Introduction of new indices to identify relative drought tolerance and resistance in wheat genotypes

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Abstract

Three new indices namely: abiotic-stress tolerance index (ATI) (Abiotic-stress Tolerance Index)[†], stress susceptibility percentage index (SSPI) (Stress Susceptibility Percentage Index) and stress non-stress production index (SNPI) were introduced to identify relatively tolerant (through ATI and SSPI) and resistant (through SNPI) genotypes under non-irrigated and irrigated conditions. Sixteen bread wheat genotypes (in 2004, under a moderate stress with SI = 0.31) and twenty durum wheat genotypes (2004 and 2005 under a severe stress with SI = 0.57) were studied in field experiments under non-irrigated and irrigated conditions. Yield changes in non-irrigated and irrigated conditions for different genotypes, the primary selection of genotypes for relative drought tolerance or resistance and a comparison between new indices and previous ones were studied. In this paper, "relative tolerance and resistance" phrases are used instead of "tolerance and resistance" because we believe that, generally, there are no complete tolerance and resistance to abiotic-stress. ATI and SSPI exhibited a positive significant simple correlation with TOL, Yp and SSI, but their correlations with RDI were significantly negative. ATI and SSPI differentiated between relative tolerant and intolerant genotypes better than TOL and SSI in some cases and were considered as a favorite index for the selection of relatively tolerant genotypes. ATI and SSPI are powerful to select extreme tolerant genotypes with yield stability and may be can use of them as parents in conformation to a QTL population for yield stability in two irrigated and non-irrigated conditions, because, both of them are related to relatively yield stability and may be state that a genotype with suitable yield stability carries drought tolerance or other related trait genes. SNPI had a positive correlation with yield changes in both non-irrigated and irrigated conditions and negative correlation with SSI and TOL, therefore, to select a genotype with appropriate, high and stable yield in both stress and non-stress conditions for commercial aims, it is suggested to use SNPI as a desirable index because this index supports stable and high yield in both conditions (especially in non-irrigated condition) simultaneously.

Key words: Drought stress indices; Relative tolerance; Relative resistance; Wheat

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[†] *Abbreviations:* ATI, Abiotic-stress Tolerance Index; SSPI, Stress Susceptibility Percentage Index; SNPI, Stress Non-stress Production Index; Yp, Potential Yield; Ys, Yield under Stress; MP, Mean Productivity; GMP, Geometric Mean Productivity; TOL, Tolerance Index; SSI, Stress Susceptibility Index; STI, Stress Tolerance Index; BWG, Bread Wheat Genotype; DWG, Durum Wheat Genotype; RT, Relative Tolerance; RR, Relative Resistance; HARM, Harmonic Mean; DRI, Drought Response Index; RDI, Relative Drought Index; SI, Stress Intensity = [1- (Mean stress yield / Mean potential yield)]; NIC, Non-irrigated and Irrigated Conditions.

1. Introduction

Plants have had to cope with periodic and unpredictable environmental stresses during growth and development because of their early migration from aquatic environments to the land. Surviving such stresses over a long evolutionary scale led them to acquire mechanisms by which they can sensitively perceive incoming stresses and regulate their physiology accordingly (Zhang et al., 2006).

In recent years, interest in crop response to environmental stresses has greatly increased because severe losses may result from heat, cold, drought and high concentrations of toxic mineral elements (Blum, 1996). Drought is one of the most damaging abiotic stresses affecting agriculture. It is an important abiotic factor affecting the yield and yield stability of food cereals and this stress acts simultaneously on many traits leading to a decrease in yield (Boyer, 1982; Ludlow and Muchow, 1990; Teulat et al., 2001; Abebe et al., 2003; Zhang et al., 2006). Despite the lack of understanding of drought tolerance mechanisms, physiological and molecular biological studies have documented several plant responses to drought stress (Schroeder et al., 2001; Luan, 2002). Hence, improved tolerance to drought has been a goal in crop improvement programs since the dawn of agriculture, but unfortunately, success in breeding for tolerance has been limited because (I) it is controlled by many genes, and their simultaneous selection is difficult (Richards, 1996; Yeo, 1998; Flowers et al., 2000) (II) tremendous effort is required to eliminate undesirable genes that are also incorporated during breeding (Richards, 1996) and (III) there is a lack of efficient selection procedures particularly under field conditions (Ribaut et al., 1997; Kirigwi et al., 2004). Drought and heat stresses cause declines in: root growth, leaf water potential, cell membrane stability, photosynthetic rate, photochemical efficiency, as well as in carbohydrate accumulation (Howard and Watschke, 1991; Carrow, 1996; Perdomo et al., 1996; Huang et al., 1998; Huang and Gao, 1999; Guttieri et al., 2000; Jiang and Huang, 2000).

Wheat grows as a rain-fed crop in semi-arid areas, where large fluctuations occur in the amount and frequency of events from year to year and insufficient water is the primary limitation to wheat production worldwide (Ashraf and Harris, 2005).

Generally, different strategies have been proposed for the selection of relative drought tolerance and resistance, so, some researchers have proposed selection under non-stress conditions (Richards, 1996; Rajaram and Van Ginkle, 2001;

Betran et al., 2003), others have suggested selection in the target stress conditions (Ceccarelli and Grando, 1991; Rathjen, 1994) while, several of them have chosen the mid-way and believe in selection under both non-stress and stress conditions (Fischer and Maurer, 1978; Clarke et al., 1992; Fernandez, 1992; Byrne et al., 1995; Rajaram and Van Ginkle, 2001). In a study on wheat (Sio-Se Mardeh et al., 2006), was resulted that grain yield under irrigated conditions was adversely correlated with rain-fed conditions and they stated that, a high potential yield under optimum conditions does not necessarily result in improved yield under stress conditions. Also, Blum (1996) suggested that genotypes with high yield may not be stress resistant, so increasing the yield in these genotypes may be solely due to their high potential yield, and not due to stress resistance mechanism. However, Richard believed that yield selection in the absence of drought is an effective method to improve yield in dry areas (Richard et al., 1990).

