Pak. J. Bot., 39(5): 1623-1637, 2007.

YIELD STABILITY ANALYSIS CONFERRING ADAPTATION OF WHEAT TO PRE- AND POST-ANTHESIS DROUGHT CONDITIONS

SYED ABDUL MAJID*, REHANA ASGHAR[1] AND GHULAM MURTAZA

Department of Botany, University of Azad Jammu & Kashmir, Muzaffarabad, Pakistan.
[1]Department of Botany, University of Arid Agriculture, Rawalpindi, Pakistan.
** Corresponding Author's e-mail: samajida@hotmail.com*

Abstract

Four wheat (*Triticum aestivum* L.) genotypes *viz*., Rawal-87, Inqalab-91, Potohar-93 and Chakwal-97 were grown under pre-anthesis, post-anthesis and terminal drought stress in comparison to the unstressed condition in lysimeters to study the adaptability of crop in different drought environments on the basis of yield and yield components. Gypsum block method was used to monitor drought stress in the soil. The performance of yield components attributable to grain yield were assessed and it was found that number of grains per spike and biological yield were positively and significantly correlated to the grain yield. Harvest index and thousand grains weight were also correlated positively but the former was significant at 5% only and the later had non-significant correlation. It was also found that number of spikelets per spike was negatively and non-significantly correlated with the grain yield of wheat under drought stress conditions imposed during this study. Present study revealed that grain yield of wheat crop under water deficit conditions can be improved by selecting the genotypes having more number of grains per spike and biological yield. Chakwal-97 had highest mean during both the years but regression coefficient closest to one was for Inqalab-91 in number of grains per spike. On the basis of number of grains per spike Inqalab-91 remained most stable for the year 2002-03 and Chakwal-97 for 2003-04. Inqalab-91 also exhibited stability for both these years on the basis of thousand grains weight. Similarly, on the basis of the major parameter judging for stability, the grain yield, Inqalab-91 with highest mean for both years and with regression coefficient closest to unity in one of the years (2003-04) looked to be the most stable genotype. Deviation from the regression fit is the measure of genotypic stability over a set of environments. Inqalab-91, with highest mean in yield and yield components and smaller deviation from the regression fit, was relatively stable in drought stress environments. Inqalab-91 with almost 90% of coefficient of determination in all the regression of yield components looked to be the best, although other varieties had higher coefficient of determination than that of Inqalab-91 in some of the yield components.

Introduction

Drought is a worldwide problem and about 43% of world land is affected to various degrees by it. It is of special concern for Pakistan as almost 15 million hectares of cultivated land is affected by this syndrome (Mujtaba & Alam, 2002). Agricultural production in these areas is primarily dependent on physical factors of climate and soil. These factors collectively determine the land potential, cropping pattern and crop productivity (Mujtaba & Alam, 2002). Drought is a complex scenario with three main components viz., (i) timing of occurrence during the season (ii) duration and (iii) intensity. These factors vary so widely in nature that it is very difficult to define specific plant attributes required for crop improvement under stress conditions (Mujtaba & Alam, 2002). Grain yield is a product of an organized interplay of its several components, which are highly susceptible to environmental fluctuations. However, yield can be estimated on the basis of performance of yield components. Enhancement in yield in most situations is more effectively fulfilled on the basis of performance of yield components, which are closely associated with grain yield (Ashfaq *et al*., 2003). Various yield components like plant height, number of tillers per plant, flag leaf area, peduncle length, number of spikelets per spike, number of grains per spike, grain weight per spike, thousand grains weight and grain yield per plant were studied to evaluate the relationship of yield and its components in drought condition in wheat (Ashfaq *et al*., 2003; Khan *et al*., 2003; Hassan *et al*., 2003; Khan *et al*., 2004; Sakin *et al*., 2005).

Consistency in yield has always been a problem in crop production due to the strong influence of environmental effects during the various stages of crop growth. G x E interactions are therefore, of major concern to plant breeders for developing commercial varieties. Many publications described the importance of G x E interactions and concluded that mean yields are not a satisfactory basis and emphasis should therefore be given on the evaluation of genotypes which could perform better irrespective of environmental fluctuations (Golmirzaie *et al.*, 1990; Kinyua, 1992; Lin *et al.*, 1986; Qari *et al.*, 1990; Sial *et al*., 2000; Yan & Hunt, 2001; Viana & Cruz, 2002; Kaya *et al*., 2002). A study of G x E interaction can lead to successful evaluation of wheat cultivars for stability in yield performance across environments. In the presence of significant G x E interactions, stability parameters are estimated to determine the superiority of individual genotypes across the range of environments.

Stability parameters of wheat varieties were studied by Kumar & Chowdhury (1991) and found highly significant genotypic differences for all the characters studied. The linear component of G x E interaction was significant for some characters. On the basis of high mean, unit regression and non-significant non-linear components they declared the genotype WH822 the best in the environments studied. Singh & Chatrath (1995) assessed the G x E interaction in Indian rain-fed wheat varieties under salt-stressed environments for yield components and classified the genotypes by explaining the linear environmental change i.e., a significant linear regression coefficient and a non-significant deviation from linear regression. Ahmad *et al*., (1996) studied G x E interaction and relative stability for grain yield of wheat varieties for 5 different locations and found 2 out of 6 varieties to be most stable and adaptable genotypes being high yielding with unit regression and non-significant non-linear deviation from regression. Sial *et al*., (2000) studied stability for yield performance and G x E interaction in 12 wheat genotypes grown at 13 contrasting sites over two years. The adaptability was analyzed by using the estimates of regression coefficient, deviation from regression coefficients and mean grain yield for each genotype over all the environments. Kaya *et al*., (2002) carried out an experiment to determine the yield performance of 20 bread wheat genotypes across six environments in Turkey using AMMI analysis and reported that the yield performance of genotypes were under the major environmental effects of G x E interactions. To study the varietal dynamics of yield stability in wheat, Kakar *et al*., (2003) used the mean yield, regression slope, correlation coefficient and coefficient of determination in an experiment carried on 10 genotypes at 3 locations. Asif *et al*., (2003) analyzed the wheat genotypes for yield stability in rainfed environments to be the best choice by using the parameters as high mean yield over the environment, unit regression coefficient (b = 1.00) and the smallest deviation from regression ($S^2d^- = 0$). Interrelationships between yield and its components for wheat were determined by correlation and path coefficient analysis to determine the association of morphological traits with grain yield (Ashfaq *et al*., 2003).

The comprehensive and thorough survey of the literature oriented this study to evaluate the adaptability and tolerance of the genotypes in different types of drought on the bases of yield and yield components of wheat (*Triticum aestivum* L.). Popularly grown wheat genotypes viz., Rawal-87, Inqalab-91, Potohar-93 and Chakwal-97 in the rainfed areas of Potohar region of Pakistan were used for the study. In addition, on the basis of regression analysis, genotypes were assessed for their grain yield stability in order to rank the genotypes for best adaptation.

