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PLANTING TIME EFFECT ON WHEAT PHENOLOGY AND YIELD TRAITS THROUGH GENOTYPE BY ENVIRONMENT INTERACTION

H. A. Haq[1], N.U. Khan[2*], H. Rahman[2], A. Latif[3], Z. Bibi[4], S. Gul[2], H. Raza[5], K. Ullah[6], S. Muhammad[1] and S. Shah[7]

[1]PCCC Central Cotton Research Institute, Multan – Pakistan; [2]Department of Plant Breeding and Genetics, The University of Agriculture, Peshawar – Pakistan; [3]Agricultural Research System, Khyber Pakhtunkhwa - Pakistan [4]Institute of Soil Science, Chinese Academy of Sciences (CAS), Nanjing – China; [5]Department of Agriculture, University of Swabi, Swabi – Pakistan; [6]PCCC Cotton Research Station, Dera Ismail Khan, Pakistan [7]Department of Food Science and Technology, The University of Agriculture Peshawar - Pakistan
[*]Corresponding author's Email: Naqib Ullah Khan <nukmarwat@yahoo.com>

ABSTRACT

Planting time effect on genetic potential of wheat advanced lines for earliness and yield traits was studied through genotype-by-environment and heritability during 2012–2013 at The University of Agriculture, Peshawar, Pakistan. The breeding material comprising fifteen wheat genotypes including 12 advanced lines and three check cultivars. All the genotypes were grown under normal and late planting conditions in a randomized complete block design with three replications. According to analysis of variance, genotypes revealed significant ($p \leq 0.01$) differences for all the traits except days to maturity. For environments, highly significant differences were observed for majority of the traits; however, flag leaf area and 1000-grain weight were non-significant. Genotype × environment interactions were highly significant for days to heading, grains per spike and grain weight per spike while for grain yield it was merely significant ($p \leq 0.05$). Significance of wheat genotypes, environments and genotype by environment interaction authenticated that differences might be due to diverse genetic makeup of the genotypes and their interaction with environments. According to genetic variability, yield traits revealed low to high heritability (0.14 to 0.64) which provides reliability and more chances to the genotypes to be recognized by expression of their phenotypes and effective selection. On average, the grain yield of the genotypes was reduced by 20.14% due to late planting. Overall, genotype DIK-2 was found superior followed by lines DIK-1, NIFA-1 and NIFA-5 under normal planting. However, lines NIFA-1 and PS/CCRI-2 were the best performers with late planting. These lines could be further utilized for commercial cultivation as well as in future breeding programs to evolve new cultivars with good yield potential.

Key words: Genotype × environment interaction (GEI), heritability, normal and late planting environments, earliness and yield traits, *Triticum aestivum* L.

INTRODUCTION

Wheat, being a winter cereal, requires specific environmental conditions for better emergence, growth and flowering and is more vulnerable if exposed to high temperatures during reproductive stages (Kalra *et al*., 2008). Among various factors responsible for low yield of wheat, sowing time and genotype potential are of primary importance (Tahir *et al*., 2009). Each single day delay in sowing from 20th November decreases the grain yield (40 kg ha^{-1} day^{-1}), while in wheat; too early sowing produces weak plants with poor root system as the temperature is above optimum. Late planting results in poor tillering; however, wheat cultivars of short duration may escape from high temperature at the grain filling stage (Qasim *et al*., 2008).

Genotype has individual's genetic make-up and its phenotypic expression depends on environments in which it grown. Genotypes, when grown under a wide range of environmental conditions (exposed to different soil types, fertility levels, moisture contents, temperatures, photoperiods, biotic and abiotic stresses and cultural practices) also function differently for various agronomic variables. Genotypes and some environmental features are controllable; however, other factors of natural environment such as day length and sunshine, rainfall, and some soil properties are generally fixed and difficult to modify (Gul *et al*., 2014). The effect of the uncontrollable factors on crop performance is as important as that of controllable factors. In crop research, the most commonly used way to evaluate the effects of the uncontrollable environmental factors on crop response is to repeat the experiments at several sites or several crop seasons or both (Gul *et al*., 2016).

Genotype expression over diverse environments is known as genotype by environment interaction (GEI) and it's vital for estimation of crop genotypes because it decrease the genotypic firmness values under different environments (Qasim *et al*., 2008). The capability of a genotype is specified by three factors, i.e., genotypic main effects (G), environmental main effects (E) and their interaction (Yan *et al*., 2007). The need for the established genotypes that properly respond over a wide range of environments becomes crucial as farmer require the consistent production quantity (Gauch *et al*., 2008). Therefore, determination of established genotypes is a significant and crucial objective in wheat breeding scheme. The knowledge of G × E interaction is important to exactly find out the stability of genotypes and increase the competence of selection in breeding programs (Sabaghnia *et al*., 2008). The configuration of GEI is a significant feature for both plant breeding schemes and introduction of superior wheat genotypes as yield durability analysis (Neacşu, 2011).

Heritability, mostly used for the division of overall variation into genotypic and phenotypic variances, has inevitable function in breeding. It gives an approximation of genetic advance that resulting from selection applied to a population in different environments. The highest the heritability estimates, the simpler the selection procedure (Khan *et al*., 2008). The amount and degree of genetic inheritance is essential for the calculation of selection-response in different environments and it gives the basis for development and evaluation of genotypes (Ahmed *et al*., 2007). Heritability leads the breeders to predict the genes-interaction in subsequent generations and hence give a fundamental element of selection-response for successful breeding program. Keeping this in view, the present study was therefore, designed to determine the effect of normal and late planting conditions on a) earliness and yield traits of wheat advanced lines in comparison with three check cultivars and b) to recognize the heritable characters which can be utilized as selection markers under normal and late planting environments.

