Pak. J. Bot., 43(5): 2359-2363, 2011.

MAGNITUDE OF HERITABILITY AND SELECTION RESPONSE FOR YIELD TRAITS IN WHEAT UNDER TWO DIFFERENT ENVIRONMENTS

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Abstract

A set of 22 $F_{5:7}$ experimental wheat lines along with four check cultivars (Dera-98, Fakhr-e-Sarhad, Ghaznavi-98 and Tatara) were evaluated as independent experiments under irrigated and rainfed environments using a randomized complete block design at Khyber Pakhtunkhwa Agricultural University, Peshawar during 2004-05. The two environments were statistically different for days to heading and spike length only. Highly significant genetic variability existed among the wheat lines ($P<0.01$) in the combined analysis across environments for all traits. Genotype × environment interactions were non-significant for all traits except 1000-grain weight indicating consistent performance of wheat genotypes across the two environments. Wheat lines and check cultivars were 2 to 5 days early in heading under rainfed environment compared to the irrigated. Plant height, spike length, 1000-grain weight, biological and grain yields were generally reduced under rainfed environment. Genetic variances were of greater magnitude than environmental variances for most of the traits in both environments. The heritability estimates were of higher magnitude (0.74 to 0.96) for days to heading, plant height, spike length, biological and grain yield, while medium (0.31 to 0.51) for 1000-grain weight. Selection differentials were negative for heading (-7.3 days in irrigated vs -9.4 days in rainfed) and plant height (-9.0 cm in irrigated vs -8.7 cm in rainfed) indicating possibility of selecting wheat genotypes with early heading and short plant stature. Positive selection differentials of 1.3 vs 1.6 cm for spike length, 3.8 vs 3.4 g for 1000-grain weight, 2488.2 vs 3139.7 kg ha^{-1} for biological yield and 691.6 vs 565.4 kg ha^{-1} for grain yield at 20% selection intensity were observed under irrigated and rainfed environments, respectively. Expected selection responses were 7.98 vs 8.91 days for heading, 8.20 vs 9.52 cm for plant height, 1.01 vs 1.61 cm for spike length, 2.12 vs 1.15 g for 1000-grain weight, 1655.8 vs 2317.2 kg ha^{-1} for biological yield and 691.6 vs 565.4 kg ha^{-1} for grain yield under the two test environments, respectively. The differential heritability and selection responses for yield and related traits suggest the simultaneous evaluation and selection of wheat lines under the two environments.

Introduction

Wheat (*Triticum aestivum* L.) is a leading food grain of Pakistan occupying the largest area of 8.5 million hectares under any single crop in a year. About 1.033 million hectares of wheat area in Pakistan entirely depends on natural precipitation. During 2002, grain yield averaged 2566 and 1178 kg ha^{-1} under irrigated and rainfed regions of the country respectively, indicating a yield gap of 1388 kg ha^{-1} between the two production environments (Anon., 2003). During 2002-03, total wheat area in Khyber Pakhtunkhwa was 732.1 thousand hectares of which 316.1 thousand hectares was irrigated and 416.0 thousand hectares or 57% rainfed. The average yield was 2018 kg ha^{-1} under irrigated vs 1025 kg ha^{-1} under rainfed regions, indicating a decrease of 993 kg or 49% ha^{-1} under rainfed condition, respectively. This shows that genetic improvement in grain yields of the currently grown wheat cultivars are not expressed to full potentials under the rainfed environment due to lack of inherent ability to resist moisture stress (Bilgin *et al.*, 2011; Laghari *et al.*, 2010; Mangi *et al.*, 2010; Waqar-ul-Haq *et al.*, 2010). The crop under rainfed area suffers a serious moisture stress throughout its life cycle beginning from seedling stage to maturity. Foulkes *et al*., (2002) have reported annual yield loss of 15% due to drought during post-anthesis period of wheat crop in UK. Even in areas where wheat is grown under the supplemental irrigation, periods of drought often occur, especially during the late stages of plant growth, causing a considerable reduction in yield. Therefore, wheat yield improvement in the rainfed regions would provide the basis for eliminating hunger and instituting socio-economic development in the Khyber Pakhtunkhwa Province of Pakistan.