Materials and Methods

The field (lysimeter) study was carried out at experimental area of the Department of Botany, University of Azad Jammu and Kashmir, Muzaffarabad, Azad Kashmir. Wheat (*Triticum aestivum* L.) seeds of four genotypes *viz*., Rawal-87, Inqalab-91, Potohar-93 and Chakwal-97 were obtained from Barani Agricultural Research Institute (BARI), Chakwal, Pakistan. Rawal-87, Potohar-93 and Chakwal-97 were selected for their drought tolerance while Inqalab-91 as general purpose variety.

Specially made for the purpose, 12 pots made of zinc sheet having size of 0.93 x 1.23 x 0.30 m were filled with equal amount of 400 kg of previously analyzed loam-textured soil of pH 7.2. Before filling the pots, the soil was fertilized with N: P: K @ of 90:90:60 Kg ha^{-1} with N, P, K components being urea, single super phosphate and sulphate of potash.

Each pot was considered one block, used for one replication of the treatments having 4 rows of all the genotypes tested on randomized basis with the distance of 20 cm according to randomized complete block design. The seeds were sown in the rows at a distance of 5 cm. For this purpose, 40 seeds were sown initially and after the germination, seedlings were thinned at the required distance.

As recommended for wheat crop (Ahmad & Arain, 1999; Siddique *et al*., 1999, 2000), 4 irrigations for the normal water requirement of the crop were applied at: a) pre-sowing, b) tillering stage, c) pre-anthesis stage and d) post-anthesis stage to the soil saturation level.

A total of 4 drought treatments as: a) no drought (control), b) pre-anthesis drought, c) post-anthesis drought and d) both pre- and post-anthesis drought (terminal drought) were used for each of the 4 wheat varieties to give a four by 4 factorial set. There were three replicates according to Trethowan (2000). All the replicates were applied with the first two irrigations. The stress was created by checking the third irrigation in one treatment, the fourth in the other treatment and both, the third and the fourth in the last treatment. Gypsum block method was used to monitor the water status of the soil during crop growth. Minimum level of 1.0 MPa water potential was maintained by applying a limited amount of water as and when needed. Protection from rain was provided by manually operated shelter equipped with movable sheet of transparent polythene on the frame made by iron-pipes. All agronomic practices like hoeing, weeding etc., were kept normal and uniform.

Yield and various individual yield components were calculated as follows:

- Spikelets were counted using 10 randomly selected spikes from each replicate and then calculated the mean value of spikelets per spike.
- Grains were also counted using the same 10 spikes as mentioned above and were calculated per spike basis.
- A sample of 1000 grains was taken from each replicate and then weighed using triple beam balance.
- Grain yield was recorded by harvesting the total plants in each replicate and then was calculated to convert the final grain yield in Kg ha^{-1}.
- Biological yield was determined using the harvested plants of each replicate and then was calculated per hectare basis.
- Harvest index was calculated by using the formula:

$$\text{Harvest Index} = \frac{\text{Grain yield}}{\text{Biological yield}} \text{ X } 100$$

The experiment was conducted using randomized complete block design (RCBD). Analysis of variance was performed on the basis of factorial experiment and least significant difference test (LSD) at 0.05 level of significance was used to separate the means according to Steel *et al.*, (1997). Yield stability analysis was done according to Eberhardt & Russel (1966) and Finlay & Wilkinson (1963). The entire statistical work was done using the computer package MSTATC.

Results and Discussion

The only way for agriculture to keep pace with population and to alleviate world hunger is to increase the intensity of production in those ecosystems that lend themselves to sustainable intensification, while decreasing intensity of production in the more fragile ecosystems (Borlaug & Dowswell, 1997). By 2020, the world's farmers will have to produce 40% more grain, most of which will have to come from yield increases (Pinstrup-Andersen *et al.*, 1999). Therefore proper investigations for the identification of genotypes on yield criteria associated with drought tolerance should be the priority issue in an experiment under water shortage. Although there is plenty of literature available on the yield component studies, none has been shown to be an exclusive indicator of drought tolerance. It has been concluded that water deficit reduced almost all yield components of wheat including number of spikelets per spike, number of grains per spike, thousand grain weight, biological yield, grain yield and harvest index (Khan *et al*., 2004; Zarea-Fizabady & Ghodsi, 2004; Ashfaq *et al*., 2003; Hassan *et al*., 2003; Khan *et al*., 2002; Shah *et al*., 2002; Joshi *et al*., 2002 Giunta *et al*., 1999; Simane *et al*., 1993 ; Kumar & Choudhary, 1991).

Number of spikelets per spike: Effect of drought stress on the number of spikelets per spike in different wheat cultivars during the years 2002-03 and 2003-04 were studied and very highly significant difference were found between both the years (Table 1). In 2002-03, Chakwal-97 showed maximum numbers (15.5), non-significantly followed by Rawal-87 (14.8) and significantly followed by Potohar-93 (14.3). Inqalab-91 showed significantly minimum (13.3) number of spikelets per spike. In next year (2003-04), again Chakwal-97 exhibited the maximum number (18.2) of spikelets per spike, followed non-significantly by Rawal-87 (17.6) and significantly by Potohar-93 (17.2). Observing the similar pattern, minimum numbers (15.3) were observed in Inqalab-91 in 2003-04 as well. Drought stress did not significantly change the number of spikelets per spike in both the years, although pre-anthesis drought in 2002-03 and terminal drought in 2003-04 decreased the numbers to maximum (Table 1). The interaction between varieties and stress imposition did not exhibit a marked effect in number of spikelets, although it ranged from 16.00 to 12.67. Maximum numbers were observed under post-anthesis drought and also under non-drought condition in Chakwal-97 and minimum numbers were observed under terminal drought in Inqalab-91. Independently, all the varieties showed a non-significant decrease in the number of spikelets under the effect of different drought stresses in 2002-03 as compared to that of control. In 2003-04, although the range between minimum and maximum was significantly higher than that of 2002-03, the trend in the effect of drought stress on number of spikelets per spike remained the same. Maximum number of spikelets was observed in Chakwal-97 and minimum number of spikelets per spike in Inqalab-91, but none of the varieties showed significant effect of different drought stresses.

The difference in number of spikelets per spike was reported by many authors (Ashfaq *et al*., 2003; Khan *et al*., 2002; Kumar & Choudhary, 1991) in different genotypes under different environments. Ashfaq *et al*., (2003) studied the association of morphological traits with grain yield in wheat and concluded that grain yield can be improved by selecting genotypes having more number of spikelets per spike, number of grains per spike and grain weight per spike. The results of the present study were in accordance with the study of Ashfaq *et al*., (2003). Giunta *et al*., (1999) concluded that an increase in fertility of spikes was due to more spikelets per spike rather than to more kernels per spikelet.