MATERIALS AND METHODS

Plant material and procedure: The experimental material comprising 15 wheat genotypes including 12 advance lines (PS/CCRI-1, PS/CCRI-2, PS/CCRI-3, PS/CCRI-4, PS/CCRI-5, NIFA-1, NIFA-2, NIFA-3, NIFA-4, NIFA-5, DIK-1 and DIK-2) and three check cultivars i.e., Janbaz (local check cultivar), Batoor-08 (commercial check cultivar and recommended/used for normal planting) and Khyber-87 (commercial check cultivar and recommended/used for late planting) were also included in the experiment for comparison. The said genotypes were procured from various Agricultural Research Institutes of Khyber Pakhtunkhwa, Pakistan (Table 1).

All the genotypes were grown with normal (12 November) and late (12 December) planting conditions during crop season 2012–2013 at The University of Agriculture, Peshawar, Pakistan. The experiment was laid out in a randomized complete block design with three replications. Each genotype was planted in six rows with five meters length, and 30 cm row to row spacing. The recommended cultural practices were uniformly applied to all the genotypes. Data were recorded on ten randomly selected plants for earliness and yield related traits, i.e., days to heading, days to maturity, plant height (cm), flag leaf area (cm^2), spike length (cm), spikelets per spike, grains per spike, grain weight per spike (g), 1000-grain weight (g) and grain yield (kg ha^{-1}).

Data analysis: Data for all the variables were subjected to genotype by environment (G × E) interaction analysis according to Gomez and Gomez (1984). Significant variations among genotypes, environments and genotype × environment interaction for various traits were compared by using the least significant difference (LSD) test at 5% level of probability (Hayter, 1986). Heritability (broad sense) was calculated following Panse and Sukhatme (1965).

RESULTS AND DISCUSSION

Analysis of variance of physiological and yield traits: According to analysis of variance, the genotypes showed significant differences for all the traits except days to maturity and grain weight per spike which were found non-significant (Table 2). The environments were also highly significant most of the traits, while significant ($p \leq 0.05$) for grain yield and non-significant for 1000-grain weight. Genotype by environment interactions (GEI) were highly significant for days to heading, grains per spike and grain weight per spike and significant for grain yield. However, days to maturity, plant height, flag leaf area, spike length, spikelets per spike and 1000-grain weight revealed non-significant mean values for G × E interactions. Mean squares indicated the presences of variability among wheat advanced lines due to their diverse genetic makeup as well as the environments in which these lines were grown. The extent of G × E interaction arises when genotypes performed differently across different environments. In past studies, the genotypes and environments (planting times) revealed significant differences for various earliness and yield traits which might be due to high temperatures during reproductive stages (Kalra *et al*., 2008). In present study, the significance of genotypes, environments and genotype by environment interactions, authenticated that differences might be due to varied genetic makeup of the genotypes and their interaction with environments. The results of the studied variables are presented and discussed herein.

Days to heading: For days to heading, the genotype mean values ranged from 110.00 to 116.00 days, while for genotype × environment interaction means the said range was 101.33 to 125.33 days (Table 4). In genotype means, the lines DIK-1, NIFA-1 and NIFA-4 took minimum and alike days to heading ranging from 110.00 to 110.33 days. However, these three genotypes were alike with three other genotypes (NIFA-5, Janbaz and PS/CCRI-1) ranging from 110.83 to 111.33 days. Maximum and equal days to heading were taken by three lines PSCCRI-4 (116.00 days), NIFA-2 (115.83 days) and PS/CCRI-5 (115.33 days) and these lines were found similar in performance with line DIK-2 (114.83 days). The remaining genotypes showed medium days to heading. In environment means, the lines showed minimum days to heading (104.14 days) with late planting than normal planting (121.12 days). In G × E interaction means, minimum and equal days to heading were taken by cultivar Khyber-87 (101.33 days), DIK-1 (102.00 days) and NIFA-4 (102.00 days) under late planting; however, these genotypes were found equal with three other lines, i.e., NIFA-1 (102.33 days), NIFA-5 (102.33 days) and PS/CCRI-1 (103.00 days). Maximum days to heading were recorded in line PS/CCRI-4 (125.33 days), and it was found at par with three other lines, i.e., PS/CCRI-5, DIK-2 and NIFA-2 ranging from 124.00 to 124.67 days with normal planting. All other G × E interactions showed medium days to heading.

Overall, the line DIK-1 followed by lines NIFA-1 and NIFA-4 showed minimum days to heading in genotypes and genotype × environment interaction means. Decline caused by late planting for days to heading was 14.02% (Table 3). For days to heading, the heritability in broad sense was moderate (0.57) (Table 3). Present results were in confirmation with findings of Khan *et al*. (2007) as they observed highly significant differences among wheat genotypes, environments and genotype × environment interaction for days to heading under different planting conditions. In present studies, late planting caused reduction for days to heading, and Hamam *et al*. (2009) also mentioned that wheat genotypes with late planting took minimum days to heading in stability studies of wheat. For a particular trait, the efficiency of selection highly depends on the genetic and environmental factors that affecting phenotypic differences among genotypes. Heritability thus is a significant factor for selection of efficient lines from a mixed wheat population (Khan and Naqvi, 2011). In this study, moderate broad sense heritability was observed for said trait which confirms the past findings in wheat lines (Ilyas *et al*., 2013).

