lk	0.7009e	0.9647h	0.4084k
TN1086	190.44n	330.33l	139.89g	260.39n	250.81l	241.59o	0.6530n	0.5764j	1.3661c	0.3522l
TN2440	301.04f	453.00f	151.96f	377.02e	369.29e	361.71d	1.0322f	0.6646g	1.0819f	0.7633e
TN2464	138.44o	204.00p	65.56m	171.220p	168.05m	164.95p	0.4747o	0.6787f	1.0364g	0.1581m
TN2461	213.63m	299.00o	85.37k	256.31o	252.73l	249.20n	0.7325m	0.7145e	0.9208h	0.3575l
TN2434	268.38i	473.33d	204.95b	370.86f	356.42g	342.54f	0.9203i	0.5670j	1.3965c	0.7110g
TN2462	268.89i	433.00h	164.11de	350.95h	341.21h	331.74h	0.9220i	0.6211i	1.2220d	0.6516h
TN2437	229.77k	486.67c	256.90a	358.22g	334.40i	312.16i	0.7879k	0.4721l	1.7025a	0.6258i
TN1960	282.79h	325.67m	42.87n	304.23l	303.46j	302.70j	0.9697h	0.8685b	0.4241k	0.5154j
TN2128	289.91g	449.00g	159.09e	369.46f	360.79f	352.33e	0.9941g	0.6457h	1.1428e	0.7286f
TN2022	321.37d	356.00k	34.63o	338.68i	338.23h	337.77g	1.1019d	0.9028a	0.3134l	0.6403ih
TN2457	342.55c	464.33e	121.79i	403.44c	398.81c	394.24c	1.1745c	0.7378d	0.8457i	0.8901c
KC210031	298.07f	467.00e	168.93d	382.54d	373.09d	363.88d	1.0220f	0.6383h	1.1667e	0.7791d
TN2458	307.55e	371.33j	63.78m	339.45i	337.94h	336.45g	1.0546e	0.8283c	0.5539j	0.6392ih
TN2439	242.90j	373.00j	130.10h	307.95k	301.00j	294.21k	0.8329j	0.6512hg	1.1250fe	0.5071j
F Value	4156.9^{**}	15057.2^{**}	1184.0^{**}	11274.1^{**}	9594.2^{**}	8099.1^{**}	4151.0^{**}	672.2^{**}	674.0^{**}	12495.3

**On the base of Duncan test, means that differ in alphabet letters are significant at 0.05 probability level.

** is significant at 0.01 probability level.

Table 2: Moments of Ys, Yp and drought tolerance indices.

Indices (traits)	Rang	Mean	S.D	S.E	P.C.V%
Ys	138.44-615.15	291.64	109.67	25.85	37.60
Yp	204.00-698.33	422.70	123.81	29.18	29.29
TOL	34.63-256.89	131.06	62.66	14.77	47.81
MP	171.22-652.91	357.17	112.68	26.56	31.55
GMP	168.05-651.82	349.76	112.78	26.58	32.24
HM	164.95-650.72	342.59	113.13	26.66	33.02
YI	0.4747-2.1093	1.0000	0.3761	0.0886	37.61
YSI	0.4721-0.9028	0.6889	0.1212	0.0286	17.59
SSI	0.3134-1.7025	1.0033	0.3908	0.0921	38.95
STI	0.1581-2.3779	0.7519	0.5443	0.1283	72.39

Table 3: Correlation coefficient of Ys, Yp and drought tolerance indices.

