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HERITABILITY ESTIMATES FOR PRODUCTION TRAITS IN BREAD WHEAT (*Triticum aestivum* L.)

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Abstract

This research was conducted to estimate heritability and genetic advance for production traits in 20 wheat genotypes including two check cultivars. The genotypes were evaluated under irrigated and rainfed conditions using Randomized Complete Block Design with three replications at The University of Agriculture, Peshawar during 2021-22 cropping season. Combined analysis of variance revealed significant differences among environments and genotypes for all the studied traits. Genotypes by environment interactions were significant for all traits except harvest index, indicating inconsistent performance of wheat genotype across the two environments. Flag leaf area, plant height, tiller meter^2, spikelets spike^{-1}, 1000-grain weight, biological yield and grain yield generally had lower values under rainfed environment. The highest grain yield of 3870 kg ha^{-1} was recorded for genotype G-306 followed by G-302 (3826 kg ha^{-1}) and G-310 (3824 kg ha^{-1}) under irrigated environment while under rainfed environment, highest grain yield was produced by genotype G-313 (3066 kg ha^{-1}) followed by G-301 (3061 kg ha^{-1}) and G-310 (3055 kg ha^{-1}). Heritability estimates were calculated under rainfed and irrigated environments for spikelets spike^{-1} (0.96 and 0.96) grains spike^{-1} (0.72 and 0.88), 1000-grain weight (0.71 and 0.78), biological yield (0.54 and 0.87) and grain yield (0.50 and 0.84). Similarly expected genetic advance values were 1.27 vs 3.24 days for days to heading, 6.51 vs 6.55 cm² for flag leaf area, 0.90 vs 2.17 cm for plant height, 9.82 vs 30.22 tiller for tillers, 0.68 vs 0.83 cm for spike length, 1.47 vs 1.72 for spikelets spike^{-1}, 4.62 vs 4.74 grains for grains spike^{-1} 4.95 vs 5.04 g for 1000-grain weight, 3161.45 vs 1042.76 kg for biological yield, 384.35 vs 243.24 kg for grain yield and 0.22 vs 0.81% for harvest index under irrigated and rainfed environments, respectively. Wheat genotypes G-306, G-302, G-310 performed well under irrigated environment while G-313, G-301 and G-310 were high yielding under rainfed environment. Therefore, these genotypes need further testing across years and locations for making concrete recommendations.

Keywords: *Triticum aestivum*, genotypes, production, heritability estimates

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Introduction

Wheat (*Triticum aestivum* L.) is self-pollinated crop that belongs to family Gramineae. Wheat can grow in both tropical and subtropical climates (Bharat *et al.,* 2012). Wheat is the third largest crop in the world, cultivated on an area of 219 million ha with a production of 760 million tons. The global wheat production was more than 778.6 million metric tons during 2020-21 (Shahbandeh, 2022). Similarly in Pakistan, total area under wheat cultivation is 9.178 million ha with production of 27.359 million tons and an average yield of 2974 kg ha^{-1} (FAO, 2022). Similarly total area under wheat cultivation in Khyber Pakhtunkhwa is 724.1 thousand hectares. Total production of wheat in Khyber Pakhtunkhwa is 1.49 million tons. Likely average wheat yield in Khyber Pakhtunkhwa is 1774 kg ha^{-1} (PBS, 2020-2021). Rain-fed wheat production is 19% of total wheat production. More than 60% of the wheat production area in Khyber Pakhtunkhwa (KPK) is rain-fed. Consequently, the KPK province has the lowest average grain yield. Rain-fed region, also known as 'Daman' areas, are characterized by modest yields and severe water shortage, resulting a large portion of the land unproductive (Fassil *et al*., 2000). Variability among individuals is due to differences in their genetic composition and environment in which they are raised (Allard, 1960; Falconer and Mackay, 1996). Reduction in genetic variability makes the crops vulnerable to diseases and adverse climatic changes (Aremu, 2012). Heritability estimates provide information about the extent to which a particular character can be transmitted to the successive generations. Knowledge of heritability of a trait thus guides a plant breeder to predict behaviour of succeeding generations for desirable selection. Selection plays an important role in plant breeding to identify plants with desired traits. Heritability and genetic advance would help the breeders in efficient selection for rapid improvement. Genetic advance indicates the degree of gain in a character obtained under a particular selection pressure. Thus, genetic advance is another important selection parameter that aids breeder in a selection program (Shukla *et al*., 2004). High heritability and genetic advance can improve selection efficiency and response to selection. As a result, selecting traits based on their high heritability facilitates improvement (Asghar *et al*., 1999). High genetic advance coupled with high heritability estimates offer the most effective condition for selection (Larik *et al*., 2000). Keeping in view the importance of wheat crop, 18 advanced wheat lines of CIMMYT with two check cultivars (Wadan and Khaista) were evaluated under irrigated and rainfed conditions to determine genetic variability among advanced wheat lines for production traits, assess genotype by environment interaction for grain yield, estimate heritability and genetic advance for yield-related traits and identify the suitable wheat line(s) for both environments.

Materials and Methods

This experiment was carried out at the experimental field of the University of Agriculture, Peshawar during Rabi 13 November 2021-22. Plant material comprising 18 advanced wheat genotypes (G-301, G-302, G-303, G-304, G-305, G-306, G-307, G-309, G-310, G-311, G-312, G-13, G-314, G-315, G-316, G-317, G-318, G-319) procured from International Wheat and Maize Improvement Centre (CIMMYT), along with two check cultivars i.e. Wadan and Khaista were evaluated under irrigated and rainfed conditions using randomized complete block (RCB) design with three replications. Each entry was grown in three rows of 4 m length with row-to-row distance of 30 cm. From seeding to harvesting, standard agronomic methods were followed. Diseases and weak seedlings were discarded.

Data recording

Data on the following parameters were recorded on five randomly selected plants from each entry.

Days to heading

Days to heading was noted from the time of sowing to the day when 50% of the plants fully emerged spikes from the flag leaf.