Drought resistance in field crops is a major factor for stable crop production in drought prone environments and thus is considered by breeders as a genuine breeding target. Although genetic improvement in wheat is continuously been made for its better adaptability to a wider range of environments, the production targets from the rainfed cropped area are not fully realized. The reason is that the arid or rainfed areas, consisting a considerable proportion of the total cropped area, are not planted with the genotypes having a better adaptability to low and uncertain moisture supply and specifically bred for these areas (Osmanzai *et al*., 1987). This situation has come under sharp focus and efforts are being made to plan and organize arid zone research in a proper manner.

So far no research has been conducted in Khyber Pakhtunkhwa to suggest that whether the breeders should target cultivars development and selection independently under the rainfed production environments or should just rely on the spillover effect of genetic improvement from irrigated to rainfed production environments. Therefore, the present study was undertaken with the objectives to determine magnitude of genetic and environmental variances and the heritability for yield contributing traits in wheat under irrigated and rainfed production environments. Selection differentials and estimated selection responses using similar selection intensity under the two environments were also determined.

Materials and Methods

This study was conducted at the Khyber Pakhtunkhwa Agricultural University, Peshawar during crop season of 2004-05. A set of 22 $F_{5:7}$ (F_5 derived lines in F_7 generation) experimental wheat lines along with four check cultivars were evaluated as independent experiments under irrigated as well as rainfed environments. These experimental lines were obtained from wheat breeding program at ARI, D.I.

Khan. The four check cultivars were Dera-98, Fakhre Sarhad, Ghaznavi-98, and Tatara. A randomized complete block design with three replications was used for both experiments. To avoid environmental influence, both the experiments were established adjacently in the same field. The irrigated experiment was regularly irrigated whenever required throughout the growing season. In contrast, the rainfed experiment did not receive any canal irrigation except the one for preparing the field for sowing. Each plot had 3 meter long 4-rows, spaced 0.30 meters apart. Both experiments were planted on October 28th, 2004 with hand hoe using seed rate of 100 kg ha^{-1}. Fertilizer was applied @ 90 kg ha^{-1} N and 60 kg ha^{-1} P_2O_5 at the time of sowing. Weeds were controlled manually in both experiments. The plots were sickle harvested about 15 days after reaching physiological maturity.

Data recorded on plant parameters viz days to heading, plant height, spike length, 1000-grain weight, biological and grain yield on 22 wheat lines (excluding check cultivars) were statistically analyzed using PROG GLM option in SAS (Anon., 2000) following linear model for a randomized complete design as proposed by Steel & Torrie (1981). Genetic and environmental variances for all traits were estimated from the 22 experimental lines under each environment independently using the PROG VARCOMP option in SAS. Broad-sense heritability (h^2_{BS}) on entry mean basis was estimated under each environment for all traits using the following formula proposed by Fehr (1993):

$$h^2_{BS}=V_g / (V_g + V_e/r)$$

Wherein Vg = genetic variance
Ve = environmental variance and
r = number of replications

Selection differential (S) for a trait was determined as the difference in the mean of the top 20% selected lines ($\bar{x}_s$) and overall mean of 22 experimental lines ($\bar{x}$). Mean of the four check cultivars ($\bar{x}_c$) was also computed. Expected response to selection (R_e) was determined using 20% selection intensity according to the procedure outlined by Falconer & Mackay (1996):

$$R_e = i_x \sqrt{V_p} \,.\, h^2$$

Wherein i_x = 20% selection intensity for trait x,
V_p = phenotypic variance for the trait x and
h^2 = heritability for the trait x.

Results and Discussion

Variability across environments: Mean squares pertaining to heading, plant height, spike length, 1000-grain weight, grain and biological yield characteristics are given in Table 1. The two test environments did not differ for plant height (P=0.46), 1000-grain weight (P=0.94), biological yield (P=0.14) and grain yield (P=0.32), but the differences were highly significant for days to heading (P<0.01) and significant for spike length (P=0.05). Highly significant genetic variation (P<0.01) was detected among wheat lines in the combined analysis over two environments for all parameters. Genotype × environment interaction was non-significant for all traits except 1000-grain weight indicating consistent performance of experimental lines across the two test environments (Table 1).

