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STRESS SELECTION INDICES AN ACCEPTABLE TOOL TO SCREEN SUPERIOR WHEAT GENOTYPES UNDER IRRIGATED AND RAIN-FED CONDITIONS

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Abstract

The climate is changing day by day and water scarcity has developed a milieu for the breeder to think accordingly. Twenty-four advanced wheat lines along with four prominent check cultivars were evaluated independently in irrigated (IRE) and rain-fed environments (RFE) for yield related traits at Khyber Pakhtunkhwa, Pakistan during 2010-11, using randomized complete block design with three replications under each test environment. Analysis of variance across the two environments exhibited highly significant variation ($p \leq 0.01$) among the genotypes for yield and associated traits. Differences among the two test environments (E) were significant for tillers m^{-2}, 1000-grain weight and harvest index. Genotype × environment interaction (G×E) effects were significant only for 1000-grain weight and grain yield. There was general reduction in 1000-grain weight, biological yield and grain yield of all genotypes under RFE as compared to IRE. Magnitude of heritabilities estimates were greater for tillers m^{-2}, spikelets spike^{-1} and grains spike^{-1} under IRE than RFE. Heritabilities were greater in RFE than IRE for spike length (0.31 vs 0.26), biological yield (0.80 vs 0.22), grain yield (0.94 vs 0.20) and harvest index (0.41 and 0.39). Relative high expected selection response was recorded for all characters under IRE except spike length, grains spike^{-1} and grain yield. In IRE, highest grain yield was produced by genotypes BRF-7 (5123 kg ha^{-1}), B-VI(N)16 (5111 kg ha^{-1}), B-IV(N)1 (5086 kg ha^{-1}) and B-VI(N)5 (5049 kg ha^{-1}), while genotypes B-VI(N)5 (4649 kg ha^{-1}), B-IV(N)1 (4595 kg ha^{-1}), BRF-7 (4486 kg ha^{-1}) and B-IV(N)16 (4462 kg ha^{-1}) were high yielding under RFE. Prominent stress selection indices used in the experiments were mean productivity (MP), tolerance (TOL), stress tolerance index (STI), trait index (TI) and trait stability index (TSI). MP and STI were the efficient and reliable selection indices in both environments (IRE & RFE). MP, TOL and STI had strong positive relationship with tillers m^{-2}, spikelets spike^{-1}, 1000-grain weight, biological yield and grain yield under IRE. Mean stress indices showed that the top ranking genotypes for MP and STI were B-VI(N)6, BRF-7, B-VI(N)5 and B-II(N)3, reflected their superior performance across both the conditions.

Introduction

In many parts of the world water stress inhibited the wheat productivity and the same has been reported in Pakistan too (Rajaram *et al*., 1996). Precipitation rate in most parts is too low than that cultivated crops evaporation demand. Hence, to meet up the crop evapotranspiration requirements, timely irrigation is very much important. Proper irrigation at the right time at appropriate developmental and growth phase is feasible rationale for the enhancement and improvement of wheat production (Muhammad *et al*., 1997). Drought stress conditions fluctuate in its effects and sternness with respect to the distribution and rate of precipitation, management and properties of soil. Wheat genotype that give maximum yield at optimum soil moisture and only display little decline in productivity in drought environment would reflect the efficiency and superior performance of that genotype. Drought resistance of a particular wheat genotype is the result of several morphological and physiological characters for which efficient standard of selection have not yet proposed (Ludlow & Muchow, 1990). The FAO had already predicted a decline worldwide in the production of wheat upto 9% from 682.4 to 676.5 million tonnes (Anon., 2010a,b). In Pakistan, wheat being the staple diet is the most important cereal crop. During the crop season 2009-2010, wheat was cultivated on an area of 9.05 million hectares with a production of 24.03 million tones and annual yield of 2657 kg ha^{-1}. Out of the total wheat cultivated area in the country, approximately 1.22 million hectares (13.5%) was rain-fed and 7.82 million hectares (86.5%) was irrigated (Pakistan Bureau of Statistics, 2010). This decline and the use of wheat worldwide as food and feed have attracted the breeders to screen and develop new lines with maximum yield potential and stability.

So, selection of superior performing wheat genotypes under both the conditions is the viable way to improve the wheat yield under drought stress environment in order to meet the yield difference between the two cropping conditions.

All over the world water stress severely inhibits the productivity of major and many domesticated crops. In the 3rd world countries where approximately thirty seven percent of the areas producing wheat are partially dry, having low soil water; the drought stress problem is very sharp there which is reducing rationale of maximum yield (Rajaram, 1996). Selection in low-drought conditions, elevated drought conditions and addition of both normal and drought conditions are some of the profound strategies for improving tolerance to water stress. Selection in favorable conditions is usually reliable and efficient for greater yield due to minimum genotype × environment interaction (G×E) effects and higher magnitude of genetic differences in such environments (Ullah *et al*., 2012). For a plant breeder it has been known to be a hard target to bring genetic variation and improve the grain yield in stress susceptible and least desirable conditions as compared to favorable and desirable conditions where improvement has been much greater in yield (Richards *et al*., 2002). It has been a hard challenge of wheat breeding program to produce appropriate and superior cultivars for erratic water stressed conditions. The key constraint has been the deficiency and unavailability of a method and skill to select a genotype tolerant to water stress, which can be utilized repeatedly in genetically segregating populations. The massive amount of features concerned with reaction of crop plants to drought conditions makes it intricate to grant a valid test of tolerance to water stress. Stress indices have been known to use for selection of genotypes tolerant to stress and which determine water stress on yield loss basis in water stress environment as compared to non-stressed environments (Moustafa *et al*., 1996). The mean yield of non-stress (normal) and stress (drought) conditions and the yield difference between non-stress and stress conditions are defined as mean productivity (MP) and stress tolerance (TOL), respectively (Rosielle & Hamblin, 1981). Similarly, stress tolerance index (STI) is also a direct and effective criterion in selection of high yielding genotypes in both non-stress and stress environments (Fernandez, 1992).

