CBCS
HTTP://AGROBIOL.SGGW.WAW.PL/CBCS

COMMUNICATIONS IN BIOMETRY AND CROP SCIENCE
VOL. 11, NO. 1, 2016, PP. 77–89

INTERNATIONAL JOURNAL OF THE FACULTY OF AGRICULTURE AND BIOLOGY,
WARSAW UNIVERSITY OF LIFE SCIENCES – SGGW, POLAND

REGULAR ARTICLE

Evaluation of drought tolerance indices for wheat (*Triticum aestivum* L.) under irrigated and rainfed conditions

Mohamed B. Ali [1*], Ashraf N. El-Sadek [2]

[1] Agronomy Department, College of Agriculture, Assiut University, Assiut 71526, Egypt.
[2] Ecology and dry land agriculture division, Desert research center, El-Matarya, Cairo, Egypt.
*Corresponding author: Mohamed B. Ali; E-mail: mohamed.ali9@agr.au.edu.eg

CITATION: Ali M.B., El-Sadek A.N. (2016). Evaluation of drought tolerance indices for wheat (*Triticum aestivum* L.) under irrigated and rainfed conditions. *Communications in Biometry and Crop Science* 11, 77–89.

Received: 25 October 2015, Accepted: 1 February 2016, Published online: 16 February 2016

ABSTRACT
Drought stress is a major abiotic stress factor, constraining wheat production and quality worldwide. Several drought indices were used to identify drought-tolerant lines among 49 wheat lines. These lines were grown in three locations in Egypt, under rainfed (Barrani and Matrouh) and irrigated (Assiut) conditions. Results showed that grain yield under stress and non-stress environments were highly correlated with the mean productivity (MP), the geometric mean productivity (GMP), stress tolerance index (STI), yield index (YI), harmonic mean (HM), drought resistance index (DRI), and modified stress tolerance index (STI). We found that MP, GMP and STI were considered the best indices for the selection of the relatively tolerant lines. Principal component analysis indicated that the first two components accounted for more than 98% of the total variations for drought tolerant indices.

Key Words: *wheat; drought stress; indices; biplot; principal component analysis.*

INTRODUCTION

Wheat is the world most important cereal crop in terms of production and area. It has been grown in a wide range of arid and semi-arid areas, where drought occurs frequently because of rainfall fluctuations in rain-fed regions (Mardeh et al. 2006), and water scarcity in irrigated regions. Drought stress tolerance is a complex trait that is obstructed by low heritability and deficiency of successful selection approaches (Blum 1988, Kirigwi et al. 2004). Therefore, selection of wheat genotypes should be adapted to drought stress. In addition, drought tolerance mechanism should be identified during the development of new cultivars in order to increase the productivity (Rajaram et al. 1996).

Stable yield performance of genotypes under both favorable and drought stress conditions is vital for plant breeders to identify drought tolerant genotypes (Pirayvatlou

2001). Moreover, high-yielding genotypes under optimum conditions may not be drought tolerant (Blum 1996, Mardeh et al. 2006); therefore, many studies preferred the selection under stress and non-stress conditions (Clarke et al. 1992, Fernandez 1992, Byrne et al. 1995, Rajaram and Van Ginkle 2001). In the same pattern, the selection in the current study was conducted under optimum, moderate, and sever stress conditions.

Many studies have used drought indices to select stable genotypes according to their performance under favorable and stress conditions (Moosavi et al. 2008, Farshadfar et al. 2013, Mursalova et al. 2015). Examples of such indices are stress susceptibility index (SSI) (Fischer and Maurer 1978), tolerance (TOL) (Rosielle and Hamblin 1981), mean productivity (MP) (Rosielle and Hamblin, 1981), geometric mean productivity (GMP) (Fernandez 1992), stress tolerance index (STI) (Fernandez, 1992), yield index (YI) (Gavuzzi et al., 1997), yield stability index (YSI) (Bousalama and Schapaugh 1984), harmonic mean (HM) (Schneider et al., 1997), sensitivity drought index (SDI) (Farshadfar and Javadinia 2011), drought response index (DSI) (Bidinger et al. 1978), drought resistance index (DI) (Lan 1998), relative drought index (RDI) (Fischer and Maurer 1978), stress susceptibility percentage index (SSPI) (Moosavi et al. 2008), and modified stress tolerance index (MSTI) (Farshadfar and Sutka 2002).

In the rainfed areas of Egypt of the north western coastal zone (NWCZ), temporal and spatial variability in precipitation plays the key role in the cereal production; this area has a unique hydrological cycle with low annual precipitation (140 mm on average) as a winter-rain peaking from December to February. The highest amount of rainfall is usually recorded in Barrani with an annual average exceeds 200 mm. Farmers in the NWCZ area grow one or two varieties which are prescribed for the area as drought tolerant cultivars, e.g., Sakha 93 or Giza 168. Wheat is usually produced in this area with no supplemental irrigation. However, in some cases supplemental irrigation is added due to insufficient rainfall.

Our study aims to: (1) compare and evaluate different yield-based drought-tolerance selection indices, (2) identify the most stable high-yielding lines under both favorable and drought stress environments, and (3) determine whether to use sever or moderate drought stress to evaluate drought stress tolerance.

MATERIALS AND METHODS

PLANT MATERIAL AND FIELD EXPERIMENT

A set of 49 wheat-breeding materials of advanced lines resulted from CIMMYT breeding programs (Table 1) were grown in three locations in Egypt (Table 2) during 2014/2015 season. These three locations represented favorable (Assiut location), severe drought stress (Barrani location) and moderate drought stress (Matrouh location). The 49 wheat lines were sown in a randomized complete block design. Each line was sown in three replications in plots (3×3.5 m^2). Each plot consisted of 10 rows of 3 m long and 35 cm apart. At harvest, a guarded square meter was used to measure potential yield (Y_p) and stress yield (Y_s) (g/m^2).

DROUGHT STRESS ENVIRONMENTS

The fully irrigated experiment in Assiut was considered the favorable condition. In Matrouh, i.e., the moderate drought stress condition, the lines were grown under rainfed conditions; however, supplemental irrigation was performed up to the amount of 300 mm (rainfall + supplemental irrigation), and the plants were irrigated at planting, stem elongation, flowering and grain filling periods. However, the Barrani location was considered the severe drought condition, with the recorded rainfall of 30.25 mm, which is less than the annual average.