Table 1. Mean squares for days to heading, plant height, spike length, 1000-grain weight, biological and grain yield of 22 wheat lines evaluated under irrigated and rainfed environments at Khyber Pakhtunkhwa Agricultural University, Peshawar during crop season 2004-05.

Source	d.f.	Days to heading	Plant height	Spike length	1000-grain weight	Biological yield (×10³)	Grain yield (×10³)
Envir (E)	1	593.93**	41.48NS	2.01*	0.38NS	60007.57NS	4547.35NS
Reps w/n E	4	26.15	63.59	0.29	80.69	18725.37	3543.56
Genotype (G)	21	233.07**	324.13**	6.91**	20.75*	20294.38**	2858.32**
G×E	21	9.55NS	2.78NS	0.40NS	27.00*	3527.42NS	436.24NS
Error	84	6.25	5.76	0.44	13.84	3271.01	652.69
CV (%)	--	1.98	5.07	5.98	1.98	15.75	20.25

NS = Non-significant' *, **= Significant at 5 and 1% probability level, respectively

Days to heading: Genetic variance for days to heading was 5 and 7-times greater than environmental variance under irrigated and rainfed environment, respectively (Table 2). Greater magnitudes of heritability (0.94 and 0.96) were observed for days to heading under both the environments indicating effectiveness of selection among the current pool of genotypes. Similar higher heritability estimates for heading were also reported from research work by Dhonde *et al*., (2000). However, medium to low heritability for days to heading have been reported by Gupta & Verma (2001) in durum wheat under irrigated and rainfed conditions. Similarly significant variation with low heritability of 40% has been reported by Muhammad *et al*., (2001) in a study involving 24 wheat lines. The experimental lines as well as check cultivars were 4 to 5 days early in heading under rainfed environment (Table 3). Thus rainfed conditions accelerated the heading due to less availability of water. Mean days to heading of 20% selected lines were 121.2 vs 114.7 under irrigated and rainfed environment showing a net difference of 6.5 days among the two environments. Significant differences for heading in wheat genotypes have also been reported by Litvinenko & Abakumenlio (1989) mainly due to existence of drought. Selection differentials for heading were -7.3 and -9.4 days with expected selection responses of 7.98 and 8.91 days under irrigated and rainfed environments, respectively (Table 4).

Table 2. Genetic variance (V_g), environmental variance (V_e) and heritability (h^2) estimates for various traits of 22 wheat lines evaluated under irrigated and rainfed environment at Khyber Pakhtunkhwa Agricultural University, Peshawar during crop season 2004-05.

Traits	Irrigated			Rainfed		
	V_g	V_e	h^2	V_g	V_e	h^2
Heading	34.5	6.9	0.94	42.2	5.6	0.96
Plant height	40.9	20.6	0.85	53.2	23.8	0.87
Spike length	0.6	0.5	0.80	1.5	0.4	0.91
1000-grain weight	4.5	13.2	0.51	2.2	14.6	0.31
Biological yield	2.03×10^6	2.7×10^6	0.74	3.7×10^6	3.7×10^6	0.74
Grain yield	3.3×10^5	3.4×10^5	0.75	3.0×10^5	9.0×10^5	0.50

Table 3. Mean of top 20% selected lines ($\bar{X}_s$), check cultivars mean ($\bar{X}_c$), mean of all lines ($\bar{X}$), selection differential (S), and expected response (R_e) to selection for various traits of wheat lines under irrigated and rainfed environments at Khyber Pakhtunkhwa Agricultural university, Peshawar during 2004-05.

Traits	Environment	$\bar{X}_s$	$\bar{X}_c$	$\bar{X}$	S	R_e
Headings (days)	Irrigated	121.2	135.0	128.3	-7.3	7.98
	Rainfed	114.7	130.2	124.1	-9.4	8.91
Plant height (cm)	Irrigated	84.5	83.9	93.5	-9.0	8.20
	Rainfed	83.7	84.0	92.4	-8.7	9.52
Spike length (cm)	Irrigated	12.9	11.0	11.6	1.3	1.01
	Rainfed	12.9	10.7	11.3	1.6	1.61
1000-Grain wt (g)	Irrigated	39.7	37.2	35.9	3.8	2.12
	Rainfed	39.2	33.6	35.8	3.4	1.15
Biological yield (kg ha^{-1})	Irrigated	13291.2	10500.0	10803.0	2488.2	1655.8
	Rainfed	15291.2	9541.6	12151.5	3139.7	2317.2
Grain yield (kg ha^{-1})	Irrigated	4916.5	4291.7	4174.2	742.3	691.6
	Rainfed	4999.7	2466.5	3803.1	1196.6	65.4

Table 4. Means for biological and grain yield of 22 wheat lines and four check cultivars under irrigated and rainfed environments at Khyber Pakhtunkhwa Agricultural University, Peshawar during crop season 2004-05.