Variances (genetic and environmental) of advance lines and earlier generations trait heritability is measured that produces valid proof about transmission of specific heritable character to the consecutive generations as well as facilitates the breeders to make favorable reliable selections (Allard, 1960; Ullah *et al*., 2011 & 2012). So, for plant breeder heritability estimation is quite vital in order to select superior genotypes in hybridization process and predict the breeding materials genetic efficiency and also from there propose effective and reliable techniques of selection. On the other hand, low trait heritability, grater G×E interaction effects and unstable experiment environments makes the selection unreliable and complicated. Such breeding programs recently have been initiated that combine greater yield receptiveness in desirable environments with mineral nutrients and efficient water utilization in stress environments (Ginkel *et al*., 1998).

Thus, the objectives of the conducted experiment were to assess the variation among wheat genotypes; estimate heritability and selection responses and to measure selection indices for yield and related traits and to select superior wheat genotypes based on these selection indices under both the environments.

Materials and Methods

Germplasm evaluation: Twenty-four wheat genotypes (Table 1) along with prominent check cultivars (recommended either or both for irrigated (IRE) and rain-fed environments (RFE)) obtained from Cereal Crops Research Institute Pirsabak Nowshehra were assessed for the selected traits and parameters during the crop season 2010-11 at Malakandher Research Farm of Khyber Pakhtunkhwa Agricultural University, Peshawar in IRE and RFE. The experiments were laid out in randomized complete block design with three replications in both the cropping environments. The experiments (IRE & RFE) were set up in the same field contiguously to one another in order to overcome the environmental bias. The RFE experiment however, was not irrigated at all through the crop season. Each genotype was planted in three rows of three-meter length. The distance between rows was 30 cm. Both experiments were sown on 3rd November, 2010 using hand hoe. The seed rate was calibrated at 100 kg ha^{-1}. For IRE experiment, fertilizers (Nitrogen: Phosphorus) rates at sowing time were 120:60kg ha^{-1} in split doses, whereas for RFE the rates were 60:30 kg ha^{-1} as a single dose. Data were recorded on those parameters, which were of greater importance throughout the world in wheat breeding program as explained in results section.

Table 1. Mean squares for tillers, spike length, spikelets and grains spike^{-1}, 1000-grain weight, biological yield, grain yield and harvest index of 28 wheat genotypes across two environments (IRE & RFE) at Khyber Pakhtunkhwa, Pakistan during 2010-11.

Sources	Df	Tillers m^{-2}	Spike length	Spikelets spike^{-1}	Grains spike^{-1}	1000-grain wt	Biological yield	Grain yield	Harvest index
Environments (E)	1	30537.05*	1.18^{NS}	1.52^{NS}	29.17^{NS}	1055.51**	4471224.74^{NS}	4916862.75^{NS}	169.64*
Reps w/n env.	4	2125.95	1.66	9.06	7.15	1.21	12627860.94	1696236.03	13.14
Genotypes (G)	27	11909.25**	1.10**	2.43**	57.22**	52.80**	4195541.56**	725003.80**	55.24**
G × E	27	6302.77^{NS}	0.35^{NS}	1.23^{NS}	16.59^{NS}	16.19**	1595645.44^{NS}	358642.33*	10.28^{NS}
Error	108	4133.26	0.33	0.86	10.70	4.65	1143719.78	217611.31	11.02
CV (%)	--	17.25	5.73	4.75	5.92	4.59	9.49	10.96	8.76

**, *, ^{NS}=Significant at 1 & 5% probability and non-significant respectively

Statistical analysis: Data pertaining to the above characters were statistically analyzed over both environments using a mixed effects model in order to enumerate the G×E effect using SAS Software (Anon., 1999). The data for each test environment was also analyzed separately to calculate genetic and environmental variances for determination of broad-sense heritability and selection response using the method of Singh & Chaudhary (1985). Expected response (Re) for the important characters in each test environment was estimated using specific selection intensity as follows.

Selection response (Re) = $i \times h^2_x \sqrt{V_p} \times$

where:

i = A constant value at 15% selection intensity.
V_p = Phenotypic variance for a trait in a particular test environment.
h^2_x = Heritability for trait x under a particular test environment.

In addition the irrigated and rain-fed experiments were assumed as normal and stressed conditions to work out the following selection indices.

1. Mean productivity = $MP = \frac{X_I + X_R}{2}$ (Hossain *et al*., 1990).

2. Tolerance = TOL = $X_I - X_R$ (Hossain *et al*., 1990).

3. Stress tolerance index = $STI = \frac{X_I \times X_R}{(\bar{X}_I)^2}$ (Fernandez, 1992).

4. Trait index = $TI = \frac{X_R}{\bar{X}_R}$ (Gavuzzi *et al*., 1997).

5. Trait stability index = $TSI = \frac{X_R}{X_I}$ (Bouslama & Schapaugh, 1984).

$\bar{X}_I = \quad \bar{X}_R =$

where:

X_I = Mean of genotype for a particular trait in irrigated environment.

X_R = Mean of genotype for a particular trait in rain-fed environment.

Grand mean for a particular trait in irrigated environment.
Grand mean for a particular character in rain-fed environment.

Correlations among the means of yield traits and their respective selection indices were determined under both the non-stressed (irrigated) and stressed (rain-fed) environments also (Mardeh *et al*., 2006).

Results and Discussion

Analysis of variance for yield & associated traits: Water stress situation largely affect the growth and performance of tillers because of low water accessibility (Rickman & Klepper, 1991). The current set of parameters studied for the wheat genotypes across the two environments are the most vital one for wheat breeding program (Sadiq *et al*., 1994; Bayoumi *et al*., 2008). Pool analysis across two environments (IRE & RFE) reflected highly significant ($p \leq 0.01$) variation among the wheat genotypes for all traits (Table 1). However, the environment effect was non-significant for most traits except 1000-grain weight, which was also highly significant ($p \leq 0.01$) while, tillers m^{-2} and harvest index were found significant at ($p \leq 0.05$). For the yield and associated traits, G×E interaction which is usually of prime importance for the breeders to develop wide adaptable genotypes; the differences were non-significant except for 1000-grain weight and grain yield, which were found significant at ($p \leq 0.01$) and ($p \leq 0.05$) respectively. Although G×E interaction was non-significant indicated trait stability across both the cropping systems (IRE vs. RFE). High significant differences were noticed among the wheat genotypes for these yield-contributing traits, which fall in line with many other researchers for different sets of wheat genotypes (Farshadfar *et al*., 2011). The non-significant G×E interaction for most of the traits comes in close association with the results of Maqbool *et al*., (2002) and Farshadfar *et al*., (2011).