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

or may not be a relatively resistant genotype. Many criteria have been suggested to increase stress tolerance, particularly drought stress, in crops. However, selection of genotypes based on these criteria has generally been unsuccessful due to their higher relation with survival mechanism of crops (rather than emphasis on stability and high yield in both conditions) and because of drought relationship with many other stress factors of salt, cold, high temperature, acid, alkaline, pathological reactions, senescence, development, cell circle, UV-B damage, wounding, embryogenesis, flowering, signal transduction, etc. Therefore, drought stress is connected with almost all aspects of biology and suggestion of a suitable index for its selection is really complex and difficult.

Fernandez (1992), divided the manifestation of plants into the four groups of (I)– genotypes that express uniform superiority in NIC (group A), (II)-genotypes which perform favorably only in non-stress conditions (group B), (III)- genotypes which yield relatively higher only in stress conditions (group C) and (IV)-genotypes which perform poorly in NIC (group D).Therefore, as Fernandez stated, the best index for stress tolerance selection is one that can be able to separate group A from others .We believe the best index for RT or RR depends on the selection aims(only selection for stability without attention to high yield or selection for commercial aims with attention to stable and high yield) and the conditions of selection (the selection aim is for non-irrigated or irrigated conditions).

Objectives of the work reported here were:
Testing of a new index (ATI) that can select group C with more emphasis on Y_P than SSI and TOL for identification of relative tolerant genotypes (stable yield in non-irrigated and irrigated conditions), testing of a new index (SSPI) for better understanding of yield changes and identification of relative tolerant genotypes (stable yield in non-irrigated and irrigated conditions), testing of a new index (SNPI) for selection of relatively resistant genotypes with relatively stable and high yield in non-irrigated and irrigated conditions and a basic study on the different wheat genotypes according to these indices and a comparison between the new indices and previous ones.

2. Materials and Methods

2.1. Plant materials

To obtain above mentioned aims, 16 bread wheat genotypes (BWGs) (*Triticun aestivum* L.,

Table 1) in 2004 and 20 durum wheat genotypes (DWGs) (Table 4) in 2004-2005 years were cultured in farm conditions in two distinct environments (drought stress and non-stress) according to randomized complete block design of 5 replicates in each environment so the longitude and latitude were $50^\circ\ 55'\ 54.45''$ and $35^\circ\ 46'\ 59.38''$ respectively. Sowing was done in November and harvesting in July for each year so, the season growing was about 9 months and the average of rainfall was about 306mm and 289 mm in the duration of season growing in 2004 and 2005 respectively. Soil texture was loam-clay, seeds were protected by fungicide but were not use any herbicide, and weed was controlled by hand. In non-stress conditions, the crops were irrigated normally (irrigation in each 14 days after winter season till harvesting) but in stress conditions the seeds were irrigated twice immediately after sowing to induce germination. Fertilizer was applied before (80 kg ha^{-1} P$_2$O$_5$) and after sowing (40 kg ha^{-1} N).

2.2. Previous indices

Some of the previous criteria that were used in this research are including:
 SSI or stress susceptibility index is calculated by (Fischer and Maurer, 1978):

$$SSI = [(1-(Y_s/Y_p))]/[1-(\overline{Y}_S/\overline{Y}_P))]$$

Rosielle defined TOL and mean productivity index (MP) (Rosielle and Hamblin, 1981).

$$TOL = [Y_p - Y_s]$$

$$MP = [Y_p + Y_s]/2$$

Fernandez (1992) suggested STI, as stress tolerance index to use for identification of high yield genotypes in both conditions and geometric mean productivity (GMP) as well:

$$STI = [Y_p * Y_s]/[\overline{Y}_P \overline{Y}_P]$$

$$GMP = \sqrt{Y_p * Y_s}$$

The other index defined as harmonic mean is represented as:

$$HARM = [2(Y_p * Y_s)]/[Y_p + Y_s]$$

Bidinger et al. (1978) suggested drought response index (DRI) with its positive values indicating stress tolerance as:

$$DRI = [Y_A - Y_{ES}]/[S_{ES}]$$

Fischer et al. (1979) introduced another index as relative drought index (RDI):

$$RDI = [Y_S / Y_p] / [\overline{Y}_S / \overline{Y}_P]$$

In the above formulas, Y_S, Y_P, $\overline{Y}_S$ and $\overline{Y}_P$ represent yield in stress and non-stress conditions for each genotype, and yield mean in stress and non-stress conditions for all genotypes, respectively. Y_A, Y_{ES} and S_{ES} are representative of yield estimate by regression in stress conditions, real yield in stress conditions, and the standard error of estimated grain yield of all genotypes. Mentioned indices have been used in different studies (Salim and Saxena, 1993; Garrity and O'Toole, 1994 ; Abebe et al., 1998; Pantuwan et al. ,2002b and Yue et al., 2005; Sio-Se Mardeh et al., 2006) and some them can't easily separate Fernandez's groups from each other. Although STI and GMP can separate group A, but they have little emphasis on stability of yield between the two conditions. In this research, new indices have been proposed (ATI and SSPI) that are able to separate relative tolerant and non tolerant genotypes better than previous indices, along with a new index (SNPI) is able to separate group A from others and has an emphasis on high and stable yield in both environmental conditions.

2.3. Introducing suggested indices

In this study, three new indices are introduced to identify relative abiotic-stress tolerance and resistance. These new indices are abiotic tolerance index (ATI), stress susceptibility percentage index (SSPI) and stress non-stress production index (SNPI) as follows:
1. Abiotic tolerance index (ATI):

$$ATI = [(Y_p - Y_s)/(\overline{Y}_p / \overline{Y}_s)] * [\sqrt{Y_p * Y_s}]$$

2. Stress susceptibility percentage index (SSPI):

$$SSPI = [\frac{Y_p - Y_s}{2(\overline{Y}_p)}] * 100$$

3. Stress non-stress production index (SNPI):

$$SNPI = [\sqrt[3]{(Y_p + Y_s)/(Y_p - Y_s)}] * [\sqrt[3]{Y_p * Y_s * Y_s}]$$

Where, Y_P and Y_S represent yield in stress and non-stress conditions respectively; $\overline{Y}_P$ and $\overline{Y}_S$ are mean yield in stress and non-stress conditions respectively (for all genotypes).