Table 1. List of 49 CIMMYT wheat lines used in the current study along with their pedigree

Code	Line pedigree	Code	Line pedigree
1	PRL/2*PASTOR	26	FRNCLN/3/KIRITATI//HUW234+LR34/PRINIA/4/FRANCOLIN #1
2	KACHU #1	27	WBLL1*2/BRAMBLING*2//BAVIS
3	MISR 1	28	CHYAK1*2/3/HUW234+LR34/PRINIA//PFAU/WEAVER
4	MUNAL #1	29	
5	BECARD #1/5/KIRITATI/4/2*SERI.1B*2/3/KAUZ*2/BOW//KAUZ	30	SWSR22T.B./2*BLOUK #1//WBLL1*2/KURUKU
6	BECARD/CHYAK	31	QUAIU #1/BECARD
7	TAITA	32	WBLL1*2/BRAMBLING/5/BABAX/LR42//BABAX*2/4/SNI/TRAP#1/3/KAUZ*2/TRAP//KAUZ
8	KACHU//KIRITATI/2*TRCH	33	WHEAR/SOKOLL/4/PRINIA/PASTOR//HUITES/3/MILAN/OTUS//ATTILA/3*BCN
9	KACHU/CHONTE	34	WHEAR//2*PRL/2*PASTOR/3/QUAIU #1
10	KIRITATI//HUW234+LR34/PRINIA/3/BAJ #1	35	WHEAR/VIVITSI//WHEAR/3/BECARD
11	MUTUS//ND643/2*WBLL1	36	TRCH*2//ND643/2*WBLL1
12	ND643/2*WBLL1/4/WHEAR/KUKUNA/3/C80.1/3*BATAVIA//2*WBLL1	37	BLOUK #1/DANPHE #1//BECARD
13	ND643/2*WBLL1//KACHU	38	BLOUK #1/4/WHEAR/KUKUNA/3/C80.1/3*BATAVIA//2*WBLL1/5/MUNAL #1
14	SUP152/QUAIU #2	39	BABAX/LR42//BABAX*2/3/PAVON 7S3, +LR47/4/ND643/2*WBLL1/5/BABAX/LR42//BABAX*2/3/PAVON 7S3, +LR47
15	MUU/FRNCLN	40	QUAIU #1/5/KIRITATI/4/2*SERI.1B*2/3/KAUZ*2/BOW//KAUZ/6/BECARD
16	SAAR//INQALAB 91*2/KUKUNA/3/KIRITATI/2*TRCH	41	CHIBIA//PRLII/CM65531/3/FISCAL/4/DANPHE #1/5/CHIBIA//PRLII/CM65531/3/SKAUZ/BAV92
17	SERI.1B*2/3/KAUZ*2/BOW//KAUZ/5/CNO79//PF70354/MUS/3/PASTOR/4/BAV92/6/ND643/2*WBLL1	42	CROSBILL #1/DANPHE/7/CNDO/R143//ENTE/MEXI_2/3/AEGILOPS SQUARROSA (TAUS)/4/WEAVER/5/2*KAUZ/6/PRL/2*PASTOR
18	BAJ #1/KISKADEE #1	43	KACHU*2/CHONTE
19	CHEWINK #1/MUTUS	44	MUTUS//KIRITATI/2*TRCH/3/WHEAR/KRONSTAD F2004
20	SERI.1B*2/3/KAUZ*2/BOW//KAUZ/4/2*MUNAL	45	ND643/2*WBLL1//2*KACHU
21	ATTILA*2/PBW65//FRNCLN/3/FRANCOLIN #1	46	WAXWING*2/TUKURU//2*FRNCLN
22	QUAIU #1/2*SUP152	47	FRANCOLIN #1*2//ND643/2*WBLL1
23	MUNAL*2/WESTONIA	48	BECARD//KIRITATI/2*TRCH/3/BECARD
24	MUTUS*2/HARIL #1	49	WHEAR//2*PRL/2*PASTOR/3/KIRITATI/2*TRCH/4/WHEAR//2*PRL/2*PASTOR
25	FRNCLN/3/ND643//2*PRL/2*PASTOR/4/FRANCOLIN #1		

Table 2. Seasonal rainfall and soil type of the test locations

Location	Condition	Latitude	Longitude	Rainfall* (mm)	Altitude (m)	Soil type
Barrani	Severe drought stress	31° 34′ 19″	25° 59′ 16″	30.75	33	Sandy Clay Loam
Matrouh	Moderate drought stress	31° 21′ 12″	27° 11′ 14″	81.60	10	Sandy Clay Loam
Assiut	Favorable (well-irrigated)	27° 11′ 18″	31° 09′ 47″	0.00	70	Clay

* Rainfall data were obtained from the Global Summary of the Day (GSOD) dataset of the National Climatic Data Center NNDC (ftp://ftp.ncdc.noaa.gov/pub/data/gsod/) for the period from November 2014 to May 2015.

DROUGHT TOLERANCE INDICES

Drought tolerance indices were calculated for lines based on grain yield (g/m²) using the following relationships:

Stress susceptibility index (SSI) = $\dfrac{1-(Y_s/Y_p)}{1-(\bar{Y}_s/\bar{Y}_p)}$ (1)

Tolerance (TOL) = $Y_p - Y_s$, (3) Mean productivity (MP) = $\dfrac{Y_s+Y_p}{2}$ (2)

Geometric mean productivity (GMP) = $\sqrt{(Y_s \times Y_p)}$ (4)

Stress tolerance index (STI) = $\dfrac{Y_s \times Y_p}{\bar{Y}_p^2}$ (5)

Yield index (YI) = $\dfrac{Y_s}{\bar{Y}_s}$ (6)

Yield stability index (YSI) = $\dfrac{Y_s}{Y_p}$ (7)

Harmonic mean (HM) = $\dfrac{2\times(Y_s \times Y_p)}{Y_s+Y_p}$ (8)

Sensitivity drought index (SDI) = $\dfrac{Y_p - Y_s}{Y_p}$ (9)

Drought resistance index (DI) = $Y_s \times \left[\dfrac{(Y_s/Y_p)}{\bar{Y}_s}\right]$ (10)

Relative drought index (RDI) = $\dfrac{(Y_s/Y_p)}{(\bar{Y}_s/\bar{Y}_p)}$ (11)

Stress susceptibility percentage index (SSPI) = $\left[\dfrac{Y_p - Y_s}{2\times\bar{Y}_p}\right]\times 100$ (12)

Modified stress tolerance index (MSTI) = KiSTI, K1= $\dfrac{Y_p^2}{\bar{Y}_p^2}$ and K2= $\dfrac{Y_s^2}{\bar{Y}_s^2}$ (13)

In the above formulas, Y_s, Y_p, and $\bar{Y}_s$, $\bar{Y}_p$ represent yield in stress and non-stress conditions for each genotype, and yield mean in stress and non-stress conditions for all genotypes, respectively. In what follows, we will use the term "Assiut-Barrani analysis" for analyzing favorable versus severe drought conditions, and the term "Assiut-Matrouh analysis" for analyzing favorable versus moderate drought conditions.

CORRELATION AND PRINCIPAL COMPONENT ANALYSIS

Correlation analysis among grain yield and drought tolerance indices was performed to determine the best drought-tolerant lines and indices. Principal component analysis (PCA) was performed based on the observations. Both correlation and PCA were performed using Microsoft® Excel 2013/XLSTAT©-Pro (Version 2015.6.01.23953, 2015, Addinsoft, Inc., Brooklyn, NY, USA).

RESULTS AND DISCUSSION

COMPARING LINES BASED ON DROUGHT TOLERANCE INDICES

Descriptive statistics of drought indices under Assiut (favorable), Barrani (severe drought stress) and Matrouh (moderate drought stress) conditions are presented in Tables 3 and 4. Many studies (e.g., Zeynali et al. 2004, Sio Se- Mardeh 2006, Talebi et al. 2009, Sanjari Pirevatlou et al. 2008 Nouri et al. 2010, Mohammadi et al. 2010) indicated that these were the most suitable parameters for screening for drought-tolerant, high-yielding lines. The lines which possess high values of STI, MP and GMP can be considered tolerant to water stress. Therefore, line 48 was ranked as the first based on STI, MP and GMP indices; and therefore, it was considered the most tolerant and high-yielding line under favorable and severe drought stress conditions (Table 5). However, line 47 was the most drought-tolerant high-yielding line under favorable and moderate drought stress conditions (Table 6).