Days to maturity: Genotype means were found to be non-significant for days to maturity; however, numerically the genotypes means were ranging from 149.67 to 152.00 days (Table 5). Although the G × E interaction means were also non-significant; however, these interactions were ranging from 139.33 to 163.00 days. In genotypes, the lines PS/CCRI-1 and NIFA-4 revealed minimum and equal days to maturity (149.67 days) followed by lines NIFA-1 (150.00 days), NIFA-2 (150.33 days) and NIFA-3 (150.53 days). Maximum days to maturity (152.00 days) were taken by line PSCCRI-5 followed by cultivar Khyber-87 (151.67 days). In environments, during late planting the genotypes revealed minimum days to maturity (140.41 days) than normal planting (161.17 days). In G × E interaction values, on average the line PS/CCRI-1 took minimum days to maturity (139.33 days) with late planting followed by two other lines, i.e., NIFA-4 and DIK-1 with same days to maturity (139.67 days) with late planting. Maximum days to maturity were taken by line PS/CCRI-5 (163.00 days) followed by cultivar Batoor-08 (162.67 days) and NIFA-5 (162.33 days) under normal planting. The remaining interactions revealed medium values for days to maturity.

On average, in genotypes and genotype × environment interaction means, the lines NIFA-4 and PS/CCRI-1 took minimum days to maturity. Late planting caused 12.88% decline and reduction for days to maturity (Table 3). For days to maturity, the heritability in broad sense was very low (0.14) (Table 3). In present study, the non-significant differences among the wheat lines for days to maturity endorsed the past findings in durum wheat germplasm (Tsegaye *et al*., 2012). However, contradictory findings with highly significant G × E interactions for days to maturity were reported in other wheat studies (Khan *et al*., 2007). Heritability estimates varied from genotype to genotype and environment to environment in study of wheat genotypes under different environments (Badole *et al*., 2010). In present study, the reason behind the non-significant G × E interactions might be due heat and terminal drought stress during wheat maturity.

Plant height: For plant height, genotype means ranged from 91.25 to 105.53 cm while G × E interactions were ranging from 84.53 to 113.70 cm (Table 6). In genotype mean values, the line NIFA-1 exhibited minimum plant height (91.25 cm) and it was found same with two other lines, i.e., PS/CCRI-1 (93.43 cm) and DIK-2 (94.23 cm). Maximum and equal plant height was produced by lines DIK-1 (105.53 cm) and PS/CCRI-2 (105.47 cm). In environment means, the lines showed minimum plant height (91.79 cm) in late planting than normal planting (104.72 cm). Genotype × environment interactions were non-significant; however, numerically the line NIFA-1 (84.53 cm) followed by lines DIK-2 (85.63 cm) and NIFA-5 (86.23 cm) revealed minimum plant height during late planting (Table 6). Maximum plant height (113.70 cm) with normal planting was produced by line PS/CCRI-2 followed by DIK-1 (111.87 cm). All other G × E interactions described medium plant height.

Overall, the genotypes NIFA-1, PS/CCRI-1 and DIK-2 exhibited minimum plant height in genotypes and G × E interaction means. For plant height, 12.30% decline was observed due to late planting (Table 3). High broad sense heritability (0.60) was recorded for plant height (Table 2). Present results were in corroboration with findings of Tahir *et al*. (2009) and reported significant differences among wheat genotypes while non-significant G × E interactions for plant height under different planting times. Late planting produced reduction in plant height because the vegetative stage squeezed and the required height was not fully attained by the plant. Present results revealed high heritability for the plant height which validates the findings of Badole *et al*. (2010) as they also observed highest heritability for wheat plant stature. However, our fallout was in contradiction with past findings of Aycicek and Yildirim (2006) as they investigated low heritability for plant height in wheat genotypes.

Flag leaf area: Among the genotypes, flag leaf area mean values varied from 27.72 to 42.23 cm^2 while in genotype × environment interactions, the mean values were ranging from 25.65 to 45.01 cm^2 (Table 7). The line NIFA-5 (42.23 cm^2) determined maximum flag leaf area and it was found alike with four other lines, i.e., NIFA-4, PS/CCRI-2, PS/CCRI-4 and PS/CCRI-1 ranging from 37.37 to 40.12 cm^2. Minimum flag leaf area was recorded for line NIFA-1 (27.72 cm^2) and it was found similar in performance with two other genotypes, i.e., Janbaz (31.30 cm^2) and PS/CCCRI-5 (32.24 cm^2). Environment means were found to be non-significant; however, on average the lines exhibited maximum flag leaf area (36.98 cm^2) in normal planting than late planting (33.22 cm^2). The G × E interactions were non-significant; however, on average maximum flag leaf area was exhibited by line NIFA-5 (45.01 cm^2) followed by NIFA-4 (42.91 cm^2) and PS/CCRI-4 (40.12 cm^2) under normal planting. Minimum leaf area was manifested by line NIFA-1 (25.65 cm^2) followed by PSCCRI-5 (26.83 cm^2) and cultivar Janbaz (28.54 cm^2) under late planting. All other G × E interactions showed medium values for flag leaf area.

Overall, the lines NIFA-5 and NIFA-4 showed maximum flag leaf area in genotypes and G × E interaction means. A total of 10.17% decline was observed for flag leaf area by late planting (Table 3). Late planting results in poor crop growth due to low temperature (Qasim *et al*., 2008). Flag leaf area plays an important role in proper filling of grain and its development. Flag leaf area has direct impact on grain yield because it manages photosynthesis and has a major contribution in spike yield and eventually grain yield. Heritability in broad sense was estimated to be low (0.33) for flag leaf area (Table 3). Moderate heritability for flag leaf area validating the findings of Ilyas *et al*. (2013) who reported same heritability (0.31) in wheat genotypes; however, moderate to low heritability makes difficult the effective and proper early selection. Present study revealed significant differences among genotypes for flag leaf area. According to Hamam *et al*. (2009), significant varied mean values were observed for flag leaf area in wheat genotypes under different environments. The G × E interactions were non-significant in this study which validates the findings of Khan and Naqvi (2011) as they reported non-significant G × E interaction over different environments in wheat cultivars. Flag leaf area could be used as a trait for selecting best performing genotypes in the absence of G × E interactions.