Means & selection indices for yield & associated traits

Means for number of tillers m^{-2} & spike length (cm): Mean tillers of genotypes ranged from 279 to 500 under IRE and from 308 to 498 under RFE (Table 2). Averaged over 28 genotypes, tillers m^{-2} were 359 under IRE and 386 under RFE. The top performing genotypes in IRE regarding tillers m^{-2} and spike length were almost common vs. in RFE for tillers m^{-2} the top ranking genotypes were differ than that which were identified for spike length. Mean spike length of the 28 genotypes under

IRE was 9.9 cm, while 10.1 cm under RFE suggested that the selected genotypes favoured the RFE. Crop plants compete to reach their life span in short period by declining their phase of vegetation in order to get access to reproductive phase. Hence, situation with water stress minimized tillers upto greater extent (Riaz & Chowdhary, 2003). Means of stress selection indices for both traits are presented in Table 2. Top ranking genotypes for MP (mean productivity) and STI (stress tolerance index) for number of tillers were B-VI (N) 6, BRF-7, B-VI (N) 5 and B-II(N)3. The most desirable values (negative) of TOL for tillers were attained by genotypes BRF-7, BRF-1, B-IV(N)10 and B-III(N)1. Similarly, favorable values of TSI (trait stability index) were achieved by wheat genotypes BRF-1, B-IV(N)10, B-III(N)1 and B-IV(N)6. Genotypes with greater values of TI (trait index) were BRF-7, B-VI(N)5, and BRF-3, BII-(N)3, reflected their better performance for the said trait under RFE. The desirable negative (TOL) and favorable higher estimates (TSI) of these indices make them more reliable and fruitful for selection under stress environment. Similarly, the computation of TOL and TSI for spike length showed that more than half of the wheat genotypes performed better under stress condition (RFE). Genotypes BVI-(N)16, B-VI(N)3, BRF-8 and BRF-7 indicated desirable TOL values. While, genotype B-VI(N)5 showed inferior performance with unfavorable TOL value and TSI value. For spike length, genotype BRF-8 showed maximum STI. Similarly, stress susceptible genotype was B-IV(N)1 with least STI value (Table 2). Wheat genotypes with greater estimates of TI were BRF-8 and B-VI(N)3. These results indicated that mean tillers m^{-2} under water stress were increased by 7% with contrast findings (Eid, 2009). MP and STI were efficient enough for selection of outstanding cultivars in both environments (Mardeh *et al*., 2006; Pireivatlou & Yazdansepas, 2008). The TOL and TSI pattern suggested that genotypes selected on the basis of these indices could bring desirable improvement for the desired character in both environments (Pireivatlou & Yazdansepas, 2008). TOL based selection proved to be enough efficient in picking up of stress tolerant cultivars but with less grain output.

Number of spikelets & grain spike^{-1}: Genotype B-IV(N)17 with 21 spikelets spike^{-1} excelled at both environments. Maximum values for spikelets spike^{-1} in respect of MP, STI and TI were observed for B-IV(N)17 and B-VI(N)3. Under RFE, only nine genotypes showed better performance in terms of more number of spikelets spike^{-1} as represented by TOL and TSI analysis (Table 3). Wheat genotypes with desirable values of TOL and TSI were BRF-7 and B-VI(N)9, respectively. While genotypes B-IV(N)6 and B-IV(N)1 reflected the most unfavorable values of TOL and TSI, respectively (Table 3). In wheat crop, grains spike^{-1} is quite vital yield component. Wheat cultivars exposing constancy for this trait are sometime water stress tolerant. In IRE, best performing genotypes regarding grains spike^{-1} were B-VI(N)5 and B-VI(N)16. Top ranking genotypes in terms of grains spike^{-1} in RFE were B-IV(N)6, B-II(N)3, B-IV(N)11 and B-VI(N)5. The top ranking wheat genotypes that reflected greater values of MP and STI under the two environments (IRE and RFE) were B-IV(N)6 and B-VI(N)5, respectively. Likewise, wheat genotypes B-II(N)1 and B-IV(N)17 had maximum values of TOL in-term of grains spike^{-1}. Genotypes B-IV(N)6 and B-II(N)3 showed greater TI values (Table 3). Wheat cultivars with lengthy spikes become more vigorous in terms of spikelets spike^{-1}. In very first growth phase later than the emergence of the leaf, spikelets numeral is determined, and the upper and lower spike florets may demise due to the moisture unavailability at this phase. A decrease in spikelets under RFE supported the findings of Qadir *et al*., (1999). Shpiler & Blum (1991) favored spikelets spike^{-1} as a selection criterion regarding new wheat varieties production. But, greater attention should be paid to grain weight when selection has to be practiced for these parameters (Kazmi *et al*., 2003; Riaz & Chowdhary, 2003).

1000-grain weight & biological yield: In wheat, 1000-grain weight and biological yield are the important yield parameters. But, stress conditions may influence these characters up to higher degree and cultivars showing performance regarding grain weight and biological yield in non-stress environment may not be capable to display that sort of performance for the same trait in stressed environment (Riaz & Chowdhary, 2003; Afiuni & Mahlouji, 2006). Maximum 1000-grain weight was recorded for wheat genotype B-VI(N)5, while genotypes B-II(N)3, B-IV(N)6 and B-VI(N)3 had the minimal grain weight under IRE. Similarly, under RFE, the superior genotypes were B-VI(N)12, BRF-15 and B-VI(N)16. Averaged over all the genotypes, 1000-grain weight was 49.51 and 44.50 in IRE and RFE, respectively. A decrease of 10% for 1000-grain weight was recorded due to stress (Table 4). Mean of 28 genotypes for biological yield ranged between 8519 and 12840 kg ha^{-1} and 9753 and 12222 kg ha^{-1} under IRE and RFE, respectively. Maximum Biological yield was recorded for genotype BRF-1 followed by B-II(N)3 and B-IV(N)1 under IRE. Similarly, Under RFE, maximum biological yield was observed for wheat genotypes B-VI(N)5 and B-IV(N)10. Mean biological yield of overall genotypes in RFE was 11107 kg ha^{-1} compared to 11433 kg ha^{-1} in IRE. This showed 326 kg ha^{-1} (3%) reduction in biological yield under RFE. Parallel findings have been reported for 1000-grain weight and biological yield (Rajaram *et al*., 1996; Ginkel *et al*., 1998). Research for grain yield in field of breeding has been accredited to increase harvest index and even a little increase in biomass (Noorka *et* al., 2013; Richards, 2002). At maturity higher biomass has been found to relate with maximum yield in water stress. Drought conditions results in reduction of biological yield up to greater extent (Ashraf *et al*., 2008).