Flag leaf area (cm^2)

Length and width of flag leaf from five randomly selected plants in each plot was measured. Leaf area was calculated by using the formula given by Francis *et al.* (1969).

$$\text{Flag leaf area (cm}^2\text{)} = Leaf\ length\ (cm) \times Leaf\ width\ (cm) \times 0.75$$

Plant height (cm)

Plant height was measured in centimetres from the base of the plant to the tip of the spike excluding awns of the main tiller. For each genotype, data for plant height was recorded on five randomly selected plants and the average plant height was calculated.

Tiller meter^{-2}

For each genotype, productive tillers were counted in one-meter row and converted into tillers m^{-2}.

Spike length (cm)

Spike length was measured in centimetres from the base of the first spikelet on the rachis to the tip of the spike excluding awns.

Spikelets spike^{-1}

Total numbers of spikelets were counted at maturity on five randomly selected spikes, for recording data on spikelets spike^{-1}.

Grains spike^{-1}

Five randomly chosen spikes in an entry were threshed individually and grains were counted and then were averaged for each spike.

1000-grain weight (g)

After harvesting, a random sample of 1000 grains for each genotype in each replication was weighed using an electronic balance.

Biological yield (kg ha^{-1})

Each experimental plot was manually harvested at maturity and dried in the sun for a week. For biological yield, each bundle was weighed individually. Biological yield was then determined by using the following formula.

$$\text{Biological yield (kg ha}^{-1}) = \frac{Biological\ yield\ plot^{-1}\ (kg)}{Plot\ size\ (m^2)} \times 10{,}000\ \text{m}^2$$

Grain yield (kg ha^{-1})

To determine grain yield of each genotype, the grains obtained after threshing the total bundles were weighed and grain yield was determined by using the following formula:

$$\text{Grain yield (kg ha}^{-1}) = \frac{Grain\ yield\ plot^{-1}\ (kg)}{Plot\ size\ (m^2)} \times 10{,}000\ \text{m}^2$$

Harvest index (%)

Harvest index was calculated by using sample data collected for total biomass and grain production. Harvest index is defined as the ratio of grain yield to total biomass. The following formula was used for harvest index:

$$\text{Harvest index (\%)} = \frac{Grain\ yield\ plot^{-1}\ (kg)}{Biological\ yield\ plot^{-1}\ (kg)} \times 100$$

Statistical analysis

Field-data on the above mentioned parameters was subjected to pooled analysis of variance following procedures determined by Steel *et al*. (1997). Upon significant genotypic into environment interaction, analysis of variance at individual environment was also carried out. Least significant difference (LSD) test was used to separate means at 5% probability level.

Estimation of heritability

Heritability in broad sense was estimated for various traits at individual environment. The variance components required for its estimation were computed using the following formulas Falconer and Mackay (1996).

$$\text{Genotypic variance} = (V_g) = \frac{\text{GMS} - \text{EMS}}{\text{r}}$$

$$\text{Environmental variance} = (V_e) = \text{EMS}$$

$$\text{Phenotypic variance} = (V_p) = V_g + V_e$$

$$\text{Heritability } h^2{}_{bs} = \frac{V_g}{V_p}$$

Where,

V_g = Genetic variance for a specific trait.

V_e = Environmental variance for a specific trait.

V_p = Phenotypic variance for a specific trait.

$h^2{}_{bs}$ = heritability in broad sense for a specific trait.

Estimation of genetic advance

To determine genetic advanced for yield and yield related factors, the following formulas was used as outlined by Allard (1960).

Genetic advance = (GA) = $i \times \sqrt{Vp} \times h^2$

i = Selection intensity at 10% (1.76)

V_p =Phenotypic variance for the specific trait

h^2 =Heritability (Broad sense).

Results and Discussions

Days to heading

Days to heading is an essential character in wheat breeding programs due to its association with plant maturity as well as insects and diseases escape mechanisms. Pooled analysis of variance showed highly significant ($P \leq 0.01$) differences among environments, genotypes and genotypes by environment interaction for days to heading (Table 1). This clearly indicated inconsistency in performance of wheat genotypes for trait across the two tested environment. Similar results for days to heading were reported by Khalil *et al.* (2008). Mean number of days to heading of wheat genotypes across both environments ranged from 116 to 121 days, Minimum numbers of day to heading were taken by genotypes G-307 and G-316 (116 days) while maximum numbers of days to heading (121 days) were recorded for genotypes G-304, G-310 and G-313 (Table 2). Similarly, mean numbers of days to heading under irrigated conditions ranged from 120 to 124 days. Early heading appeared in genotype G-307, G-309 and G-316 (120 days) while late heading was observed in genotype G-301, G-304, G-313 and G-317 (124 days). Likewise, under rainfed conditions, mean value of days to heading ranged from 112 to 120 days. Genotypes G-307, G-314 and G-316, with 112 days each appeared with early heading while genotypes G-310 with 120 days appeared as late heading genotype. Genetic and environmental variances for days to heading were generally lower (1.19 and 1.54, respectively) under irrigated conditions than under rain-fed conditions (5.13 and 2.60, respectively) (Table 8). Under irrigated condition, broad sense heritability estimate was observed moderate (0.44) while heritability was observed high (0.66) under rainfed condition. Days to heading showed genetic advance values of 1.27 and 3.24 days for days to heading. Ikramullah *et al.* (2011) also reported moderate heritability value and low genetic advance for this trait.

