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Assessment of drought tolerance in oat (*Avena sativa*) genotypes

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ABSTRACT

This investigation was performed to evaluate 21 oat genotypes and varieties based on agronomic traits and drought tolerance indices under rainfed and irrigated conditions in Kermanshah, Iran during 2009-2010 cropping season. A randomized complete blocks design with three replications was used for each environment. Drought tolerance indices i.e., stress tolerance index (STI), stress susceptibility index (SSI), tolerance index (TOL), mean productivity (MP), harmonic mean(HAM) and geometric mean productivity (GMP) were calculated. The results of analysis of variance for cell membran stability, grain yield, biomass, straw yield, plant height, 1000 seed weight, number of panicles and number of grains per panicle in rainfed and supplemental irrigation conditions indicated that differences among genotypic were highly significant (p<0.01). The combined ANOVA indicated the significant differences among genotypes for all traits. A positive and significant correlation was observed between grain yield under rainfed(Ys) and irrigated (Yp) with MP, GMP , HAM, STI indicated that these indices are the most suitable indices to screen genotypes in drought stress condition. Brusher and Tarahumara had the highest MP,GMP,STI and HAM. Therefor, they could be know as the drought tolerant varieties. Principal component analysis introduced two components. First vector showed 78.68 percent of variations and the second PCA explained 20.98% of the total variability. It separates the stress–tolerant genotypes from non-stress tolerant ones. Cluster analysis classified the genotypes into three groups. In conclusion, this study showed that drought stress reduced the yield of some genotypes while others were tolerant to drought, suggesting genetic variability of drought tolerance in these materials. Therefore, breeders can select tolerant varieties of oat genotypes based on MP,GMP,STI and HAM.

Keywords: oat, drought tolerance indices, principal component analysis, cluster analysis, Iran.

Abbreviations: *PH – plant height, BIO – biomass, NE – number of panicles, NG – number of grains per panicle, TSW – 1000-seed weight, GY – grain yield, Yp – grain yield under irrigated conditions, Ys – grain yield under rainfed conditions, STI – stress tolerance index, SSI – stress susceptibility index, TOL – tolerance index, MP – mean productivity, GMP – geometric mean productivity, HAM-harmonic mean .*

INTERODUCTION

Oat (*Avena sativa*) is one of the important forage cereals in temperate areas and economically is ranked as one of the eight important crops in the world [32]. Oat is unknown crop for farmers in Iran and in FAO statistic website no data can be found for oat production in Iran. Besides , there are very limited studies about oat specially drought tolerance in oat in Iran. Therefore, regarding to the importance of oat as multi-purpose crop, the research on this crop to develop or introduce new superior genotypes or varieties would be of value. Drought stress is one of the major causes of crop loss worldwide specially in arid and semiarid regions with mediteranean climate, reducing average yields for most major crop plants by more than 50% [35]. Drought stress may reduce all yield components in wheat particularly the number of fertile spikelet per unit area and the number of grains per panicle [16]. While seed weight is negatively influenced by high temperatures and drought during grain filling period [8]. In dry and semi-dry areas, the most important factor to limit economical yield is water and its availibility in critical growth stages of different agricultural plants [9,10]. Drought stress may occur throughout the growing season, early or late season, but its effect on yield reduction is highest when it occurs after anthesis [4]. Drought tolerance in crop plants is different from wild species when crop plant encounters severe water deficit, it dies or seriously loses yield while wild plants survive better and give less yield loss [19]. Genetic variation among genotypes is very important for plant breeding [31]. Understanding plant responses to drought is of great importance and also a fundamental part of developing crop stress tolerant [27,36]. The relative yield performance of genotypes in drought-stressed and favorable environments seems to be a common starting point in the identification of desirable genotypes for unperdictable rainfed conditions [21]. Some researchers believe in selection under favorable condition [3]. Selection in the target stress condition has been highly recommended too [26]. Some researchers have chosen a mid –way and believe in selection under both favorable and stress conditions [5].

