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DROUGHT TOLERANCE INDICES AND THEIR CORRELATION WITH YIELD IN EXOTIC WHEAT GENOTYPES

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Abstract

Performance of nineteen exotic genotypes along with local check variety was studied during 2009-10 at Wheat Research Institute, AARI, Faisalabad, Pakistan. The experiment was conducted under two field conditions i.e., stress and irrigated conditions. In case of water stress experiment, only soaking irrigation was applied for seed bed preparation and no further irrigation was applied up to maturity. While, four irrigations were applied at critical growth stages to the second experiment (irrigated). At maturity, grain yield was recorded in both experiments (stress Y_s and irrigated Y_p). From grain yield data, some drought tolerance/resistance indices such as tolerance index (TOL), mean productivity (MP), harmonic mean (HM), stress susceptibility index (SSI), geometric mean productivity (GMP), stress tolerance index (STI), yield index (YI), yield stability index (YSI) and modified stress tolerance index (k_1STI & k_2STI) were calculated. Genotypic correlation, genetic components and heritability were also calculated for grain yield and all indices. Significant differences among genotypes were observed for Y_p, Y_s and all other drought tolerance indices. Moderate to high heritability and genetic advance were observed for Y_p, Y_s and all drought tolerance indices. Grain yield under irrigated environment (Y_p) was positively and significantly correlated with MP, HM, GMP, STI and k_1STI. Similarly, positive and significant association has also been observed between grain yield under stress condition (Y_s) and MP, HM, GMP, STI, YI and k_2STI so they were the better predictor of potential yield Y_p and Y_s than TOL, SSI and YSI. According to Fernandez model; genotypes No. 2, 4, 6, 7, 9 and 13 have uniform superiority under both conditions (stress and irrigated). Genotypes No. 1, 11, 15, 16, 17, 18 and 19 were recommended for irrigated conditions. Genotypes No. 3 and 5 were identified suitable for stress conditions. While genotypes No. 8, 10, 12, 14 and 20 performed poorly under either environments (stress and irrigated).

Introduction

Wheat is the main cereal crop of Pakistan and it is a prime food of the people. It contributes 14.4% to the value added in agriculture and 3.1% to GDP. In Pakistan during 2009-10 it was grown on an area of 9.042 million hectares with the production of 23.864 million tons and average yield of 2647 kg/ha (Anon., 2010). Almost 10% of the area is being grown under rainfed conditions in Punjab and remaining suffer with severe shortage of canal water as well as non-availability of supplemental irrigation by tube well due to drastic load shedding of electricity. The water availability during Rabi season (for major crop such as wheat), is, however, estimated at 26.0 MAF, which is 28.6% less than the normal availability and 4.4% more than last year's Rabi. During the monsoon season (July-September, 2009) the normal rainfall was 137.5 mm while the actual rainfall received stood at 101.8 mm, indicating a decrease of 26.0%. Likewise, during the winter (January to March 2010), the actual rainfall received was 49.2 mm while the normal rainfall during this period has been 70.5 mm, indicating a decrease of 30.2% over the normal rainfall (Anon., 2010).

The impact of water shortage (availability at farm gate) and lower rainfall during the sowing period seems to be the main reason for lesser acreage under wheat crop and reduction in wheat production. Therefore, breeding for drought tolerant wheat is an important task and objective in the present scenario. For effective breeding of drought tolerant wheat varieties good selection criteria is needed to identify the drought tolerant wheat genotypes. Findings of some earlier researchers who reported different drought tolerance indices are summarized below:

Drought indices which provide a measure of drought based on loss of yield under drought-conditions in comparison to normal conditions have been used for screening drought-tolerant genotypes (Mitra, 2001). These indices are either based on drought resistance or susceptibility of genotypes (Fernandez, 1992). Drought resistance is defined by Hall (1993) 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 (Blum, 1988). Rosielle & Hamblin (1981) defined stress tolerance (TOL) as the differences in yield between the stress (Y_s) and non-stress (Y_p) environments and mean productivity (MP) as the average yield of Y_s and Y_p. Fischer & Maurer (1978) proposed a stress susceptibility index (SSI) of the cultivar. Fernandez (1992) defined a new advanced index (STI= stress tolerance index), which can be used to identify genotypes that produce high yield under both stress and non-stress conditions. Other yield based estimates of drought resistance are geometric mean (GM), mean productivity (MP) and TOL. The geometric mean is often used by breeders interested in relative performance since drought stress can vary in severity in field environment over years (Ramirez & Kelly, 1998). These indices have been compared by different researchers (Fernandez, 1992; Richard, 1996) and their genetic parameters have also been studied (Link *et al.*, 1999; Golabadi *et al.*, 2006).

