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Screening quantitative indicators of drought tolerance in bread wheat (*Triticum aestivum* L.) landraces

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ABSTRACT

In order to study the response of twenty different bread wheat (T. aestivum L.) landraces to drought stress, an experiment was conducted in a randomized complete block design with three replications under rainfed and irrigated conditions during 2010-2011 cropping season. Significant positive correlation was found between grain yield in the stress condition (Ys) with indices stress tolerance index (STI), geometric mean productivity (GMP), mean productivity (MP), yield index (YI), yield stability index (YSI), drought response index (DRI), drought resistance index (DI), relative drought index (RDI), abiotic tolerance index (ATI), stress non-stress production index (SNPI) and modified stress tolerance index (MSTI). Significant negative correlation was found between Ys with RDY and SSI indices. Principal component analysis (PCA), indicated that first and second PCA accounted for 98.87% of variations among the indices. Biplot diagram indicated that the most suitable indices for screening drought tolerant genotypes were GMP, MP, STI, K_1STI, K_2STI, YI, DRI, DI, SNPI, RDI and YSI. Screening drought tolerant genotypes using ranking method discriminated genotypes (18), (10), (2) and (5) as the most drought tolerant. Therefore they are recommended to be used as parents for genetic analysis, gene mapping and improvement of drought tolerance in common wheat.

Key words: Bread wheat landraces, drought tolerance indicators, Principal component analysis, ranking method.

INTRODUCTION

One possible way to ensure future food needs of the increasing world populations should involve a better use of water by the development of crop varieties which needs less amount of water and more tolerance of crops to drought [1].

In the absence of an understanding of the special mechanisms of tolerance the quantification of drought tolerance should be based on the grain yield in both stress and non-stress environments that can lead to selection of high yielding genotypes under stress condition since, the response of selection under non-stress condition is maximal and heritability of the yield under these conditions is high [2, 3, 4].

Thus, drought indices which provide a measure of drought based on yield loss under drought conditions in comparison to normal conditions have been used for screening drought-tolerant genotypes [5]. These indices are based on drought resistance or susceptibility of genotypes [6]. Drought resistance is defined by Hall [7] as the relative yield of a genotype compared to other genotypes subjected to the same drought stress. Drought susceptibility of a genotype is often measured as a function of the reduction in yield under drought stress [8] whilst the values are confounded with differential yield potential of genotypes [2, 9].

It is worthwile, therefore, to look at the methods that have been used to quantify tolerance. Several selection critera have been proposed to select genotypes based on their performance in stress and non–stress environments. Rosielle and Hamblin [10] defined stress tolerance (TOL) as the differences in yield between stress and irrigated environments and mean productivity (MP) as the average yield of genotypes under stress and non-stress conditions. Fischer and Maurer [11] suggested the stress susceptibility index (SSI) for measurement of yield stability that apprehended the changes in both potential and actual yields in variable environments. Clarke et al. [12] used SSI to evaluate drought tolerance in wheat genotypes and found year-to-year variation in SSI for genotypes and could rank their pattern. Guttieri et al. [13] suggested that SSI more and less than 1 indicates above and below-average susceptibility to drought stress, respectively. Fischer et al. [14] introduced another index as relative drought index (RDI). Bidinger et al. [15] suggested drought response index (DRI) with its positive values indicating stress tolerance.

The geometric mean productivity (GMP) is often used by breeders interested in relative performance, since drought stress can vary in severity in field environments over years [9]. Also, Gavuzzi et al. [16], Bouslama and Schapaugh [17] and Choukan et al. [18] introduced the yield index (YI), yield stability index (YSI), and yield reduction percentage (% Reduction), respectively. Fernandez [6] defined a new stress tolerance index (STI) and divided the manifestation of plants into the four groups of (1) – genotypes that express uniform superiority in non-irrigated and irrigated conditions (group A), (2) - genotypes which perform favorably only in non-stress conditions (group B), (3) - genotypes which yield relatively higher only in stress conditions (group C) and (4) - genotypes which perform poorly in non-irrigated and irrigated conditions (group D). Therefore, as Fernandez stated, the best index for stress tolerance selection is one that can be able to separate group A from others. To improve the efficiency of STI a modified stress tolerance index (MSTI) was suggested by Farshadfar and Sutka [19] which corrects the STI as a weight.