Drought tolerance consists of the ability of crop to grow and produce under water deficit conditions [19]. To differentiate drought resistance genotypes several selection indices tolerance (TOL), mean productivity (MP), stress susceptibility index (SSI), Geometric Mean (GMP), stress tolerance index (STI), Harmonic Mean (HAM) have been employed under various conditions. TOL has been defined as the differences in yield between the stress and irrigated environments and MP as the average yield of genotypes under irrigated and rainfed conditions [28]. SSI has been suggested for measurement of yield stability that calculated the changes in both potential and actual yields in variable environments [14,24]. Fernandez (1992) defined a new advanced index ,the STI which can be used to identify genotypes that produce high yield under both stressd and non-stressed conditions [11]. The other yield based estimates of drought resistance are GMP, which is often used by breeders interested in relative performance, since, drought stress can vary in severity in field environment over years [25]. Akcura and Ceri (2011) suggested that an STI, GMP, MP and HAM could be used to identify genotypes that produce high yield under both stressed and non-stressed conditions [2]. Selection of different genotypes under environmental stress conditions is one of the main tasks of plant breeders for exploiting genetic variation to improve stress-tolerant cultivars [6]. The present study was undertaken to assess the selection criteria to identify drought tolerance in oat genotypes, so that suitable genotypes or varieties can be recommanded for cultivation in drought-prone areas of Iran.

MATERIALS AND METHODS

21 oat (*Avena sativa*.L) genotypes and varieties from different part of the world (Table 1) were selected among 50 oat genotypes obtained from South Australian Research and Development Institute (SARDI). These genotypes were selected based on the results of initial experiments carried out in Kermanshah, Iran (Unpublished data). Experiments were conducted at the Research Farm of the Campus of Agriculture and Natural Resources, Razi university, Kermanshah in 2009-2010. The characteristics of the farm is latitude 34 21 north, longitude 47 9 east, altitude 1319 m above the sea level, soil with silt-loam texture and the average annual precipitation between 450-480mm. The precipitation at the cropping season of the experiment was about 490 mm. Experimental layout was in a Randomized Complete Blocks Design (RCBD) with three replications. Each plot consisting of five rows of 2m and 0.20m row spacing at 450/m^2 seeding rate. Supplemental irrigation was performed once in the non-stressed site at the begining of grain filling stage. For the purpose of this study, CMS (cell membrane stability) was estimated according to the method adopted by Zarei et al [33] using the following equation:

$$CMS(\%)=100-\{1-(1-T1/T2)/(1-C1/C2)*100\}$$

The total dry weight, grain yield (Kg/ha), and the thousand seed weight(TSW) were measured at crop maturity. Five plants were randomly chosen from each plot to measure the number of grains per panicle (NG) and plant height (PH). The number of panicles (NP) per m^2 was determind at maturity from a sample of 1 m of a central row on each plot. Drought tolerance indices were calculated using the following equations:

$$STI = (Ys_i)(Yp_i)/(\overline{Yp})^2 \; [11]$$

$$SSI=(1-(Ys_i / Yp_i)) / SI \quad , \quad SI= 1-(\overline{Ys}/\overline{Yp}) \; [14]$$

Where Ys_i is the yield of genotype under stress, Yp_i the yield of genotype under irrigated condition, $\overline{Ys}$ and $\overline{Yp}$ are the mean yields of all genotypes under stressed and non-stressed conditions, respectively , and $1-(\overline{Ys}/\overline{Yp})$ is the stress intensity. The irrigated experiment was considered to be a non-stressed condition in order to have a better estimation of the optimum environment.

$TOL = (YP_i - YS_i)$ [28]
$MP = (YP_i + YS_i) / 2$ [28]

GMP= $\sqrt{(Ypi)(YSi)}$ [11]
HM = $2(Yp_i \times Ys_i) / (Yp_i + Ys_i)$ [7]

Data were analyzed using MSTAT-C to analyse variance (ANOVA) and mean comparison of traits. Principal component analysis (PCA) was used to classify the screening methods as well as the genotypes. In order to group genotypes, we used cluster analysis based on significant traits in ANOVA according to standardized data and by WARD method. All statistical analysis were carried out using SPSS software version 16.0 (SPSS,2007).