Spike length: Genotypes mean values for spike length varied from 10.25 to 12.47 cm, while in G × E interactions the said range was 9.70 to 13.27 cm (Table 8). In genotype means, maximum spike length was observed for line PS/CCRI-2 (12.47 cm) followed by four other lines, i.e., NIFA-2, NIFA-5, PS/CCRI-5 and DIK-1 ranging from 11.54 to 11.65 cm. However, these lines were found alike with two other lines, i.e., NIFA-4 (11.18 cm) and NIFA-3 (11.15 cm). Minimum spike length was revealed by line NIFA-1 (10.25 cm) and it was found at par with five other genotypes, i.e., Batoor-08, PS/CCRI-4, Janbaz, PS/CCRI-3 and DIK-2 ranging from 10.46 to 10.78 cm. In environment means, on average the genotypes showed maximum spike length of 11.68 cm with normal planting than late planting (10.52 cm). Although G × E interaction means were non-significant; however, on average the line PS/CCRI-2 (13.27 cm) showed maximum spike length followed by lines NIFA-5 (12.43 cm) and PS/CCRI-5 (12.22 cm) with normal planting (Table 8). Minimum spike length was determined by line NIFA-1 (9.70 cm) followed by Janbaz (9.83 cm), Khyber-87 (10.00 cm) and DIK-2 (10.02 cm) under late planting. The remaining G × E interaction mean values with normal and late planting conditions revealed medium values for spike length.

On average, in genotypes and G × E interactions, the line PS/CCRI-2 manifested maximum spike length. For spike length, the estimated broad sense heritability was high (0.50); however, reduction of 9.93% was observed in spike length due to late planting (Table 3). High heritability was also observed in past studies of wheat genotypes (Mohsin *et al*., 2009). Genotypic variance is a parameter which represents the magnitude of heritable effects and genetic variation. A high genotypic variance indicates that selection can be successfully applied in this population. Regarding spike length, availability of significant genetic variability in the population indicates that selection may be effective with respect to improvement in the said trait. Late planting results in reduced spike length and other yield contributing traits and eventually decreased grain yield in wheat populations under diverse planting environments (Qasim *et al*., 2008).

Spikelets per spike: For spikelets per spike, the mean values of the genotypes ranged from 17.15 to 20.78, while for G × E interactions the said range was 16.13 to 21.90 (Table 9). In genotype mean values, the maximum spikelets per spike were produced by cultivar Janbaz (20.78) followed by NIFA-5 (19.97); however, these genotypes were further alike with cultivar Khyber-87

(19.47) and line DIK-1 (19.27). Minimum and equal number of spikelets per spike was observed in the lines NIFA-1 (17.15) and PS/CCRI-3 (17.30); however, these lines were found similar in performance with line NIFA-2 (17.90). According to environments, all the lines produced maximum spikelets (19.45) with normal planting than late planting (17.95). The GEI means were found non-significant for spikelets per spike; however, on average the cultivar Janbaz (21.90) produced maximum spikelets per spike followed by NIFA-5 (21.23), Batoor-08 (20.47), DIK-1 (20.10) and PS/CCRI-2 (20.07) under normal planting. While minimum spikelets were observed in the line NIFA-1 (16.13) followed by PS/CCRI-3 (16.90), NIFA-2 (17.23) and PS/CCRI-5 (17.40) with late planting. All others G × E interaction values of different genotypes with normal and late planting showed medium spikelets per spike.

Overall, in genotypes and G × E interactions, the cultivar Janbaz and NIFA-5 exhibited maximum spikelets per spike. Late planting caused 7.71% decline for spikelets per spike (Table 3). In past studies, the spikelets per spike and grains per spike were severely affected due to late sowing (Ilyas *et al*., 2013). Significant differences were observed among wheat genotypes and the environments for spikelets per spike (Bnejdi and El-Gazzah, 2010) which strongly supported present findings. Wheat lines grown under normal planting showed maximum spikelets per spike than late planting because of the early vegetative developmental stage just after leaf initiation. The environments interaction with genotypes did not found to be significant in this study, and Bnejdi and El-Gazzah (2010) also reported non-significant differences among G × E interactions for spikelets per spike in wheat. For spikelets per spike, the broad sense heritability estimates were high (0.64) (Table 3). High heritability in present study determines the highest influence of genes and less effect of environments on wheat lines. High heritability was observed for spikelets per spike among wheat genotypes (Mohammad *et al*., 2011).

Grains per spike: Mean values of the genotypes for grains per spike varied from 41.82 to 55.52, while for genotype × environment interactions these values were ranging from 38.80 to 64.07 (Table 10). In genotypes, the line NIFA-5 showed maximum grains per spike (55.52) followed by PS/CCRI-1 (52.18). However, for grains per spike these lines were found alike with two other lines, i.e., PS/CCRI-2 (49.90) and PS/CCRI-4 (49.63). Minimum and equal number of grains per spike were revealed by the lines NIFA-2 (41.82) and PS/CCRI-5 (41.95) and these lines were found at par with three other lines viz., NIFA-3, Khyber-87 and DIK-2 ranging from 42.53 to 44.37 grains per spike. In environment means, the lines with normal planting manifested maximum grains per spike (49.73) than late planting (43.92). In G × E interactions, the line NIFA-5 (64.07) showed maximum grains per spike followed by the line PS/CCRI-2 (56.63) under normal planting. These genotypes were found similar with two other lines, i.e., PS/CCRI-1 (56.07) and DIK-1 (54.33) (Table 10). Minimum and equal number of grains per spike were observed in lines PS/CCRI-5 (38.80) and NIFA-2 (39.13) with late planting. However, these lines were found equal with two other genotypes, i.e., NIFA-3 (41.23) and Batoor-08 (42.27) under late and normal plantings, respectively. All other G × E interactions manifested medium grains per spike under both planting conditions.