Moosavi et al. [20] introduced abiotic tolerance index (ATI), stress susceptibility percentage index (SSPI) and stress non-stress production index (SNPI) for screening drought tolerant genotypes in stress and nonstress conditions. Relative decrease in yield (RDY) was also proposed by Emre Dlker et al. [21] in wheat. However, the optimal selection criterion should distinguish genotypes that express uniform superiority in both stressed and non-stressed environments from the genotypes that are favorable only in one environment.

The objectives of the present investigations were: (i) screening quantitative indicator of drought tolerance and (ii) identification of drought-tolerant landraces of common wheat.

MATERIALS AND METHODS

Plant genetic materials

Twenty landraces of bread wheat (*Triticum aestivum* L.) listed in **Table 1** were provided from Seed and Plant Improvement Institute of Karaj, Iran. They were assessed using a randomized complete block design with three replications under two irrigated and rainfed conditions during 2010-2011 growing season in the experimental field of the College of Agriculture, Razi University, Kermanshah, Iran (47° 20′ N, 34° 20′ E and 1351 m above sea level). Mean precipitation in 2010–2011 was 509.50 mm. The soil of experimental field was clay loam with pH7.1.

Field operations

Sowing was done by hand in plots with three rows 2 m in length and 20 cm apart. The seeding rate was 400 seeds per m^2 for all plots. At the rainfed experiment, water stress was imposed after anthesis. Nonstressed plots were irrigated three times after anthesis, while stressed plots received no water. At harvest time, yield potential (Yp) and stress yield (Ys) were measured from 3 rows 1 m in length.

Drought tolerance indices calculation

Drought resistance indices were calculated using the following relationships:

Stress susceptibility index = $SSI = \frac{1-(Y_S/Y_P)}{1-(\bar{Y}_S/\bar{Y}_P)}$ [11], relative drought index = RDI= $(Ys/Y_p)/(\bar{Y}_S/\bar{Y}_P)$ [14],

Tolerance = TOL = $Y_P - Y_S$ and mean productivity = $MP = \frac{Y_S + Y_P}{2}$ [10], stress tolerance index =

$STI = \frac{Y_S \times Y_P}{\bar{Y}_P^2}$ and geometric mean productivity = $GMP = \sqrt{(Y_S \times Y_P}$ [6], yield index = $YI = \frac{Y_S}{\bar{Y}_S}$ [16], yield stability index = $YSI = \frac{Y_S}{Y_P}$ [17], drought response index = DRI= $(Y_A-Y_{ES}) /(S_{ES})$ [15], drought resistance index (DI) = Ys × (Ys/Yp)/ $\overline{Y}_S$ [22], modified stress tolerance index = MSTI = ki STI , $k_1 = Y_p^2/ \overline{Y}_P^{\,2}$ and $k_2 = Y_s^2/ \overline{Y}_S^{\,2}$ [19] where ki is the correction coefficient, relative decrease in yield (RDY) = 100-(Ys/100 x Yp) [21], abiotic tolerance index = ATI =[(Yp-Ys) / ($\overline{Y}_P / \overline{Y}_S$)]×[√Yp × Ys], stress susceptibility percentage index = SSPI=[Yp-Ys /2($\overline{Y}_P$)]×100 and stress non-stress production index = SNPI=[^{3}√(Yp+Ys) / (Yp - Ys)] × [^{3}√ Yp × Ys × Ys] [20],

In the above formulas, Y_S, Y_P, $\overline{Y}_S$ and $\overline{Y}_P$ represent yield under stress, yield under non-stress for each genotype, yield mean in stress and nonstress conditions for all genotypes, respectively. Y_A, Y_{ES} and S_{ES} are representative of yield estimate by regression in stress condition, real yield in stress condition and the standard error of estimated grain yield of all genotypes.

Statistical analysis

Correlation analysis and principal component analysis (PCA), based on the rank correlation matrix and biplot analysis were performed by SPSS ver. 16, STATISTICA ver. 8 and Minitab ver.16.

Rank sum (RS) = Rank mean ($\overline{R}$) + Standard deviation of rank (SDR) and SDR= $(S^2_i)^{0.5}$.