Table 2. Mean and selection indices for tillers m^{-2} and spike length of 28 genotypes evaluated under IRE and RFE at Khyber Pakhtunkhwa, Pakistan during 2010-11.

Genotypes	Tillers m^{-2} (no.)							Spike length (cm)						
	IR	RF	MP	TOL	STI	TI	TSI	IR	RF	MP	TOL	STI	TI	TSI
B-IV(N)1	392	371	381	21	1.13	0.96	0.95	9.4	9.4	9.4	-0.06	0.90	0.94	1.01
B-IV(N)11	344	308	326	36	0.82	0.80	0.89	9.4	9.6	9.5	-0.17	0.92	0.95	1.02
B-IV(N)16	335	392	364	-57	1.02	1.02	1.17	9.5	9.4	9.5	0.04	0.91	0.94	1.00
B-IV(N)17	377	314	346	63	0.92	0.81	0.83	10.6	11.0	10.8	-0.40	1.19	1.09	1.04
B-VI(N)3	326	320	323	7	0.81	0.83	0.98	10.1	11.0	10.6	-0.96	1.13	1.10	1.10
B-VI(N)5	410	473	442	-63	1.50	1.22	1.15	10.2	9.3	9.8	0.90	0.97	0.92	0.91
B-VI(N)6	500	402	451	98	1.56	1.04	0.80	10.0	9.7	9.8	0.33	0.99	0.96	0.97
B-VI(N)8	423	351	387	72	1.15	0.91	0.83	10.8	9.9	10.4	0.87	1.09	0.99	0.92
B-VI(N)9	460	383	421	77	1.36	0.99	0.83	10.5	10.4	10.4	0.07	1.11	1.03	0.99
B-VI(N)12	289	323	306	-34	0.72	0.84	1.12	10.0	10.2	10.1	-0.26	1.04	1.02	1.03
B-VI(N)16	300	339	319	-39	0.79	0.88	1.13	9.5	10.8	10.1	-1.27	1.04	1.07	1.13
B-VI(N)17	308	322	315	-13	0.77	0.83	1.04	9.5	9.9	9.7	-0.43	0.96	0.98	1.05
BRF-1	330	428	379	-98	1.10	1.11	1.30	10.2	10.7	10.5	-0.53	1.12	1.07	1.05
BRF-3	382	444	413	-63	1.31	1.15	1.16	9.8	9.7	9.8	0.07	0.97	0.97	0.99
BRF-7	394	498	446	-104	1.52	1.29	1.26	9.8	10.4	10.1	-0.57	1.04	1.03	1.06
BRF-8	396	371	384	26	1.14	0.96	0.94	10.6	11.3	10.9	-0.73	1.22	1.12	1.07
BRF-15	328	341	335	-12	0.87	0.88	1.04	9.7	9.6	9.7	0.04	0.95	0.96	1.00
BRF-17	279	333	306	-54	0.72	0.86	1.19	9.8	10.2	10.0	-0.37	1.02	1.01	1.04
SAWT50	330	375	352	-45	0.96	0.97	1.14	9.8	9.9	9.8	-0.10	0.98	0.98	1.01
B-II(N)1	340	326	333	13	0.86	0.85	0.96	9.7	10.1	9.9	-0.43	1.00	1.00	1.04
B-II(N)3	420	444	432	-24	1.44	1.15	1.06	10.3	10.2	10.2	0.07	1.07	1.01	0.99
B-III(N)17	324	414	369	-90	1.04	1.07	1.28	9.8	9.9	9.8	-0.10	0.98	0.98	1.01
B-IV(N)6	320	406	363	-86	1.01	1.05	1.27	9.9	9.2	9.6	0.70	0.94	0.92	0.93
B-IV(N)10	323	418	371	-96	1.05	1.08	1.30	9.6	9.9	9.8	-0.30	0.98	0.99	1.03
S-2000	367	461	414	-94	1.31	1.19	1.26	9.6	9.8	9.7	-0.23	0.96	0.98	1.02
PS-2008	375	354	365	21	1.03	0.92	0.94	10.2	10.5	10.4	-0.27	1.10	1.04	1.03
PS-2005	344	519	431	-175	1.38	1.34	1.51	9.0	9.4	9.2	-0.40	0.86	0.93	1.04
Sul-96	341	383	362	-42	1.01	0.99	1.12	10.1	10.3	10.2	-0.17	1.06	1.02	1.02
Mean	359b	386 a	373	-27	1.08	1.00	1.09	9.9 a	10.1 a	10.0	-0.17	1.02	1.00	1.02
[1]LSD	77.7	126.9	--	--	--	--	--	0.8	1.0	--	--	--	--	--
[2]LSD	--	--	73.5	--	--	--	--	--	--	0.7	--	--	--	--
[3]LSD	--	--	19.6	--	--	--	--	--	--	---	--	--	--	--
[4]LSD	--	--	---	--	--	--	--	--	--	---	--	--	--	--

IR (irrigated), RF (rain-fed), MP (mean productivity), TOL (tolerance), STI (stress tolerance index), TI (trait index), TI (trait stability index), [1]LSD for G under separate environment, [2]LSD for G averaged over environments, [3]LSD (not given) for environment and [4]LSD (not given) for G×E each at 5% level of probability

Table 3. Mean and selection indices for spikelets and grains spike^{-1} of 28 genotypes evaluated under IRE and RFE at Khyber Pakhtunkhwa, Pakistan during 2010-11.