Table 3. Descriptive statistics of drought indices for the Assiut-Barrani analysis

Drought Index	Min.	Max.	Mean	Standard deviation
Y_p‡	357.1	902.4	544.4	97.7
Y_s‡	2.08	18.94	7.68	4.22
SSI‡	0.97	1.01	1.00	0.01
TOL‡	354.99	885.39	536.7	95.4
MP‡	179.6	459.7	276.0	50.1
GMP‡	27.45	123.89	62.9	21.4
STI‡	0.00	0.05	0.01	0.01
YI‡	0.27	2.47	1.00	0.55
YSI‡	0.00	0.04	0.01	0.01
HAM‡	4.14	36.28	15.1	8.17
SDI‡	0.96	1.00	0.99	0.01
DI‡	0.00	0.11	0.02	0.02
SSPI‡	32.6	81.32	49.3	8.8
K1.STI‡	0.43	2.75	1.03	0.40
K2.STI‡	0.07	6.08	1.29	1.38

‡(Y_p) grain yield (g/m^2) of lines under favorable condition (Assiut); (Y_s) grain yield (g/m^2) of lines under severe drought stress (Barrani); (SSI) Stress susceptibility index; (TOL) tolerance; (MP) mean productivity; (GMP) Geometric mean productivity; (STI) Stress tolerance index; (YI) Yield index; (YSI) Yield stability index; (HAM) Harmonic mean; (SDI) Sensitivity drought index; (DI) Drought resistance index; (SSPI) Stress susceptibility percentage index; (K1-STI) Modified stress tolerance index for favorable condition; and (K2-STI) Modified stress tolerance index for stress condition

Table 4. Descriptive statistics of drought indices for the Assiut-Matrouh analysis

Drought Index	Min.	Max.	Mean	Standard deviation
Y_p‡	357.10	902.40	544.4	97.7
Y_s‡	29.82	326.60	133.2	80.6
SSI‡	0.41	1.26	1.00	0.19
TOL‡	133.80	698.10	411.1	106.4
MP‡	224.98	553.35	338.8	72.0
GMP‡	113.37	480.71	257.7	92.5
STI‡	0.04	0.78	0.25	0.18
YI‡	0.22	2.45	1.00	0.61
YSI‡	0.05	0.69	0.25	0.14
HAM‡	55.78	439.95	203.6	103.1
SDI‡	0.31	0.95	0.75	0.14
DI‡	0.01	1.54	0.32	0.36
SSPI‡	12.29	64.12	37.8	9.8
K1.STI‡	0.43	2.75	1.03	0.40
K2.STI‡	0.05	6.01	1.36	1.54

‡(Y_p) grain yield (g/m^2) of lines under favorable condition (Assiut); (Y_s) grain yield (g/m^2) of lines under moderate drought stress (Matrouh); (SSI) Stress susceptibility index; (TOL) tolerance; (MP) mean productivity; (GMP) Geometric mean productivity; (STI) Stress tolerance index; (YI) Yield index; (YSI) Yield stability index; (HAM) Harmonic mean; (SDI) Sensitivity drought index; (DI) Drought resistance index; (SSPI) Stress susceptibility percentage index; (K1-STI) Modified stress tolerance index for favorable condition; and (K2-STI) Modified stress tolerance index for stress condition

Table 5. Drought tolerance indices of 49 wheat lines based on grain yield for the Assiut-Barrani analysis

Line‡	Y_p‡	Y_s‡	SSI‡	TOL‡	MP‡	GMP‡	STI‡	YI‡	YSI‡	HAM‡	SDI‡	DI‡	SSPI‡	K1-STI‡	K2-STI‡
1	561.9	9.46	1.00	552.5	285.7	72.9	0.018	1.23	0.017	18.60	0.983	0.021	50.7	1.07	1.52
2	495.2	7.75	1.00	487.5	251.5	62.0	0.013	1.01	0.016	15.26	0.984	0.016	44.8	0.83	1.02
3	485.2	7.18	1.00	478.0	246.2	59.0	0.012	0.93	0.015	14.15	0.985	0.014	43.9	0.79	0.87
4	558.3	7.50	1.00	550.8	282.9	64.7	0.014	0.98	0.013	14.80	0.987	0.013	50.6	1.05	0.95
5	573.8	12.45	0.99	561.4	293.1	84.5	0.024	1.62	0.022	24.37	0.978	0.035	51.6	1.11	2.63
6	673.8	7.40	1.00	666.4	340.6	70.6	0.017	0.96	0.011	14.63	0.989	0.011	61.2	1.53	0.93
7	488.1	6.96	1.00	481.2	247.5	58.3	0.011	0.91	0.014	13.71	0.986	0.013	44.2	0.80	0.82
8	445.2	2.71	1.01	442.5	224.0	34.7	0.004	0.35	0.006	5.39	0.994	0.002	40.6	0.67	0.12
9	581.0	4.05	1.01	577.0	292.5	48.5	0.008	0.53	0.007	8.04	0.993	0.004	53.0	1.14	0.28
10	451.9	2.86	1.01	449.0	227.4	36.0	0.004	0.37	0.006	5.68	0.994	0.002	41.2	0.69	0.14
11	464.3	4.59	1.00	459.7	234.5	46.2	0.007	0.60	0.010	9.09	0.990	0.006	42.2	0.73	0.36
12	483.3	2.08	1.01	481.2	242.7	31.7	0.003	0.27	0.004	4.14	0.996	0.001	44.2	0.79	0.07
13	638.1	5.73	1.01	632.4	321.9	60.4	0.012	0.75	0.009	11.35	0.991	0.007	58.1	1.37	0.56
14	430.5	2.27	1.01	428.2	216.4	31.2	0.003	0.29	0.005	4.51	0.995	0.002	39.3	0.63	0.09
15	554.8	7.60	1.00	547.2	281.2	64.9	0.014	0.99	0.014	14.99	0.986	0.014	50.3	1.04	0.98
16	619.8	9.49	1.00	610.3	314.7	76.7	0.020	1.24	0.015	18.69	0.985	0.019	56.1	1.30	1.53
17	550.0	5.92	1.00	544.1	278.0	57.1	0.011	0.77	0.011	11.71	0.989	0.008	50.0	1.02	0.59
18	357.1	2.11	1.01	355.0	179.6	27.5	0.003	0.27	0.006	4.20	0.994	0.002	32.6	0.43	0.08
19	554.8	14.44	0.99	540.4	284.6	89.5	0.027	1.88	0.026	28.15	0.974	0.049	49.6	1.04	3.53
20	435.7	9.06	0.99	426.7	222.4	62.8	0.013	1.18	0.021	17.74	0.979	0.025	39.2	0.64	1.39
21	508.0	4.02	1.01	504.0	256.0	45.2	0.007	0.52	0.008	7.98	0.992	0.004	46.3	0.87	0.27
22	431.0	3.70	1.01	427.3	217.4	39.9	0.005	0.48	0.009	7.34	0.991	0.004	39.3	0.63	0.23
23	464.3	6.65	1.00	457.7	235.5	55.6	0.010	0.87	0.014	13.10	0.986	0.012	42.0	0.73	0.75
24	565.5	5.00	1.01	560.5	285.3	53.2	0.010	0.65	0.009	9.90	0.991	0.006	51.5	1.08	0.42
25	504.8	2.68	1.01	502.1	253.7	36.8	0.005	0.35	0.005	5.33	0.995	0.002	46.1	0.86	0.12
26	464.3	7.80	1.00	456.5	236.1	60.2	0.012	1.01	0.017	15.33	0.983	0.017	41.9	0.73	1.03
27	452.4	2.45	1.01	450.0	227.4	33.3	0.004	0.32	0.005	4.86	0.995	0.002	41.3	0.69	0.10
28	509.5	6.49	1.00	503.0	258.0	57.5	0.011	0.84	0.013	12.82	0.987	0.011	46.2	0.88	0.71
29	454.8	5.09	1.00	449.7	229.9	48.1	0.008	0.66	0.011	10.06	0.989	0.007	41.3	0.70	0.44
30	669.0	12.60	1.00	656.4	340.8	91.8	0.028	1.64	0.019	24.73	0.981	0.031	60.3	1.51	2.69
31	547.6	11.33	0.99	536.3	279.5	78.8	0.021	1.48	0.021	22.20	0.979	0.031	49.3	1.01	2.18
32	590.5	7.84	1.00	582.7	299.2	68.0	0.016	1.02	0.013	15.46	0.987	0.014	53.5	1.18	1.04
33	638.8	6.83	1.00	632.0	322.8	66.0	0.015	0.89	0.011	13.51	0.989	0.009	58.0	1.38	0.79
34	511.2	3.68	1.01	507.5	257.4	43.3	0.006	0.48	0.007	7.30	0.993	0.003	46.6	0.88	0.23
35	521.4	8.96	1.00	512.5	265.2	68.3	0.016	1.17	0.017	17.61	0.983	0.020	47.1	0.92	1.36
36	478.6	7.59	1.00	471.0	243.1	60.3	0.012	0.99	0.016	14.93	0.984	0.016	43.3	0.77	0.98
37	616.7	9.17	1.00	607.5	312.9	75.2	0.019	1.19	0.015	18.07	0.985	0.018	55.8	1.28	1.43
38	478.6	6.90	1.00	471.7	242.8	57.5	0.011	0.90	0.014	13.59	0.986	0.013	43.3	0.77	0.81
39	554.8	3.76	1.01	551.0	279.3	45.7	0.007	0.49	0.007	7.47	0.993	0.003	50.6	1.04	0.24
40	692.9	16.61	0.99	676.3	354.8	107.3	0.039	2.16	0.024	32.44	0.976	0.052	62.1	1.62	4.68
41	428.6	18.94	0.97	409.7	223.8	90.1	0.027	2.47	0.044	36.28	0.956	0.109	37.6	0.62	6.08
42	631.0	12.27	0.99	618.7	321.6	88.0	0.026	1.60	0.019	24.07	0.981	0.031	56.8	1.34	2.55
43	492.9	8.07	1.00	484.8	250.5	63.1	0.013	1.05	0.016	15.87	0.984	0.017	44.5	0.82	1.10
44	528.6	3.73	1.01	524.9	266.2	44.4	0.007	0.49	0.007	7.41	0.993	0.003	48.2	0.94	0.24
45	600.0	6.05	1.00	594.0	303.0	60.3	0.012	0.79	0.010	11.98	0.990	0.008	54.6	1.21	0.62
46	642.9	14.87	0.99	628.0	328.9	97.8	0.032	1.94	0.023	29.07	0.977	0.045	57.7	1.39	3.75
47	745.2	10.86	1.00	734.3	378.0	90.0	0.027	1.41	0.015	21.41	0.985	0.021	67.4	1.87	2.00
48	902.4	17.01	1.00	885.4	459.7	123.9	0.052	2.21	0.019	33.39	0.981	0.042	81.3	2.75	4.90
49	645.2	13.89	0.99	631.3	329.6	94.7	0.030	1.81	0.022	27.19	0.978	0.039	58.0	1.40	3.27