Indices (traits)	Ys	Yp	TOL	MP	GMP	HM	YI	YSI	SSI
Yp	0.86^{**}								
TOL	-0.04^{ns}	0.47^{ns}							
MP	0.96^{**}	0.97^{**}	0.23^{ns}						
GMP	0.97^{**}	0.95^{**}	0.18^{ns}	0.99^{**}					
HM	0.98^{**}	0.94^{**}	0.14^{ns}	0.99^{**}	0.99^{**}				
YI	0.99^{**}	0.86^{**}	-0.04^{ns}	0.96^{**}	0.97^{**}	0.98^{**}			
YSI	0.52^{*}	0.03^{ns}	-0.85^{**}	0.27^{ns}	0.31^{ns}	0.36^{ns}	0.52^{*}		
SSI	-0.52^{*}	-0.03^{ns}	0.85^{**}	-0.27^{ns}	-0.32^{ns}	-0.36^{ns}	-0.52^{*}	-0.99^{**}	
STI	0.97^{**}	0.92^{**}	0.11^{ns}	0.98^{**}	0.98^{**}	0.98^{**}	0.97^{**}	0.35^{ns}	-0.35^{ns}

* and ** are significant at 0.05 and 0.01 probability levels, respectively.
^{ns}, is not significant.

Table 5: Principal component analysis of Ys, Yp and drought tolerance indices.

Indices (traits)	Eigenvectors		Correlation coefficient	
	Prin1	Prin2	Prin1	Prin2
Ys	0.3684	0.0152	0.99^{**}	0.03^{ns}
Yp	0.3136	0.2770	0.85^{**}	0.52^{*}
TOL	-0.0253	0.5202	-0.07^{ns}	0.98^{**}
MP	0.3516	0.1594	0.95^{**}	0.30^{ns}
GMP	0.3567	0.1339	0.97^{**}	0.25^{ns}
HM	0.3607	0.1096	0.98^{**}	0.21^{ns}
YI	0.3684	0.0152	0.99^{**}	0.03^{ns}
YSI	0.2014	-0.4417	0.54^{*}	-0.89^{**}
SSI	-0.2013	0.4417	-0.55^{*}	0.96^{**}
STI	0.3562	0.1084	0.97^{**}	0.20^{ns}
Eigenvalue	7.35	3.57		
Proportion (%)	66.82	32.48		
Cumulative (%)	66.82	99.30		

* and ** are significant at 0.05 and 0.01 probability levels, respectively.
^{ns}, is not significant.

There were very strong and high significant correlations between MP, GMP and HM indices. If there were significant correlation between MP, GMP and HM, HM can be considered to reflect a little better the performance under stress, than MP and GMP. Like GMP the correlation of HM with yield under stress being slightly better ($r=0.98^{**}$ vs. $r=0.94^{**}$ for stress and normal condition, respectively), but the correlation of MP with yield under optimum condition being slightly better ($r=0.97^{**}$ vs. $r=0.96^{**}$ for optimum and stress condition, respectively). The stress tolerance index (STI) introduced by Fernandez (1992), was perfectly correlated with MP, GMP and HM. therefore, from which it is calculated, we can consider that it contains the same information. Like HM it is correlated with both Yp and Ys and the correlation of it with yield under stress than yield under non-stress being slightly better ($r=0.97^{**}$ vs. $r=0.92^{**}$ for stress and normal conditions, respectively). There was a positive and high significant correlation among SSI and TOL (Table 3). Therefore, these indices can be considered to reflect the same information. Association of YSI with TOL and SSI was negative and high significant (-0.85^{**} and -0.99^{**}, respectively). Thus, a big value of this index is desirable and selection for this parameter would also tend to favor low yielding genotypes.

The regression analysis of grain yield on environmental index provided enough information on the drought resistance and adaptability of genotypes. Therefore, it can be used as useful method to study the response of genotypes to variable environments under mild stress conditions. Fernandez *et al*. (1992) proposed STI index which discriminates genotypes with high yield and stress tolerance potentials. In this study, a general linear model regression of grain yield under drought stress on STI ($\hat{Ys}=144.30+195.96STI$) revealed a positive correlation between this criterion with a similar coefficient of determination ($R^2=0.94$). Based on linear model of regression (Figure 1), TN1084 and TN2464 lines were identified as genotypes with high and low production and tolerant and sensitive to drought stress, respectively.

