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Drought Resistance Indices: A Selection Tool for Enhancing Yield Resilience in Bread Wheat Genotypes

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Abstract

Climate change is the primary cause of global warming, which ultimately results in increased drought and disrupted rainfall patterns. Considering this context, the present research was conducted at Malakandher Research Farm, University of Agriculture, Peshawar, during 2021-2022. Nine wheat genotypes were evaluated for drought tolerance under irrigated and rainfed conditions. A randomized complete block design with three replications was used in both experiments. Six drought tolerance indices were calculated: stress susceptibility index (SSI), mean productivity (MP), geometric mean productivity (GMP), tolerance index (TOL), yield index (YI), and yield stability index (YSI). Pooled analysis of variance revealed highly significant differences among genotypes and environments, whereas genotype × environment interaction was non-significant. Genotype MPT8 exhibited the highest MP among the studied genotypes. Moderate heritability was observed for grain yield under both environments. Based on YSI and TOL values, none of the genotypes showed superiority in the rainfed environment compared to irrigated environment. However, MPT6 demonstrated high tolerance, while Pirsabak-2005 was identified as a susceptible genotype. Highly significant positive correlation was observed between the two environments for grain yield. Grain yield in rainfed conditions was strongly associated with MP, TOL, YI, YSI, and SSI. Indices MP and GMP emerged as the best selection tools for both environments, while YI was optimal for rainfed environments.

Keywords: Selection indices; Drought stress; Heritability; Correlation and wheat

Introduction

Drought is one of the major factors reducing agricultural production worldwide and is a serious problem in wheat producing areas [1]. This is a challenge for crop scientists, especially for breeders, to develop new cultivars and hybrids of crops that would be able to adapt to the changed climate [2]. Wheat is cultivated in a range of climate while, in arid and semi-arid areas, the grain yield is severely reduced by water stress and depends on the availability of water [3]. High yield and stability of a cultivar over a wide range of environmental conditions has a prime importance [4] because plants tolerate stress condition at the cost of yield. Drought stress decrease grains yield at different growth stages differently at maturity an average of 10% yield reduction occurs while, moderate stress has no effect on yield during the early vegetative stage [5].

Ineffective selection techniques and poor understanding of drought tolerance mechanisms are major problems in drought tolerant cultivars development [6]. In case of maximum genetic variation and minimum genotype × environment interactions selection would be more fruitful for high yield in optimum environment [7]. There is no strong relationship between yield stability and yield [4], therefore, genotypes selected in optimum environments may not perform well in drought-stress environments. Effective method is to evaluate genotypes under irrigated and drought conditions and take help of increased selection response in early generation while preserving alleles for high yield in drought stress condition [8]. Heritability estimation in early generations gives precise and accurate information about a trait that is transmitted to the next generations which should be helpful in selection [9].

Drought tolerance is a quantitative trait and there is no direct method to measure it. Drought indices measure yield loss under drought environment compared to irrigated environment to identify drought-tolerant genotypes [10]. Mean productivity (MP) and geometric mean productivity (GMP) are able to identify genotypes producing high yield in case of less severe drought stress conditions. In severe drought stress conditions, stress susceptibility index (SSI) is a more useful index for cereal crops breeding to identify resistant cultivars. Larger value of tolerance (TOL) and SSI indicate relatively more sensitivity to drought stress, so smaller value is favored because of less sensitivity to stress. Selection based on TOL will identify genotypes which have low gap in yield between the two target environments. Yield index (YI) identify genotypes on the basis of their performance in stress environment while yield stability index (YSI) ranks genotypes having good performance under both irrigated and rainfed environments.

Selection in stress is more difficult when testing conditions are not uniform and heritability is low for that trait [11]. For optimum performance and adaptation to drought stress, yield potential and specific adaptation traits are useful criteria in breeding for drought environment [12]. Therefore, this study was conducted to identify the best selection indices as a tool among the studied indices for selection, genotypic variability, broad sense heritability and drought tolerant genotypes.

Material and Methods

The research work was conducted at Malakandher Research Farm, The University of Agriculture, Peshawar during 2021-22, on nine wheat genotypes, i.e., seven advance lines (MPT1, MPT2, MPT5, MPT6, MPT7, MPT8 and MPT9) and two check cultivars (Pirsabak-2005 and Pirsabak-2008). This set of genotypes was grown independently in two experiments, under irrigated and rainfed environments. All these genotypes were provided by cereal crops research institute (CCRI), Pirsabak. Rainfed experiment was totally dependent on rainfall and was not irrigated throughout the growing season. In both of the experiments a randomized complete block design with three replications was used. Each plot was consist 3 rows having 3 meter length and row to row space was 0.30m. Both of the experiments were planted on the same date with hand hoe, using seed rate of 110kg ha^{-1}. After harvesting each bundle was threshed separately, weighed and then converted to kg ha^{-1}.