‡(Line) Lines code; (Y_p) grain yield (g/m^2) of lines under favorable condition (Assiut); (Y_s) grain yield (g/m^2) of lines under severe drought stress (Barrani); (SSI) Stress susceptibility index; (TOL) tolerance; (MP) mean productivity; (GMP) Geometric mean productivity; (STI) Stress tolerance index; (YI) Yield index; (YSI) Yield stability index; (HAM) Harmonic mean; (SDI) Sensitivity drought index; (DI) Drought resistance index; (SSPI) Stress susceptibility percentage index; (K1-STI) Modified stress tolerance index for favorable condition; and (K2-STI) Modified stress tolerance index for stress condition.

Table 6. Drought tolerance indices of 49 bread wheat lines based on grain yield under for the Assiut-Matrouh analysis

Line‡	Y_p‡	Y_s‡	SSI‡	TOL‡	MP‡	GMP‡	STI‡	YI‡	YSI‡	HAM‡	SDI‡	DI‡	SSPI‡	K1-STI‡	K2-STI‡
1	561.9	213.90	0.82	348.0	387.9	346.7	0.41	1.61	0.38	309.85	0.62	0.61	32.0	1.07	2.58
2	495.2	265.30	0.61	229.9	380.3	362.5	0.44	1.99	0.54	345.50	0.46	1.07	21.1	0.83	3.97
3	485.2	140.90	0.94	344.3	313.1	261.5	0.23	1.06	0.29	218.38	0.71	0.31	31.6	0.79	1.12
4	558.3	269.90	0.68	288.4	414.1	388.2	0.51	2.03	0.48	363.89	0.52	0.98	26.5	1.05	4.11
5	573.8	246.80	0.75	327.0	410.3	376.3	0.48	1.85	0.43	345.15	0.57	0.80	30.0	1.11	3.43
6	673.8	326.60	0.68	347.2	500.2	469.1	0.74	2.45	0.48	439.95	0.52	1.19	31.9	1.53	6.01
7	488.1	139.80	0.94	348.3	314.0	261.2	0.23	1.05	0.29	217.35	0.71	0.30	32.0	0.80	1.10
8	445.2	211.20	0.70	234.0	328.2	306.6	0.32	1.59	0.47	286.49	0.53	0.75	21.5	0.67	2.51
9	581.0	184.70	0.90	396.3	382.9	327.6	0.36	1.39	0.32	280.29	0.68	0.44	36.4	1.14	1.92
10	451.9	182.50	0.79	269.4	317.2	287.2	0.28	1.37	0.40	260.00	0.60	0.55	24.7	0.69	1.88
11	464.3	119.50	0.98	344.8	291.9	235.6	0.19	0.90	0.26	190.08	0.74	0.23	31.7	0.73	0.80
12	483.3	142.40	0.93	340.9	312.9	262.3	0.23	1.07	0.29	219.98	0.71	0.31	31.3	0.79	1.14
13	638.1	156.40	1.00	481.7	397.3	315.9	0.34	1.17	0.25	251.22	0.75	0.29	44.2	1.37	1.38
14	430.5	296.70	0.41	133.8	363.6	357.4	0.43	2.23	0.69	351.29	0.31	1.54	12.3	0.63	4.96
15	554.8	157.70	0.95	397.1	356.3	295.8	0.30	1.18	0.28	245.59	0.72	0.34	36.5	1.04	1.40
16	619.8	134.60	1.04	485.2	377.2	288.8	0.28	1.01	0.22	221.17	0.78	0.22	44.6	1.30	1.02
17	550.0	99.02	1.09	451.0	324.5	233.37	0.18	0.74	0.18	167.83	0.82	0.13	41.4	1.02	0.55
18	357.1	92.86	0.98	264.2	225.0	182.10	0.11	0.70	0.26	147.39	0.74	0.18	24.3	0.43	0.49
19	554.8	99.77	1.09	455.0	327.3	235.3	0.19	0.75	0.18	169.13	0.82	0.13	41.8	1.04	0.56
20	435.7	58.92	1.14	376.8	247.3	160.2	0.09	0.44	0.14	103.80	0.86	0.06	34.6	0.64	0.20
21	508.0	40.96	1.22	467.0	274.5	144.3	0.07	0.31	0.08	75.81	0.92	0.02	42.9	0.87	0.09
22	431.0	29.82	1.23	401.2	230.4	113.4	0.04	0.22	0.07	55.78	0.93	0.02	36.9	0.63	0.05
23	464.3	67.51	1.13	396.8	265.9	177.0	0.11	0.51	0.15	117.88	0.85	0.07	36.4	0.73	0.26
24	565.5	33.07	1.25	532.4	299.3	136.8	0.06	0.25	0.06	62.49	0.94	0.01	48.9	1.08	0.06
25	504.8	36.39	1.23	468.4	270.6	135.5	0.06	0.27	0.07	67.89	0.93	0.02	43.0	0.86	0.07
26	464.3	65.07	1.14	399.2	264.7	173.8	0.10	0.49	0.14	114.14	0.86	0.07	36.7	0.73	0.24
27	452.4	71.04	1.12	381.4	261.7	179.3	0.11	0.53	0.16	122.80	0.84	0.08	35.0	0.69	0.28
28	509.5	52.14	1.19	457.4	280.8	163.0	0.09	0.39	0.10	94.60	0.90	0.04	42.0	0.88	0.15
29	454.8	99.21	1.04	355.6	277.0	212.4	0.15	0.74	0.22	162.89	0.78	0.16	32.7	0.70	0.55
30	669.0	36.29	1.25	632.7	352.7	155.8	0.08	0.27	0.05	68.85	0.95	0.01	58.1	1.51	0.07
31	547.6	31.15	1.25	516.5	289.4	130.6	0.06	0.23	0.06	58.95	0.94	0.01	47.4	1.01	0.05
32	590.5	98.05	1.10	492.5	344.3	240.6	0.20	0.74	0.17	168.18	0.83	0.12	45.2	1.18	0.54
33	638.8	31.40	1.26	607.4	335.1	141.6	0.07	0.24	0.05	59.86	0.95	0.01	55.8	1.38	0.06
34	511.2	114.20	1.03	397.0	312.7	241.6	0.20	0.86	0.22	186.69	0.78	0.19	36.5	0.88	0.74
35	521.4	102.30	1.06	419.1	311.9	231.0	0.18	0.77	0.20	171.04	0.80	0.15	38.5	0.92	0.59
36	478.6	61.91	1.15	416.7	270.3	172.1	0.10	0.46	0.13	109.64	0.87	0.06	38.3	0.77	0.22
37	616.7	121.20	1.06	495.5	367.0	273.4	0.25	0.91	0.20	202.59	0.80	0.18	45.5	1.28	0.83