Number of grains per spike: The number of grains per spike of wheat cultivars were studied in 2002-03 and 2003-04 under the effect of drought stress and found significant difference between both years (Table 2). In 2002-03, maximum number of grains was noted in Inqalab-91 (47.7), significantly followed by Rawal-87 (44.3) and Chakwal-97 (44.2). Potohar-93 produced minimum (38.5) number of grains per spike of wheat. In the next year, varieties behaved differently. Maximum number of grains was noted in Chakwal-97 (45.4) followed by Inqalab-91 (42.9) non-significantly and by Rawal-87 (40.9) significantly. Potohar-93 in this year too produced minimum number (38.2) of grains per spike. Terminal drought decreased number of grains maximum (41.9), however, other two drought stresses also decreased the numbers significantly as compared to control (46.3) in the year 2002-03. In the next year, again significant decrease (39.9) was observed under terminal drought, but pre- and post-anthesis drought did not decrease the number significantly as compared to control (43.6). Under pre-, post-anthesis and terminal drought, different varieties behaved differentially. In 2002-03, Inqalab-91 and Chakwal-97 did not show any significant response to drought stress, although variably decreased number of grains was observed as compared to control, while Rawal-87 and Potohar-93 exhibited the significant change under different drought stresses in 2002-03. In the next year (2003-04), only the Rawal-87 showed a significantly decreased pattern under the stress conditions but all other varieties did not respond to drought significantly. However, some increase in number of grains was also observed under pre-anthesis drought in Inqalab-91 and under terminal drought in Chakwal-97 as compared to control, although difference was non- significant (Table 2).

Table 1. Effect of drought stress on number of spikelets per spike of wheat.

Stress→ varieties↓	Control	Pre-anthesis drought	Post-anthesis drought	Terminal drought	Means
Year 2002-03					
Rawal-87	14.667 abc	15.333 ab	15.000 abc	14.333 abcd	14.833 AB
Inqalab-91	13.333 cd	13.333 cd	13.667 bcd	12.667 d	13.250 C
Potohar-93	14.667 abc	14.000 bcd	14.333 abcd	14.333 abcd	14.333 B
Chakwal-97	16.000 a	15.000 abc	16.000 a	15.000 abc	15.500 A
Means	14.667 A	14.417 A	14.750 A	14.083 A	**14.479***
Year 2003-04					
Rawal-87	17.870 ab	18.267 ab	17.500 abc	16.700 bc	17.584 AB
Inqalab-91	15.833 cd	15.900 cd	14.567 d	14.900 d	15.300 C
Potohar-93	17.067 abc	17.033 abc	18.000 ab	16.733 bc	17.208 B
Chakwal-97	18.567 a	17.733 ab	18.600 a	17.800 ab	18.175 A
Means	17.334 A	17.233 A	17.167 A	16.533 A	**17.067***

Means followed by similar letters are not significant to each other at $P = 0.05$ by LSD.
*Significant at P=0.001(Year mean)

Table 2. Effect of drought stress on number of grains per spike of wheat.

Stress→ varieties↓	Control	Pre-anthesis drought	Post-anthesis drought	Terminal drought	Means
Year 2002-03					
Rawal-87	46.367 abcd	42.633 bcde	47.067 abc	40.967 def	44.258 B
Inqalab-91	49.600 a	48.333 ab	47.867 abc	45.133 abcd	47.733 A
Potohar-93	43.100 bcde	36.533 f	38.300 ef	36.233 f	38.542 C
Chakwal-97	46.033 abcd	42.900 bcde	42.233 cdef	45.433 abcd	44.150 B
Means	46.275 A	42.600 B	43.867 AB	41.942 B	**43.671***
Year 2003-04					
Rawal-87	45.167 ab	44.500 abcd	38.600 cdef	35.167 f	40.858 BC
Inqalab-91	44.533 abc	46.133 ab	40.767 bcdef	40.133 bcdef	42.892 AB
Potohar-93	38.933 cdef	38.400 ef	38.467 def	36.867 f	38.167 C
Chakwal-97	45.800 ab	43.133abcde	45.167 ab	47.300 a	45.350 A
Means	43.608 A	43.042 A	40.750 AB	39.867 B	**41.817***

Means followed by similar letters are not significant to each other at $P = 0.05$ by LSD.
*Significant at P=0.001(Year mean)

Differences in number of grains per spike in different wheat cultivars in different agro-climatic conditions were also studied by Kumar & Choudhary (1991), Choudhary *et al*., (1996), Joshi *et al*., (2002) and Khan *et al*., (2004). Simane *et al*., (1993) using path analysis, found that the number of kernels per spike and kernel weight had significant, positive and direct effects on grain yield under moisture stress conditions, as well as under well watered conditions. The authors identified the number of grains per spike as having the most significant effect on yield. Singh & Chatrath (1995) concluded that stability in grain yield depends upon stable performance in number of grains per ear and 1000-grains weight. Number of grains per spike significantly affected by drought stress in short stature wheat cultivar to tall normal crop was reported by Ehdaie & Waines (1996). Similar results were obtained by Dencic *et al*., (2000) in a study of wheat cultivars and landraces under low moisture regimes. Guttieri *et al*., (2001) concluded that wheat cultivars did not differ for kernel weight, but differed significantly in the number of kernels per spike under moisture stress. Water deficit reduced harvest index and yield components like number of spikes per meter square, number of kernel per spike and 1000-kernel weight (Zarea-Fizabady & Ghodsi, 2004). Our results were in agreement with the literature reported above.

Table 3. Effect of drought stress on thousand grains weight (gram) of wheat.

Stress→ Varieties↓	Control	Pre-anthesis Drought	Post-anthesis Drought	Terminal Drought	Means
		Year 2002-03			
Rawal-87	26.077 abc	22.967 cdef	23.960 cde	21.640 cdef	23.66 B
Inqalab-91	29.720 ab	30.573 a	29.743 ab	25.170 abcd	28.80 A
Potohar-93	18.900 ef	19.680 def	24.463 bcde	17.453 f	20.12 C
Chakwal-97	22.183 cdef	23.140 cdef	23.037 cdef	19.863 def	22.06 BC
Means	24.22 A	24.09 A	25.30 A	21.03 B	**23.66***
		Year 2003-04			
Rawal-87	32.457 abcd	33.323 abc	28.187 bcde	26.900 de	30.22 B
Inqalab-91	32.900 abc	34.660 a	33.627 ab	32.963 abc	33.54 A
Potohar-93	26.873 de	23.920 e	23.770 e	25.463 e	25.01 C
Chakwal-97	28.363 bcde	27.947 bcde	25.933 e	27.863 cde	27.53 BC
Means	30.15 A	29.96 A	27.88 A	28.30 A	**29.07***

Means followed by similar letters are not significant to each other at P = 0.05 by LSD.
*Significant at P=0.001(Year mean)