RESULTS AND DISCUSSION

Water stress consistently lowered the yield of wheat genotypes in non-irrigated rather than irrigated conditions (**Table 2**). Based on the stress tolerance index (STI) and grain yield, genotypes no. 18, 15, 5, 2, and 10 were found drought_tolerant with high STI and grain yield under rainfed and irrigated conditions, while genotypes no. 17, 6, 20, 16 and 4 displayed the lowest amount of STI and grain yield under rainfed condition. Other genotypes were identified as semi-tolerant or semi-sensitive to drought stress (**Table 2**).

According to tolerance index (TOL), genotypes 8, 4, 6 and 18 exhibited the most and genotypes 12, 16 and 13 the least relative tolerances, respectively. For stress susceptibility index (SSI) the genotypes 18, 2, 10, 5 and 15 were the most and 12, 16 and 17 were the least relative tolerant genotypes and for stress susceptibility percentage index (SSPI) genotypes 8, 4, 6, and 18 were the most and genotypes 12 and 16 the least relative tolerant genotypes. Genotypes 18, 15, 5, 2 and 10 revealed high geometric mean productivity (GMP) and mean productivity index (MP), while genotypes 17, 6, 4 and 20 showed the lowest amount. According to yield index (YI) and drought response index (DRI) genotypes 18, 15, 2, 5 and 10 were the most and 17, 6, 20 and 16 were the least relative tolerant genotypes. Based on yield stability index (YSI) genotypes 18, 2, 10, 5 and 15 were found drought_tolerant while genotypes 12, 16, 17 and 20 indicated the lowest amount of YSI. Based on the Drought resistance index (DI) genotypes 18, 15, 2, 5 and 10 were the most and genotypes 17, 12, 16 and 6 were the least relative tolerant genotypes and for drought response index (DRI) genotypes 18, 2, 10 and 5 were found drought_tolerant, while genotypes 12, 16, 17 and 13 exhibited the lowest amount. Using k_1STI as the optimal selection criteria the most desirable genotype for irrigated and rainfed conditions were 15, 18, 5, 2 and 2 while, genotypes 17, 6, 4 and 8 displayed the lowest amount of k_1STI. Genotypes 18, 15, 2, 5 and 10 showed the highest and 17, 6, 20 and 4 revealed the lowest amount of k_2STI. With regard to abiotic tolerance index (ATI) genotypes 6, 4, 8 and 17 were found drought_tolerant with the lowest amount of ATI, while genotypes 12, 15, 16 and 5 were sensitive and showed high ATI. With regard to stress non-stress production index (SNPI), which indicates relative resistance, genotypes 18, 15, 2, 5 and 10 were the most and 17, 6, 20 and 16 the least relative tolerant genotypes (**Table 2**). The highest amount of relative decrease in yield (RDY) was attributed to genotypes 17, 6, 4, 20 and 8, while genotypes 18, 15, 5, 2 and 10 had the lowest RDY.

Correlation analysis

Yield in stress (Ys) and non-stress (Yp) conditions were significantly and positively correlated with DI, RDI, ATI, SNPI, K_1STI, K_2STI, STI, GMP, MP, YI, YSI and DRI indicating that these criteria are able to discriminate group A (genotypes that express uniform superiority in non-irrigated and irrigated conditions) [6] from the others and negatively correlated with RDY and SSI (**Table 3**). Significant correlation were not observed between SSPI and TOL with yield in stress (Ys) and non-stress (Yp) conditions. Khalilzade and Karbalayi Khiavi [23] and Farshadfar et al. [24] believe that the most suitable indices for selection of drought tolerant cultivars, are indicators which show a relatively high correlation with grain yield in both stress and nonstress conditions.