38	478.6	116.20	1.00	362.4	297.4	235.8	0.19	0.87	0.24	187.00	0.76	0.21	33.3	0.77	0.76
39	554.8	143.40	0.98	411.4	349.1	282.1	0.27	1.08	0.26	227.90	0.74	0.28	37.8	1.04	1.16
40	692.9	136.70	1.06	556.2	414.8	307.8	0.32	1.03	0.20	228.35	0.80	0.20	51.1	1.62	1.05
41	428.6	122.20	0.95	306.4	275.4	228.9	0.18	0.92	0.29	190.18	0.71	0.26	28.1	0.62	0.84
42	631.0	41.93	1.24	589.1	336.5	162.7	0.09	0.31	0.07	78.63	0.93	0.02	54.1	1.34	0.10
43	492.9	102.50	1.05	390.4	297.7	224.8	0.17	0.77	0.21	169.71	0.79	0.16	35.9	0.82	0.59
44	528.6	98.71	1.08	429.9	313.7	228.4	0.18	0.74	0.19	166.36	0.81	0.14	39.5	0.94	0.55
45	600.0	160.10	0.97	439.9	380.1	309.9	0.32	1.20	0.27	252.76	0.73	0.32	40.4	1.21	1.44
46	642.9	171.60	0.97	471.3	407.3	332.2	0.37	1.29	0.27	270.89	0.73	0.34	43.3	1.39	1.66
47	745.2	310.10	0.77	435.1	527.7	480.7	0.78	2.33	0.42	437.95	0.58	0.97	34.0	1.87	5.42
48	902.4	204.30	1.02	698.1	553.4	429.4	0.62	1.53	0.23	333.17	0.77	0.35	64.1	2.75	2.35
49	645.2	287.00	0.74	358.2	466.1	430.3	0.62	2.15	0.44	397.28	0.56	0.96	32.9	1.40	4.64

‡(Line) Lines code; (Y_p) grain yield (g/m^2) of lines under favorable condition (Assiut); (Y_s) grain yield (g/m^2) of lines under moderate drought stress (Matrouh); (SSI) Stress susceptibility index; (TOL) tolerance; (MP) mean productivity; (GMP) Geometric mean productivity; (STI) Stress tolerance index; (YI) Yield index; (YSI) Yield stability index; (HAM) Harmonic mean; (SDI) Sensitivity drought index; (DI) Drought resistance index; (SSPI) Stress susceptibility percentage index; (K1-STI) Modified stress tolerance index for favorable condition; and (K2-STI) Modified stress tolerance index for stress condition.

These two lines, 48 and 47, were ranked differently in both Assiut-Barrani and Assiut-Matrouh conditions due to high genotype × environment interaction. We found that Barani, the severe drought stress environment, was less discriminative than Matrouh, the moderate drought stress environment, for some indices, e.g. STI, YSI, SDI and DI. Severe drought stress causes reduction in metabolic activity rather than moderate drought stress (Ma et al., 2006; Naya et al., 2007). This explains the huge reduction in yield under severe drought stress (Barrani) for all lines. Therefore, we recommend using moderate drought stress environments to identify drought tolerant lines.

CORRELATION ANALYSIS

Correlation coefficients between grain yield and drought indices are presented in Tables 7 and 8. There was a positive significant correlation between Y_p and Y_s (r=0.56) and (r=0.30) in the Assiut-Barrani and Assiut-Matrouh analyses, respectively (Tables 7 and 8). This indicates that high yield performance under favorable condition resulted in relatively high yield under stress conditions.

Both Y_p and Y_s in the Assiut-Barrani analysis were significantly and positively correlated (P<0.05) with TOL and SSPI (r=1.00 and 0.54), MP (r=1.00 and 0.59), GMP (r=0.76 and 0.96), STI (r=0.78 and 0.94), YI (r=0.56 and 1.00), HAM (r=0.57 and 1.00), DI (r=28 and 0.91), KI-STI(r=0.99 and 0.57) and K2-STI (r=0.51 and 0.97). This indicates that these indices were more effective in identifying high yielding lines under drought stress as well as non-stress conditions (Table 7). The correlation between Y_s and either SSI or SDI was significant and negative (r= - 0.92). On the other hand, the correlation between Y_p and either SSI or SDI was negligible (r= - 0.22).

The Y_s was significantly correlated (P<0.01) with all indices. On the other hand, Y_p was highly significantly correlated with only six indices (TOL, SSPI, MP, GMP, STI and KI-STI). Highly correlated indices with both the Y_s and Y_p are most appropriate for identifying stress tolerant cultivars (Farshadfar et al. 2011).The MP, GMP and STI indices, which highly positively significantly correlated to the grain yields in both favorable and drought stress environments, were introduced as the best indices.