Genotype	Spikelets spike^{-2}							Grains spike^{-2}						
	IR	RF	MP	TOL	STI	TI	TSI	IR	RF	MP	TOL	STI	TI	TSI
B-IV(N)1	20	19	19	1.3	0.97	0.96	0.93	55	52	54	2.67	0.93	0.95	0.95
B-IV(N)11	20	20	20	0.0	1.07	1.05	1.00	54	58	56	-4.33	1.00	1.06	1.08
B-IV(N)16	19	19	19	0.0	0.90	0.96	1.00	56	57	56	-1.33	1.02	1.04	1.02
B-IV(N)17	21	21	21	-0.3	1.13	1.08	1.02	57	51	54	6.66	0.94	0.92	0.88
B-VI(N)3	20	21	20	-0.7	1.07	1.06	1.03	56	58	57	-2.00	1.05	1.06	1.04
B-VI(N)5	20	19	20	1.0	0.99	0.98	0.95	60	58	59	2.00	1.11	1.05	0.97
B-VI(N)6	20	19	19	1.0	0.95	0.96	0.95	56	58	57	-1.67	1.04	1.05	1.03
B-VI(N)8	19	19	19	0.0	0.97	0.99	1.00	57	58	57	-0.67	1.06	1.05	1.01
B-VI(N)9	19	20	20	-1.0	0.99	1.03	1.05	52	54	53	-2.00	0.91	0.99	1.04
B-VI(N)12	20	20	20	-0.3	1.05	1.05	1.02	58	56	57	2.00	1.05	1.02	0.97
B-VI(N)16	20	20	20	0.7	1.04	1.01	0.97	60	56	58	4.66	1.08	1.02	0.92
B-VI(N)17	20	20	20	0.3	1.02	1.01	0.98	57	55	56	1.67	1.01	1.00	0.97
BRF-1	20	20	20	0.3	1.05	1.03	0.98	56	58	57	-1.34	1.05	1.05	1.02
BRF-3	20	19	20	0.3	0.99	0.99	0.98	59	52	56	6.34	0.99	0.95	0.89
BRF-7	18	21	20	-2.3	0.98	1.06	1.13	55	55	55	-0.66	0.98	1.01	1.01
BRF-8	19	19	19	0.0	0.90	0.96	1.00	52	48	50	4.00	0.80	0.87	0.92
BRF-15	18	18	18	-0.7	0.84	0.94	1.04	48	46	47	2.33	0.71	0.83	0.95
BRF-17	20	20	20	-0.3	1.02	1.03	1.02	55	56	56	-1.00	1.01	1.03	1.02
SAWT50	20	19	20	1.0	0.99	0.98	0.95	52	51	52	1.00	0.87	0.94	0.98
B-II(N)1	20	21	20	-1.0	1.05	1.06	1.05	58	51	55	6.67	0.96	0.94	0.89
B-II(N)3	20	19	20	0.3	0.99	0.99	0.98	55	60	58	-5.00	1.07	1.09	1.09
B-III(N)17	19	19	19	0.3	0.95	0.98	0.98	55	57	56	-2.33	1.01	1.04	1.04
B-IV(N)6	21	19	20	1.7	1.02	0.98	0.92	59	62	60	-3.00	1.17	1.12	1.05
B-IV(N)10	20	20	20	-0.7	1.04	1.05	1.03	58	54	56	3.34	1.01	0.99	0.94
S-2000	19	19	19	0.7	0.94	0.96	0.97	50	53	52	-3.00	0.86	0.97	1.06
PS-2008	20	20	20	0.7	1.04	1.01	0.97	63	59	61	3.67	1.21	1.08	0.94
PS-2005	19	18	19	1.7	0.89	0.91	0.91	52	52	52	0.33	0.87	0.94	0.99
Sul-96	20	18	19	1.3	0.93	0.94	0.93	55	51	53	4.33	0.90	0.92	0.92
Mean	20 a	19 a	20	0.19	0.99	1.00	0.99	56 a	55 a	55	0.83	0.99	1.00	0.99
[1]LSD	1.3	1.7	--	--	--	--	--	4.9	5.8	--	--	--	--	--
[2]LSD	--	--	1.1	--	--	--	--	--	--	3.7	--	--	--	--
[3]LSD	--	--	--	--	--	--	--	--	--	--	--	--	--	--
[4]LSD	--	--	--	--	--	--	--	--	--	--	--	--	--	--

IR (irrigated), RF (rain-fed), MP (mean productivity), TOL (tolerance), STI (stress tolerance index), TI (trait index), TI (trait stability index), [1]LSD for G under separate environment, [2]LSD for G averaged over environments, [3]LSD (not given) for environment and [4]LSD (not given) for G×E each at 5% level of probability

Table 4. Mean and selection indices for 1000-grain weight and biological yield of 28 genotypes evaluated under IRE and RFE at Khyber Pakhtunkhwa, Pakistan during 2010-11.