2.4. Statistical analyses

Data were analyzed and relative tolerance and relative resistance estimates computed. The correlation of indices with Y_P and Y_S was evaluated by SPSS software. Principal component analysis, bi-plots, 3 dimensional and casement plots were obtained in Minitab and Stat-Graph softwares.

3. Results

3.1. Bread wheat genotypes

Water stress consistently lowered the yield of BWGs in non-irrigated rather than irrigated conditions (Table 1). According to TOL, genotypes 10, 12, 15, 1 and 14 exhibited the most and genotypes 4, 9 and 3 the least relative tolerances respectively. For ATI the genotypes 1,12,15,14 and 10 were the most and 4 and 9 were the least relative tolerance genotypes and for SSPI genotypes 10, 12, 15, 1 and 14 were the most and genotypes 4, 9 the least relative tolerance genotypes. STI showed that genotypes 10, 8, 16 and 9 were the most, whereas genotypes 3, 6, 2 and 5 the least RT genotypes. As to SNPI, which indicates relative resistance, genotypes 10, 8, 11 and 16 were the most and 3, 6, 5 and 2 the least RR genotypes (Table 1).

ATI and SSPI were significantly and positively correlated with each other, TOL, Y_P, and SSI and negatively correlated with RDI. SNPI also exhibited negative correlation with SSI and TOL, but it was positively correlated with Y_S, HARM, GMP, STI, MP, RDI and Y_P (Table 2).

Principal component analysis (PCA) showed that the first two principal components explained 99.24% and 99.42% of variation for previous indices and the three new indices, respectively. The first component expressed 70.03% and 51.62% of total variation for previous as well as for new indices respectively and had a pretty high positive relationship with STI, Y_S and Y_P for previous indices and a high negative relationship with SNPI, Y_S and Y_P for new indices. The second component accounted for 29.21% and 46.90% of total variation for previous and new indices respectively. The second component showed a positive relationship with TOL and SSI and a negative relationship with Ys for previous indices and a positive relationship with Y_P and Y_S for new indices (Table 3).

Graphs 1 and 2 showed that genotypes 10,16,11,12 according to previous indices and genotypes 10, 8, 16, 7 to new indices, were the best ones for RT or RR respectively.

Three-dimensional graphs (3, 4 and 5) were used for identifying the relationship among yield changes in stress (X-axis), non-stress (Y-axis) conditions and ATI, SSPI or SNPI (Z-axis). These graphs showed that low ATI and SSPI amounts separated

genotypes, mainly in group C, while high SNPI amount separated genotypes (10 and 8) in group A.

3.2. Durum wheat genotypes

Such as BWGs, in this data set, water stress decreased the yield of DWGs in stress rather than in non-stress conditions in both years and average of years. According to TOL, ATI and SSPI genotypes 17, 13, 19 and 6 exhibited the most and genotypes 14, 9, 15 and 12 the least RT respectively. The results of STI showed that genotypes 5, 14, 15 and 9 were the most, whereas genotypes 6, 16, 2 and 10 the least RT genotypes. As for SNPI, which indicates relative resistance, genotypes 5, 17, 20 and 15 were the most and 4, 6, 10 and 16 the least RR genotypes (Table 4).

ATI and SSPI were significantly and positively correlated with each other, TOL, Y_P, SSI, MP, GMP and STI and negatively correlated with RDI. SNPI also exhibited negative correlation with TOL and SSI and it was positively correlated with Y_S, HARM, GMP, STI, MP and Y_P respectively (Table 5).

Principal component analysis (PCA) showed that the first two principal components explained 99.89% and 99.99% of variation for previous and the three new indices, respectively. The first component of DWG data, expressed 66.84% and

62.94% of total variation for previous as well as for new indices respectively and had a high positive relationship with Y_P, Y_S and STI from previous indices and Y_P, Y_S and SNPI from new indices. The second component accounted for 33.05% and 37.05% of total variation for previous and new indices respectively. The second component showed a negative relationship with Ys and STI and a positive relationship with SNPI and Y_S for both either of indices groups but indicated a positive correlation with SSI and TOL from previous and a negative relationship with ATI and SSPI from the new indices (Table 6).

From Graphs 6 and 7, it can be observed that genotypes 5, 20 and 11 were the best for RT according to previous indices and genotypes 5, 20 and 15 were the best ones RT and RR according to new indices respectively.

Casemate plot by levels of ATI, SSPI and SNPI (Graph 8, 9 and 10) were used for separating the genotypes according to Yp, Ys and one of the three new index quarantines. ATI, SSPI and SNPI separated genotypes in 5, 6 and 5 groups respectively. ATI and SSPI selected the genotypes 13, 17 and 14, 9 as the best and the worst relatively tolerant genotypes, while for SNPI the genotype 5, 20, 15, 14, 17, 19 and 6,10,4 are the best and the worst relatively resistant genotypes respectively.