Plant height

Plant breeders are interested in short stature and uniform wheat genotypes having resistance against lodging and actively respond to fertilizers. Combined analysis of variances for plant height revealed highly significant ($P \leq 0.01$) differences among environments, genotypes and genotypes by environment interaction (Table 1). This clearly indicates inconsistent performance of wheat genotypes for this trait across the two tested environments. These results are similar to those of Thapa *et al.,* (2019) who also observed significant variations among genotypes as well as genotype by environment interaction. Average height of wheat genotypes under both environments ranged from 95.5 to 98.6 cm. Minimum plant height was obtained by genotype G-311 (95.5 cm) while maximum plant height (98.6 cm) was recorded for genotype G-303 (Table 2). Likewise, average plant height under irrigated environment ranged from 97.5 to 99.9 cm. Genotype G-311 exhibited minimum plant height of 97.5 cm. While maximum plant height of 99.9 cm was recorded for genotype G-302. Similarly, mean value of plant height under rain-fed environment ranged from 93.3 to 98.1 cm shortest plant height of 93.3 cm was displayed by G-314 while maximum plant height of 98.1 cm was recorded for genotype G-303. When averaged over 20 wheat genotypes, plant height under irrigated and rain-fed conditions were 98.9 and 95.1 cm, respectively. Genetic variances for plant height were 0.35 and 1.66 while environmental variances were 0.11 and 0.13 under irrigated and rain-fed environments, respectively. However, high broad sense heritability (0.76 and 0.93) and genetic advance (0.90 and 2.17 cm) were recorded for plant height under irrigated and rain-fed environments, respectively (Table 8). These results were in accordance with the findings of Yaqoob (2016) who also reported moderate heritability for plant height in wheat genotypes. In contrast, Kumar *et al*. (2019) reported high heritability estimates for plant height.

Flag leaf area

Flag leaf area plays vital role in contributing grain yield. Physiological studies displayed that flag leaf area is major photosynthetic site during grain filling stages. Hence flag leaf area and yield have a direct association with each other. Leaf photosynthesis rate is affected by leaf position; however, in winter wheat the flag leaf and second leaf are photosynthetically the most active part of a plant (Olszewsky *et al*. 2008). Pooled analysis of variance for flag leaf area displayed highly significant ($P \leq 0.05$) differences among environments, genotypes and genotype × environment interaction (Table 1). This shows inconsistency in wheat genotypes for this trait across both the tested environments. Azam *et al.* (2013) also reported significant differences among genotypes for the said trait. Mean value for flag leaf area across both environments ranged from 19.0 to 32.6 cm^2. Maximum flag leaf area was observed in genotype G-313 (32.6 cm^2) while minimum flag leaf area was recorded for genotype G-

318 (19.0 cm^2) (Table 3). Mean value of flag leaf area under irrigated environment ranged from 15.8 to 31.0 cm^2. Maximum flag leaf area was observed in G-313 (31.0 cm^2) while minimum flag leaf area was noted in genotype G-318 (15.8 cm^2). Similarly, mean value of flag leaf area under rain-fed environment ranged from 22.3 to 37.2 cm^2 where maximum flag leaf area was observed in genotype G-306 (37.2 cm^2) while minimum flag leaf area was observed in genotype G-118. When averaged across 20 wheat genotypes, a mean value of flag leaf area was 24.4 cm^2 and 28.3 cm^2 under irrigated and rain-fed conditions, respectively. The genetic variances for flag leaf area were 14.46 and 14.42, while environmental variances were 0.73 and 0.49 under irrigated and rain-fed environment, respectively. However, broad sense heritability (0.95) with low genetic advance of 6.51 cm^2 was recorded for flag leaf area under irrigated environment. Similarly, under rain-fed environment heritability (0.97) along with genetic advance of 6.55 cm^2 was recorded for flag leaf area (Table 8). This indicates that the traits were highly influenced by the environmental factor as compared to genetic factor. The present results were in accordance with those of Ghuttai *et al.* (2015) reported low value of heritability for the said trait in wheat genotypes. However, contrary to our findings Khan *et al.* (2017) reported high heritability estimates for flag leaf area.

Tiller meter^{-2}

Tiller meter^{-2} is one of the most important yield contributing trait. Pooled analysis of variance for tiller meter^{-2} depicted highly significant ($P \leq 0.01$) differences among environments; genotypes and genotype by environment interaction (Table 1). This clearly indicates that the tillering ability of wheat genotypes differed significantly across the two tested environments. Earlier, Khan and Mohammad (2018) also reported significant variation among wheat genotypes and environments for tiller meter^{-2}. Mean value of tiller meter^{-2} across both environments ranged from 368 to 412. Maximum numbers of tiller meter^{-2} were produced by genotype G-317 (412) followed by genotypes G-314 (404) and G-309 (402) while minimum numbers of tiller meter^{-2} were recorded for genotype G-303 (368) (Table 3). Mean value for tiller meter^{-2} under irrigated condition ranged from 403 to 426. The maximum number of tiller meter^{-2} were observed in genotype G-317 (426), followed by genotypes G-314 and G-316 (420 each) and G-313 (419) and G-306 (418) while minimum number of tiller meter^{-2} was recorded for genotype Khaista (403). Similarly, under the rainfed environment, tiller meter^{-2} ranged from 327 to 399. Maximum numbers of tiller meter^{-2} were recorded for genotype G-317 (399) followed by G-309 (391) and G-314 (388) while minimum numbers of tiller meter^{-2} were observed in genotype G-303 (327). When averaged over 20 wheat genotypes, mean tiller meter^{-2} were 412 and 362 tillers under irrigated and rainfed environments, respectively. Genotypic and environment variance for tiller meter^{-2} were (34.21 and 3.17, respectively) under irrigated environment than under rainfed environment (389.70 and 122.44, respectively) (Table 8). However, high broad sense heritability (0.92) along with genetic advance of 9.82 was recorded for tiller meter^{-2} under irrigated environment. Similarly, under rainfed environment high heritability (0.76) with genetic advance of 30.22 tillers was recorded for tiller meter^{-2} moderate value of broad Sense heritability for tiller meter^{-2} is in line with the finding of Safi *et al.* (2017).