Lan [22] defined new index of drought resistance index (DI) which was commonly accepted to identify genotypes producing high yield under both stress and nonstress conditions. Obviously, compared with yield stability index(YSI), DI and STI consider not only the ability of genotypes to grow well under stressed environments, but also good performance in non-stressed environments. Thus, they identify materials which are compatible with stressful and optimal conditions, to achieve ideotypes that can tolerate long intervals between irrigations or possibly no irrigation at sensitive growth stages [25]. Selection through SSI chooses genotypes with relatively low YP but high YS. This index ranges between 0 and 1 and the greater this index, the greater susceptibility of the genotype to stress. The main disadvantage of this index is the lack of separation of group A from group C [6]. Clarke et al. [12] showed that yield-based SSI index did not differentiate between potentially drought resistant genotypes and those that possessed low overall yield potential. Similar limitations were reported by White and Singh [26]. Selection through TOL chooses genotype with low YP but with high YS (group C), hence, TOL deficiencies to distinguish between group C and group A [6]. MP is mean yield for a genotype in two stress and non-stress conditions. MP can select genotypes with high YP but with relatively low YS (group B) and it fails to distinguish group A from group B. By decreasing TOL and increasing MP, the relative tolerance increases [6, 10]. A high STI demonstrates a high tolerance, and the best advantage of STI is its ability to separate group A from others. MP, GMP and STI values are useful to select higher yielding genotypes in both conditions. However, drought tolerance can be defined as an ability of plant to be stable in stressed environment compared to non-stress conditions. Therefore, a genotype with higher yielding capacity can not be always perceived as tolerant. GMP is more powerful than MP in separating group A and has a lower susceptibility to different amounts of YS and YP, so MP, which is based on arithmetic mean, will be bias when the difference between YS and YP is high. The higher GMP value, the greater the degree of relative tolerance. Talebi et al. [2] also reported that cultivars producing high yield in both drought and well watered conditions can be identified by STI, GMP and MP values. Pireivatlou et al. [27] was also noted that STI can be a reliable index for selecting high yielding genotypes. Our findings indicated that RDY, TOL and SSI values can be used for determining tolerance levels of wheat genotypes whereas STI, GMP and MP values are better parameters to identify high yielding genotypes under both drought and favorable conditions. İlker et al. [21] concluded that MP, GMP and STI values are convenient parameters to select high yielding wheat genotypes in both stress and non-stress conditions whereas in relation to relative decrease in yield, TOL and SSI values are better indices to determine tolerance levels.

ATI or SSPI select genotypes especially on the basis of yield stability, while, selection by SNPI is based on two characteristics simultaneously, namely yield stability as well as high YP and YS (with more emphasis on high YS than high YP) so, this index has a very strong and significant positive correlation with Ys in both data sets (**Table 3**). Although SNPI and STI are very similar and highly correlated, but in addition to high yield in stress and non-stress conditions and stable yield more emphasized is on SNPI than on STI and these characteristics, make SNPI a better index than STI for identifying genotypes with stable and high yield in both stress and non-stress conditions [20].

Biplot diagram

Biplot diagram showed that the first component (PCA_1) was high and the second component (PCA_2) was low for genotypes 2, 5 10, 15 and 18 (**Fig. 1**). The biplot diagram also indicated that the most suitable indices for screening drought tolerant genotypes were GMP, MP, STI, K_1STI, K_2STI, YI, DRI, DI, SNPI, RDI and YSI. According to the most suitable indices the genotypes 2, 5, 10, 15 and 18 were identified as drought tolerant with yield stability.

Screening drought tolerance indicators and drought tolerant genotypes

(i) *Principal component analysis*

To better understand the relationships, similarities and dissimilarities among the non-parametric stability estimates, principal component analysis (PCA), based on the rank correlation matrix was used. The main advantage of using PCA over cluster analysis is that each statistics can be assigned to one group only [28].

The relationships among different indices are graphically displayed in a biplot of PCA_1 and PCA_2 (**Fig. 2**). The PCA_1 and PCA_2 axes which justify 98.87% of total variation, mainly distinguish the indices in different groups. Indices RDI and YSI we refer to group 1(G_1). The PCs axes separated SNPI, DI, STI, YI, DRI, K_1STI, K_2STI, GMP, MP, Ys and Yp in a single group 2 (G_2). ATI was separated as groups 3 (G_3), TOL, SSPI and SSI were separated as groups 4 (G_4) and RDY in a single group 5 (G_5). The cosine of the angle between the vectors of two indices approximates the correlation between them. For example, G_1 indices were positively correlated (an acute angle), the same conclusion was obtained for the G_2 indices, while G_1 was negatively correlated with G_4 indices (an obtuse angle). Independence (right angle), negative (obtuse angle) or very weak correlation (almost right angle) were observed between G_1 with G_2 and G_2 with G_3 indices. The cosine of the angles does not precisely translate into correlation coefficients, since the biplot does not explain all of the variation in a dataset. Nevertheless, the angles are informative enough to allow a whole picture about the interrelationships among the stability estimates [29]. Similarly Moosavi et al. [20] in wheat observed that TOL and SSI showed a negative relationship with Ys. Using

STI, k_1STI and k_2STI as the optimal selection criteria the most desirable genotypes for irrigated and rainfed conditions were 2, 5, 10, 15 and 18. A three-dimensional plot between Yp, Ys and STI (**Fig. 3**) was used to distinguish the group A genotypes from the other three groups (B, C and D) [6, 24]. In this case the most desirable genotypes for irrigated and rainfed conditions were identified as genotypes 2, 5, 10, 15 and 18.