Table 1. Quantities of YP, Y_S and different indices in 2004 (16 bread wheat genotypes with SI= 0.31)

Genotypes	No.	Y_P	Y_S	SSI	TOL	MP	STI	GMP	HARM	RDI	ATI	SSPI	SNPI
Sardari	1	374.6	306.7	0.59	67.9	340.6	0.39	338.9	337.2	1.62	137.1	6.3	662.2
Azar2	2	384.0	230.3	1.29	153.6	307.2	0.30	297.4	287.9	1.19	272.2	14.2	408.0
Kavir	3	464.4	184.8	1.94	279.6	324.6	0.29	293.0	264.4	0.79	488.2	25.8	314.0
Tabasi	4	740.3	305.9	1.89	434.4	523.1	0.77	475.9	432.9	0.82	1232.0	40.1	516.9
Gaspard	5	462.1	226.9	1.64	235.1	344.5	0.36	323.8	304.4	0.97	453.8	21.7	387.6
Meroa	6	438.1	192.8	1.81	245.3	315.4	0.29	290.6	267.7	0.87	424.8	22.6	327.6
Ghods	7	666.9	425.7	1.17	241.2	546.3	0.97	532.8	519.6	1.26	765.8	22.3	765.0
Omid	8	754.2	578.7	0.75	175.5	666.4	1.49	660.6	654.9	1.52	690.9	16.2	1157
Karaj1	9	708.3	426.6	1.28	281.7	567.4	1.03	549.6	532.4	1.19	922.7	26.0	751.8
Roshan	10	729.0	685.8	0.19	43.2	707.4	1.70	707.0	706.7	1.86	182.0	4.0	2073
Adle jadid	11	590.4	489.6	0.55	100.8	540.0	0.98	537.6	535.3	1.64	322.9	9.3	1070
Rashid	12	468.0	412.2	0.38	55.8	440.1	0.66	439.2	438.3	1.74	146.0	5.1	1005
Line	13	440.1	331.2	0.80	108.9	385.6	0.50	381.7	377.9	1.49	247.7	10.0	654.9
Bezostaya	14	397.8	319.5	0.64	78.3	358.6	0.43	356.5	354.3	1.59	166.3	7.2	673.4
Azadi	15	429.3	362.7	0.50	66.6	396.0	0.53	394.6	393.2	1.67	156.6	6.1	818.4
Navid	16	620.1	503.1	0.61	117.0	561.6	1.06	558.5	555.5	1.60	389.4	10.8	1064
Mean		541.7	373.9	1.00	167.8	457.8	0.73	446.1	435.2	1.36	437.4	15.5	790.9
Std.		140.6	141.6	0.58	109.4	130.1	0.44	132.9	136.6	0.35	317.6	10.1	436.5

Table 2. Simple correlation quantities for YP, YS and different indices in 2004 (16 bread wheat genotypes)

	Y_P	Y_S	SSI	TOL	MP	STI	GMP	HARM	RDI	ATI	SSPI	SNPI
Y_P	1											
Y_S	0.69**	1										
SSI	-0.02	-0.70**	1									
TOL	0.38	-0.40	0.89**	1								
MP	0.92**	0.92**	-0.40	-0.01	1							
STI	0.86**	0.95**	-0.46	-0.12	0.98**	1						
GMP	0.88**	0.95**	-0.48	-0.10	0.99**	0.99**	1					
HARM	0.83**	0.97**	-0.55*	-0.19	0.98**	0.98**	0.99**	1				
RDI	0.02	0.70**	-1**	-0.90*	0.39	0.46	0.47	0.55*	1			
ATI	0.68**	-0.02	0.61*	0.89**	0.36	0.24	0.27	0.20	-0.62*	1		
SSPI	0.58*	-0.40	0.80**	0.92**	-0.01	-0.12	-0.11	-0.19	-0.90**	0.90**	1	
SNPI	0.55*	0.95**	-0.75**	-0.52*	0.80**	0.85**	0.84**	0.86**	0.75**	-0.22	-0.52	1

**, * significant at 1 and 5 percent respectively.

Table 3. First two component quantities for Y_P, Y_S and different indices in 2004 (16 bread wheat genotypes)

Previous indices										
RDI	HARM	GMP	STI	MP	TOL	SSI	Y_S	Y_P	%Var.	Components
0.26	0.4	0.39	0.39	0.37	-0.13	-0.26	0.39	0.35	70.03	1
-0.46	0.08	0.14	0.14	0.19	0.57	0.45	-0.05	0.40	29.21	2

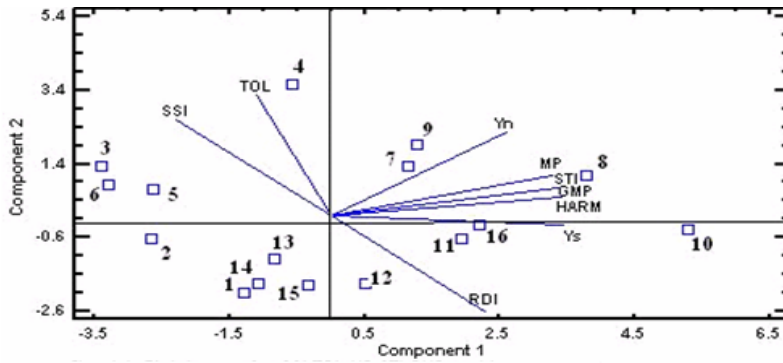| New indices						
SNPI	SSPI	ATI	Y_S	Y_P	%Var.	Components
-0.61	0.37	0.16	-0.60	-0.31	51.62	1
0.04	0.51	0.62	0.16	0.56	46.90	2

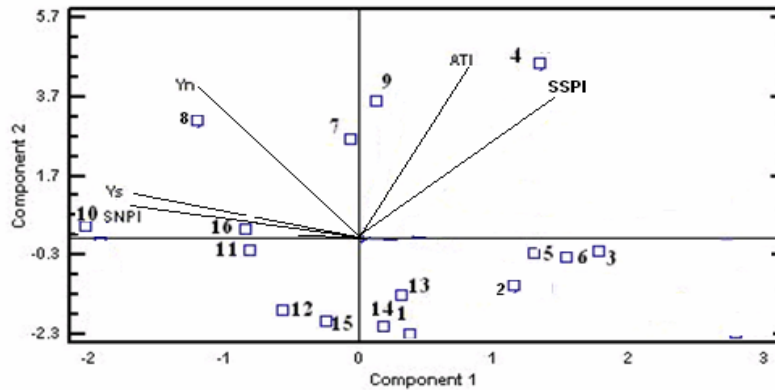Fig. 1. Biplot graph for previous indices (BWGs)