Spikelet's spike^{-1}

Combined analysis of variance for spikelets spike^{-1} showed highly significant ($P \leq 0.01$) differences among genotypes, environments, and genotype by environment interaction (Table 1). This clearly indicated inconsistency in performance of wheat genotypes for this trait across the two tested environments. Significant differences among genotypes for spikelets spike^{-1} confirmed earlier findings of Mohapatra *et al.,* (2019). Mean value of spikelets spike^{-1} across both environments ranged from 15 to 18. The highest number of spikelets spike^{-1} (18) were recorded for genotype G-302, while minimum number of spikelets spike^{-1} (15) were recorded for genotypes G-306, G-307, G-310, G-312, G-319 and cultivar Wadan (Table 4). Likewise, number of spikelets spike^{-1} under irrigated environment ranged from 14 to 17. Maximum number of spikelets spike^{-1} (17) were recorded for genotypes G-302, G-311 and G-313 while minimum number of spikelets spike^{-1} (14) were recorded for genotypes G-306, G319 and cultivar Wadan. Similarly, under rain-fed condition mean value of spikelets spike^{-1} ranged from 15 to 19. Maximum number of spikelets spike^{-1} (19) were recorded for genotype G-302 while minimum number of spikelets spike^{-1} (15) were recorded for genotypes G-306, G-307, G-310, G-312 and G-19. When averaged over 20 wheat genotypes, mean number of spikelets spike^{-1} were 16 under irrigated and rain-fed environments, respectively. The genetic and environmental variance for spikelets spike^{-1} were (0.73 and 0.03, respectively) under irrigated environment than under rain-fed environment (1.00 and 0.05, respectively) (Table 8). However high broad sense heritability (0.96) along with genetic advance of 1.47 was recorded for spikelets spike^{-1} under irrigated environment. Similarly, under rain-fed environment high sense heritability (0.96) with genetic advance of 1.72 was recorded for spikelets spike^{-1}. These results confirmed the findings of Ullah *et al*. (2018) who reported moderate heritability estimates for this trait in wheat genotypes. In contrast, Tomar *et al*. (2019) reported high heritability estimates for spikelets spike^{-1}.

Spike length

Spike length is an essential parameter as it is directly associated with numbers of grains spike^{-1} and grain yield as it accommodates greater number of spikelets (Khan *et al*. 2013). Wheat genotype bearing long spikes generally have more contribution towards grain yield due to more spikelets and seed set (Shabbir *et al*. 2011). Analysis of variance showed highly significant ($P \leq 0.01$) variation among the wheat genotypes, environment and genotype x environment interaction for spike length (Table 1). This reveals inconsistency in performance of wheat genotypes for this trait across the tested environments. Our results are in line with those of Mwadzingeni *et al.* (2017) who also noted significant differences among wheat genotypes for this trait. Mean values of spike length across both environments ranged from 7.8 to 9.1 cm. Maximum value (9.1 cm) of spike length was recorded for genotype G-302 while minimum (7.8 cm) spike length was noticed for genotypes G-303 and G-305 (Table 4). Likewise mean value of spike length under irrigated environment ranged from 7.3 to 8.9cm. Maximum value (8.9cm) of spike length was recorded for genotypes G-304 and G-317. While minimum value (7.3cm) for spike length was recorded for G-303. Similarly, under rain-fed environment spike length ranged from 7.9 to 9.5cm. Maximum value (9.5cm) of spike length was recorded for genotype G-302, followed by genotypes G-314, G-316, G-318 and cultivar Khaista (9.4 cm each) and G-317 and Wadan (9.1 cm) while minimum value (7.9 cm) was exhibited by genotype G-305. When averaged over 20 genotypes wheat genotype, mean spike length was 8.2cm to 8.8cm under irrigated and rain-fed environments, respectively. The genetic and environmental variance for spike length were generally lower (0.18 and 0.04 respectively) under irrigated environment than under rain-fed environment (0.25 and 0.03, respectively) (Table 8). However, the values of broad sense heritability (0.82 and 0.90) and genetic advance (0.68 and 0.83cm) were high for spike length under irrigated and rain-fed environments, respectively. Mohsin *et al.* (2009) supported our results by reporting moderate value of heritability for the said trait.

Grains spike^{-1}

Grains spike^{-1} is dependent on spike length, spike density and spikelets spike^{-1}. Maximum number of grains spike^{-1} would be useful if they are healthy and having adequate weight (Firouzain *et al*. 2003). Pooled analysis of variances across two environments revealed highly significant ($P \leq 0.01$) difference among genotypes, environments and genotype x environment interactions (G x E) for grains spike^{-1} (Table 1). (Ullah *et al.,* 2018) also reported significant differences among wheat genotypes as well as genotype by environment interaction for grains spike^{-1}. Mean value of grain spike^{-1} across environments ranged from 26 to 38 where maximum number of grains spike^{-1} (38) were produced by genotype G-312 followed by genotype G-319 (36) while minimum number of grains spike^{-1} were recorded for genotype G-315 (26) (Table 5). Likewise, mean value of grains spike^{-1} under irrigated environment ranged from 31 to 46. Maximum numbers of grains spike^{-1} (46) were recorded for genotype G-312 followed by genotype G-316 (41) while minimum numbers of grains spike^{-1} were produced by genotype G-315 (31). Similarly, under rainfed environment number of grains spike^{-1} ranged from 22 to 35. Maximum numbers of spikes^{-1} were produced by genotype G-319 (35) followed by genotype G-301 (33) while minimum numbers of grains spike^{-1} were recorded for genotype G-315 (22). When averaged over 20 wheat genotypes, mean number of grains spike^{-1} were 38 and 29 under irrigated and rainfed environments, respectively. Genetic variances for grains spikes^{-1} were 7.89 and 10.16 while environmental variances were 1.10 and 4.01 under irrigated and rainfed conditions, respectively (Table 8). However, high broad sense heritability (0.88) with genetic advance of 4.62 was recorded for grains spike^{-1} under irrigated environment. Similarly, high heritability (0.72) along with genetic advance of 4.74 was recorded for grains spike^{-1} under rainfed environment. These results are in conformity with previous findings of Iqbal *et al.* (2017) who reported moderate value of the said trait in wheat genotypes.