Genotype	Biological yield (kg ha^{-1})		Grain yield (kg ha^{-1})	
	Irrigated	Rainfed	Irrigated	Rainfed
IR10	10333	11667	4167	4000
IR11	11000	10833	4500	3833
IR14	12333	13833	4833	4000
IR15	14333	14166	4333	4333
IR17	9833	10000	3666	2833
IR18	9166	8333	3333	3166
IR2	8333	8500	2500	1833
IR20	10166	10333	4166	4000
IR21	10333	9166	4166	2833
IR5	10333	12333	4333	3833
IR7	11500	11500	3666	3000
RF10	8333	11166	3333	3333
RF2	8333	11166	3666	3333
RF21	12166	13666	4666	4000
RF29	13833	16833	5000	5333
RF31	11000	13166	4833	4666
RF33	11166	14666	5000	3666
RF35	12666	15666	4166	5000
RF36	11000	14000	4500	3833
RF47	9000	11333	3333	4000
RF5	9666	13166	4666	4000
RF9	12833	12166	5000	5000
Dera-98	7500	7166	3000	2333
F.Sarhad	11333	12833	4666	1700
Ghaznavi-98	13666	8333	4000	3000
Tatara	9500	9833	9833	2833
LSD $_{(0.05)}$	**3292.6**	**3456.4**	**1213.4**	**794.5**

Plant height: Plant height is an important selection trait in wheat breeding programs. Plant breeders are interested in short stature uniform plants because of their lodging resistance and positive response to chemical fertilizers and irrigation. Both the environments showed significant differences among the genotypes for plant height. Magnitudes of genetic variances compared to the environmental variances were almost identical under the two environments (Table 2). Genetic and environmental variances were 40.9 and 20.6 vs 53.2 and 23.8 under irrigated and rainfed environments, respectively. Heritability estimates were of greater magnitude (0.85 and 0.87) in both the environments (Table 2). There was a general tendency of shorter plant stature under rainfed environment (Table 3). Check cultivars were 9.6 and 8.4 cm shorter than the mean height of 22 wheat genotypes under irrigated and rainfed environment. Plant height of selected genotypes averaged 84.5 cm in irrigated vs 83.7 cm in rainfed environment. Negative selection differentials under both the environments indicate equal opportunity of selection for reduced plant height (Table 3). Expected selection responses for plant height under irrigated and rainfed environment were 8.20 and 9.52 cm, respectively (Table 3). Subhani & Alam (1998) have also reported greater magnitude of broad sense heritability and expected genetic advances for plant height in a population derived from four wheat crosses. Heritability estimates ranging from 50-80% for plant height with higher genetic advance in F_2 population of 12 diallel crosses of four bread wheat varieties has been reported by Ansari *et al*., (1991).

Spike length: Spike length usually has direct relationship with grain weight spike^{-1} as well as final yield per unit area. Genetic and environmental variances for spike length were 0.6 and 0.5 vs 1.5 and 0.4 under irrigated and rainfed environment, respectively (Table 2). Greater magnitude of broad sense heritability (0.80 and 0.91) for spike length was observed in both the environments. Spike length of check cultivars and selected wheat genotypes averaged 11.0 and 12.9 cm in irrigated vs 10.7 and 12.9 cm in rainfed environment, respectively (Table 3). The top 20% selected lines exhibited the same spike length resulting in selection differentials of 1.3 and 1.6 cm under irrigated and rainfed environments (Table 3). Expected selection response for spike length was positive (1.01 and 1.61) for irrigated and rainfed environments. Moderate to high range of heritability with higher coefficient of genetic variation for spike length has been reported by Kheiralla (1993) in a two cycles of selection. Similar results are also reported by Khan *et al*., (2003) in F_2 population of six cross combinations indicating greater magnitude of heritability with greater genetic advance for yield and other agronomic characters.