On average, in genotype sand G × E interaction means, the lines NIFA-5, PS/CCRI-1 and PS/CCRI-2 produced maximum grains per spike. Late planting revealed a decline of 11.68% for grains per spike (Table 3). Heritability (broad sense) was moderate (0.38) for grains per spike (Table 3). The grains per spike is an important yield associated parameter and has direct impact on grain yield. In present study, the genotypes showed maximum grains per spike under normal planting and decline with late planting. The reduction in number of grain per spike due to heat stress developed due to late planting of wheat genotypes (Sial *et al*., 2005; Khalifa *et al*., 2012). Significant G × E interaction inferred that relative gain in grains per spike was genotype specific over planting dates. Moderate heritability in this study showed that selection might be effective in early generations for this trait, and moderate heritability (0.35) was also reported for grains per spike in the past wheat studies (Mohammad *et al*., 2011).

Grain weight per spike: For grain weight per spike, the mean values varied from 1.53 to 2.38 g and 1.41 to 2.89 g for genotypes and G × E interactions, respectively (Table 11). In genotypes, the line NIFA-5 (2.38 g) revealed maximum grain weight per spike and it was found alike with NIFA-4 (2.13 g). Minimum and equal grain weight per spike was determined by lines NIFA-2 (1.53 g) and NIFA-1 (1.57 g). However, these lines were found equal with three other lines, i.e., NIFA-3, DIK-2 and PS/CCRI-4 ranging from 1.74 to 1.77 g. In environments, the lines with normal planting revealed maximum grain weight (2.07 g) followed by late planting (1.73 g). In G × E interaction means, the maximum grain weight per spike was produced by line NIFA-5 (2.89 g) followed by Janbaz (2.34 g) with normal planting (Table 11). These genotypes were found similar in performance with seven other lines, i.e., PS/CCRI-5, NIFA-4, PS/CCRI-2, DIK-1, Batoor-08, NIFA-4 and PS/CCRI-1 ranging from 2.02 to 2.24 g under normal and late planting conditions. Minimum grain weight per spike was observed in line NIFA-2 (1.41 g) with late planting, and it was found alike with six other lines, i.e., NIFA-1, PS/CCRI-5, DIK-2, NIFA-3, Khyber-87, NIFA-1 ranging from 1.45 to 1.71 g with late planting. The remaining G × E interactions observed with medium values for grain weight per spike.

Overall, in genotypes and G × E interactions the line NIFA-5 followed by NIFA-4 and cultivar Janbaz exhibited maximum grain weight per spike. A decline of 16.43% was observed due to late planting for grain weight per spike (Table 3). For grain weight per spike, the estimated heritability in broad sense was low (0.30) (Table 3). Low heritability for grain weight per spike was also reported in durum wheat populations (Yagdi and Sozen, 2009). In present study, significant differences among genotypes and G × E interactions indicated that the relative gain in grain weight per spike was genotype-specific over the planting dates. Late planting showed negative effect on spike length and therefore, it caused reduction in grain weight per spike. Wheat lines sown at standard planting time produced maximum grain weight per spike while late planting significantly reduced the grain size and grain weight per spike.

Thousand grain weight: For 1000-grain weight, the mean values of the genotypes ranged from 37.38 to 44.97 g, while for G × E interactions, the mean values ranged from 35.53 to 46.53 g (Table 12). In genotypes, the maximum and equal 1000-grain weight was revealed by three lines i.e., NIFA-5 (44.97 g), PS/CCRI-5 (44.88 g) and PS/CCRI-3 (44.45 g) and these lines were found alike with three other lines viz., PS/CCRI-2, NIFA-4 and DIK-1 ranging from 42.67 to 43.57 g. Minimum and equal 1000-grain weight was observed in the lines PS/CCRI-4 (37.38 g) and NIFA-2 (37.65 g), and these genotypes were found similar with three other genotypes, i.e., Batoor-08, DIK-2 and PS/CCRI-1 ranging from 38.43 to 39.80 g. Environment means were non-significant; however, maximum 1000-grain weight was shown by the lines with late planting (41.66 g) than normal (41.16 g). Genotype × environment interaction means were also non-significant; however, on average, the genotype PS/CCRI-5 (46.53 g) showed maximum 1000-grain weight followed by NIFA-4 (46.43 g) and PS/CCRI-3 (44.23 g) with normal planting. Minimum 1000-grain weight was observed for wheat line PS/CCRI-4 (37.57 g) followed by DIK-2 (38.67 g) and NIFA-2 (39.77 g). The remaining G × E interactions showed medium values for 1000-grain weight.

Overall, the genotypes and G × E interaction means revealed that lines NIFA-5, NIFA-4 and PS/CCRI-5 were superior for 1000-grain weight. Wheat lines caused no reduction for 1000-grain weight due to late planting (Table 3). The broad sense heritability was moderate (0.52) for 1000-grain weight (Table 3). In this study, significant differences among wheat lines with non-significant G × E interactions showed stability in performance of wheat lines and were in conformity with past findings as reported significant variation among wheat genotypes for 1000-grain weight (Inamullah *et al*., 2007). In present study, the wheat lines performed similarly under normal and late plantings for 1000-grain weight and no decline was noted due to late planting. Moderate heritability in this study showed that selection for said trait might be effective. Ilyas *et al*. (2013) reported medium values of heritably for 1000-grain weight in different wheat populations.