Table 7. Correlation between different drought tolerance indices (n=49) for the Assiut-Barrani analysis

	Y_p‡	Y_s‡ or YI‡	SSI‡ or SDI‡	TOL‡ or SSPI‡	MP‡	GMP ‡	STI‡	YSI‡	HAM ‡	DI‡	K1-STI‡
Y_p											
Y_s or YI	0.56										
SSI or SDI	−0.22	−0.92									
TOL or SSPI	1.00	0.53	−0.18								
MP	1.00	0.59	−0.25	1.00							
GMP	0.76	0.96	−0.78	0.74	0.78						
STI	0.78	0.94	−0.73	0.75	0.80	0.98					
YSI	0.22	0.92	−1.00	0.18	0.25	0.78	0.73				
HAM	0.57	1.00	−0.91	0.54	0.60	0.96	0.94	0.91			
DI	0.28	0.91	−0.96	0.24	0.31	0.76	0.76	0.96	0.90		
KI-STI	0.99	0.57	−0.22	0.99	0.99	0.76	0.79	0.22	0.57	0.29	
K2-STI‡	0.51	0.97	−0.90	0.48	0.54	0.89	0.91	0.90	0.97	0.95	0.53

0.28 ≤|r| ≤0.31 and |r|>0.31 are significant at 5% and 1% level of probability, respectively.
‡ (Y_p) grain yield (g/m²) of lines under favorable condition (Assiut); (Y_s) grain yield (g/m²) of lines under severe drought stress (Barrani); (SSI) Stress susceptibility index; (TOL) tolerance; (MP) mean productivity; (GMP) Geometric mean productivity; (STI) Stress tolerance index; (YI) Yield index; (YSI) Yield stability index; (HAM) Harmonic mean; (SDI) Sensitivity drought index; (DI) Drought resistance index; (SSPI) Stress susceptibility percentage index; (K1-STI) Modified stress tolerance index for favorable condition; and (K2-STI) Modified stress tolerance index for stress condition.

Table 8. Correlation between different drought tolerance indices (n=49) for the Assiut-Matrouh analysis

	Y_p‡	Y_s‡ or YI‡	SSI‡ or SDI‡	TOL‡ or SSPI‡	MP‡	GMP ‡	STI‡	YSI‡	HAM ‡	DI‡	K1-STI‡
Y_p											
Y_s or YI	0.30										
SSI or SDI	0.02	-0.94									
TOL or SSPI	0.69	-0.48	0.73								
MP	0.85	0.76	-0.51	0.20							
GMP	0.51	0.96	-0.82	-0.26	0.88						
STI	0.56	0.95	-0.77	-0.21	0.91	0.98					
YSI	-0.02	0.94	-1.00	-0.73	0.51	0.82	0.77				
HAM	0.37	0.99	-0.89	-0.41	0.80	0.99	0.97	0.89			
DI	0.13	0.94	-0.95	-0.60	0.62	0.83	0.83	0.95	0.89		
KI-STI	0.99	0.31	0.01	0.68	0.84	0.51	0.57	-0.01	0.38	0.14	
K2-STI‡	0.32	0.97	-0.89	-0.44	0.76	0.90	0.93	0.89	0.93	0.97	0.32

$0.30 \leq |r| \leq 0.37$ and $|r| > 0.37$ are significant at 5% and 1% level of probability, respectively.
‡ (Y_p) grain yield (g/m²) of lines under favorable condition (Assiut); (Y_s) grain yield (g/m²) of lines under moderate drought stress (Matrouh); (SSI) Stress susceptibility index; (TOL) tolerance; (MP) mean productivity; (GMP) Geometric mean productivity; (STI) Stress tolerance index; (YI) Yield index; (YSI) Yield stability index; (HAM) Harmonic mean; (SDI) Sensitivity drought index; (DI) Drought resistance index; (SSPI) Stress susceptibility percentage index; (K1-STI) Modified stress tolerance index for favorable condition; and (K2-STI) Modified stress tolerance index for stress condition.

PRINCIPAL COMPONENT ANALYSIS (PCA)

The PCA showed that the first two components explained about 98% of the total variance in both Assiut-Barrani and Assiut-Matrouh analyses (Tables 9 and 10). Therefore, the bi-plot was drawn based on the first two components (Figures 1 and 2). In the Assiut-Barrani analysis, the first PCA explained 73.43% of the obtained variation , and showed high coordination with Y_p, Y_s, TOL, MP, GMP, STI, YSI, HAM, DI, SSPI, K1-STI and K2-STI indices. Thus, the first dimension can be named as the yield potential and drought tolerance. This component separates drought tolerant genotypes with high yield in both environments. The PC2 explained 25.08% of the total obtained variation, and had positive correlation with Y_p, SSI, TOL, MP, GMP, STI, SDI, SSPI, K1-STI (Table 9). This component had negative correlation with yield under stress conditions, thus it can be named drought susceptible dimension with high yield under non-stressed and low yield under stressed environment.

For the Assuit-Matrouh analysis, the PC1 explained 71.33% of the obtained variation with a positive correlation with all indices except TOL, SDI and SPI. This component had a mild positive correlation (0.31) with the yield under the stress environment and low correlation (0.08) with the yield under the non-stress environment. However, the PC2, which explained only 26.8% of the total variation, had a positive correlation with all indices except YSI and DI (Table 10). The second component was not correlated (0.018) with Y_s and positively correlated (0.468) with Y_p. The relationships among the indices were graphically presented in biplots of the PC1 and PC2 (Figure 1 and 2).

Lines that possessed high PC1 and low PC2 values are more stable under both drought stress and favorable conditions (Golabadi et al. 2006). Based on the first two components in the Assuit-Barrani analysis, lines 41, 19 and 46 were identified as the most stable high-yielding genotypes in both environments. On the other hand, some lines (e.g., 13 and 9 and 45) were classified as drought-sensitive genotypes (Figure 1). In the Assuit-Matrouh analysis, lines 2, 4 and 5 were more stable than the other lines; however, lines 30, 33 and 40 were most susceptible (Figure 2).

Perfect correlations were found between TOL, SSPI, Y_p, K1-STI and MP (Table 7, Figure 1). So these indices can be used interchangeably.

Stable genotypes under both favorable and drought conditions are vital for plant breeding programs in areas prone to drought stress. However, the level and time of drought stress events are not predictable in rainfed areas; for this reason it is better to evaluate wheat genotypes under various levels of drought stresses. Therefore, a genotype that shows low fluctuations of yield under various levels of drought stress conditions can be considered drought tolerant. Further, drought indices could be good indicators of genotypes stability. In the present study, we found highly significant correlation between some indices, indicating that some of them measure similar aspects of drought tolerance.

Table 9. Principal component analysis for drought tolerance indices for the Assiut-Barrni analysis

PC‡	Percentage of Variance	Cumulative percentage	Eigen Values	Y_p‡	Y_s‡	SSI‡	TOL‡	MP‡	GMP‡
PC1	73.433	73.433	11.015	0.219	0.294	-0.247	0.212	0.226	0.298
PC2	25.078	98.511	3.762	0.352	-0.109	0.290	0.365	0.339	0.033

‡ (PC) principal component; (Y_p) grain yield (g/m^2) of lines under favorable condition (Assiut); (Y_s) grain yield (g/m^2) of lines under severe drought stress (Barrani); (SSI) Stress susceptibility index; (TOL) tolerance; and (MP) mean productivity.