Thousand grains weight (TGW): There was a very highly significant increase in thousand grains weight of wheat varieties as affected by drought stress in the year 2003-04 (29.07 g) as compared to that (23.66 g) in 2002-03 (Table 3). In 2002-03, Inqalab-91 showed highest TGW (28.80 g), significantly followed by that (23.66 g) of Rawal-87 and Chakwal-97 (22.06 g) which were non-significant to each other. Potohar-93 showed minimum TGW (20.12 g) significant to others except Chakwal-97 in 2002-03. In the next year again, Inqalab-91 showed maximum TGW (33.54 g), with the similar pattern significantly followed by Rawal-87 (30.22 g) and Chakwal-97 (27.53 g) which were non-significant to each other. Minimum TGW (25.01 g) was recorded in Potohar-93 similar to last year, significant to others except Chakwal-97 (Table 3). In the year 2002-03, only the terminal drought stress decreased TGW (21.03 g) significantly as compared to control (24.22 g), but post-anthesis drought increased TGW (25.30 g). However, pre- (24.09 g) and post-anthesis drought stresses did not affect significantly in 2002-03. In 2003-04, pre- (29.96 g), post-anthesis (27.88 g) and terminal (28.30 g) drought stresses non-significantly decreased TGW as compared to 30.15 g of control. Drought stresses affected the TGW in different wheat varieties not in a definite pattern. Pre-anthesis drought induced maximum TGW in Inqalab-91, even more than that of control. Although terminal drought decreased the TGW more as compared to control, the decrease was non-significant in both pre-anthesis and terminal stresses. Similarly, other varieties also showed an increase in TGW under pre-, post-anthesis and terminal drought stresses differentially. In 2003-04, an increase or decrease in TGW under effect of different drought stresses was not in a definite pattern. Inqalab-91 under all stress conditions and Rawal-87 under pre-anthesis drought only induced more TGW as compared to control in response to drought stress non-significantly. The other two varieties did not induce an increase in the TGW under any stress condition, rather a non-significant decrease was observed.

TGW studied by the researchers were reported in the literature as an invariably important yield component (Khan *et al*., 2004; Zarea-Fizabady & Ghodsi, 2004; Hassan *et al*., 2003; Ashfaq *et al*., 2003; Khan *et al*., 2002; Shah *et al*., 2002). The results of present study were in accordance with the previous findings.

Table 4. Effect of drought stress on biological yield (Kg ha^{-1}) of wheat.

Stress→ Varieties↓	Control	Pre-anthesis Drought	Post-anthesis Drought	Terminal Drought	Means
			Year 2002-03		
Rawal-87	8519.15 a	6908.06bcdef	6388.37 cdefg	5850.81 efg	6916.60 A
Inqalab-91	8309.85 ab	7132.86abcde	7717.48 abcd	4195.63 h	6838 96 A
Potohar-93	6983.35ab cdef	6328.67defg	7890.44 abc	5081.58 gh	6571.01 A
Chakwal-97	8473.19 a	5456.87 fgh	5361.30 gh	5641.02efgh	6233.09 A
Means	8071.39 A	6456.61 B	6839.40 B	5192.26 C	**6639.9***
			Year 2003-04		
Rawal-87	5967.89 a	3834.84 bc	4219.48 bc	3625.03 c	4411.81 AB
Inqalab-91	5793.05 a	4813.94 abc	4930.50 abc	4114.58 bc	4913.02 A
Potohar-93	4674.07 abc	3869.80 bc	3764.90 bc	3508.47 c	3954.31 B
Chakwal-97	5233.56 ab	3951.40 bc	4674.07 abc	3706.62 bc	4391.41 AB
Means	5417.14 A	4117.49 B	4397.24 B	3738.67 B	**4417.6***

Means followed by similar letters are not significant to each other at $P = 0.05$ by LSD.
*Significant at P=0.001(Year mean)

Biological yield (BY): Effect of drought stress on the biological yield of wheat cultivars showed very highly significant decrease during 2003-04 (4417.6 Kg.ha^{-1}) as compared to that (6639.9 Kg.ha^{-1}) during 2002-03 (Table 4). All cultivars showed non-significant difference in BY, although it ranged between 6916.6-6233.1 Kg.ha^{-1}, maximum for Rawal-87 and minimum for Chakwal-97 in 2002-03. In the next (2003-04) year, Inqalab-91 showed (4913.0 Kg.ha^{-1}) highest BY, followed non-significantly by Rawal-87 (4411.8 Kg.ha^{-1}) and Chakwal-97 (4391.4 Kg.ha^{-1}) and significantly followed only by Potohar-93 (3954.3 Kg.ha^{-1}) that was non-significant to other two cultivars. Terminal drought decreased BY maximum (5192.3 Kg.ha^{-1}) followed by pre- (6456.6 Kg.ha^{-1}) and post-anthesis drought (6839.4 Kg.ha^{-1}) as compared to control (8071.4 Kg.ha^{-1}) in 2002-03. In the next year, similar pattern was observed. Maximum decrease in BY was noted in terminal drought (3738.7 Kg.ha^{-1}), followed by pre- (4117.5 Kg.ha^{-1}) and post-anthesis drought (4397.2 Kg.ha^{-1}) as compared to control (5417.1 Kg.ha^{-1}) in 2003-04. The interactive effect of drought stress differentially appeared in the wheat varieties. Rawal-87 and Potohar-93, with a similar pattern, showed a decrease in BY under all types of stresses significantly as compared to control, although not significant to each other in 2002-03 (Table 4). Inqalab-91 showed significant decrease only in the terminal drought condition while pre- and post-anthesis drought did not change BY significantly, although, a decrease was observed as compared to that of control. In Potohar-93, post-anthesis drought increased BY significantly as compared to pre-anthesis and terminal drought and non-significantly to control in the year 2002-03. In 2003-04, both Potohar-93 and Chakwal-97 did not exhibit significant change in BY, although a decrease due to drought was observed under pre-, post-anthesis and terminal drought stresses. Rawal-87 responded a significant decrease in BY under all the stresses, although non-significant to each other in 2003-04. Similarly Inqalab-91 also showed the similar pattern which was followed by Rawal-87.

Our results confirmed the study of Hassan *et al*., (2003) that Inqalab-91 produced more grain yield, bhoosa yield and harvest index as compared to other varieties tested in rainfed conditions. Kumar & Choudhary (1991) evaluated different wheat cultivars on the basis of yield components including biological yield and recommended their suitability for different environments.

Table 5. Effect of drought stress on grain yield (Kg ha^{-1}) of wheat.