Pooled analysis of variance was done across the two environments using MSTAT-C and Microsoft Office Excel software. Broad sense heritability was estimated for grain yield under both environments according to Singh & Chaudhery [13]. Mean data were used to find out stress selection indices

Where:

$$Heritability = h^2_{BS} = \frac{\sigma^2_g}{(\sigma^2_g + \sigma^2_e / r)} = \frac{\sigma^2_g}{\sigma^2_p}$$

Selection response (Re) was calculated under both environments using 20% specific selection intensity by the following formula:

$$Selection\ response\ (\mathrm{Re}) = K \times h^2 \times \sqrt{\sigma^2_p}$$

Where:

k = Constant value at specific selection intensity

σ^2_p = Phenotypic variance.

h^2 = estimated heritability for that trait.

The following indices were evaluated by considering irrigated and rainfed environments as non-stress and stress environments, respectively.

1. Stress Susceptibility Index (SSI): $= \frac{1-(Y_R / Y_I)}{1-(\bar{Y}_R / \bar{Y}_I)}$ [14]
2. Mean Productivity (MP): $MP = \frac{Y_I + Y_R}{2}$ [15]
3. Geometric Mean Productivity (GMP): $GMP = \sqrt{Y_I \times Y_R}$ [16]
4. Tolerance Index (TOL): $TOL = Y_I - Y_R$ [15]
5. Yield Index (YI): $YI = \frac{Y_R}{\bar{Y}_R}$ [14]
6. Yield Stability Index (YSI): $YSI = \frac{Y_R}{Y_I}$ [14]

Y_I = Average grain yield of a genotype under irrigated condition.

Y_R = Average grain yield of a genotype under rainfed condition.

$\bar{Y}_I =$ Grand average of grain yield of all genotypes under irrigated condition.

$\bar{Y}_R =$ Grand average of grain yield of all genotypes under rainfed condition.

Correlation was determined between two environments and selection indices with the procedure of Mardeh et al. [17].

Results

Pooled analysis of variance showed highly significant variations among the genotypes and environments while genotype × environment interaction was non-significant (Table 1). Genotype MPT8 produced maximum grain yield (4568 and 6963kg/ha) under rainfed and irrigated environments, respectively and remained best among the studied genotypes (Table 2). Moderate heritability of 37 and 49 coupled with selection response of 280 and 478 were calculated under rainfed and irrigated environments, respectively. Environmental variance (181520 and 254280) was greater than genetic variance (107929 and 240347) under rainfed and irrigated environments, respectively (Table 3).

Maximum MP and GMP (5765 and 5639kg/ha) were recorded for genotype MPT8 while minimum (4265 and 4132kg/ha) for

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genotype MPT1, respectively. Maximum YI (1.17) was recorded for genotype MPT8 while minimum (0.83) for genotype MPT1. Highest value (1.19) of SSI was calculated for cheek cultivar Pirsabak-2005 while lowest (0.78) for genotype MPT6. Maximum YSI (0.71) and TOL (2975kg/ha) were recorded for genotype MPT6 while minimum YSI (0.55) and TOL (1802 kg/ha) for Pirsabak-2005.

Table 1: Mean squares of grain yield of nine wheat genotypes across two environments.

Source of Variation	DF	Grain Yield
Environment (E)	1	73846085**
Reps w/n E	4	48976
Genotypes (G)	8	1219479**
G x E	8	261151NS
Error	32	217900
CV (%)	-	9.23

** = Significant at ($P \leq 0.01$),* = Significant at ($P \leq 0.05$),NS = Non significant.

Table 2: Means (kg ha^{-1}) and resistance indices for grain yield of nine wheat genotypes evaluated under rainfed and irrigated conditions.

Genotypes	Rainfed	Irrigated	MP	TOL	GMP	YI	YSI	SSI
MPT1	3210	5321	4265	2111	4132	0.83	0.6	1.06
MPT2	3494	5481	4487	1987	4376	0.9	0.64	0.97
MPT5	3938	6667	5302	2728	5124	1.01	0.59	1.09
MPT6	4358	6160	5259	1802	5181	1.12	0.71	0.78
MPT7	3901	6358	5129	2456	4980	1	0.61	1.03
MPT8	4568	6963	5765	2395	5639	1.17	0.66	0.92
MPT9	3975	5852	4913	1876	4823	1.02	0.68	0.85
Pirsabak-2005	3691	6667	5179	2975	4960	0.95	0.55	1.19
Pirsabak-2008	3877	6593	5234	2716	5055	0.99	0.59	1.1
Mean	3890	6229	5059	2338	4919	1	0.63	1
LSD	737	872						

Table 3: Genetic variances (σ^2_g), environmental variances (σ^2_e) and heritability (h^2) for grain yield of nine wheat genotypes evaluated under rainfed and irrigated conditions.