Saba *et al.*, (2001), Golabadi *et al.*, (2006) and Gholipouri *et al.*, (2009) reported that significant differences were noted for all drought indices except SSI. Golabadi *et al.*, (2006) also reported significant and positive correlations of Y_p and (MP, GMP and STI) and Y_s and (MP, GMP and STI) under both the seasons as well as significant negative correlation of SSI and TOL under moisture stress environment (E_1) revealed that selection could be conducted for high MP, GMP and STI under both environments and low SSI and TOL under E_1 conditions. Yagdi & Sozen (2009) reported the positive and significant correlation between yield and yield parameters. Gholipouri *et al.*, (2009) reported four categories of cultivars according to Fernandez model.

The objectives of present studies were: i) to compare different drought resistance indices, ii) to estimate genetic parameters like heritability and association of these indices with grain yield and indentifying the potential genotypes for moisture stress and irrigated conditions.

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Materials and Methods

Nineteen exotic spring wheat cultivars received from CIMMYT, Mexico and one local variety (Faisalabad 08) were grown in two field experiments i.e., under water stress and irrigated conditions on December 11, 2009 at Wheat Research Institute, Faisalabad. In case of water stress experiment, only soaking irrigation was applied for seed bed preparation and later on no irrigation was applied upto maturity. While, four irrigations were applied at critical growth stages to the second experiment (irrigated). Genotypes in each experiment were planted in a randomized complete block design with three replications. Each experimental plot consisted of six rows, 6 meters long and 27 cm apart, seeded at an average rate of 100 kg/ha with self propelled mechanical planter and maintained 5 meters length of the plot after germination. The whole dose of nutrients i.e. nitrogen 100 kg/ha and P_2O_5 85 kg/ha was applied at the time of seedbed preparation. In water stress experiment weeds were controlled manually (hoeing) but in irrigated experiment weeds were controlled by spraying the chemicals.

For determining the final yield, 8.1m^2 (6 rows of 5 meter long) was harvested at maturity and yield was recorded in both experiments. The drought tolerance indices were calculated as follows:

1. Tolerance index (TOL) and mean productivity (MP) as done by Rosielle & Hamblin (1981):

$$TOL = (Y_p - Y_s) \quad \text{and} \quad MP = (Y_s + Y_p) / 2$$

Y_p and Y_s were the yield of each cultivars, non-stressed and stressed, respectively.

2. Harmonic mean (HM) (Kristin *et al.*, 1997):

$$HM = 2(Y_p * Y_s) / (Y_p + Y_s)$$

3. Stress susceptibility index (SSI) (Fisher & Maurer, 1978):

$$SSI = 1 - (Y_s / Y_p) / SI, \quad \text{while } SI = 1 - (\hat{Y}_s / \hat{Y}_p)$$

whereas SI is stress intensity and $\hat{Y}_s$ and $\hat{Y}_p$ are the means of all genotypes under stress and well water conditions, respectively.

4. Geometric mean productivity (GMP) and stress tolerance index (STI) (Fernandez, 1992; Kristin *et al.*, 1997):

$$GMP = (Y_p * Y_s)^{1/2} \qquad STI = (Y_p * Y_s) / (\hat{Y}_p)^2$$

5. Yield Index (YI) (Gavuzzi *et al.*, 1997; Lin *et al*., 1986)

$$YI = Y_s / \hat{Y}_s$$

6. Yield Stability Index (YSI) (Bouslama & Schapaugh, 1984)

$$YSI = Y_s / Y_p$$

7. Modified stress tolerance index (MSTI) as reported by Farshadfar & Sutka, (2002):

$$MSTI = k_iSTI \quad \text{while } k_1 = (Y_p^2) / (\hat{Y}_p^2) \text{ and } k_2 = (Y_s^2) / (\hat{Y}_s^2)$$

where k_i is the correction coefficient.

Analysis of variance was conducted for each index according to Steel & Torrie (1980) through computer program MSTATC and graph by SPSS software. Genotypic correlations were determined by the method of Johnson *et al.,* (1955).

Results and Discussion

The analysis of variance showed highly significant differences for yield (Y_p and Y_s) and all drought tolerance indices (Table 1), which indicated that genotypes were differing for genes controlling yield and drought tolerance indices (Saba *et al.*, 2001; Golabdi *et al.*, 2006; Gholipouri *et al*., 2009; Yagdi & Sozen, 2009).