Grain yield: For grain yield, the genotypes ranged from 2934 to 4039 kg ha^{-1}, while for genotype × environment interactions the range was 2707 to 4678 kg ha^{-1} (Table 13). In genotypes, the maximum grain yield was produced by the line DIK-2 (4039 kg ha^{-1}) and it was found alike in performance with five other lines, i.e., NIFA-1, PS/CCRI-2, DIK-1, PS/CCRI-5 and PS/CCRI-3 ranging from 3778 to 3971 kg ha^{-1}. Minimum grain yield was observed in cultivar Janbaz (2934 kg ha^{-1}); however, it was found similar with two other lines, i.e., NIFA-2 (3128 kg ha^{-1}) and PS/CCRI-4 (3260 kg ha^{-1}). In environments, the lines with normal planting showed maximum grain yield (3974 kg ha^{-1}) than late planting (3174 kg ha^{-1}). In G × E interactions, the maximum grain yield was produced by the line DIK-2 (4678 kg ha^{-1}) and it was found alike with five other lines, i.e., PS/CCRI-5, NIFA-1, DIK-1, PS/CCRI-2 and Batoor-08 ranging from 4222 to 4396 kg ha^{-1} with normal planting. Minimum grain yield was manifested by line NIFA-2 (2707 kg ha^{-1}) with late planting, and it was found equal with eight other lines, i.e., PS/CCRI-4, NIFA-5, Janbaz, NIFA-3, Khyber-87, PS/CCRI-1, NIFA-4 and PS/CCRI-5 ranging from 2741 to 3274 kg ha^{-1} with late planting. The remaining G × E interactions revealed medium values for grain yield.

Table 1. Wheat advanced lines and check cultivars evaluated under normal and late planting conditions.

Name	Breeding Center
PS/CCRI-1	Cereal Crops Research Institute, Pirsabak - Nowshera, Pakistan
PS/CCRI-2	Cereal Crops Research Institute, Pirsabak - Nowshera, Pakistan
PS/CCRI-3	Cereal Crops Research Institute, Pirsabak - Nowshera, Pakistan
PS/CCRI-4	Cereal Crops Research Institute, Pirsabak - Nowshera, Pakistan
PS/CCRI-5	Cereal Crops Research Institute, Pirsabak - Nowshera, Pakistan
NIFA-1	Nuclear Institute for Food and Agriculture, Peshawar, Pakistan
NIFA-2	Nuclear Institute for Food and Agriculture, Peshawar, Pakistan
NIFA-3	Nuclear Institute for Food and Agriculture, Peshawar, Pakistan
NIFA-4	Nuclear Institute for Food and Agriculture, Peshawar, Pakistan
NIFA-5	Nuclear Institute for Food and Agriculture, Peshawar, Pakistan
DIK-1	Agriculture Research Institute, Dera Ismail Khan, Pakistan
DIK-2	Agriculture Research Institute, Dera Ismail Khan, Pakistan
Janbaz	The University of Agriculture, Peshawar, Pakistan
Batoor-08	Nuclear Institute for Food and Agriculture, Peshawar, Pakistan
Khyber-87	Cereal Crops Research Institute, Pirsabak-Nowshera, Pakistan

Table 2. Mean square of genotypes, environments and G × E interactions for various traits in wheat genotypes evaluated under normal and late planting conditions.

Variables	Environments	Replications with in environment	Genotypes	G × E	Error	CV (%)
d.f.	1	4	13	13	52	–
Days to heading	6052.01^{**}	5.90	27.54^{**}	5.60^{**}	1.48	1.08
Days to maturity	9052.19^{**}	4.77	3.42^{NS}	1.09^{NS}	3.24	1.20
Plant height	3504.99^{**}	65.47	110.06^{**}	14.15^{NS}	8.85	3.10
Flag leaf area	297.19^{**}	155.97	89.12^{**}	26.36^{NS}	18.63	12.29
Spike length	28.58^{**}	0.31	2.26^{**}	0.21^{NS}	0.22	4.25
Spikelets spike^{-1}	46.65^{**}	0.48	5.82^{**}	0.62^{NS}	0.42	3.46
Grains spike^{-1}	708.76^{**}	13.50	103.16^{**}	40.16^{**}	5.06	4.80
Grain weight spike^{-1}	2.40^{**}	0.10	0.31^{NS}	0.12^{**}	0.05	11.4
1000-grain weight	5.20^{NS}	5.16	41.12^{**}	7.07^{NS}	4.36	5.04
Grain yield	13444240.37^{*}	1361250.10	694125.31^{**}	211408.64^{*}	109478.65	9.26

*, **– significant at 5% and 1% level of probability, ns – non-significant, d.f. – degree of freedom, CV – coefficient of variation

Table 3. Mean ranges, decline (%), best populations and heritability (broad sense) for various traits of wheat genotypes evaluated under normal and late planting conditions.

Variables	Mean ranges (normal planting)	Mean ranges (late planting)	Reduction / Decline (%)	Best populations	Heritability (bs)
Days to heading	118-125	101-107	14.02	DIK-1	0.57
Days to maturity	160-163	139-141	12.88	NIFA-4	0.14
Plant height (cm)	98-113	84-99	12.30	NIFA-1	0.60
Flag leaf area (cm^2)	30-45	26-40	10.17	NIFA-5	0.33
Spike length (cm)	11-13	10-12	9.93	PS/CCRI-2	0.50
Spikelets spike^{-1}	18-22	16-20	7.71	Janbaz	0.64
Grains spike^{-1}	42-64	39-48	11.68	NIFA-5	0.38
Grain weight spike^{-1} (g)	1.6-2.9	1.4-2.0	16.43	NIFA-5	0.30
1000-grain weight (g)	36-47	38-45	-1.20	NIFA-5	0.52
Grain yield (kg ha^{-1})	2814-4677	2707-3585	20.14	DIK-2	0.36

Table 4. Days to heading of wheat advanced lines and check genotypes evaluated under normal and late planting conditions.