Table 9. (Continued)

PC‡	STI‡	YI‡	YSI‡	HAM‡	SDI‡	DI‡	SSPI‡	K1-STI‡	K2-STI‡
PC1	0.295	0.294	0.247	0.294	-0.247	0.252	0.212	0.220	0.284
PC2	0.054	-0.109	-0.290	-0.104	0.290	-0.257	0.365	0.348	-0.130

‡ (PC) principal component; (GMP) Geometric mean productivity; (STI) Stress tolerance index; (YI) Yield index; (YSI) Yield stability index; (HAM) Harmonic mean; (SDI) Sensitivity drought index; (DI) Drought resistance index; (SSPI) Stress susceptibility percentage index; (K1-STI) Modified stress tolerance index for favorable condition; and (K2-STI) Modified stress tolerance index for stress condition.

Table 10. Principal components analysis for drought tolerance indices for the Assiut-Matrouh analysis

PC‡	Percentage of Variance	Cumulative percentage	Eigen Values	Y_p‡	Y_s‡	SSI‡	TOL‡	MP‡	GMP‡
PC1	69.998	69.998	10.500	0.082	0.308	-0.293	-0.158	0.228	0.292
PC2	28.145	98.144	4.222	0.468	0.018	0.139	0.416	0.328	0.132

‡ (PC) principal component; (Y_p) grain yield (g/m^2) of lines under favorable condition (Assiut); (Y_s) grain yield (g/m^2) of lines under moderate drought stress (Matrouh); (SSI) Stress susceptibility index; (TOL) tolerance; and (MP) mean productivity.

Table 10. (Continued)

PC‡	STI‡	YI‡	YSI‡	HAM‡	SDI‡	DI‡	SSPI‡	K1-STI‡	K2-STI‡
PC1	0.288	0.308	0.293	0.303	-0.293	0.296	-0.158	0.084	0.299
PC2	0.160	0.018	-0.139	0.057	0.139	-0.066	0.416	0.465	0.030

‡ (PC) principal component; (GMP) Geometric mean productivity; (STI) Stress tolerance index; (YI) Yield index; (YSI) Yield stability index; (HAM) Harmonic mean; (SDI) Sensitivity drought index; (DI) Drought resistance index; (SSPI) Stress susceptibility percentage index; (K1-STI) Modified stress tolerance index for favorable condition; and (K2-STI) Modified stress tolerance index for stress condition.

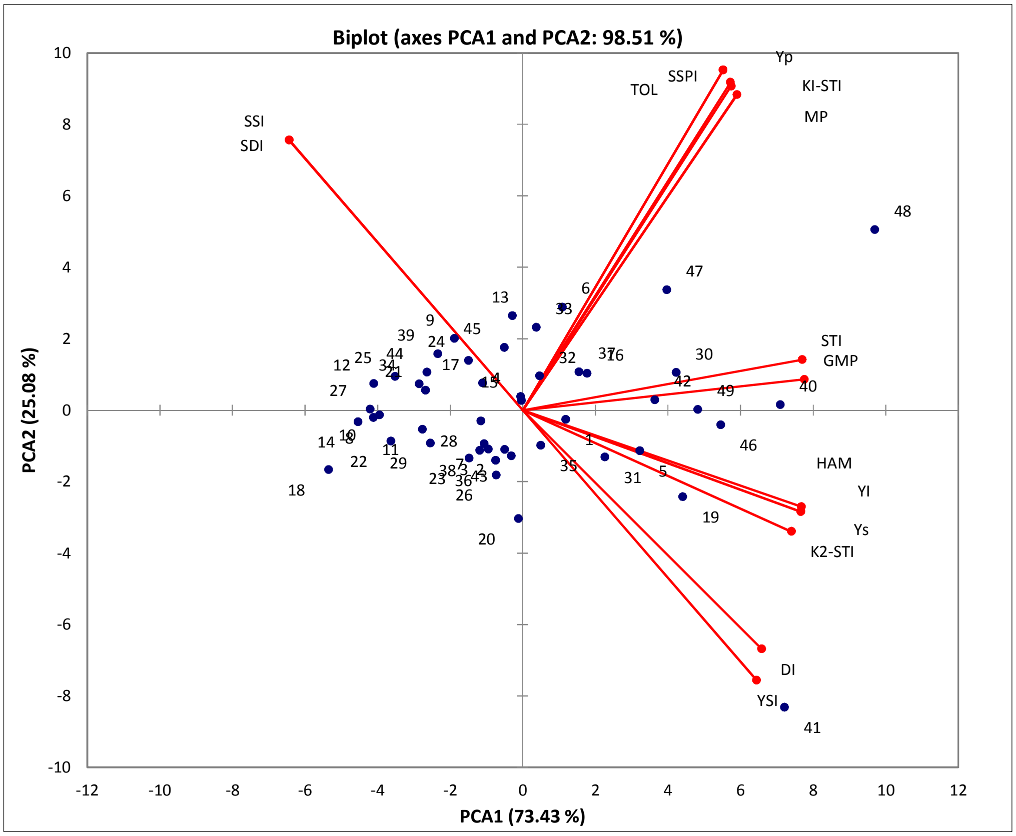

Figure 1. Biplot of the first two principal component axes for 49 wheat lines for the Assiut-Barrani analysis

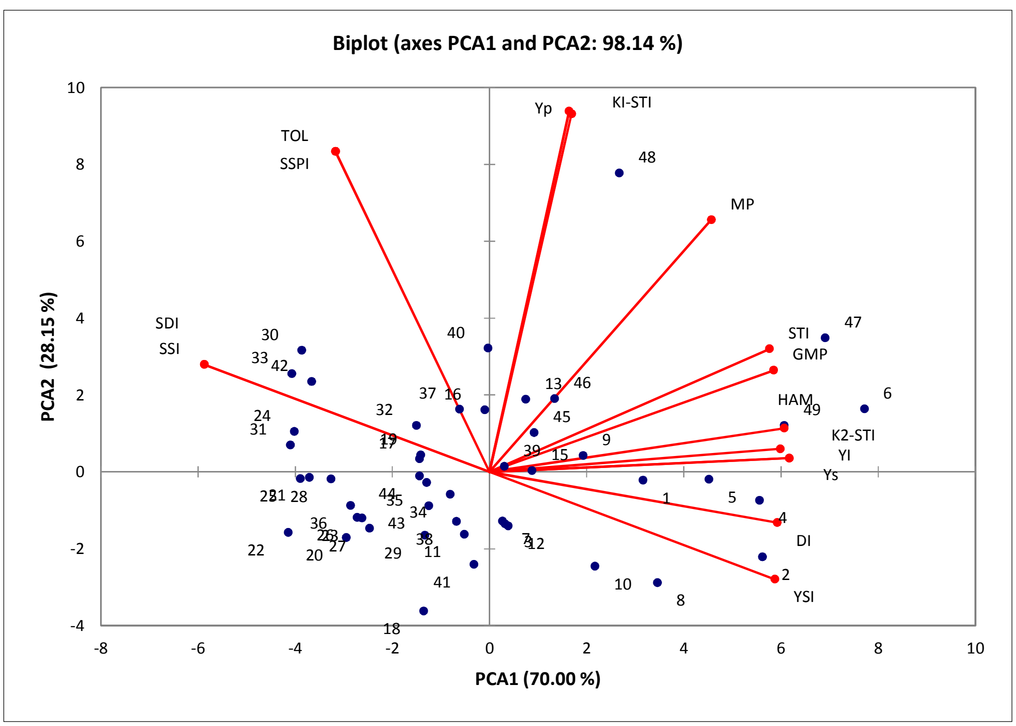

Figure 2. Biplot of the first two principal component axes for 49 wheat lines for the Assiut-Matrouh analysis

CONCLUSIONS

Selection of drought-tolerant lines should be well adopted to stress and non-stress conditions.. In the present study, a high positive correlation was recorded between grain yield and the drought indices studied. In addition, we observed that mean productivity, geometric mean productivity and stress tolerance index are the best indices for selecting drought-tolerant lines. It can be recommended that lines 47 and 48 are promising to be cultivated in drought stress or drought prone rainfed areas in Egypt. Moderate drought stress environments should be used for screening for drought-tolerant genotypes rather than severe drought stress environments. Therefore, plant breeders should pay attention to severity of drought stress when selecting drought-tolerant wheat lines.