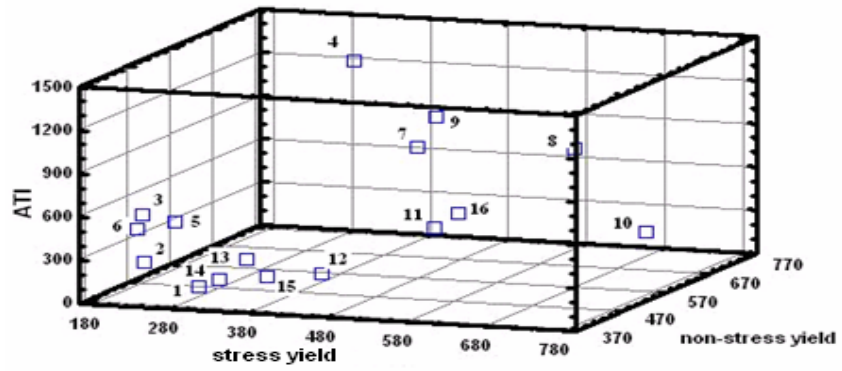Fig. 2. Biplot graph for new indices (BWGs)

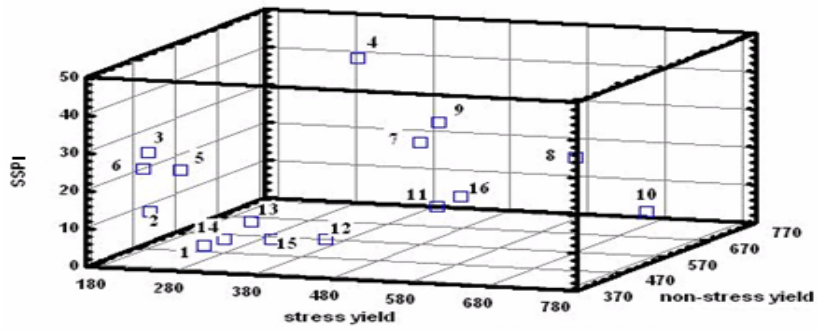Fig. 3. Three-dimensional plot of   ATI, Y_P and Y_S (BWGs)

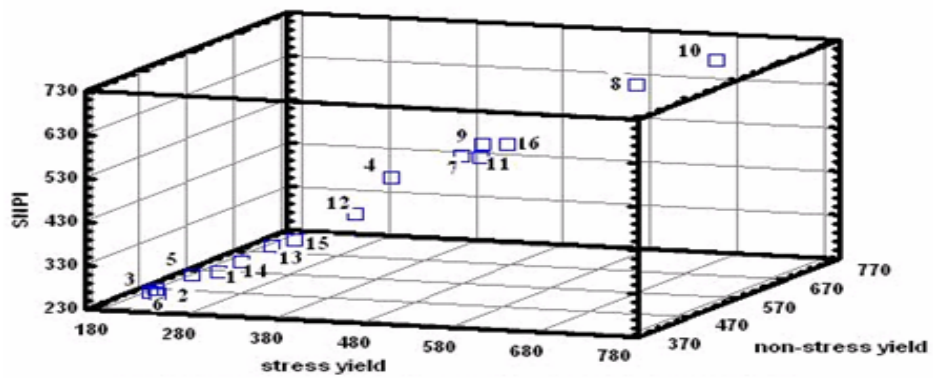Fig. 4. Three-dimensional plot of   SSPI, Y_P and Y_S (BWGs)

Fig. 5. Three-dimensional plot of   SNPI, YP and YS (BWGs)

Table 4. Quantities of YP, Y_S and different indices in 2004 -2005 (20 durum wheat genotypes with SI=0.57)

Gen.	$Y_{P (2004)}$	$Y_{S (2004)}$	$Y_{P (2005)}$	$Y_{S (2005)}$	$Y_{P (Mean)}$	$Y_{S (Mean)}$	SSI	TOL	MP	STI	GMP	HARM	RDI	ATI	SSPI	SNPI
1	5900.2	2525.04	5500.10	2480.01	5700.15	2502.53	0.99	3197.6	4101.	0.42	3776.9	3478	1.01	3720.6	27.6	4143.7
2	5680.1	2425.10	5420.11	2305.08	5550.11	2365.09	1.01	3185.0	3957.	0.39	3623.1	3316.7	0.98	3705.9	27.5	3915.8
3	6450.3	2500.03	5350.08	2407.52	5900.19	2453.78	1.03	3446.4	4176.	0.43	3804.9	3466	0.96	4010.1	29.8	4060.4
4	5950.0	2325.01	5750.07	2245.21	5850.05	2285.11	1.08	3564.9	4067.	0.40	3656.2	3286.4	0.90	4148	30.8	3786.9
5	6900.0	2875.30	6000.25	2900.24	6450.15	2887.77	0.98	3562.3	4668.	0.55	4315.8	3989.4	1.03	4145	30.8	4777.9
6	5480.1	2300.07	4820.10	2307.51	5150.09	2303.79	0.98	2846.3	3726.	0.35	3444.5	3183.5	1.03	3311.8	24.6	3820.2
7	6390.1	2575.02	5210.08	2162.52	5800.09	2368.77	1.05	3431.3	4084.	0.41	3706.6	3363.7	0.94	3992.5	29.7	3921.3
8	6150. 2	2575.08	5350.14	2385.10	5750.08	2480.09	1.00	3269.9	4115.	0.43	3776.3	3465.4	0.99	3804.8	28.3	4105.1
9	6800.1	2475.11	5900.21	2652.50	6350.14	2563.81	1.05	3786.3	4456.	0.49	4034.9	3652.8	0.93	4405.6	32.7	4241.2
10	5820.0	2300.09	5480.10	2347.53	5650.06	2323.81	1.04	3326.2	3986.	0.39	3623.5	3293.1	0.95	3870.3	28.8	3847.5
11	6200.1	2575.13	5300.24	2602.51	5750.17	2588.82	0.97	3161.3	4169.	0.45	3858.2	3570.2	1.04	3678.4	27.4	4289.0
12	6400.1	2175.10	6000.21	2890.08	6200.14	2532.59	1.04	3667.5	4366.	0.47	3962.6	3596.2	0.94	4267.4	31.7	4189.7
13	5480.0	2325.20	5020.16	2682.59	5250.11	2503.90	0.92	2746.2	3877.	0.40	3625.7	3390.6	1.10	3195.4	23.8	4163.9
14	6700.1	2825.20	6100.15	2382.49	6400.12	2603.85	1.05	3796.2	4501.	0.50	4082.2	3701.7	0.94	4417.2	32.8	4306.5
15	6950.0	2700.21	5650.07	2540.11	6300.06	2620.16	1.03	3679.9	4460.	0.50	4062.9	3701.1	0.96	4281.8	31.8	4332.9
16	5500.0	2200.10	5400.07	2512.51	5450.04	2356.31	1.00	3093.7	3903.	0.39	3583.6	3290.1	1.00	3599.8	26.7	3902.4
17	5450.0	2775.22	5150.20	2575.31	5300.12	2675.27	0.87	2624.8	3987.	0.43	3765.5	3555.7	1.16	3054.2	22.7	4470.4
18	5620.2	2375.11	5380.11	2572.48	5500.16	2473.80	0.97	3026.3	3986.	0.41	3688.7	3412.7	1.04	3521.3	26.2	4100.1
19	5520.1	2625.19	5280.23	2565.08	5400.17	2595.14	0.92	2805.0	3997.	0.42	3743.5	3505.6	1.11	3263.8	24.3	4316.7
20	6080.2	2800.18	5620.21	2505.11	5850.21	2652.65	0.97	3197.5	4251.	0.46	3939.3	3650.1	1.05	3720.5	27.7	4395.0
Mean	6071.1	2512.62	5484.14	2501.07	5777.62	2506.85	1.00	3270.7	4142.	0.43	3803.7	3493.4	1.00	3805.7	28.3	4154.3
Std.	509.94	210.39	338.61	193.23	393.87	149.70	0.05	348.58	241.6	0.05	209.31	190.5	0.07	405.6	3.1	249.7