Genotype	1000-grain weight (g)							Biological yield (kgha^{-1})						
	IR	RF	MP	TOL	STI	TI	TSI	IR	RF	MP	TOL	STI	TI	TSI
B-IV(N)1	45.5	43.4	44.5	2.13	0.81	0.98	0.95	12469	11852	12160	617	1.13	1.07	0.95
B-IV(N)11	48.2	44.8	46.5	3.40	0.88	1.01	0.93	12346	10864	11605	1481	1.03	0.98	0.88
B-IV(N)16	47.6	39.6	43.6	8.00	0.77	0.89	0.83	11235	11728	11481	-494	1.01	1.06	1.04
B-IV(N)17	51.3	46.0	48.7	5.27	0.96	1.03	0.90	12222	11358	11790	864	1.06	1.02	0.93
B-VI(N)3	45.5	45.9	45.7	-0.40	0.85	1.03	1.01	12469	10494	11481	1975	1.00	0.94	0.84
B-VI(N)5	63.3	46.7	55.0	16.6	1.21	1.05	0.74	12346	12222	12284	123	1.15	1.10	0.99
B-VI(N)6	50.4	45.5	47.9	4.93	0.93	1.02	0.90	11852	11111	11481	741	1.01	1.00	0.94
B-VI(N)8	53.2	45.2	49.2	7.97	0.98	1.02	0.85	11358	10370	10864	988	0.90	0.93	0.91
B-VI(N)9	52.7	44.5	48.6	8.17	0.96	1.00	0.84	11481	10247	10864	1235	0.90	0.92	0.89
B-VI(N)12	54.2	50.2	52.2	3.97	1.11	1.13	0.93	11605	11111	11358	494	0.99	1.00	0.96
B-VI(N)16	52.6	47.3	49.9	5.27	1.01	1.06	0.90	11605	10617	11111	988	0.94	0.96	0.91
B-VI(N)17	48.8	41.2	44.9	7.63	0.82	0.93	0.84	11605	9753	10679	1852	0.87	0.88	0.84
BRF-1	47.2	41.7	44.4	5.50	0.80	0.94	0.88	12840	11358	12099	1481	1.12	1.02	0.88
BRF-3	48.1	41.2	44.7	6.87	0.81	0.93	0.86	13086	10988	12037	2099	1.10	0.99	0.84
BRF-7	49.1	46.3	47.7	2.80	0.93	1.04	0.94	11852	10864	11358	988	0.99	0.98	0.92
BRF-8	49.9	45.5	47.7	4.40	0.93	1.02	0.91	11481	11358	11420	123	1.00	1.02	0.99
BRF-15	48.8	48.2	48.5	0.60	0.96	1.08	0.99	11358	11728	11543	-370	1.02	1.06	1.03
BRF-17	48.5	45.4	46.9	3.04	0.90	1.02	0.94	10247	10247	10247	0	0.80	0.92	1.00
SAWT50	47.9	45.8	46.9	2.10	0.89	1.03	0.96	9259	10864	10062	-1605	0.77	0.98	1.17
B-II(N)1	50.1	44.5	47.3	5.54	0.91	1.00	0.89	8519	10123	9321	-1605	0.66	0.91	1.19
B-II(N)3	43.8	44.3	44.0	-0.47	0.79	0.99	1.01	12469	12099	12284	370	1.15	1.09	0.97
B-III(N)17	49.7	42.2	45.9	7.53	0.86	0.95	0.85	9506	10370	9938	-864	0.75	0.93	1.09
B-IV(N)6	44.4	38.4	41.4	6.03	0.70	0.86	0.86	10864	10741	10802	123	0.89	0.97	0.99
B-IV(N)10	46.5	41.2	43.9	5.24	0.78	0.93	0.89	11852	12222	12037	-370	1.11	1.10	1.03
S-2000	50.2	46.2	48.2	4.06	0.95	1.04	0.92	11358	12222	11790	-864	1.06	1.10	1.08
PS-2008	45.3	39.8	42.6	5.50	0.74	0.89	0.88	9753	9753	9753	0	0.73	0.88	1.00
PS-2005	52.5	47.6	50.1	4.93	1.02	1.07	0.91	12716	12593	12654	123	1.23	1.13	0.99
Sul-96	51.1	47.3	49.2	3.77	0.99	1.06	0.93	10370	11728	11049	-1358	0.93	1.06	1.13
Mean	49.5a	44.5b	47.0	5.01	0.90	1.00	0.90	11433a	11107a	11270	326	0.97	1.00	0.98
[1]LSD	4.0	3.0	--	--	--	--	--	2396	628	--	--	--	--	--
[2]LSD	--	--	2.5	--	--	--	--	--	--	1223	--	--	--	--
[3]LSD	--	--	1.3	--	--	--	--	--	--	--	--	--	--	--
[4]LSD	--	--	1.5	--	--	--	--	--	--	--	--	--	--	--

IR (irrigated), RF (rain-fed), MP (mean productivity), TOL (tolerance), STI (stress tolerance index), TI (trait index), TI (trait stability index), [1]LSD for G under separate environment, [2]LSD for G averaged over environments, [3]LSD for environment and [4]LSD for G×E each at 5% level of probability

Grain yield & harvest index: Grain yield is usually remain a prime objective in almost all breeding programs especially in under developed countries. In both environments, the best performing genotypes were BRF-7, and B-IV(N)1 (Table 5). Mean grain yield of all of the genotypes in IRE was 4427 kg ha^{-1}, while in RFE it was 4085 kg ha^{-1}. Thus, stress reduced grain yield by 342 kg ha^{-1}. Means of 28 genotypes for harvest index ranged between 32 and 45% under IRE and from 31 to 41% under RFE (Table 5). Maximum values of harvest index were noted for B-VI(N)16, followed by B-VI(N)8 and SAWT50 under IRE. However, under RFE, genotypes BRF-7, B-VI(N)8 and B-VI(N)9 had acceptable magnitude of harvest index. The only genotypes which exhibited maximum harvest index in both environments was identified as B-VI(N)8. Average across 28 genotypes, harvest index of 37% was observed in RFE, while it was 39% in IRE. Wheat genotypes proven to superior performance under non-stress environment might not be able to perform well under stress-condition regarding grain yield. However, at maturity maximum grain yield was found to be related with total dry biomass in drought-stress (Fischer & Wood, 1979). Furthermore, effects of water stress on kernel growth and its yield relieved on strength of the stress effects and growth phases of the crop in which the stress effects took place (Anwar *et al.,* 2011; Bayoumi *et al*., 2008). On the basis of stress selection indices top performing wheat genotypes were B-VI(N)5, B-IV(N)1 and BRF-7 with greater MP values for grain yield. STI represents the same genotypic ranking as was recorded for MP with greater STI. The desirable TOL and TSI were achieved by wheat genotypes B-IV(N)16, B-II(N)1 and SAWT50. TOL and TSI estimation indicated that among 24 advance wheat lines, only 5 lines shown better performance in RFE. Maximum TI was attained by wheat genotypes B-VI(N)5 and B-IV(N)1 for grain yield. Superior genotypes in terms of MP, STI and TI were BRF-7, SAWT50 and B-VI(N)8 for harvest index. Wheat genotypes B-IV(N)16, BRF-17 and B-VI(N)6 had negative desirable TOL and higher TSI values (Table 5). Using GGE biplot techniques Farshadfar *et al*., (2012) reported stability and improvement in a set of wheat hybrids and parents for drought tolerance in yield and related traits. Khayatnezhad *et al*., (2010) also reported for grain yield and harvest index that TOL with minimum estimates showed resistance to water stress, while TOL with greater values display susceptibility to drought stress.

Table 5. Mean and selection indices for grain yield and harvest index of 28 genotypes evaluated under IRE and RFE at Khyber Pakhtunkhwa, Pakistan during 2010-11.