Table 1. Name, origin and genotypic code of evaluated genotypes

No	Code/Name	Origin
1	Ozark	Arkansas (USA)
2	UPF775456	Brazil
3	Wallaroo	SARDI (Aus)
4	Euro	SARDI (Aus)
5	Wintaroo	SARDI (Aus)
6	GA Mitchell	Georgia (USA)
7	Potoroo	SARDI (Aus)
8	13Zop95	Saskatchewan (Canada)
9	Mortlock	WADA (Aus)
10	OH1022	Ohio (USA)
11	IA91098-2	Iowa (USA)
12	4Zop95	Saskatchewan (Canada)
13	Swan	WA (Aus)
14	Kalott	Sweden
15	Tarahumara	Mexico
16	C1/130	Minnesota (USA)
17	UFRGS 948886	Brazil
18	Nasta	Finland
19	Brusher	SARDI (Aus)
20	Arnold	-------
21	Quoll	SA (Aus)

RESULTS AND DISCUSSION

The results of combined analysis of variance for all traits in rainfed and irrigated conditions indicated that genotypic differences were highly significant (Table 2). This indicates existence of genetic variation and possibility of selection for favorable genotypes in both environments. In both environments, Brusher, Tarahumara and Potoroo performed better grain yield than others. Although, the average of grain yield in both conditions were much higher than what previously reported in Isfahan and other parts of the world with similar annual rainfall [2, 15, 34] but this increase in grain yield in drought-stressed condition was higher which could be because of low stress intensity and/or Kermanshah conditions. Table 2. showed that genotype x environment interaction is not significant for grain and biological yield, number of panicles, number of grains per panicle and 1000-seed weight. This finding means that genotypes in both environments did the similar response. The data reported by Jazayeri and Rezai (2006) showed the similar results for G*E interaction for grain yield [15]. Kalott, Arnold and Mortlock with 35, 31 and 31 percentage of grain yield reduction were the least stable and Wintaroo and Wallaroo with 4 and 6% reduction were the most stable varieties. Brusher, Tarahumara and Potoroo were the best in both conditions and the percentage of reductions were about 27, 21 and 18 (Table 3). G *E interaction always is a serious problem in crop production while recommending a variety for some region/area. Environment for commerical cultivation cannot be changed but genotype can be modified by hybridization and bio-technology methods to suit to available soil and climate related environmental conditions. For this purpose, breeders are always collecting and creating genetic variation in crops to develop varieties suitable for diverse agro-climatic zones. One cultivar cannot be grown all over the country having multitude of environments. Crop outcome is a product of the genotype and the environment in which crop has been grown. Ideal variety is always one, which prossesses general adoptation with higher yield potential [13]. But, in mild drought stress no significant interaction was found for most of the traits. Thus, it could be possible to recommend an oat variety to different drought stress conditions.

Environments were significantly differ for grain and biological yield of genotypes (Table 2). This indicates that drought stress significantly reduced both grain and biological yield.

Table 2. Mean squares for yield and related traits of oat genotypes

S.O.V	df	Mean of Squares						
		GY	PH	BIO	SY	NP	NG	TSW
Environment	1	43653778.9**	145.5 ^{ns}	104352810.71 **	13019192.8 ^{ns}	180578.6^{ns}	582.0 ^{ns}	91.8^{ns}
Replication	4	502174.1	26.9	1975728.0	1999501.8	58411.1	682.2	14.4
Genotype	20	11126141.6**	1799.7**	20045676.8 **	10828485.9**	56581.0**	14.7**	178.2**
E*G	20	650352.3^{ns}	235.5**	4780880.6 ^{ns}	3049636.3*	10163.6 ^{ns}	101.0^{ns}	12.2^{ns}
Error	80	717776.2	105.6	2841658.1	1584673.2	12207.8	101.6	8.2
CV%		16.64	9.74	12.78	15.54	26.60	22.79	9.19

GY; grain yield, PH; plant height, BIO; biomass, SY; straw yield, NP; number of panicle/m^2, NG; number of grains per panicle, TSW; 1000-seed weight,

To assess drought tolerance of oat genotypes and varieties Y_S, Y_P, STI, GMP, MP, TOL, SSI and HAM were calculated based on grain yield in stressed and non-stressed environment.