Table 5. Simple correlation quantities for Y_P, Y_S and different indices in 2004 -2005 (20 durum wheat genotypes)

	$Y_{P (Mean)}$	$Y_{S (Mean)}$	SSI	TOL	MP	STI	GMP	HARM	RDI	ATI	SSPI	SNPI
Y_P	1											
Y_S	0.475*	1										
SSI	0.604**	-0.409	1									
TOL	0.926**	0.107	0.858**	1								
MP	0.962**	0.697**	0.366	0.788**	1							
STI	0.878**	0.837**	0.156	0.633**	0.975**	1						

**, * significant at 1 and 5 percent respectively.

Table 6. First two component quantities for Y_P, Y_S and different indices in 2004 2005 (20 durum wheat genotypes)

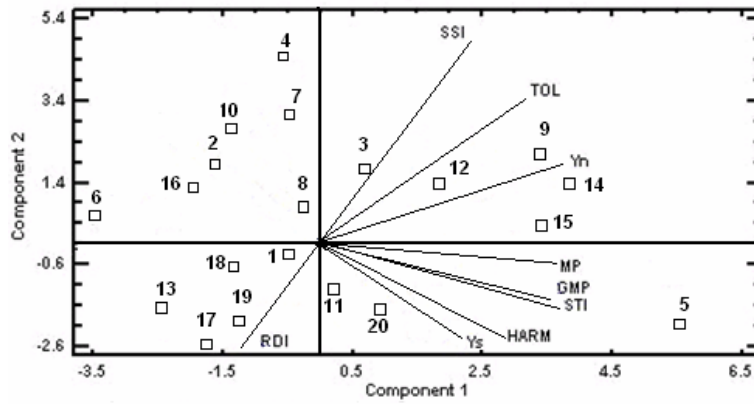|		Previous indices								
Components	%Var.	$Y_{P (Mean)}$	$Y_{S (Mean)}$	SSI	TOL	MP	STI	GMP	HARM	RDI
1	66.84	0.39	0.27	0.16	0.32	0.4	0.39	0.39	0.36	-0.16
2	33.05	0.13	-0.42	0.53	0.34	-0.02	-0.14	-0.14	-0.27	-0.53
		New indices								
Components	%Var.	$Y_{P (Mean)}$	$Y_{S (Mean)}$		ATI		SSPI		SNPI	
1	62.94	0.56	0.31		0.50		0.50		0.30	
2	37.05	-0.06	0.61		-0.33		-0.33		0.62	

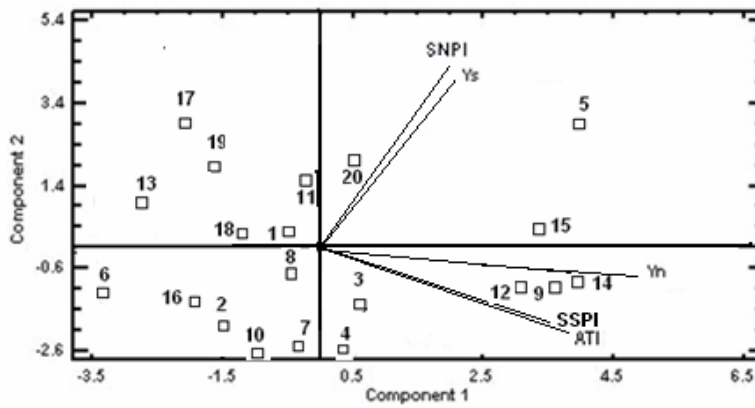Fig. 6. Biplot graph for previous indices (DWGs)

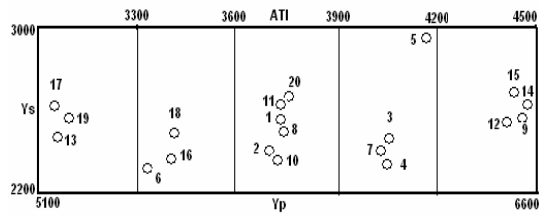Fig. 7. Biplot graph for new indices (DWGs)
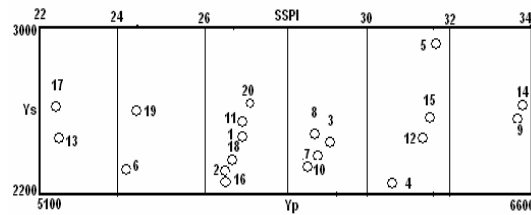