Stress→ Varieties↓	Control	Pre-anthesis Drought	Post-anthesis Drought	Terminal Drought	Means
			Year 2002-03		
Rawal-87	2686.78 a	1847.64cdef	1716.62 defg	1181.28 ghi	1858.08 A
Inqalab-91	2549.70 ab	2023.19bcde	2222.24 abcd	935.67 i	1932.70 A
Potohar-93	1625.70 efg	1333.33fghi	2058.48 bcde	842.10 i	1464.90 B
Chakwal-97	2280.54 abc	1064.04 hi	1501.75 efgh	1169.58 ghi	1503.98 B
Means	2285.68 A	1567.05 C	1874.77 B	1032.16 D	**1689.9***
			Year 2003-04		
Rawal-87	1870.31 ab	1232.98 cd	1161.97 cd	950.12 d	1303.85 BC
Inqalab-91	2071.60 a	1693.59 abc	1690.14 abc	1323.36 bcd	1694.67 A
Potohar-93	1252.11 cd	1043.08 d	961.62 d	845.07 d	1025.47 C
Chakwal-97	1922.54 a	1211.27 cd	1240.03 cd	1298.12 cd	1417.99 AB
Means	1779.14 A	1295.23 B	1263.44 B	1104.17 B	**1360.5***

Means followed by similar letters are not significant to each other at $P = 0.05$ by LSD.
*Significant at P=0.001 (Year mean)

Grain yield (GY): Very highly significant decrease in GY (1360.5 Kg.ha^{-1}) was observed in 2003-04 as compared to 1689.9 Kg.ha^{-1} in 2002-03 (Table 5). Inqalab-91 showed maximum GY (1932.7 Kg.ha^{-1}); followed non-significantly by Rawal-87 (1858.1) and significantly by Chakwal-97 (1504.0 Kg.ha^{-1}) and Potohar-93 (1464.9 Kg.ha^{-1}), although last two were non-significant to each other, during 2002-03. In the next year again, Inqalab-91 showed the highest GY (1694.7 Kg.ha^{-1}) non-significantly followed by Chakwal-97 (1418.0 Kg.ha^{-1}) and significantly followed by Rawal-87 (1303.9 Kg.ha^{-1}) and Potohar-93 (1025.5 Kg.ha^{-1}). Rawal-87 and Potohar-93 non-significantly differed in GY. Post-anthesis drought stress significantly decreased the GY (1874.8 Kg.ha^{-1}) as compared to control (2285.7 Kg.ha^{-1}), followed significantly by pre-anthesis (1567.1 Kg.ha^{-1}) and terminal drought (1032.2 Kg.ha^{-1}) in the year 2002-03. In the year 2003-04, all stresses decreased the GY significantly (1295.2, 1263.4 and 1104.2 Kg.ha^{-1}) as compared to control (1779.1 Kg.ha^{-1}) but those all were non-significant to each other. Rawal-87 exhibited the stress response maximum in terminal drought while other two stresses, although non-significant to each other, also decreased the GY significantly. Inqalab-91 also responded maximum under terminal drought stress by decreasing GY. Post-anthesis drought decreased GY of Inqalab-91 less than that of Pre-anthesis drought in 2002-03. Potohar-93 showed a non-significant increase in GY as compared to control. Pre-anthesis drought significantly and terminal drought non-significantly decreased the GY of Potohar-93 in 2002-03. Chakwal-97 showed a decreasing response under the stress conditions (Table 5). In the year 2003-04, Rawal-87 and Chakwal-97 showed a similar pattern that all the stresses decreased the GY significantly as compared to control but had non-significant difference in GY to each other. Inqalab-91 showed significant decrease in GY only in terminal drought stress and pre- and post-anthesis drought stress did not respond significantly, although a decrease in GY was observed. Potohar-93 did not respond significantly under all the stress conditions in the year 2003-04.

Grain yield is the ultimate objective of the agricultural activities of the world. The basic aim of all the research activities in agriculture and crop sciences is to increase the grain yield. Many recent reports are available in the literature regarding grain yield studies under drought condition in wheat (Khan *et al*., 2004; Zarea-Fizabady & Ghodsi, 2004; Hassan *et al*., 2003; Ashfaq *et al*., 2003; Khan *et al*., 2002; Shah *et al*., 2002). Our results were in accordance with the literature and confirmed the studies of aforesaid authors with regard to GY of the wheat under drought stress.

Table 6. Effect of drought stress on harvest index of wheat.

Stress→ Varieties↓	**Control**	**Pre-anthesis Drought**	**Post-anthesis Drought**	**Terminal Drought**	**Means**
			Year 2002-03		
Rawal-87	32.253 a	26.740 ab	25.567 abc	19.700 bc	26.065 A
Inqalab-91	24.337 abc	28.047 ab	28.800 ab	22.210 bc	25.848 A
Potohar-93	23.040 abc	20.487 bc	26.430 ab	16.507 c	21.616 A
Chakwal-97	26.770 ab	21.677 bc	31.840 a	20.673 bc	25.240 A
Means	26.600 A	24.237 AB	29.159 A	19.773 B	**24.692***
			Year 2003-04		
Rawal-87	32.123 abcd	28.507 abcd	28.460 abcd	26.290 bcd	28.845 BC
Inqalab-91	35.717 ab	35.283 ab	34.133 abc	31.970 abcd	34.276 A
Potohar-93	26.680 bcd	26.743 bcd	25.550 cd	24.200 d	25.793 C
Chakwal-97	36.967 a	30.893 abcd	26.467 bcd	34.963 abc	32.322 AB
Means	32.872 A	30.357 A	28.652 A	29.356 A	**30.309***

Means followed by similar letters are not significant to each other at $P = 0.05$ by LSD.
*Significant at P=0.001(Year mean)

Harvest index (HI): A very highly significant increase (30.3) in HI was observed in 2003-04 when compared to that (24.7) of the year 2002-03 (Table 6). All the varieties studied showed a non-significant difference in HI in 2002-03, although it ranged between 26.1-21.6% in a decreasing order from Rawal-87 – Chakwal-97 – Inqalab-91 to Potohar-93. In the next year highest HI (34.3) was of Inqalab-91, followed non-significantly by Chakwal-97 (32.3) and significantly by Rawal-87 (28.8) and Potohar-93 (25.8). The last both were non-significant to each other. Post-anthesis drought showed highest HI in 2002-03, non-significantly increased than control and pre-anthesis drought and significantly increased than post-anthesis drought stress (Table 6). Pre-anthesis stress showed increased HI than post-anthesis drought but non-significant to each other. In 2003-04, all the stress conditions responded non-significantly, although decreased HI were noted as compared to control. Rawal-87 exhibited less HI under pre- and post-anthesis drought stress, although non-significant, as compared to control and significantly decreased under terminal drought. All the other three varieties showed maximum HI under post-anthesis drought, even more than control. Pre-anthesis and terminal drought conditions decreased the HI in the year 2002-03 as compared to control (Table 6). In 2003-04, only Chakwal-97 responded under post-anthesis stress significantly where HI was decreased significantly as compared to control. Terminal and pre-anthesis drought although decreased the HI but non-significantly to control. All other three cultivars did not respond to any type of drought stress significantly, however the decrease in HI was observed under pre-, post-anthesis and terminal drought stresses as compared to control of respective cultivars except Potohar-93 which showed an increase in HI under pre-anthesis drought as compared to control in the year 2003-04 (Table 6).