Genotypic coefficient of variability (GCV%), broad sense heritability (h^2), genetic advance as percentage of mean (GA%) were high for Y_p, Y_s and all drought tolerance indices (Table 2). Hence substantial improvement in these indices may be achieved through selection under drought stress conditions. These results are in agreement with the findings of Saba *et al.*, (2001); Yagdi & Sozen (2009).

Different drought tolerance indices were calculated on the basis of grain yield of the genotypes under irrigated (Y_p) and stressed (Y_s) conditions (Table 3). It is depicted from Table 3, that greater the value of TOL, larger the yield reduction under stress conditions and higher the drought sensitivity. Negative value of TOL showed more yield in stress than irrigated conditions. The ranks of the genotypes for MP, HM, GMP and STI were almost identical (Richard, 1996; Ramirez & Kelly, 1998; Saba *et al*., 2001).

To determine the most desirable drought tolerance criteria, the genotypic correlation coefficient (r_g) between Y_p, Y_s and other quantitative indices of drought tolerance were calculated (Table 4). The yield (Y_p) under irrigated conditions has a very weak association with stress conditions (Y_s) depicting that high yield potential under best possible conditions does not anticipate superior yield under stress conditions. Therefore, indirect selection for stresses environment based on the performance of irrigated conditions would not be effective. These are in agreement with the results of Gholipouri *et al*., (2009). Grain yield under irrigated conditions (Y_p) was positively and significantly correlated with MP, HM, GMP, STI and k_1STI similarly, positive and significant association has also been observed among grain yield under stress condition (Y_s) and MP, HM, GMP, STI, YI and k_2STI so they were the better predictor of potential yield Y_p and Y_s than TOL, SSI and YSI. These findings are in consistence with the findings of Fernandez (1992) in mungbean, Golabadi *et al*., (2006) in spring wheat and Farshadfar (2002) in maize. In stress condition, grain yield showed negative association with TOL and SSI (Gholipouri *et al*., 2009). Therefore, TOL and SSI indices are suitable factors to identify wheat genotypes with low yield and tolerant to drought because under stress yield decreased with increasing SSI. There was no significant association of TOL with MP, HM, GMP, STI, YI, k_1STI and k_2STI. It had significant and positive correlation with SSI. It gave the impression that SSI and TOL had same capability in performing tolerance against stress. Mean productivity (MP) was significantly and positively correlated with HM, GMP, STI, YI, k_1STI and k_2STI (Link *et al*., 1999. Similarly, HM also had positive and significant genotypic correlation with GMP, STI, YI, k_1STI and k_2STI. SSI showed significant and negative correlation with YSI and weak negative association with GMP, STI, YI and k_2STI. Even though STI and genotype yield had significant and positive association both under stress and irrigated conditions, was used to draw three-dimensional graphs to find drought resistant genotypes (Fig. 1). According to Fernandez (1992) model, studied genotypes were divided into four categories based on their performance in stressed and irrigated conditions: genotypes No. 2, 4, 6, 7, 9 and 13 positioned in group A and these genotypes had high yield under both conditions (stressed and irrigated); genotypes No. 1, 11, 15, 16, 17, 18 and 19 placed in group B and having maximum yield in irrigated conditions; genotypes No. 3 and 5 were situated in group C and produced high yield under stress conditions; and genotypes No. 8, 10, 12, 14 and 20 found to be in group D exhibiting low yield in both conditions (stressed and irrigated). Fernandez (1992), Farshadfar & Sutka (2002) and Gholiouri *et al*., (2009) considered it the best possible selection criteria where genotypes of Group A should be distinguished from the genotypes of other three groups.

Table 1. Mean squares of Y_p, Y_s and different drought tolerance indices in wheat.