The drought stress intensity was 0.21 which is mild drought stress. The reason was raining at the anthesis time (two weeks before giving stress). The results revealed that Brusher, Tarahumara and Potoroo were the most tolerant varieties with STIs equal to 2.11,1.81 and 1.54 , respectively and IA91098-2, Kalott and Arnold were the most suscptible varieties with STIs equal to 0.35, 0.39 and 0.40, respectively (Table 3). According to SSI, Wintaroo and Kalott were the most tolerant and susceptible varieties, respectively. High value of TOL

index shows the susceptibility of the variety, therefore the tolerant genotypes are selected based on low TOL. As shown in Table 3, the highest and lowest TOL was calculated for Brusher and Wintaroo, respectively. Since genotypes which had lower amounts of this index , identified as tolerant genotypes, selection genotypes according to this index lead to choosing genotypes which had high grain yield in drought stress conditions and low yield in normal irrigation condition, so this index and SSI can not be helpful to identify tolerant genotypes [29]. Two varieties with low/high yield may have equal SSI rate in both conditions, so selection process on the basis of this index cause to breeders to make a mistake [22]. In Overall, highest STI, GMP, MP, and HAM indices was observed in Brusher (Y_P= 9700.22, Y_S= 7010.76 Kg/ha) and the least values was in IA91098-2 (Y_P= 3579.78, Y_S= 3188.36 Kg/ha).

Table 3. Resistance indices of oat genotypes under rainfed and irrigated conditions

Genotype	Y_S (Kg/ha)	Y_P (Kg/ha)	STI	GMP	MP	TOL	SSI	HAM	Reduction%
Ozark	3794.31	5302.71	0.62	4485.55	4548.51	1508.40	1.37	4423.46	28.45
UPF775456	3559.82	3884.30	0.43	3718.52	3722.06	324.48	0.40	3714.99	8.35
Wallaroo	4595.91	4906.84	0.70	4748.83	4751.38	310.93	0.31	4746.29	6.34
Euro	5594.13	6865.51	1.19	6197.30	6229.82	1271.38	0.89	6164.96	18.52
Wintaroo	4714.49	4912.40	0.72	4812.43	4813.45	197.91	0.19	4811.41	4.03
GA Mitchell	5436.93	5912.36	1.00	5669.66	5674.65	475.42	0.39	5664.69	8.04
Potoroo	6349.38	7837.42	1.54	7054.27	7093.40	1488.04	0.92	7015.36	18.99
13Zop95	4034.80	5339.60	0.67	4641.58	4687.20	1304.80	1.18	4596.40	24.44
Mortlock	3982.44	5793.11	0.71	4803.20	4887.78	1810.67	1.51	4720.09	31.26
OH1022	5015.73	6683.91	1.04	5790.05	5849.82	1668.18	1.20	5730.90	24.96
IA91098-2	3188.36	3579.78	0.35	3378.40	3384.07	391.42	0.53	3372.75	10.93
4Zop95	4494.76	5475.42	0.76	4960.92	4985.09	980.67	0.86	4936.86	17.91
Swan	3739.96	5201.64	0.60	4410.66	4470.80	1461.69	1.36	4351.33	28.10
Kalott	2861.02	4419.20	0.39	3555.76	3640.11	1558.18	1.70	3473.36	35.26
Tarahumara	6783.87	8607.02	1.81	7641.26	7695.45	1823.16	1.02	7587.46	21.18
C1/130	3813.02	4539.29	0.54	4160.34	4176.16	726.26	0.77	4144.58	15.99
UFRGS948886	4330.09	4713.11	0.63	4517.54	4521.60	383.02	0.39	4513.49	8.13
Nasta	3299.15	4460.84	0.46	3836.27	3880.00	1161.69	1.26	3793.04	26.04
Brusher	7010.76	9700.22	2.11	8246.57	8355.49	2689.46	1.34	8139.07	27.73
Arnold	2954.13	4320.84	0.40	3572.72	3637.49	1366.71	1.53	3509.11	31.63
Quoll	5020.66	6839.69	1.06	5860.02	5930.18	1819.03	1.28	5790.68	26.59

Yp; grain yield under irrigated conditions, Ys; Grain yield under rainfed conditions, STI ;stress tolerance index, GMP; geometric mean productivity, MP; mean productivity, TOL; tolerance index, SSI ; stress susceptibility index, HAM; harmonic mean

This study indicated that STI, GMP, MP and HAM were significantly correlated with grain yield in both conditions (Table 4). These indices are suitable to screen drought tolerant and high yielding genotypes (Genotypes19,15,7) in rainfed and irrigated conditions. Similar results were reported by some researchers [21,31]. The STI, GMP and MP were used in different plants for screening drought tolerant high yielding genotypes in the both conditions [12, 21]. Grain yield under stressed condition (Y_S) had significantly positive correlation ($r=0.923^{**}$) with grain yield under irrigated condition (Y_P) showing that the stress intensity was low. Therefore, indirect selection in mild drought stress will be efficient based on the results of irrigated condition for oat varieties [2]. This finding did not confirm the results of the other reported studies [11,21]. It could be due to high stress intensity in their experiments.