(ii) Ranking method

The calculation of indicators (**Table 2**) exhibited that the identification of drought tolerant genotypes based on a single criterion was contradictory. For example, according to STI genotypes no. 18, 15, 5, 2, and 10 were found drought tolerant, while according to TOL genotypes 8, 4, 6 and 18 exhibited the most relative tolerances. To determine the most desirable drought tolerant genotypes according to the all indices mean rank and standard deviation of ranks of all criteria were calculated and based on these two criteria the most desirable drought tolerant lanraces were identified.

In consideration to all indices, genotypes (18), (10), (2) and (5) showed the best mean rank and low standard deviation of ranks in stress condition, hence they were identified as the most drought tolerant genotypes, while genotypes (17), (6), (12) and (16) as the most sensitive, therefore they are recommended for crossing and genetic analysis of drought tolerance using diallel mating design or generation mean analysis and also for the QTLs (quantitative trait loci) mapping and marker assisted selection. The same procedures have been used for screening quantitative indicators of drought tolerance in wheat [30], in maize (*Zea mays* L.) [19], and in rye (*Secale cereale* L.) [31, 32].

Table 1. Genotype codes

Genotype	Code	Genotype	Code
WC – 5047	1	WC – 47636	11
WC – 4530	2	WC – 4584	12
WC - 4780	3	WC – 46697 – 11	13
WC – 4566	4	WC – 4823	14
WC – 47360	5	Pishtaz	15
WC – 4640	6	WC– 47341	16
WC – 47456	7	WC – 47619	17
WC - 47628	8	WC – 4931	18
WC – 47367	9	WC – 47381	19
WC – 47399	10	WC - 5053	20

Table 2. Ranks (R), ranks mean ($\overline{R}$) and standard deviation of ranks (SDR) of drought tolerance indicators

Genotypes	Y_S (g/m^2)	R	Y_P (**g**/m^2)	R	STI	R	GMP (g/m^2)	R	MP (g/m^2)	R	SSI	R	TOL (g/m^2)	R
1	267.79	7	377.71	13	0.62	10	318.04	10	322.75	12	1.00	10	109.92	10
2	413.84	3	507.12	4	1.30	4	458.11	4	460.48	4	0.63	2	93.28	6
3	242.38	14	370.39	15	0.56	15	299.62	15	306.39	15	1.19	15	128.01	14
4	228.25	16	301.39	18	0.43	18	262.28	18	264.82	18	0.84	7	73.14	2
5	410.82	4	516.40	3	1.31	3	460.59	3	463.61	3	0.71	4	105.58	9
6	199.27	19	279.75	19	0.35	19	236.37	19	239.74	19	0.99	9	80.03	3
7	286.43	6	388.17	12	0.69	6	333.44	6	337.30	6	0.90	8	101.74	8
8	248.29	13	317.46	17	0.49	16	280.75	16	282.88	16	0.75	5	69.17	1
9	254.33	11	372.61	14	0.59	13	307.84	13	313.47	14	1.10	11	118.28	12
10	383.88	5	472.81	5	1.12	5	426.03	5	428.35	5	0.65	3	88.93	5
11	266.85	9	400.34	10	0.66	8	326.85	8	333.60	8	1.15	12	133.49	16
12	230.31	15	429.76	6	0.60	12	314.61	12	330.04	9	1.60	20	199.45	20
13	251.76	12	401.62	9	0.61	11	317.98	11	326.69	10	1.29	17	149.86	18
14	259.01	10	391.74	11	0.63	9	318.54	9	325.38	11	1.17	13	132.73	15
15	435.24	2	560.58	1	1.51	2	493.95	2	497.91	2	0.77	6	125.34	13
16	227.71	17	404.84	8	0.57	14	303.62	14	316.28	13	1.51	19	177.13	19
17	150.29	20	250.78	20	0.23	20	194.14	20	200.54	20	1.38	18	100.49	7
18	464.29	1	547.87	2	1.58	1	504.35	1	506.08	1	0.53	1	83.58	4
19	267.41	8	406.95	7	0.67	7	329.88	7	337.18	7	1.18	14	139.54	17
20	219.42	18	337.35	16	0.46	17	272.07	17	278.39	17	1.21	16	117.93	11