1000-grain weight

Thousand grain weight is an important yield attributing trait that can be used in wheat enhancement program as potential selection criteria. Differences were highly significant among genotypes, environments and genotype by environment interaction (Table 1). This clearly indicated inconsistency of wheat genotypes under irrigated and rainfed environments. Mwadzingeni *et al*. (2017) and Saleem *et al.* (2016) also reported similar findings of significant variations among genotypes as well as genotype by environment interaction. Mean for thousand grain weight across both environments ranged from 31.7 to 43.3 g. Maximum thousand grain weight was recorded for genotype G-304 (43.3 g) followed by genotype (40.8 g). While minimum thousand grain weight was recorded for genotypes G-314 and cultivar Khaista (31.7 g) (Table 5). Likewise, mean value of thousand grain weight under irrigated environment ranged from 38.3 to 51.7 g. Maximum thousand grain weight was recorded for genotype G-304 (51.7) followed by genotypes G-313 and G-316 (48.3 g each). While minimum thousand grain weight was recorded for genotype cultivar Khaista (38.3 g). Similarly, under rainfed environment thousand grain weight ranged from 23.3 to 35.0 g. Maximum thousand grain weight was recorded for genotypes G-303, G-304 and G-319 (35.0 g) followed by genotypes G-301, G-306, G-307 and G-318 (31.7g each). While minimum thousand grain weight was noticed for genotypes G-311 and G-314 (23.3 g). When averaged over 20 wheat genotypes, mean value of thousand grain weights under irrigated and rainfed environments were 44.1 g and 29.0 g, respectively. Genetic variances for 1000-grain weight were 10.26 and 11.67 while environmental variances were 2.97 and 4.82 under irrigated and rainfed environments, respectively (Table 8). However, high broad sense heritability (0.78) along with genetic advance of 4.95 g was recorded for 1000-grain weight under irrigated environment. Similarly, under rainfed environment high broad sense heritability (0.71) along with genetic advance of 5.04 g was recorded for 1000-grain weight. The present results were in accordance with previous findings of Kumar *et al*. (2017) who reported moderate heritability for this trait in wheat genotypes.

Biological yield

Biomass is the most essential yield related component in cereal crops when selection is made under stress environment. Analysis of variance across the two environments revealed highly significant ($P < 0.01$) difference for biological yield among genotypes, environments and genotype by environment interaction (Table 1). This shows inconsistency in performance of wheat genotypes for this trait across both the tested environment. The results of significant variations among genotypes for biological yield are in line with earlier findings of Varsha *et al.* (2019) and Khan *et al.* (2015) whereas Ghallab *et al.* (2016) reported similar results of significant differences among wheat genotypes as well G × E interaction for biological yield. Mean value for biological yield over both environments ranged from 7073.6 to 11038.9 kg ha^{-1}. Maximum (11038.9 kg ha^{-1}) biological yield was obtained by genotype G-302, followed by genotype G-301 (11037.1 kg ha^{-1}) while minimum biological yield (7073.6 kg ha^{-1}) was noticed for genotype G-309 (Table 6). Likewise, biological yield under irrigated environment ranged from 6647.2 to 12994.4 kg ha^{-1}. Maximum (12994.4 kg ha^{-1}) biological yield was recorded for genotype G-304 followed by genotypes G-305 (12796.3 kg ha^{-1}) and G-301 (12459.3 kg ha^{-1}) while minimum (6647.2 kg ha^{1}) biological yield was observed for genotype G-309. Similarly, under rainfed condition biological yield ranged from 6990.7 to 10611.1 kg ha^{-1}. Maximum (10611.1 kg ha^{-1}) biological yield was recorded for genotype G-302 followed by G-301 (9615.0 kg ha^{-1}) and G-304 (8851.9 kg ha^{-1}) while minimum (6990.7 kg ha^{-1}) biological yield was recorded for G-314.When averaged over 20 wheat genotypes, mean biological yield under irrigated and rainfed conditions was 10237.8 kg ha^{-1} and 7981.8 kg ha^{-1} respectively. Genetic variances for biological yield were 3727463.26 and 651434.47 while environmental variances were 554153.29 and 550630.33 under irrigated and rainfed conditions, respectively. Furthermore, high broad sense heritability (0.87) along with genetic advance of 3161.45 kg was recorded for biological yield under irrigated environment (Table 8). Similarly, under rainfed environment moderate heritability (0.54) with genetic advance of 1042.76 kg was recorded for biological yield. Talebi and Fayyaz (2012) reported low heritability for the said trait in wheat genotypes. In contrast, Morteza *et al.* (2018) reported high heritability estimates for biological yield.