Table 4. Simple correlation between different drought tolerance indices (n=21)

	Ys	Yp	STI	GMP	MP	TOL	SSI	HAM
Ys	1							
Yp	.923**	1						
STI	.964**	.981**	1					
GMP	.979**	.982**	.992**	1				
MP	.975**	.986**	.992**	1**	1			
TOL	.388	.713**	.592**	.566**	.584**	1		
SSI	-.150	.234	.076	.048	.069	.835**	1	
HAM	.984**	.977**	.991**	1**	.999**	.548*	.027	1

Yp; grain yield under irrigated conditions, Ys; Grain yield under rainfed conditions, STI;stress tolerance index, GMP; geometric mean productivity, MP; mean productivity, TOL; tolerance index, SSI ; stress susceptibility index, HAM; harmonic mean

STI, GMP, MP, HAM had a positive correlation with NS, cell membrane stability (CMS) and GY under both conditions, which indicates that these parameters are suitable to select tolerant and highyield varieties in conditions. In this study Genotype 19 (Brusher) had the highest GY value. This genotype had the highest NE and CMS and lowest plant height. A significant positive correlation was found between CMS and STI, GMP, MP, HAM (Table 5) showing that the higher CMS could be used as an indicator to differentiate the tolerant verieties. Jabari et al (2006) evaluated the response of seven varieties of bread wheat to drought stress and found that there is a negative correlation between percentage of damage to cell membranes with grain yield [18]. They concluded that the grain yield will be higher when cell membrane maintain integrity under the drought stress. CMS is a measurement of resistance induced in plants that are exposed to desiccation created artifically by polyethylene glycol [30]. The mentioned indices had a negative correlation with NG under rainfed condition, which indicates that this parameter are not suitable for rainfed condition. In the case of PH, a negative correlation was observed between this trait and STI,MP,GMP,HAM in both condition (Table 5).

Table 5. Simple correlation coefficients between resistance indices and plant height, biomass, number of panicle, number of grain per panicle and grain yield of oat genotypes in irrigated (i) and rainfed (r) conditions.

	STI	GMP	TOL	SSI	HAM	MP
BYi	.518*	.502*	.257	-.038	.504*	.499*
BYr	.708**	.707**	.705**	.424	.699**	.715**
SYi	-.209	-.238	-.010	.105	-.239	-.237
SYr	.077	.074	.348	.410	.067	.081
TSWi	.305	.379	-.010	-.243	.384	.374
TSWr	.338	.399	.093	-.156	.401	.397
NPi	.562**	.564**	.426	.106	.559**	.568**
NPr	.558**	.558**	.256	-.091	.558**	.557**
NGi	-.227	-.274	.064	.251	-.278	-.270
NGr	-.407	-.465*	-.055	.233	-.469*	-.461*
PHi	-.685**	-.719**	-.271	.152	-.721**	-.716**
PHr	-.414	-.453*	-.236	.001	-.452*	-.454*
CMS	.666**	.687**	.329	-.03	.688**	.685**

Yp; grain yield under irrigated conditions, Ys; Grain yield under rainfed conditions, STI ;stress tolerance index, GMP; geometric mean productivity, MP; mean productivity, TOL; tolerance index, SSI ; stress susceptibility index, HAM; harmonic mean, PH; plant height, BIO; biomass, SY; straw yield, NP; number of panicles/m^2, NG; number of grains per panicle, TSW; 1000-seed weight, CMS; cell membrane stability.