Genotype	Grain yield (kgha^{-1})							Harvest index (%)						
	IR	RF	MP	TOL	STI	TI	TSI	IR	RF	MP	TOL	STI	TI	TSI
B-IV(N)1	5086	4595	4841	491	1.19	1.12	0.90	41	39	40	2.11	1.04	1.05	0.95
B-IV(N)11	4889	4148	4519	741	1.03	1.02	0.85	40	38	39	1.58	1.00	1.03	0.96
B-IV(N)16	4148	4462	4305	-314	0.94	1.09	1.08	37	38	37	-1.15	0.93	1.03	1.03
B-IV(N)17	4444	3612	4028	832	0.82	0.88	0.81	37	33	35	4.05	0.79	0.88	0.89
B-VI(N)3	4679	3963	4321	716	0.95	0.97	0.85	38	38	38	-0.28	0.94	1.03	1.01
B-VI(N)5	5049	4649	4849	400	1.20	1.14	0.92	41	38	40	3.00	1.04	1.04	0.93
B-VI(N)6	4556	4358	4457	198	1.01	1.07	0.96	39	39	39	-0.71	1.00	1.06	1.02
B-VI(N)8	5012	4069	4541	943	1.04	1.00	0.81	44	40	42	4.07	1.14	1.07	0.91
B-VI(N)9	4840	4151	4495	689	1.03	1.02	0.86	42	40	41	1.57	1.12	1.10	0.96
B-VI(N)12	4617	4314	4465	304	1.02	1.06	0.93	40	39	39	1.17	1.02	1.05	0.97
B-VI(N)16	5111	4106	4609	1005	1.07	1.01	0.80	45	39	42	5.75	1.14	1.05	0.87
B-VI(N)17	4407	3664	4036	743	0.82	0.90	0.83	38	38	38	0.54	0.94	1.02	0.99
BRF-1	4975	3958	4467	1017	1.00	0.97	0.80	39	35	37	4.26	0.91	0.95	0.89
BRF-3	4321	3590	3956	731	0.79	0.88	0.83	33	33	33	0.38	0.72	0.89	0.99
BRF-7	5123	4486	4805	637	1.17	1.10	0.88	43	41	42	2.11	1.17	1.11	0.95
BRF-8	3691	3491	3591	200	0.66	0.85	0.95	32	31	31	1.38	0.65	0.83	0.96
BRF-15	4185	3884	4035	301	0.83	0.95	0.93	37	33	35	3.85	0.80	0.89	0.90
BRF-17	3938	4010	3974	-72	0.81	0.98	1.02	38	39	39	-0.86	0.99	1.06	1.02
SAWT50	4111	4284	4198	-173	0.90	1.05	1.04	44	39	42	4.92	1.15	1.07	0.89
B-II(N)1	3420	3677	3548	-257	0.64	0.90	1.08	40	36	38	3.59	0.97	0.99	0.91
B-II(N)3	4852	3854	4353	998	0.95	0.94	0.79	39	32	36	7.06	0.83	0.87	0.82
B-III(N)17	3941	4069	4005	-128	0.82	1.00	1.03	42	39	40	2.38	1.08	1.06	0.94
B-IV(N)6	3753	3610	3681	143	0.69	0.88	0.96	34	33	34	0.73	0.75	0.91	0.98
B-IV(N)10	4802	4119	4460	684	1.01	1.01	0.86	41	34	37	6.83	0.91	0.91	0.83
S-2000	3802	4341	4072	-538	0.84	1.06	1.14	34	36	35	-1.96	0.79	0.96	1.06
PS-2008	4106	3941	4023	165	0.83	0.96	0.96	43	40	42	2.54	1.15	1.10	0.94
PS-2005	3965	4489	4227	-523	0.91	1.10	1.13	31	35	33	-4.15	0.73	0.96	1.13
Sul-96	4123	4477	4300	-353	0.94	1.10	1.09	39	38	39	1.53	0.99	1.03	0.96
Mean	4427a	4085a	4256	342	0.93	1.00	0.93	39a	37b	38	2.01	0.95	1.00	0.95
[1]LSD	1071	136	--	--	--	--	--	6.1	4.7	--	--	--	--	--
[2]LSD	--	--	533	--	--	--	--	--	--	3.8	--	--	--	--
[3]LSD	--	--	--	--	--	--	--	--	--	1.0	--	--	--	--
[4]LSD	--	--	247	--	--	--	--	--	--	--	--	--	--	--

IR (irrigated), RF (rain-fed), MP (mean productivity), TOL (tolerance), STI (stress tolerance index), TI (trait index), TI (trait stability index), [1]LSD for G under separate environment, [2]LSD for G averaged over environments, [3]LSD for environment and [4]LSD for G×E each at 5% level of probability

Correlations, expected response to selection and heritabilities for yield & associated traits: Correlation is the indirect index to select and breed for the desired trait. A strong positive correlation of the two environments IRE & RFE was observed for spike length, grains spike^{-1}, 1000-grain weight, biological yield and grain yield. However, no association in both environments was noticed number of tillers and spikelets spike^{-1} (Table 6). All the traits were significantly ($p \leq 0.01$) correlated with MP and STI under both of the IRE and RFE. Similarly, a strong positive correlation of the RFE with IRE for TOL was observed for number of tillers, spikelets spike^{-1}, 1000-grain weight, biological yield and grain yield. On the other hand for these traits under RFE the TOL had a strong negative and significant correlation. Another selection index with greater impact was TSI also had strong negative but significant correlation at IRE for all traits except grains spike and for spikelets where it had negative correlation with no association. Under RFE the TSI had positive correlation for most traits. Selection of genotypes based on TI would be fruitful only in drought stress conditions (Gavuzzi *et al*., 1997; Mardeh *et al*., 2006). Previous study suggested that plant breeders took keen interest to breed cultivars with lengthy spikes due to the reason that selection of spike with greater length could better maximize the grain output (Khan *et al*., 2010). However, a decline in spike length has also been recorded by several researchers (Saleem, 2003) because of unavailability of water at the initial growth stage of spike. Maximum MP and STI values are the better indication to pick superior performer genotypes over both the environments (Mardeh *et al*., 2006). These results are well matched with the investigations of Dadbakhsh & Sepas, (2011) who also reported positive and useful correlation for yield and associated traits between the two conditions.

Table 6. Correlation among test environments (IRE & RFE) and stress selection indices for yield and yield associated traits.