Table 2 continued

Genotypes	YI	R	YSI	R	DRI	R	DI	R	RDY	R	RDI	R	ATI	R
1	0.95	7	0.70	10	1.09	7	0.6652	8	-9.11	11	0.9981	10	248.3	7
2	1.45	3	0.82	2	2.81	3	1.1834	3	-19.98	4	1.1489	2	303.52	13
3	0.85	14	0.64	15	0.79	14	0.5557	14	-7.97	15	0.9213	15	272.42	10
4	0.80	16	0.76	7	0.63	16	0.6057	12	-5.87	18	1.0662	7	136.25	2
5	1.44	4	0.80	4	2.77	4	1.1452	4	-20.21	3	1.12	4	345.4	17
6	0.70	19	0.71	9	0.29	19	0.4973	17	-4.57	19	1.0028	9	134.96	1
7	1.00	6	0.74	8	1.31	6	0.7406	6	-10.11	6	1.0388	8	240.95	6
8	0.87	13	0.78	6	0.86	13	0.6804	7	-6.88	16	1.1011	5	137.93	3
9	0.89	11	0.68	11	0.93	11	0.6083	11	-8.47	13	0.9609	11	258.62	8
10	1.35	5	0.81	3	2.45	5	1.0921	5	-17.15	5	1.143	3	269.1	9
11	0.93	9	0.67	12	1.07	9	0.6232	9	-9.68	8	0.9384	12	309.9	14
12	0.81	15	0.54	20	0.66	15	0.4324	19	-8.89	12	0.7544	20	445.69	20
13	0.88	12	0.63	16	0.91	12	0.553	15	-9.12	10	0.8825	17	338.46	16
14	0.91	10	0.66	13	0.99	10	0.600	13	-9.14	9	0.9308	13	300.3	12
15	1.53	2	0.79	5	3.06	2	1.19	2	-23.39	2	1.0931	6	439.74	19
16	0.79	17	0.56	19	0.62	17	0.4488	18	-8.21	14	0.7918	19	381.99	18
17	0.53	20	0.60	18	-0.29	20	0.3156	20	-2.76	20	0.8437	18	138.56	4
18	1.63	1	0.85	1	3.40	1	1.3787	1	-24.43	1	1.1931	1	299.4	11
19	0.94	8	0.65	14	1.08	8	0.6157	10	-9.88	7	0.9251	14	326.95	15
20	0.77	18	0.62	17	0.53	18	0.5	16	-6.40	17	0.9157	16	227.89	5

Table 2 continued.

Genotypes	SSPI	R	SNPI	R	K_1STI	R	K_2STI	R	$\overline{R}$	RS	SDR
1	13.679	10	570.58	7	0.5479	13	0.5459	9	9.50	11.5	2.00
2	11.608	6	978.69	3	2.0711	4	2.7339	3	4.05	6.55	2.50
3	15.93	14	499.71	15	0.4726	15	0.4011	13	14.27	15.49	1.22
4	9.101	2	503.3	14	0.2397	18	0.2726	17	12.55	18.79	6.24
5	13.138	9	944.35	4	2.1709	3	2.7234	4	4.94	8.44	3.50
6	10.015	3	423.92	19	0.1677	19	0.1687	19	14.44	21.15	6.71
7	12.661	8	621.26	6	0.6428	9	0.6938	6	7.05	8.67	1.62
8	8.607	1	563.21	8	0.3048	17	0.3696	15	10.44	16.28	5.84
9	14.719	12	531.48	12	0.5048	14	0.4662	12	11.88	13.37	1.49
10	11.066	5	901.14	5	1.557	5	2.0344	5	4.88	6.15	1.27
11	16.612	16	552.91	9	0.657	8	0.5786	8	10.27	13.00	2.73
12	24.82	20	459.33	16	0.6864	7	0.3907	14	15.11	19.81	4.70
13	18.649	18	511.83	13	0.6095	10	0.47474	11	13.22	16.29	3.07
14	16.517	15	535.15	11	0.5975	11	0.5177	10	11.38	13.29	1.91
15	15.598	13	980.22	2	2.9422	1	3.5156	2	4.66	9.78	5.12
16	22.043	19	455.15	17	0.5797	12	0.3635	16	16.11	19.15	3.04
17	12.505	7	303.02	20	0.0909	20	0.0647	20	17.33	22.63	5.30
18	10.401	4	1152.95	1	2.9299	2	4.1708	1	2.00	4.44	2.44
19	17.365	17	550.56	10	0.6915	6	0.5919	7	10.16	14.01	3.85
20	14.675	11	450.76	18	0.3232	16	0.271	18	15.66	19.03	3.37