To comprehend the better conversion of photosynthates into consumable portion of the plant product, it is necessary to estimate the HI of the yield of crop under study. The present study revealed that Inqalab-91 showed promising results and in agreement with the literature (Joshi *et al*., 2002; Giunta *et al*., 1999; Gent & Kiyomoto, 1998; Sharma & Bhargava, 1996; Kumar & Chowdhry, 1991).

Correlation: Grain yield is a product of an organized interplay of several factors, which are highly susceptible to environmental fluctuations. However, yield can be estimated on the basis of performance of yield components. Yield is a complex character dependent upon the interaction of environment and genetic make-up of the wheat plant. Apart from direct selection of grain yield, enhancement in most situations is more effectively fulfilled on the basis of performance of yield components, which are closely associated with grain yield. Wheat genotypes differ from each other in yield potential. The higher yield of wheat can be achieved identifying high yielding genotypes. The genetic make-up of a variety was tried to exploit in the water deficit conditions artificially imposed at different stages of growth in the wheat crop in this study. The performance of yield components attributable to grain yield was assessed and found that number of grains per spike (r = 0.627) and biological yield (r = 0.844) were positively and significantly correlated to the grain yield. These results were in accordance with Aruna & Raghaviah (1997), Singh & Singh (1999, 2001) and Giunta *et al*., (1999). Harvest index (r = 0.421) and thousand grains weight (r = 0.299) were also correlated positively. These results are in agreement with Giunta *et al*., (1999) and the later had non-significant correlation in agreement with Chowdhry *et al*., (2000). It was also found that number of spikelets per spike was negatively and non-significantly correlated (r = -0.296) with the grain yield of wheat under drought stress conditions imposed during this study. Present study revealed that grain yield of wheat crop under water deficit conditions can be improved by selecting the genotypes having more number of grains per spike and biological yield among the yield components which were analyzed.

Yield stability: Yield of a crop can be defined as the amount of edible harvest per unit of land (Cleveland, 2001). The rationale for plant breeders to increase the yield in sustainable agriculture can be achieved by attempting to enhance yield in:

a- Environments that have been optimal and high yielding, but where stress on plant production is increasing as inputs are being reduced to reduce production costs and negative environmental impacts and

b- Environments that are marginal and low-yielding, those of many of the world's farmers who have not adopted modern-crop-varieties, but whose farmer-crop-varieties often have inadequate yields.

As a goal of plant breeding, the stability of yield is often considered to be of equally important to yield itself. Yield stability is a measure of a crop variety under different environments in comparison to other varieties. It is a special case of genotype-by-environment interaction (G x E), defined as the degree to which different genotypes behave consistently across different environments. The two most important factors affecting G x E for yield of a crop variety (and thus its yield stability), are the degree of similarity between the environment where it is selected or tested and the environment where it will be grown and the level of genetic diversity of the variety.

A number of statistics have been proposed to measure genotypic stability. Several of these have been summarized and compared by Lin *et al*., (1986). All of these statistical analyses can be computed using the observed means in a two-way genotype x environment table.

In most breeding programmes the breeder is interested in a particular set of genotypes and in how they perform over a more or less limited range of environments. From the selections under test he is interested in those which have a high yield and which are relatively stable over the environments tested. For this purpose he should look for a high mean, $y_{i.,}$ a relatively low ecovalence, W_i^2, (low contribution to the genotype x environment interaction) and a slope, b_i, of a linear regression on the environmental index which is close to 1.

Table 7. Stability parameters analysis for yield and its components under drought stress conditions of wheat varieties.

Parameters	**μ**		**b_i**		**δ_i^2**		**R_i^2**	
Years	**2002-3**	**2003-4**	**2002-3**	**2003-4**	**2002-3**	**2003-4**	**2002-3**	**2003-4**
Number of spikelets per spike								
Rawal-87	14.83	17.58	0.671	1.659	0.217	0.126	0.218	0.811
Inqalab-91	13.25	15.30	1.315	0.971	0.031	0.485	0.883	0.277
Potohar-93	14.33	17.21	0.310	0.675	0.098	0.362	0.116	0.198
Chakwal-97	15.50	18.18	1.703	0.695	0.110	0.240	0.781	0.284
Number of grains per spike								
Rawal-87	44.26	40.86	1.230	2.662	4.621	0.472	0.642	0.986
Inqalab-91	47.73	42.89	0.798	1.508	1.825	1.684	0.656	0.867
Potohar-93	38.54	38.17	1.640	0.401	0.371	0.433	0.975	0.642
Chakwal-97	44.15	45.35	0.333	-0.572	4.607	2.900	0.116	0.352
Thousand grain weight (g)								
Rawal-87	23.66	30.22	0.679	1.807	2.918	0.650	0.444	0.956
Inqalab-91	28.80	33.54	1.224	0.186	1.457	0.852	0.839	0.150
Potohar-93	20.12	25.01	1.313	0.160	5.119	3.090	0.630	0.035
Chakwal-97	22.06	27.53	0.783	0.269	0.383	1.449	0.890	0.179
Grain yield (Kg ha^{-1})								
Rawal-87	1858.8	1303.8	1.092	1.360	83314	226	0.857	0.999
Inqalab-91	1932.7	1694.7	1.274	0.995	54699	13818	0.925	0.901
Potohar-93	1464.9	1025.5	0.754	0.574	153540	2196	0.608	0.950
Chakwal-97	1504.0	1417.9	0.880	1.071	130345	25636	0.713	0.851

μ: Varietal Mean
b_i: Regression Coefficient (Slope)
δ_i^2: Deviation from Regression
R_i^2: Coefficient of Determination

Ahmad *et al*., (1996) studied G x E interaction and relative stability for grain yield of wheat varieties for 5 different locations and found 2 out of 6 varieties to be most stable and adaptable genotypes being high yielding with unit regression and non-significant non-linear deviation from regression. Sial *et al*., (2000) studied stability for yield performance and G x E interaction in 12 wheat genotypes grown at 13 contrasting sites over two years. The adaptability was analyzed by using the estimates of regression coefficient, deviation from regression coefficients and mean grain yield for each genotype over all the environments. To study the varietal dynamics of yield stability in wheat, Kakar *et al*., (2003) used the mean yield, regression slope, correlation coefficient and coefficient of determination in an experiment carried on 10 genotypes at 3 locations. Asif *et al*., (2003) analyzed the wheat genotypes for yield stability in rainfed environments to be the best choice by using the parameters as high mean yield over the environment, unit regression coefficient (b= 1.00) and the smallest deviation from regression ($S^2d^- = 0$). Interrelationships between yield and its components for wheat were determined by correlation and path coefficient analysis in a study to determine the association of morphological traits with grain yield (Ashfaq *et al*., 2003).