S. No.	Drought tolerance indices	Mean squares		
		Replication (df = 2)	Genotype (df = 19)	Error (df = 38)
1.	Yield in non-stressed (Y_p)	188031.91	281033.90**	38964.67
2.	Yield in stressed (Y_s))	35013.62	202525.29**	20506.00
3.	Tolerance index (TOL)	236882.53	349870.65**	46862.50
4.	Mean productivity (MP)	52300.37	154310.87**	18019.84
5.	Harmonic mean (HM)	43176.53	154514.34**	16922.93
6.	Stress susceptibility index (SSI)	0.580	0.903**	0.113
7.	Geometric mean productivity (GMP)	47393.63	153816.63**	17338.98
8.	Stress tolerance index (STI)	0.011	0.036**	0.004
9.	Yield index (YI)	0.003	0.020**	0.002
10.	Yield stability index (YSI)	0.014	0.022**	0.003
11.	Modified stress tolerance index for non-stressed (k_1STI)	0.088	0.161**	0.025
12.	Modified stress tolerance index for stressed (k_2STI)	0.031	0.154**	0.021

** = Significant at 0.01 probability level

Table 2. Mean, genotypic coefficient of variability (GCV%), heritability in broad sense (h^2) and genetic advance as percentage of mean (GA%) of Y_p, Y_s and different drought tolerance indices in wheat.

S. No.	Parameters	Mean	GCV%	h^2	GA%
1.	Yield in non-stressed (Y_p)	3745.84 ± 44.66	7.58	67.44	10.93
2.	Yield in stressed (Y_s))	3157.94 ± 36.78	7.80	74.74	11.83
3.	Tolerance index (TOL)	587.90 ± 49.64	54.06	68.31	78.41
4.	Mean productivity (MP)	3451.89 ± 32.52	6.17	71.60	9.17
5.	Harmonic mean (HM)	3416.41 ± 32.34	6.27	73.05	9.40
6.	Stress susceptibility index (SSI)	0.965 ± 0.079	53.18	69.97	78.07
7.	Geometric mean productivity (GMP)	3434.07 ± 32.36	6.21	72.40	9.28
8.	Stress tolerance index (STI)	0.845 ± 0.016	12.22	72.72	18.29
9.	Yield index (YI)	1.000 ± 0.012	7.75	75.00	11.77
10.	Yield stability index (YSI)	0.849 ±0.013	9.37	67.86	13.55
11.	Modified stress tolerance index for non-stressed (k_1STI)	0.870 ± 0.034	24.47	64.46	34.48
12.	Modified stress tolerance index for stressed (k_2STI)	0.868 ± 0.033	24.26	67.86	35.07

Table 3. Mean values of yield in non-stressed (Y_P), yield in stressed (Y_s), tolerance index (TOL), mean productivity (MP), harmonic mean (HM), stress susceptibility index (SSI), geometric mean productivity (GMP), stress tolerance index (STI), yield index (YI), yield stability index (YSI) and modified stress tolerance index for non-stressed (k_1STI & k_2STI) in wheat.

Genotype	Y_p	Y_s	TOL	MP	HM	SSI	GMP	STI	YI	YSI	K_1STI	K_2STI
1	3988.89	3116.05	872.84	3552.47	3493.80	1.377	3522.98	0.885	0.987	0.784	1.009	0.864
2	3604.11	3287.24	316.87	3445.68	3437.71	0.557	3441.69	0.845	1.041	0.913	0.784	0.916
3	3377.37	3336.21	41.15	3356.79	3354.98	0.065	3355.89	0.803	1.057	0.990	0.656	0.896
4	3885.60	3618.93	266.67	3752.26	3743.13	0.414	3747.69	1.004	1.146	0.935	1.105	1.339
5	3180.25	3351.85	-171.60	3266.05	3261.15	-0.353	3263.60	0.759	1.062	1.055	0.547	0.857
6	3864.20	3467.90	396.30	3666.05	3654.83	0.652	3660.43	0.955	1.098	0.898	1.019	1.155
7	3939.10	3276.54	662.55	3607.82	3576.58	1.073	3592.16	0.920	1.038	0.832	1.019	0.997
8	3474.49	3056.79	417.69	3265.64	3245.23	0.735	3255.41	0.756	0.968	0.885	0.659	0.712
9	4216.05	3297.94	918.11	3757.00	3699.33	1.383	3728.04	0.991	1.045	0.783	1.262	1.086
10	3514.40	3235.39	279.01	3374.90	3367.99	0.494	3371.44	0.811	1.024	0.923	0.722	0.854
11	4204.12	3166.26	1037.86	3685.18	3611.22	1.569	3648.01	0.949	1.003	0.754	1.198	0.954
12	3458.44	2790.54	667.90	3124.49	3084.51	1.210	3104.41	0.688	0.883	0.810	0.593	0.540
13	3942.39	3397.12	545.27	3669.75	3643.00	0.858	3656.34	0.953	1.075	0.865	1.060	1.103
14	3527.57	2649.38	878.19	3088.48	3025.25	1.583	3056.69	0.666	0.839	0.752	0.591	0.469
15	3797.53	3078.19	719.34	3437.86	3399.60	1.208	3418.68	0.834	0.975	0.811	0.861	0.798
16	4011.93	3185.19	826.75	3598.56	3548.68	1.304	3573.52	0.911	1.009	0.795	1.050	0.928
17	4086.01	2840.74	1245.27	3463.37	3347.37	1.921	3404.81	0.828	0.899	0.699	1.008	0.675
18	3862.14	3211.94	650.21	3537.04	3506.11	1.081	3521.54	0.887	1.017	0.831	0.955	0.940
19	3730.45	3160.91	569.54	3445.68	3421.55	0.968	3433.59	0.841	1.001	0.848	0.837	0.843
20	3251.85	2633.74	618.11	2942.80	2906.25	1.194	2924.43	0.610	0.834	0.813	0.462	0.425
LSD (0.05)	326.30	236.70	357.80	221.90	215.00	0.556	217.70	0.105	0.074	0.091	0.261	0.240