REFERENCES

Bidinger F.R., Mahalakshmi V., Rao G.D.P. (1978). Assessment of drought resistance in millet. Factors effecting yields under stress. *Australian Journal of Agricultural Research* 38, 37–78.

Blum A. (1988). *Plant breeding for stress environments*. CRC Press, Boca Raton, FL, 38–78.

Blum A. (1996). Yield potential and drought resistance: are they mutually exclusive? In: Reynolds M.P., Rajaram S., Mc Nab A. (Eds.) *Increasing yield potential in wheat. Breaking the barriers*, 90–101.

Bouslama M., Schapaugh W.T. (1984). Stress tolerance in soybeans. I. Evaluation of three screening techniques for heat and drought tolerance. *Crop Science* 24(5), 933–937.

Byrne P.F., Bolanos J., Edmeades G.O., Eaton D.L. (1995). Gains from selection under drought versus multilocation testing in related tropical maize populations. *Crop Science* 35, 63–69

Clarke J.M., DePauw R.M., Townley-Smith T.F. (1992). Evaluation of methods for quantification of drought tolerance in wheat. *Crop Science* 32, 423–428.

Farshadfar E., Javadinia J. (2011). Evaluation of Chickpea (*Cicer arietinum* L.) genotypes for drought tolerance. *Seed and Plant Improvement Journal* 27, 517–537.

Farshadfar E., Sutka J. (2002). Screening drought tolerance criteria in maize. *Acta Agronomica Hungarica* 50, 411–416.

Farshadfar E., Mohammadi R., Farshadfar M., Dabiri S. (2013). Relationships and repeatability of drought tolerance indices in wheat-rye disomic addition lines. *Australian Journal of Crop Science* 7, 130–138.

Fernandez G.C.J. (1992). Effective selection criteria for assessing stress tolerance. In: Kuo, C.G. (Ed.) *Proceedings of the International Symposium on Adaptation of Vegetables and Other Food Crops in Temperature and Water Stress*. Tainan, Taiwan.

Fischer R.A., Maurer R. (1978). Drought resistance in spring wheat cultivars. I. Grain yield responses. *Crop and Pasture Science* 29, 897–912.

Gavuzzi P., Rizza F., Palumbo M., Campanile R.G., Ricciardi G. L., Borghi B. (1997). Evaluation of field and laboratory predictors of drought and heat tolerance in winter cereals. *Canadian Journal of Plant Science* 77, 523–531.

Golabadi M., Arzani A., Maibody S.M. (2006). Assessment of drought tolerance in segregating populations in durum wheat. *African Journal of Agricultural Research* 1, 162–171.

Kirigwi F.M., Van Ginkel M., Trethowan R., Sears R.G., Rajaram S., Paulsen G.M. (2004). Evaluation of selection strategies for wheat adaptation across water regimes. *Euphytica* 135, 361–371.

Lan J. (1998). Comparison of evaluating methods for agronomic drought resistance in crops. *Acta Agric Boreali-occidentalis Sinica* 7, 85–87.

Ma Q.Q., Wang W., Li Y.H., Li D.Q., Zou Q. (2006). Alleviation of photoinhibition in drought-stressed wheat (*Triticum aestivum*) by foliar-applied glycinebetaine. *Journal of Plant Physiology* 163, 165–175.

Mardeh A.S.S., Ahmadi A., Poustini K., Mohammadi V. (2006). Evaluation of drought resistance indices under various environmental conditions. *Field Crops Research* 98, 222–229.

Mohammadi R., Armion M., Kahrizi D., Amri A. (2010). Efficiency of screening techniques for evaluating durum wheat genotypes under mild drought conditions. *Journal of Plant Production* 4, 11–24

Moosavi S.S., Yazdi-Samadi B., Naghavi M.R., Zali A.A., Dashti H., Pourshahbazi A. (2008). Introduction of new indices to identify relative drought tolerance and resistance in wheat genotypes. *Desert* 12, 165–178.

Mursalova J., Akparov Z., Ojaghi J., Eldarov M., Belen S., Gummadov N., Morgounov A. (2015). Evaluation of drought tolerance of winter bread wheat genotypes under drip irrigation and rain-fed conditions. *Turkish Journal of Agriculture and Forestry* 39, 1–8.

Naya L., Ladrera R., Ramos J., González E.M., Arrese-Igor C., Minchin F.R., Becana M. (2007). The response of carbon metabolism and antioxidant defenses of alfalfa nodules to drought stress and to the subsequent recovery of plants. *Plant Physiology* 144, 1104–1114.

Nouri A., Etminan A., Teixeira da Silva J.A., Mohammadi R. (2011). Assessment of yield, yield-related traits and drought tolerance of durum wheat genotypes (*Triticum turjidum* var. *durum* Desf.). *Australian Journal of Crop Science* 5, 8–16.

Pirayvatlou A.S. (2001). Relations among yield potential, drought tolerance and stability of yield in bread wheat cultivars under water deficit conditions. *Proceedings of the 10th Australian Agronomy Conference.* Hobart, January 29, 2001

Rajaram S., Van Ginkle M. (2001). Mexico, 50 years of international wheat breeding. Bonjean A.P., Angus W.J., (Eds.) *The world wheat book: A history of wheat breeding*. Lavoisier Publishing, Paris, France, 579–604.

Rajaram S., Braun H.J., Van Ginkel M. (1996). CIMMYT's approach to breed for drought tolerance. *Euphytica* 92, 147–153.

Rosielle A.A., Hamblin J. (1981). Theoretical aspects of selection for yield in stress and non-stress environment. *Crop Science* 21, 943–946.

Sanjari Pireivatlou A, Yazdansepas A. (2008). Evaluation of wheat (*Triticum aestivum* L.) Genotypes under Pre-and post -anthesis drought stress conditions. *Journal of Agricultural Science and Technology* 10, 109–121.

Schneider K.A., Rosales-Serna R., Ibarra-Perez F., Cazares-Enriquez B., Acosta-Gallegos J. A., Ramirez-Vallejo P., Wassimi N., Kelly J.D. (1997). Improving common bean performance under drought stress. *Crop Science* 37, 43–50.

Talebi R., Fayaz F., Naji A.M. (2009) Effective selection criteria for assessing drought stress tolerance in durum wheat (*Triticum durum* DESF.). *General and Applied Plant Physiology* 35, 64-74

Zeinali Khanghah H., Izanlo A., Hosseinzadeh A., Majnoun Hosseini N. (2004). Determine of appropriate drought resistance indices in imported soybean cultivars. *Iran Journal of Agricultural Science* 354, 875–885.