Parameters	Rainfed				Irrigated			
	σ^2_g	σ^2_e	h^2	Re	σ^2_g	σ^2_e	h^2	Re
Grain yield	107929	181520	37	280	240347	254280	49	478

Table 4: Simple correlation between environments and drought resistance indices for grain yield.

Parameters	Rain	Irri	MP	GMP	TOL	YI	YSI
Irri	0.93**						
MP	0.95**	0.96**					
GMP	0.57NS	0.67*	0.71*				
TOL	0.92**	0.96**	0.91**	0.47NS			
YI	1.00**	0.93**	0.95**	0.57NS	0.92**		
YSI	0.95**	0.92**	0.89**	0.46NS	0.96**	0.95**	
SSI	0.95**	0.99**	0.97**	0.63NS	0.97**	0.95**	0.95**

** = Significant at ($P \leq 0.01$),* = Significant at ($P \leq 0.05$),NS = Non significant.

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Grain yield under irrigated environment was highly significant and positively correlated with grain yield under stress environment. Yield in rainfed condition was also strongly associated with MP, TOL, YI, YSI and SSI while non-significant with GMP. MP was significantly correlated with TOL, YI, YSI, SSI and GMP. TOL was highly significantly correlated with YI, YSI and SSI. Similarly, YI was highly significantly correlated with YSI and SSI and YSI was also highly significantly correlated with SSI (Table 4).

Discussion

Drought indices measure yield reduction in stress environment as compared to normal environment to identify drought tolerant genotypes [10]. Non significant interaction shows consistency of the genotypes across the two environments. Similar results of significant variation among the genotypes while non-significant interaction was also published by Yavas & Unay [18] in a study on bread wheat genotypes for drought resistance. Genotype MPT8 produced maximum grain yield under rainfed and irrigated environments and remained best among the studied genotypes (Table 2). Moderate heritability coupled with selection response was calculated under rainfed and irrigated environments. Environmental variance was greater than genetic variance under rainfed and irrigated environments (Table 3). It indicates that this trait is influenced by the environment. According to this experiment under rainfed environment value of environmental variance is far greater than genetic variance which is clear indication of more environmental influence on genotype under rainfed environment than irrigated. Under water stress condition less genes were expressed as compared to irrigated environment that is why which showed moderate heritability. Moderate heritability for grain yield in wheat under stress environment was reported by [19,20].

Maximum MP and GMP were recorded for genotype MPT8 while minimum for genotype MPT1. These results showed that selection based on MP and GMP would be reliable because only these indices indicate genotypes which produced maximum grain yield. None of the genotypes have YSI value 1 because none of these genotypes were totally tolerant although genotype MPT6 was showed maximum value. TOL shows reduction in performance of a genotype under rainfed environment as compare to irrigated environment. In this experiment none of the genotypes showed zero reduction under rainfed environment as compared to irrigated environment although minimum reduction was recorded for genotype MPT6 and maximum in cultivar Pirsabak-2005. The ranks of genotypes for MP and GMP were similar to Anwar et al. [21] and Richard [7]. Five genotypes had YI values greater than unity, showing more grain yield than the average yield of all genotypes under rainfed environment. This shows that these are better performing compared to other studied genotypes.

Grain yield under irrigated environment was highly significant and positively correlated with grain yield under stress environment. It indicates that high yield potential under irrigated condition expect superior yield under rainfed condition because in this experiment all environmental conditions was same except irrigation. Therefore, indirect selection for stress environment on the basis of performance of irrigated environment would be fruitful due to this positive correlation. Yield in rainfed condition was also strongly associated with MP, TOL, YI, YSI and SSI while non-significant with GMP. Effective selection can be made by using these indices except GMP. Grain yield in irrigated environment was also significantly correlated with the above mentioned indices. Similar results were also published by Ahmadizadeh et al. [10] and Karimizadeh et al. [22]. MP was significantly correlated with TOL, YI, YSI, SSI and GMP. TOL was highly significantly correlated with YI, YSI and SSI. Similarly, YI was highly significantly correlated with YSI and SSI and YSI was also highly significantly correlated with SSI (Table 4). These results showed that in case of positive correlation we may use other indices, but it advantages depend on the value of correlation. MP is confidently used as selection criteria according to these findings.

Conclusion

Our findings showed that sufficient genetic variability was observed among the genotypes. Genotypes MPT8 produced higher grain yield under rainfed environment followed by MPT6, while, under irrigated environment MPT8 and MPT5 were high yielding genotypes. MP was remain the best selection index for both environments and YI for rainfed environment. TOL, YSI and SSI would be reliable selection indices under severe drought stress conditions. These indices and estimated heritability could be used as selection tools in future breeding programs.

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