Table 3 . Correlation coefficients between drought tolerance indices

	DI	RDY	RDI	ATI	SSPI	SNPI	K_1STI	K_2STI	STI	GMP	MP
DI	1										
RDY	-0.958**	1									
RDI	0.854**	-0.674**	1								
ATI	0.290	-0.537*	-0.210	1							
SSPI	-0.397	0.133	-0.790**	0.755**	1						
SNPI	0.995**	-0.977**	0.804**	0.366	-0.316	1					
K_1STI	0.933**	-0.988**	0.640**	0.529*	-0.129	0.954**	1				
K_2STI	0.958**	-0.978**	0.714**	0.413	-0.249	0.971**	0.990**	1			
STI	0.959**	-1.00**	0.676**	0.534**	-0.136	0.978**	0.988**	0.979**	1		
GMP	0.946**	-0.933**	0.654**	0.582**	-0.082	0.968**	0.965**	0.948**	0.993**	1	
MP	0.934**	-0.990**	0.624**	0.612**	-0.043	0.959**	0.963**	0.942**	0.990**	0.999**	1
SSI	-0.853**	0.673**	-1.00**	0.211	0.791**	-0.803**	-0.638**	-0.713**	-0.675**	-0.653**	-0.623**
TOL	-0.396	0.133	-0.790**	0.756**	1.00**	-0.315	-0.128	-0.248	-0.135	-0.081	-0.042
YI	0.985**	-0.990**	0.759**	0.451*	-0.234	0.994**	0.963**	0.965**	0.990**	0.988**	0.981**
YSI	0.861**	-0.685**	1.00**	-0.196	-0.782**	0.812**	0.651**	0.723**	0.687**	0.664**	0.635**
DRI	0.985**	-0.989**	0.759**	0.451*	-0.234	0.994**	0.962**	0.965**	0.990**	0.988**	0.981**
Yp	0.854**	-0.953**	0.462*	0.754**	0.154	0.886**	0.928**	0.883**	0.952**	0.972**	0.980**
Ys	0.985**	-0.989**	0.760**	0.450*	-0.235	0.994**	0.962**	0.964**	0.990**	0.988**	0.981**

Table 3 continued.

	SSI	TOL	YI	YSI	DRI	Yp	Ys
SSI	1						
TOL	0.790**	1					
YI	-0.758**	-0.233	1				
YSI	-0.999**	-0.781**	0.768**	1			
DRI	-0.758**	-0.233	1.00**	0.768**	1		
Yp	-0.46*	0.155	0.925**	0.474*	0.925**	1	
Ys	-0.759**	-0.234	1.00**	0.769**	1.00**	0.924**	1