The stability parameters analysis for the yield and some of the selected yield components was performed in the present study (Table 7). The regression coefficients (b_i) calculated for both of the years separately under study, ranged between 0.310-1.703 in number of spikelets per spike, 0.333-2.662 in number of grains per spike, 0.160-1.807 in thousand grains weight and 0.574-1.360 in grain yield. Similarly the mean yield (μ) for number of spikelets per spike ranged 13.25-18.18, for number grains per spike 38.17-45.35, for thousand grains weight 20.12-30.22 g and for grain yield 1025.5-1932.7 $Kg.ha^{-1}$. According to Finlay & Wilkinson (1963), a variety with highest yield mean (μ) and unit regression over the environments ($b_i = 1.00$) would be stable in all the environments. The present study revealed that on the basis of number of spikelets per spike Chakwal-97 had highest mean during both (2002-03 and 2003-04 years but regression coefficient closest to one was for Inqalab-91. On the basis of number of grains per spike Inqalab-91 remained most stable for the year 2002-03 and Chakwal-97 remained for 2003-04. Inqalab-91 also looked stable for both of the year on the basis of thousand grains weight. Similarly, on the basis of the major parameter for stability test, the grain yield, Inqalab-91 with highest mean during both years and with closest unit regression in one of the years (2003-04) looked to be the most stable genotype. The unit regression for the year 2002-03 ranked at second position in grain yield.

The other parameter for the stability test proposed by Eberhardt & Russell (1966), deviation from regression (δ_i^2) was also assessed (Table 7). This parameter ranged 0.031-0.485 for number of spikelets per spike during both of the year, 0.371-4.621 for number of grains per spike, 0.383-5.119 for thousand grains weight and 226-153540 for grain yield. Deviation from regression as small as possible is the measure of genotypic stability over a set of environments. The values, although smallest was not for Inqalab-91, exhibited in the table were not with a definite pattern. Even then Inqalab-91 with highest mean in yield and its components looked to be the stable in drought stress environments according to this parameter having smaller values.

The coefficient of determination (R_i^2) discussed by Petersen (1989) as one of the stability parameters was assessed in this study (Table 7). It measures the proportion of the variation in the mean yield or a genotype which is accounted for by the fitted model or it is the percent of variation that can be explained by the regression equation or in other words it is the explained variation divided by the total variation. According to this parameter of stability Inqalab-91 with almost 90 % of determination of coefficient in all the yield components looked to be the best, although other varieties had some more R_i^2 than that of Inqalab-91in some of the yield components.

References

Ahmad, M. and M.A. Arain. 1999**.** Effect of drought simulation on grain weight, protein and lysine content of bread wheat (*Triticum aestivum* L.). *Pak. J. Bot.,* 31: 109-114.

Ahmad, J., M.H. Chaudry, S. Salah-ud-din and M.A. Ali. 1996**.** Stability for grain yield in wheat. *Pak. J. Bot.,* 28: 61-65.

Aruna, C. and P. Raghavaiah. 1997**.** Correlation and path analysis of yield and quality in aestivum wheat (*Triticum aestivum* L.). *J. Res.,* 25: 21-25.

Arzani A. 2002**.** Grain quality of durum wheat germplasm as affected by heat and drought stress at grain filling period. *Wheat Inf. Serv.,* 94: 9-13.

Ashfaq, M., A.S. Khan and Z. Ali. 2003**.** Association of morphological traits with grain yield in wheat (*Triticum aestivum* L.). *Int. J. Agric. Biol.,* 5: 264-267.

Asif, M., M. Asim, M.Y. Mujahid, S.Z. Mustafa, N.S. Kisana, Z. Ahmad, I. Ahmad and M. Sohail. 2003. Analysis of wheat genotypes for yield stability in rainfed environments. *Pak. J. Biol.l Sci.,* 6: 1509-1511.

Borlaug, N.E. and C.R. Dowswell. 1997**.** The acid lands: One of agriculture's last frontiers. In: *Plant-Soil Interactions at Low pH.* (Eds): Moniz *et al*., *Brazilian Soil Science Society* Brazil. pp. 5-15.

Chowdhry, M.A., M.T. Mahmood, N. Mahmood and I. Khaliq. 1996**.** Genetic analysis of some drought and yield related characters in Pakistani spring wheat varieties. *Wheat Inf. Serv.,* 82: 11-18.

Chowdhry, M.A., M. Ali, G.M. Subhani and I. Khaliq. 2000**.** Path coefficient analysis for water use efficiency, evapo-transpiration efficiency and some yield related traits in wheat. *Pak. J. Biol. Sci.,* 3: 313-317.

Cleveland, D.A. 2001. Is plant breeding science objective truth or social construction? The case of yield stability. *Agric. Hum. Values,* 18: 251-270.

Dencic, S., R. Kastori, B. Kobiljski and B. Duggan. 2000**.** Evaluation of grain yield and its components in wheat cultivars and landraces under near optimal and drought conditions. *Euphytica,* 113: 43-52.

Duwayri, M. and M.M. Nachit. 1989. Utilization of durum wheat (*Triticum turgidum* L. var. durum) landraces to improve yield and yield stability in dry areas. *Wheat Inf. Serv.,* 69: 5-8.

Eberhardt, S.A. and W.A. Russell. 1966. Stability parameters for comparing varieties. *Crop Sci.,* 6: 36-40.

Ehdaie, B. and J.G. Waines. 1996. Dwarfing genes, water-use efficiency and agronomic performance of spring wheat. *Can. J. Plant Sci.,* 76: 707-714.

Finlay, K.W. and G.N. Wilkinson. 1963**.** The analysis of adaptation in a plant breeding programme. *J. Agric. Res.,* 14: 742-754.

Gent, M.P.N. and R.K. Kiyomoto. 1998. Physiological and agronomic consequences of Rht genes in wheat. *J. Crop Prod.,* 1: 27-46.

Giunta, F., R. Motzo and M. Deidda. 1999**.** Grain yield analysis of a triticale (x *Triticosecale* Wittmack) collection grown in a Mediterranean environment. *Field Crops Res.,* 63:199-210.

Golmirzaie, A.M., J.W. Schmidt and A.F. Dreier. 1990**.** Components of variance and stability parameters in studies of cultivar x environment interactions in wheat (*Triticum aestivum* L.). *Cereal Res. Cumm.,* 18: 249-256.

Guttieri, M.J., J.C. Stark, K. O'Brienand E. Souza. 2001. Relative sensitivity of spring wheat grain yield and quality parameters to moisture deficit. *Crop Sci.,* 41: 327- 335.