1000-grain weight: 1000-grain weight is very important yield contributing character and is given more emphasis during cultivar selection process. Environmental variances for 1000-grain weight were 2.9 and 6.6 times greater than genetic variance in irrigated and rainfed environments, respectively (Table 2). Thus, there was more environmental influence on quantitatively inherited 1000-grain weight resulting in medium (0.51) heritability in irrigated and low in rainfed (0.31) environment. Average 1000-grain weight of 20% selected wheat lines was almost identical under the two environments (39.7 vs 39.2 g), however, 1000-grain weight of check cultivars averaged 37.2 g in irrigated vs 33.6 in rainfed environment (Table 3). Selection differentials were identical under the two environments, but selection responses were comparatively greater under irrigated (2.12 g) than rainfed (1.15 g) environment.

Biological yield: Highly significant differences were observed among wheat genotypes for biological yield in both the environments. Genetic and environmental variances were of similar magnitude both in irrigated and rainfed environments (Table 2). Broad-sense heritability estimates were also identical (0.74) in both the environments. Maximum biological yield of 14333 and 14166 kg ha^{-1} was recorded for genotype IR15 under irrigated and rainfed environments, respectively (Table 4). Several among the wheat lines evaluated produced more biological yield under rainfed environment due to more and timely rain in the growing season of 2004-05. Wheat lines, whether selected or not, had on the average more biological yield in rainfed environment. However, the checks produced more biological yield under irrigated than rainfed. When averaged over 22-wheat genotypes, mean biological yield was 10803.0 kg ha^{-1} in irrigated vs 12151.5 kg ha^{-1} in rainfed environment showing a net difference of 1348.5 kg ha^{-1} in two environments (Table 3). Mean biological yield of top 20% selected lines was 13291.2 and 15291.2 kg ha^{-1} in irrigated and rainfed environments, respectively. Gupta & Verma (2001) have reported high heritability estimates coupled with high genetic advance for biological yield under normal and rainfed conditions. Bijendra *et al*., (1992) have also reported high heritability and genetic advance for biological yield. Selection differentials for biological yield were comparatively greater under rainfed environment (Table 3). Similarly, expected response to selection was greater under rainfed environment.

Grain yield: Grain yield was significantly different among wheat genotypes under both the environments. Genetic and environmental variances were of similar magnitude under irrigated environment. In contrast, environmental variance was 3-times greater than genetic under rainfed environment. Heritability estimates were 0.75 in irrigated vs 0.50 in rainfed indicating more selection effectiveness under irrigated environment (Table 2). Water stress under rainfed environment generally reduced the grain yield of wheat genotypes except RF29, RF35 and RF47 which produced more grain yield under rainfed than irrigated environment. Similarly, three wheat genotypes viz., IR15, RF9 and RF10 had identical yields under the two environments (Table 4). Averaged across 22 wheat genotypes, gain yield was 4174.2 kg ha^{-1} in irrigated vs 3803.1 kg ha^{-1} in rainfed environment showing average yield reduction of 371.1 kg ha^{-1} due to non-availability of required water during crop growth and development. In contrast, grain yield of 20% selected lines averaged 4916.5 kg ha^{-1} in irrigated vs 4999.7 kg ha^{-1} in rainfed environment, while yield of four checks averaged 4291.7 in irrigated vs 2466.5 kg ha^{-1} in rainfed. Selection differentials were 742.3 and 1196.6 kg ha^{-1}, while expected selection responses were 691.6 and 565.4 kg ha^{-1} under irrigated and rainfed environment (Table 3).

Subhani & Alam (1988) and Muhammad *et al*., (1997) have reported moderate to high range of heritability estimates for wheat yield and related components.

Conclusions

The differential expression of genetic variation, heritability and selection responses for maturity and yield related traits suggest that breeders should simultaneously evaluate wheat genotypes under the two production environments before release as cultivars. This would help in trimming the existing wheat yield gap between irrigated and rainfed regions of the country.

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(Received for publication 4 January 2009)