A better approach than a correlation analysis such as a biplot is needed to identify superior genotypes for both stress and non-stressed environments, as the genotypes in biplot analysis are compareed simultaneously for all the attributes. The first two principal component analyses (PCAs) accounted for about 99.65% of total variation of data set. Therefore, the first two PCs were employed to generate biplot. PCA indicated that the indices could discriminate the oat genotypes. Biplot analysis (Figure 1) confirmed correlation analysis between all studied indices. PCA revealed that the first PCA explained 78.68% of the variation with Ys,Yp, STI, GMP, MP and HAM. The first dimension can be named as the yield potential and drought tolerance [2]. The second PCA explained 20.98% of the total variability. The second component can be named as stress- tolerant dimension and it separates the stress–tolerant genotypes from non-stress tolerant ones [23]. Therefore, selection of genotypes that have high PCA1 and low PCA2 are suitable for both stress and non stress environment [29]. Thus, genotypes 4 (Euro), 6 (GA Mitchell), 7 (Potoroo) and15 (Tarahumara) with higher PCA1 and lower PCA2 are superior genotypes under both stressed and non-stressed conditions (Figure 1). These genotypes have stable performance in the circumstances of low sensitivity to water stress and drought.These genotypes also had high Y_P,Y_S, GMP, MP, STI and HAM. These indices are able to separate and identify genotypes with high grain yield in both conditions [11]. Genotype 10 (OH1022), 19 (Brusher) and 21 (Quoll) had the highest values for STI, GMP, MP, HAM,Y_S and Y_P while their TOL were the highest . These genotypes are suitable for irrigated condition. Semi-drought tolerant genotypes are 1(Ozark),8(13Zop95),9 (Mortlock),13 (Swan),14 (Kalott),18 (Nasta) and 20 (Arnold). Genotypes 2 (UPF775456), 3 (Wallaroo), 5(Wintaroo), 11 (IA91098-2), 12 (4Zop95), 16 (C1/130) and 17 (UFRGS948886) had a relatively low yield potential, but they were more stable genotypes than the other groups.

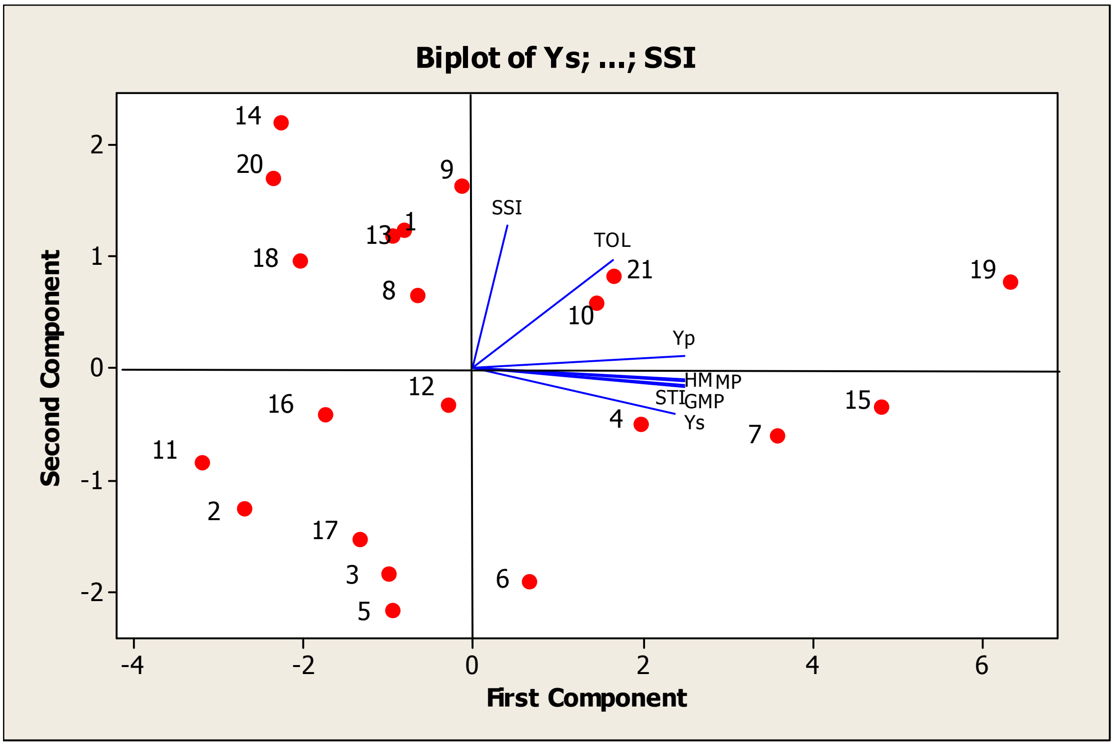

Figure 1. Principal Component analysis of drought tolerant indices.