Selection based on a combination of indices may provide a more useful criterion for improving drought resistance of lentil, but study of correlation coefficients are useful in finding the degree of overall linear association between any two attributes. Thus, a better approach than a correlation analysis such as biplots of principal component analysis (PCA) is needed to identify the superior genotypes for both stress and non-stress environments. Principal component analysis revealed the first component explained 66.82% of the total variation. This component positively correlated with Ys, Yp, Mp, GMP, HM, YI, YSI and STI (Table 4). Consequently, the first dimension can be named as the yield potential and drought tolerance. Considering the high and positive value of this component, genotypes that have high values of these indices will be high yielding under stress and non-stress environments. As a result, TN1084 genotype with high PC1 was more suitable for stress and non-stress conditions (Figure 3). The second component explained 32.48% of the total variation and correlated positively with Yp, TOL and SSI, but negatively with YSI. Therefore, the second component can be named as a stress-tolerant dimension and it separates the stress-tolerant genotypes from non-stress tolerant ones. In consequence, selections of genotypes that have high PCA2 are suitable for non-stress environments. KC210034 genotype with high PC2 was more suitable for non-stress than for stress environment (Figure 3). Narouie Rad *et al*. (2009), in lentil lines of Iran gene bank showed similar results. Density plot of principal component analysis (Figure 4) showed that major of lines had medium amount of PCA1 and PCA2. TN1084 and KC210034 were formed two separate groups. TN1084 and KC210034 lines had maximum PCA1 and PCA2, respectively.

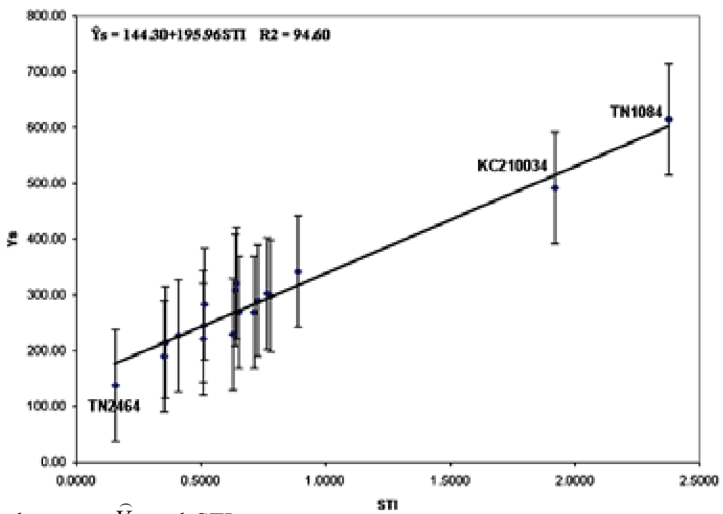

Fig. 1: Relationship between $\widehat{Y}$s and STI

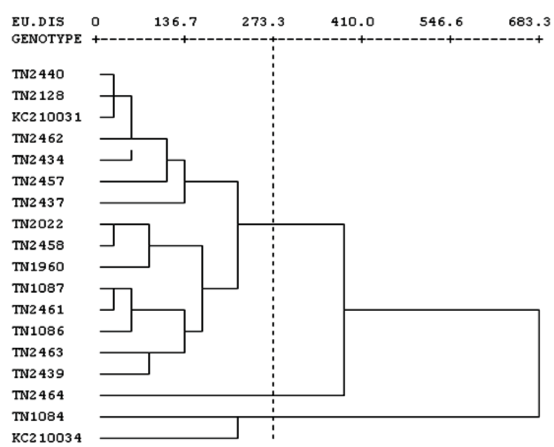

Fig. 2: Dendrogram of cluster analysis of 18 lentil lines for Ys, Yp and drought tolerance indices using Euclidian distance and between group linkage method.