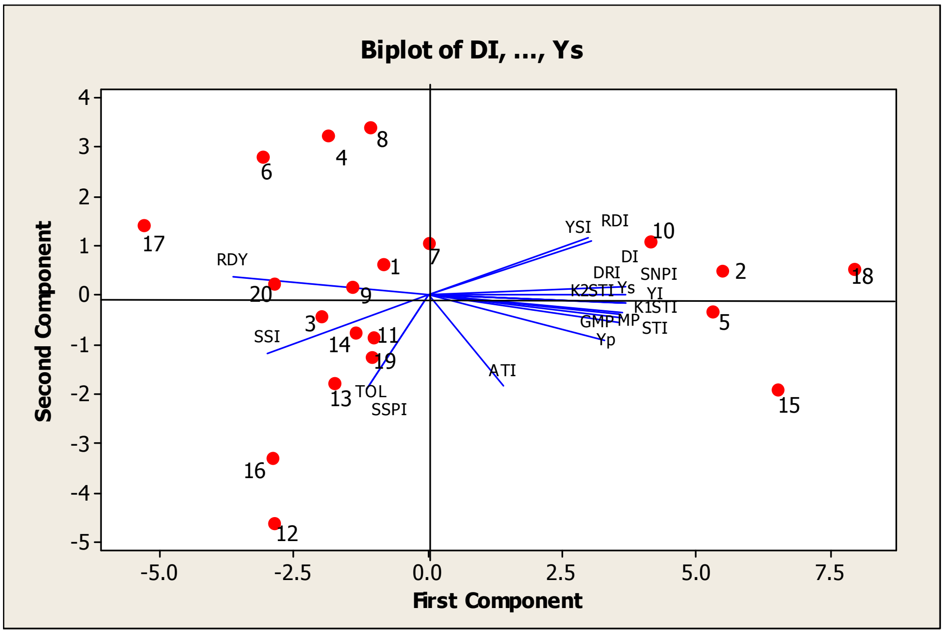

Fig. 1. Biplot based on first and second components of drought tolerance indices

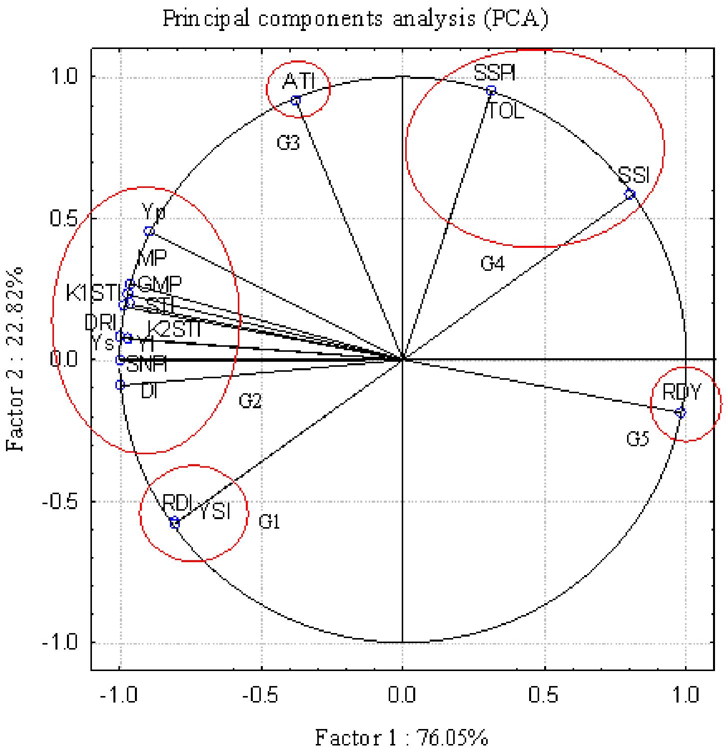

Fig. 2. Screening drought tolerance indicators using biplot analysis.

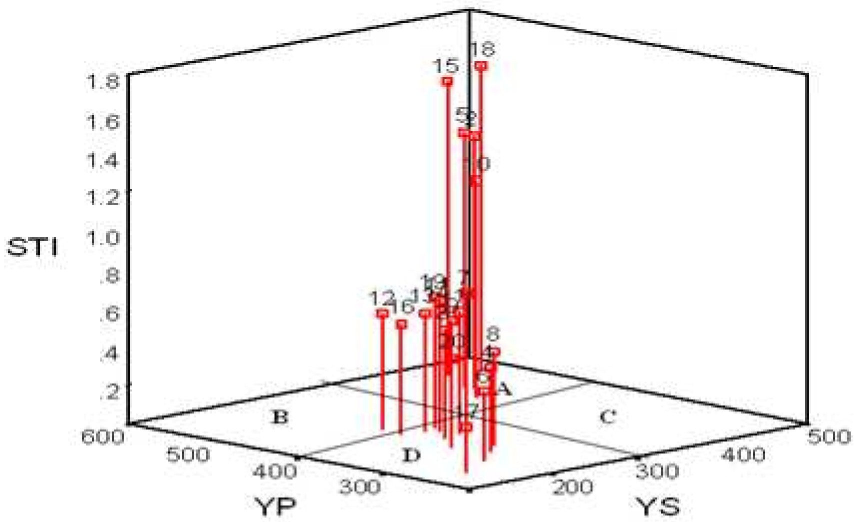

Fig. 3. Three-dimensional plot between Yp, Ys and STI

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