Wheat genotypes	Days to heading (days)		
	Normal sowing	**Late sowing**	**Means (days)**
PS/CCRI-1	119.67	103.00	111.33
PS/CCRI-2	120.67	104.67	112.67
PS/CCRI-3	119.67	105.00	112.33
PS/CSCRI-4	125.33	106.67	116.00
PS/CCRI-5	124.67	106.00	115.33
NIFA-1	118.33	102.33	110.33
NIFA-2	124.00	107.67	115.83
NIFA-3	121.67	105.67	113.67
NIFA-4	118.67	102.00	110.33
NIFA-5	119.33	102.33	110.83
DIK-1	118.00	102.00	110.00
DIK-2	124.33	105.33	114.83
Batoor-08/Khyber-87	123.00	101.33	112.17
Janbaz	118.33	104.00	111.17
Means (days)	121.12	104.14	

$LSD_{0.05}$ Genotypes = 1.40, Environments = 1.11, GEI = 1.99

Table 5. Days to maturity of wheat advanced lines and check genotypes evaluated under normal and late planting conditions.

Wheat genotypes	Days to maturity (days)		
	Normal sowing	**Late sowing**	**Means (days)**
PS/CCRI-1	160.00	139.33	149.67
PS/CCRI-2	161.33	140.67	151.00
PS/CCRI-3	161.67	141.33	151.50
PS/CCRI-4	160.67	141.00	150.83
PS/CCRI-5	163.00	141.00	152.00
NIFA-1	160.00	140.00	150.00
NIFA-2	160.00	140.67	150.33
NIFA-3	161.00	140.00	150.50
NIFA-4	159.67	139.67	149.67
NIFA-5	162.33	140.67	151.50
DIK-1	160.67	139.67	150.17
DIK-2	161.67	140.00	150.83
Batoor-08/Khyber-87	162.67	140.67	151.67
Janbaz	161.67	141.00	151.33
Means (days)	161.17	140.41	

$LSD_{0.05}$ Genotypes = ns, Environments = 0.49, GEI = ns

Table 6. Plant height of wheat advanced lines and check genotypes evaluated under normal and late planting conditions.

Wheat genotypes	Plant height (cm)		
	Normal sowing	**Late sowing**	**Means (cm)**
PS/CCRI-1	98.97	87.90	93.43
PS/CCRI-2	113.70	97.23	105.47
PS/CCRI-3	108.70	94.80	101.75
PS/CCRI-4	106.87	95.63	101.25
PS/CCRI-5	108.60	92.43	100.52
NIFA-1	97.97	84.53	91.25
NIFA-2	102.37	90.43	96.40
NIFA-3	101.30	94.37	97.83
NIFA-4	104.33	93.90	99.12
NIFA-5	103.77	86.23	95.00
DIK-1	111.87	99.20	105.53
DIK-2	102.83	85.63	94.23
Batoor-08/Khyber-87	102.90	91.07	96.98
Janbaz	101.83	91.77	96.80
Means (cm)	104.72	91.79	

$LSD_{0.05}$ Genotypes = 3.44, Environments = 1.77, GEI = ns

Table 7. Flag leaf area of wheat advanced lines and check genotypes evaluated under normal and late planting conditions.

Wheat genotypes	Flag leaf area (cm^2)		
	Normal sowing	Late sowing	Means (cm^2)
PS/CCRI-1	38.51	36.23	37.37
PS/CCRI-2	36.74	40.37	38.55
PS/CCRI-3	35.65	37.23	36.44
PS/CCRI-4	40.12	35.28	37.70
PS/CCRI-5	37.66	26.83	32.24
NIFA-1	29.79	25.65	27.72
NIFA-2	36.53	30.85	33.69
NIFA-3	34.69	32.37	33.53
NIFA-4	42.91	37.33	40.12
NIFA-5	45.01	39.45	42.23
DIK-1	38.30	30.88	34.59
DIK-2	36.37	29.24	32.80
Batoor-08/Khyber-87	31.38	34.76	33.07
Janbaz	34.05	28.54	31.30
Means (cm^2)	36.98	33.22	

$LSD_{0.05}$ Genotypes = 5.00, Environments = ns, GEI = ns

Table 8. Spike length of wheat advanced lines and check genotypes evaluated under normal and late planting conditions.

Wheat genotypes	Spike length (cm)		
	Normal sowing	Late sowing	Means (cm)
PS/CCRI-1	11.57	10.30	10.94
PS/CCRI-2	13.27	11.70	12.47
PS/CCRI-3	11.32	10.02	10.67
PS/CCRI-4	10.72	10.35	10.53
PS/CCRI-5	12.22	10.87	11.54
NIFA-1	10.80	9.70	10.25
NIFA-2	12.07	11.20	11.63
NIFA-3	11.43	10.87	11.15
NIFA-4	11.75	10.62	11.18
NIFA-5	12.43	10.87	11.65
DIK-1	12.13	10.90	11.52
DIK-2	11.54	10.02	10.78
Batoor-08/Khyber-87	10.92	10.00	10.46
Janbaz	11.37	9.83	10.60
Means (cm)	11.68	10.52	

$LSD_{0.05}$ Genotypes = 0.54, Environments = 0.21, GEI = ns

Table 9. Spikelets per spike of wheat advanced lines and check genotypes evaluated under normal and late planting conditions.

Wheat genotypes	Spikelets per spike		
	Normal sowing	Late sowing	Means
PS/CCRI-1	19.53	18.03	18.78
PS/CCRI-2	20.07	17.97	19.02
PS/CCRI-3	17.70	16.90	17.30
PS/CCRI-4	18.80	18.47	18.63
PS/CCRI-5	18.80	17.40	18.10
NIFA-1	18.17	16.13	17.15
NIFA-2	18.57	17.23	17.90
NIFA-3	18.63	17.73	18.18
NIFA-4	19.27	18.03	18.65
NIFA-5	21.23	18.70	19.97
DIK-1	20.10	18.43	19.27
DIK-2	19.00	18.20	18.60
Batoor-08/Khyber-87	20.47	18.47	19.47
Janbaz	21.90	19.67	20.78
Means	19.45	17.95	

$LSD_{0.05}$ Genotypes = 0.75, Environments = 0.36, GEI = ns

Table 10. Grains per spike of wheat advanced lines and check genotypes evaluated under normal and late planting conditions.