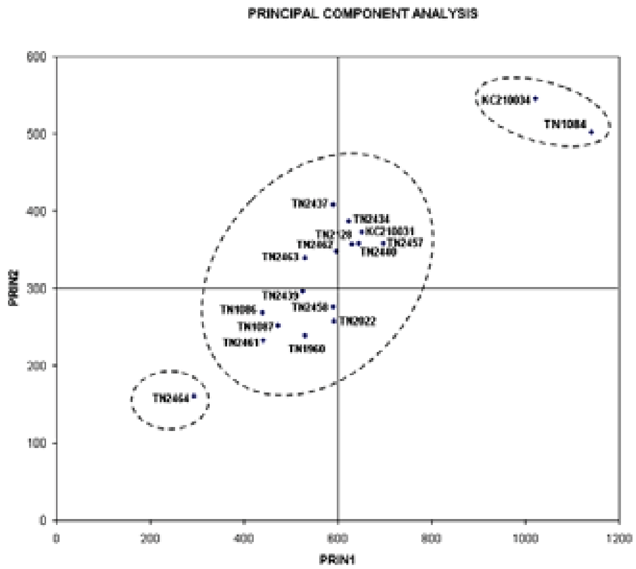

Fig. 3: Biplot of principal component analysis of 18 lentil lines for Ys, Yp and drought tolerance indices.

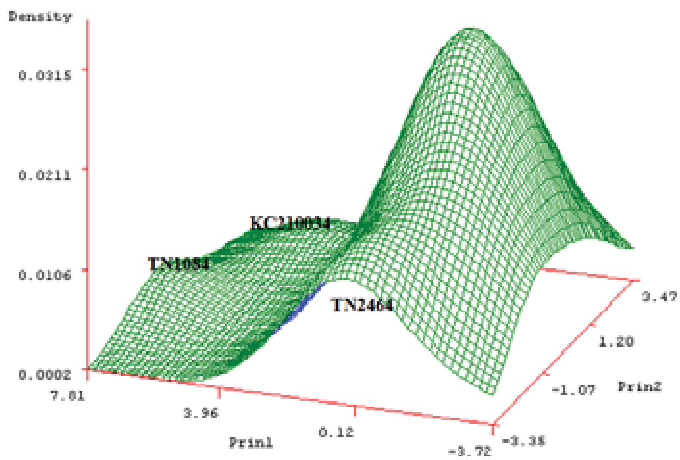

Fig. 4: Density plot of principal component analysis of 18 lentil lines for Ys, Yp and drought tolerance indices.

Biplot based on grain yield of lines under stress and non-stress conditions (Figure 5) showed that TN2437, TN2434, KC210031, TN2128, TN2462, TN2463, TN2440 and TN2457 lines had the highest grain yields under non-stress condition, TN2439, TN2458, TN2022, TN1960, TN1084, TN1086, TN2461 and TN2464 lines had the highest grain yields under stress condition and TN1084 and KC210034 lines had the highest grain yield under both stress and nonstress conditions. TN1084 than KC210034 line had higher yield in stress condition, showing its adaptation to stressed environment. These results revealed the results of principal component analysis and showed the possibility of diversifying the legume-predominant farming systems in the Sistan. The highest yielding line such as TN1084 had higher yield in stress condition, showing its adaptation to stressed environment can be recommended for cultivation and can be used as parental material for breeding efforts to develop higher yielding varieties.