Grain yield

Grain yield of wheat is directly influenced by yield attributing traits i.e. tillers $meter^{-2}$, spikelets $spike^{-1}$, grains $spike^{-1}$, grain weight $spik^{-1}$, 1000-grain weight and biological yield. Therefore, plant breeder pays more attention to these parameters for improving yield and adaptation of new cultivars to environmental stresses in breeding programmes. Combined analysis of variance across two environments (Irrigated and rainfed) depicted highly significant variation ($P \leq 0.01$) for grain yield among environments, genotypes and genotype by environment interaction (G×E) (Table 1). This clearly indicated unstable performance of wheat genotypes across both the environmental conditions for grain yield. Our results of significant differences among studied genotypes by environment interaction are in conformity with previous findings of Ilyas *et al.* (2013) and Khan *et al.* (2007). Mean value for grain yield over both environments ranged from 2760.2 to 3439.8 kg ha^{-1}. Maximum grain yield was produced by genotype G-310 (3439.8 kg ha^{-1}) followed by G-301 (3360.2 kg ha^{-1}), G-313 (3323.1 kg ha^{-1}) and G-306 (3299.1 kg ha^{-1}) while minimum grain yield was produced by genotype G-315 of (2760.2 kg ha^{-1}) (Table 6). Likewise, grain yield of 20 wheat genotypes under irrigated condition ranged from 3151.9 to 3870.4 kg ha^{-1}. The highest grain yield of 3870.4 kg ha^{-1} was recorded for genotype G-306 followed by G-302 (3826.4 kg ha^{-1}) and G-310 (3824.1 kg ha^{-1}) while lowest grain yield was recorded for genotype G-315 (3151.9 kg ha^{-1}). Similarly, grain yield under rainfed environment ranged from 2368.5 to 3066.7 kg ha^{-1}. Maximum grain yield was produced by genotype G-313 (3066.7 kg ha^{-1}) followed by G-301 (3061.1 kg ha^{-1}) and G-310 (3055.6 kg ha^{-1}) while lowest grain yield was recorded for genotype G-315 of 2368.5 kg ha^{-1}. When averaged over both environments, means for grain yield under irrigated and rainfed conditions were 3418.6 kg ha^{-1} and 2724.7 kg ha^{-1} respectively. Genetic and environmental variance for grain yield were (56977.49 and 10711.03, respectively) under irrigated environment than under rainfed environment (38489.03 and 38630.68, respectively) (Table 8). However, high broad sense heritability (0.84) along with genetic advance of 384.35 kg was recorded for grain yield under irrigated condition. Similarly, under rainfed condition moderate sense heritability (0.50) along with genetic advance of 243.24 kg was recorded for grain yield. Previously, Iqbal *et al.* (2017) also reported moderate heritability for the said trait in wheat genotypes. But contrary to our findings, Tyagi *et al.* (2016) reported high heritability estimates for grain yield.

Harvest Index (%)

Harvest index has a direct relationship with grain yield. Kamrozzamman *et al.* (2016) explained that the harvest index is a measure of the ability of a crop to convert dry matter into grain or economic yield. Pooled analysis of variance for harvest index was recorded non-significant (P ≤ 0.01) for environments, genotypes and genotype by environment interaction (Table 1). This indicates consistency in performance of wheat genotype for this trait across the two-cropping system (Irrigated vs rainfed). These results for harvest index were in accordance with the findings of Ullah *et al*. (2014) also reported non-significant differences for the said trait. Mean value of harvest index across both environments ranged from 30.9 to 39.9%. Maximum harvest index was recorded for genotype G-319 (39.9%) followed by genotypes G-303 (38.5%) and G-312 (35.2%) while minimum harvest index was recorded for genotype G-302 (30.9 %) (Table 7). Likewise, mean value of harvest index under irrigated environment ranged from 31.3 to 42.4%. Maximum harvest index was recorded for genotype G-303 (42.4%) followed by genotypes G-319 (40.9%) and cultivar Wadan (39.8%) while minimum harvest index was recorded for genotype G-301 (31.3%). Similarly, under rainfed condition mean of 20 wheat genotypes for harvest index ranged from 27.6 to 38.9%. Maximum harvest index was recorded for genotype G-319 (38.9%) followed by harvest index was observed for genotype G-312 (36.7) while minimum harvest index was recorded for genotype G-302 (27.6). When averaged over both environments, means for harvest index under irrigated and rainfed conditions were 35.12% and 31.85% respectively. The genetic and environmental variance for harvest index were (0.70 and 30.27, respectively) under irrigated environment than under rainfed environment (2.03 and 17.34, respectively) (Table 8). However, low sense heritability (0.02) along with expected genetic advance of 0.22% was recorded for harvest index under irrigated environment. Similarly, under rainfed environment low heritability (0.10) along with expected genetic advance of 0.81% was recorded for harvest index. These results were in accordance with the findings of Azam *et al.* (2013) who reported moderate heritability for the said trait in wheat genotypes.

Table 1. **Means squares for various morphological traits of 20 wheat genotypes evaluated across two environments at the University of Agriculture, Peshawar during 2021-22.**

Traits	Env df =1	Reps (Env) df=4	Genotypes df=19	G×E df=19	Error df=76	CV%
Days to heading	1287.07**	0.54	16.16*	6.95**	2.07	1.21
Plant height	421.69**	0.14	4.28*	1.97**	0.12	0.36
Flag leaf area	474.80**	1.55	71.15**	16.69**	0.61	2.96
Tillers meter^{-2}	73986.55**	83.86	963.00*	434.33**	62.81	2.05
Spikelets spike^{-1}	15.55**	0.11	4.50**	0.78**	0.04	1.24
Spike length	8.28**	0.02	1.06**	0.29**	0.03	2.15
Grains spike^{-1}	2577.43**	2.01	41.49*	17.79**	2.55	4.80
1000-grain weight	6825.21**	2.68	54.51*	19.07**	3.89	5.40
Biological yield	152692320.9**	1244992.2	10034916.0*	4206560.8**	552391.8	8.16
Grain yield	14444466.1**	45600.2	232999.3*	102742.0**	24670.9	5.11
Harvest index	320.09^{ns}	122.59	32.67^{ns}	23.12^{ns}	23.81	14.58

**=highly significant at 1%, *=significant at 5%, ns= non-significant

Tables 2. Means for days to heading and plant height of 20 wheat genotypes evaluated under irrigated and rainfed environments at the University of Agriculture, Peshawar during 2021-22.

	Days to heading			Plant height (cm)		
Genotypes	Irrigated	Rainfed	Means	Irrigated	Rainfed	Means
G-301	124	116	120	99.1	95.5	97.3
G-302	121	115	118	99.9	96.7	98.3
G-303	123	116	120	99.1	98.1	98.6
G-304	124	118	121	99.2	95.8	97.5
G-305	121	113	117	99.1	95.0	97.1
G-306	122	116	119	99.3	94.4	96.9
G-307	120	112	116	98.8	94.3	96.5
G-309	120	117	118	99.5	93.9	96.7
G-310	122	120	121	99.0	94.4	96.7
G-311	121	113	117	97.5	93.5	95.5
G-312	121	114	117	97.6	93.8	95.7
G-313	124	118	121	99.1	95.2	97.2
G-314	122	112	117	98.2	93.3	95.8
G-315	123	117	120	98.6	93.8	96.2
G-316	120	112	116	99.4	95.0	97.2
G-317	124	116	120	98.8	94.2	96.5
G-318	122	115	118	98.4	95.9	97.2
G-319	122	113	117	98.2	96.0	97.1
WADAN	122	116	119	99.3	96.7	98.0
KHAISTA	122	119	120	99.3	96.9	98.1
Means	122	115.4	118.6	98.9	95.1	97.0
Geno	1.18	1.53	1.35	0.31	0.34	0.32
LSD $_{(0.05)}$ Env	--	--	0.04	--	--	0.02
G×E	--	--	1.30	--	--	0.32

Tables 3. Means for flag leaf area and tillers meter^{-2} of 20 wheat genotypes evaluated under irrigated and rainfed environments at the University of Agriculture, Peshawar during 2021-22.