Table 4. Genotypic correlation (r_g) of yield in non-stressed (Y_p), yield in stressed (Y_s), tolerance index (TOL), mean productivity (MP), harmonic mean (HM), stress susceptibility index (SSI), geometric mean productivity (GMP), stress tolerance index (STI), yield index (YI), yield stability index (YSI) and modified stress tolerance index for non-stressed (k_1STI & k_2STI) in wheat.

	Y_p	Y_s	TOL	MP	HM	SSI	GMP	STI	YI	YSI	K_1STI
Y_p											
Y_s	0.288										
TOL	0.670	-0.517									
MP	0.833*	0.770*	0.148								
HM	0.765*	0.836*	0.036	0.993*							
SSI	0.579	-0.610	0.990*	0.033	-0.076						
GMP	0.800*	0.805*	0.091	0.998*	0.998*	-0.022					
STI	0.796*	0.790*	0.099	0.987*	0.987*	-0.012	0.989*				
YI	0.290	1.007*	-0.522	0.775*	0.842*	-0.616	0.810*	0.795*			
YSI	-0.586	0.617	-1.002*	-0.034	0.076	-1.012*	0.022	0.011	0.622		
K_1STI	0.968*	0.524	0.459	0.948*	0.905*	0.354	0.928*	0.922*	0.527	-0.359	
K_2STI	0.535	0.952*	-0.259	0.907*	0.947*	-0.360	0.929*	0.918*	0.959*	0.363	0.737

* Significant at 0.01 probability levels.

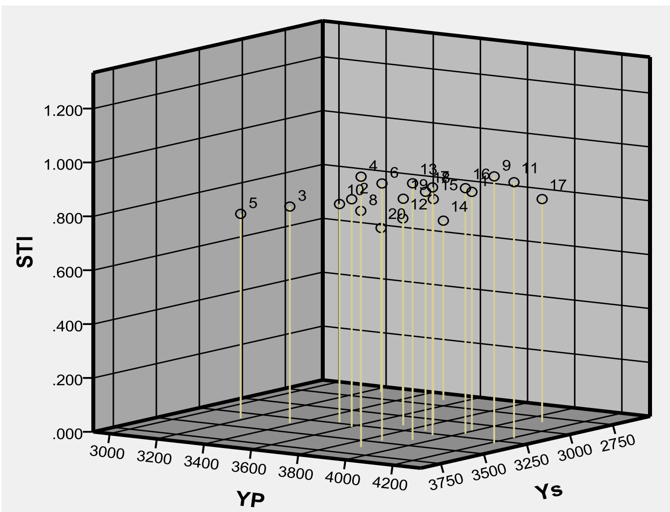

Fig. 1. Selection of drought tolerant genotypes based on Fermandez model.

It is concluded from the present studies that having positive and significant association of Y_p with MP, HM, GMP, STI & k_1STI and Y_s with MP, HM, GMP, STI, YI and k_2STI they were the better predictor of potential yield Y_p and Y_s than TOL, SSI and YSI. It is further concluded that genotypes No. 2, 4, 6, 7, 9 and 13 have uniform superiority under both conditions (stress and irrigated). Genotypes No. 1, 11, 15, 16, 17, 18 and 19 were recommended for irrigated conditions. Genotypes No. 3 and 5 were identified suitable for stress conditions while genotypes No. 8, 10, 12, 14 and 20 performed poorly in either conditions (stress and irrigated).

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