Fig. 8. Casemate plot by levels of ATI (DWGs)
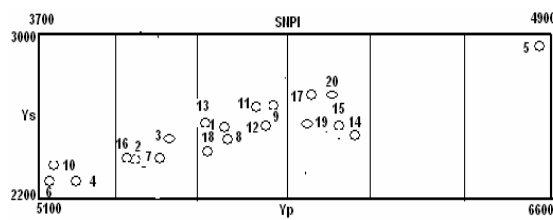
Fig. 9. Casemate plot by levels of SSPI (DWGs)

Fig. 10. Casemate plot by levels of SNPI (DWGs)

4. Discussion

4.1. Previous indices

In addition to three new indices, several different previously common indices have also been utilized to detect RT. In here, at first; through will be a discussion about the properties and deficiencies of the previous indices then the new indices will be discussed.

Selection through SSI chooses genotypes with relatively low Y_P but high Y_S. 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 (Fernandez, 1992). Clarke et al. (1992) 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 (1991). Selection through TOL chooses genotype with low Y_P but with high Y_S (group C), hence, TOL deficiencies to distinguish between group C and group A (Fernandez, 1992). MP is mean yield for a genotype in two stress and non-stress conditions. MP can select genotypes with high Y_P but with relatively low Y_S (group B) and it fails to distinguish group A from group B. By decreasing TOL and increasing

MP, the relative tolerance increases (Rosielle and Hamblin, 1981; Fernandez, 1992). A high STI demonstrates a high tolerance and the best advantage of STI is its ability to separate group A from others. GMP is more powerful than MP in separating group A and has a lower susceptibility to different amounts of Y_S and Y_P so; MP, which is based on arithmetic mean, will be bias when the difference between Y_S and Y_P is high. The higher GMP value, the greater the degree of RT. The geometric mean is often used by breeders interested in relative performance since drought stress can vary in severity in field environments and over years (Fernandez, 1992). For HARM, the higher the HARM, the higher relative tolerance of the cultivar and in the case of the last index, if RDI>1, the genotype is relatively drought tolerant and if RDI<1, it's drought susceptible (Fischer et al., 1979).

4.2. New indices

The two new indexes namely ATI and SSPI reveal the RT of a cultivar to drought stress. The nature of ATI and SSPI are such that they rely on crop survival mechanisms in stress conditions although these genotypes can have either high or low yields in two conditions so, they hasn't exhibited a significant correlation with high Y_S but have shown a significant correlation with Y_P .The

yield stability is more importance than high yield in NIC for these indices (Tables 2 and 5). In fact, these show the relative stability of yield with conditions changes, and the smaller ATI and SSPI the more RT crop is. Although ATI and SSPI have high correlation together and both of them select group C, but ATI has a more emphasis on Y_P than SSPI, SSI and TOL. Among the mentioned genotypes and according to ATI and SSPI, genotypes 1,12,15,14 and 10 were the most whereas 4 and 9 were the least RT genotypes in BWGs and 17, 13, 19 and 6 were the most and 14, 9, 15, 12 were the least RT genotypes in DWGs. The result of selection according to these two new indices was appropriate for cultivars with potential stress tolerance, but may be not for cultivars with high yield in both of NIC generally. The nature and structure of ATI and SSPI are similar to TOL and SSI so, they are significantly and positively correlated with both of these indices in both data sets, but their correlations with RDI were negative (Tables 2 and 5). ATI can mainly separate group C with more emphasis on Y_P than SSI and TOL and SSPI can do it with a better understanding of yield changes in NIC (Graphs 3, 4, 8 and 9). ATI, in comparison with TOL, has a bigger quantities and standard error and for this reason, it can show better difference between relative tolerant and intolerant genotypes and could separate them easier (Tables 1 and 4). PCA indicated a positive relationship between ATI and SSPI and significantly negative correlation with Y_S and the second principal component in both data sets. As lower ATI and SSPI and higher quantities of Y_S are desirable (with increasing Y_S, both of these indices will decrease and high Y_S is the one aspect of yield stability) then the second component would be an index for susceptibility (Tables 3 and 6). Actually, SSPI is similar to ATI, TOL in nature and represents relative tolerance of a cultivar to abiotic stresses but it give us a better understanding of yield changes in two stresses and non-stress conditions because SSPI shows the percentage of yield changes. It should be noted that, the wider range of genotypes and environments, the more actual the trial. To identify the relationship among Y_P, Y_S and ATI or SSPI, three-dimensional graphs for bread wheat data and casement plot for durum wheat were employed. These graphs showed the ability of these indices to detect Fernandez groups (Graphs 3, 4, 9 and 10).