	Flag leaf area (cm^2)			Tillers meter^{-2}		
Genotypes	Irrigated	Rainfed	Means	Irrigated	Rainfed	Means
G-301	25.6	29.6	27.6	407	347	377
G-302	21.5	23.3	22.4	409	368	389
G-303	19.3	29.1	24.2	409	327	368
G-304	26.9	29.0	27.9	409	339	374
G-305	19.8	28.4	24.1	408	373	391
G-306	26.0	37.2	31.6	418	374	396
G-307	25.5	25.2	25.4	408	336	372
G-309	27.3	29.6	28.4	413	391	402
G-310	17.8	23.0	20.4	407	349	378
G-311	26.5	29.2	27.8	410	356	383
G-312	22.7	28.3	25.5	409	377	393
G-313	31.0	34.3	32.6	419	368	394
G-314	23.3	25.6	24.5	420	388	404
G-315	25.6	24.1	24.9	413	378	395
G-316	25.6	26.4	26.0	420	363	392
G-317	28.2	29.7	28.9	426	399	412
G-318	15.8	22.3	19.1	406	336	371
G-319	28.3	31.2	29.8	411	370	391
WADAN	25.3	32.6	29.0	417	374	395
KHAISTA	25.4	28.8	27.1	403	335	369
Means	24.4	28.3	26.4	412	362	387
Geno	0.81	0.66	2.01	1.69	10.5	10.2
LSD $_{(0.05)}$ Env	--	--	0.08	--	--	0.59
G×E	--	--	0.73	--	--	7.44

Tables 4. Means for spikelets spike^{-1} and spike length of 20 wheat genotypes evaluated under irrigated and rainfed environments at the University of Agriculture, Peshawar during 2021-22.

	Spikelets spike^{-1}			Spike length (cm)		
Genotypes	Irrigated	Rainfed	Means	Irrigated	Rainfed	Means
G-301	16	16	16	8.5	8.3	8.4
G-302	17	19	18	8.6	9.5	9.1
G-303	15	16	16	7.3	8.2	7.8
G-304	16	16	16	8.9	8.9	8.9
G-305	16	16	16	7.7	7.9	7.8
G-306	14	15	15	7.7	8.3	8.0
G-307	15	15	15	8.4	9.0	8.7
G-309	15	16	16	8.0	8.6	8.3
G-310	15	15	15	8.4	8.7	8.6
G-311	17	17	17	8.0	8.4	8.2
G-312	15	15	15	8.0	8.2	8.1
G-313	17	17	17	8.7	8.9	8.8
G-314	16	18	17	8.4	9.4	8.9
G-315	16	17	16	8.4	8.5	8.4
G-316	16	17	17	8.7	9.4	9.0
G-317	16	16	16	8.9	9.1	9.0
G-318	16	18	17	7.8	9.4	8.6
G-319	14	15	15	7.8	8.2	8.0
WADAN	14	16	15	8.3	9.1	8.7
KHAISTA	16	17	16	8.3	9.4	8.8
Means	16	16	16	8.2	8.8	8.5
Geno	0.17	0.20	0.43	0.19	0.15	0.26
LSD $_{(0.05)}$ Env	--	--	0.02	--	--	0.01
G×E	--	--	0.18	--	--	0.17

Tables 5. **Means for grains spike^{-1} and 1000-grain weight of 20 wheat genotypes evaluated under irrigated and rainfed environments at the University of Agriculture, Peshawar during 2021-22.**

	Grains spike^{-1}			1000-grain weight (g)		
Genotypes	Irrigated	Rainfed	Means	Irrigated	Rainfed	Means
G-301	38	33	35	40.0	31.7	35.8
G-302	39	29	34	41.7	26.7	34.2
G-303	34	29	32	43.3	35.0	39.2
G-304	37	29	33	51.7	35.0	43.3
G-305	37	27	32	46.7	28.3	37.5
G-306	37	32	35	45.0	31.7	38.3
G-307	37	25	31	46.7	31.7	39.2
G-309	40	30	35	43.3	30.0	36.7
G-310	38	27	33	41.7	28.3	35.0
G-311	40	31	35	43.3	23.3	33.3
G-312	46	30	38	43.3	28.3	35.8
G-313	38	32	35	48.3	26.7	37.5
G-314	37	25	31	40.0	23.3	31.7
G-315	31	22	26	43.3	25.0	34.2
G-316	41	28	35	48.3	28.3	38.3
G-317	39	30	34	45.0	28.3	36.7
G-318	37	22	29	45.0	31.7	38.3
G-319	38	35	36	46.7	35.0	40.8
WADAN	38	31	34	40.0	26.7	33.3
KHAISTA	36	26	31	38.3	25.0	31.7
Means	38	29	33	44.1	29.0	36.5
Geno	1.00	1.91	2.08	1.64	2.09	2.15
LSD $_{(0.05)}$ Env	--	--	0.09	--	--	0.10
G×E	--	--	1.50	--	--	1.85

Tables 6. Means for biological yield and grain yield of 20 wheat genotypes evaluated under irrigated and rainfed environments at the University of Agriculture, Peshawar during 2021-22.