Selection indices	IRE	RFE	IRE	RFE
	Tillers m^{-2}		**Spike length**	
(RFE)	0.31^{NS}	---	0.54**	---
MP	0.78**	0.83**	0.84**	0.91**
TOL	0.52**	-0.65**	0.26^{NS}	-0.67**
STI	0.80**	0.82**	0.84**	0.91**
TI	0.31^{NS}	1.00**	0.53**	1.00**
TSI	-0.52**	0.65**	-0.27^{NS}	0.67**
	Spikelets spike^{-1}		**Grains spike^{-1}**	
(RFE)	0.34^{NS}	---	0.56**	---
MP	0.77**	0.86**	0.86**	0.90**
TOL	0.45**	-0.69**	0.35^{NS}	-0.59**
STI	0.78**	0.85**	0.86**	0.90**
TI	0.35^{NS}	1.00**	0.55**	0.99**
TSI	-0.46**	0.68**	-0.31^{NS}	0.61**
	1000-grain weight		**Biological yield**	
(RFE)	0.55**	---	0.48**	---
MP	0.92**	0.84**	0.91**	0.80**
TOL	0.68**	-0.23^{NS}	0.74**	-0.24^{NS}
STI	0.91**	0.84**	0.90**	0.81**
TI	0.56**	0.99**	0.47**	0.99**
TSI	-0.55**	0.39*	-0.76**	0.19^{NS}
	Grain yield			
(RFE)	0.37*	---		
MP	0.89**	0.74**		
TOL	0.78**	-0.30^{NS}		
STI	0.89**	0.75**		
TI	0.38*	1.00**		
TSI	-0.74**	0.35^{NS}		

*, **, ^{NS} = Significant at 5 &1 % probability level, & non-significant respectively

Expected response to selection at RFE was higher than IRE for spike length, grains spike and grain yield suggested that selection would be effective for these traits under the RFE. In contrast, the expected response to selection for number of tillers, spikelets spike^{-1} and 1000-grain weight was effective under IRE. For 1000-grain weight and grain yield the selection differential was enough high suggested to breed under IRE. Using 15% selection intensity, for some of the traits the top ranking four genotypes under both environments were same, made possible to breed at one station under limited resources (Table 7). The magnitude of broad sense heritabilities for the selected traits varied from low to moderate however, for 1000-grain weight, biological and grain yield it was high under RFE. Low heritability under rain-fed condition indicated that the trait was under environmental control. Moderate heritability estimates were noticed in non-stress, while low heritability estimates were recorded in stress condition (Table 8). With low heritabilities for spike length, spikelets spike^{-1} and harvest index either under IRE or RFE our findings were not in agreement with the results of Subhani & Chowdhry (2000). However, low to moderate heritabilities among other wheat genotypes for these traits have also reported (Fethi & Mohamed, 2010; Ullah *et al.*, 2011). Magnitude of high broad sense heritabilities especially for grain yield, harvest index and 1000-grain weight under different stress environments are addressed (Golabadi *et al.*, 2005; Talebi *et al.*, 2009).

Table 7. Mean of overall population ($\overline{X}$), selected lines ($\overline{X_s}$), check cultivars ($\overline{X_c}$), selection differential (S), expected response (R_e) and selected genotypes for yield related traits under IRE and RFE.

Traits	Environments	$\overline{X}$	X_s	$\overline{X_c}$	S	Re	Top ranking four genotypes using 15% selection intensity
Tillers m^{-2}	IRE	359	451	357	92	46.2	B-VI(N)6, B-VI(N)9B-VI(N)8, B-II(N)3
	RFE	386	465	429	79	25.42	BRF-7, B-VI(N)5 BRF-3, B-II(N)3
Spike length (cm)	IRE	9.9	10.6	9.7	0.7	0.24	B-VI(N)8, B-IV(N)17 BRF-8, B-VI(N)9
	RFE	10.1	11.0	10.0	0.9	0.36	BRF-8, B-IV(N)17 B-VI(N)3, B-VI(N)16
Spikelets spike^{-1}	IRE	20	21	20	1.0	0.48	B-IV(N)17, B-IV(N)6B-IV(N)11, B-VI(N)3
	RFE	19	21	19	2.0	0.46	B-IV(N)17, B-VI(N)3BRF-7, B-II(N)1
Grains spike^{-1}	IRE	56	60	55	4.0	2.89	B-VI(N)5, B-VI(N)16B-IV(N)6, BRF-3
	RFE	55	60	54	5.0	3.25	B-IV(N)6, B-II(N)3B-IV(N)11, B-VI(N)5
1000 grain weight (g)	IRE	49.5	55.8	49.8	6.3	4.57	B-VI(N)5, B-VI(N)12B-VI(N)8, B-VI(N)9
	RFE	44.5	48.1	45.2	3.6	3.43	B-VI(N)12, BRF-15B-VI(N)16, B-VI(N)5
Grain yield (kgha^{-1})	IRE	4427	5092	3999	665	227.61	BRF-7, B-VI(N)16B-IV(N)1, B-VI(N)5
	RFE	4085	4548	4312	463	495.51	B-VI(N)5, B-IV(N)1BRF-7, B-IV(N)16

Table 8. Genetic (V_g), environmental (V_e) variances and heritabilities for various traits of 28 wheat genotypes evaluated under IRE and RFE at Khyber Pakhtunkhwa, Pakistan during 2010-11.

Parameters	Irrigated			Rain-fed		
	V_g	V_e	h^2_{BS}	V_g	V_e	h^2_{BS}
Tillers m^{-2}	1917.5	2254.7	0.46	1397.7	6011.9	0.19
Spike length	0.09	0.26	0.26	0.17	0.39	0.31
Spikelets spike^{-1}	0.29	0.58	0.33	0.35	1.14	0.24
Grains spike^{-1}	7.50	8.94	0.46	9.96	12.47	0.44
1000-grain weight	12.8	5.9	0.68	7.1	3.4	0.68
Biological yield	588675.0	2140350.7	0.22	579240.8	147088.9	0.80
Grain yield	108019.0	428278.9	0.20	108122.1	6943.7	0.94
Harvest index	8.64	13.77	0.39	5.86	8.26	0.41

Conclusions and Recommendations

Though analysis of variance will be a good tool to know about the level of diversity and variation among the genotypes. But selecting on the basis of single year mean performance of the genotypes is not authentic without having interaction effect of G×E. Better way to screen the genotypes according to the breeder will under limited resources is to select on the basis of correlations, selection indices such as MP, STI, TOL, TI and TSI and heritabilities estimates.

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