Principal component analysis biplot of Ys, Yp and drought indices (Figure 6) suggest three groups of parameters including MP, GMP, HM, YI and STI group, TOL and SSI group and YSI group. Therefore, it will be sufficient to use one of either members of each group for better characterization of drought tolerance of lentil lines. A suitable genotype will be that having high values (for MP, GMP, HM, YI, YSI and STI) or low values (for TOL and SSI) for these parameters which show good performance under both drought and irrigated conditions. Analyzing of tolerance indices to environmental stress conditions showed that efficiency of these indices modifies with genotypes yield variation and evaluation aims. Selection based on lower TOL and SSI and upper YSI favored genotypes with low grain yield potential under non-stress conditions and high yield under stress conditions as in the case of TN2022 line (Table 1). Selection based on MP, GMP, HM, YI and STI will result in genotypes with higher stress tolerance and higher yield potential as in the case of TN1084 line (Table 1). Moreover, SSI can recognize genotypes as tolerant or sensitive, regardless their yield and have good efficiency to find genotypes with resistance genes. TOL has a conditional efficiency, after classifying genotypes to equal TOL we can select resistant genotypes with MP. Finding equal TOL in different groups is very hard. With regard to TOL and MP role, genotypes with high MP may not be in the least TOL groups and selecting superior genotypes may be difficult. GM uses stress and non-stress yield and geometric mean. There is problem and it is coupling data geometric equation that has natural difference. Moreover, effectiveness of selection indices depends on the stress severity supporting the idea that only under moderate stress conditions, potential yield greatly influences yield under stress (Blum, 1996; Panthuwan *et al*., 2002).

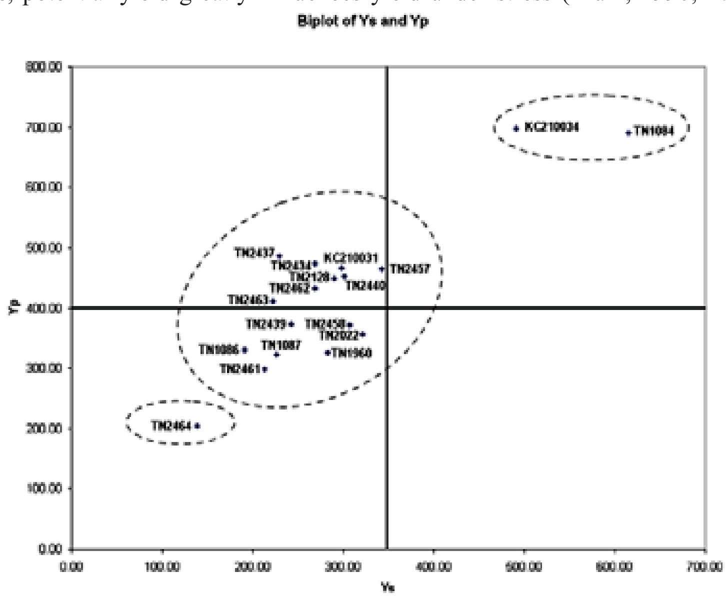

Fig. 5: Biplot of Ys and Yp for 18 lentil lines.

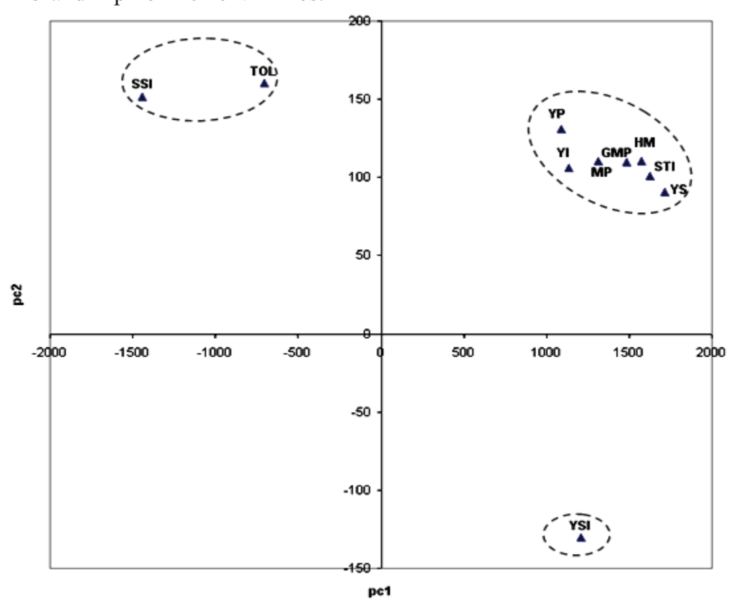

Fig. 6: Biplot of principal component analysis of Ys, Yp and drought tolerance indices for 18 lentil lines