	Biological yield (kg ha^{-1})			Grain yield (kg ha^{-1})		
Genotypes	Irrigated	Rainfed	Means	Irrigated	Rainfed	Means
G-301	12459.3	9615.0	11037.1	3659.4	3061.1	3360.2
G-302	11466.7	10611.1	11038.9	3826.4	2701.1	3263.7
G-303	9485.2	7335.6	8410.4	3302.5	2666.7	2984.6
G-304	12994.4	8851.9	10923.1	3266.0	3016.7	3141.4
G-305	12796.3	7731.5	10263.9	3183.7	2407.4	2795.5
G-306	10935.2	7222.2	9078.7	3870.4	2727.8	3299.1
G-307	11407.6	7463.0	9435.3	3263.0	2661.1	2962.0
G-309	6647.2	7500.0	7073.6	3292.6	2933.4	3113.0
G-310	7777.8	7268.5	7523.1	3824.1	3055.6	3439.8
G-311	7361.1	7175.9	7268.5	3483.3	2742.6	3113.0
G-312	12083.3	8333.3	10208.3	3396.3	2835.2	3115.7
G-313	8925.9	8240.7	8583.3	3579.6	3066.7	3323.1
G-314	8592.6	6990.7	7791.7	3094.4	2444.4	2769.4
G-315	11425.9	7500.0	9463.0	3151.9	2368.5	2760.2
G-316	11759.3	8490.7	10125.0	3366.7	2427.8	2897.2
G-317	11916.7	8379.6	10148.1	3679.6	2433.6	3056.6
G-318	9481.5	7361.1	8421.3	3246.3	2793.0	3019.7
G-319	10814.8	8009.3	9412.0	3195.0	2701.9	2948.4
WADAN	8768.5	8287.0	8527.8	3175.9	2687.0	2931.5
KHAISTA	7657.4	7268.5	7463.0	3515.3	2763.0	3139.1
Means	10237.8	7981.8	9109.8	3418.6	2724.7	3071.7
LSD $_{(0.05)}$ Geno	710.4	708.1	1011.8	98.76	187.56	158.12
LSD $_{(0.05)}$ Env	--	--	73.01	--	--	13.97
G×E	--	--	697.8	--	--	147.47

Tables 7. Means for harvest index of 20 wheat genotypes evaluated under irrigated and rainfed environments at the University of Agriculture, Peshawar during 2021-22.

	Harvest index (%)		
Genotypes	Irrigated	Rainfed	Means
G-301	31.3	32.6	31.9
G-302	34.1	27.6	30.9
G-303	42.4	34.6	38.5
G-304	34.2	33.9	34.1
G-305	32.1	31.2	31.6
G-306	32.4	32.7	32.5
G-307	32.7	33.3	33.0
G-309	33.0	33.3	33.2
G-310	36.0	30.6	33.3
G-311	39.4	30.4	34.9
G-312	33.7	36.7	35.2
G-313	36.6	30.2	33.4
G-314	34.5	28.1	31.3
G-315	34.7	30.4	32.5
G-316	32.1	30.7	31.4
G-317	37.4	30.3	33.8
G-318	31.5	32.7	32.1
G-319	40.9	38.9	39.9
WADAN	39.8	29.5	34.6
KHAISTA	33.5	29.2	31.3
Means	35.12	31.85	33.47
Geno	5.2	3.9	2.37
LSD $_{(0.05)}$ Env	--	--	0.72
G×E	--	--	4.58

Tables 8: Genetic and environmental variance, broad sense heritability and genetic advance for various traits of 20 wheat genotypes evaluated under irrigated and rainfed environments at the University of Agriculture, Peshawar during 2021-22.

Traits	Environment	Vg	Ve	h^2	G.A
Days to heading	Irrigated	1.19	1.54	0.44	1.27
	Rainfed	5.13	2.60	0.66	3.24
Flag leaf area (cm^2)	Irrigated	14.46	0.73	0.95	6.51
	Rainfed	14.42	0.49	0.97	6.55
Plant height (cm)	Irrigated	0.35	0.11	0.76	0.90
	Rainfed	1.66	0.13	0.93	2.17
Tillers $meter^{-2}$	Irrigated	34.21	3.17	0.92	9.82
	Rainfed	389.70	122.44	0.76	30.22
Spike length (cm)	Irrigated	0.18	0.04	0.82	0.68
	Rainfed	0.25	0.03	0.90	0.83
Spikelets $spike^{-1}$	Irrigated	0.73	0.03	0.96	1.47
	Rainfed	1.00	0.05	0.96	1.72
Grains $spike^{-1}$	Irrigated	7.89	1.10	0.88	4.62
	Rainfed	10.16	4.01	0.72	4.74
1000-grain weight (g)	Irrigated	10.26	2.97	0.78	4.95
	Rainfed	11.67	4.82	0.71	5.04
Biological yield (kg ha^{-1})	Irrigated	3727463.3	554153.3	0.87	3161.5
	Rainfed	651434.5	550630.3	0.54	1042.8
Grain yield (kg ha^{-1})	Irrigated	56977.5	10711.0	0.84	384.3
	Rainfed	38489.0	38630.7	0.50	243.2
Harvest index (%)	Irrigated	0.70	30.27	0.02	0.22
	Rainfed	2.03	17.34	0.10	0.81

Vg = Genetic variance, Ve = Environmental variance, h^2 = Heritability and G.A = Genetic advance

Conclusions and Recommendations

Based on the results, the following conclusions and recommendations are performance of CIMMYT wheat lines varied under irrigated and rainfed conditions. Highly significant differences were observed among genotypes for all the parameters except harvest index. High heritability were observed for the flag leaf area, spike length, spikelet per spike, and 1000-grain weight. Moderate heritability was observed for all the other traits except harvest index which showed low heritability. The potential CIMMYT wheat lines under rainfed condition observed were G-301, G-313, and G-310 while under irrigated condition potential genotypes were G-302, G-306, and G-310. Thus, these genotypes could be used in further breeding programs for the development of high yielding wheat genotypes for rainfed and irrigated locations.

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