Wheat genotypes	Grains per spike		
	Normal sowing	Late sowing	Means
PS/CCRI-1	56.07	48.30	52.18
PS/CCRI-2	56.63	43.17	49.90
PS/CCRI-3	44.97	44.43	44.70
PS/CCRI-4	52.77	46.50	49.63
PS/CCRI-5	45.10	38.80	41.95
NIFA-1	47.70	44.07	45.88
NIFA-2	44.50	39.13	41.82
NIFA-3	43.83	41.23	42.53
NIFA-4	50.97	46.13	48.55
NIFA-5	64.07	46.97	55.52
DIK-1	54.33	43.10	48.72
DIK-2	45.77	42.97	44.37
Batoor-08/Khyber-87	42.27	43.23	42.75
Janbaz	47.20	46.80	47.00
Means	49.73	43.92	

$LSD_{0.05}$ Genotypes = 2.60, Environments = 3.02, GEI = 3.68

Table 11. Grain weight per spike of wheat advanced lines and check genotypes evaluated under normal and late planting conditions.

Wheat genotypes	Grain weight per spike (g)		
	Normal sowing	Late sowing	Means (g)
PS/CCRI-1	2.01	1.92	1.96
PS/CCRI-2	2.18	1.83	2.00
PS/CCRI-3	1.95	1.88	1.92
PS/CCRI-4	1.77	1.78	1.77
PS/CCRI-5	2.25	1.48	1.86
NIFA-1	1.68	1.45	1.57
NIFA-2	1.66	1.41	1.53
NIFA-3	1.82	1.67	1.74
NIFA-4	2.24	2.02	2.13
NIFA-5	2.89	1.86	2.38
DIK-1	2.18	1.89	2.04
DIK-2	1.97	1.54	1.75
Batoor-08/Khyber-87	2.04	1.71	1.87
Janbaz	2.34	1.81	2.08
Means (g)	2.07	1.73	

$LSD_{0.05}$ Genotypes = 0.25, Environments = 0.16, GEI = 0.35

Table 12. Thousand grain weight of wheat advanced lines and check genotypes evaluated under normal and late planting conditions.

Wheat genotypes	1000 grain weight (g)		
	Normal sowing	Late sowing	Means (g)
PS/CCRI-1	39.23	40.37	39.80
PS/CCRI-2	42.13	45.00	43.57
PS/CCRI-3	44.23	44.67	44.45
PS/CCRI-4	37.20	37.57	37.38
PS/CCRI-5	46.53	43.23	44.88
NIFA-1	39.90	41.73	40.82
NIFA-2	35.53	39.77	37.65
NIFA-3	40.80	40.10	40.45
NIFA-4	42.70	43.27	42.98
NIFA-5	46.43	43.50	44.97
DIK-1	42.07	43.27	42.67
DIK-2	40.70	38.67	39.68
Batoor-08/Khyber-87	37.07	39.80	38.43
Janbaz	41.73	42.30	42.02
Means (g)	41.16	41.66	

$LSD_{0.05}$ Genotypes = 2.41, Environments = NS, GEI = ns

Table 13. Grain yield of wheat advanced lines and check genotypes evaluated under normal and late planting conditions.

Wheat genotypes	Grain yield (kg ha^{-1})		
	Normal sowing	Late sowing	Means (kg ha^{-1})
PS/CCRI-1	3744	3137	3441
PS/CCRI-2	4237	3511	3874
PS/CCRI-3	4074	3481	3778
PS/CCRI-4	3778	2741	3260
PS/CCRI-5	4396	3274	3835
NIFA-1	4357	3585	3971
NIFA-2	3548	2707	3128
NIFA-3	3607	3030	3319
NIFA-4	4052	3200	3626
NIFA-5	3889	2800	3345
DIK-1	4241	3473	3857
DIK-2	4678	3400	4039
Batoor-08/Khyber-87	4222	3044	3633
Janbaz	2815	3052	2934
Means (kg ha^{-1})	3974	3174	

$LSD_{0.05}$ Genotypes = 383.30, Environments = 466.36, GEI = 542.12

Overall, the lines DIK-2 and NIFA-1 were superior in grain yield. Like yield contributing traits, grain yield also showed 20.14% decrease due to late planting (Table 3). The heritability (bs) for grain yield was estimated as moderate (0.36) (Table 3). Low heritability (0.36) was also reported in past wheat heritability studies (Aydin *et al*., 2010). Grain yield and its components are the main selection criteria for improving adaptation to different environments. In present study, sufficient genotypic differences among wheat lines with significant G × E interactions for grain yield showed the inconsistency of wheat lines across two environments and are in confirmation with the findings of Inamullah *et al*. (2007) as they reported significant effect of planting dates on genotypes for grain yield. The higher grain yield was produced when planting was carried out at standard sowing time and late planting caused reduction in grain yield. Late sowing expose the wheat crop to heat shock of late summer, resulting enforced maturity. Moderate broad sense heritability for grain yield verified that selection might be effective for high yielding wheat lines. Majority of the yield related traits revealed medium to high heritability which provides reliability and more chances to the genotype to be recognized by the expression of its phenotype and effective selection. However, low heritability revealed that selection of these traits might not be effective due to non-additive gene effects for the traits in wheat populations (Tsegaye *et al*., 2012).

Conclusion: Genotypes and environments played major role in phenotypic manifestation of various traits. Overall, grain yield of the genotypes was reduced by 20.14% due to late planting. Genotype DIK-2 performed better followed by lines DIK-1, NIFA-1 and NIFA-5 with normal planting conditions. Lines NIFA-1 and PS/CCRI-2 were the best performers under late planting conditions. The above promising lines could be further utilized for commercial cultivation as well as in future breeding programs to evolve new wheat cultivars with good yield potential.

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