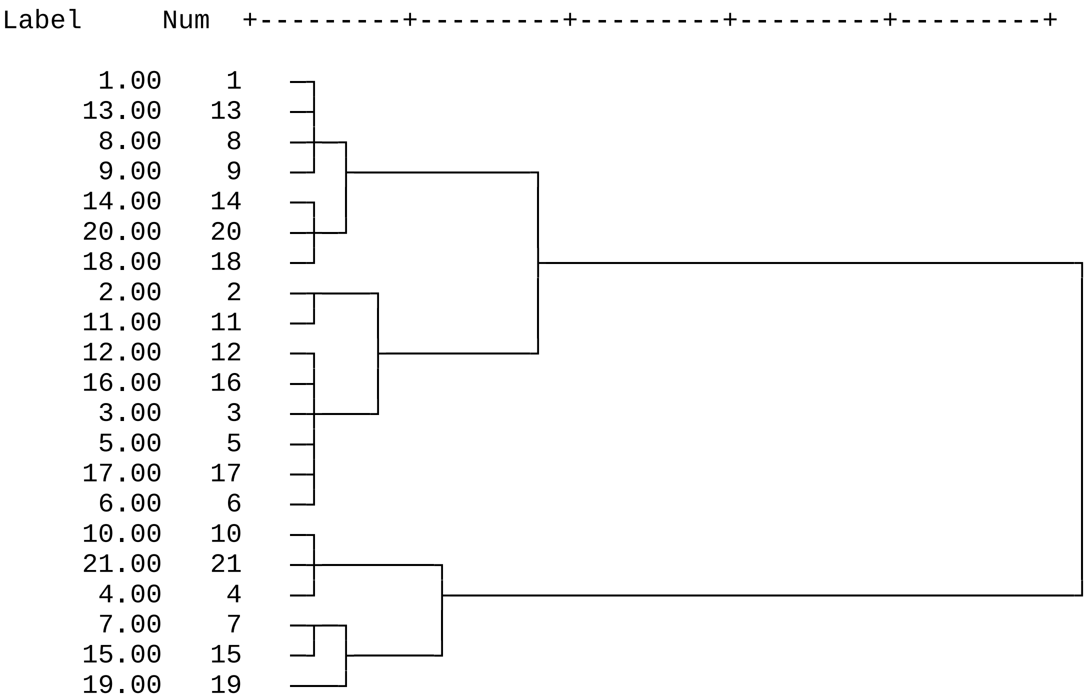

Fig 2. Dendrogram using average Ward method showing grouping of genotypes based on tolerant indices (The dotted line represents grouping based on discriminate analysis). The X-axis is a rescaled distance cluster combined.

Cluster analysis has been widely used for description of genetic diversity and grouping based on similar characteristics [17, 20]. In this study, cluster analysis showed that the genotypes tended to be categorized into three groups based on STI, GMP, MP, HAM, SSI and TOL (Figure 2). In this analysis ,the third group (Genotypes 10, 21, 4, 7, 15, 19) had the highest STI,GMP,MP,HAM and was thus considered to be the most desirable cluster for both conditions. The second group (Genotypes 2,11,12,16,3,5,17,6) had the lowest STI, GMP, MP, HAM and the lowest SSI ,TOL. Therefore, the genotypes of this group were considered to be stable in rainfed conditions. The first group (Genotypes 1,13,8,9,14,20,18) had the lowest STI,GMP,MP,HAM and highest SSI and TOL. Thus, they were susceptible to drought and only suitable for irrigated conditions.

CONCLUSION

Considering the results of this study as a first report of growing oat in Kermanshah, we can say that oat has a good potential to give the acceptable and well performance in rainfed and irrigated conditions when compared to the grain yield obtained in the other parts of the world with similar annual rainfall [2, 34]. In mild drought stress, there was no significant interaction between genotype and environment which could help to select genotypes easier. We concluded that STI, GMP, MP and HAM were significantly correlated with grain yield in both stressed and non-stressed conditions and therefore, these indices are suitable to screen drought tolerant and high yielding genotypes in rainfed and irrigated conditions. Based on the mentioned indices, Potoroo, Tarahumara and Brusher were the most tolerant varieties when the stress intensity is mild. According to biplot analysis Euro, GA Mitchell, Potoroo and Tarahumara were superior varieties. The other result that we need to insist on is a significant positive correlation that was found between CMS and STI, GMP, MP, HAM indicating that the higher CMS could be used as an indicator to know the tolerant verieties.

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