Principal component analysis biplot of Ys, Yp and drought indices (Figure 6) revealed the correlation coefficient among them. The correlation coefficient among any two indices is approximately by the cosine of the angle between their vectors. Thus, r = Cos180°= -1, Cos0°=1, and Cos90°=0 (Yan and Rajcan, 2002). The most prominent relations revealed by these biplot are: (i) a strong negative association between SSI and TOL with YSI, as indicated by the large obtuse angles between their vectors, (ii) a near zero correlation between SSI and YSI with Yp and also TOL with Ys, as indicated by the near perpendicular vectors, (iii) a high significant positive association between Yp and Ys with MP, GMP, HM, YI and STI, as indicated by the acute angles and (iv) a strong positive association between MP, GMP, HM, YI and STI, and also between TOL and SSI, as indicated by the acute angles. As a result, biplot graph confirmed correlation analysis.

We also used cluster method to classify different genotypic groups in similar classes. As it is appear in Figure 2, with linear slicing from equality point of 273.3Eu.dis, the genotypes are classified to three groups with high intra-group and low extra-group similarities, each of which having 15, 1 and 2 genotypes, respectively. First group had medium amount of PCA1 and PCA2, outcome the medium amount of Ys, Yp and drought tolerance indices. Second group that consist of TN2464 line, had the smallest value for PCA1 and PCA2, consequently the least amount of the studied criteria. Hence, this line had low yield positional under stress and non-stress conditions. Third group that consist of TN1084 and KC210034 lines had the highest amount of PCA1 and PCA2, consequently the highest amount of Yp, Ys, GMP, MP, HM, YI and STI, and it was, hence, known as one of the most desirable cluster. This group had high yield under stress and non-stress conditions and ranked as the best group.

Baker (1994) introduced the definition of stress tolerance and selection index. It was concluded that selection index in non-stress environments would be more effective than direct selection for productivity under stress whenever the correlation between the two types of environments exceeds the heritability of productivity under stress. There is the need to be incorporate drought tolerance mechanisms into germplasm with high yielding capacity to develop both high yielding and drought tolerant cultivars. Two primary schools of thought have influenced plant breeders who target their germplasm to drought-prone areas. The first of these philosophies states that high input responsiveness and inherently high yielding potential, combined with stress-adaptive traits will improve performance in drought-affected environments (Richards, 1996; Van Ginkel *et al*., 1998; Rajaram and Van Ginkle, 2001; Betran *et al*., 2003). The breeders advocate selection in favorable environments follows this philosophy. Therefore, producers prefer cultivars that produce high yields when water is not so limiting, but suffer a minimum loss during drought seasons (Nasir Ud-Din *et al*., 1992). The second is the belief that progress in yield and adaptation in drought-affected environments can be achieved only by selection under the prevailing conditions found in target environments (Ceccarelli and Grando, 1991). The theoretical framework to this issue has been provided by Falconer (1952) who told that, ''yield in low and high yielding environments can be considered as separate traits which are not necessarily maximized by identical sets of alleles''. Over all, drought stress reduced significantly the yield of some genotypes and some of them revealed tolerance to drought, which suggested the genetic variability for drought tolerance in this material. Therefore, based on this limited sample and environments, testing and selection under nonstress and stress conditions alone may not be the most effective for increasing yield under drought stress. Nonetheless, if the strategy of breeding program is to improve yield in a stressed and non-stressed environments, it may be possible to focus on local adaptation to increase gains from selection concluded directly in that environment (Atlin *et al*., 2000; Hohls, 2001). However, selection should be based on the resistance indices calculated from the yield under both conditions, when the breeder is looking for the genotypes adapted for a wide range of environments or location with unpredictable conditions.

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