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 Y_P and Y_S (with more emphasis on high Y_S than high Y_P) so, this index has a very strong and significant positive correlation with Ys in both data sets (Tables 2 and 5). Although SNPI and STI are very similar and highly correlated, but in addition to high yield in stress and non-stress conditions, stable yield and high Y_S are more emphasized in SNPI than in 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. The formula of this index is composed from 2 parts. The first part (i.e. $\sqrt[3]{(Y_P + Y_S)/(Y_P - Y_S)}$) emphasizes stability of yield and the high value of this part is favorite because the high quantity of that means high yield in non-stress and stress conditions (according to $\sqrt[3]{Y_P + Y_S}$) and as well as low susceptibility to yield changes in two conditions (according to $\sqrt[3]{1/Y_{P-S}}$). Second part (i.e. $\sqrt[3]{Y_P * Y_S * Y_S}$) emphasizes high yield in two NIC especially on Y_S. The reason of using 3rd root (instead of 2nd root) in first part is; decreasing the role of first part than second part (for more emphasis on high Y_P and Y_S instead of yield stability) and the reason of that for second part is; increasing the role of Y_S. With this strategy, the formula has a more emphases on Ys instead of Yp and for this reason it has a more strong correlation with Y_S than STI in BWGs and DWGs (Tables 2 and 5). The high correlation between this index and Ys (r = 0.95 and 0.99 in two data sets) has a direct effect on genotype selection with this index so the much value of Ys has a very important role for selection of a genotype (Tables 1, 4 and Graphs 5, 10). SNPI easily separated genotypes in group A and showed a positive correlation with yield changes. Selection by SNPI can be useful to identify a cultivar with desirable yield in two non-irrigated and irrigated conditions (Graphs 5 and 10). The suitability of this index to identify group A genotypes is well illustrated in graphs 2, 5, 6 and 10. According to graphs 5 and 10, genotypes 10 and 8 for BWGs and 5, 17, 20 and 15 for DWGs were the ones located in group A with high and acceptable yield in NIC (Tables 1 and 4) and actually. When a wide range of genotypes and environments is considered, a high SNPI means a high and stable yield in both conditions. Therefore, this index is an indicator of the relative stress resistance (because this index select tolerant genotypes with high yield in stress and non-stress conditions) while, the two first indices (ATI, SSPI) show relative stress tolerance. It is suggested that if extreme parents are needed for conformation of a QTL population, you can do your selection according to ATI or SSPI. It is

desired to select a parent with relatively stable and high yield in both conditions you can select by SNPI. The genotypes with the highest and the least SNPI were placed in group A and D (Table 2, 5 and Graph 5, 10) respectively. This index was positively correlated with Y_S, HARM, GMP, STI, MP, Y_P and RDI and negatively correlated with SSI, so it may be stated that this index possesses the all advantages of STI, MP, GMP, HARM and RDI (Table 1, 2 and Graphs 1, 2).

Bi-plot graphs have been employed in order to investigate the relationships among more than three variables simultaneously. Given from the data in table 3 and 6 for new indices, the most variation among the data was due to the two first components (99.428% and 99.99%). For new indices, the two first components expressed 51.42% and 62.94% of total variation and had a pretty high relationship with yield in both conditions and also with SNPI in BWGs and DWGs respectively. If a genotype takes a low value in BWGs and high value in DWGs for first component it should be selected because of low and high Y_P, Y_S and SNPI in two data sets respectively. Therefore, the first component can be called "yield potential component" that we should select low values of this component in BWGs and high values in DWGs according to negative and positive relationships between these two first component and Y_P, Y_S and SNPI respectively. Also for new indices, the two-second components involved 46.90% and 37.05% of variations (Table 3 and 6). These components were positively related with SNPI and Ys in both data sets analysis. Since a high SNPI and Y_S are desirable, by increasing the second component, the cultivars with high yield in stress conditions are selected. Then the second component can be called "stress tolerance component" and this mean we should select the genotypes high values of second components in both data sets analysis. According to bi-plot results, genotypes 10, 8, 16 and 7 were respectively the best and 3, 6, 5 and 2 the worst genotypes for BWGs and genotypes 5,15and 20 were respectively the best and 6, 16 and 2 the worst genotypes for DWGs (Graphs 2 and 7). Bi-plot graphs for new indices have separated the different genotypes well, by considering to the yields of these genotypes (Tables 2 and 5). For example, the new indices bi-plot for BWGs (Graph 2) has placed genotype 4 in group B, whereas another bi-plot placed it in group C (Graph 1). According to table 1, the yield of this genotype was high in non-stress and low in stress conditions, i.e. it should be placed in group B. Also in graphs 6 and 7, the result of selection by new indices biplot

(Genotypes 5, 15 and 20) is better than previous indices (5, 20 and 11). Furthermore, according to the indices, genotype 12 is a tolerant genotype (Table 1) and for a lack of desirable yield placed in group A, while the bi-plot of new indices (Graph 2) has better separated it from the other genotypes compared to the bi-plot of previous indices. The bi-plot of the new indices for DWGs (Graph 7) has selected 5, 15 and 20 while graph 6 selected 5, 20 and 11genotypes so, if we look at the table 4, we can say that the selection results are better for new indices. Therefore, the new indices graph not only has the performance of the previous index graph but also it can separate genotypes better than the other. The similarity of correlation trends and variation percentages in both data set bi-plots demonstrate the suitable performance of these three new indices (Compare two parts in Table 3 and 6).

It may be stated that these three new indices possess the performance and advantages of all previous indices and in some aspects, they have been shown to be of more advantages in comparison so these three new indices has a very strong relationship with the components and their two components including more variation than previous indices in both data analysis results (Tables 3 and 6).

In the final part for second data set, instead of three-dimensional plot, we used of casement plot for three new indices. This method is a kind of three-dimensional classifying of genotypes and it very useful for distinguish of genotypes according to their yield in stress and non-stress conditions and one of favorite indices. According to graphs 9 and 10, ATI and SSPI selected the genotypes 14, 9 and 13, 17 as the best and the worst tolerant genotypes, while for SNPI the 5, 20, 15, 14, 17, 19 and 6,10,4 the best and the worst resistant genotypes respectively.

According to results in this study, the following suggestions are made:
1. In order to select a genotype with stable and high yield in NIC, SNPI is proposed as the more suitable index. Selection by this index can be useful to identify a cultivar with desirable yield in both stress and non-stress conditions (group A), although it's better that, the selection is done according to PCA results (namely by using several indices instead of only one index information).
2. In order to identify extreme parents for yield stability and conformation of a QTL population, may be can make the first selection according to either ATI or SSPI indices.
3. These three new indices can be used with similar or some times with better performance than the previous ones.

4. It should be noted that, the wider range of genotypes and environments, the more informative the trial.

5. In both sets of results, especially for correlation table and bi-plot analysis, new indices had a better result and distinguished easily than previous in some cases.

6. These new indices are pretty good and suitable only for two different conditions and may be they are not suitable for several sites and conditions.

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