Hassan, M., Wasiullah, J. Iqbal and M. Ilyas. 2003**.** Evaluation of wheat under the agro-climatic condition of Barani Agricultural Research Station, Kohat. *Pak. J. Agron.,* 2: 8-12.

Inamullah, Z.A. Swati, A. Latif and Sirajuddin. 1999. Evaluation of lines for drought tolerance in wheat (*Triticum aestivum* L.). *Sci. Khyber,* 12: 39-48.

Joshi, S.K., S.N. Sharma, D.L. Singhania and R.S. Sain. 2002. Genetic analysis of quantitative and quality traits under varying environmental conditions in bread wheat. *Wheat Inf. Serv.,* 95: 5-10.

Kakar, K.M., Sanaullah, Z. Kakar and M.I. Shawani. 2003. Varietal dynamics of yield stability in wheat. *OnLine J. Biol. Sci.,* 3: 137-140.

Kaya, Y., C. Palta and S. Taner. 2002. Additive main effects and multiplicative interaction analysis of yield performances in bread wheat genotypes across environments. *Tur. J. Agric. For.,* 26: 275-279.

Khan, A.S., I. Salim and Z. Ali. 2003. Heritability of various morphological traits in wheat. *Int. J. Agric. Biol.,* 5: 138-140.

Khan, M.F., A.H. Shahand and M. Hussain. 2002. Studies on some hexaploid wheat varieties (*Triticum aestivum* L.) under the agro-ecological conditions of district Poonch, Azad Kashmir. *Pak. J. Agron.,* 1: 110-111.

Khan, N., M. Qasim, S. Ali and N.S. Kisana. 2004. Genotypic variation in wheat genotypes under agro-climatic condition of Kaghan Valley. *Asian J. Plant Sci.,* 3: 569-570.

Kinyua, M.G. 1992. Genotype x environment effects on wheat grown over multiple locations and years in Kenya. *In*: 7th Regional Wheat Workshop for Eastern, Central and Southern Africa. Nakuru, Kenya. ISBN 968-6127-62-3:103-107.

Kumar, A. and R.K. Chowdhury. 1991. Stability parameters of grain yield and its components in durum wheat. *Wheat Inf. Serv.,* 72: 35-41.

Lin, C.S., M.R. Binns and L.P. Lefkovitch. 1986. Stability analysis: Where do we stand? *Crop Sci.,* 26: 894-900.

Mujtaba, S.M. and S.M. Alam. 2002. Drought phenomenon and crop growth. http://www.Pakistaneconomist. com/issue2002/issue13/i&e4.htm

Paroda, R.S. and J.D. Hayes. 1971. Investigation of genotype environment interaction for rate of ear emergence in spring barley. *Heredity,* 26: 157-176.

Perkins, J.M. and J.L. Jinks. 1968. Environmental and genotype-environmental components of variability. *Heredity,* 23: 339-359.

Petersen, R.G. 1989. *Special Topics in Biometry*. Pakistan Agric. Res. Council, Islamabad. 68 pp.

Pinstrup-Andersen, P., R. Pandya-Lorch and M.W. Rosegrant. 1999. *World food prospects: Critical issues for the early twenty-first century*. 2020 Vision Food Policy Report. IFPRI, Washington, DC 32 pp.

Qari, M.S., N.I. Khan and M.A. Bajwa. 1990. Comparison of wheat cultivars for stability in yield performance. *Pak. J. Agric. Res.,* 11: 73-77.

Sakin, M.A., A. Yildrim and S. Gokmen. 2005. Determining some yield and quality characteristics of mutants induced from a durum wheat (*Triticum durum* Desf.) cultivar. *Turk. J. Agric. For.,* 29: 61-67.

Shah, W.A., J. Bakht, M. Shafi and M.A. Khan. 2002. Yield and yield component of different cultivars of wheat, barley and oat under rainfed conditions. *Asian J. Plant Sci.,* 1: 148-150.

Sharma, H.P. and S.C. Bhargava. 1996. Relative sensitivity of wheat genotypes under moisture stress conditions. *Ann. Biol.,* 12: 39-42.

Sial, M.A., M.A. Arain and M. Ahmad. 2000. Genotype environment interaction on bread wheat grown over multiple sites and years in Pakistan. *Pak. J. Bot.,* 32: 85-91.

Siddique, M.R.B., A. Hamid and M.S. Islam. 1999. Drought stress effects on photosynthetic rate and leaf gas exchange of wheat. *Bot. Bull Acad. Sin.,* 40: 141-145.

Siddique, M.R.B., A. Hamid and M.S. Islam. 2000. Drought stress effects on water relation of wheat. *Bot. Bull. Acad. Sin.,* 41: 35-39.

Simane, B., P.C. Struik, M.M. Nachit and J.M. Peacock. 1993. Ontogenetic analysis of yield components and yield stability of durum wheat in water-limited environments. *Euphytica,* 17: 211-219.

Singh, K.H. and T.B. Singh. 1999. Character association regarding generations of bread wheat. *Agric. Sci. Digest (Karnal),* 19: 207-210.

Singh, S.B. and T.B. Singh. 2001. Correlation and path analysis in common wheat (*Triticum aestivum* L.) under light texture soil. G.B.P.U.A. and T. Res. Station, Ujhani-243 (UP), India. *Res. Crops,* 2: 99-101.

Singh, K.N. and R. Chatrath. 1995. Genotype x environmental interactions in some Indian rainfed varieties of bread wheat under salt stress conditions. *Wheat Inf. Serv.,* 80: 6-11.

Steel, R.G.D., J.H. Torrie and D.A. Dickey. 1997. Principles and Procedures of Statistics. 3rd ed. McGraw Hill, New York.

Swati, M.S., H. Rahman and J. Afsar. 1985. Response of wheat (*Triticum aestivum* L.) cultivars to different levels of water stress. *Sarhad J. Agric.,* 1: 295-304.

Trethowan, R.M. 2000. Breeding wheat for marginal environments. www.cimmyt.org/research/wheat/map/research_results/reshighlights/pdfs/resHigh_BreedWht.pdf

Viana, J.M.S. and C.D. Cruz. 2002**.** Analysis of stability and adaptability through different models of linear regression. *Cienc Agrotec Lavras,* 26: 455-462.

Yan, W. and L.A. Hunt. 2001. Interpretation of genotype x environment interaction for winter wheat yield in Ontario. *Crop Sci.,* 41: 19-25.

Yates, F. and W.G. Cochran. 1938. The analysis of groups of experiments. *J. Agric. Sci.,* 28: 556-580.

Zarea-Fizabady, A. and M. Ghodsi. 2004. Evaluation of yield and yield components of facultative and winter bread wheat genotypes (*Triticum aestivum* L.) under irrigation regimes in Khorasan province. *Iranian J. Agron.,* 3: 184-187.

(Received for publication 20 July 2007)